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Environmental Energy Technologies Division

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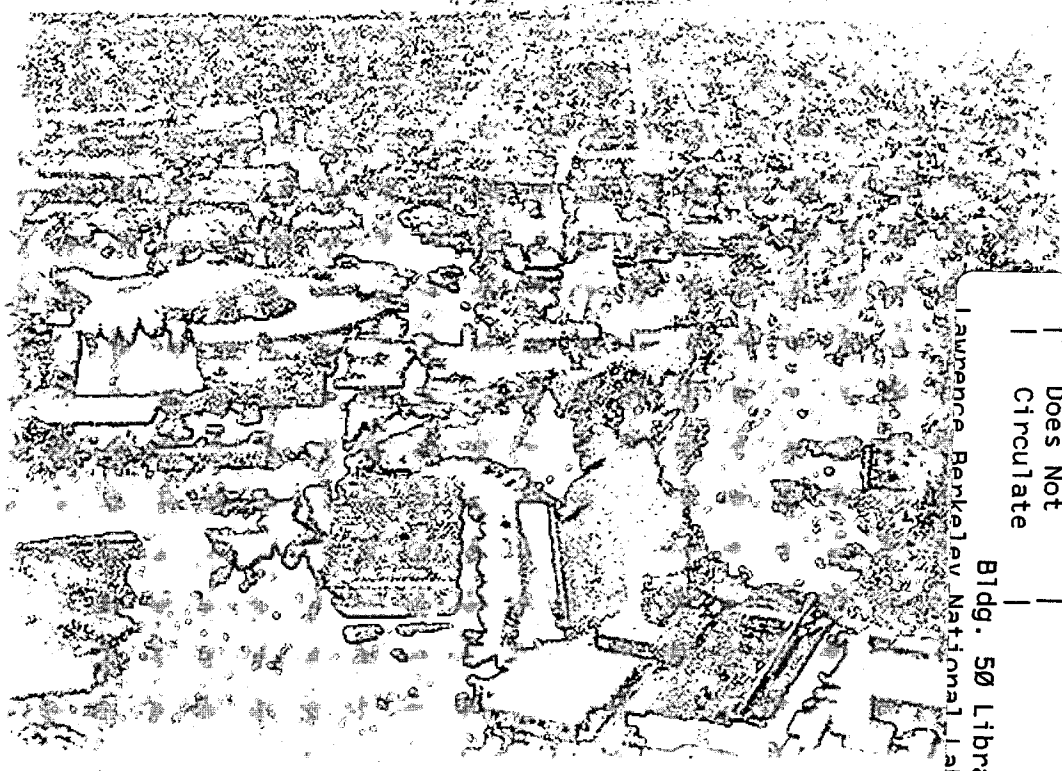

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Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation

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Abstract

The large scale implementation of high-albedo building materials and urban surfaces and the reforestation of low vegetation urban areas are being encouraged as energy-saving measures. These strategies will result in modification of the physical properties of millions of buildings (e.g., roof reflectance) and their microclimates (e.g., shading, wind, and evapotranspiration effects of trees). This paper is about the atmospheric impacts of regional scale changes in building properties, paved-surface characteristics, and their microclimates. It discusses the possible meteorological and ozone air quality impacts of increases in surface albedo and urban trees in California's South Coast Air Basin (SoCAB). The photochemical model simulations of a late August period indicate that implementing high-albedo materials in the SoCAB would have a net effect of reducing ozone concentrations. Domain-wide population-weighted exceedance exposure to ozone above the California Ambient Air Quality Standard would be decreased by up to 12% during peak afternoon hours. With respect to the National Standard, exceedance exposure would be reduced by up to 17%. The simulations also indicate that the net effect of increased urban vegetation is a decrease in ozone concentrations if the additional vegetation (trees) are low emitters of biogenic hydrocarbons. With respect to the California standard, domain-wide population-weighted exceedance exposure to ozone above this threshold would be decreased by up to 14% during peak afternoon hours. With respect to the National Standard, the reduction would be up to 22%. In terms of total daytime exposure, these strategies can decrease exceedance exposure by up to 12% with respect to the California Standard and up to 20% with respect to the National Standard. Comparing the simulated air quality impacts of increased albedo and vegetation cover with the impacts of other strategies reveals that they are of the same order of magnitude. For instance, the simulations for this episode, using updated 1987 emission inventories for the SoCAB, indicate that the air quality benefits of albedo and vegetation increase strategies are comparable to those of converting at least 50% of the mobile sources operating in 1987 in the SoCAB to zero emitting vehicles (these findings are for ozone reductions only; removing or converting motor vehicles has several other advantages as well). At this time, this comparison is preliminary as there are uncertainties in the modeling system and emission inventories. In particular, mobile source emissions may be underestimated by as much as two-fold. These findings will be updated when other episodes are modeled and more representative emission inventories become available.

