4.7 COMPARISON OF SIMULATED OZONE GENERATED WITH GROWTH-AND-CONTROL VS. UNIFORMLY-REDUCED EMISSION INVENTORIES IN CALIFORNIA

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1. INTRODUCTION

Photochemical models have been commonly applied in California to simulate the attainment of the federal 1-hour ozone standard and applications are underway to investigate the attainment of the 8-hour ozone standard. One method used for modeling-based attainment demonstrations is to simulate the target attainment year using an emission inventory specific to that year. Such future-year (FY) emission estimates can be developed based upon Growth-and-Control (G&C) factors, including projected population increase/decrease and implementation of adopted emission controls.

If the model does not show attainment with the attainment-year inventory, emissions are further reduced uniformly across the entire domain incrementally until attainment is demonstrated. A plan is then prepared to include additional controls needed to reduce emissions by the amount that had shown attainment. This uniform-reduction (UR) approach is not expected to be as precise as the FY approach, since the UR approach does not account for the spatial or temporal variability in the emissions, nor does it account for the type of pollutants emitted. However, it has the advantage of being easy and fast to implement. It also provides an estimate of the level of emission reduction needed to show attainment.

The goal of this study is to investigate the accuracy of the UR approach compared to the FY approach. This investigation is motivated by two key questions. The first question is whether extending the FY inventory with uniform emission reductions is a robust method for demonstrating attainment. The second question is whether the UR approach can provide a suitably accurate estimate of a FY inventory to avoid producing an FY inventory altogether and to avoid the associated time, effort and expense.

To conduct this study, we analyzed the 3-day episode from 31 July - 2 August, a high ozone period captured during the summer 2000 Central California Ozone Study [CCOS, Fujita et al. (2001)]. The CCOS provided a base year (BY) modeling emissions inventory (2000) as well as three different FY inventories (2007, 2012 and 2018). For the UR approach, we calculated the differences between BY and FY inventories. Then we created new modeling inventories by reducing emissions in the difference amount uniformly across the modeling domain. The CCOS provided a unique opportunity to conduct this investigation because three FY inventories were available. To determine the accuracy of the UR approach, we directly compared the UR inventories against the FY inventories and compared photochemical modeling results obtained from simulations using each of these inventories.

2. EMISSIONS

Emissions for this study were prepared by the California Air Resources Board and are available from their public ftp server [California Air Resources Board (CARB) (2005)]. Four major source categories were consid-

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ered in the inventory: area, motor vehicles, biogenic, and point sources. With the exception of the biogenic sources, the remaining three categories were anthropogenic in nature. In this paper, emission reductions were applied only to anthropogenic sources. Emissions from point sources were not included in the simulations because large point sources in the BY inventory contained variations due to day-specific plant operations while FY inventories assumed typical operations.

The daily total NOx and VOC emissions for BY and three future years are shown in Table 1 for the remaining anthropogenic sources. Variations in daily totals are primarily due to differences in motor vehicle emissions from daily temperature variations. Emissions for future-years were prepared by applying Growth-and-Control factors to the emissions of the base year 2000 (see Pechan-Avanti Group (1999) for an example of the G&C technique).

To create UR inventories for the three future years, we first averaged emissions of NOx and VOC for the episode period (31 July - 2 August) for the BY inventory and each of the FY inventories. Then the corresponding percent reductions by mass were calculated with respect to the BY inventory (Table 1). These reduction factors were applied uniformly across the modeling domain to the BY inventory to create UR inventories. For example, the average reductions in NOx and VOC emissions in 2007 were 23% and 11% respectively, corresponding to 77% and 89% of the BY 2000 emissions. No attempt was made to account for future potential changes in the VOC reactivity. The exact reductions applied to produce each FY year are shown in Table 1.

For each year, the FY and UR inventories have the same total emissions for the simulation period by definition. However, differences are expected due to spatial and temporal variations in the FY inventories that reflect spatial surrogates of individual source categories. Differences between each pair of UR and FY inventories were defined as

$$\delta = E_{UR} - E_{FY}. \qquad (1)$$

These differences were generally near zero for both NOx and VOC over most of the domain, indicating that the FY inventories for many categories were obtained by uniform reductions of the BY inventory. However, local differences were found at times. For example, areas with positive δ for NOx (between +12 kg/hour and

Table 1: Total NOx and VOC anthropogenic emissions (tons/day) from area sources and motor vehicles over the CCOS domain for the base-year 2000 and the future-years 2007, 2012, and 2018.

