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# Modeling Weekday/Weekend Emissions and Ozone in the Los Angeles Basin for 1997 and 2010

## Final Report

## August 2007


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**3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022**

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Final Report

**CRC PROJECT A-56**

# Modeling Weekday/Weekend Emissions and Ozone in the Los Angeles Basin for 1997 and 2010

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# EXECUTIVE SUMMARY

Numerous studies of ambient ozone in the Los Angeles area have found both increases and decreases in high ozone concentrations on the weekend compared to weekdays. Furthermore, the magnitudes and locations of ozone increases and decreases change over time. The objective of CRC project A-56 was to investigate how Los Angeles weekday/weekend ozone differences are expected to evolve in the near future (2010) according to projected emission inventories and numerical ozone models. Ozone modeling was based on the August 3-7, 1997 episode that occurred during the Southern California Ozone Study (SCOS).

The California Air Resources Board (ARB) provided weekday emission inventories for 1997 and 2010 and data on weekend differences in emissions activity levels. We developed relatively complete descriptions of weekday/weekend nitrogen oxide (NOx) emission changes for the Los Angeles basin with 80% of the mass of NOx emissions receiving an adjustment in 1997 and 67% in 2010. Weekend NOx decreases of 34% on Saturday and 45% on Sunday relative to weekdays for 1997 are predicted to become slightly greater by 2010 and are dominated by NOx decreases for on-road vehicles (especially heavy-duty diesel vehicles) and off-road construction equipment. Weekend anthropogenic reactive organic gas (ROG) emission decreases (12% on Saturday and 16% on Sunday for 1997) are smaller than for NOx and become even smaller in 2010. However, there is less certainty in the weekend ROG emission changes because only 47% of the mass of ROG emissions received a weekend adjustment in 1997 and only 21% in 2010. More data are needed to better characterize weekend ROG emissions.

The ozone modeling used three different meteorological realizations and two chemical mechanisms to evaluate the consistency of findings. The three sets of meteorological data were:

1. Prognostic model data developed using the MM5 model by Environ and used in a previous CRC weekend ozone modeling study, project A-36.
2. Prognostic model data developed by San Jose State University for the ARB using MM5.
3. Diagnostic model data developed by the South Coast Air Quality Management District using the CALMET model data for the 2003 Los Angeles Air Quality Management Plan.

The two chemical mechanisms were version 4 of the Carbon Bond mechanism (CB4) and the 1999 version for the Statewide Air Pollution Research Center mechanism (SAPRC99). When the base year ozone model performance was evaluated, two meteorological realizations (Environ MM5 and CALMET) performed better with CB4 chemistry whereas the San Jose State MM5 meteorology performed better with SAPRC99 chemistry. Inert tracer simulations showed that emissions from central Los Angeles were dispersed more rapidly by the San Jose State MM5 meteorology than the other meteorological realizations. These results illustrate how different realizations for meteorology and chemistry may exert opposing, and roughly compensating, influences on ozone model performance.

The ozone modeling found weekend ozone increases in the central area of the Los Angeles basin in response to weekend NOx and ROG decreases for both 1997 and 2010, with both the SAPRC99 and CB4 chemical mechanisms, and with three different meteorological datasets. There also were weekend ozone decreases in other areas of the basin in all models, and the balance between areas with increases and decreases changed from 1997 to 2010. Comparing 2010 to 1997, weekend ozone increases are smaller and confined to a smaller part of the Los Angeles basin near the Pacific coast, whereas weekend ozone decreases are larger and more widespread in 2010. These effects are consistent with changes in the ROG/NOx ratio of the total (anthropogenic plus biogenic) emissions, which increase from 1997 to 2010 because anthropogenic ROG and NOx emissions decline but biogenic ROG emissions remain constant. For 2010, all models show lower 8-hr ozone on Sunday than weekdays in the Riverside/San Bernardino area that now experiences the largest number of days exceeding the ozone standard in the Los Angeles basin.

The weekday/weekend ozone changes for 2010 are sensitive to the choice of initial and boundary concentrations. Sensitivity tests showed that reducing the ROG and NOx initial and boundary concentrations enlarges the area with weekend ozone increases and reduces the area with weekend ozone decreases in 2010.

Weekday/weekend ozone differences were sufficiently large for 2010 (up to 20 ppb for 8-hr ozone) that they should continue to be considered in air quality planning activities for the Los Angeles basin.

# Modeling Weekday/Weekend Emissions and Ozone in the Los Angeles Basin for 1997 and 2010

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## ABSTRACT

Numerous studies of ambient ozone in the Los Angeles area have found both increases and decreases in high ozone concentrations on the weekend compared to weekdays. Furthermore, the magnitudes and locations of ozone increases and decreases change over time. We used numerical models to investigate how weekday/weekend ozone differences in the Los Angeles area change from 1997 to 2010. The modeling used three different meteorological realizations and two chemical mechanisms to evaluate the consistency of findings. We developed relatively complete descriptions of weekday/weekend nitrogen oxide (NOx) emission changes for the Los Angeles basin with 80% of the mass of NOx emissions receiving an adjustment in 1997 and 67% in 2010. Weekend NOx decreases of 34% on Saturday and 45% on Sunday relative to weekdays for 1997 are predicted to become slightly greater by 2010 and are dominated by NOx decreases for on-road vehicles (especially heavy-duty diesel vehicles) and off-road construction equipment. Weekend anthropogenic reactive organic gas (ROG) emission decreases (12% on Saturday and 16% on Sunday for 1997) are smaller than for NOx and become even smaller in 2010. However, there is less certainty in the weekend ROG emission changes because only 47% of the mass of ROG emissions received a weekend adjustment in 1997 and only 21% in 2010. The ozone modeling found weekend ozone increases in the central area of the basin in response to weekend NOx and ROG decreases for both 1997 and 2010, with both the SAPRC99 and CB4 chemical mechanisms, and with three different meteorological datasets. There also were weekend ozone decreases in other areas of the basin in all models, and the balance between areas with increases

and decreases changed from 1997 to 2010. Comparing 2010 to 1997, weekend ozone increases are smaller and confined to a smaller part of the Los Angeles basin near the Pacific coast, whereas weekend ozone decreases are larger and more widespread in 2010. These effects are consistent with changes in the ROG/NOx ratio of the total (anthropogenic plus biogenic) emissions. For 2010, all models show lower 8-hr ozone on Sunday than weekdays in the Riverside/San Bernardino area that now experiences the largest number of days exceeding the ozone standard in the LA basin. The weekday/weekend ozone changes for 2010 are sensitive to the choice of initial and boundary concentrations. Reducing the ROG and NOx initial and boundary concentrations enlarges the area with weekend ozone increases and reduces the area with weekend ozone decreases in 2010. Weekday/weekend ozone differences are large for 2010 (up to 20 ppb for 8-hr ozone) and should continue to be considered in air quality planning activities for the Los Angeles basin.

**Keywords:** Weekday/weekend ozone, photochemical modeling, CAMx, NOx emissions, ROG emissions, weekday/weekend emissions.

## INTRODUCTION

Emissions of nitrogen oxides (NOx) and reactive organic gasses (ROG) from both man-made and natural sources react in the presence of sunlight to form ground-level ozone.[1,2] Since human activity patterns vary between weekdays and weekends, NOx and ROG emissions and ozone concentrations may be expected to vary over the course of the week. If the weekday/weekend ozone differences are large, they could influence compliance with ozone air quality standards, in which case they should be considered in air quality management plans. Detailed studies of ambient ozone in the Los Angeles (LA) basin[3,4,5,6,7,8,9] have found both increases and decreases in weekend high ozone compared to weekdays. From 1981 to 2000, peak ozone in the basin decreased. Nevertheless, during this period, the weekday/weekend effect assumed greater importance as the geographical area with higher ozone on weekends increased.[6] This study uses available data on weekday/weekend activity differences[10,11] in LA to calculate weekend emission changes in 1997 and 2010, and then uses numerical models to evaluate weekend ozone differences in both years. Several modeling databases are employed to investigate whether modeled weekend ozone effects are consistent when different meteorological input data and photochemical mechanisms are used in the modeling.

Several hypotheses have been considered to explain how weekend emission changes could cause higher weekend ozone in LA[8,9] including decreased mass of NOx emissions on weekends, changed timing of NOx emissions on weekends, increased mass of VOC emissions on weekends and carryover of effects from preceding days. Ozone modeling studies[11,12] and analyses of ambient data[7,13] have concluded that the principal explanation is lower weekend NOx resulting in less ozone titration and less inhibition of ozone production in densely populated parts of the LA basin with high anthropogenic emissions. Ozone titration is the direct removal of ozone by NO emissions due to the reaction $NO + O_3 \rightarrow NO_2 + O_2$. NOx-inhibition of ozone production results from reactions such as $NO_2 + OH \rightarrow HNO_3$ which suppress hydroxyl radical (OH) concentrations, slowing down ozone production. The existing LA modeling studies have considered historical years and focused on emission changes for on-road vehicle emissions,[11,12] and there is a need to model future years and consider changes for other emission categories to improve future air quality planning activities for LA.

## METHODS

Photochemical modeling was performed for the August 3–7, 1997 ozone episode that occurred during the Southern California Ozone Study (SCOS97), thus providing enhanced data (e.g., upper air meteorological data and regional air quality data) to support numerical modeling. The episode began with warm temperatures at the surface and aloft and weak pressure gradients directed offshore opposing onshore sea breezes. August 3 was a model initialization day and is not discussed. Ozone was relatively low on August 4 in most locations with the highest ozone occurring inland in the mountains and passes consistent with onshore flow (Figure 1 provides a map showing terrain). On August 5, temperatures increased reaching 29 °C at LA International Airport (LAX) and 49 °C at Palm Springs. The offshore pressure gradient increased in intensity and the episode maximum ozone concentration was 187 ppb at Riverside, consistent with continued weak onshore flow. By August 6, the offshore pressure gradients had weakened and inland temperatures cooled (43 °C at Palm Springs). The maximum ozone on August 6 occurred in the mountains at Crestline. On August 7, pressure gradients turned onshore and the onshore winds strengthened so that the highest ozone concentrations occurred far inland. The meteorological patterns during the August 3–7, 1997 period fit a typical pattern for LA ozone episodes: High ozone levels occurred because the period was relatively stagnant, tending to trap precursors and ozone within the LA basin.

Ozone modeling was performed with three independent realizations of the episode meteorology and with two different chemical mechanisms, as discussed below. Six model configurations were evaluated and, based on model performance, three were selected to investigate weekday/weekend ozone. The August 3-7, 1997 period was actually a Sunday-Thursday period which is not suited to investigating weekday/weekend effects. For purposes of evaluating ozone model performance, the episode was modeled using the day specific emission inventories for Sunday-Thursday. For purposes of evaluating weekday/weekend effects, we performed sensitivity tests that compared modeling all days as weekdays to modeling August 4-6 as a Friday-Sunday.[11] Weekday/weekend ozone effects were investigated for both historical 1997 emission levels and projected future 2010 emission levels.

## Atmospheric Models

Ozone modeling used version 4.20 of the Comprehensive Air-quality Model with extensions (CAMx).[14] CAMx simulates the emission, dispersion, reaction, and removal of ozone precursors and ozone in an Eulerian (grid) framework. The modeling domain (Figure 1) covered an area of 65 by 40, 5-km grid cells that has been used in past air quality management plans for the LA area. The CAMx layer structure was determined by the source of meteorological data as summarized in Table 1. The photochemistry of ozone formation was simulated using two different condensed chemical mechanisms: (1) The Carbon Bond 4 (CB4) mechanism[15] with updates for low-NOx conditions and isoprene reactions,[14] which contains 37 species and 96 reactions, and (2) the fixed stoichiometry version of the SAPRC99 mechanism[16] with 74 species and 211 reactions. For the standard simulations for 1997 and 2010, the CAMx initial and boundary conditions were set to 40 ppb ozone, 1 ppb NOx, 100 ppbC ROG, and 200 ppb CO. These concentrations represent some regional pollution of clean background Pacific air. For some sensitivity simulations for 2010, the ROG initial and boundary concentrations were reduced to 60 ppbC and the NOx concentrations to 0.53 ppb. These concentrations were determined by linear rollback of the concentration increment above clean air, i.e.,

$$ROG(sens.) = f_{ROG} \times [ROG(std.) - ROG(clean)] + ROG(clean) \qquad (1)$$

where ROG(sens.), ROG(std.) and ROG (clean) are the concentrations for the sensitivity simulations, standard simulations and clean air, respectively, and $f_{ROG}$ is the ratio of anthropogenic ROG emissions in 2010 to 1997.

Meteorological input data for CAMx were developed using two models, the Penn State/NCAR Mesoscale Model, version 5 (MM5)[17] prognostic model and the CALMET[18] diagnostic model. The MM5 simulates meteorology based on fundamental physical equations but also permits assimilation of observed data to nudge simulated meteorological fields toward observed data. MM5 was run with assimilation of SCOS97 measurement data (i.e., radar wind profiler upper-air data and surface-site data) and large scale analyses from the National Centers for Environmental Prediction. The ENVIRON MM5 data have been used previously for LA ozone modeling[11] whereas the San Jose State (SJS) MM5 data[19] have not previously been used for ozone modeling. The main differences between the two MM5 configurations are that SJS used an urbanized version of MM5 and more vertical layers. The SJS MM5 run ended at 4 am on August 7. CALMET is a diagnostic meteorological model that generates 3-D gridded fields by interpolating observed data. CALMET data for this study were provided by the South Coast Air Quality Management District (SCAQMD).[20]

## Emissions Data

The 1997 and 2010 emission inventories were provided by the California Air Resources Board (CARB)[21] and include the impact of current and future emission controls required by the CARB as of June, 2005, along with growth in population and vehicle-miles traveled. On-road vehicle emissions were based on transportation model activity data calibrated using observed traffic counts and the EMFAC2002 emission factor model[22], which accounts for regulatory programs including the Smog Check program, low emissions vehicles (LEVII), reformulated gasoline (Phase 3), and low sulfur diesel fuel. The on-road vehicle emissions were day-specific due to adjustments for temperature and measured traffic counts. The day-specific on-road vehicle emissions provided by the CARB were used for model performance evaluation; however, for weekday/weekend experiments, emissions for a single weekday (August 5) were taken as the basis for all days and then adjusted for weekend days as described below. Other categories of anthropogenic emissions provided by the CARB included off-road mobile sources, area sources, and point sources. Biogenic ROG emissions were estimated using the BEIGIS model[23] with daily temperatures, and ROG emission totals varied between 257 and 416 tons/day depending on the temperatures. Wildfire emissions were included in the CARB inventory and were substantial on August 5–7, 1997 because of a wildfire in northern Ventura County. However, this wildfire had little impact on ozone levels in the LA basin because the emissions and subsequent ozone formation occurred far from the basin. Wildfire emissions were included in ozone modeling for performance evaluation but were excluded from weekday/weekend modeling where the focus was on anthropogenic emission effects.

## Weekend Emission Changes

Weekend emission adjustments were based on a CARB study by Sullivan et al.[24] and previous LA weekend ozone modeling by Yarwood et al.[11] Sullivan et al. conducted surveys of over 800 households, analyzed surface street traffic counts in 10 neighborhoods, and analyzed freeway traffic counts at 10 locations to characterize weekday/weekend activity differences. Emission adjustments recommended by Sullivan et al., are shown in Table 2. Sullivan et al. made no recommendations for adjusting on-road vehicle diurnal emissions, so the adjustments previously developed by Yarwood et al., were used. This approach is reasonable because the other on-road vehicle activity adjustments derived by Sullivan et al. and Yarwood et al. are similar in magnitude. Resting loss emissions were assumed to remain constant for all days of the week because they are related to vehicle off-time, which is relatively constant for any day of the week.[11] The temporal profiles (hour of day) for on-road emissions also were changed from weekdays to weekends based on traffic counts.[11] Biogenic emissions received no day-of-week adjustment but were date specific due to temperature effects.[23]

The weekday and weekend anthropogenic emission totals (i.e., excluding biogenic emissions and wildfires) for 1997 and 2010 are shown in Table 3. Total NOx and ROG emissions decrease on both Saturday and Sunday relative to weekdays with the largest decreases occurring for on-road vehicles, off-road construction equipment, and industrial paints/solvents. On-road vehicles account for 70% of the weekday to Sunday NOx decrease in 1997 falling to 62% in 2010. Off-road construction equipment accounts for 29% of the weekday to Sunday NOx decrease in 1997 rising to 37% in 2010. Combined, on-road vehicles and off-road construction equipment account for 99% of the NOx decreases on Saturday and Sunday for both 1997 and 2010. In contrast, on-road vehicles and off-road construction equipment together account for about two-thirds of the weekend ROG decrease in 1997 falling to about one-third in 2010. Industrial solvents and paints account for about one-third of the weekend ROG decrease in 1997 rising to about two-thirds in 2010. ROG emissions from recreational boats and off-road vehicles increase on weekends but the combined change is small (less than 5% of the weekend ROG change) and does not significantly counteract ROG decreases from other categories.

For 1997, 80% of the mass of NOx emissions and 47% of the mass of anthropogenic ROG emissions received a weekend adjustment, providing some confidence that the majority of the weekend emissions effects are accounted for, especially for NOx. For 2010, the mass of emissions receiving a weekend adjustment declined to 67% of NOx and 21% of ROG emissions. Smaller percentages of 2010 emissions receive weekend adjustments primarily because the contribution of on-road vehicle emissions declines substantially from 1997 to 2010. There is less certainty in the weekend emissions adjustments for 2010 than for 1997, especially for ROG emissions. Further work on weekday/weekend emission changes is warranted for ROG emissions, especially for source categories that have not yet been investigated.

The relative changes in total emissions from Table 3 are summarized in Table 4 and the following points are noted. (1) Relative emission changes for Friday are small and may be negligible. (2) Both ROG and NOx emissions decrease on Saturday and Sunday. (3) Saturday and Sunday percentage emissions decreases are greater for NOx than for ROG and, therefore, ROG/NOx ratios increase on weekends. (4) Weekend NOx percentage decreases are similar in 1997 and 2010. (5) Weekend ROG percentage decreases are smaller in 2010 than 1997. (6) ROG/NOx ratios increase more on weekends in 2010 than 1997.

## RESULTS

### Model Performance

CAMx model performance was evaluated using day-specific emissions. The first 2 days are considered model initialization days and excluded from the performance evaluation. Model performance for 1-hr ozone was evaluated at 48 sites in the modeling domain. Hourly ozone was evaluated to avoid cancellation of errors within 8-hr time averaging. Modeled ozone levels were statistically evaluated using metrics (peak accuracy, normalized bias and normalized gross error) recommended by the U.S. Environmental Protection Agency (EPA) as shown in Table 5. Graphical comparisons of modeled and observed daily maximum 1-hr ozone are shown for August 6, 1997 in Figure 2. The objective of the model performance evaluation was to select model configurations most suitable for modeling weekday/weekend ozone differences.

The ENVIRON MM5 data resulted in good ozone model performance with the CB4 mechanism but poor performance with the SAPRC99 mechanism, consistent with our previous LA modeling results.[11] The main reason for poorer performance with SAPRC99 is more rapid ozone production leading to ozone levels that exceed those observed. This result does not imply that one chemical mechanism is more accurate than another because modeled ozone levels depend upon other factors beside chemistry. In fact, the San Jose State MM5 data (SJS-MM5) performed better with the SAPRC99 than CB4 mechanism showing that meteorology and chemistry can have opposing influences on model performance that approximately compensate.

The ENVIRON MM5 data with the CB4 mechanism satisfied all of the 9 model performance goals (3 metrics for each of 3 days) for August 5-7; whereas, with the SAPRC99 mechanism, only 4 of 9 performance goals were satisfied because of an ozone over-prediction bias. The ENVIRON MM5 data with CB4 achieved low bias and error statistics on all days because both the spatial distribution and magnitude of ozone were simulated relatively well. On August 6, the observed peak ozone was 154 ppb at Crestline (near San Bernardino) where the model prediction is about 140 ppb. The modeled peak of 174 ppb is about 15 km south of the observed peak and close to an observed value of 151 ppb. High ozone (about 130-140 ppb) also is predicted in the San Fernando Valley (north of the West LA monitor marked in Figure 1) close to observed values of 132 ppb and 134 ppb. An isolated area of predicted high ozone (~130 ppb) in northern

Ventura County is due to a wildfire that occurred there on this day. The spatial pattern of modeled ozone with SAPRC99 is similar to CB4 but ozone is over-predicted.

Using the SJS MM5 data (which does not include August 7) with the SAPRC99 mechanism satisfied all of the 6 model performance goals (3 metrics for each of 2 days). However, with the CB4 mechanism, only 3 of 6 performance goals were satisfied because of an ozone under-prediction bias. There are similarities in the spatial patterns of ozone predicted with the MM5 meteorology from SJS and ENVIRON with both datasets predicting high ozone on the north side of the LA basin where the San Gabriel mountains block and channel the onshore sea breeze, consistent with the observations. The following description of model performance is for the SJS MM5 simulation with SAPRC99 chemistry that performed well. On August 6, the observed peak was 154 ppb at Crestline where the model prediction is about 150 ppb. The modeled high ozone levels in Riverside/San Bernardino agree well with the observed values. The modeled peak of 172 ppb in northern LA County is due to emissions from the wildfire that occurred in northernVentura County. High ozone of about 150 ppb was predicted in the San Fernando Valley close to observed values of 132 ppb and 134 ppb.

Ozone model performance with CALMET data was poorer than with either MM5 dataset. CALMET performance may be considered better with CB4 than SAPRC99 because 6 of 9 ozone performance goals were satisfied with CB4, whereas only 3 of 9 performance goals were satisfied with SAPRC99. The CALMET simulation with CB4 failed the unpaired peak performance goal on all days due to both under- and over-prediction errors. The spatial agreement for CALMET with CB4 was better for August 6 than other days. The observed peak was 154 ppb at Crestline where the model prediction is about 120 ppb. Just to the south of Crestline, in the Riverside/San Bernardino area, the model predictions agree well with the observed values of up to 151 ppb. The modeled peak of 228 ppb in northern Ventura County is due to emissions from a wildfire. High ozone values of 132 ppb and 134 ppb observed in the San Fernando Valley were under-predicted by about 20-40 ppb.

The ENVIRON MM5/CB4, SJS MM5/SAPRC99, and CALMET/CB4 configurations all correctly predict a strong gradient from lower ozone near the coast to higher ozone inland, but tend to over-predict lower ozone observed near the coast and mid-basin. These configurations also predict slightly elevated ozone offshore (~50 ppb) at Catalina Island where observed ozone was 45 to 62 ppb.

## Comparison of 1997 and 2010 Modeling Results

The 1997 and 2010 episode maximum 1-hr and 8-hr ozone levels are compared in Table 6 to characterize how LA ozone levels change with these models and weekday emission inventories. Anthropogenic emission decreases from 1997 to 2010 were 53% for NOx and 50% for ROG. Relative reductions in peak 1-hr and 8-hr ozone were similar within each model but appear to depend upon the chemical mechanism used. Ozone decreases from 1997 to 2010 were about 20% with CB4 (17.7% to 21.5%) and about 10% with SAPRC99 (8.5% to 11.9%). Observed ozone trends[25] are generally consistent with the modeled trends with annual 1-hr maximum having declined 14.6% from 1997 to 2006 (from 205 ppb to 175 ppb) and the three-year 8-hr design value having declined 17.6% from 1996-1998 to 2004-2006 (from 159 ppb to 131 ppb). Modeled ozone decreased less than emissions decreased because the chemical relationship between ozone and precursors is non-linear and because the contributions from the boundary conditions and biogenic emissions were held constant in the results in Table 6 (ozone boundary condition of 40 ppb).

## Weekend Ozone Changes

The better performing model configuration for each set of meteorological input data was selected to investigate weekday/weekend ozone. Simulations were performed with weekday or weekend anthropogenic emissions, date specific biogenic emissions, and no wildfire emissions. Figure 3 shows the spatial distributions of hourly ozone changes on Saturday and Sunday at 10 am and 3 pm. On both Saturday and Sunday mornings, the ozone levels are higher across most of the densely populated LA basin, i.e., approximately the area below 400 m elevation in Figure 1 extending from the coast inland to Riverside. The morning ozone increases are caused by lower NOx emissions on weekend mornings[7,11,12,13] resulting in less ozone titration and less inhibition of ozone production on weekends. The geographical area where morning ozone increases is similar for all three models because it is closely related to where NOx emissions decrease in the emissions inventory, which is identical for all three models. The morning ozone increases are stronger on Sunday than Saturday because NOx emissions decrease more on Sunday. Outside of the LA basin, where anthropogenic emission levels are lower and ozone production is not inhibited by NOx, there are ozone decreases on Saturday and Sunday morning. By mid-afternoon, ozone increases persist across much of the LA basin on both Saturday and Sunday with all three models. However, the area where ozone increases tends to shrink from morning to afternoon as ozone decreases outside the LA basin tend to intensify and spread into the basin. This is consistent with ozone production becoming more NOx-sensitive (i.e., decreasing NOx reduces ozone) in the afternoon in downwind areas inland from the coast. There are greater differences between models in the afternoons than mornings because differences in meteorological realization become more important as ozone photochemistry progresses through the day.

The 1997 and 2010 episode maximum 1-hr and 8-hr ozone levels for the weekday and weekend emission scenarios are compared in Table 6. For 1997, peak ozone levels tended to increase when the weekend was introduced on August 5$^{th}$ and 6$^{th}$, with peak 1-hr ozone increasing by 4 to 28 ppb and peak 8-hr ozone changing by −2 to 24 ppb. In contrast, 2010 peak ozone levels tended to decrease when the weekend was introduced, with peak 1-hr ozone decreasing by 2 to 9 ppb and peak 8-hr ozone remaining constant or decreasing up to 6 ppb. These results are specific to the episodes and assumptions of this study, but they suggest a change from a recent tendency for higher peak ozone on LA weekends to a future tendency for similar or lower peak ozone levels on weekends, relative to weekdays.

Daily maximum 8-hr ozone results for 1997 are shown in Figure 4 at a series of monitor locations (Figure 1) running west to east across the LA basin from near the coast to Crestline. This presentation of results focuses on ozone differences within the densely populated LA basin and locations of transitions between weekend ozone increases and decreases. On Saturday, all three meteorological datasets show higher 8-hr ozone across the LA basin from West LA to Crestline. The increases in Saturday 8-hr ozone are greatest at mid-basin monitors (Azusa and Upland) and are about 15-30 ppb. On Sunday, the models with CB4 chemistry result in higher weekend 8-hr ozone across the LA basin from West LA to Crestline but the model with SAPRC99 chemistry shows a transition from weekend ozone increases to decreases between

Upland and Riverside. In other words, ozone formation in the Riverside area is more responsive to NOx reductions in the SJS-MM5/SAPRC99 model than the other models. This different model response could be attributable to the meteorological data, but more likely reflects a difference between the SAPRC99 and CB4 mechanisms. The ROG/NOx ratio of anthropogenic emissions increases by more on Sunday (51%) than Saturday (34%) which is consistent with ozone production in some locations becoming more NOx-sensitive on Sunday than Saturday.

