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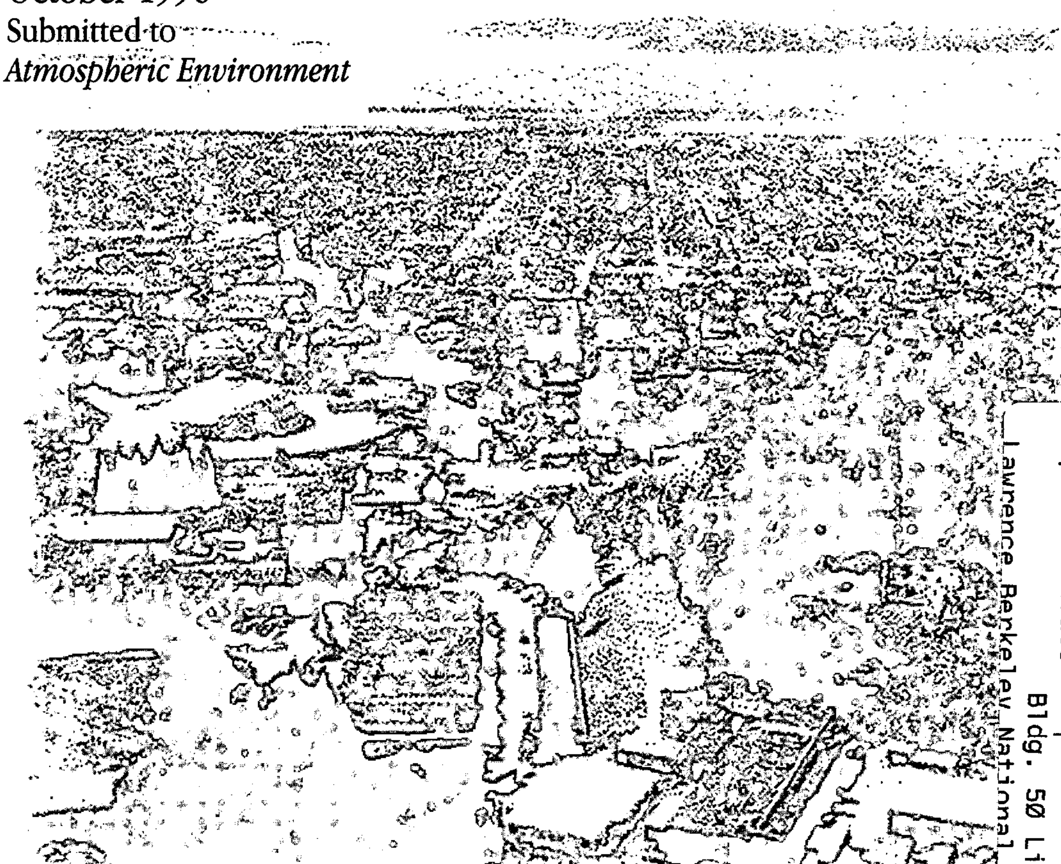

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ABSTRACT

It is expected that high-albedo materials will be used widely in urban areas particularly in warm and hot climates of the U.S. This will likely happen if high-albedo measures are adopted in building energy codes and urban planning regulations. The changes would mean that portions of urbanized airsheds may become more reflective to solar radiation than they currently are. This paper describes a modeling study that aimed at analyzing the mesoscale meteorological and ozone air quality impacts of large-scale increases in surface albedo in California's South Coast Air Basin (SoCAB). For a late-August episode, the simulations indicate that implementing high-albedo materials in the SoCAB would have a net effect of reducing ozone concentrations. With extreme increases in albedo, peak concentrations at 3 pm on August 27 decrease by up to 7% (from 220 down to 205 ppb) while the total ozone mass in the mixed layer decreases by up to 640 metric tons (a decrease of 4.7%). Largest reductions in concentrations at 3 pm are on the order of 50 ppb whereas the largest increases are on the order of 20 ppb. With respect to the National Ambient Air Quality Standard, domain-wide population-weighted exceedance exposure to ozone decreases by up to 16% during peak afternoon hours and by up to 10% during the daytime.

Keywords: Ambient temperatures, Mesoscale modeling, Photochemistry, Urban Airshed Model.

INTRODUCTION

Several studies have demonstrated and quantified the potential savings in cooling energy use due to increasing the albedo of building and urban surfaces (e.g., Akbari et al. 1994a,1994b). In parallel, meteorological modeling work that investigated the role of surface properties in mesoscale meteorology showed that large-scale increases in albedo can be effective in decreasing ambient air temperatures (e.g., Taha et al. 1988, Taha 1994a, Sailor 1993). Based on these and related findings, it is now being suggested that U.S. cities in warm and hot climates gradually implement the large-scale use of high-albedo materials to lower surface and air temperatures and save energy.

A case in a point is the Los Angeles Basin, an ozone non-attainment area with a combination of topography, meteorology, and emissions that earned it an "extreme" ozone non-attainment classification. The Southern California Edison Company (SCE) and the Los Angeles Department of Water and Power (LADWP) are considering the widespread use of high-albedo materials as a measure for reducing energy use. The South Coast Air Quality Management District (SCAQMD) has considered the implementation of high albedo materials in its 1994 Air Quality Management Plan (AQMP) as a potential strategy for improving the ozone air quality in the Los Angeles basin (SCAQMD 1994a).

The purpose of this modeling study is to quantify the impacts of large-scale albedo increases on air quality in the SoCAB. Increasing surface albedo may prevent a significant rise in surface temperatures which, in turn, will keep the air relatively cooler in the modified areas and downwind of them. The implications of lower ambient temperatures include 1) a decrease in photochemical reaction rates, 2) a decrease in temperature-dependent biogenic emissions, 3) a decrease in evaporative losses of organic compounds from mobile and stationary sources, and 4) a decreased need for cooling energy, generating capacity, and, thus, emissions from power plants. However, decreasing the near-surface temperatures can also decrease the depth of the mixed layer at some locations in the airshed potentially resulting in higher ozone concentrations there.

In this study, the Systems Applications International (SAI) version of the Colorado State University Mesoscale Model (CSUMM) was used to simulate the SoCAB's meteorology and its sensitivity to changes in surface albedo. The Urban Airshed Model (UAM) was used to simulate the impacts of the changes in meteorology and emissions on ozone air quality. A version of UAM IV that allows the import of three-dimensional temperature, humidity, and wind fields from the CSUMM was used in this study. The impact of changes in meteorology on emissions was accounted for via several preprocessors to the UAM (SAI 1990).