	NOx					VOC				
Year	31 July	1 August	2 August	Average	% of 2000	31 July	1 August	2 August	Average	% of 2000
2000	1818	1777	1786	1794	100%	1626	1631	1621	1626	100%
2007	1401	1375	1385	1387	77%	1446	1449	1440	1445	89%
2012	1110	1093	1100	1101	61%	1333	1335	1329	1332	82%
2018	881	871	875	876	49%	1303	1305	1300	1303	80%

+30 kg/hour) were found along major traffic arteries near some urban centers in the vicinity of Sacramento and near San Jose in the southern San Francisco Bay Area, during rush hours. Areas with positive δ indicate regions with greater future emission controls in the FY inventory. The only two areas with negative δ for NOx were the San Francisco airport (about -100 kg/hour) and Bakersfield (-15 kg/hour) in the southern San Joaquin Valley. Since they have negative δ, these two areas are expected to expand and produce higher emissions compared to uniform reductions. Values of δ for VOC were negative and relatively small (about -20 kg/hour) over scattered areas in the San Joaquin Valley. Positive values of δ for VOC were found near San Francisco and San Jose.

In general, as the projection year increased relative to the base year, the absolute value of δ increased for both NOx and VOC. For example, the maximum value of δ for NOx increased from 271 kg/hour in 2012 to 367 kg/hour in 2018. VOC increased from 247 kg/hour to 340 kg/hour for the same period.

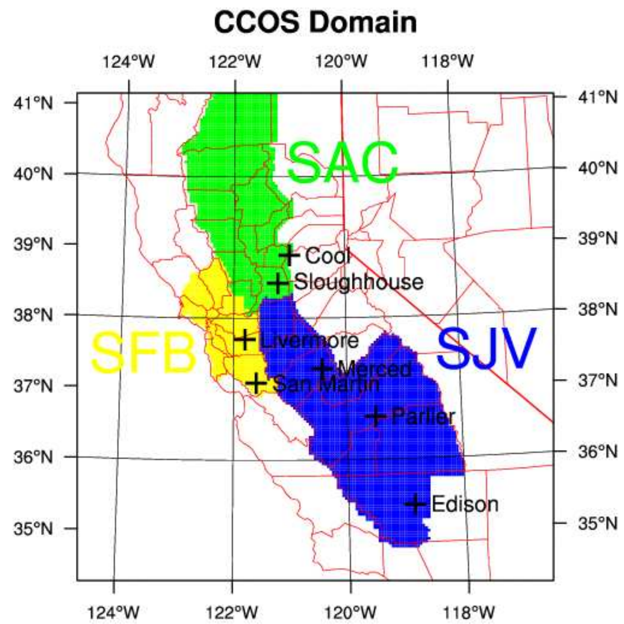

Figure 1: The modeling domain for the 2000 CCOS study, with the three regions (SFB, SAC, and SJV) and the locations of selected stations.

3. CAMx SIMULATIONS

All air quality simulations described in this study were conducted with CAMx, the Comprehensive Air Quality Model with eXtensions (ENVIRON 2004), which was run for 5 days starting on 29 July 2000 at 0500 PST. The first two days of this simulation period were used for model initialization.

a. Settings

The modeling domain covered most of California and western Nevada (Figure 1). The horizontal resolution was 4 km on a 185 x 185 grid. In the vertical, 20 layers were used with increasing resolution near the ground. Meteorological inputs were prepared using the MM5 model (Wilczak et al. 2004; Soong et al. 2006). Details of the CAMx model set up and model performance can be found in Soong et al. (2004).

b. Results

The analyses of this study focused on three main regions: San Francisco Bay Area (SFB), Sacramento area (SAC) and the San Joaquin Valley (SJV). For each region, 2-3 key sites (among a total of 53 sites in these regions) that were representative of the regions 8-hour design value were selected for comparisons. The seven selected sites were (Figure 1): Livermore and San Martin in the SFB, Cool and Sloughhouse in SAC, Merced in the northern SJV (NSJV), Parlier in the central SJV (CSJV), and Edison in the southern SJV (SSJV).