Daily maximum 8-hr ozone results for 2010 are shown in Figure 5 in the same format as Figure 4 for 1997 and using the same initial and boundary concentrations as for 1997. On Saturday, all three meteorological datasets show a transition from weekend ozone increases to decreases between Upland and Riverside. Saturday 8-hr ozone is higher by up to 10 ppb from West LA to Upland and lower from Riverside to Crestline by up to 7 ppb. On Sunday, all three meteorological datasets show a transition from weekend ozone increases to decreases between LA N. Main and Upland. Sunday 8-hr ozone is higher by up to 18 ppb from West LA to LA N. Main and lower from Upland to Crestline by up to 20 ppb. On both Saturday and Sunday the transition from ozone increases to decreases occurs closer to the coast with the SAPRC99 chemistry than with CB4, which is consistent with the 1997 results. Comparing 2010 to 1997, weekend ozone increases are smaller and confined to a smaller part of the LA basin, whereas weekend ozone decreases are larger and more widespread. All models show lower 8-hr ozone on Sunday than weekdays in the Riverside/San Bernardino area that now experiences the largest number of days exceeding the ozone standard in the LA basin.[25]

These 2010 modeling results are consistent with ozone production becoming more NOx-sensitive in 2010 than 1997. The modeled ozone sensitivity to emissions is influenced by the ROG/NOx ratio of the emissions and the boundary conditions. Anthropogenic ROG and NOx emissions reduced about equally (50% and 53%, respectively) from 1997 to 2010 for almost no change in the anthropogenic ROG/NOx ratio [moleC/mole] of 4.1 to 4.4 on weekdays. However, the ROG/NOx ratio of all emissions increased from 1997 to 2010 because biogenic ROG emissions were constant from 1997 to 2010. Including 350 tons/day of biogenic ROG emissions, the total ROG/NOx ratio on weekdays increased from 4.9 to 5.9 and the Sunday ratio increased from 7.6 to 10.1 between 1997 and 2010. The weekday/weekend change in total

ROG/NOx ratio is greater in 2010 than 1997 because anthropogenic emissions are ~50% lower in 2010. The higher ROG/NOx emission ratios on weekends are consistent with ozone production being more NOx-sensitive on weekends and with this effect becoming greater in 2010 than 1997.

The initial and boundary concentrations used for the simulations in Figures 4 and 5 include some impact of anthropogenic emissions. Consequently, the reductions in anthropogenic emissions from 1997 to 2010 should reduce these concentrations. To investigate the impact of this secondary effect of emission reductions, we conducted sensitivity simulations for 2010 with the initial and boundary concentrations of ROG and NOx reduced from 100 ppbC to 60 ppbC and from 1 ppb to 0.53 ppb, respectively (Eq. [1]). (The initial and boundary concentrations of ozone and CO were unchanged.) The results of these simulations are presented in Figure 6. A comparison of Figures 5 and 6 shows that reducing the boundary concentrations reduced peak 8-hr ozone at nearly all locations from West LA to Crestline by 5-20 ppb. The peak 8-hr ozone is reduced for both weekday and weekend emissions but the decreases are larger for the weekday emissions. As a result, the transition from weekend ozone increases to decreases is farther from the coast in Figure 6 compared to Figure 5, occurring between Riverside and Crestline on Saturday and between Azusa and Riverside on Sunday with the reduced boundary concentrations. The predicted weekday/weekend ozone differences for 2010 are clearly sensitive to the assumed initial and boundary concentrations, and a reduction in the initial and boundary concentrations reduces the sensitivity of ozone production to NOx.

## CONCLUSIONS

We have developed relatively complete descriptions of weekday/weekend NOx emission changes for the LA basin with 80% of the mass of NOx emissions receiving an adjustment in 1997 and 67% in 2010. Weekend NOx decreases of 34% on Saturday and 45% on Sunday relative to weekdays for 1997 are predicted to become slightly greater by 2010 and are dominated by NOx decreases for on-road vehicles (especially heavy-duty diesel vehicles) and off-road construction equipment. Weekend ROG decreases (12% on Saturday and 16% on Sunday for 1997) are smaller than for NOx and become even smaller in 2010. On-road vehicles and off-road construction equipment account for about two-thirds of the weekend ROG decrease in 1997 falling to about one-third in 2010. Industrial solvents and paints account for about one-third of the weekend ROG decrease in 1997 rising to about two-thirds in 2010. ROG emissions from recreational boats and off-road vehicles increase on weekends but the combined change is small. There is less certainty in the weekend ROG emission changes because only 47% of the mass of anthropogenic ROG emissions received a weekend adjustment in 1997 and only 21% received an adjustment in 2010. We recommend further study of weekend ROG emissions, especially for source categories other than on-road vehicles. As mobile source emissions decline, weekend differences for other categories could exert more influence on weekday/weekend emissions differences.

The ozone modeling showed lower peak 1-hr and 8-hr ozone on weekdays in 2010 compared to 1997 with both the SAPRC99 and CB4 chemical mechanisms and with three different meteorological data sets. With all model configurations, the results also showed weekend ozone increases in the central area of the LA basin in response to weekend NOx and ROG decreases for both 1997 and 2010.. There were weekend ozone decreases in other areas of the basin in all models, and the balance between areas with increases and decreases changed from 1997 to 2010. For 1997, weekend ozone increases occurred throughout most of the densely populated LA basin. The weekend ozone increases are caused by lower weekend NOx resulting in less ozone titration and less inhibition of ozone production on weekends. For 1997, ozone decreases occurred mainly outside the LA basin where anthropogenic emission levels are lower and ozone production is not inhibited by NOx. Comparing 2010 to 1997, weekend ozone increases are smaller and confined to a smaller part of the LA basin near the Pacific coast, whereas weekend ozone decreases are larger and more widespread. For 2010, all models show lower 8-hr ozone on Sunday than weekdays in the Riverside/San Bernardino area that now experiences the largest number of days exceeding the ozone standard in the LA basin. The modeling results are consistent with ozone production becoming NOx-sensitive in 2010 in this region of the basin. This conclusion, however, assumes that the large anthropogenic emission reductions from 1997 to 2010 (Table 3) will be achieved. The SAPRC99 chemical mechanism appeared to respond in a more NOx-limited manner than the CB4 mechanism. The SAPRC99 chemical mechanism also appeared to respond less to emission reductions between 1997 and 2010 than the CB4 mechanism. The weekday/weekend ozone changes for 2010 are sensitive to the choice of initial and boundary concentrations. Reducing the ROG and NOx initial and boundary concentrations via Eq. (1) enlarges the area with weekend ozone increases in 2010, reduces the area with weekend ozone decreases, and reduces the sensitivity of ozone production to NOx.

Weekday/weekend ozone differences are large for 2010 (up to 20 ppb for 8-hr ozone) and should continue to be considered in air quality planning activities for the LA basin. Weekday/weekend differences in high ozone levels (i.e., exceeding ozone standards) should be evaluated by sub-region within the basin to provide an indication of how ozone will respond to further NOx and ROG emission reductions.

**ACKNOWLEDGMENT**

This work was sponsored by the Coordinating Research Council Atmospheric Impacts Committee. The California Air Resources Board and South Coast Air Quality Management District provided data to support the modeling. Professor R. Bornstein of San Jose State University made available the meteorological modeling results of Boucouvala et al. (2003) for use in this study. The conclusions are those of the authors.

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# Tables

**Table 1**. CAMx layer structures used with three meteorological input datasets.

| Layer Structure | ENVIRON MM5 | San Jose State MM5 | SCAQMD CALMET |
|---|---|---|---|
| Number of CAMx layers | 10 | 21 | 16 |
| Surface layer depth (m) | 60 | 15 | 20 |
| Number of layers below 1500 m | 7 | 13 | 10 |
| CAMx model top (m) | 4091 | 5000 | 4644 |

**Table 2**. Day of week adjustments relative to weekday emissions.

| Emissions Category | Fridays | Saturdays | Sundays | Source |
|---|---|---|---|---|
| LDV[a]: Exhaust, Running Loss[b] | 3.5% | -15% | -30% | Sullivan et al., (2003) |
| LDV[a]: Hot Soak[c] | 10% | -20% | -30% | Sullivan et al., (2003) |
| LDV[a]: Diurnal[d] | -3% | 23% | 59% | Yarwood et al. (2003) |
| HDV[e]: Exhaust, Hot Soak and Running Loss[b,c] | 0% | -63% | -78% | Sullivan et al., (2003) |
| HDV[e]: Diurnal[d] | 0% | 136% | 289% | Yarwood et al. (2003) |
| Recreational boats | -1% | 17% | -1% | Sullivan et al., (2003) |
| Off-road recreational vehicles | 3% | 9% | 5% | Sullivan et al., (2003) |
| Off-road construction equipment | 0% | -90% | -99% | Sullivan et al., (2003) |
| Industrial paints/solvents | 0% | -77% | -89% | Sullivan et al., (2003) |
| Pesticides and fertilizers | 0% | -91% | -96% | Sullivan et al., (2003) |
| Major NOx point sources | 0% | -6% | -6% | Sullivan et al., (2003) |

[a] LDV means light-duty, on-road vehicle.
[b] Running losses are vehicle evaporative emissions while the engine is operating.
[c] Hot soak emissions are evaporative emissions while the engine is off but above ambient temperature.
[d] Diurnal emissions are evaporative emissions resulting from the increase and decrease of ambient temperature.
[e] HDV means heavy-duty, on-road vehicle.

**Table 3**. Weekday and weekend anthropogenic emissions for 1997 and 2010.

| Emissions Category | Weekday | Friday | Saturday | Sunday |
|---|---|---|---|---|
| **1997 NOx (tons/day)** | | | | |
| On-road vehicles | 972.1 | 991.5 | 628.0 | 482.2 |
| Recreational boats | 5.62 | 5.57 | 6.58 | 5.57 |
| Off-road recreational vehicles | 0.55 | 0.57 | 0.60 | 0.58 |
| Pesticides and fertilizers | 0 | 0 | 0 | 0 |
| Industrial paints/solvents | 0 | 0 | 0 | 0 |
| Off-road construction equipment | 209.0 | 209.0 | 20.9 | 2.09 |
| Major NOx point sources | 72.6 | 68.6 | 68.1 | 68.1 |
| Sources with no adjustment | 309.9 | 309.9 | 309.9 | 309.9 |
| **Total** | **1570** | **1585** | **1034** | **868** |
| **2010 NOx (tons/day)** | | | | |
| On-road vehicles | 303.5 | 305.3 | 138.4 | 93.0 |
| Recreational boats | 6.82 | 6.75 | 7.98 | 6.75 |
| Off-road recreational vehicles | 0.60 | 0.62 | 0.66 | 0.63 |
| Pesticides and fertilizers | 0 | 0 | 0 | 0 |
| Industrial paints/solvents | 0 | 0 | 0 | 0 |
| Off-road construction equipment | 126.5 | 126.5 | 12.65 | 1.27 |
| Major NOx point sources | 62.3 | 58.8 | 58.4 | 58.4 |
| Sources with no adjustment | 244.0 | 244.0 | 244.0 | 244.0 |
| **Total** | **744** | **742** | **462** | **404** |
| **1997 ROG (tons/day)** | | | | |
| On-road vehicles | 719.3 | 740.5 | 600.2 | 529.4 |
| Recreational boats | 45.3 | 44.9 | 53.0 | 44.9 |
| Off-road recreational vehicles | 13.8 | 14.2 | 15.0 | 14.5 |
| Pesticides and fertilizers | 0.06 | 0.06 | 0.01 | 0 |
| Industrial paints/solvents | 141.9 | 141.9 | 32.6 | 15.6 |
| Off-road construction equipment | 40.2 | 40.2 | 4.02 | 0.40 |
| Major NOx point sources | 49.0 | 49.0 | 49.0 | 49.0 |
| Sources with no adjustment | 1152 | 1152 | 1152 | 1152 |
| **Total** | **2161** | **2183** | **1906** | **1806** |
| **2010 ROG (tons/day)** | | | | |
| On-road vehicles | 93.8 | 96.4 | 79.2 | 71.9 |
| Recreational boats | 12.9 | 12.8 | 15.1 | 12.8 |
| Off-road recreational vehicles | 4.54 | 4.67 | 4.95 | 4.77 |
| Pesticides and fertilizers | 0.03 | 0.03 | 0 | 0 |
| Industrial paints/solvents | 74.0 | 74.0 | 17.0 | 8.14 |
| Off-road construction equipment | 12.8 | 12.8 | 1.28 | 0.13 |
| Major NOx point sources | 30.7 | 30.7 | 30.7 | 30.7 |
| Sources with no adjustment | 855.1 | 855.1 | 855.1 | 855.1 |
| **Total** | **1084** | **1087** | **1003** | **983** |

**Table 4**. Percent changes in total anthropogenic emissions from typical weekday emissions.

| Emissions Year | Friday | Saturday | Sunday |
|---|---|---|---|
| 1997 | | | |
| NOx | 1% | -34% | -45% |
| ROG | 1% | -12% | -16% |
| ROG/NOx | 0% | 34% | 51% |
| 2010 | | | |
| NOx | 0% | -38% | -46% |
| ROG | 0% | -7% | -9% |
| ROG/NOx | 0% | 49% | 67% |

**Table 5**. Statistical measures of model performance for 1-hr ozone for six model configurations.

| | Goal (%) | CB4 Chemistry | | | SAPRC99 Chemistry | | |
|---|---|---|---|---|---|---|---|
| | | ENV-MM5 | CALMET | SJS-MM5 | ENV-MM5 | CALMET | SJS-MM5 |
| **August 5, 1997** | | | | | | | |
| Observed Peak (ppb) | | 187 | 187 | 187 | 187 | 187 | 187 |
| Modeled Peak (ppb) | | 157.2 | 147.0 | 138.9 | 188.3 | 189.5 | 164.3 |
| Unpaired Peak (%) | +/- 20 | -15.9 | -21.4 | -25.7 | 0.7 | 1.3 | -12.2 |
| Normalized Bias (%) | +/- 15 | -11.7 | -8.6 | -26.4 | 9.1 | 15.2 | -13.1 |
| Normalized Error (%) | < 35 | 22.3 | 24.2 | 30.3 | 27.6 | 32.7 | 27.5 |
| **August 6, 1997** | | | | | | | |
| Observed Peak (ppb) | | 154 | 154 | 154 | 154 | 154 | 154 |
| Modeled Peak (ppb) | | 174.1 | 228.1 | 149.3 | 217.9 | 253.0 | 172.5 |
| Unpaired Peak (%) | +/- 20 | 13.0 | 48.1 | -3.0 | 41.5 | 64.3 | 12.0 |
| Normalized Bias (%) | +/- 15 | -5.7 | -4.9 | -20.9 | 16.4 | 23.1 | -9.7 |
| Normalized Error (%) | < 35 | 24.2 | 26.2 | 29.9 | 34.8 | 39.2 | 29.0 |
| **August 7, 1997** | | | | | | | |
| Observed Peak (ppb) | | 150 | 150 | | 150 | 150 | |
| Modeled Peak (ppb) | | 159.7 | 189.1 | | 193.2 | 225.5 | |
| Unpaired Peak (%) | +/- 20 | 6.5 | 26.1 | | 28.8 | 50.3 | |
| Normalized Bias (%) | +/- 15 | -4.3 | -7.1 | | 19.7 | 23.6 | |
| Normalized Error (%) | < 35 | 30.2 | 23.9 | | 38.7 | 33.5 | |

Notes:

Statistical measures were calculated above a cutoff of 60 ppb for 48 monitors
The SJS-MM5 simulations do not include August 7, 1997
Gray shaded values lie outside the performance goal

**Table 6**. Modeled episode maximum 1-hr and 8-hr ozone (ppb) with 1997 and 2010 emissions for three model configurations.[a]

| Year and Type of Emissions | ENV-MM5 with CB4 | SJS-MM5 with SAPRC99 | CALMET with CB4 |
|---|---|---|---|
| | | **Episode maximum 1-hr ozone (ppb)** | |
| **1997 Weekday** | 171.4 | 170.4 | 172.0 |
| **2010 Weekday** | 134.6 | 156.0 | 137.7 |
| **Reduction from 1997 to 2010** | -21.5% | -8.5% | -19.9% |
| **1997 Weekend** | 175.6 | 197.4 | 200.0 |
| **2010 Weekend** | 125.4 | 153.9 | 135.2 |
| | | **Episode maximum 8-hr ozone (ppb)** | |
| **1997 Weekday** | 137.8 | 138.9 | 152.3 |
| **2010 Weekday** | 109.2 | 122.4 | 125.4 |
| **Reduction from 1997 to 2010** | -20.8% | -11.9% | -17.7% |
| **1997 Weekend** | 135.4 | 140.1 | 176.2 |
| **2010 Weekend** | 104.2 | 122.4 | 119.3 |

[a] The initial and boundary concentrations are the same for 1997 and 2010.

## Figures

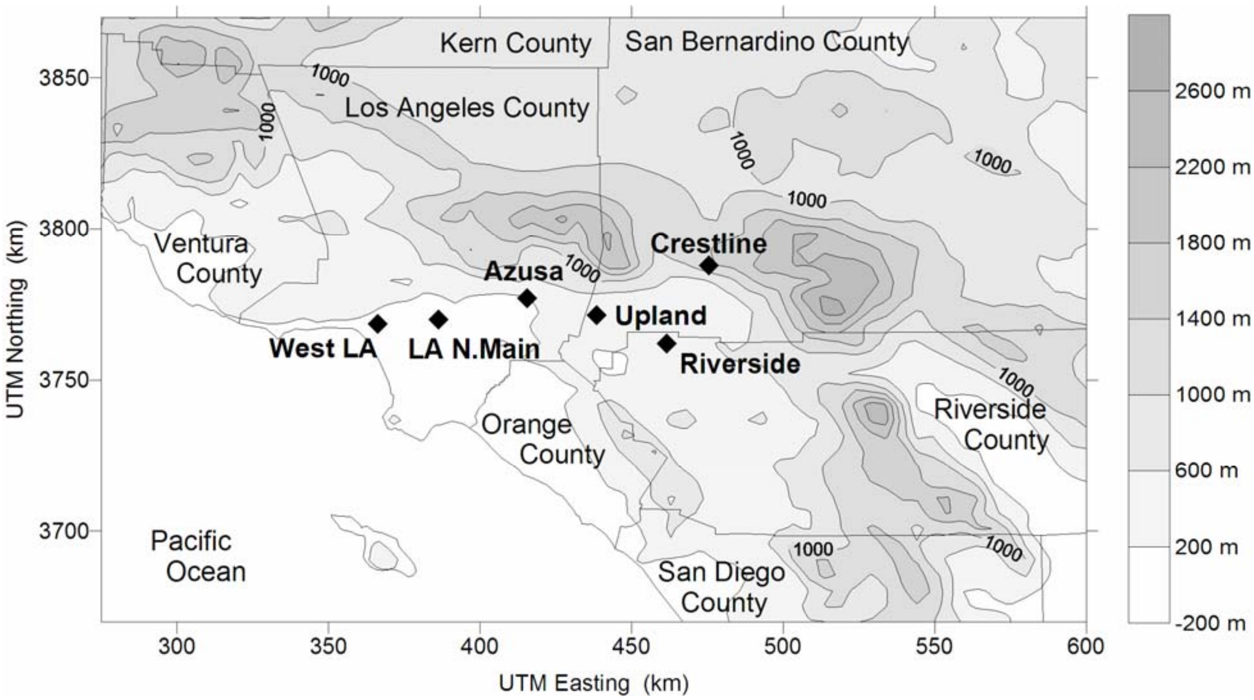


**Figure 1.** Ozone modeling domain in UTM zone 11 coordinates showing terrain (gridded at 5-km) and the locations of selected monitoring sites across the Los Angeles basin.

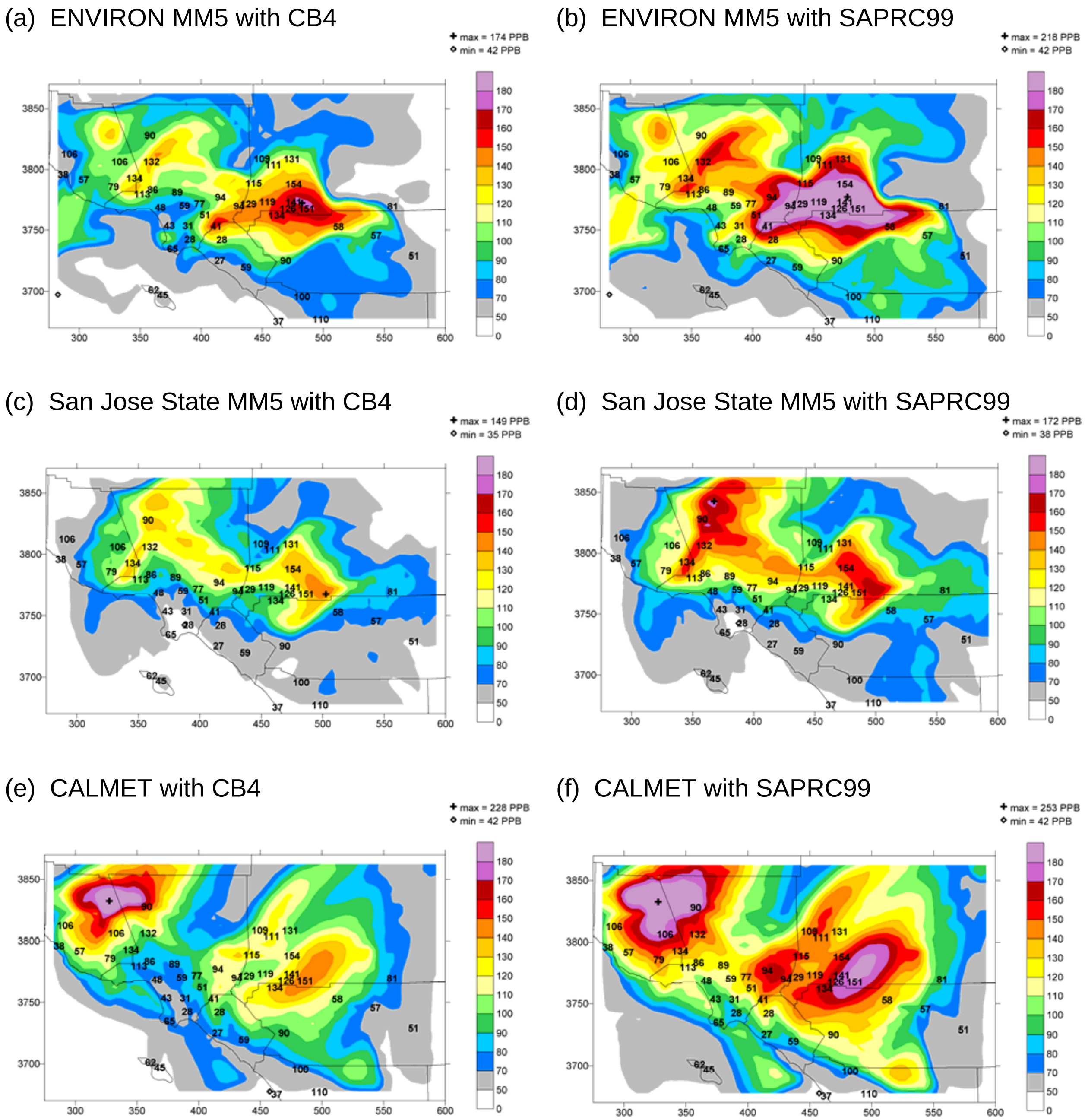


**Figure 2**. Daily maximum 1-hr ozone (ppb) for August 6, 1997 with six different CAMx model configurations (colored contours) and monitored values (numbers).

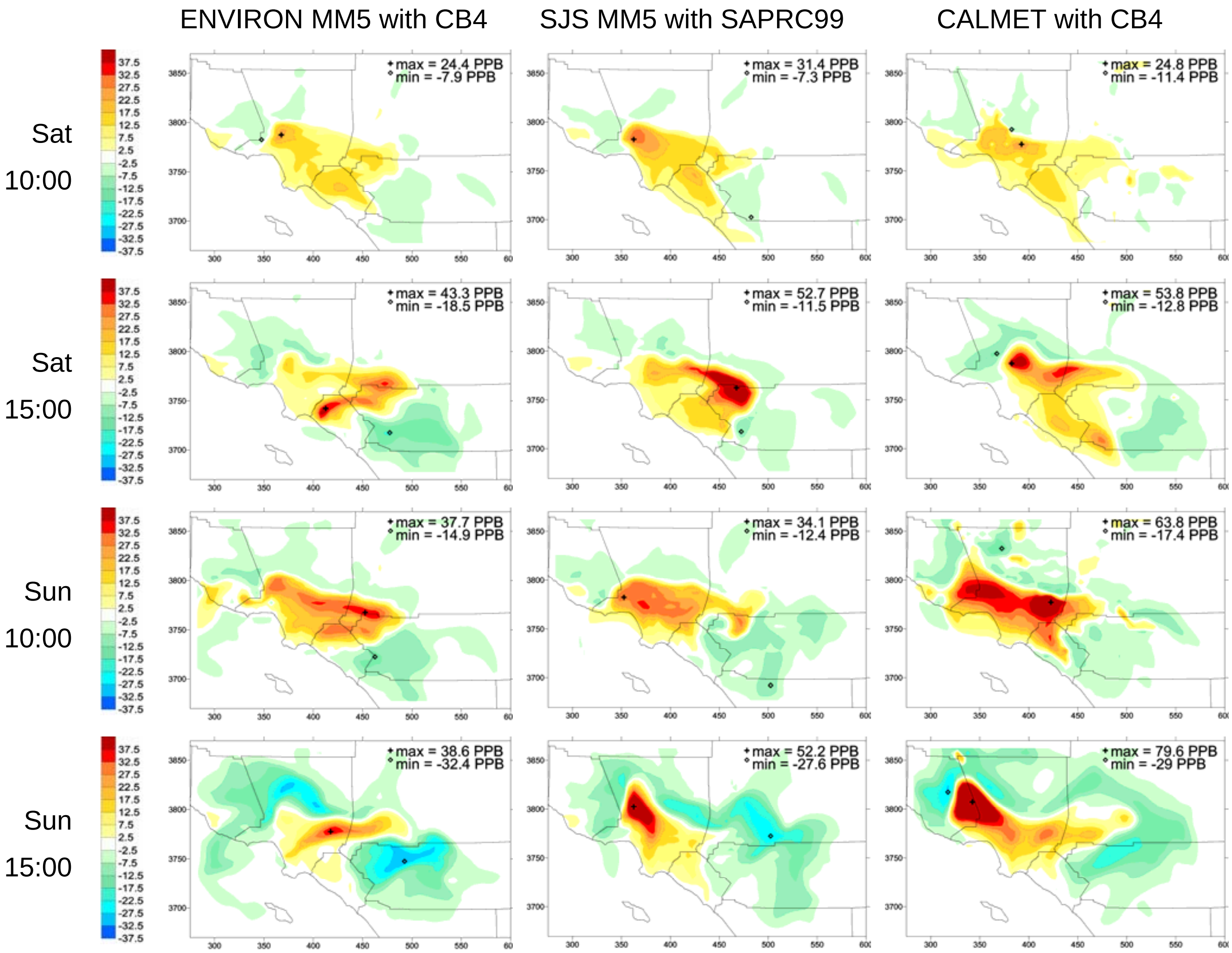


**Figure 3**. Differences in 1997 hourly ozone (ppb) between weekend and weekday emissions at 10 am and 3 pm on Saturday and Sunday with three model configurations. Results shown are weekend ozone minus weekday ozone.