ALBEDO AND ITS MODIFICATIONS

For a heterogeneous area, i.e., with a variety of surface types, let albedo be defined as:

$$\alpha = \Sigma f_i \alpha_i \tag{1}$$

where f_i is area fraction of surface "i" whose albedo is α_i. In this study, albedo is defined at a scale of 5×5 km, i.e., the size of the model's grid.

For the purpose of this study, a gridded albedo database for the SoCAB was developed from AVHRR satellite data of August 29, 1991 (Liu 1994). Albedo was derived from AVHRR's bands in the visible (0.58-0.68 μm), near infrared (0.725-1.1 μm), and middle infrared (3.55-3.93 μm) following a method devised by Brest and Goward (1987). In addition, Taha (1994b) obtained direct measurements of the SoCAB's albedo from low-altitude flights in summer 1993. These measurements were continuous in the spectrum between 0.28 and 2.8 μm. The gridded albedo is shown in Figure 1 which also depicts the modeling domain defined in terms of UTM coordinates in Zone 11. Albedo ranges from a high of 0.22 in some portions of the Mojave desert to a low of 0.08 over the Pacific Ocean and mountain ranges. The average land albedo of the SoCAB is 0.138.

Theoretically speaking, the albedo of individual surfaces could be increased to up to 0.95 or even higher. Building and urban surface albedos in the order 0.80 have been measured in the field (Taha et al. 1992) and albedos of over 0.95 have been measured in the laboratory (Berdahl and Bretz 1995). However, for practical and visual environmental considerations, there is reason to believe that such a large increase in albedo is difficult to achieve in urban settings and especially at large scales. Also, except for heavily urbanized areas, e.g., Downtown, there is not much impervious surface area available for albedo modification. Thus, at the scale of a grid cell (5×5 km), the maximum increase in albedo will probably never exceed 0.30. Accordingly, a maximum albedo increase of 0.30 over existing values was deemed an extreme upper bound and used as such in this modeling work.

Using a procedure originally devised by Sailor (1993), later modified by Taha (1994a), the land use composition in each of 2600 cells in the modeling domain is examined to determine the fraction of each cell that can be subject to albedo increase relative to its base-case value. The author will use the term "albedoable" to indicate that a certain land use category could be candidate for albedo increase.

Within each 5×5-km cell, 23 land use categories were sorted and their fractional areas identified according to a database by Horie et al. (1990). Certain land use categories were found to be albedoable e.g., residential areas, offices/commercial areas, and parking lots but others, such as parks, heavily vegetated areas, and deserts were not. In this study, it was also assumed that freeways were not albedoable. The new albedo of a cell is defined by:

$$\alpha'_{i,j} = \alpha_{i,j} + \delta\alpha \sum_{L=1}^{n} f_L \qquad (2)$$

where $\alpha_{i,j}$ is the original albedo of cell (i,j,) $\delta\alpha$ is a nominal (maximum) amount of increase in albedo (that could be achieved if a cell were 100% albedoable), and f is the area fraction of land use "L". Two nominal albedo increases were simulated: a moderate increase ($\delta\alpha$=+0.15) and an extreme increase ($\delta\alpha$=+0.30). These levels correspond to increasing the average albedo of the entire land portion of the SoCAB modeling domain from a base-case value of 0.138 to 0.155 and 0.171, respectively. For those grid cells whose albedo was increased, the average increase in albedo for the moderate case was 0.07 and for the extreme case, it was 0.13. There were 392 cells (of 2158 land cells) whose albedo could potentially be modified (Figure 2).

MODELS

The CSUMM and UAM were used in simulating the mesoscale meteorology and ozone air quality. The models essentially solve a set of coupled governing equations for prognostic meteorological fields and pollutant species concentrations representing the conservation of mass (continuity), potential temperature (heat), momentum, water vapor, and chemical species continuity, respectively:

$$\frac{\partial \rho}{\partial t} = -(\nabla \cdot \rho \vec{V}) \quad (3)$$

$$\frac{\partial \theta}{\partial t} = -\vec{V} \cdot \nabla \theta + S_\theta \quad (4)$$

$$\frac{\partial \vec{V}}{\partial t} = -\vec{V} \cdot \nabla \vec{V} - \frac{1}{\rho} \nabla p - g\vec{k} - 2\vec{\Omega} \times \vec{V} \quad (5)$$

$$\frac{\partial q}{\partial t} = -\vec{V} \cdot \nabla q + S_q \quad (6)$$

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (\vec{u} c_i) = \nabla \cdot (\vec{K} \nabla c_i) + R_i + S_i + D_i \quad (7)$$

In equations 3-7, ρ is density, V is the wind velocity vector, θ is potential temperature, S_θ is sink/source term for potential temperature, p is pressure, Ω is angular velocity vector, q specific humidity, S_q is source/sink term for specific humidity, c_i is the concentration of species "i", K is the turbulent diffusion coefficient, and R, S, and D are the reaction, source, and sink (deposition) terms for species "i".

The CSUMM is a hydrostatic, primitive-equation, three-dimensional Eulerian model originally developed by Pielke (1974). The model is incompressible, and employs a σ_z coordinate system. It uses a first order closure scheme in treating sub-grid scale terms of the governing differential equations (3-6). The model's domain is about 10 km high with an underlying soil layer about 50 cm deep. The CSUMM generates three-dimensional fields of prognostic variables as well as a mixing height field that can be used as input to the UAM.

The UAM is a three-dimensional, Eulerian, photochemical model capable of treating inert and chemically-reactive atmospheric pollutants. It has been recommended by the EPA for ozone air quality modeling studies of urban areas (EPA 1986). The UAM simulates the advection, diffusion, transformation, emission, and deposition of pollutants (equation 7). It treats about 30 chemical species and uses the carbon bond CB-IV mechanism (Gery et al. 1988). The UAM accounts for emissions from area and point sources, elevated stacks, mobile and stationary sources, and vegetation (biogenic emissions).

The rectangular modeling domain in this study is defined by UTM coordinates (275,3670), (275,3865), (595,3865), and (595,3670) km in Zone 11. The meteorological and photochemical models were run with a grid size of 5×5 km. The meteorological simulations were started at 4 am on August 26 and stopped at midnight on August 27. The photochemical simulations were initiated at 3 pm on August 26 and ended at 8 pm on August 27.

RESULTS

Results discussed in this paper are from the second day of the simulation (August 27), with particular emphasis on 3 pm. This choice has the advantage of minimizing the effects of initial conditions on the simulated fields and capturing the impacts of albedo changes on peak ozone concentrations that usually occur between 12 noon and 4 pm. It also keeps the discussion compact.