Keywords: Air quality; Albedo; Meteorology; Mesoscale modeling; Ozone; Photochemistry; Urban vegetation

1. Introduction

One place being considered for the implementation of high albedo and increased urban vegetation strategies is the Los Angeles Basin. This is an ozone non-attainment area with a combination of topography, meteorology, and emissions resulting in the worst ozone air quality in the US (Los Angeles is the only area in the US to be designated 'extreme' in ozone non-attainment classification). The Southern California Edison Company (SCE) and the Los Angeles Department of Water and Power (LADWP) as well as the South Coast Air Quality Management District (SCAQMD) are considering high-albedo materials and tree-planting programs as measures that could potentially improve urban climates and urban air quality and save energy. The SCAQMD has incorporated high-albedo materials and urban vegetation in its 1994 Air Quality Management Plan (AQMP) as potential strategies for alleviating the ozone air quality problem [1].

Increasing surface albedo of, and vegetative cover around, millions of buildings will lower surface and near-surface air temperatures and that in turn will limit warming in the modified areas and downwind. The potential air quality benefits of lowered summertime air temperatures include a decrease in some photochemical reaction rates, a decrease in temperature-dependent biogenic hydrocarbon emissions from existing and newly-planted vegetation, a decrease in running and resting-loss evaporative organic gas emissions from mobile sources, a decrease in evaporative losses from stationary sources, and a decreased need for cooling energy and, thus, generating capacity and emissions from power plants. How-

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ever, increasing the surface albedo and vegetative cover in the SoCAB may have an effect on the local sea-breeze circulation and thus on the transport of precursor pollutants and ozone from one area to another within the airshed [2,3]. Also, decreasing the near-surface temperatures can reduce the depth of the atmospheric layer in which pollutants are mixed, potentially resulting in higher ozone concentrations in some locations. Finally, introducing new trees in the airshed might lead to an increase in biogenic hydrocarbon emissions (and possibly accelerated smog formation) depending on the species selected for the tree planting programs.

It is thus important to analyze the impacts of these interrelated effects on the ozone air quality through mesoscale modeling. Since the SoCAB is an extreme non-attainment area, it is imperative to ascertain to the best we can that implementation of any energy or emission control strategy in the airshed would not worsen the air quality. This type of analysis is also important in quantifying any possible positive (beneficial) impacts of any strategy to be implemented in the basin. For a discussion of the models used in this study and the preparation of inputs, see Taha et al. [2].

2. Surface characterization

It is important to characterize surface albedo and vegetation cover (among other surface properties) in the study area for two main reasons. The first is that gridded albedo and vegetative cover data are needed to characterize the lower boundary for the meteorological and air quality models. The second is that this information is necessary for scoping studies to develop possible implementation schemes and determine upper bounds for increasing albedo and urban vegetation in the affected areas.

2.1. Albedo characterization

Surface albedo, defined as the ratio of hemispheric reflected radiation to hemispheric incoming radiation, is an important factor in surface energy balance and near-surface climates [4]. Its spatial distribution is an important factor in the determination of an airshed's meteorology [5,2]. An accurate characterization of surface albedo is an important input to meteorological and air quality models.

In this study, a gridded albedo field was obtained by processing NOAA AVHRR satellite data [6]. Narrow-band reflectivity was calculated in the visible (0.58–0.68 μm), NIR (near-infrared, 0.725–1.10 μm) and MIR (middle-infrared 3.55–3.93 μm) ranges, and weighted by modeled insolation fluxes within the respective broader spectral regions [7].

2.2. Biomass and biogenic emissions characterization

The second important aspect of the input to the meteorological and air quality models is vegetation biomass and its related attributes, e.g. biogenic hydrocarbon emissions. A land-use database compiled by Horie et al. [8] was selected as the basis for estimating green leaf biomass in the SoCAB. Biogenic hydrocarbon emission rate data from Winer et al. [9] and Benjamin et al. [10] was used in this study to develop gridded biogenic emission input to the photochemical model.