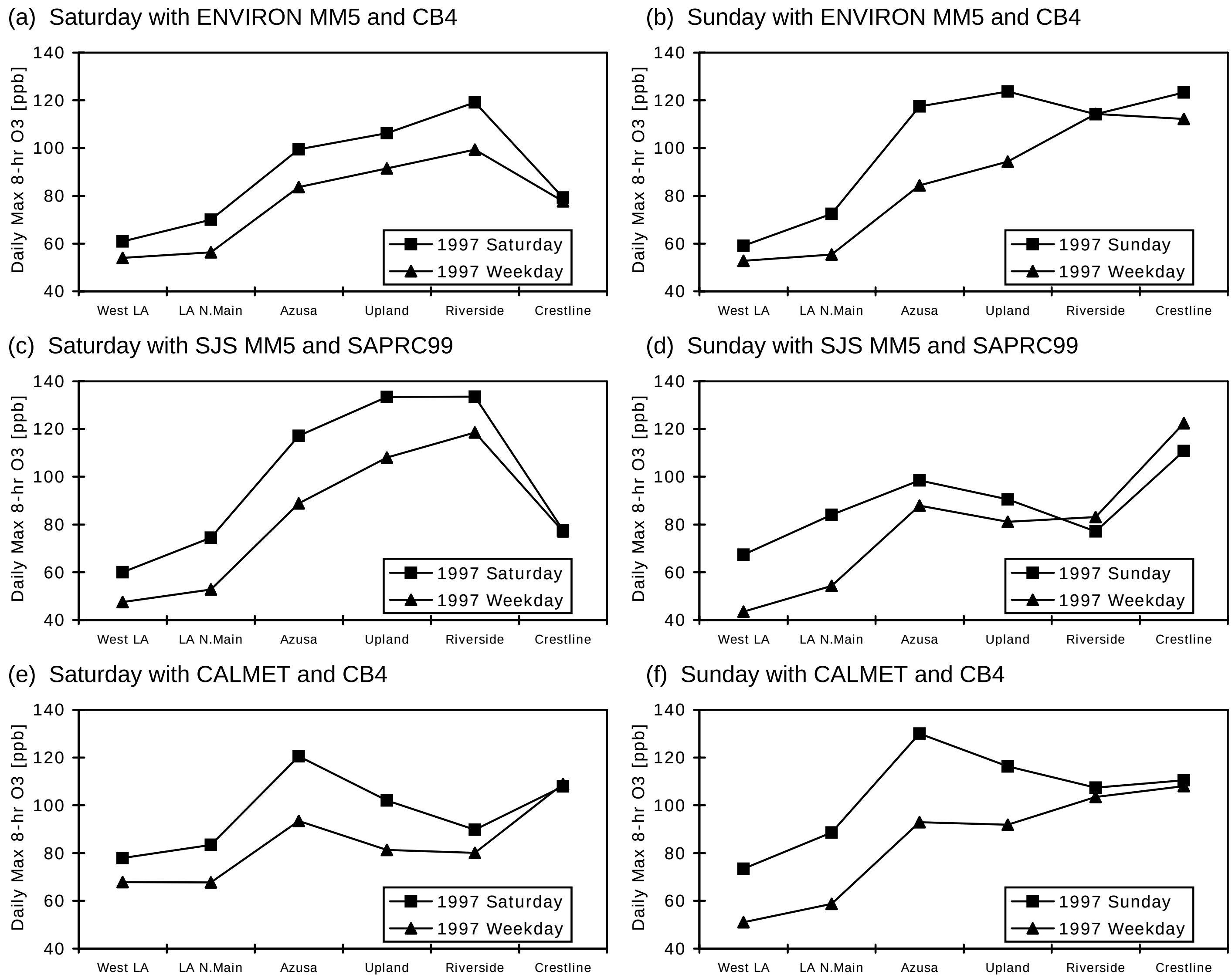


**Figure 4**. Daily maximum 8-hr ozone (ppb) for 1997 weekend and weekday emissions at monitoring sites across the Los Angeles basin with three model configurations.

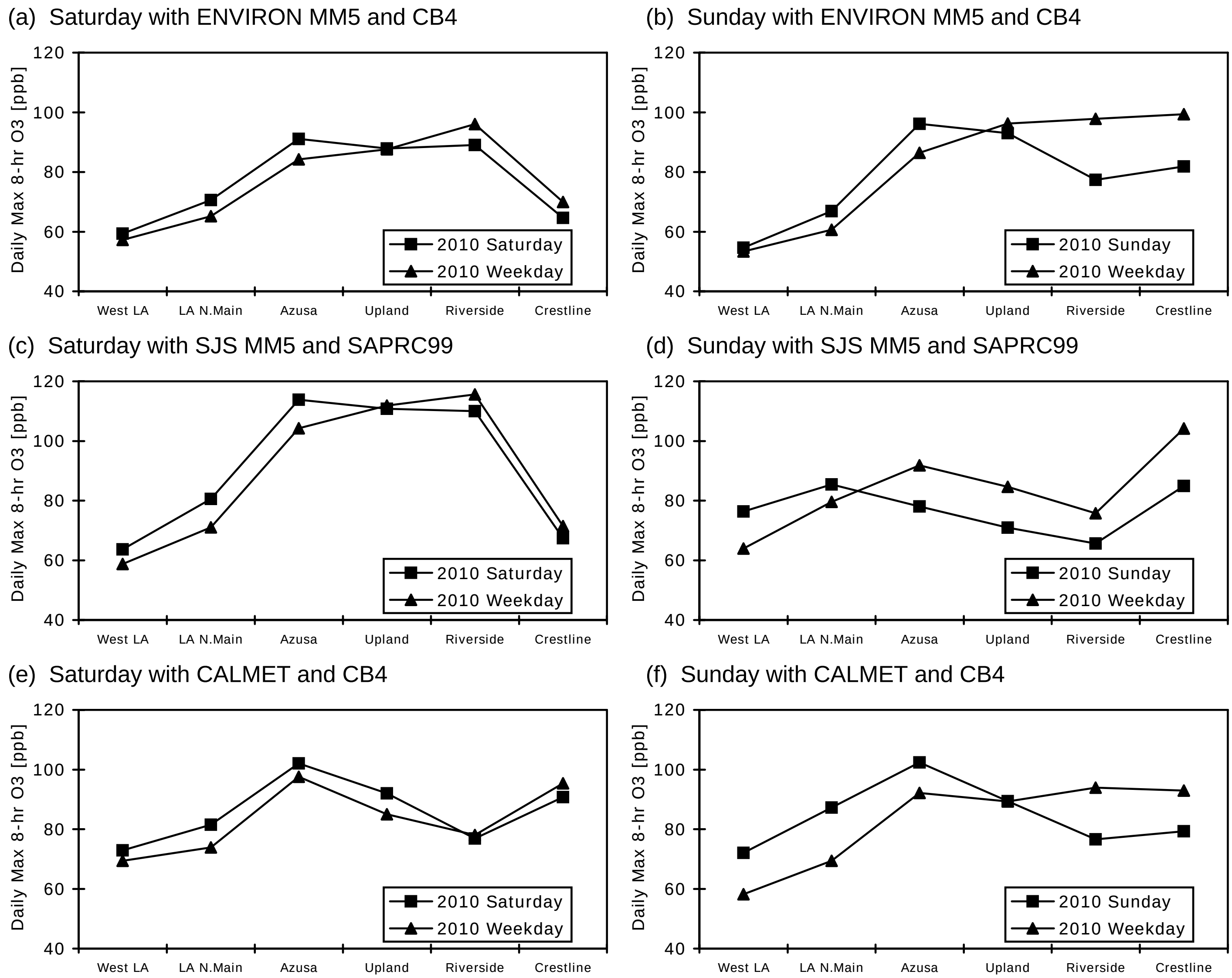


**Figure 5**. Daily maximum 8-hr ozone (ppb) for 2010 weekend and weekday emissions at monitoring sites across the Los Angeles basin with three model configurations. The initial and boundary concentrations are the same as for 1997.

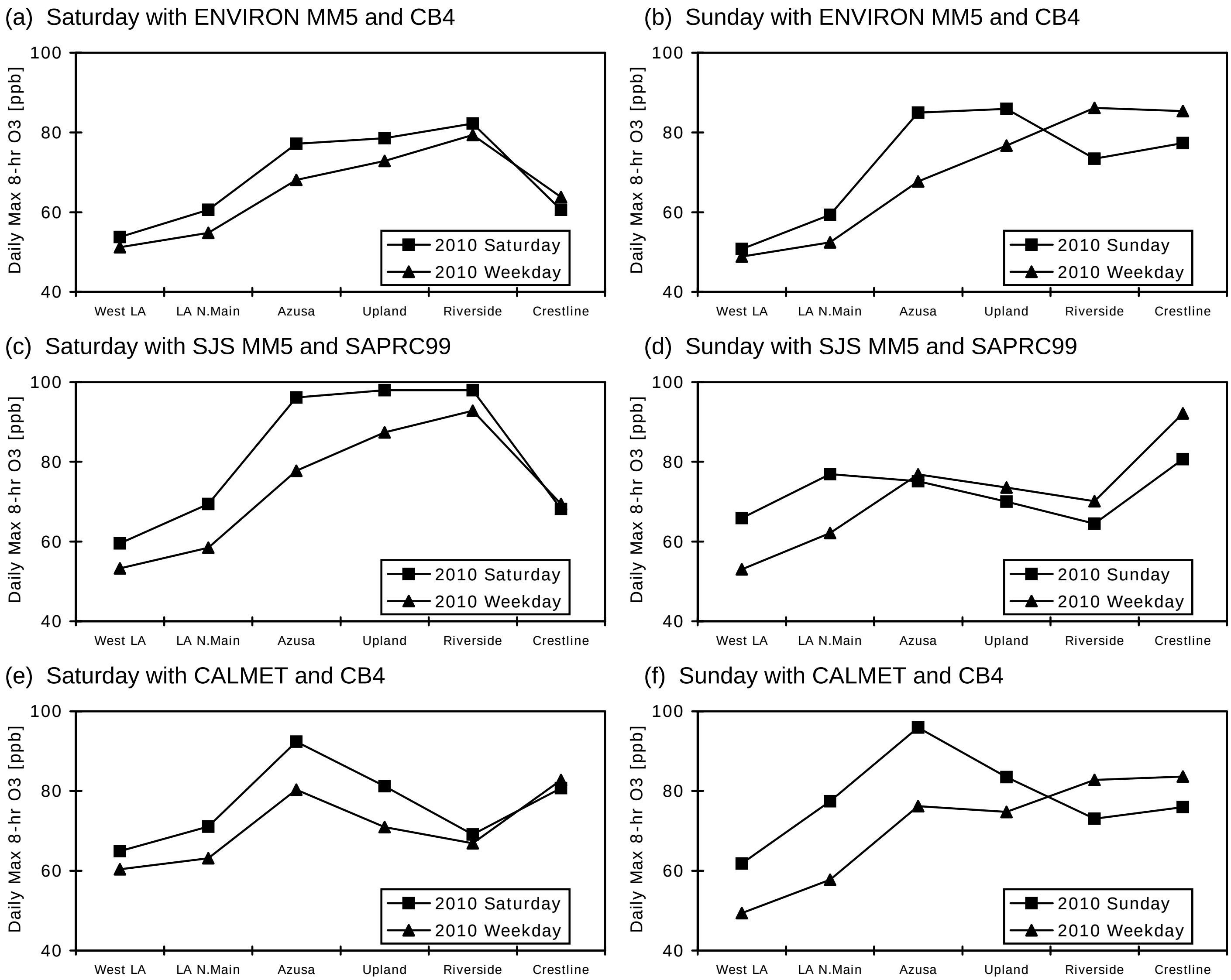


**Figure 6**. Daily maximum 8-hr ozone (ppb) for 2010 weekend and weekday emissions at monitoring sites across the Los Angeles basin for three model configurations. Same as Figure 5 except that the initial and boundary concentrations for ROG were reduced from 100 ppbC to 60 ppbC and those for NOx from 1 ppb to 0.53 ppb.

Modeling Plan

# Weekend/Weekday Ozone Changes in Los Angeles With 2010 Emission Inventories

CRC Project A-56

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# INTRODUCTION

CRC project A-56 is using proximate ozone modeling to investigate weekday/weekend (WD/WE) ozone differences for Los Angeles with 2010 future year emission inventories. The ozone modeling is based on the August 3-7, 1997 episode that occurred during the Southern California Ozone Study (SCOS). The California Air Resources Board (ARB) has provided 1997 and 2010 emission inventories for this project (Allen, 2005) and data on WD/WE differences in emissions activity levels (Sullivan et al., 2003).

Three alternate sets of meteorological input data are available to this project for modeling the August SCOS episode:

1. ENVIRON MM5 data used in the pervious WD/WE modeling study for CRC (Yarwood et al., 2003).
2. San Jose State MM5 data developed for the ARB (Boucouvala et al., 2003; Boucouvala and Bornstein, 2003).
3. SCAQMD CALMET data (Mitsutomi, 2005) for the 2003 AQMP (SCAQMD, 2004).

The MM5 is a prognostic meteorological model (Dudhia, 1993) whereas CALMET is a diagnostic model (Earth Tech, 2004).

## Proximate Modeling

Proximate modeling is approach to ozone modeling that develops standardized emission inventories for a weekday, Friday, Saturday and Sunday. These standardized emission inventories eliminate day-to-day variations in anthropogenic emissions that are unrelated to the day-of-week (e.g., temperature effects) in order to focus exclusively on day-of-week effects. Strengths of the proximate modeling approach are that WD/WE emissions changes are clearly understood and documented, and that weekend may be positioned anywhere within the modeling episode without regard to whether days were actually on a weekend. This approach was employed successfully in ENVIRON’s earlier proximate ozone modeling study for CRC (Yarwood et al., 2002 and 2003).

## Purpose of the Modeling Plan

The modeling plan reports the results of Tasks 1-3 of Project A-56. The purposes are to:

1. Present ozone model performance evaluation results for the August 3-7,1997 SCOS episode with the three alternate meteorological input data sets using the 1997 ARB emission inventory.

2. Present the results of a tracer re-circulation analysis for the August 3-7,1997 SCOS episode with three alternate meteorological input datasets.

3. Summarize the 1997 and 2010 modeling emission inventories provided by the ARB.

4. Present the WD/WE emission changes for 1997 and 2010 emission inventories calculated from the data of Sullivan et al. (2003) and Allen (2005).

5. Recommend model configuration(s) to be used for the 2010 proximate modeling analysis.

## OZONE MODEL PERFORMANCE EVALUATION

CAMx modeling was performed using the old Air Quality Management Plan (AQMP) domain of 65 by 40, 5-km grid cells shown in Figure 1. This domain was used because all three meteorological model inputs could be mapped to this domain with little or no coordinate distortion. CAMx vertical layer structures were matched to the meteorological model resulting in different layer structures in each case as summarized in Table 1. The CAMx layer structure used with the ENVIRON MM5 data was retained from the previous WD/WE modeling study and has some aggregation of MM5 layers above the surface layer. The CAMx layer structures used with the SJS-MM5 and CALMET data exactly match the met model layers to minimize the assumptions in transferring meteorological information to CAMx.

**Table 1**. CAMx layer structures used with three different meteorological input datasets.

| | ENVIRON MM5 | San Jose State MM5 | SCAQMD CALMET |
|---|---|---|---|
| Number of CAMx layers | 10 | 21 | 16 |
| CAMx model top (m agl) | 4091 | 5000 | 4644 |
| Number of layers below 1500 m | 7 | 13 | 10 |
| Surface layer depth (m) | 60 | 15 | 20 |

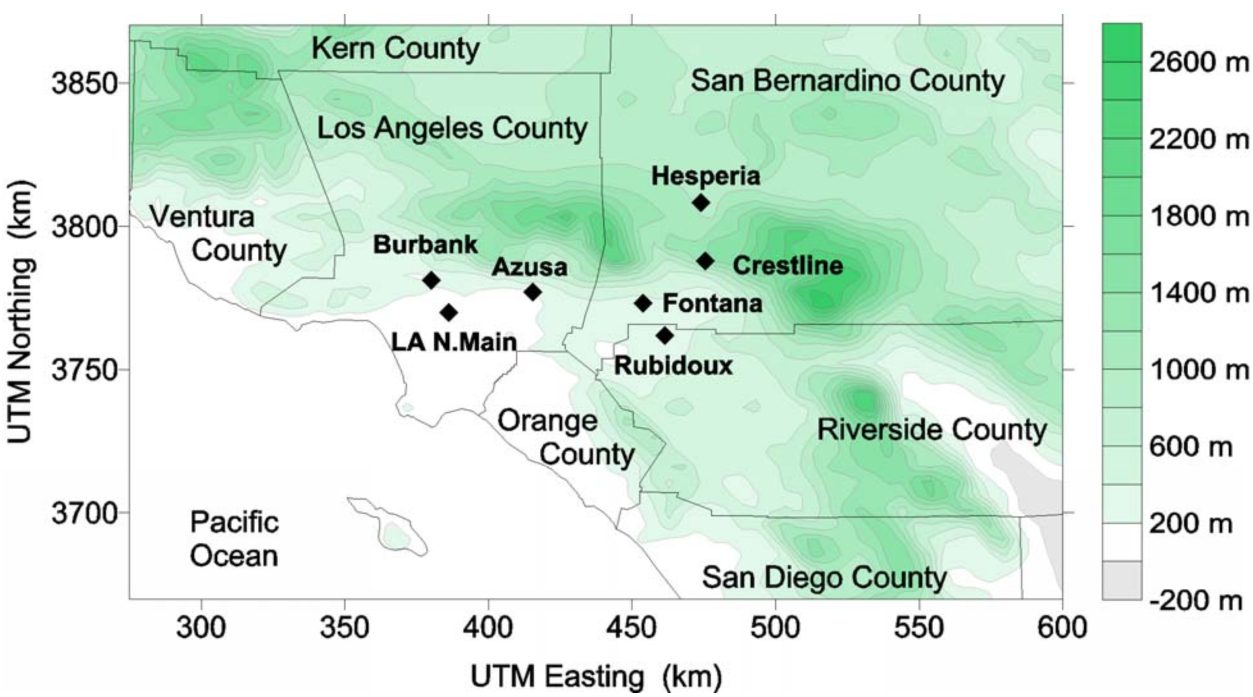


**Figure 1**. CAMx modeling domain for the Los Angels area showing terrain elevation.

## ENVIRON MM5

The ENVIRON MM5 data (ENV-MM5) have been used in a previous proximate modeling study of WD/WE ozone for the August 1997 SCOS episode (Yarwood et al., 2003). This study has a newer emission inventory from the ARB and a newer version of CAMx (v4.20). Model performance evaluation was performed using the 1997 base emissions provided by ARB rather than adjusted WD/WE emissions developed here for proximate modeling. Model performance evaluation focused on 1-hour, rather the 8-hour, averages to avoid cancellation of errors within 8-hour time averaging.

Model performance for ozone with the ENV-MM5 data is good with the CB4 mechanism (Gery et al., 1989) but poor with the SAPRC99 mechanism (Carter, 2000). The basic reason for poorer performance with SAPRC99 is more rapid ozone production leading to ozone levels that exceed those observed. This result does not support a conclusion that one chemical mechanism is more accurate than another because modeled ozone levels depend upon other factors, such as the emission inventory and the meteorology, in addition to chemistry. In fact, ozone model performance with the San Jose State MM5 data (SJS-MM5) is better with SAPC99 than CB4 confirming that meteorology and chemistry can have compensating influences.

**Table 2.** Model performance statistical measures for 1-hour ozone.

| | EPA Goal | CB4 | | | SAPRC99 | | |
|---|---|---|---|---|---|---|---|
| | | ENV-MM5 | CALMET | SJS-MM5 | ENV-MM5 | CALMET | SJS-MM5 |
| **August 5, 1997** | | | | | | | |
| Observed Peak (ppb) | | 187.0 | 187.0 | 187.0 | 187.0 | 187.0 | 187.0 |
| Modeled Peak (ppb) | | 157.2 | 147.0 | 138.9 | 188.3 | 189.5 | 164.3 |
| Unpaired Peak (%) | +/- 20 | -15.9 | -21.4 | -25.7 | 0.7 | 1.3 | -12.2 |
| Normalized Bias (%) | +/- 15 | -11.7 | -8.6 | -26.4 | 9.1 | 15.2 | -13.1 |
| Normalized Error (%) | < 35 | 22.3 | 24.2 | 30.3 | 27.6 | 32.7 | 27.5 |
| **August 6, 1997** | | | | | | | |
| Observed Peak (ppb) | | 154.0 | 154.0 | 154.0 | 154.0 | 154.0 | 154.0 |
| Modeled Peak (ppb) | | 174.1 | 228.1 | 149.3 | 217.9 | 253.0 | 172.5 |
| Unpaired Peak (%) | +/- 20 | 13.0 | 48.1 | -3.0 | 41.5 | 64.3 | 12.0 |
| Normalized Bias (%) | +/- 15 | -5.7 | -4.9 | -20.9 | 16.4 | 23.1 | -9.7 |
| Normalized Error (%) | < 35 | 24.2 | 26.2 | 29.9 | 34.8 | 39.2 | 29.0 |
| **August 7, 1997** | | | | | | | |
| Observed Peak (ppb) | | 150.0 | 150.0 | | 150.0 | 150.0 | |
| Modeled Peak (ppb) | | 159.7 | 189.1 | | 193.2 | 225.5 | |
| Unpaired Peak (%) | +/- 20 | 6.5 | 26.1 | | 28.8 | 50.3 | |
| Normalized Bias (%) | +/- 15 | -4.3 | -7.1 | | 19.7 | 23.6 | |
| Normalized Error (%) | < 35 | 30.2 | 23.9 | | 38.7 | 33.5 | |

Notes:

Statistical measures were calculated above a cutoff of 60 ppb in the observed values
Statistical measures outside the EPA goal are shaded
The SJS-MM5 simulations do not include August 7, 1997

Statistical evaluation of 1-hour ozone model performance (Table 2) shows that CAMx with ENV-MM5 meteorological data and the CB4 mechanism meet the established EPA performance goals for the accuracy of the unpaired peak (within +/- 20%), normalized bias (within +/- 15%) and normalized error (within 35%) on August 5-7, 1997. With the SAPRC99 mechanism, CAMx with ENV-MM5 meteorological data exceeds the performance goals for the unpaired peak and the normalized bias on August 6 and 7, and for the normalized error on August 7. Model performance was not evaluated for the August 3 and 4 spin-up days.

Isopleth plots of daily maximum 1-hr ozone in August 5 and 6, 1997, are shown in Figure 1 for the ENV-MM5 data. Observed values superimposed as numbers. Spatial patterns of modeled ozone with CB4 and SAPRC99 are similar but ozone levels are much higher with SAPRC99. The following description of model performance is restricted to the simulation with CB4 chemistry that performed well.

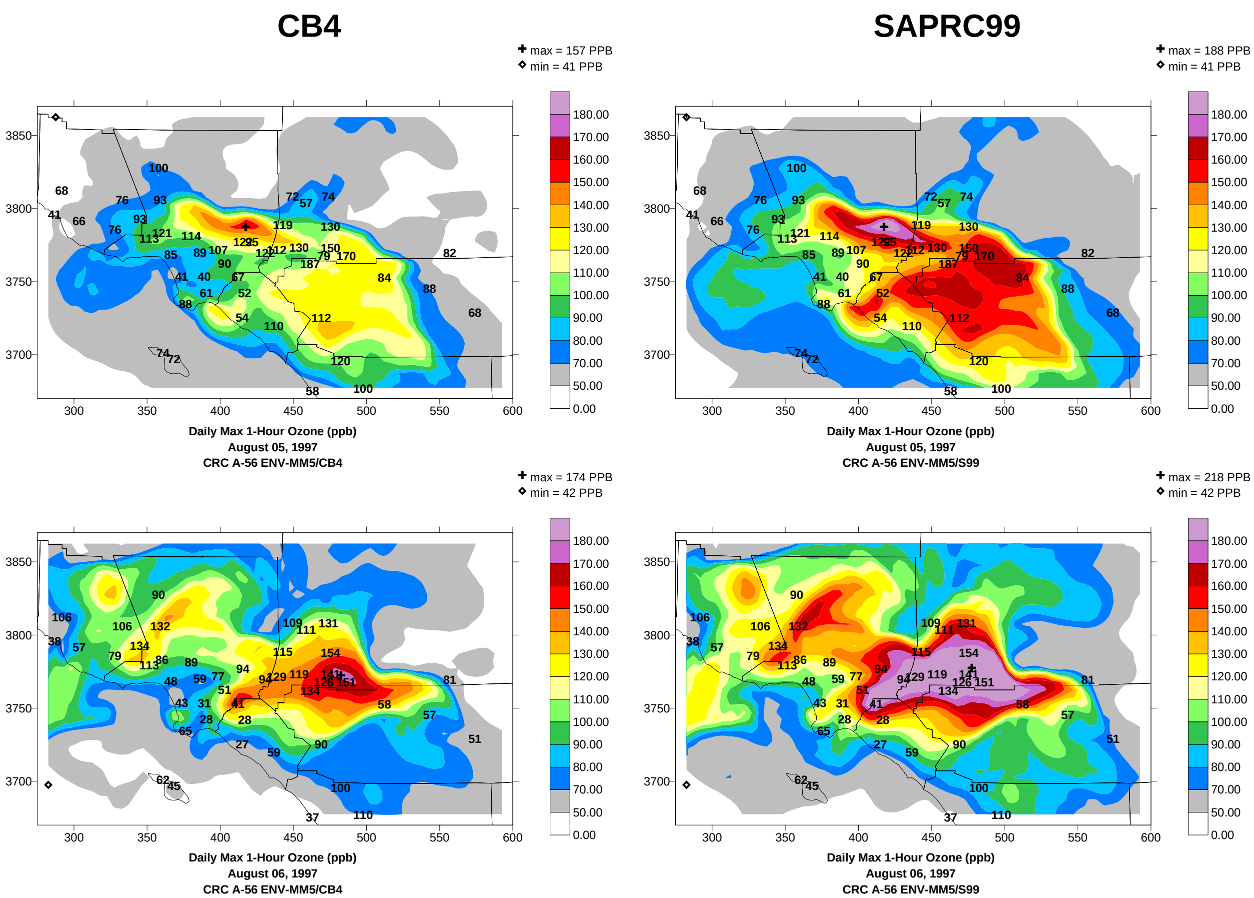


**Figure 2**. Daily maximum 1-hour ozone with ENVIRON MM5 meteorology for August 5 (top) and August 6 (bottom) 1997.

The spatial agreement for 1-hr maximum ozone on August 5th with ENV-MM5/CB4 is fairly good (Figure 2). The observed peak was 187 ppb near Riverside where the model prediction was about 110 ppb. The model generally under-predicted the highest observed ozone levels of 150-187 ppb in the Riverside/San Bernardino area by about 40-70 ppb on this day. The modeled peak of 157 ppb was in the San Gabriel Mountains ~50 km northwest of the observed peak and close to an observed value of 122 ppb. An area of high ozone (about 130-150 ppb) was predicted along the southern side of the San Gabriel Mountains consistent with observed values in this area. High ozone (~130 ppb) also was predicted in the south of the modeling domain, near Temecula, close to observed values of 112 ppb and 120 ppb. The model correctly predicted a strong gradient from lower ozone near the coast to higher ozone inland, but tended to over-predict low values observed near the coast. Slightly elevated ozone was predicted offshore (>50 ppb) at Catalina Island where observed ozone was 72 to 74 ppb.