Meteorological and biogenic emissions impacts of albedo changes

Since the main focus in this paper is on the air quality aspects, the discussion of the meteorological impacts of albedo changes will be kept short. The base-case meteorology of this episode was established by simulating the SoCAB with the latest AVHRR-based gridded albedo data developed by Liu (1994) for this study. Other surface properties, boundary and initial conditions, and aspects of the input to the meteorological model are discussed in Taha (1994a) and Taha et al. (1994).

Following establishment of this base-case meteorology, the next step involved simulating the impacts of increasing the albedo in the albedoable portions of the modeling domain. The potential amount of increase in each cell was determined from equation (2) with the term "f_L" obtained from the land use database of Horie et al. (1990). As seen in Figure 2, most of the possible albedo changes occur in the west basin and, to a lesser extent, in the San Fernando Valley, the east basin, and Riverside. While all meteorological fields respond in varying degrees to the changes in surface albedo, the most important change is in the temperature field (Taha et al. 1994). Within the lowest 10 m of the atmosphere, a decrease of up to 2°C in air temperatures may be possible with moderate increases in albedo. In this case, most of the temperature depression occurs in the central basin, with changes of about 1°C in surrounding areas. With extreme increases in albedo, reductions of up to 4.5°C can be achieved in the west and central basins, with an average decrease of 2°C in surrounding areas (Figure 3).

The impacts of lowered air temperatures on biogenic hydrocarbons emission from existing vegetation in the SoCAB were calculated in order to regenerate the biogenic emissions inventory. The correction of isoprene and monoterpenes emission for solar radiation and domain-varying temperatures was carried out using an algorithm developed by Tingey et al. (1979,1980). The corrections were performed for each hour and each grid cell using output from the CSUMM mesoscale simulations of that episode. The plant biomass distribution in the SoCAB was based on the data of Horie et al. (1990) while the biogenic emission factors were obtained from a SCAQMD database updated by Bloch and Winer (1994). The decrease in biogenic emissions from existing vegetation as a result of increasing the albedo was found to be 7 metric tons per day (mtpd) or about 2% for the moderate albedo increase and 13 mtpd (3.5%) for the extreme albedo increase. Although these reductions are small, they are nevertheless accounted for in the photochemical simulations discussed in this paper.

Ozone air quality impacts of albedo changes

The ozone air quality impacts of albedo changes discussed in this section include the effects of changes in air temperature (reaction rates), depth of the mixed layer, wind field, and biogenic emissions from existing vegetation. In a later section, the air quality impacts of changes in anthropogenic emissions from power plants and mobile sources (following changes in albedo and air temperature) will be discussed. Figure 4 shows the simulated base-case ozone concentrations field (in ppb, at 3pm on August 27). Concentrations on the order of 200 ppb are found in the San Fernando Valley, central basin, San Bernardino, east basin, areas in Riverside, and south of Orange County. There are 385 grid cells in the modeling domain with ozone concentrations over 120 ppb (the federal ozone standard) and 1360 cells over the California standard of 90 ppb. Excluding the ocean portion of the UAM modeling domain, this is equivalent to saying that 20% and 70%, respectively, of the land portion of the SoCAB is above the standards during that hour.

When albedo is increased and temperature drops, a decrease in ozone concentrations is generally expected. The main mechanism through which temperature affects ozone is believed to be the chemistry of peroxyacetyl nitrate (PAN) (Cardelino and Chameides 1990). In sensitivity simulations with the UAM, Taha et al. (1994) showed that decreasing the SoCAB's temperature alone always resulted in decreasing ozone concentrations. For example, an average decrease in concentrations of 12% is possible with a domain-wide average decrease of 1.5°C in air temperature. However, when albedo is increased, it is not only temperature that decreases but also the depth of the mixed layer at some locations (other meteorological variables will be affected but to a lesser extent). Thus, both increases and decreases in ozone concentrations can be expected depending on location-specific meteorological conditions and emissions. Additionally, when ozone is prevented from forming in one area (because of lower air temperatures), its precursors can still be transported downwind or recirculated to an upwind location where they can cause a local increase or decrease in ozone.

It is also worth mentioning that many high-albedo materials are poor reflectors in the ultra-violet (UV) range (Berdahl and Bretz 1995). Thus, increasing the albedo of a region by properly selecting this type of high-albedo materials will not affect the rate of NO_2 photolysis and the potential for ozone formation will not increase.

Figure 5 shows the difference in ozone concentrations (ppb) from the base-case (at 3 pm on August 27) for a case with moderate increase in albedo. There are increases in concentrations over the Santa Monica mountains, in the Burbank-Glendale area, and offshore. But the magnitude of the decreases in concentrations in other locations is generally larger than that of the increases and the net basin-wide effect is a reduction in ozone mass and concentrations. At 3 pm there are 240 metric tons (2%) less ozone in the mixed layer due to the moderate increase in albedo. In the extreme albedo increase (Figure 6), the largest decreases are on the order of 50 ppb whereas the largest increases are on the order of 20 ppb. The total area with ozone decreases is larger than that with ozone increases and the net effect is again a reduction in ozone. At 3 pm, there are 640 metric tons (4.7%) less ozone in the mixed layer due to the extreme increase in albedo.

To assess the local implications of albedo changes, and at other hours as well, time series of ozone concentrations on August 27 were examined at several locations in the modeling domain. In general, the amount of decrease in ozone concentrations is larger than the amount of increase. For example, in Burbank, LA Civic Center, and Long Beach, the increase in albedo results in decreasing the ozone concentrations between 11 am and 6 pm. At 3 pm, the extreme albedo increases result in reducing the concentrations by 25 ppb, 70 ppb, and 35 ppb in these areas, respectively. In the Civic Center area, the concentrations go from 160 ppb down to about 90 ppb, well below the national standard. There is, however, some increase later in the day at certain locations (e.g., Burbank and LA Civic Center), but the increases (10-15 ppb at most) are not as large as the decreases in concentrations. In Anaheim and surrounding areas, the albedo strategies seem to cause an increase in concentrations in the early afternoon and some decrease after 4 pm. However, both increases and decreases are small (about 10 ppb at most). Finally, in inland areas such as San Bernardino and Riverside, both of which have high base-case ozone concentrations, the albedo increase strategies seem to have no effect on ozone air quality. This still is a positive consequence since it suggests that energy savings from high albedo materials can be achieved without negative impacts on air quality in the warm inland areas of the SoCAB.