3. Modeling system

In this study, the Colorado State University Mesoscale Model (CSUMM) and the Urban Airshed Model (UAM) were used for analyzing the interaction between the mesoscale meteorology and ozone air quality. These models essentially solve a set of coupled governing equations for atmospheric behavior and pollutant species concentrations representing the conservation of mass (continuity), potential temperature (heat), momentum, water vapor, and chemical species continuity, respectively:

$$\frac{\partial \rho}{\partial t} = -(\nabla \cdot \rho \mathbf{V}) \tag{1}$$

$$\frac{\partial \theta}{\partial t} = -\mathbf{V} \cdot \nabla \theta + S_\theta \tag{2}$$

$$\frac{\partial \mathbf{V}}{\partial t} = -\mathbf{V} \cdot \nabla \mathbf{V} - \frac{1}{\rho}\nabla p - g\mathbf{k} - 2\mathbf{\Omega} \times \mathbf{V} \tag{3}$$

$$\frac{\partial q}{\partial t} = -\mathbf{V} \cdot \nabla q + S_q \tag{4}$$

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (\mathbf{V} c_i) = \nabla \cdot (\mathbf{K} \nabla c_i) + R_i + S_i + D_i \tag{5}$$

where ρ is density, $\mathbf{V}$ is the wind velocity vector, θ is potential temperature, S_θ is a source/sink term for potential temperature, p is pressure, Ω is angular velocity vector, q specific humidity, S_q is a source/sink term for specific humidity, c_i is the concentration of species i, $\mathbf{K}$ is the turbulent diffusion coefficient, and R, S, and D are the reaction, source, and sink (deposition) terms for species i. The term R_i involves computing chemical reaction rate constants for appropriate species which is particularly important to this study since temperature is a major variable that we modify.

The CSUMM is a hydrostatic, primitive-equation, Eulerian, three-dimensional model originally developed by Pielke [11]. The model uses the incompressible approximation and a terrain-following coordinate system. A first order closure scheme is adopted. The model treats an atmosphere about 10 km deep and an underlying soil layer on the order of 50 cm deep. The CSUMM generates three-dimensional fields of prognostic variables as well as a boundary layer height profile that can be used as input to a photochemical model (e.g., the UAM). For more information regarding the CSUMM, see Pielke [11] and Kessler and Douglas [12].

The UAM is a three-dimensional, Eulerian, photochemical model that is capable of treating inert and chemically-reactive

atmospheric pollutants. It simulates the advection, diffusion, transformation, emission, and deposition of pollutants in a three-dimensional domain which, in this study, matches the domain of the CSUMM, except in the vertical. The UAM treats about 30 chemical species and uses the Carbon Bond IV (CB-IV) chemical mechanism [13]. It accepts as input emissions from area, low-level point, elevated point, mobile, and biogenic sources. The UAM requires two primary types of input: (i) meteorological fields; and (ii) emission inventories. For additional information on the UAM, see EPA [14]. For a discussion on using these models for this study of the SoCAB, see Taha [15,16].

4. Base case simulations

In this section we provide results from base case simulations of the SoCAB in which we used the AVHRR-based gridded albedo developed by Liu [6]. Other surface properties, boundary and initial conditions, and aspects of the input to the meteorological model are discussed in Taha et al. [2]. The simulated meteorological fields for the two-day period (August 26, 27) show that downslope flow is predominant in the surface layer at night and during the early morning hours. During this time, the simulated sea breeze dissipates and alongshore flow develops at the coastline. At 9 a.m. on August 27, the winds are in transition, with the sea breeze beginning to develop along the coast and the downslope flow dissipating. Winds are light and variable over the basin. By 3 p.m., the sea breeze reaches the eastern basin.

The simulated mixing heights exhibit typical diurnal profiles and the effects of terrain are apparent. In general, mixing heights over the SoCAB range from 100 to 600 m. The simulated near-surface air temperatures range from a minimum of 12°C at 3 a.m. over the San Bernardino Mountains to a maximum of 35°C at 3 p.m. in the southeast portion of the modeling domain. Specific humidity ranges from a minimum of 4317 ppm in the southeast corner of the domain to 28 965 ppm in the eastern basin at 9 p.m. on August 26. The pattern reflects moisture advection by the sea breeze and the dry conditions in the high desert areas.