The spatial agreement for 1-hr maximum ozone on August 6$^{th}$ with ENV-MM5/CB4 is better than for August 5$^{th}$ (Figure 2). The observed peak was 154 ppb near San Bernardino where the model prediction is about 140 ppb. The modeled peak of 174 ppb was also near San Bernardino only ~15 km south of the observed peak and close to an observed value of 151 ppb. High ozone (about 130-140 ppb) also was predicted in the San Fernando Valley close to observed values of 132 ppb and 134 ppb. An isolated area of predicted high ozone (~130 ppb) in northwest Ventura County is due to emissions from a wildfire that occurred there on this day. The model correctly predicted a strong gradient from lower ozone near the coast to higher ozone inland, but tended to over-predict low values observed near the coast and mid-basin. Slightly elevated ozone was predicted offshore (~50 ppb) at Catalina Island where observed ozone was 45 to 62 ppb.

## SAN JOSE STATE MM5

Model performance for ozone with the San Jose State MM5 data (SJS-MM5) is good with the SAPRC99 mechanism but poor with the CB4 mechanism. This result is opposite the findings with the ENV-MM5 data described above. There are strong similarities in the spatial patterns of ozone predicted using the SJS-MM5 and ENV-MM5 meteorological data, but ozone levels tend to be lower with the SJS-MM5 data. Consequently, the stronger ozone production from SAPRC99 works better with the SJS-MM5 data whereas CB4 works better with the ENV-MM5 data. The tracer analyses, described below, suggest that the SJS-MM5 data tend to produce lower ozone than the ENV-MM5 data because there is stronger boundary layer ventilation by slope flows up the San Gabriel Mountains (and possibly other terrain) with the SJS-MM5 data.

Statistical evaluation of 1-hour ozone model performance (Table 2) shows that with SJS-MM5 meteorological data and the SAPRC99 mechanism CAMx meets the established EPA performance goals on August 5 and 6, 1997. There is no evaluation for August 7 because the SJS-MM5 simulation ended early in the morning of August 7, 1997. With the CB4 mechanism, CAMx performance is outside the goals for the unpaired peak on August 5 and 6, and for the normalized bias on August 6.

Isopleth plots of daily maximum 1-hr ozone in August 5 and 6, 1997, are shown in Figure 3 for the SJS-MM5 data. Spatial patterns of modeled ozone with SAPRC99 and CB4 are similar but ozone levels are much lower with CB4. The following description of model performance is restricted to the simulation with SAPRC99 chemistry that performed well.

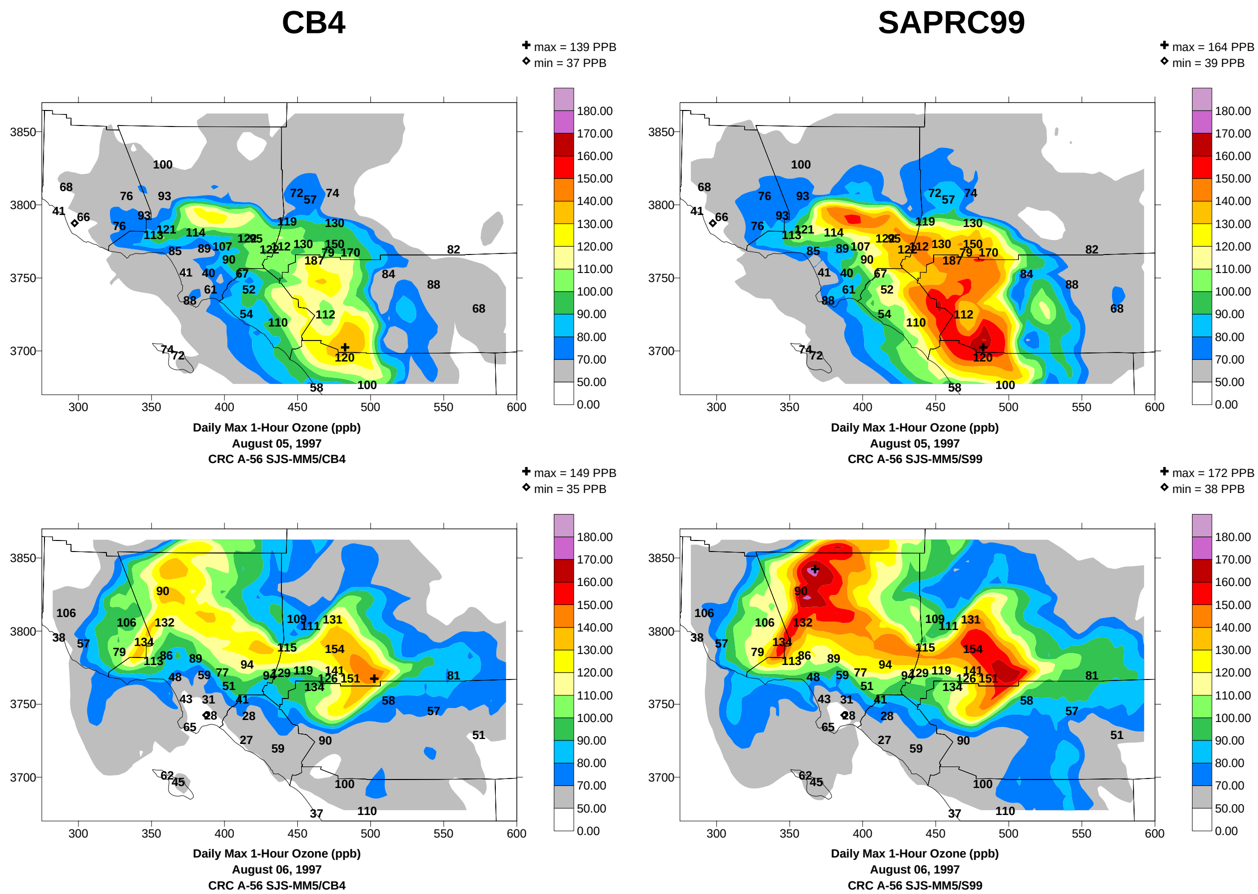


**Figure 3**. Daily maximum 1-hour ozone with San Jose State MM5 meteorology for August 5 (top) and August 6 (bottom) 1997.

The spatial agreement for 1-hr maximum ozone on August 5$^{th}$ with SJS-MM5/SAPRC99 is fairly good (Figure 3). The observed peak was 187 ppb near Riverside where the model prediction is about 140 ppb. The model generally under-predicted the highest observed ozone levels of 150-187 ppb in the Riverside/San Bernardino area by about 20-40 ppb on this day. The modeled peak of 164 ppb was in the south of the modeling domain, near Temecula, close to an observed value of 120 ppb. High ozone (about 130-150 ppb) was predicted along the southern side of the San Gabriel Mountains consistent with observed values in this area. The model correctly predicted a strong gradient from lower ozone near the coast to higher ozone inland. Slightly elevated ozone was predicted offshore (~50 ppb) at Catalina Island where observed ozone was 72 to 74 ppb.

The spatial agreement for 1-hr maximum ozone on August 6$^{th}$ with SJS-MM5/SAPRC99 is better than for August 5$^{th}$ (Figure 3). The observed peak was 154 ppb near San Bernardino where the model prediction is about 150 ppb. The modeled high ozone levels in the Riverside/San Bernardino agree very well with the observed values on this day. The modeled peak of 172 ppb was in northern Los Angeles County and is likely due to emissions from a wildfire that occurred nearby in Ventura County on this day. High ozone (about 150 ppb) also was predicted in the San Fernando Valley close to observed values of 132 ppb and 134 ppb. The model correctly predicts a strong gradient from lower ozone near the coast to higher ozone inland. Slightly elevated ozone was predicted offshore (~50 ppb) at Catalina Island where observed ozone was 45 to 62 ppb.

## SCAQMD CALMET

Model performance for ozone with the SCAQMD CALMET data is poor for both the CB4 and SAPRC99 mechanisms. Ozone levels are higher with SAPRC99 than CB4.

Statistical evaluation of 1-hour ozone model performance (Table 2) shows that CAMx with CALMET meteorological failed to meet all performance goals with either the CB4 or SAPRC99 mechanism. Model performance may be considered better with CB4 than SAPRC99 because CB4 met 6 of 9 performance goals whereas SAPRC99 met only 3 of 9 performance goals. The CALMET/CB4 simulation met the normalized bias and error goals on all days but exceeded the unpaired peak performance goal on all days (August 5, 6 and 7).

Isopleth plots of daily maximum 1-hr ozone in August 5 and 6, 1997, are shown in Figure 4 for the CALMET data. Spatial patterns of modeled ozone with SAPRC99 and CB4 are similar. The following description of model performance is for the simulation with CB4 chemistry.

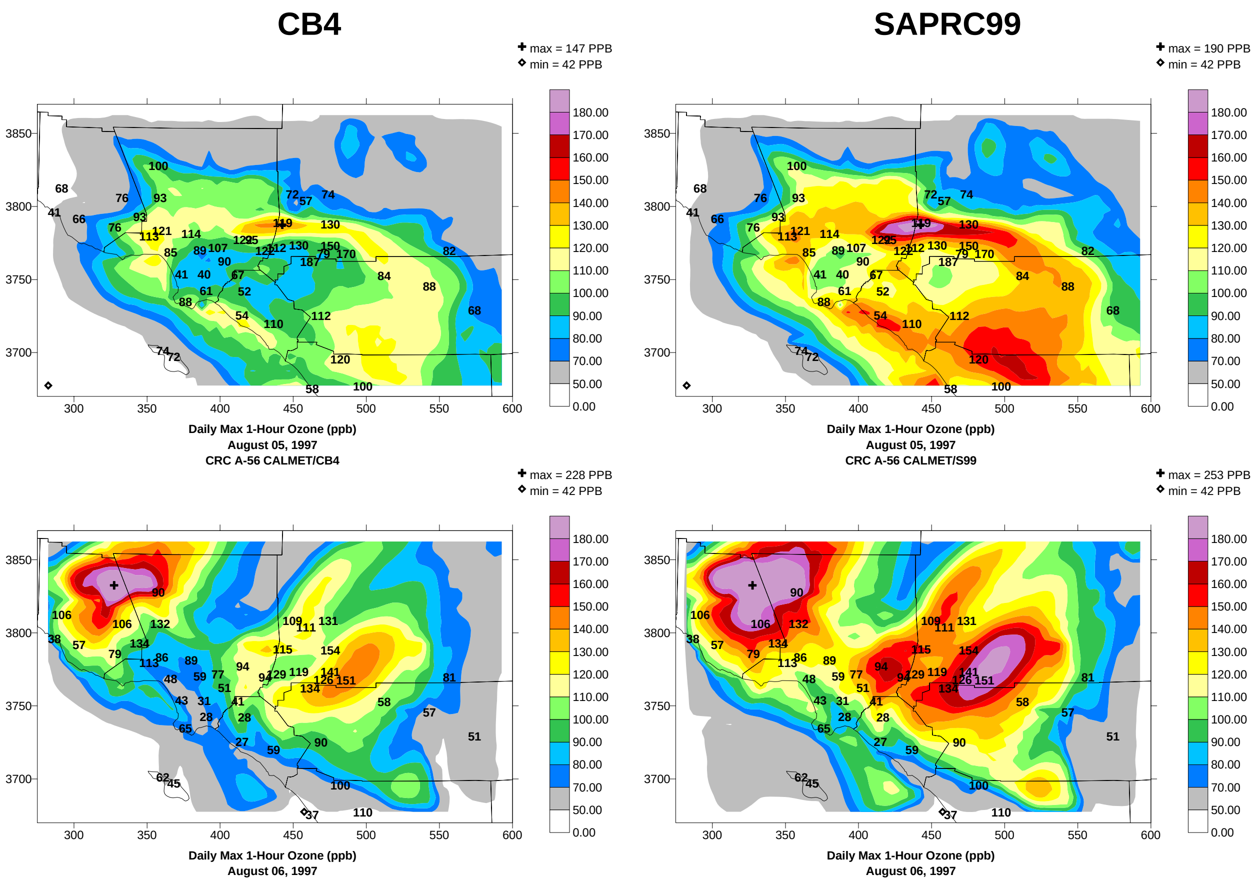


**Figure 4**. Daily maximum 1-hour ozone with SCAQMD CALMET meteorology for August 5 (top) and August 6 (bottom) 1997.

The spatial agreement for 1-hr maximum ozone on August 5 with CALMET/CB4 is poor (Figure 4). The observed peak was 187 ppb near Riverside where the model prediction is about 90 ppb. The model generally under-predicted the highest observed ozone levels of 150-187 ppb in the Riverside/San Bernardino area by about 60-90 ppb on this day. The modeled peak of 147 ppb was in the San Gabriel Mountains ~35 km northwest of the observed peak and close to an observed value of 119 ppb. An area of high ozone (about 120-150 ppb) was predicted along the San Gabriel Mountains but is north of observed high values in this area. High ozone (~110 ppb) also was predicted in the south of the modeling domain, near Temecula, close to observed values of 112 ppb and 120 ppb. The model over-predicted low values observed near the coast. Slightly elevated ozone was predicted offshore (~50 ppb) at Catalina Island where observed ozone was 72 to 74 ppb.

The spatial agreement for 1-hr maximum ozone on August 6 with CALMET/CB4 is better than for August 5 (Figure 4). The observed peak was 154 ppb near San Bernardino where the model prediction is about 120 ppb. The modeled high ozone levels in the Riverside/San Bernardino agree with the observed values on this day. The modeled peak of 228 ppb was in northern Ventura County and due to emissions from a wildfire that occurred on this day. High ozone values of 132 ppb and 134 ppb observed in the San Fernando Valley were under-predicted by about 20-40 ppb. The model correctly predicts a strong gradient from lower ozone near the coast to higher ozone inland. Slightly elevated ozone was predicted offshore (~50 ppb) at Catalina Island where observed ozone was 45 to 62 ppb.

## Ozone Time Series

Ozone time series for the Rubidoux monitor (location shown in Figure 1) are compared in Figure 5. The Rubidoux monitor is where the episode peak 1-hour ozone of 187 ppb was observed on August 5, 1997. All three meteorological realizations perform well in reproducing the observed morning rise and afternoon fall in ozone levels, but under-predict the episode peak concentration on August 5. The CALMET meteorology under-predicts the episode peak by wider margins than both MM5 cases. Daily ozone maximums are consistently higher with SAPRC99 than CB4, which sometimes improves and sometimes degrades model performance. The shapes of the daily ozone maximums agree better with observations for the MM5 cases than CALMET. Time-series for other monitors are included as an appendix and also show that the MM5 cases generally performed better than CALMET in describing the shapes of the daily ozone maximums. The appendix includes time-series for several monitors across the South Coast Air Basin (SoCAB).

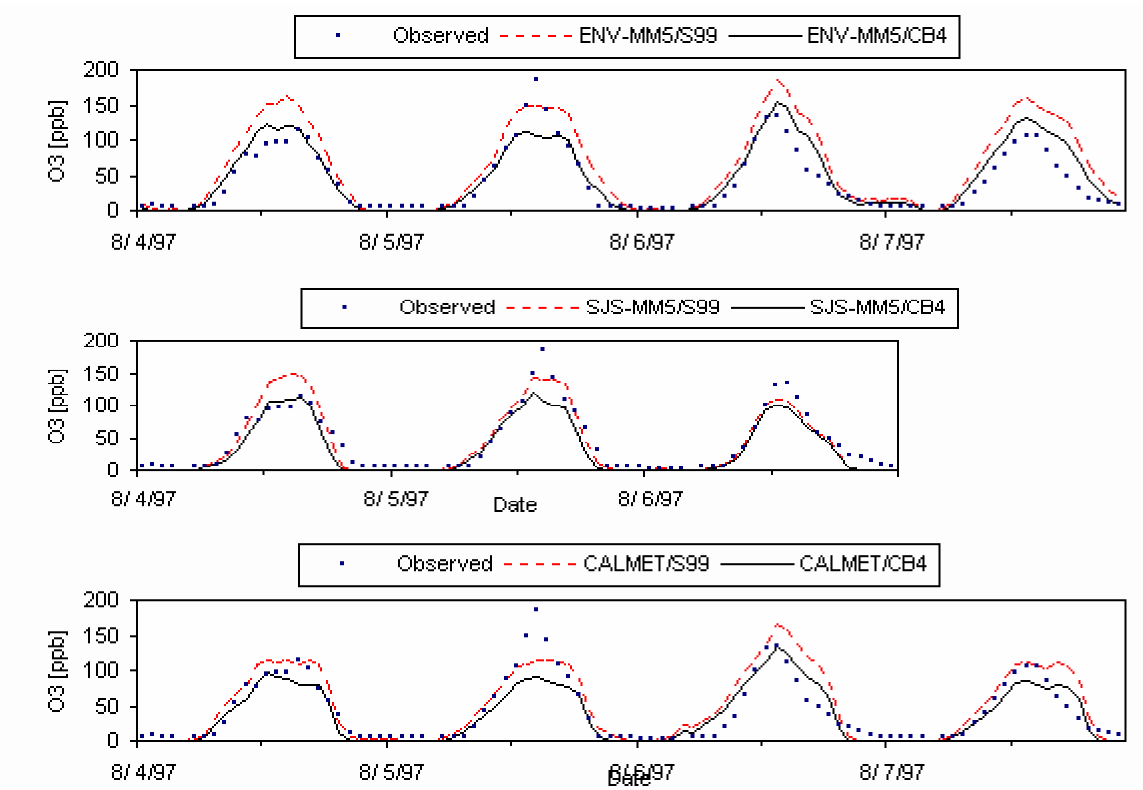


**Figure 5**. Ozone time series for the Rubidoux monitor (near Riverside) where the episode peak 1-hour ozone of 187 ppb was observed on August 5, 1997.

## Model Performance for NOx

We performed a limited model evaluation for ozone precursors to compare differences between simulations with different meteorology and chemistry. The evaluation was performed for NOx because this species has the most extensive precursor data available. We calculated the same statistical measures as for ozone, but with lower cutoff of 10 ppb in observed values (Table 3). The 10 ppb cutoff was chosen to eliminate values near the monitoring detection limit. The consequence of setting a 10 ppb cutoff is that most data used in the evaluation are at night and in the morning. There are no established performance goals for NOx statistical performance.

The model performance statistics for NOx show that there is little effect from switching between CB4 and SAPRC99 chemistry. This is likely because most of the data above the 10 ppb cutoff are at night and in the morning when CB4/SAPRC chemistry differences have less impact than during the day. Changing meteorology does affect the NOx performance statistics. NOx is over-predicted (positive bias) in all cases. The bias is greater with CALMET than either of the MM5 cases, and this is likely due differences in the nocturnal boundary layer depth predicted by different meteorological models. It is unclear how over-predicting surface NOx at night and in the early morning will influence ozone model performance without performing additional sensitivity tests with altered vertical mixing assumptions.

**Table 3.** Model performance statistical measures for 1-hour NOx.

| | CB4 | | | SAPRC99 | | |
|---|---|---|---|---|---|---|
| | ENV-MM5 | CALMET | SJS-MM5 | ENV-MM5 | CALMET | SJS-MM5 |
| **August 5, 1997** | | | | | | |
| Observed Peak (ppb) | 300 | 300 | 300 | 300 | 300 | 300 |
| Modeled Peak (ppb) | 430 | 465 | 388 | 429 | 465 | 388 |
| Unpaired Peak (%) | 43 | 55 | 29 | 43 | 55 | 29 |
| Normalized Bias (%) | 104 | 109 | 82 | 102 | 106 | 80 |
| Normalized Error (%) | 156 | 162 | 133 | 155 | 162 | 132 |
| **August 6, 1997** | | | | | | |
| Observed Peak (ppb) | 306 | 306 | 306 | 306 | 306 | 306 |
| Modeled Peak (ppb) | 336 | 594 | 281 | 336 | 593 | 280 |
| Unpaired Peak (%) | 10 | 94 | -8 | 10 | 94 | -9 |
| Normalized Bias (%) | 54 | 122 | 69 | 53 | 119 | 66 |
| Normalized Error (%) | 113 | 165 | 123 | 114 | 166 | 123 |
| **August 7, 1997** | | | | | | |
| Observed Peak (ppb) | 185 | 185 | | 185 | 185 | |
| Modeled Peak (ppb) | 220 | 580 | | 219 | 586 | |
| Unpaired Peak (%) | 19 | 213 | | 18 | 217 | |
| Normalized Bias (%) | 15 | 92 | | 15 | 94 | |
| Normalized Error (%) | 87 | 132 | | 88 | 135 | |

Notes:

Statistical measures calculated above a cutoff of 10 ppb in the observed values

## RECIRCULATION ANALYSIS

Several of the hypotheses advanced to explain the WD/WE ozone differences in the SoCAB involve re-circulation of ozone and/or precursors aloft or at the surface. An inert tracer analysis was conducted to investigate air re-circulation in the three alternate modeled wind fields for the SoCAB. Four tracers were released as follows:

1. Downtown LA (386.2 km, 3770.0 km) surface tracer release from at 6-9 am to evaluate the potential re-circulation of ozone/precursors from the morning downtown rush hour.

2. Downtown LA surface tracer release from at 4-7 pm to evaluate the potential re-circulation of ozone/precursors from the evening downtown rush hour.

3. Mid-basin (Claremont; 430.8 km, 3769.6 km) surface tracer release at 2-5 pm to evaluate the potential re-circulation of ozone/precursors at the surface from a typical high ozone location.

4. Mid-basin release tracer at 1000 m. aloft at 2-5 pm to evaluate the potential re-circulation of ozone/precursors aloft from a typical high ozone location.

The tracer experiments were performed on August 4-6 for each available meteorological realization (SJS- MM5, ENVIRON-MM5 and SCAQMD-CALMET). In each case, 3 million moles of inert tracer were released in CAMx at the specified location over a 3-hour period. For reference, 3 million moles of CO weigh about 90 tons.

The total amount of each tracer within the CAMx domain was calculated at each hour to investigate the residence time of the tracer within the model (i.e., how soon is each tracer advected out of the domain?) Figures 6 and 7 show time-series of total tracer mass for the 4 different tracer releases on August 4 (Figure 6) and August 5 (Figure 7). The following points are noted:

- Tracer concentrations rise over 3-hour periods corresponding to each release.
- Following each tracer release there is a period of several hours when the total tracer is constant at 3 million moles showing that CAMx conserves the tracer masses.
- Tracer mass starts to decline from 3 million moles when the wind fields start to advect tracer mass out of the CAMx domain.
- The CALMET meteorology retains tracers within the CAMx domain longer than either MM5 meteorology.
- The San Jose State meteorology generally retains tracers within the CAMx domain for the shortest period of time: meaning tracer mass starts to fall sooner and more rapidly with the SJS-MM5 meteorology.
- There is almost no difference between the surface and 1000 m releases at Claremont showing that all three meteorologies have a mixed layer at least 1000 m deep at Claremont at 2-5 pm on August 4 and 5.

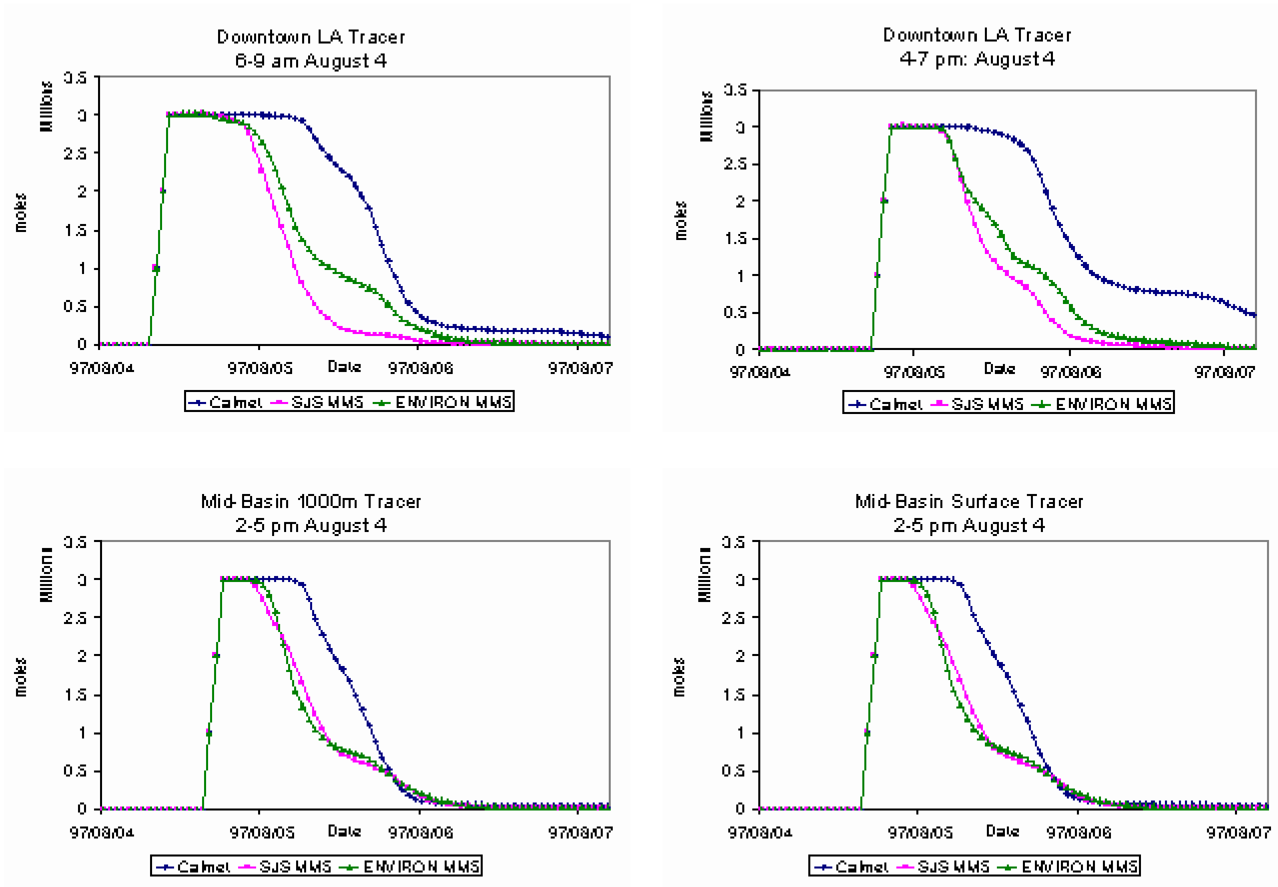


**Figure 6**. Inert tracer releases from several locations on August 4, 1997. The time series show the total tracer amount within the CAMx domain for different meteorological input data.