Exposure assessment

To provide a single basin-wide evaluation of the potential air quality impacts of extensively using high-albedo materials, a simple exposure analysis is discussed in this section. For this purpose, it is assumed that exposure assessment depends solely on ambient (outdoor) conditions and that different individuals react similarly to a given level of exposure. Population's movement and age-distribution are not accounted for. With that in mind, we can define percent exceedance exposure as:

$$E\% = \frac{\sum_{x=1}^{X} \sum_{h=1}^{H} P_{(x)} \left[C_{(i,x,h)} - C_t \right] H_{(\Delta C)}}{\sum_{x=1}^{X} \sum_{h=1}^{H} P_{(x)} \, Cb_{(x,h)}} \tag{8}$$

where x is grid-cell identifier (location), h is hour identifier (time), P is population in grid cell (x), $C_{(i,x,h)}$ is ozone concentration (ppb) in cell (x) at hour (h) for case (i), C_t is a reference threshold concentration, H is the Heavyside function which is equal to 1 if concentrations are in the range given by ΔC, that is when $C_{(i,x,h)} > C_t$, and 0 otherwise (when $C_{(i,x,h)} \le C_t$), and $Cb_{(x,h)}$ is base-case total ozone concentration in cell (x) at hour (h). Three thresholds (C_t) are considered: 1) 90 ppb (California Ambient Air Quality Standard, CAAQS), 2) 120 ppb (National Ambient Air Quality Standard, NAAQS), and 3) 200 ppb (California Stage-I health alert). In the following paragraphs, exceedance exposure is first discussed for the hour of 3 pm on August 27 and then for all daytime hours on that day.

In the simulated base-case conditions, 34% of the basin-wide population-weighted exposure at 3 pm is over the CAAQS but is only 32% and 30% in the moderate and extreme albedo increases, respectively (Table 1). In terms of the NAAQS, the base-case conditions exhibit 18% exposure over the standard. In the moderate and extreme albedo increases, exposure drops to 16% and 15%, respectively. With respect to the California Stage-I health alert, there is 0.5% exposure above the threshold in the base case but negligible exceedance exposure in the modified-albedo cases. The basin-wide net effects of increasing albedo seem to be significant, keeping in mind the severity of this episode.

Table 1. Percent exceedance exposure to ozone at 3 pm on August 27.

	>CAAQS	>NAAQS	>Stage I
Base case	34%	18%	0.5%
Moderate albedo increase	32%	16%	0.1%
Extreme albedo increase	30%	15%	0%

CAAQS: California Ambient Air Quality Standard (90 ppb O_3)
NAAQS: National Ambient Air Quality Standard (120 ppb O_3)
1st stage: California Stage-I health alert (200 ppb O_3)

In terms of total daytime population-weighted exposure to ozone on August 27, the effects of the albedo strategies are summarized in Table 2. For a threshold of 90 ppb (CAAQS), the moderate and extreme albedo increases bring down the total daytime exceedance exposure by 4% and 12%, respectively. For a threshold of 120 ppb (NAAQS), the effectiveness of the moderate- and extreme-albedo increases amounts to reducing the exceedance exposure by 5% and 10%, respectively.

Table 2. Percent exceedance exposure for 8am-7pm on August 27.

Case	>CAAQS	>NAAQS	>1st stage
Base	24%	10%	0.1%
Moderate albedo increase	23%	9%	0%
Extreme albedo increase	21%	9%	0%

To determine the relative importance of these findings compared to the impacts of other strategies, like mobile-source emission control, a standard UAM test was performed in which the same episode was simulated with and without motor vehicle emissions. Although the results need further investigation, the current findings suggest that the extreme albedo increases are about one-half as effective as removing all motor vehicles operating in 1987 in the SoCAB. Of course, the relative effectiveness of albedo changes will fare differently with different emission inventories, episodes, locations, or meteorological conditions. One should also bear in mind the uncertainties associated with the current emission inventories.

Other impacts of albedo increase

The changes in albedo and air temperatures may also have an effect on emissions from power plants and mobile sources. These are briefly described in this section.

To quantify the potential impacts of albedo increases on emissions from power plants located in the SoCAB, the direct (microscale) and indirect (mesoscale) effects of albedo modifications on system-wide electric load in the SoCAB were assessed for the SCE and LADWP service territories. Load shapes for the base case and each of the albedo scenarios were developed through a combination of 1) objective analysis of utility and weather data and 2) detailed numerical energy simulations of a large number of prototypical buildings in various climate zones within the airshed (Fishman 1994). The time- and space-varying meteorology generated by the CSUMM was used as weather input in the building energy simulations. The resulting load shapes were then used in the ELFIN model to estimate the possible reductions in power plant emissions. Hall and Hall (1995) estimate that for the major LADWP power plants in the SoCAB, weekday emission of NOx would be reduced by 2.42 mtpd for a case with extreme albedo increase. ROG emissions would be reduced by 0.05 mtpd and CO by 0.02 mtpd. For the major SCE power plants in the SoCAB, the high increase in albedo would cause the following reductions in emissions: 4.74 mtpd of NOx, 0.2 mtpd of PM10, 0.15 mtpd of ROG, and 1.1 mtpd of CO. UAM simulations of this episode indicate that these small reductions in precursor (NOx,ROG) emissions have negligible impacts on the ozone air quality in the SoCAB.

The impacts of temperature decrease, brought on by the increases in albedo, on mobile source emissions were estimated by Haney and Fieber (1994) using the EMFAC7F and DTIM-2 models (Caltrans 1994). Two cases were tested; a base case and a case equivalent to the extreme albedo scenario. Results indicate that the differences in mobile source emissions between the two cases are small. Part of the reason is that the simulated ambient temperatures of the SoCAB for this episode are within the range of temperatures in which emission control devices are at optimal performance. For August 27, simulated domain-wide daily TOG emissions from mobile sources are reduced by about 1.5% whereas NOx and CO emissions remain relatively unchanged. The UAM simulations in this modeling study suggest that these changes in mobile source emissions would decrease the population-weighted exposure to ozone at 3 pm on August 27 by 4%, 7%, and 40% with respect to the CAAQS, NAAQS, and Stage-I alert level, respectively.

BASECASE MODEL PERFORMANCE

Taha (1995) discusses the base-case model performance evaluation for the meteorological and photochemical simulations in this study. Part of that discussion is repeated here. The Mean Relative Error (MRE) and Unpaired Accuracy of the Peak Concentration (UAPC) will be used for this purpose. These indicators are defined in Taha (1995) and EPA (1991).

Observational meteorological and ozone air quality data from 28 stations in the SoCAB in 1987 and 1991 were analyzed to identify those days in late August most appropriate for model validation. Statistics for three days are reported in this section; August 23 (clear, warm day), August 27 (cooler day), and August 13 (in between). These days are used to represent a range of conditions in late August rather than date-specific situations which a PBL model without data assimilation cannot be expected to exactly reproduce. The MRE and UAPC analysis presented in this section includes daytime and nighttime statistics.