UAM simulations were performed to establish base case ozone concentrations corresponding to the base case meteorology discussed above. Fig. 1 shows the simulated base case ozone concentration field (in ppb, at 3 p.m. on August 27) that will be used as a reference in following sections. Concentrations on the order of 200 ppb are simulated in the San Fernando Valley, central basin, San Bernardino, east basin, areas in Riverside, and south of Orange County. The high simulated concentrations along the southern shore (south of Orange County) are likely caused by a southeast deflection of the sea breeze and advection of ozone and its precursors in that direction from sources in Orange county. At this hour, the west basin (an area with corners at West Los Angeles, Downtown, Anaheim, Orange, Long Beach, and Palos Verdes) has concentrations in the neighborhood of 60 ppb. Base case population-weighted exposure to ozone will be discussed in a later section, when comparing the ozone air quality impacts of albedo and vegetation strategies with those of the base case.

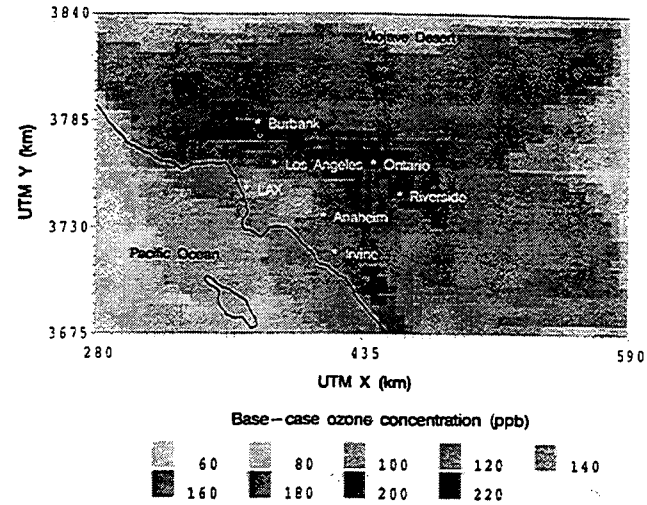

Fig. 1. Simulated base-case ozone concentration field (ppb), at 3 p.m. on August 27. Lowest layer of the model. Highest concentration ~228 ppb, lowest concentration ~45 ppb.

5. Albedo and its modifications

Using a procedure originally devised by Sailor [3] and later modified by Taha [15,16], the land-use composition in each of 2600 cells in the CSUMM modeling domain for the SoCAB was examined to determine the fraction of each cell that could be subject to albedo increase relative to its base value. Within each 5 × 5 km cell, 23 land-use categories were sorted and their fractional areas identified according to data from Horie et al. [8]. Certain land-use categories were found to be 'albedo-able' e.g., residential areas, offices/commercial areas, and parking lots but others, such as parks, heavily-vegetated areas and deserts were not.

Two nominal albedo scenarios were simulated: a moderate (feasible) increase in which the maximum increase in a fully-developed cell is 0.15, and a high (extreme) increase scenario in which the maximum increase in a fully-developed cell is 0.30. In those grid cells that were modified (whose albedo was increased), the average increase in albedo for the moderate and high increase cases was 0.07 and 0.13, respectively. The corresponding domain-wide average albedo of the SoCAB increases from a base value of 0.138 to 0.155 in the moderate increase case, and to 0.171 in the high albedo increase case. There are 392 albedo-able cells (out of 2158 land cells). Incorporation of albedo modifications in the modeling analysis was accomplished through adjustment of the CSUMM albedo input field. Taha et al. [2] discuss these issues in detail.

6. Vegetation cover and its modifications

Vegetation changes are handled in a manner similar to the procedure described above for albedo changes. The fraction of each cell that is 'tree-able' is identified based on land-use data from Horie et al. [8]. Two levels of vegetation increase were simulated: a moderate (feasible) increase (max = +0.15) and a high (extreme) increase (max = +0.30). There are 394 tree-able cells (out of 2158 land cells) in which vegetation was increased. For the moderate increase case, the average increase in vegetation cover in these 394 cells was 0.06, whereas in the high increase case, the average increase was 0.12.