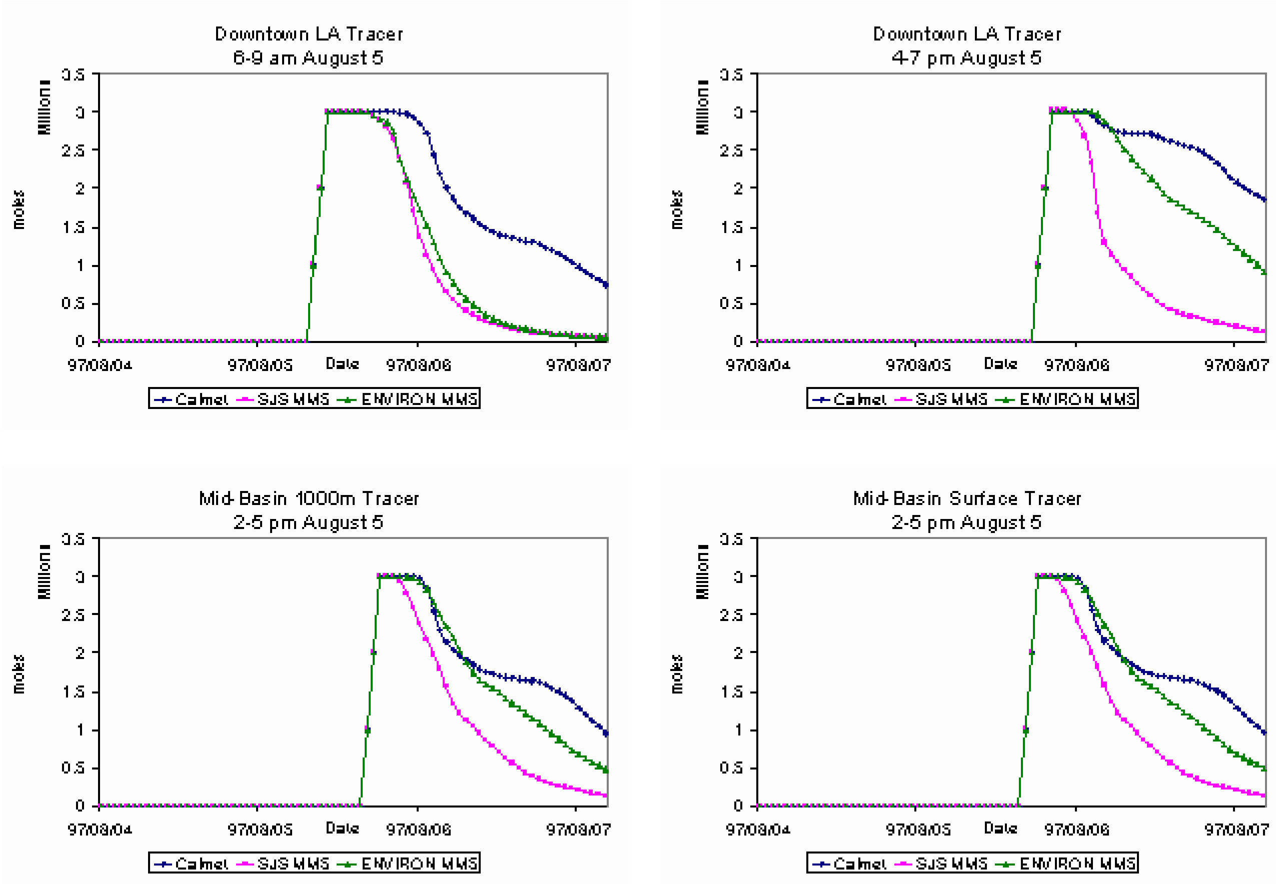


**Figure 7**. Inert tracer releases from several locations on August 5, 1997. The time series show the total tracer amount within the CAMx domain for different meteorological input data.

The time-series plots reveal differences in how long tracers are retained within the CAMx domain, but do not show how tracers move within the CAMx domain and are then lost from the CAMx domain. Horizontal and vertical cross-sections were used to find where tracers were located in three dimensions. Several examples of surface tracer distributions are shown in Figures 8-10 for 6 am on the day following each tracer release. These Figures confirm that the SJS-MM5 generally retains less tracer mass in the surface layer on the morning after a release. The fact that tracers are generally found in the interior of the domain rather than at a boundary suggests that the SJS-MM5 winds remove tracer mass from the surface layer by moving the tracer aloft.

The 3-D distribution of tracers was investigated by preparing plots of horizontal and vertical cross-sections. The tracer release from Downtown LA on the morning (6-9 am) of August 4 was studied in detail and cross-section plots are shown in Figures 11-13 for 4 pm on the same day. Each Figure shows (clockwise from bottom left) the surface concentration distribution, the aloft distribution at 1500 m, a West-East vertical cross-section and a South-North vertical cross-section. The vertical cross-sections extend from the ground to the model top (see Table 1) and have the 1500 m. level marked. When looking at the vertical cross-sections, remember that CAMx layers are not evenly spaced (layers are more closely spaced near the ground) and that CAMx is a terrain following model (the bottom of the model is not flat). The terrain is shown in

Figure 1. In particular, the South-North cross-sections ascend terrain that is ~1500 m. high at about the place where high surface tracer concentrations occur in Figures 11-13.

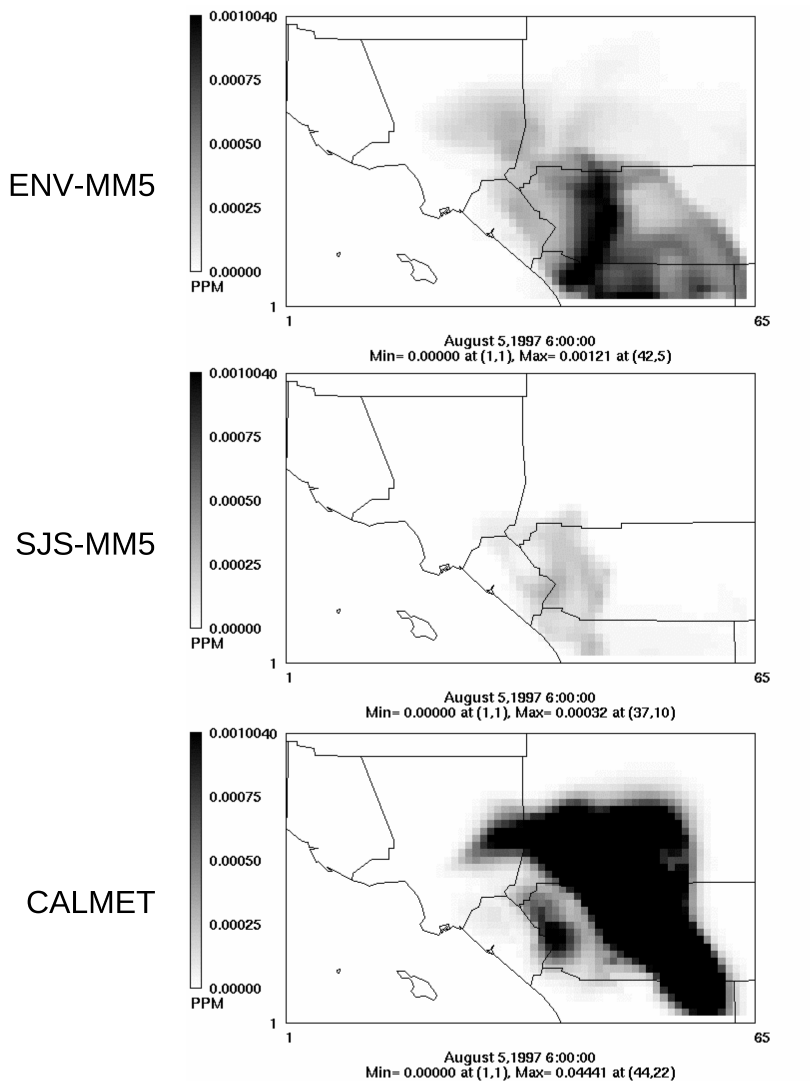


**Figure 8**. Modeled surface layer distribution at 6 am on August 5 of the tracer released from downtown LA at 6-9 am on August 4, 1997.

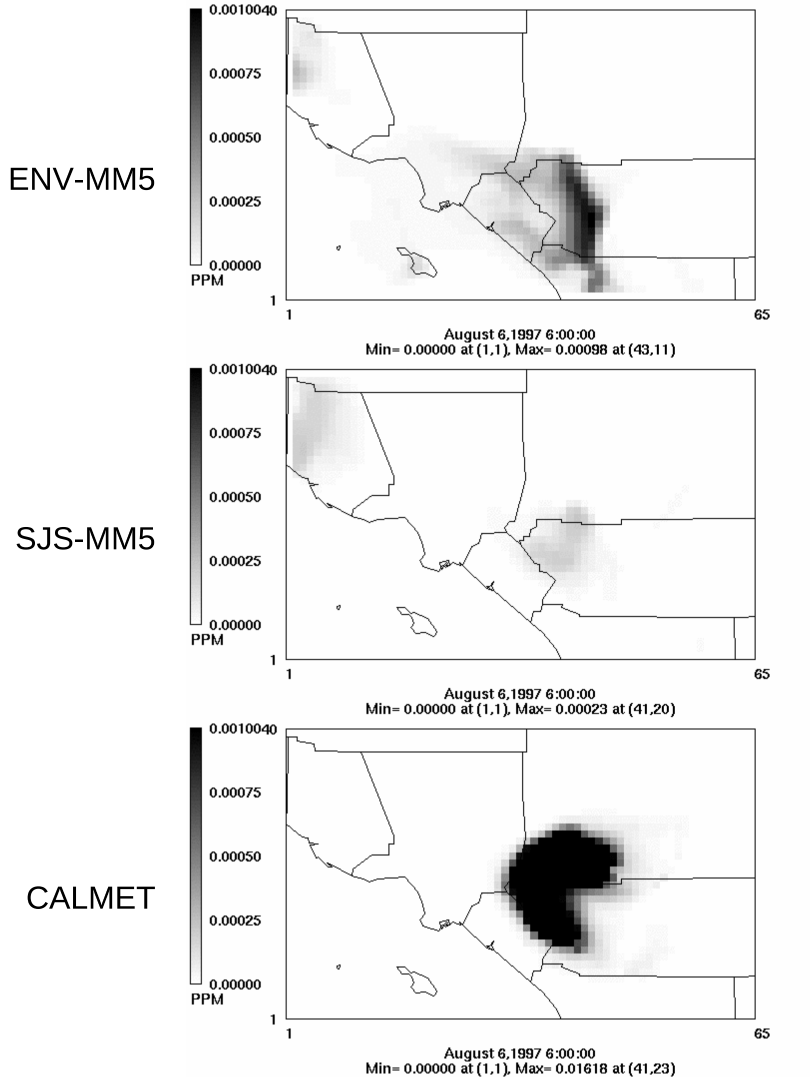


**Figure 9**. Modeled surface layer distribution at 6 am on August 6 of the tracer released from downtown LA at 6-9 am on August 5, 1997.

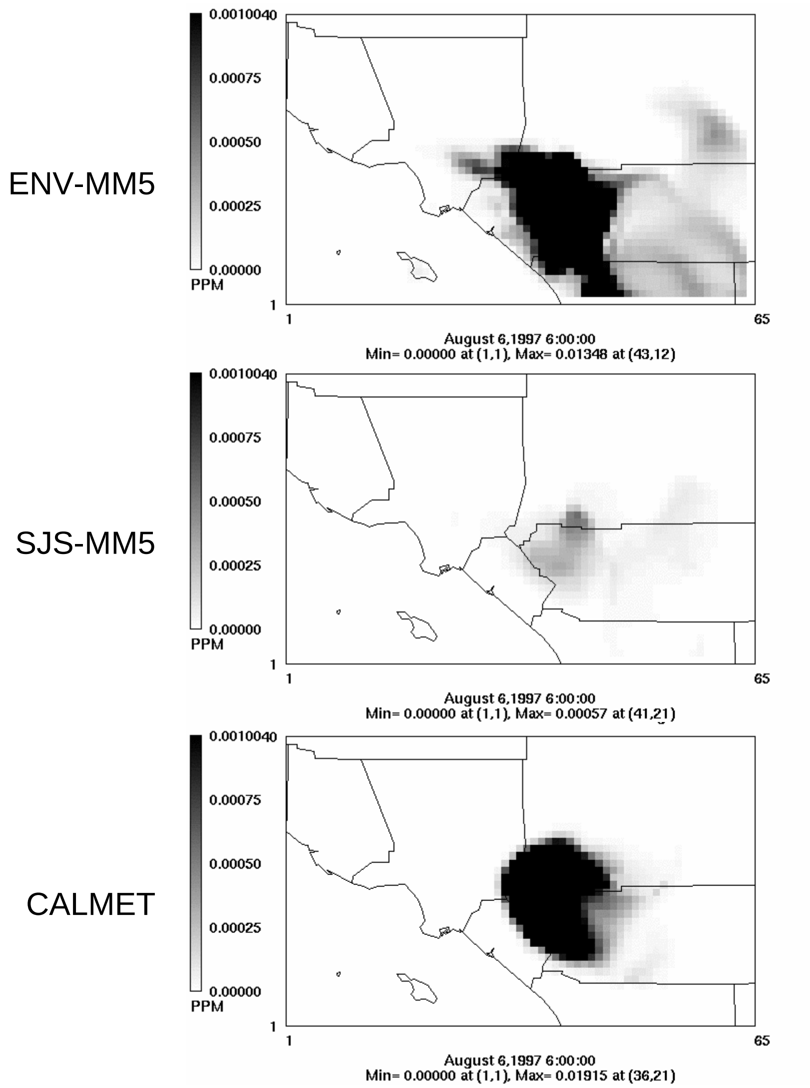


**Figure 10**. Modeled surface layer distribution at 6 am on August 6 of the tracer released from Claremont (mid-basin, surface release) at 2-5 pm on August 5, 1997.

## ENVIRON MM5

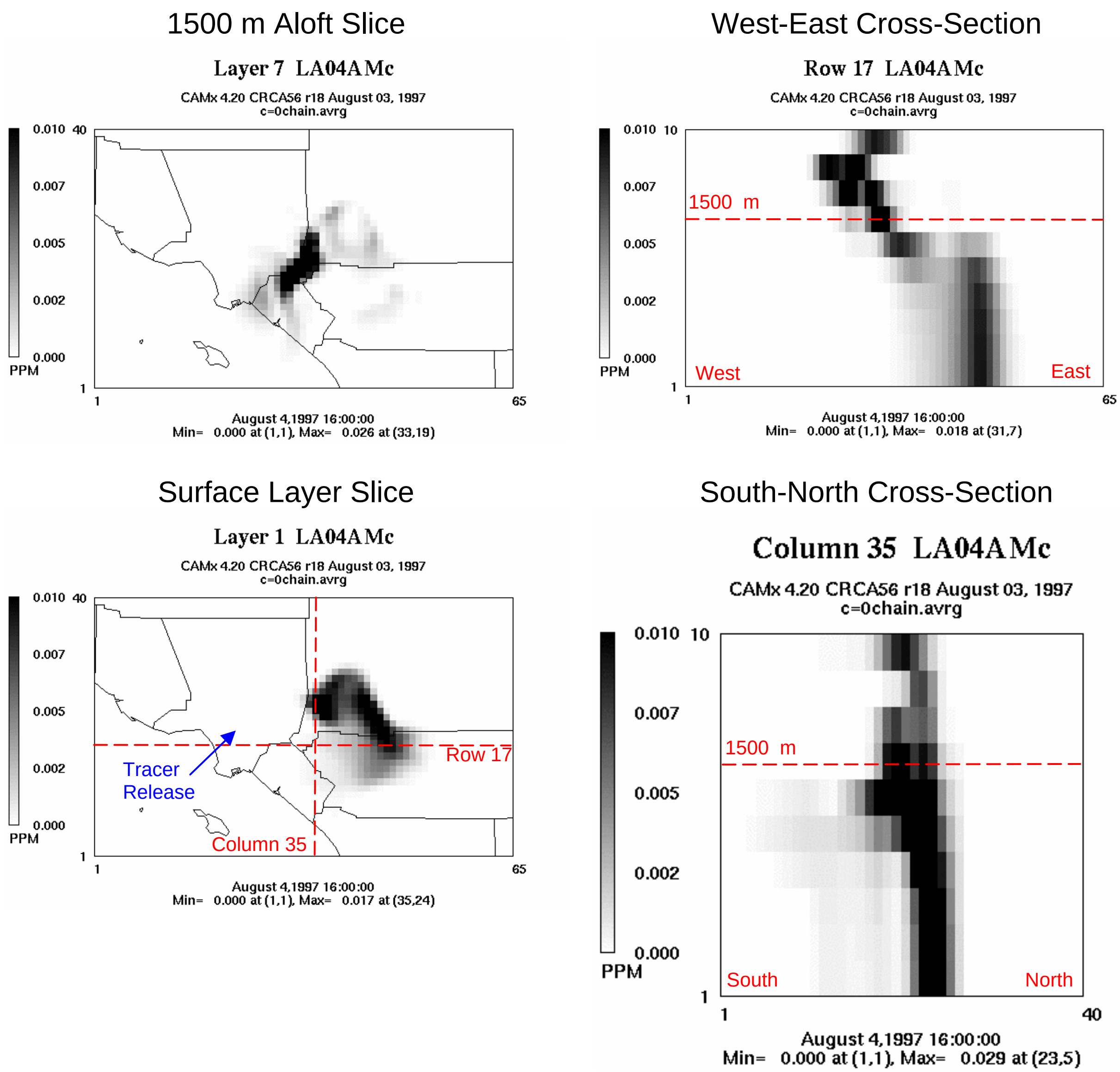


**Figure 11**. Tracer distributions at 4 pm on August 4 for a tracer released from Downtown LA at 6-9 am on August 4 using the ENVIRON MM5 meteorology.

## San Jose State MM5

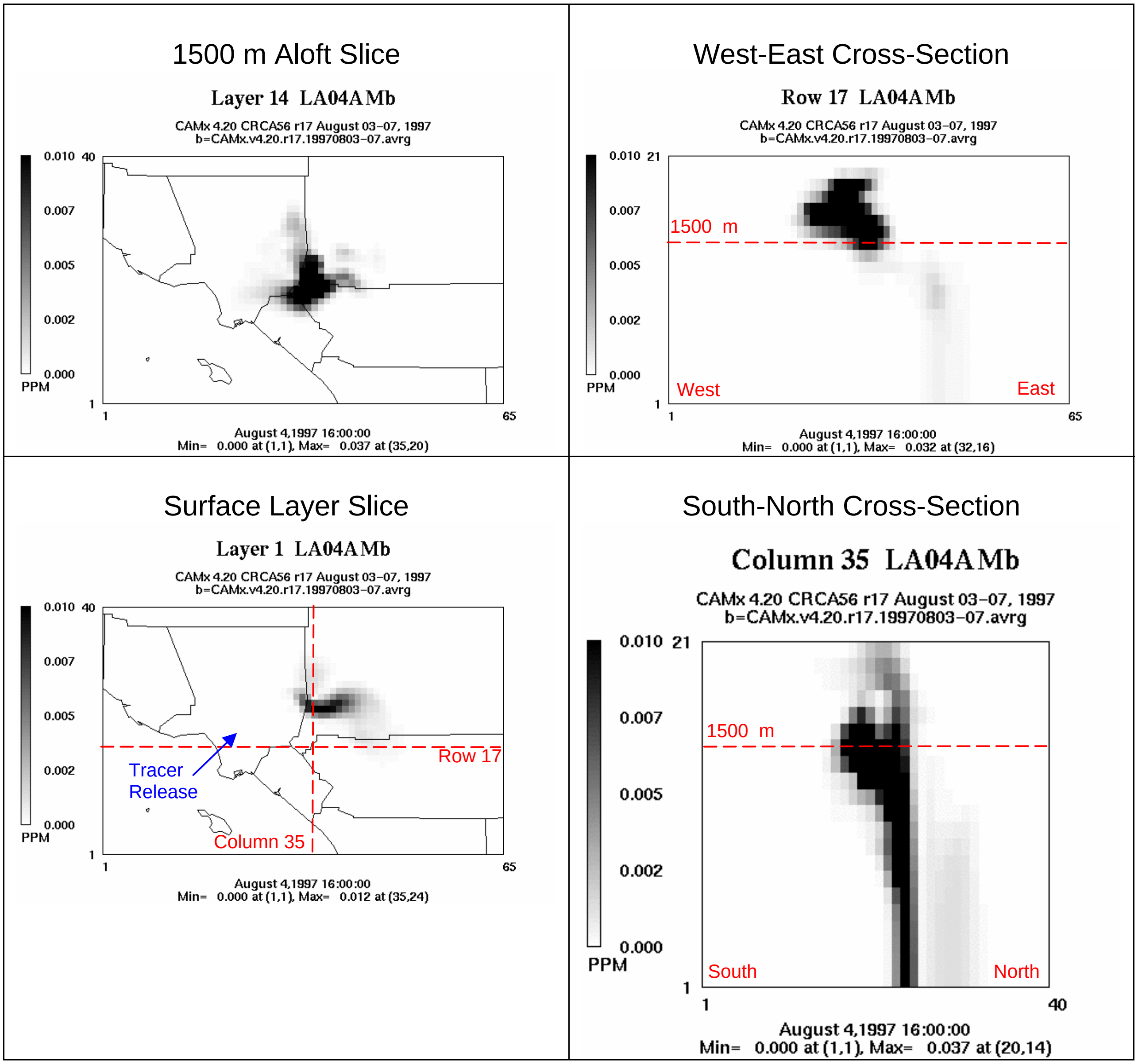


**Figure 12**. Tracer distributions at 4 pm on August 4 for a tracer released from Downtown LA at 6-9 am on August 4 using the San Jose State MM5 meteorology.

## SCAQMD CALMET

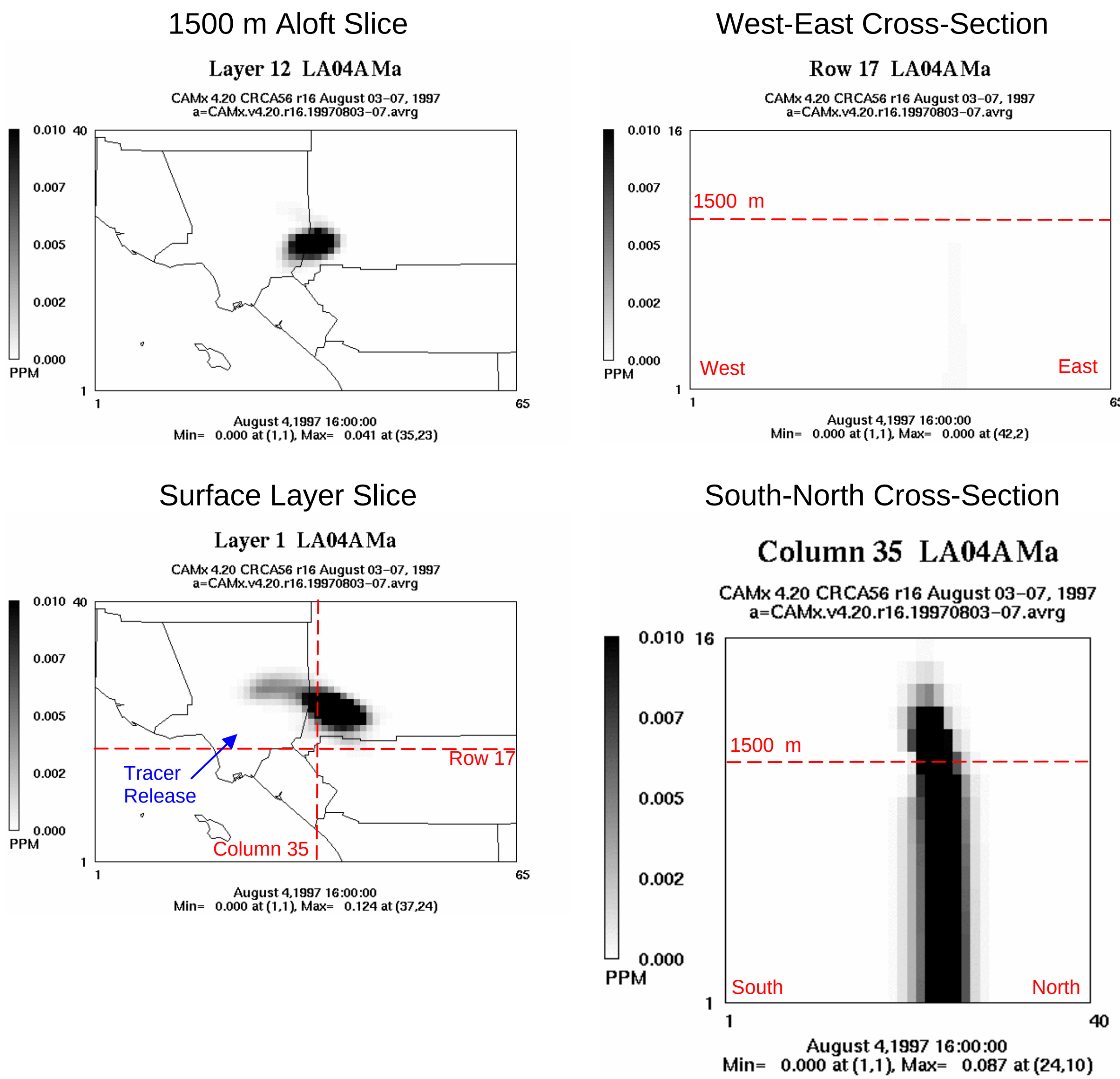


**Figure 13**. Tracer distributions at 4 pm on August 4 for a tracer released from Downtown LA at 6-9 am on August 4 using the SCAQMD CALMET meteorology.

The vertical cross-sections of tracer concentration fields shown in Figures 11-13 show a difference between the MM5 and CALMET wind fields. Both MM5 simulations move tracer from the surface to about 1500 m aloft via up-slope flows along the southern slopes of the San Gabriel Mountains. Once tracers enter layers at ~1500 m. aloft they are transported south/southwest by synoptic winds blowing over the top of the San Gabriel Mountains. This mechanism moves tracer mass out of the boundary layer and then rapidly transports it south and out of the CAMx modeling domain. This boundary layer ventilation process proceeds more efficiently in the SJS-MM5 than the ENV-MM5 wind fields leading to shorter retention of tracer mass within the CAMx domain for the SJS-MM5 than ENV-MM5 wind fields. CALMET does not show the same behavior and retains tracer mass within the CAMx domain for longer than both MM5 simulations.