To aid the analyses, we produced a set of isopleth diagrams at these stations by reducing the anthropogenic BY 2000 emission inventory by 20%, 40%, and 60% uniformly across the modeling domain and by simulating 8-hour maximum ozone concentrations. Note again that point source emissions were not included in these simulations. For comparison with the isopleths generated with uniform emission reductions, we plotted marks on the isopleth diagrams to indicate 8-hour ozone maxima obtained with each of the FY inventories. For each region, only the day with the worst ozone exceedances (based on observations) is shown: 31 July for SFB, 1

August for SAC, and 2 August for SJV.

In the SFB region, at Livermore and San Martin stations (Figure 2), FY inventories produced lower ozone concentrations than uniform reductions. For example, in 2018 at San Martin maximum 8-hour ozone from the FY inventory is 75.4 ppb, whereas with uniform reductions it is between 76.5 and 79 ppb (the two nearby isolines). Similarly, at Livermore in 2007 maximum 8-hour ozone obtained with the FY inventory was 82.7 ppb, whereas with UR it was 83.8 ppb. During this episode on this particular day, these SFB stations appear to be VOC limited. For example, by reducing NOx by 20% while keeping VOC the same, 8-hour ozone maxima increased from 82.1 to 84.7 ppb in Livermore (Figure 2).

In the SAC region, Cool and Sloughhouse were selected for comparisons (Figure 1). In this region, as for the SFB region, FY inventories are more effective at reducing ozone than are uniform reductions, especially in the later years (2012 and 2018). The ozone isopleths (Figure 3) also show that the SAC region can be NOx limited. Under these episodic conditions, reductions in VOC may lead to little or no reductions in ozone, whereas NOx reductions appear more beneficial.

The SJV region, the largest of the three regions examined in this paper, does not respond uniformly. For the three SJV sites shown (Figure 4), the FY inventories were more effective than uniform reductions. For some other sites in the SJV region, however, UR inventories were more effective than FY inventories. For these simulations, the northern portion of the SJV ozone production was NOx limited (Merced), the southern was VOC limited (Edison), and the central (Parlier) responded to both NOx and VOC emission reductions.

A statistical analysis of the results obtained with FY versus UR emission inventories was generated by examining simulated ozone at the locations of each of the 53 stations. Example scatter plots are shown in Figure 5, where maximum 8-hour ozone concentrations simulated with FY emission inventory (x-axis) are plotted against maximum 8-hour ozone concentrations obtained with UR of the BY inventory (y-axis), for each year.

Figure 5 shows that the two FY and UR approaches lead to similar results. All stations are aligned along the 1:1 line, which indicates a perfect equality between the two approaches. The best match was on 31 July 2007, with a correlation coefficient of 99.7% and an average ozone bias of -0.06 ppb, expressed as the difference between the maximum 8-hour ozone concentration obtained with UR (O_3^{UR}) minus that obtained with the FY inventory (O_3^{FY}) (Table 2).

Table 2: Correlation coefficient ρ and average difference between maximum 8-hour ozone concentrations obtained with uniform reductions across the CCOS domain (O_3^{UR}) and future-year emission inventory (O_3^{FY}).

Day	Year	ρ	O_3^{UR}-O_3^{FY}
31 July	2007	99.7	-0.06
	2012	99.4	+0.56
	2018	99.1	+0.71
1 August	2007	99.7	-0.30
	2012	99.5	+0.78
	2018	99.3	+1.19
2 August	2007	99.4	-0.16
	2012	99.5	+0.88
	2018	99.2	+1.27
Average (by year)	2007	99.6	-0.17
	2012	99.5	+0.74
	2018	99.2	+1.06
Average	All	99.4	+0.54

The inventory for year 2007 was the only one that produced a negative bias, that is, for year 2007, UR emissions produced lower ozone on average than was produced with the FY emissions (e.g., -0.30 ppb on 1 August and -0.17 ppb on average over the three days). In contrast, emission inventories for years 2012 and 2018 produced positive biases (e.g., bias was +0.56 in 2012 and +0.71 ppb in 2018 on 31 July from Table 2). A positive bias indicates that uniform reductions lead to higher ozone concentrations than FY inventories and therefore the UR approach can be considered conservative.