Temperature MRE for August 13,23, and 27 was found to be 13%, 11%, and 32% respectively, indicating that the meteorological model can simulate reasonably well clear and warm days in August but not cooler days, as expected. For mixing height evaluation, data from only August 27 were available. The "observed" mixing height was derived from soundings and surface temperature data interpolated using a method suggested by Cassmassi and Durkee (1990). Based on data from four locations (Reseda, Rubidoux, Anaheim, and Azusa), the MRE for the mixing height field was found to be 18%.

The UAM-simulated ozone concentration field was similarly analyzed for the hottest and coolest days in late August. A threshold of 60 ppb ozone was used as per EPA recommendations (EPA 1991). MRE for August 23 and 27 was calculated at 9% and 35%, respectively. The EPA-recommended range is < ±15%. The UAPC for these days was found to be 7% and -9%, respectively and the EPA-recommended range is < ±20%. These statistics indicate that the UAM-simulated ozone concentration fields are accurate for August 23 but not so for August 27. For the purpose of this study, the UAM base-case model performance was deemed appropriate since the emission inventory was reprocessed using the meteorological simulation of a warm day. One should evaluate these indices keeping in mind that the simulations with the CSUMM used no data assimilation, and that the focus of this study is mainly on the relative changes in meteorological and ozone air quality conditions, not their absolute values. The objective of this study is to analyze the changes in these fields following modifications in boundary conditions. For all of these reasons, the base-case models performance was deemed good for this study.

CONCLUSIONS

This modeling study aimed at analyzing the impacts of large-scale use of high-albedo materials in urbanized areas on the ozone air quality in the South Coast Air Basin (SoCAB) during a late August period. A land-use database of the SoCAB was used to determine the potential amount of change in albedo in each cell relative to a base-case albedo value. The latter was determined from AVHRR satellite data. Two levels of nominal increase in albedo were tested; a moderate increase (change of 0.15) and an extreme increase (change of 0.30).

The simulations suggest that large-scale increases in albedo can cause both positive and negative local impacts on ozone air quality. However, the net effect over the entire airshed is a reduction in ozone and a decrease in population-weighted exposure to this pollutant. With respect to the CAAQS, exposure above the threshold can be reduced by up to 12% during peak hours and by up to 12% during the daytime. With respect to the NAAQS, peak hour- and daytime total-reduction in exposure can reach up to 16% and 10%, respectively. This is about half as effective as removing all motor vehicles from the SoCAB during that episode.

This modeling study suggests that large-scale use of high-albedo materials can significantly reduce exposure to ozone in the SoCAB. But one should also keep in mind that the results are location- and episode-specific and are thus non-transferable. They cannot be used to project the impacts of albedo modifications on air quality in another airshed or another episode. The emission inventories used in these simulations contain uncertainties that one should also bear in mind. Other episodes, emission inventories, and locations will be modeled in the future to gain a more general assessment of the effectiveness of high-albedo strategies in improving the regional ozone air quality in affected areas.

Another issue to address in the future is that of the length of the simulations. Results reported in this paper were based on 2-day simulations, which may be shorter than desired. By EPA standards, simulations of 72 hours are recommended. In the future, similar modeling work will be based on longer simulations. This paper has presented results obtained so far in a multi-year research effort.

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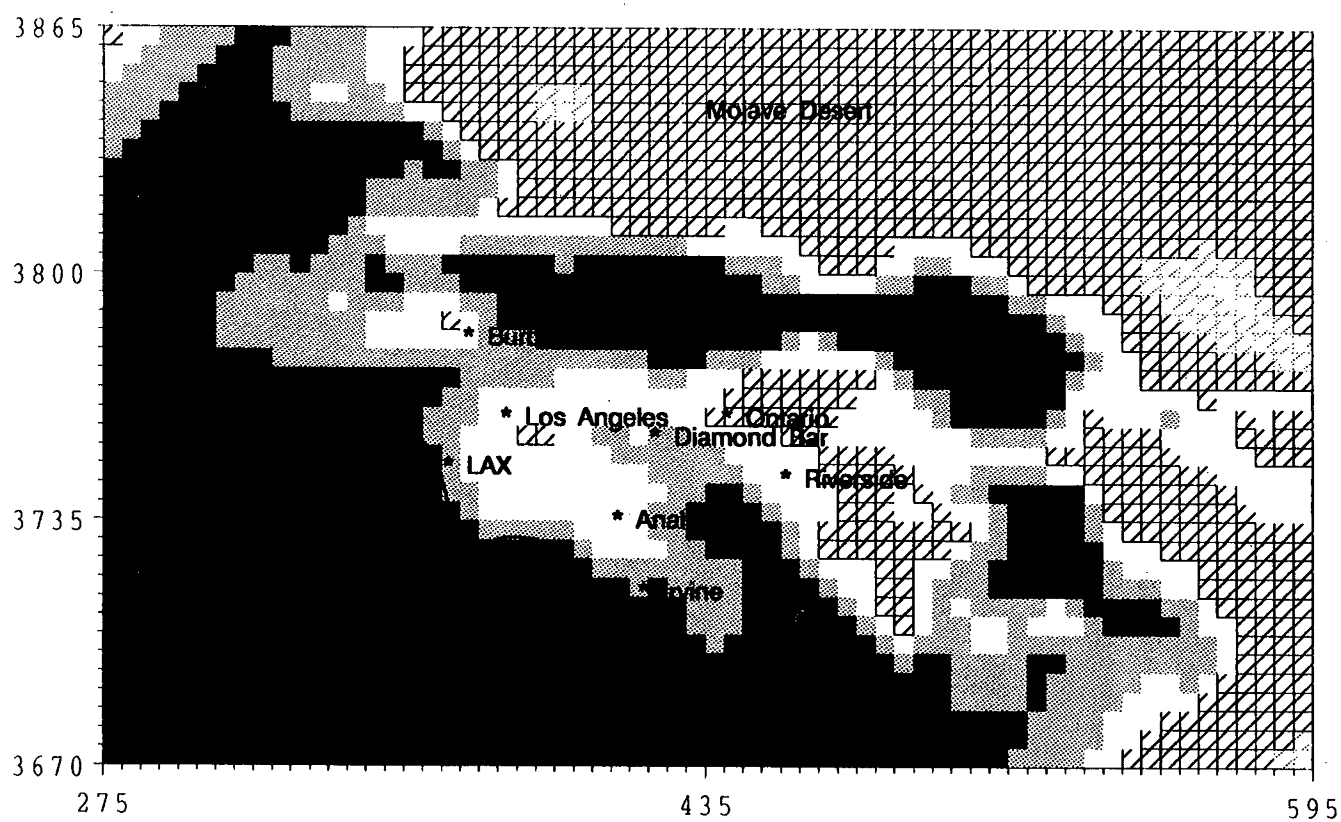


Figure 1: The SoCAB modeling domain used in this study. Also shown is gridded basecase albedo from cloud-free AVHRR scene on August 29, 1991.