## WEEKDAY/WEEKEND EMISSION CHANGES

Emission inventories were prepared for the August 3-7, SCOS episode period for 1997 and 2010. The ARB provided emission inventories for 1997 and 2010 (Allen, 2005) in the Modeling Emissions Data System format (ARB, 2001) as used by the ARB's Gridded Emissions Model (GEM) software. MEDS format data specify emissions by grid cell, Source Category Code (SCC) and pollutant.

### Base Emissions for 1997 and 2010

The ARB base emissions for 1997 and 2010 are summarized by major source category in Tables 4 and 5. Emission totals are for the old AQMP modeling domain (Figure 1), which is smaller than the SCOS domain. The days of week shown in Tables 4 and 5 are for the actual episode and were changed for the proximate modeling described below.

**Table 4.** ARB emission totals (tons/day) for the AQMP domain area for August 3-7, 1997.

| | Sunday 3-Aug | Monday 4-Aug | Tuesday 5-Aug | Wednesday 6-Aug | Thursday 7-Aug |
|---|---|---|---|---|---|
| **NOx** | | | | | |
| Onroad Mobile | 645.7 | 915.5 | 972.1 | 940.4 | 930.6 |
| Other Surface | 419.8 | 508.8 | 509.7 | 509.2 | 509.5 |
| Point Sources | 97.9 | 104.8 | 88.0 | 92.7 | 101.6 |
| Wildfire | 4.4 | 0.9 | 47.5 | 234.8 | 105.7 |
| Biogenic | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **1167.8** | **1529.9** | **1617.3** | **1777.1** | **1647.4** |
| **ROG** | | | | | |
| Onroad Mobile | 574.8 | 653.2 | 719.3 | 680.6 | 641.0 |
| Other Surface | 1472.4 | 1417.9 | 1404.3 | 1375.2 | 1391.8 |
| Point Sources | 24.9 | 25.1 | 37.7 | 66.6 | 50.8 |
| Wildfire | 36.8 | 7.3 | 394.6 | 1948.0 | 872.4 |
| Biogenic | 295.7 | 313.4 | 415.7 | 347.1 | 256.9 |
| **Total** | **2404.6** | **2417.0** | **2971.6** | **4417.5** | **3213.0** |
| **CO** | | | | | |
| Onroad Mobile | 4947.0 | 6053.0 | 6555.0 | 6301.0 | 5940.0 |
| Other Surface | 2897.8 | 1450.9 | 1446.4 | 1439.6 | 1443.1 |
| Point Sources | 45.8 | 50.2 | 51.9 | 59.3 | 57.2 |
| Wildfire | 169.7 | 33.9 | 1826.0 | 9019.0 | 4058.0 |
| Biogenic | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **8060.3** | **7587.9** | **9879.3** | **16818.9** | **11498.3** |

Note: NOx includes HONO emissions

**Table 5.** ARB 2010 future year emission totals (tons/day) for the AQMP domain area for August 3-7, 1997.

| | Sunday 3-Aug | Monday 4-Aug | Tuesday 5-Aug | Wednesday 6-Aug | Thursday 7-Aug |
|---|---|---|---|---|---|
| **NOx** | | | | | |
| Onroad Mobile | 192.6 | 286.5 | 303.5 | 295.5 | 293.2 |
| Other Surface | 331.7 | 374.1 | 374.1 | 374.2 | 374.1 |
| Point Sources | 60.5 | 66.1 | 66.1 | 66.1 | 66.1 |
| Wildfire | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Biogenic | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **584.8** | **726.7** | **743.7** | **735.8** | **733.4** |
| **ROG** | | | | | |
| Onroad Mobile | 74.4 | 83.6 | 93.8 | 87.5 | 81.3 |
| Other Surface | 915.0 | 961.7 | 961.7 | 961.7 | 961.6 |
| Point Sources | 27.0 | 28.4 | 28.3 | 28.4 | 28.4 |
| Wildfire | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Biogenic | 295.7 | 313.4 | 415.7 | 347.1 | 256.9 |
| **Total** | **1312.1** | **1387.1** | **1499.5** | **1424.7** | **1328.3** |
| **CO** | | | | | |
| Onroad Mobile | 1553.7 | 1897.6 | 2052.4 | 1984.6 | 1878.4 |
| Other Surface | 2308.3 | 1200.0 | 1200.4 | 1200.2 | 1199.7 |
| Point Sources | 58.4 | 63.7 | 63.8 | 63.7 | 63.7 |
| Wildfire | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Biogenic | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **3920.5** | **3161.3** | **3316.6** | **3248.5** | **3141.8** |

Note : NOx includes HONO emissions

The ARB 1997 and 2010 modeling emission inventories for the August SCOS episode (Tables 4 and 5) may be compared to other emission estimates prepared by the SCAQMD (Table 6) and ARB (Table 7). The biogenic and wildfire emissions from Tables 4 and 5 should be omitted from comparisons with Tables 6 and 7.

For example, ARB emissions (no biogenic or wildfire) for Tuesday August 5$^{th}$ (extracted from Table 4 and 5) are as follows

| Year | TOG (Tons/day) | ROG (Tons/day) | NOx (Tons/day) |
|---|---|---|---|
| 1997 | 2305 | 2161 | 1570 |
| 2010 | 1177 | 1084 | 744 |

**Table 6.** Summer planning anthropogenic emission inventories for the South Coast Air Basin (SoCAB) from the 2003 AQMP (SCAQMD, 2004b).

| | TOG (Tons/day) | VOC (Tons/day) | NOx (Tons/day) |
|---|---|---|---|
| 1997 | 1830 | 1222 | 1165 |
| 2010 base | 1271 | 659 | 764 |
| 2010 control plan | | 310 | 530 |
| 2020 base | 1282 | 617 | 532 |

**Table 7.** Annual average anthropogenic emission inventories for the SCAQMD area from the ARB emissions almanac (ARB, 2004).

| | TOG (Tons/day) | ROG (Tons/day) | NOx (Tons/day) |
|---|---|---|---|
| 1995 | 1956 | 1314 | 1360 |
| 2000 | 1607 | 1019 | 1223 |
| 2010 | 1204 | 614 | 780 |

The 1997 anthropogenic TOG and NOx emissions for August 5 in Table 4 are higher than both the SCAQMD 1997 summer planning inventory (Table 6) and the ARB 1995 annual average inventory (Table 7). This may be because the AQMP modeling domain reported in Table 4 covers a larger area than the South Coast Air Basin (SoCAB) reported in Tables 6 and 7. Similarly, the 2010 TOG and NOx emissions for August 5 in Table 5 are higher than both the SCAQMD 2010 base (Table 6) and the ARB 2010 annual average inventory (Table 7).

## Developing WD/WE Adjustments

The weekday and weekend adjustments were obtained from a report by Sullivan et al., (2003) from Sonoma Technology, Inc. (STI) – "Collection and Analysis of Weekend/Weekday Emissions Activity Data in the South Coast Air Basin" (May 2004). They performed surveys and analyzed vehicle counts to characterize WD/WE activity difference and found that activity levels generally decline on the WE (especially Sunday) relative to weekdays

In the ARB data itself, the differences from weekday to weekend were inconsistent with the STI findings. Since the ARB factors were not documented, they were not used. (For example, the ARB data shows that activity for Recreational Boats is 400% higher on Sunday compared to the weekday. However, based on STI data, Recreational Boats activity decreases by 1% on Sunday compared to a weekday.)

## On-road Vehicles

To gather data on WD/WE activity changes for on-road vehicles, STI used a combination of surveys of over 800 households, surface street traffic counts in 10 neighborhoods, and freeway traffic counts at 10 locations. From these data, STI developed recommendations for weekend adjustment factors to be applied to the weekday emission inventory for the SoCAB.

The report recommends for on-road vehicles the following adjustments be made to the weekday inventory:

- Slightly increase light-duty vehicle VMT by approximately 3.5% on Fridays. Reduce light-duty vehicle VMT by approximately 10%-20% on Saturdays and approximately 30% on Sundays.
- Increase the number of light-duty vehicle soaks by approximately 10% on Fridays. Reduce the number of light-duty vehicle soaks by approximately 20% on Saturdays and 30% on Sundays.
- Reduce heavy-duty vehicle activity by approximately 55%-70% on Saturdays and approximately 75%-80% on Sundays.

These recommendations were used by ENVIRON to estimate emissions adjustment factors for Friday, Saturday and Sunday for Light and Heavy Duty Exhaust, Running Loss and Hot Soak emissions, as listed in Table 8.

STI made no recommendations for adjusting diurnal emissions, so the adjustments previously developed by ENVIRON (ENVIRON, 2003) were used. This approach is consistent with STI's analysis because the other on-road vehicle activity adjustments derived by STI and ENVIRON are similar in magnitude.

For resting loss emissions, it was assumed that these would remain constant for all days of the week (ENVIRON, 2003). Resting losses are related to vehicle off-time, and the amount of vehicle off-time is relatively constant for any day of the week.

**Table 8**. Daily adjustment factors for on-road vehicles as percent change relative to typical weekday emissions.

| Vehicle Class | Emissions Process | Fridays | Saturdays | Sundays | Source |
|---|---|---|---|---|---|
| Light-Duty | Exhaust, Running Loss | 3.5% | -15.0% | -30.0% | Sullivan et al., (2003) |
| Light-Duty | Hot Soak | 10.0% | -20.0% | -30.0% | Sullivan et al., (2003) |
| Light-Duty | Diurnal | -3.0% | 23.0% | 59.0% | ENVIRON (2003) |
| Heavy-Duty | Exhaust, Hot Soak and Running Loss | 0.0% | -62.5% | -77.5% | Sullivan et al., (2003) |
| Heavy-Duty | Diurnal | 0.0% | 136.0% | 289.0% | ENVIRON (2003) |

The ARB emissions data (Tables 4 and 5) were not split up by light and heavy-duty vehicle emissions. Therefore, ENVIRON developed domain-wide split factors by running EMFAC 2002 (v2.2) for the SoCAB. From this EMFAC run, the relative contributions of emissions from each process (exhaust, diurnal, etc) were determined for light-duty vs. heavy-duty vehicles. Split factors were developed and applied to each pollutant and on-road emissions category in the ARB inventory in order to disaggregate light and heavy-duty vehicle emissions. The relevant adjustments from Table 8 were then applied to the fully disaggregated emissions. This was performed for both 1997 and 2010.

### Offroad Vehicles and Area Sources

To gather data on WD/WE activity changes for off-road vehicles and area sources, STI surveyed residences and small businesses (construction businesses in particular were surveyed separately) in the SoCAB via telephone and mail about various emission-related activities. Some of the surveys targeted five specific neighborhoods of LA that are close to key air quality monitoring sites, while the rest of the surveys were distributed randomly in the SoCAB.

Using the data from the STI report, the following adjustment factors were compiled and then applied to emissions in the ARB dataset matching by source category code (SCC) description.

**Table 9.** Daily adjustment factors for off-road and area sources as percent change relative to typical weekday emissions.

| Group | Fridays | Saturdays | Sundays | Source |
|---|---|---|---|---|
| Recreational Boats | -1.0% | 17.0% | -1.0% | Figure 3-3 of Sullivan et al., (2003) |
| Off Road RV | 3.0% | 9.0% | 5.0% | Figure 3-3 of Sullivan et al., (2003) |
| Construction | 0.0% | -90.0% | -99.0% | Table 3-3 in Sullivan et al., (2003) |
| Industrial Paints/Solvents | 0.0% | -77.0% | -89.0% | Table 3-3 in Sullivan et al., (2003) |
| Pesticides and Fertilizers | 0.0% | -91.0% | -96.0% | Table 3-3 in Sullivan et al., (2003) |

## NOx Point Sources

STI obtained continuous emission monitoring systems (CEMS) data for a 6-month period in 2002 for 84 facilities in the counties near Los Angeles. STI concluded after a statistical analysis on this data that NOx emissions from facilities were reduced on the weekends by approximately 6% (this value was calculated by normalizing the emissions for each facility according to the relative magnitude of emissions at each facility). This adjustment was applied to point source NOx from SCCs in the ARB emissions data that were judged likely to be similar to sources monitored by CEMS (i.e., large combustion sources). Matching the CEMS adjustment to point sources by SCC is highly subjective and subject to uncertainty.

## WD/WE Emission Results

Tables 10 and 11 show emissions for 1997 and 2010 with the WD/WE emission adjustments developed above applied to weekday emissions from the August 5 episode day. Wildfire emissions were set to zero because they are an unusual event. Biogenic emissions receive no WD/WE adjustment. Categories of anthropogenic emissions for which no WD/WE adjustment has been estimated are listed on a separate line.

The percentages of weekday emissions receiving WD/WE adjustments are as follows:

- 80 percent of 1997 weekday NOx receives a WD/WE adjustment
- 55 percent of 1997 weekday ROG receives a WD/WE adjustment
- 67 percent of 2010 weekday NOx receives a WD/WE adjustment
- 43 percent of 2010 weekday ROG receives a WD/WE adjustment

The WD/WE emissions reported in Tables 10 and 11 are ready to be used in proximate ozone modeling analyses.

**Table 10**. 1997 emissions with WD/WE emission adjustments applied. (no wildfire or biogenics)

| | Weekday | Friday | Saturday | Sunday |
|---|---|---|---|---|
| **NOx (tons/day)** | | | | |
| MV | 972.10 | 991.51 | 627.98 | 482.17 |
| Recreational Boats | 5.62 | 5.57 | 6.58 | 5.57 |
| Off Road RV | 0.55 | 0.57 | 0.60 | 0.58 |
| Pesticides and Fertilizers | 0.00 | 0.00 | 0.00 | 0.00 |
| Industrial Paints/Solvents | 0.00 | 0.00 | 0.00 | 0.00 |
| Construction | 208.98 | 208.98 | 20.90 | 2.09 |
| Major NOx Points | 72.63 | 68.63 | 68.05 | 68.05 |
| No Adjustment | 309.92 | 309.92 | 309.92 | 309.92 |
| **Grand Total** | **1569.81** | **1585.18** | **1034.04** | **868.38** |
| **ROG (tons/day)** | | | | |
| MV | 719.32 | 740.45 | 600.17 | 529.44 |
| Recreational Boats | 45.34 | 44.88 | 53.04 | 44.88 |
| Off Road RV | 13.80 | 14.22 | 15.04 | 14.49 |
| Pesticides and Fertilizers | 0.06 | 0.06 | 0.01 | 0.00 |
| Industrial Paints/Solvents | 141.89 | 141.89 | 32.64 | 15.61 |
| Construction | 40.15 | 40.15 | 4.01 | 0.40 |
| Major NOx Points | 48.97 | 48.97 | 48.97 | 48.97 |
| No Adjustment | 1151.91 | 1151.91 | 1151.91 | 1151.91 |
| **Grand Total** | **2161.44** | **2182.54** | **1905.80** | **1805.71** |
| **CO (tons/day)** | | | | |
| MV | 6555.00 | 6757.23 | 5202.62 | 4219.37 |
| Recreational Boats | 180.85 | 179.04 | 211.59 | 179.04 |
| Off Road RV | 72.24 | 74.40 | 78.74 | 75.85 |
| Pesticides and Fertilizers | 0.00 | 0.00 | 0.00 | 0.00 |
| Industrial Paints/Solvents | 0.00 | 0.00 | 0.00 | 0.00 |
| Construction | 387.92 | 387.92 | 38.79 | 3.88 |
| Major NOx Points | 23.58 | 23.58 | 23.58 | 23.58 |
| No Adjustment | 834.02 | 834.02 | 834.02 | 834.02 |
| **Grand Total** | **8053.61** | **8256.19** | **6389.34** | **5335.74** |

Note:

The weekday is August 5, 1997 with wildfire emissions set to zero.
Friday, Saturday and Sunday are scaled from August 5 using WD/WE adjustments.

**Table 11.** 2010 emissions with WD/WE emission adjustments applied. (no wildfire or biogenics)

| | Weekday | Friday | Saturday | Sunday |
|---|---|---|---|---|
| **NOx (tons/day)** | | | | |
| MV | 303.50 | 305.32 | 138.48 | 92.95 |
| Recreational Boats | 6.82 | 6.75 | 7.98 | 6.75 |
| Off Road RV | 0.60 | 0.62 | 0.66 | 0.63 |
| Pesticides and Fertilizers | 0.00 | 0.00 | 0.00 | 0.00 |
| Industrial Paints/Solvents | 0.00 | 0.00 | 0.00 | 0.00 |
| Construction | 126.53 | 126.53 | 12.65 | 1.27 |
| Major NOx Points | 62.27 | 58.84 | 58.35 | 58.35 |
| No Adjustment | 244.04 | 244.04 | 244.04 | 244.04 |
| **Grand Total** | **743.76** | **742.10** | **462.16** | **403.99** |
| **ROG (tons/day)** | | | | |
| MV | 93.80 | 96.42 | 79.23 | 71.87 |
| Recreational Boats | 12.91 | 12.78 | 15.11 | 12.78 |
| Off Road RV | 4.54 | 4.67 | 4.95 | 4.77 |
| Pesticides and Fertilizers | 0.03 | 0.03 | 0.00 | 0.00 |
| Industrial Paints/Solvents | 74.02 | 74.02 | 17.02 | 8.14 |
| Construction | 12.82 | 12.82 | 1.28 | 0.13 |
| Major NOx Points | 30.71 | 30.71 | 30.71 | 30.71 |
| No Adjustment | 855.05 | 855.05 | 855.05 | 855.05 |
| **Grand Total** | **1083.88** | **1086.50** | **1003.35** | **983.45** |
| **CO (tons/day)** | | | | |
| MV | 2052.40 | 2116.54 | 1640.08 | 1332.22 |
| Recreational Boats | 158.68 | 157.10 | 185.66 | 157.10 |
| Off Road RV | 70.07 | 72.17 | 76.38 | 73.57 |
| Pesticides and Fertilizers | 0.00 | 0.00 | 0.00 | 0.00 |
| Industrial Paints/Solvents | 0.00 | 0.00 | 0.00 | 0.00 |
| Construction | 326.92 | 326.92 | 32.69 | 3.27 |
| Major NOx Points | 26.19 | 26.19 | 26.19 | 26.19 |
| No Adjustment | 681.90 | 681.90 | 681.90 | 681.90 |
| **Grand Total** | **3316.17** | **3380.82** | **2642.91** | **2274.26** |

Note:

The weekday is August 5 with wildfire emissions set to zero.
Friday, Saturday and Sunday are scaled from August 5 using WD/WE adjustments.

The WD/WE changes in total emission levels from Tables 10 and 11 (i.e., without biogenic emissions and wildfires) are summarized in Table 12.

**Table 12**. Percent changes from weekday total emissions. (does not include wildfire or biogenics)

| | Friday | Saturday | Sunday |
|---|---|---|---|
| **1997** | | | |
| **NOx** | 1% | -34% | -45% |
| **ROG** | 1% | -12% | -16% |
| **ROG/NOx** | 0% | 34% | 51% |
| **2010** | | | |
| **NOx** | 0% | -38% | -46% |
| **ROG** | 0% | -7% | -9% |
| **ROG/NOx** | 0% | 49% | 67% |

The following points are noted from Table 12:

- The relative emission changes for Friday are small and may be negligible.
- Both ROG and NOx emissions decrease on Saturday and Sunday.
- Weekend (Saturday and Sunday) percentage emissions decreases are greater for NOx than for ROG; therefore, ROG/NOx ratios increase on weekends.
- Weekend NOx percentage decreases are similar in 2010 and 1997.
- Weekend ROG percentage decreases are greater for 2010 than 1997.
- Weekend ROG/NOx ratios decline less in 2010 than 1997.

## RECOMMENDATIONS

ENVIRON requested input from CRC on two main issues:

1. CRC should review the WD/WE emission adjustments for any changes needed before proceeding to ozone modeling.

2. CRC should review the model performance evaluation and tracer analysis results to select meteorological data for the ozone modeling.

ENVIRON made the following recommendations on model inputs for the WD/WE ozone modeling:

1. The ENVIRON MM5 meteorology with CB4 chemistry provides the best model performance of the available candidates and is the first choice for proximate modeling. The August 3-7 modeling days should be assigned as Thursday-Monday with the weekend on August 5 and 6. This is the same configuration as used in the previous CRC proximate modeling study (Yarwood et al., 2003).

2. The San Jose State meteorology with SAPRC99 chemistry performs almost as well as the ENVIRON MM5 meteorology with CB4 chemistry and is a second choice. The SJS-

MM5 data do not include August 7, so carryover from the weekend to Monday could not be studied. This is a minor limitation.

3. Omit the CEM-based adjustment to NOx point sources because it is unclear which sources should be adjusted and the adjustment is small. CRC decided to keep the point source adjustment.

4. Change the temporal activity profiles for on-road mobile sources on weekends (Friday-Sunday) to the profiles developed by Yarwood et al. (2003). All other anthropogenic sources have the same temporal profiles for weekends as weekdays.

Task 4 of project A-56 includes a base case and three sensitivity tests for one model (e.g., CAMx with the ENV-MM5 meteorology and CB4 chemistry) in both 1997 and 2010. Potential sensitivity tests were discussed in our proposal. Proposed sensitivity tests are listed in Table 13.

**Table 13**. Proposed proximate modeling experiments.

| | 1997 | 2010 |
|---|---|---|
| Base Case | Weekday emissions for every episode day<br>Biogenic emissions for the actual day<br>No wildfire emissions | |
| Sensitivity Test 1 | Adjust *all anthropogenic emissions* for August 4-6 to be like a Friday, Saturday and Sunday | |
| Sensitivity Test 2 | Adjust *on-road mobile source emissions* for August 4-6 to be like a Friday, Saturday and Sunday | |
| Sensitivity Test 3 | Like Sensitivity Test 1 for 1997 but move the weekend to August 3-5 | Like Sensitivity Test 1 for 2010 but adjust 2010 emission levels to be like the 2010 control plan |

The cost to add additional sensitivity tests is $1,982 each (two runs, one for 1997 and one for 2010).

The cost to add a second model (e.g., CAMx with the SJS-MM5 meteorology and SAPRC99 chemistry) to the program listed in Table 13 is $7,932. Note that San Jose State requested that CRC assist with a publication of the base case ozone model performance with SJS-MM5 data should CRC choose to utilize the data. The performance evaluation presented above shows that the SJS-MM5 data do provide interesting results that could be published.

## CRC Decisions and Updated Project Schedule

CRC decided to proceed with modeling using three combinations of meteorology/emissions speciation

1. ENVIRON MM5 with CB4
2. San Jose State MM5 with SAPRC99
3. CALMET with CB4

CRC reviewed and accepted the WD/WE emissions adjustments developed by ENVIRON, including keeping the CEM-based adjustment to point source NOx emissions discussed above.

CRC did not yet select sensitivity tests 2 and 3. CRC will select sensitivity tests 2 and 3 after the base case and sensitivity test 1 have been modeled for 1997 and 2010. ENVIRON will complete the base case and sensitivity test 1 for 1997 and 2010 and summarize the results for CRC in a Power Point presentation by February 3, 2006.