In the CSJV and SSJV sub-regions, several points fell below the 1:1 line, in the part of the plot marked as "Uniform Reduction more effective" (Figure 5), especially in 2007. This suggests that the central and southern parts of the San Joaquin Valley are not expected to reduce ozone as much as in the rest of the domain. Conversely, SFB, SAC, and NSJV are above the 1:1 line in all three years; this indicates that these sub regions are expected to reduce ozone more than the domain-average. In other words, projections suggest that emission control strategies in SFB, SAC, and NSJV will be more successful than in the rest of the CCOS domain.

Finally, the absolute value of the ozone bias increased from 2007 to 2018 for all three days (Table 2), a finding that was expected from the similar behavior of the emission differences (δ) discussed above, where it was shown that the similarity between FY and UR emission inventories diminishes for later years.

4. SUMMARY AND CONCLUSIONS

In this study, for each FY inventory (2007, 2012, and 2018), the average percent reduction of NOx and VOC was calculated with respect to the 2000 BY inventory. When the same percent reductions were applied across the domain to the BY inventory, maximum 8-hour ozone concentrations at 53 key sites often did not differ substantially from those obtained with the FY inventories. Correlations coefficients between ozone concentrations simulated by CAMx with the two approaches were very high (i.e., over 99%). As such, uniform emission reductions across the domain represent an effective tool to obtain estimates of ozone levels when an appropriate FY emission inventory is unavailable, especially if the change in emissions relative to the base year is relatively small (less than about 20% for this episode).

Ozone bias, defined as the difference in maximum 8-hour ozone concentration simulated with UR and with FY inventories, was usually positive, indicating that, on average, uniform reductions gave conservative ozone estimates. However, in 2007 (i.e., one case out of three), uniform reductions across the domain were overall more effective at reducing maximum 8-hour ozone concentrations than FY inventories. In this case, the UR method was not conservative.

Of the various sub-regions, in SAC, SFB, and the northern portion of SJV, FY inventories were always more effective than uniform emission reductions. As such, it appears that local emissions in these areas were projected to be reduced more than the domain average. In contrast, in central and southern SJV, uniform emission reductions were often more effective than FY inventories at reducing ozone maxima, which indicates that, in these areas, emissions were projected to be reduced less than the domain average.

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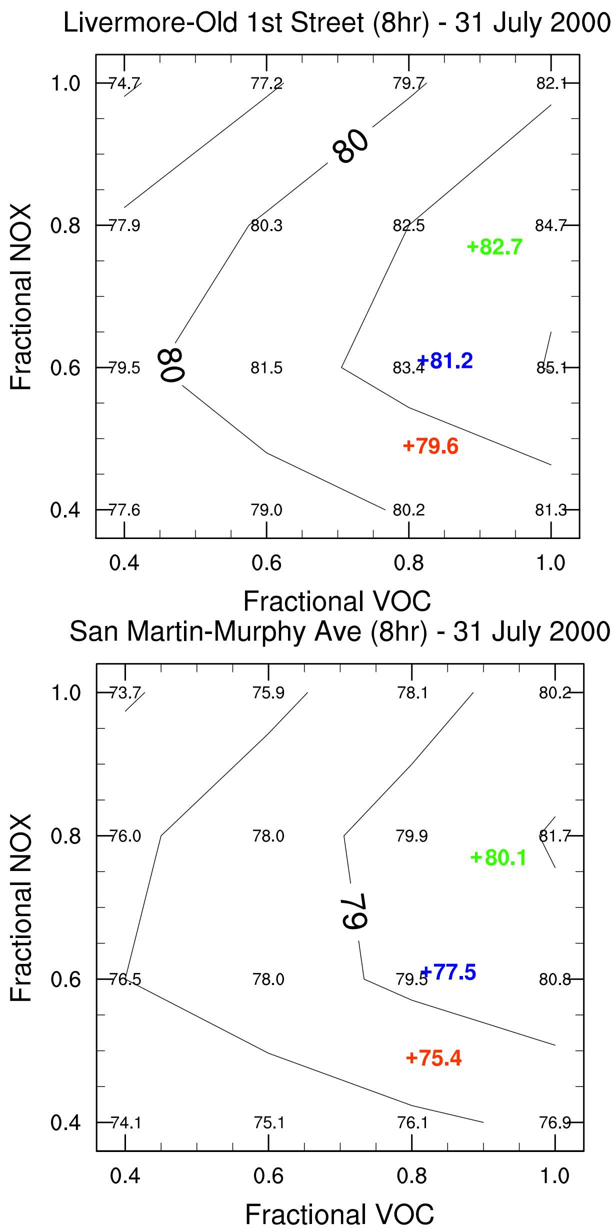