ALBEDO 0.06 0.08 0.10 0.12 0.14
0.16 0.18 0.20 0.22

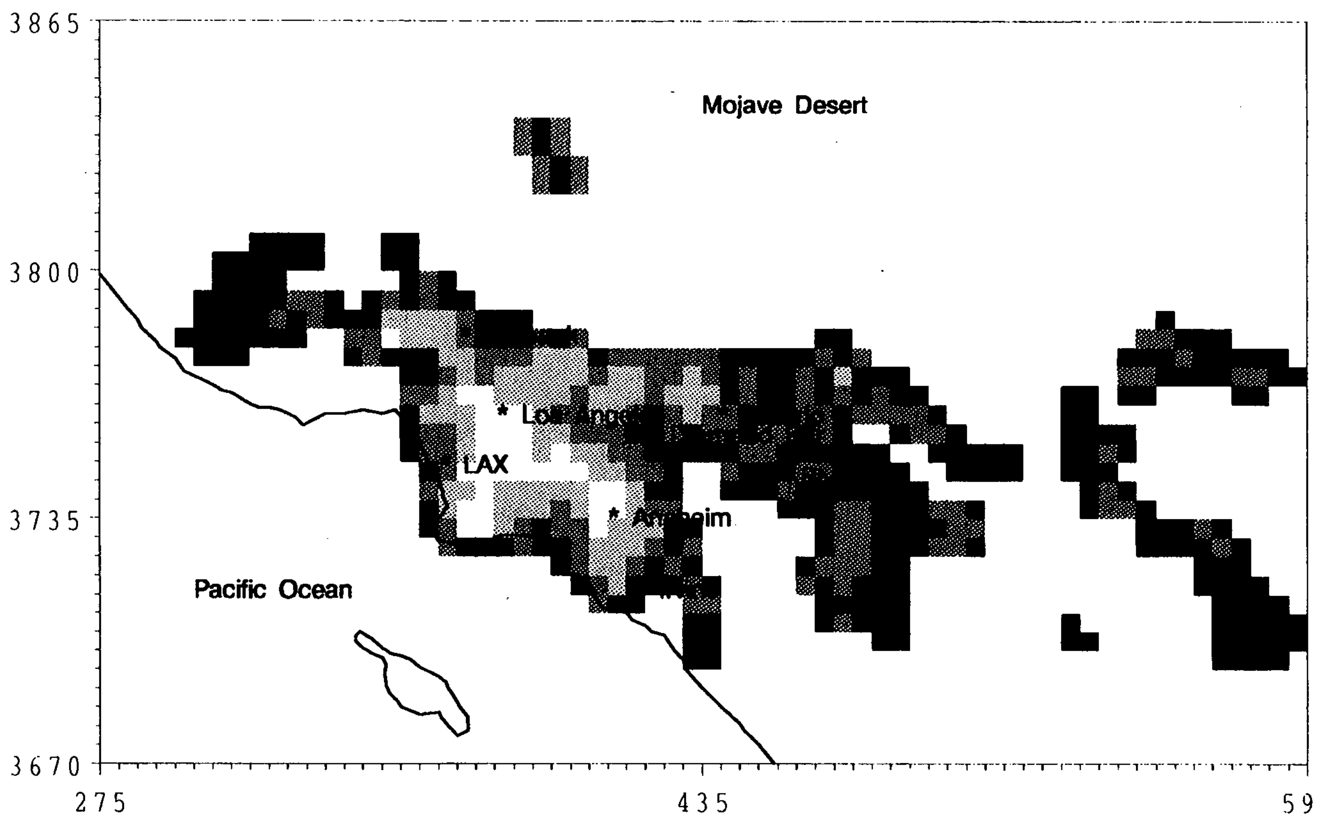


Figure 2: Areas in the SoCAB where albedo can be increased. The shades of grey show the levels of increase corresponding to the high-albedo increase scenario ($\delta\alpha$=+0.30 points).