It is estimated that the additional tree cover needed to achieve the levels of increase mentioned above is on the order of 10 million trees (basin-wide total) for the moderate increase case, and 20 million trees for the high (extreme) increase case. The number is a crude estimate and is intended to only give an order of magnitude. In a related note, *Tree People* and *California Releaf* had set a goal to plant 20 million trees before the year 2000 [17].

When additional trees are introduced into the basin, they alter the meteorology through evapotranspiration and increased roughness (both effects were considered in the CSUMM simulations). They also alter the air quality through increased biogenic hydrocarbon emissions and increased dry deposition of chemical species such as ozone and NO_x (modification of the biogenic emissions is described in Section 8). Taha [16] discusses these issues in detail.

7. Impacts of albedo changes

We discuss results from the second day of the meteorological and air quality simulations and, in most cases, for 3 p.m. on that day. This choice has the advantage of minimizing the effect of initial conditions on the simulated fields and capturing the impacts of albedo and/or vegetation increases on peak ozone concentrations which usually occur between 12 noon and 4 p.m. Also, we discuss only the simulation results for the lowest (near-surface) layer of the model since it is the most relevant in terms of thermal comfort, energy use, and ozone concentrations (breathing zone).

All meteorological variables respond, in varying degrees, to the changes in surface energy balance following modifications in surface albedo. In general, increasing the albedo tends to weaken the sea breeze due to reduced temperature/pressure gradients, but the effects are small. The impacts on specific humidity are very small. However, the impacts of albedo changes on temperature are significant. Fig. 2 shows that a decrease of up to 2°C in air temperatures at 3 p.m. is simulated when albedo is increased by a moderate (feasible) amount. Most of the temperature depression occurs in the central basin, with changes of 1°C in surrounding areas. If albedo is increased further (high increase scenario) then decreases of up to 4.5°C are achieved in the central and west basins, with an average decrease of 2°C in surrounding areas. It should be mentioned that as a result of albedo increases, the air aloft does warm up slightly in some inland areas of the domain as a result of weakening in the sea breeze circulation. The impacts of this warming on ozone formation aloft and possible fumigation to the surface later on is likely quite small. In any case, that effect is accounted for in the UAM simulations performed in this study.

Increased albedo affects air quality through decreased air temperature (which leads to decreased reaction rates), changes in the depth of the mixed layer, and decreased biogenic hydrocarbon emissions from existing vegetation. The decrease in air temperature may also decrease anthropogenic emissions, mainly evaporative loss hydrocarbon emissions from mobile and stationary sources.

Fig. 3 shows the deviation in ozone concentrations (ppb) from the base case (at 3 p.m. on August 27) for the moderate albedo increase case. There are increases and decreases in ozone in various parts of the domain, but the magnitude of the decrease is larger than that of the increase and the net effect over the basin is a reduction in ozone mass in the mixed

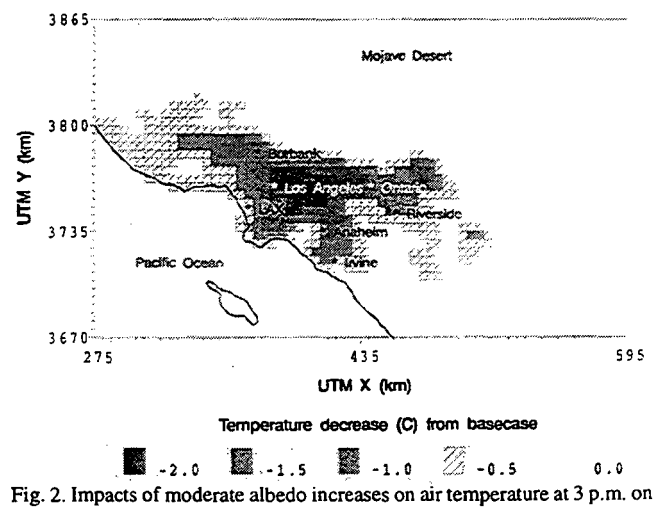

Fig. 2. Impacts of moderate albedo increases on air temperature at 3 p.m. on August 27.