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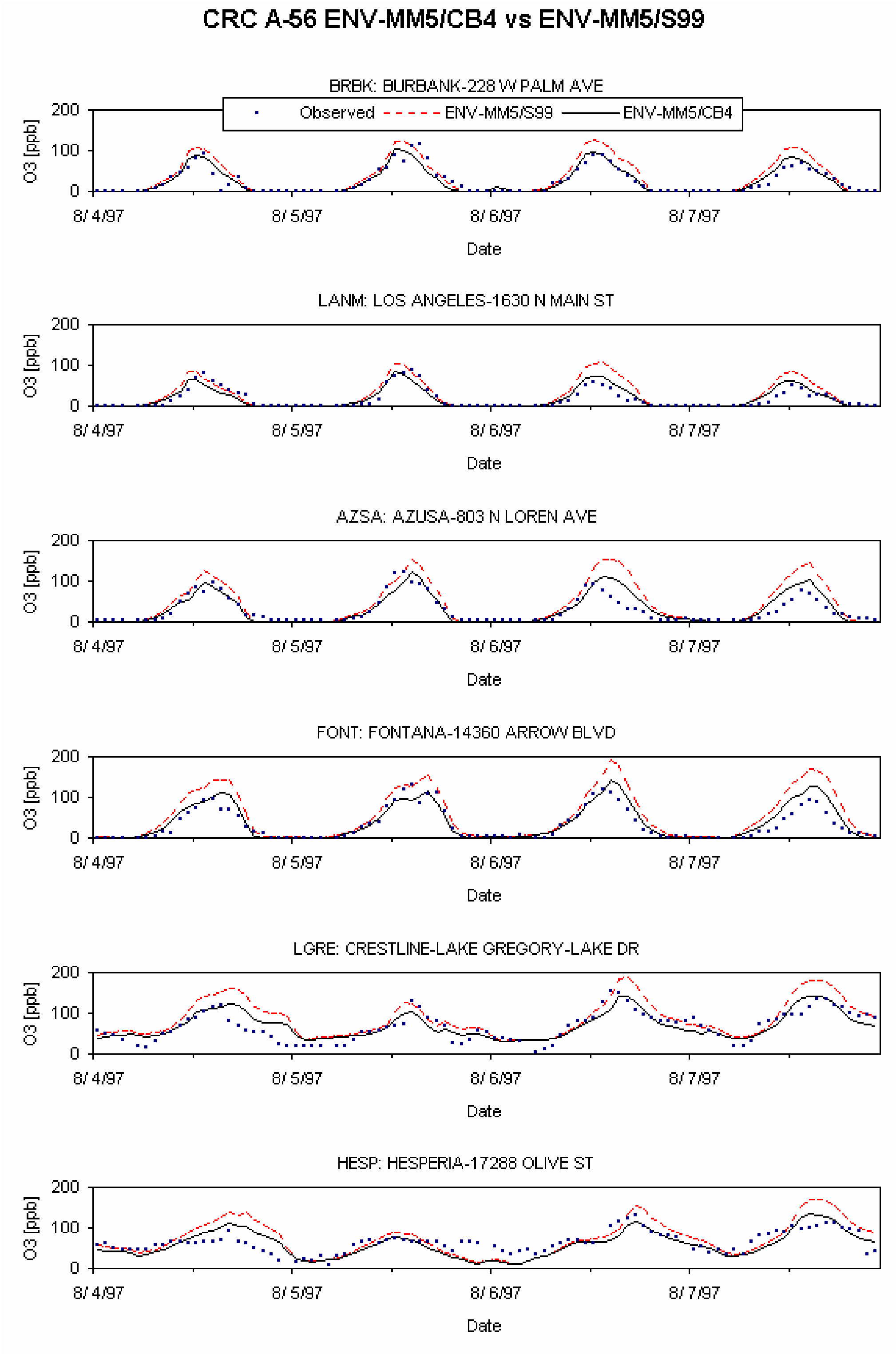
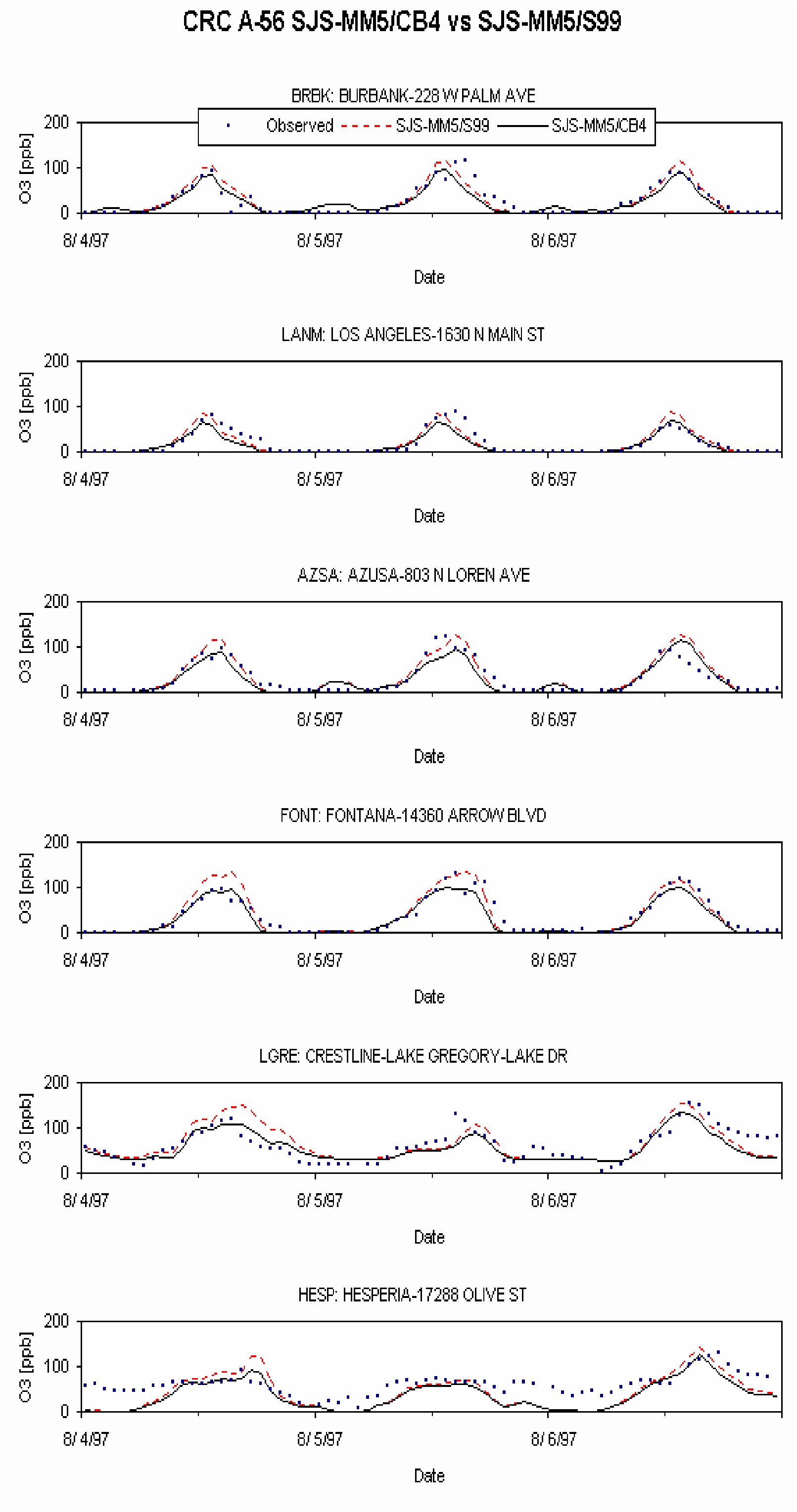
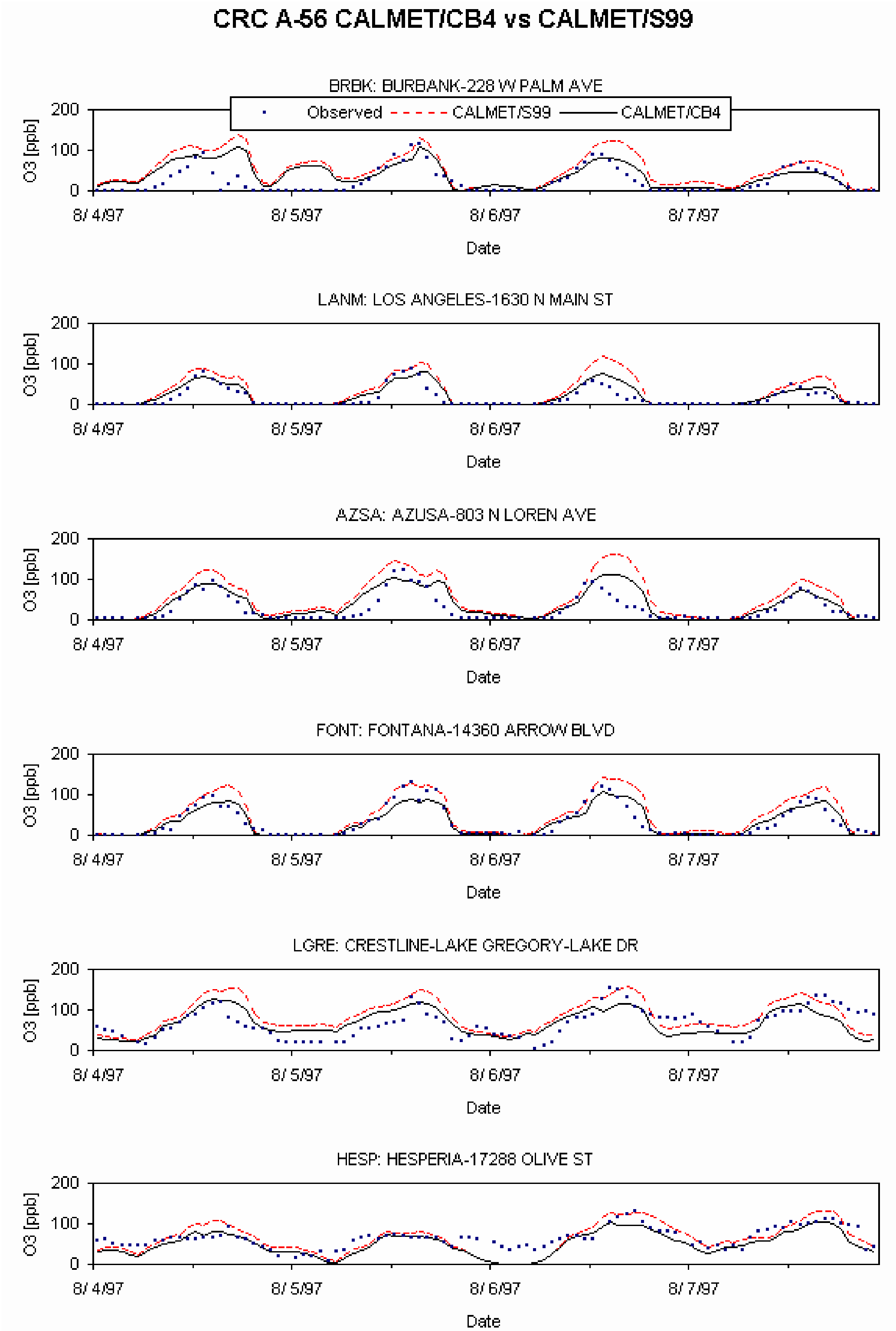
# Appendix: Additional Ozone Time-Series Comparisons




CRC A-56 SJS-MM5/CB4 vs SJS-MM5/S99
Observed
SJS-MM5/S99
SJS-MM5/CB4
BRBK: BURBANK-228 W PALM AVE
LANM: LOS ANGELES-1630 N MAIN ST
AZSA: AZUSA-803 N LOREN AVE
FONT: FONTANA-14360 ARROW BLVD
LGRE: CRESTLINE-LAKE GREGORY-LAKE DR
HESP: HESPERIA-17288 OLIVE ST
O3 [ppb]
200
100
0
8/4/97
8/5/97
8/6/97
Date


CRC A-56 CALMET/CB4 vs CALMET/S99
BRBK: BURBANK-228 W PALM AVE
Observed
CALMET/S99
CALMET/CB4
O3 [ppb]
200
100
0
8/ 4/97
8/ 5/97
8/ 6/97
8/ 7/97
Date
LANM: LOS ANGELES-1630 N MAIN ST
AZSA: AZUSA-803 N LOREN AVE
FONT: FONTANA-14360 ARROW BLVD
LGRE: CRESTLINE-LAKE GREGORY-LAKE DR
HESP: HESPERIA-17288 OLIVE ST

## Appendix A: Weekday/Weekend Differences in Hourly Ozone

This appendix presents tile plots differences (weekend–weekday) in hourly ozone (ppb). Each figure shows differences on Saturday and Sunday at 10 am and 3 pm. Three meteorology/chemistry cases are presented for five scenarios (fifteen figures):

1. 1997 Base Case – Impact of weekend emissions in 1997.
2. 2010 Base Case – Impact of weekend emissions in 2010.
3. 2010 "VOC Control" Case – Impact of weekend emissions in 2010 after all anthropogenic VOC emissions were cut by 50%.
4. 2010 "Sensitivity IC/BC" Case – Impact of weekend emissions in 2010 with the VOC boundary concentrations (BCs) and initial conditions (ICs) reduced from 100 ppbC to 60 ppbC VOC and 0.53 ppb NOx.
5. 1997 "Weekend Shift" Case – Impact of weekend emissions in 1997 with the weekend on August 4$^{th}$ and 5$^{th}$ rather than August 5$^{th}$ and 6$^{th}$.

### Key to figures in Appendix A

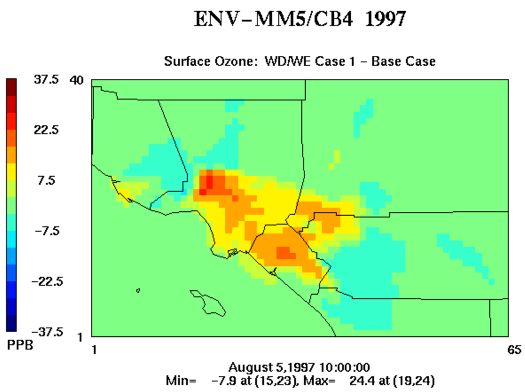
| Figure Number | Description |
|---|---|
| Figure A-1 | 1997 Base Case for ENVIRON MM5 meteorology with CB4 chemistry |
| Figure A-1 | 1997 Base Case for CALMET meteorology with CB4 chemistry |
| Figure A-3 | 1997 Base Case for San Jose State meteorology with SAPRC99 chemistry |
| Figure A-4 | 2010 Base Case for ENVIRON MM5 meteorology with CB4 chemistry |
| Figure A-5 | 2010 Base Case for CALMET meteorology with CB4 chemistry |
| Figure A-6 | 2010 Base Case for San Jose State meteorology with SAPRC99 chemistry |
| Figure A-7 | 2010 "VOC Control" Case for ENVIRON MM5 meteorology with CB4 chemistry |
| Figure A-8 | 2010 "VOC Control" Case for CALMET meteorology with CB4 chemistry |
| Figure A-9 | 2010 "VOC Control" Case for San Jose State meteorology with SAPRC99 chemistry |
| Figure A-10 | 2010 "Sensitivity IC/BC" Case for ENVIRON MM5 meteorology with CB4 chemistry |
| Figure A-11 | 2010 "Sensitivity IC/BC" Case for CALMET meteorology with CB4 chemistry |
| Figure A-12 | 2010 "Sensitivity IC/BC" Case for San Jose State meteorology with SAPRC99 chemistry |
| Figure A-13 | 1997 "Weekend Shift" Case for ENVIRON MM5 meteorology with CB4 chemistry |
| Figure A-14 | 1997 "Weekend Shift" Case for CALMET meteorology with CB4 chemistry |
| Figure A-15 | 1997 "Weekend Shift" Case for San Jose State meteorology with SAPRC99 chemistry |

## Figure A-1

## 1997 WD/WE Base Case

## ENVIRON MM5 with CB4 Chemistry

### Saturday 10 am

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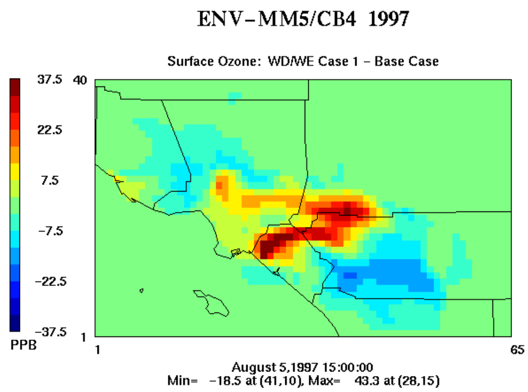
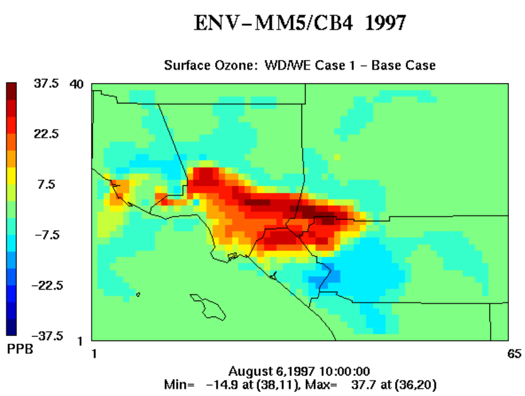
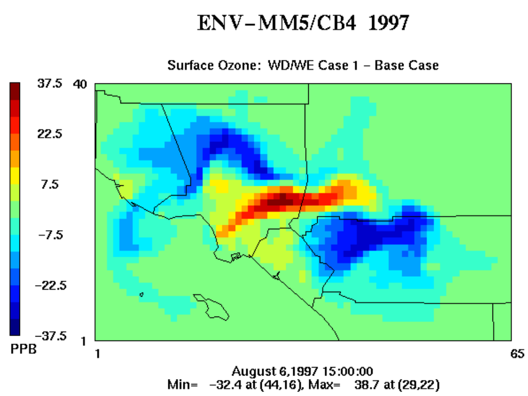