CHANGE 0.00 0.05 0.10 0.15 0.20 0.25 0.30

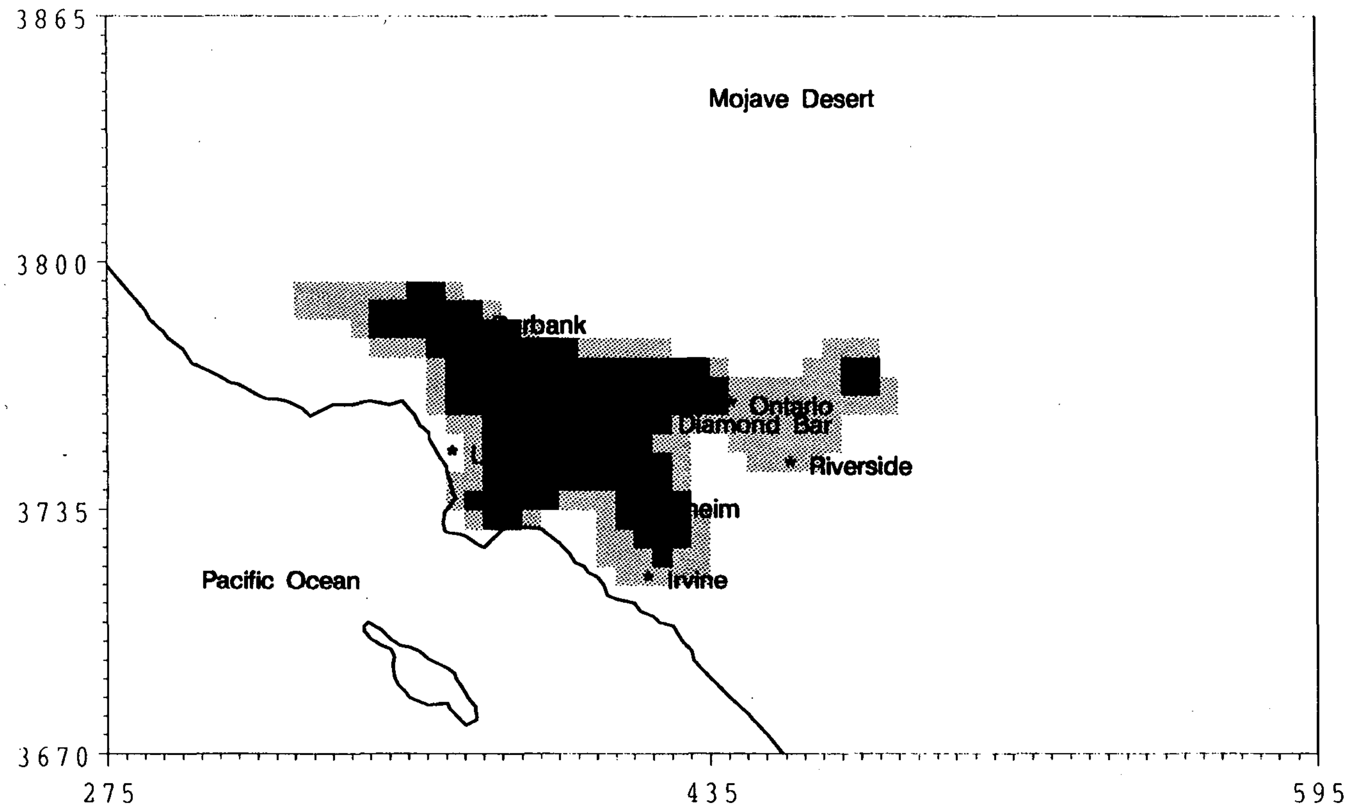


Figure 3: Temperature difference (°C) between a high-albedo increase case and the basecase. Shown is the hour at 3 pm on August 27. Darker tones indicate larger reductions in temperature.

C -5 -4 -3 -2 -1 0

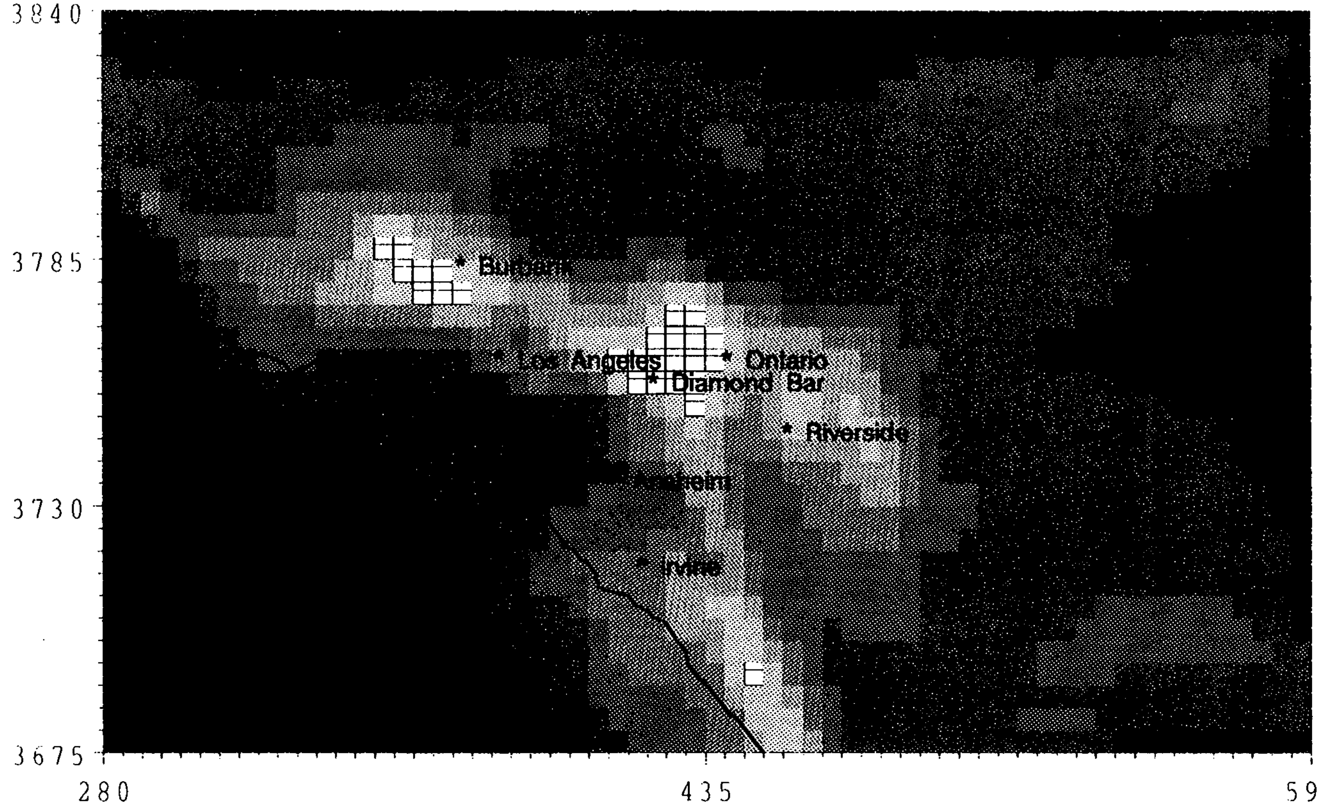


Figure 4: Basecase ozone concentrations field (ppb) at 3 pm on August 27. Lighter is higher concentrations.