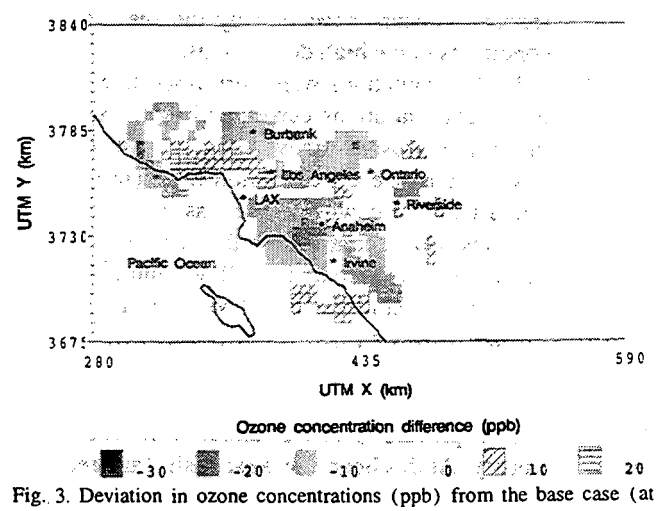

Fig. 3. Deviation in ozone concentrations (ppb) from the base case (at 3 p.m. on August 27) for the moderate albedo increase case.

layer. Whereas the largest decrease in ozone concentrations at this hour is 34 ppb, the largest increase is 25 ppb. In the high (extreme) albedo increase case, the largest decreases are in the order of 50 ppb whereas the largest increases are in the order of 20 ppb. The net effect is again a reduction in ozone mass in the mixed layer.

To provide a basin-wide evaluation of the potential air quality impacts of the use of high-albedo materials, a simple exposure analysis was performed and is discussed in this section using 1990 census population data. We define percent population-weighted exceedance exposure as:

$$E\% = \left[\frac{\sum_{x=1}^{X} \sum_{h=1}^{H} P_{(x)} (C_{(i,x,h)} - C_t) H_{(\Delta C)}}{\sum_{x=1}^{X} \sum_{h=1}^{H} P_{(x)} Cb_{(x,h)}} \right] \times 100 \qquad (6)$$

where x is grid-cell identifier (location), h is hour identifier (time), P is population in grid cell (x), X is the total number of cells, $C_{(i,x,h)}$ is ozone concentration (ppb) in cell (x) at hour (h) and 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 $C_{(i,x,h)} \leq C_t$), and $Cb_{(x,h)}$ is the base case simulated ozone concentration in cell (x) at hour (h). Three thresholds (C_t) are considered: (i) 90 ppb (California Ambient Air Quality Standard, CAAQS); (ii) 120 ppb (National Ambient Air Quality Standard, NAAQS); and (iii) 200 ppb (California Stage-I health alert).

In the base case simulated conditions at 3 p.m. on August 27, 34% of the population-weighted exposure is over the CAAQS. The corresponding values for the moderate and high albedo increase cases are 32% and 30%, respectively. In terms of the NAAQS, the base case conditions exhibit 18% exceedance exposure. In the moderate and high albedo cases, this percentage drops to 16% and 15%, respectively. With respect to the California Stage-I health alert, there is a small exposure above the threshold in the base case simulation and a negligible exceedance exposure in the moderate and high albedo increases.

In terms of total daytime population-weighted exposure to ozone on August 27, the moderate and high albedo increases bring down the total daytime exceedance exposure above CAAQS by 4% and 12% from the base case value, respectively. For a threshold of 120 ppb (NAAQS), the effectiveness of the moderate and high albedo increases is to reduce the exceedance exposure by 5% and 10%, respectively. In summary, the meteorological and air quality simulations of the August 26–28 episode indicate that the net effect of increasing urban albedo in the SoCAB is a reduction in ozone concentrations and population-weighted exposure to this pollutant.

8. Impacts of vegetation changes

By increasing the vegetative cover, the additional evaporative cooling effect of trees would allow the air to stay cooler. Compared to the base case simulation at 3 p.m., the moderate vegetation increase case exhibits temperatures up to 2°C lower in the central basin and up to an average of 1°C lower in surrounding areas (Fig. 4). Adding more vegetation (high vegetation increase case) results in simulated decreases of up to 3°C in the west basin and an average of 1°C in surrounding areas in the basin.