Figure 2: Isopleths of maximum 8-hour ozone concentrations (ppb) simulated in the SFB Region on 31 July 2000, at Livermore and San Martin. The marks indicate the maximum 8-hour ozone concentrations simulated with future-year emission inventories for years 2007 (green), 2012 (blue), and 2018 (red). Contours are shown every 2.5 ppb.

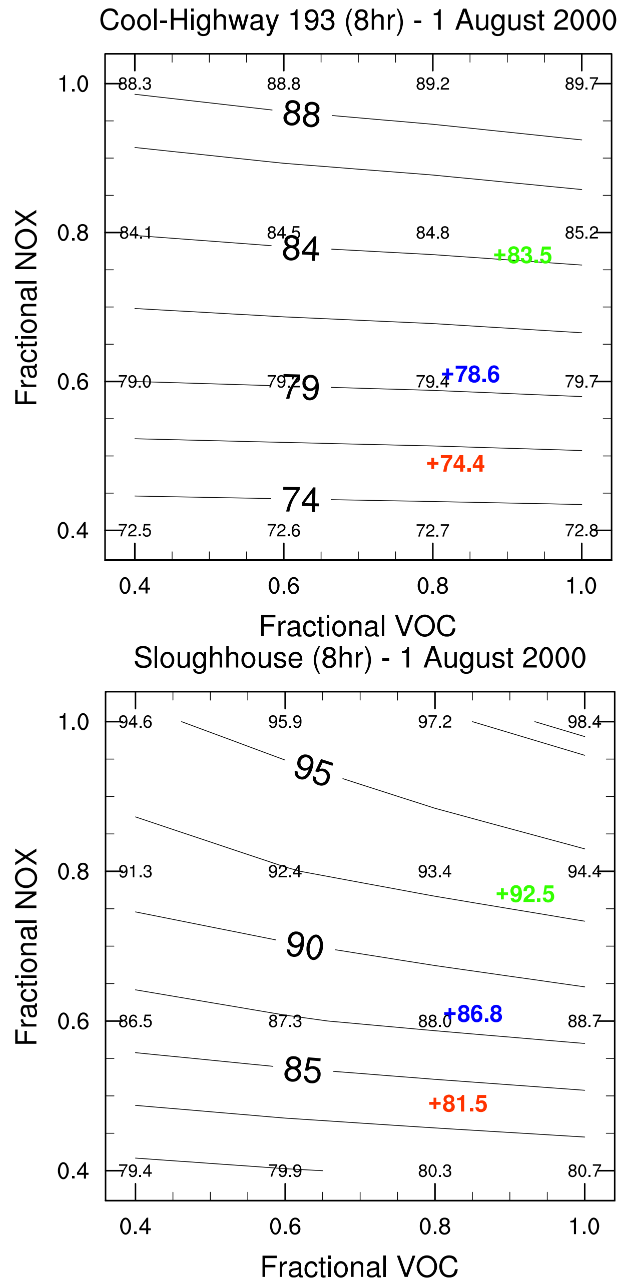

Figure 3: Same as Figure 2, but for the SAC Region, at Cool and Sloughhouse on 1 August 2000.