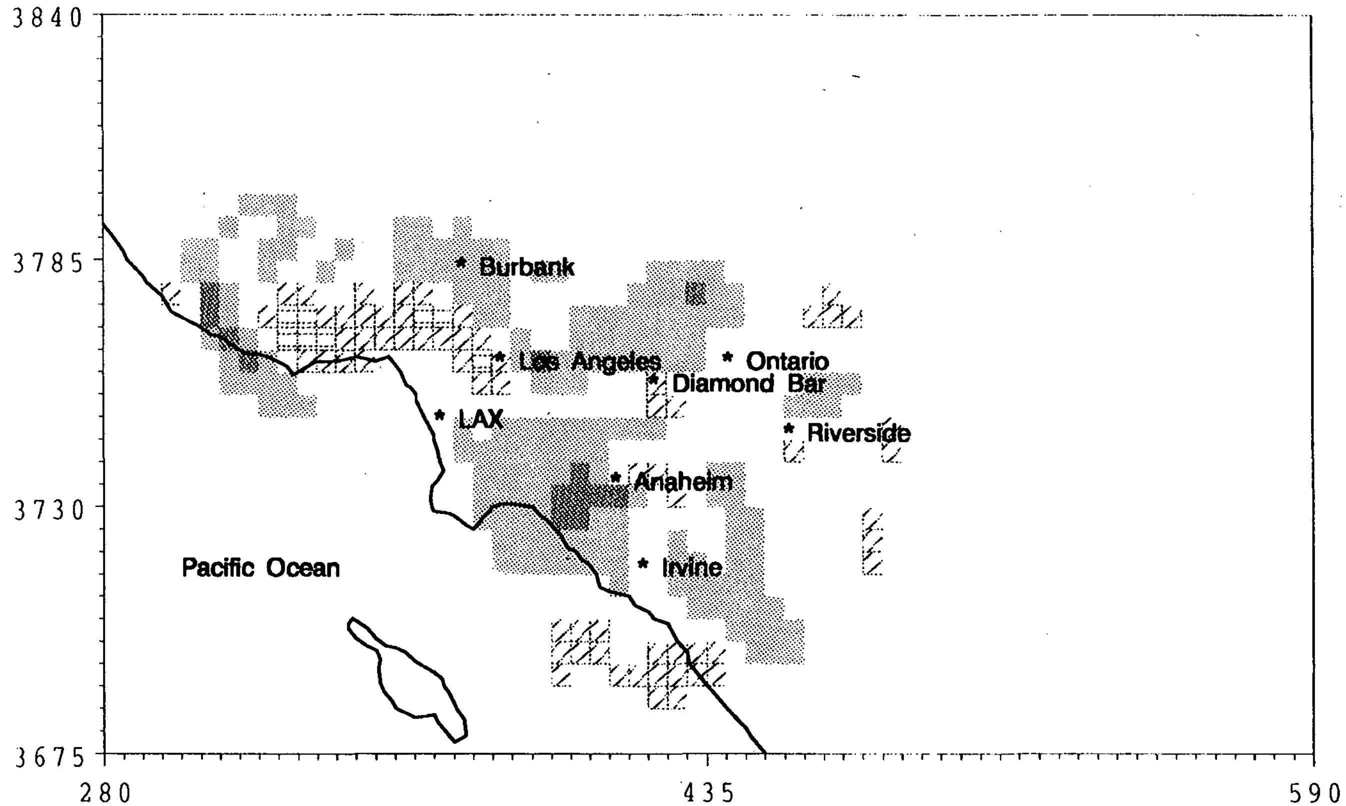
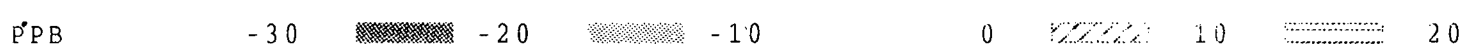


Figure 5: Differences in ozone concentrations (ppb) between a moderate albedo increase case and the basecase. Shown is the hour at 3 pm on August 27. Grey is improved air quality, hatching is worsening of air quality.



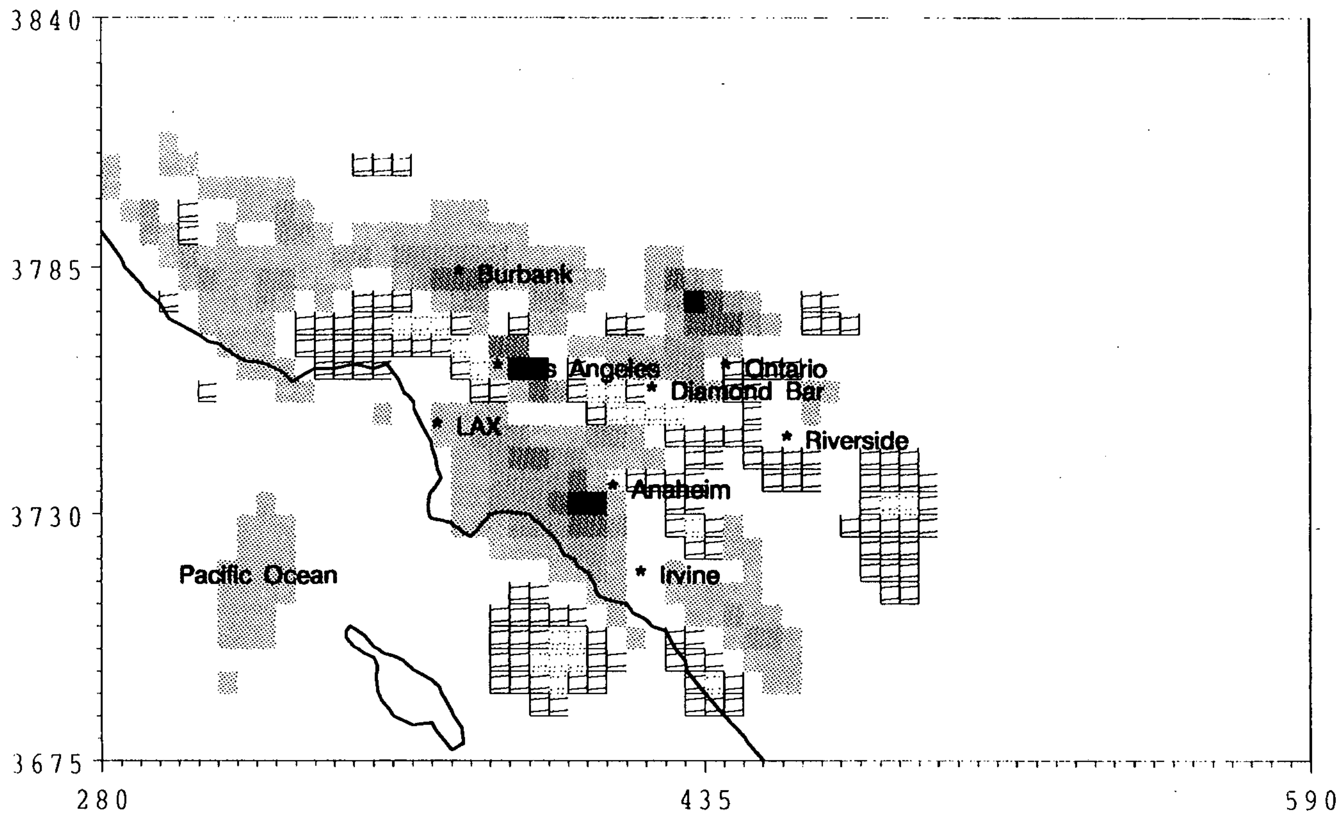
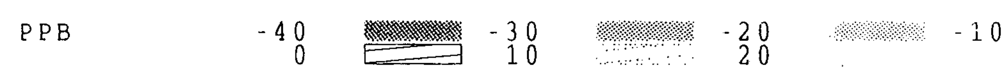


Figure 6: Differences in ozone concentrations (ppb) between a high albedo increase case and the basecase. Shown is the hour at 3 pm on August 27. Grey is improved air quality, hatching is worsening of air quality.



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