### Sunday 10 am




### Sunday 3 pm

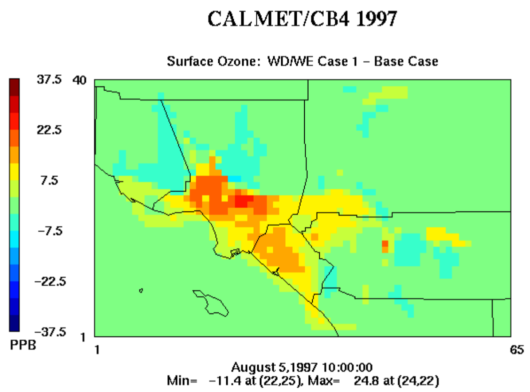


# Figure A-2

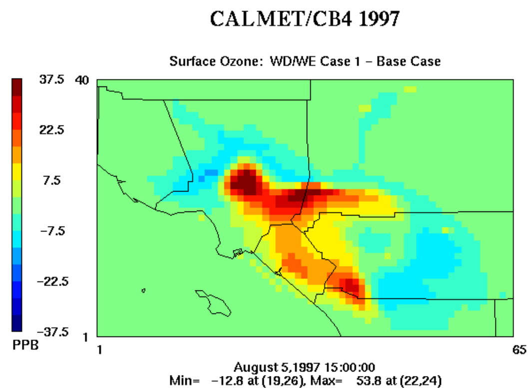
## 1997 WD/WE Base Case

## CALMET with CB4 Chemistry

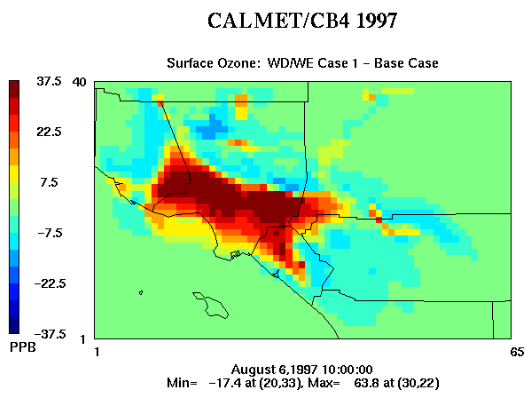
### Saturday 10 am



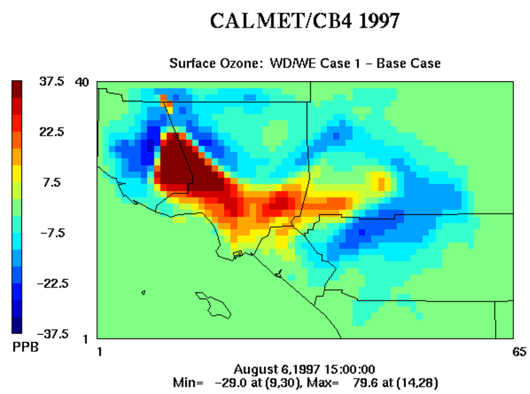

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

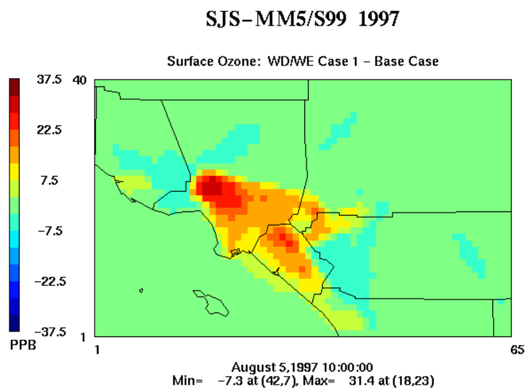


# Figure A-3

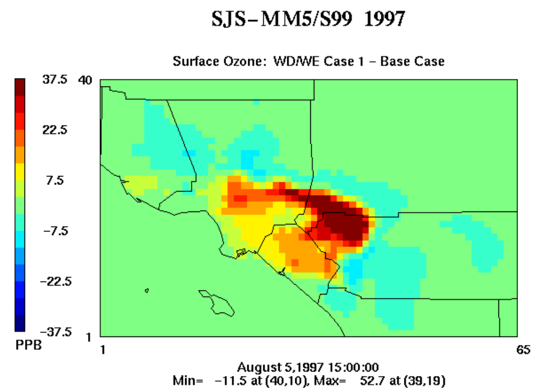
## 1997 WD/WE Base Case

## San Jose State MM5 with SAPRC99 Chemistry

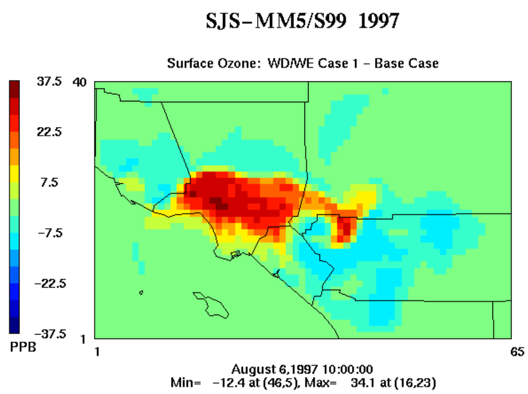
### Saturday 10 am



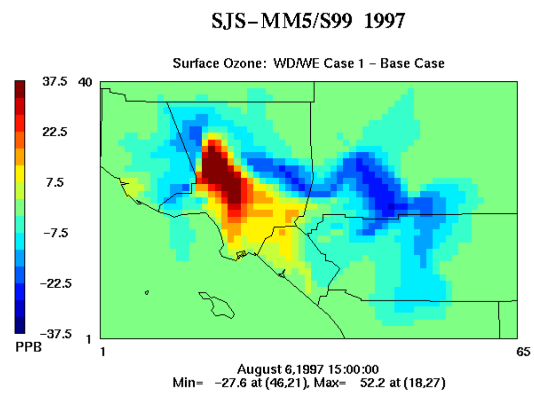

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

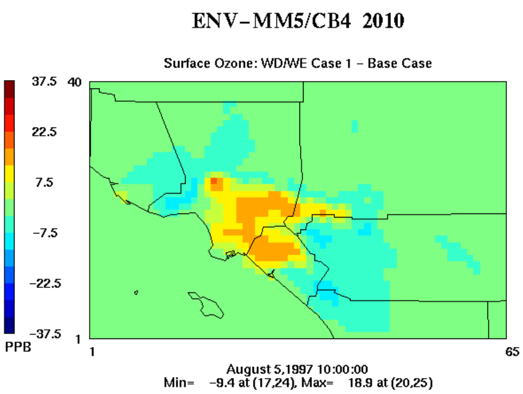


# Figure A-4

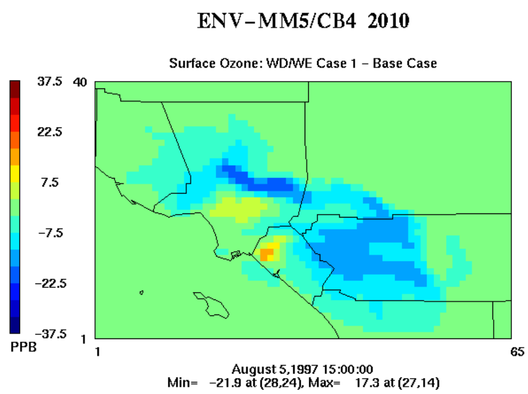
## 2010 WD/WE Base Case

## ENVIRON MM5 with CB4 Chemistry

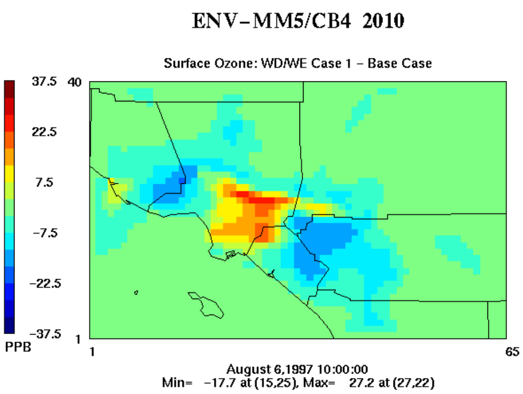
### Saturday 10 am



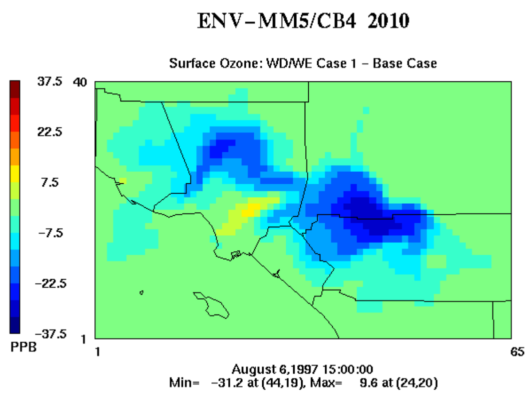

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

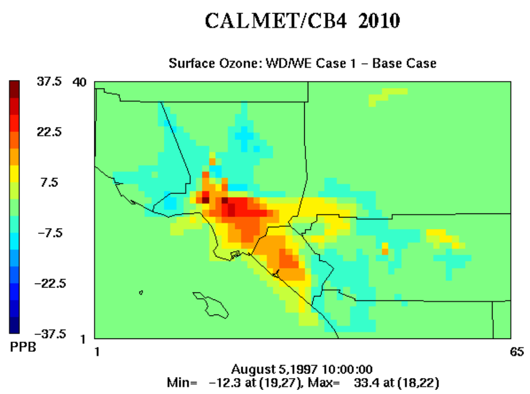


# Figure A-5

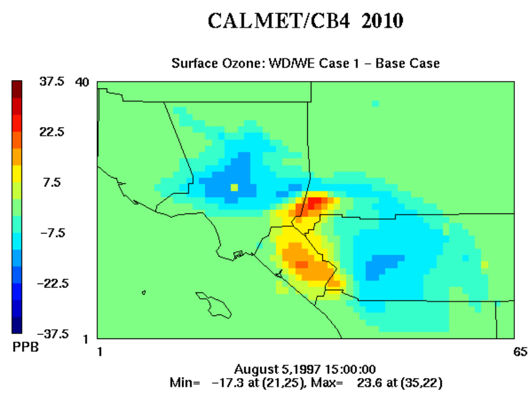
## 2010 WD/WE Base Case

## CALMET with CB4 Chemistry

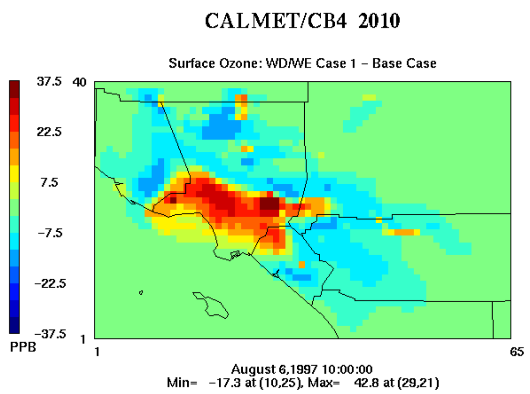
### Saturday 10 am



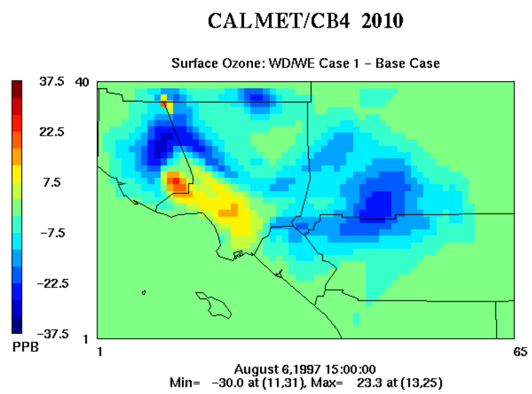

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

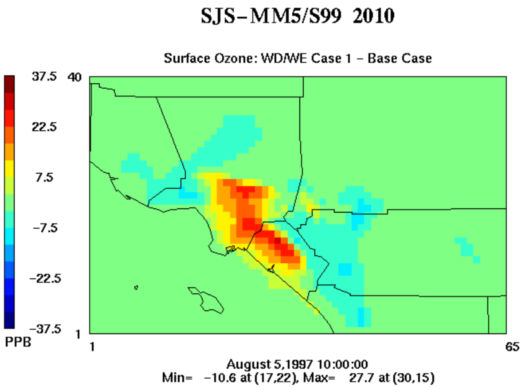


## Figure A-6

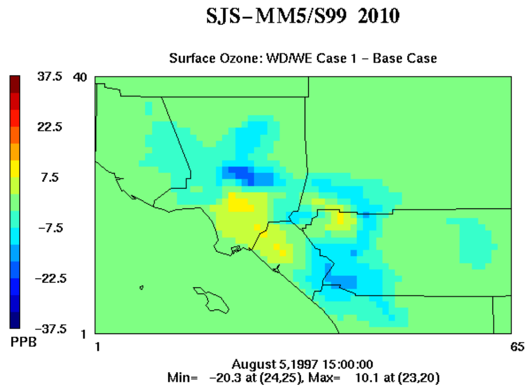
## 2010 WD/WE Base Case

## San Jose State MM5 with SAPRC99 Chemistry

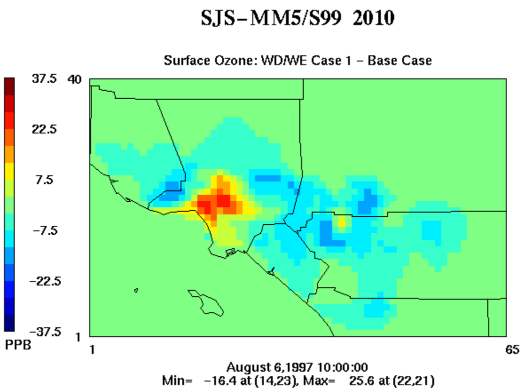
### Saturday 10 am



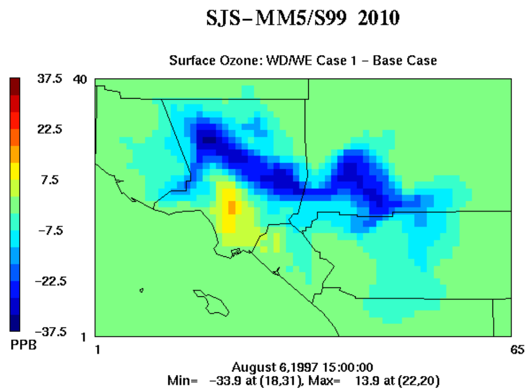

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

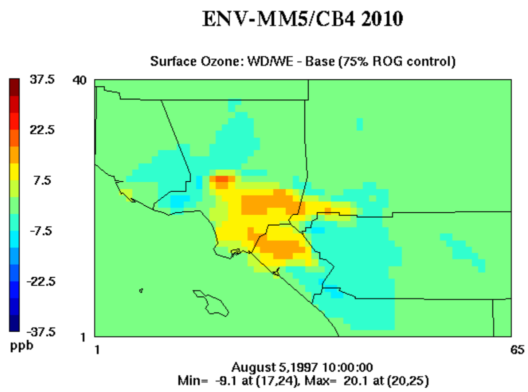


## Figure A-7

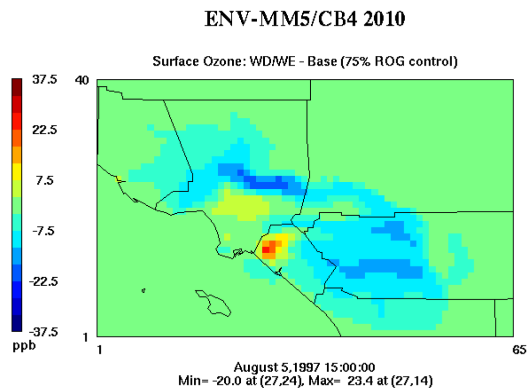
## 2010 "VOC Control" Case

## ENVIRON MM5 with CB4 Chemistry

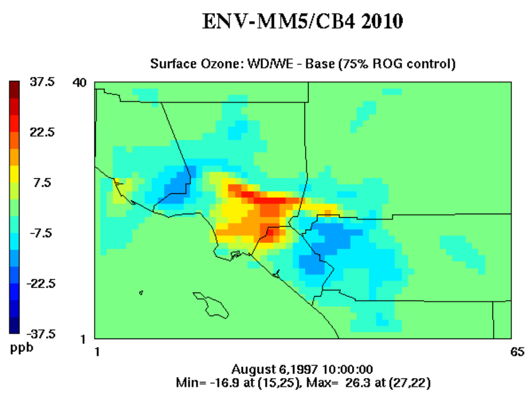
### Saturday 10 am



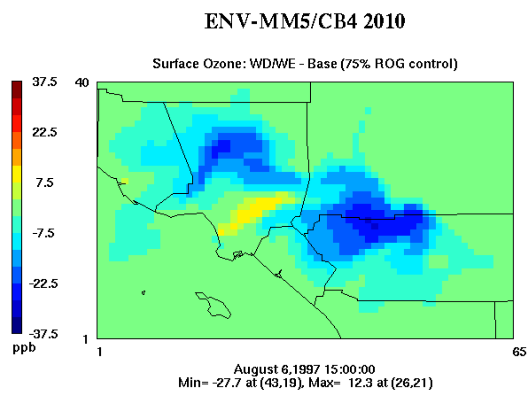

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm



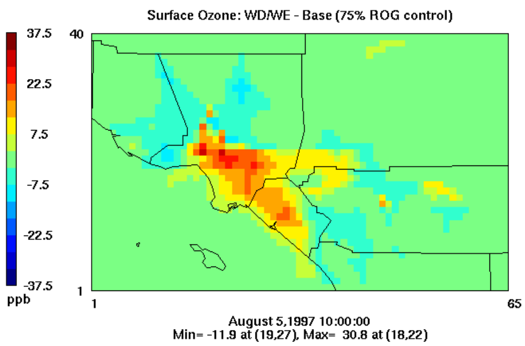
## Figure A-8

## 2010 “VOC Control” Case

## CALMET with CB4 Chemistry

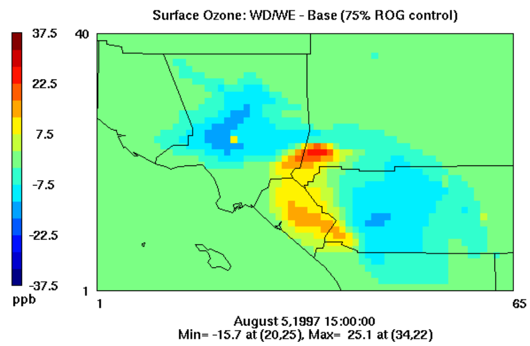
### Saturday 10 am

CALMET/CB4 2010



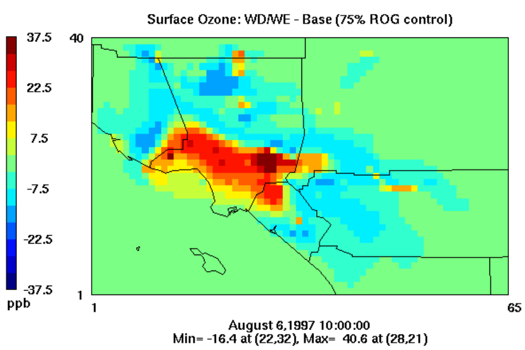

### Saturday 3 pm

CALMET/CB4 2010



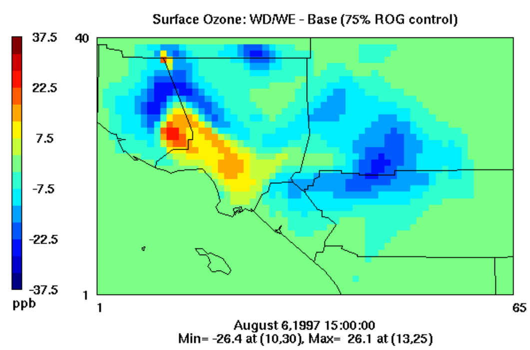

### Sunday 10 am

CALMET/CB4 2010




### Sunday 3 pm

CALMET/CB4 2010

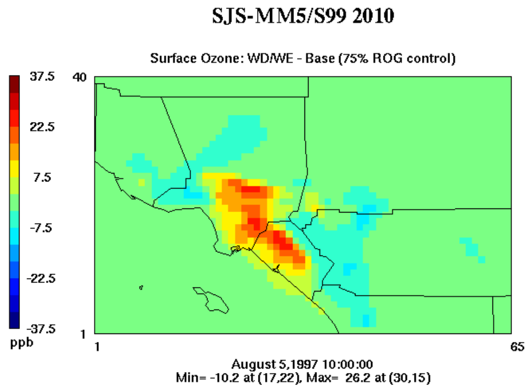


# Figure A-9

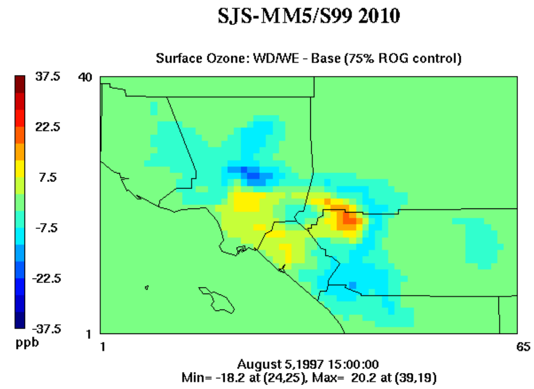
## 2010 “VOC Control” Case

## San Jose State MM5 with SAPRC99 Chemistry

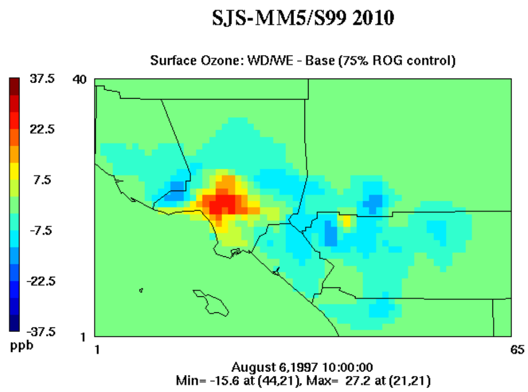
### Saturday 10 am



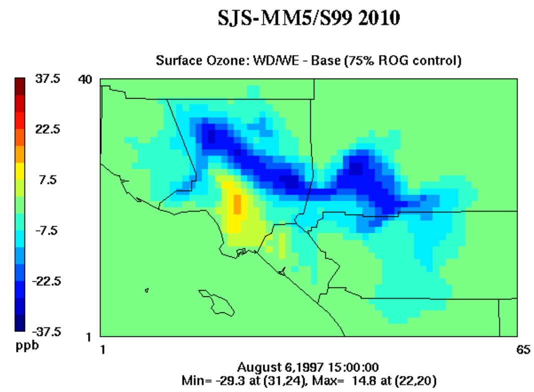

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

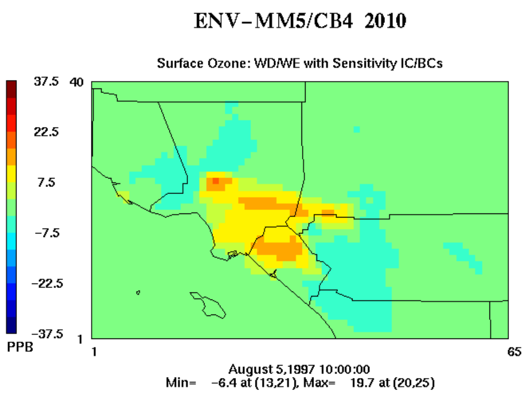


# Figure A-10

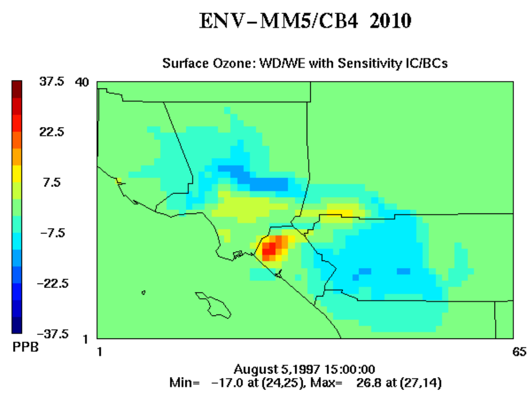
## 2010 "Sensitivity IC/BC" Case

## ENVIRON MM5 with CB4 Chemistry

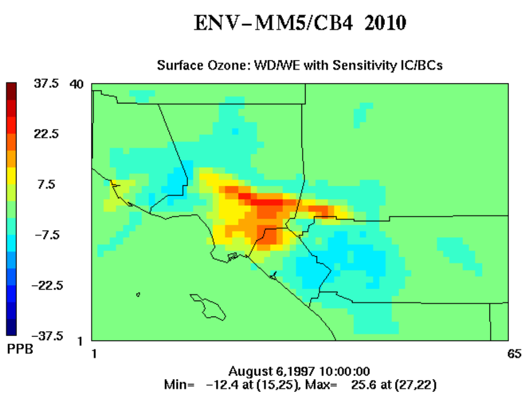
### Saturday 10 am



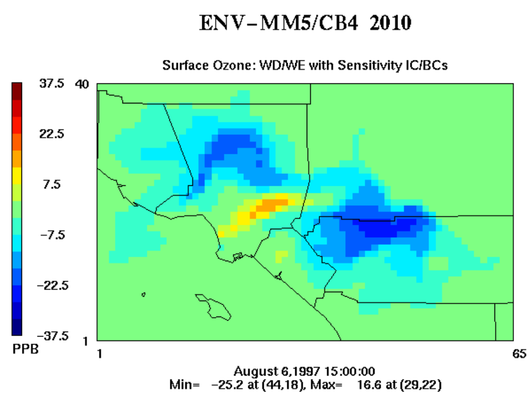

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

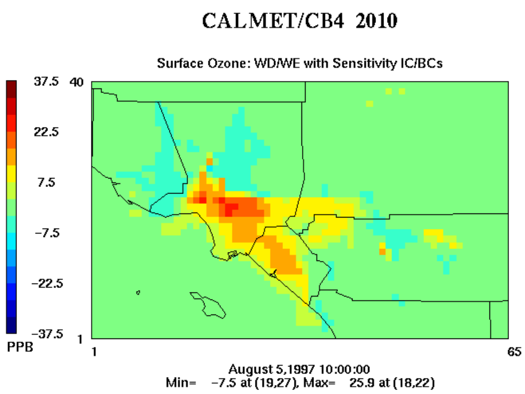


## Figure A-11

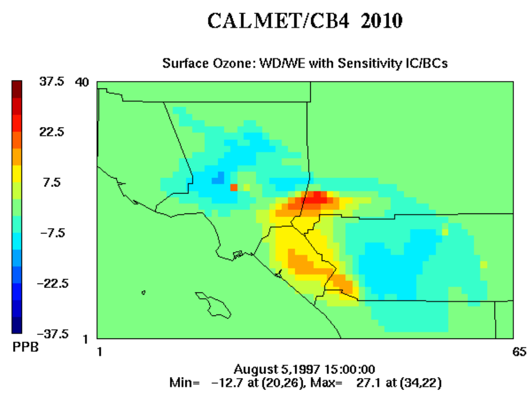
## 2010 “Sensitivity IC/BC” Case

## CALMET with CB4 Chemistry

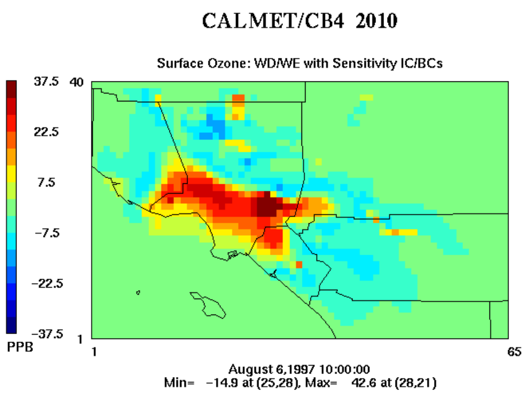
### Saturday 10 am



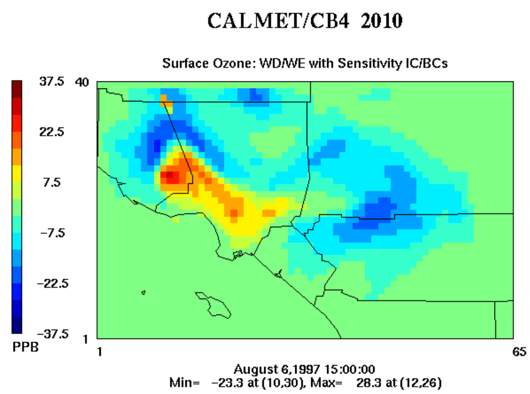

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

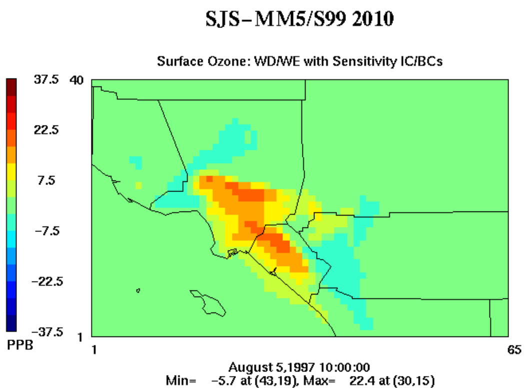


## Figure A-12

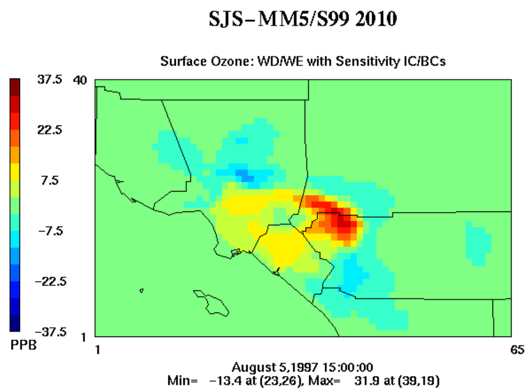
## 2010 “Sensitivity IC/BC” Case

## San Jose State MM5 with SAPRC99 Chemistry

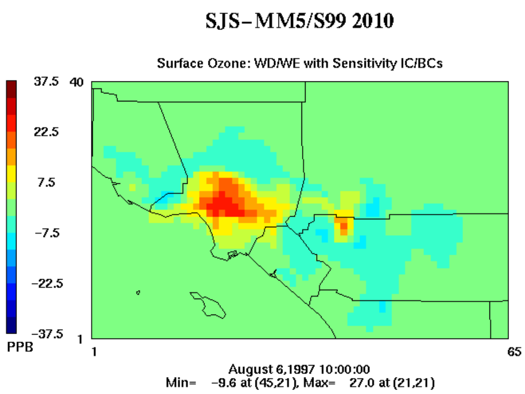
### Saturday 10 am



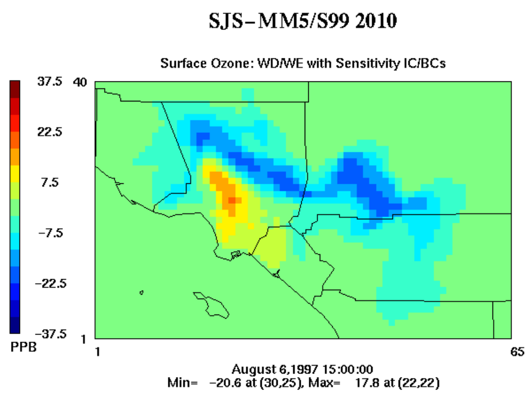

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

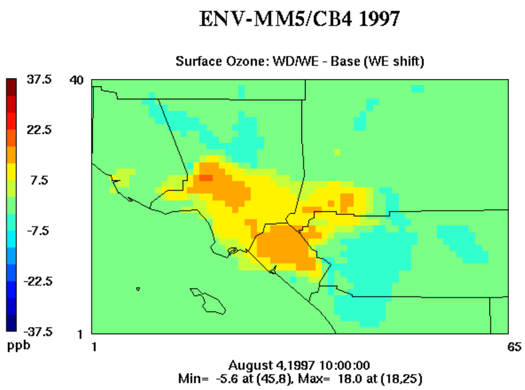


# Figure A-13

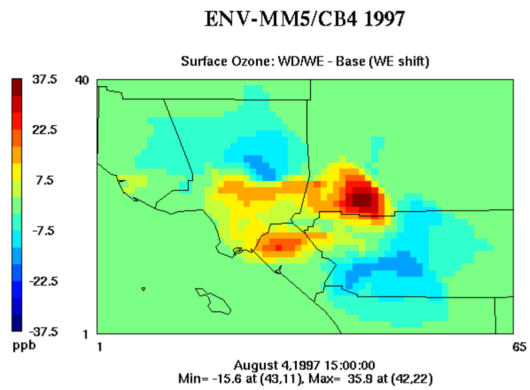
## 1997 "Weekend Shift" Case

## ENVIRON MM5 with CB4 Chemistry

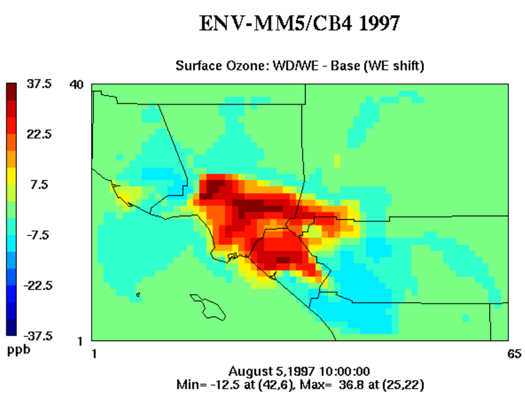
### Saturday 10 am



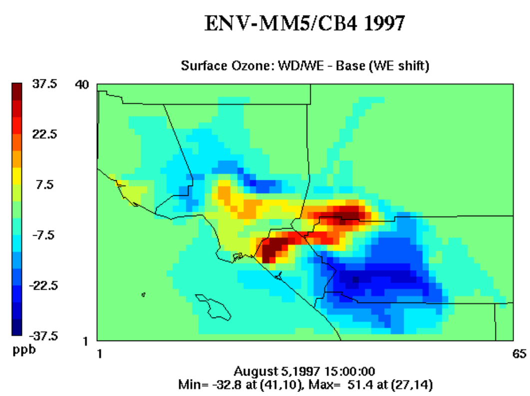

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

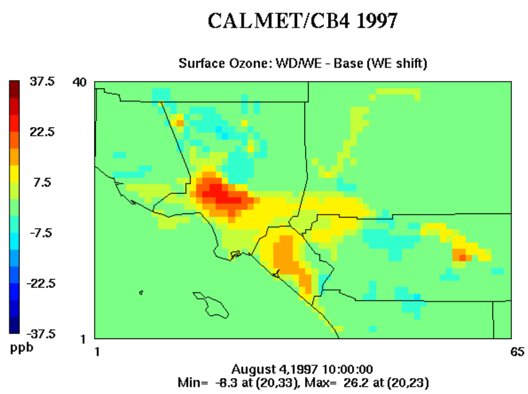


## Figure A-14

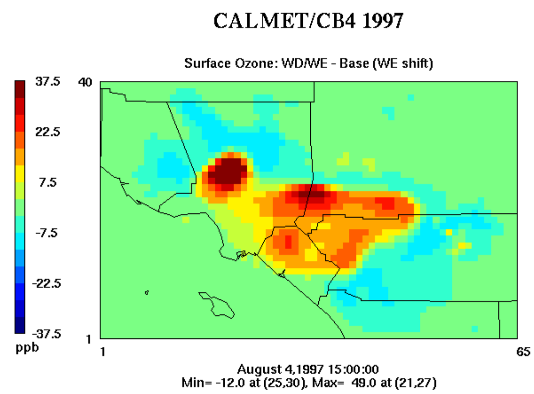
## 1997 “Weekend Shift” Case

## CALMET with CB4 Chemistry

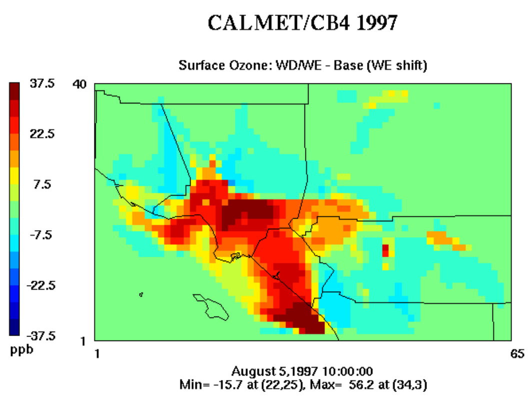
### Saturday 10 am



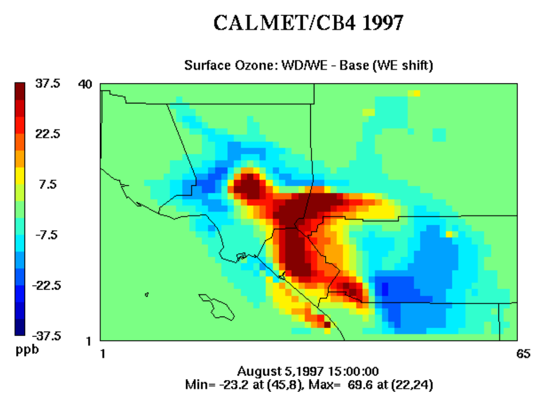

### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm

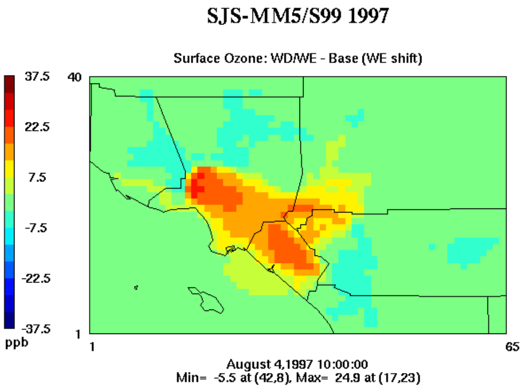


# Figure A-15

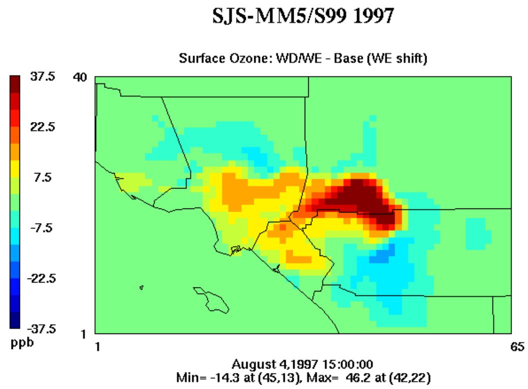
## 1997 "Weekend Shift" Case

## San Jose State MM5 with SAPRC99 Chemistry

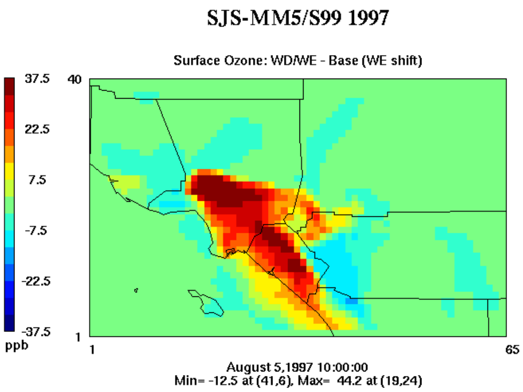
### Saturday 10 am




### Saturday 3 pm




### Sunday 10 am




### Sunday 3 pm