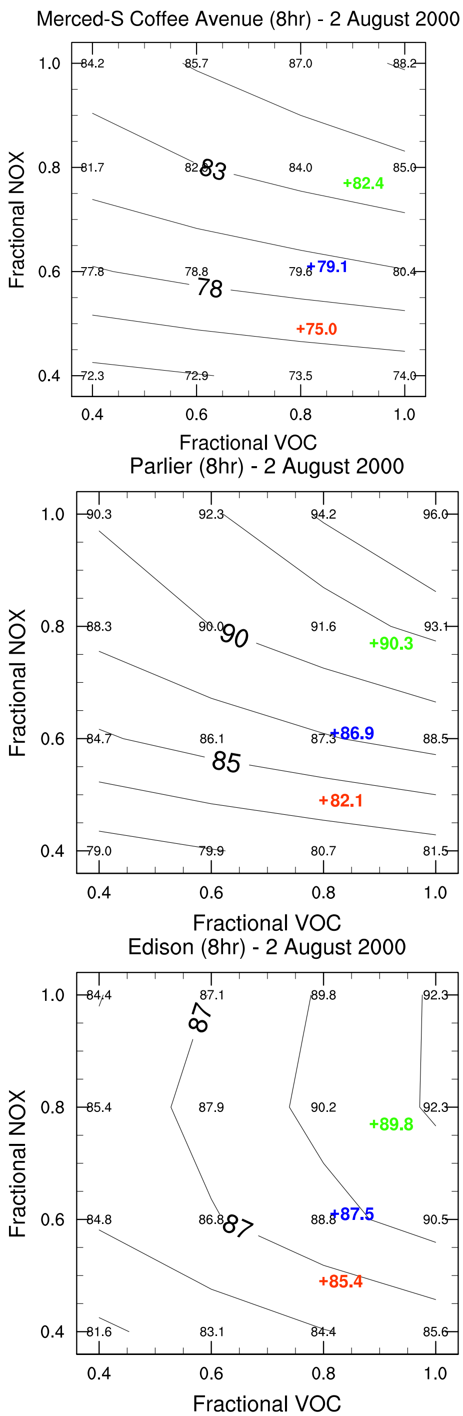

Figure 4: Same as Figure 2, but for the SJV Region, at Merced, Parlier, and Edison on 2 August 2000.

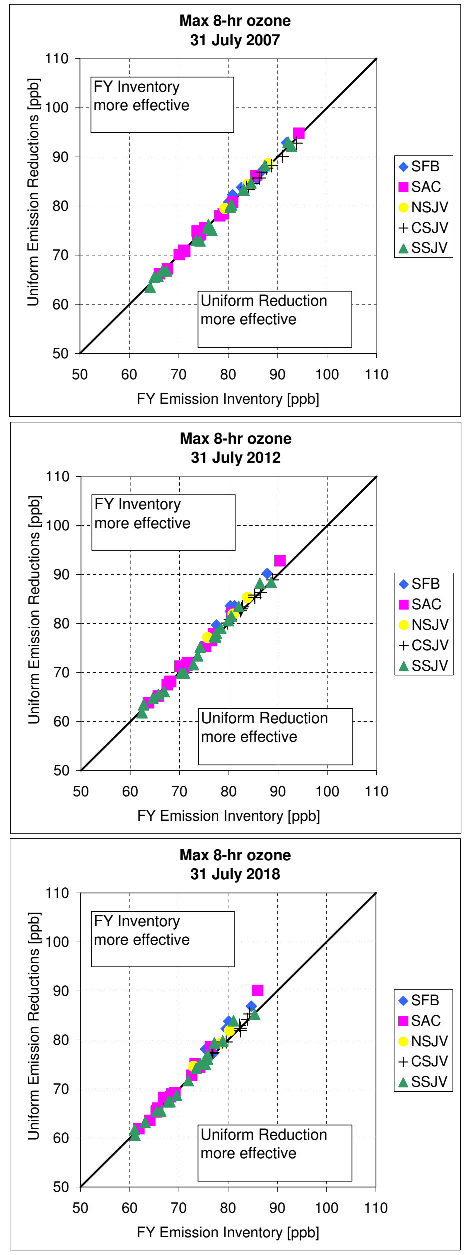

Figure 5: Scatter plot of simulated maximum 8-hour ozone concentrations obtained with future-year emission inventories (2007, 2012, and 2018) versus those obtained with uniformly reduced base-year emission inventory (2000) on 31 July at all stations.