Additional vegetation in the basin can affect air quality in several different ways. A potential disbenefit is an increase in biogenic hydrocarbon emissions (depending on species). On the positive side, additional vegetation can cool the air and thus potentially slow down the photochemical production of ozone. Vegetation also dry-precipitates and adsorbs pollutants and by doing so, decreases the mass of airborne gases and particulate matter. Introducing low emitting tree species serves to cool the air and scavenge pollutants. The cooler air may result in decreased biogenic emissions from other (existing) species without introducing additional hydrocarbon emissions. Medium and high emitting species have adverse effects on ozone air quality since they significantly increase the amount of biogenic hydrocarbons emitted into the airshed. In this study, medium emitters were defined as those species emitting on the average 4 μg/g/h of isoprene and 2 μg/g/h of monoterpenes (micrograms of emitted compound per gram dry-leaf mass per hour). High emitters were defined as those emitting on the average 20 and 5 μg/g/h of these compounds, respectively. Low emitters were defined as those emitting under 2 μg/g/h of isoprene and 1 μg/g/h of monoterpenes. Since it is unlikely that all trees planted will be high emitters, we model only the low and medium emitting cases. We assume that the entire stock of new trees introduced into the SoCAB is of the same type, i.e., emitting the same amount of biogenic hydrocarbons.

Fig. 5 shows concentration differences (for a moderate vegetation increase case) from the base case at 3 p.m. using low emitting species. There are more cells with lowered ozone concentrations than cells with increased concentrations. The magnitude of the decreases (up to 30 ppb) is larger

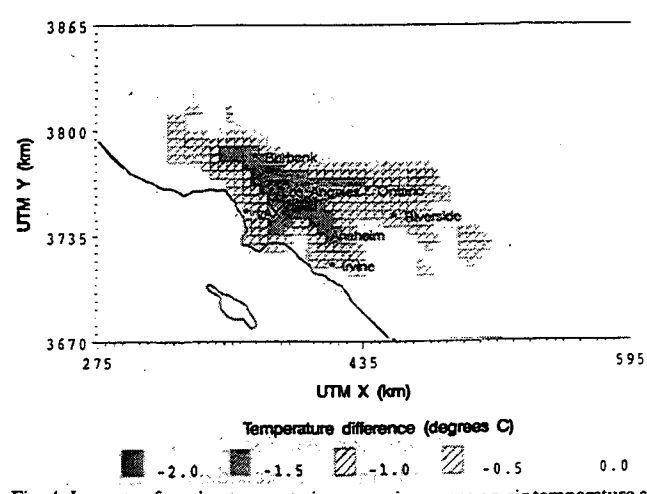

Fig. 4. Impacts of moderate vegetation cover increases on air temperature at 3 p.m. on August 27.

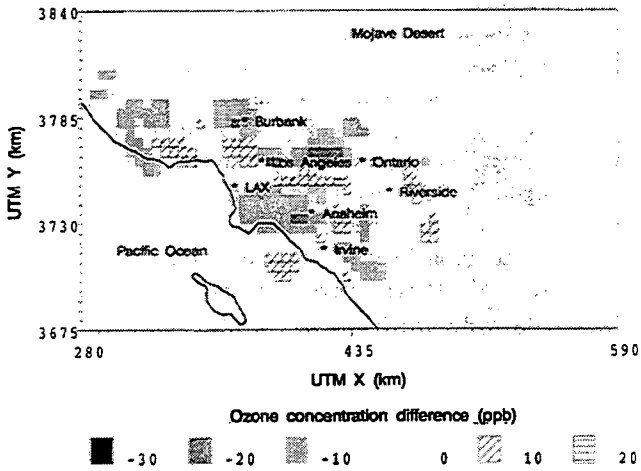

Fig. 5. Deviation in ozone concentrations (ppb) from the base case (at 3 p.m. on August 27) for the moderate vegetation cover increase case. This is a case where low emitting trees have been added.

than the magnitude of the increase (up to 20 ppb) and the net effect is a decrease in ozone mass in the mixed layer. These results are of similar magnitudes as those in the moderate albedo increase scenario. However, if medium emitting tree species are introduced, the air quality worsens. In this case, there is a significant amount of increase in ozone concentrations. This is so because introducing medium emitters into the basin has the effect of increasing the biogenic ROG inventory from 340 metric tons per day (tpd) to 460 tpd.

In a case with large increases in low emitting vegetation, the largest reductions in concentrations are in the order of 40 ppb whereas the largest increases are in the order of 10 ppb. The UAM simulations suggest that large increases in vegetation cover have greater net beneficial impacts on ozone air quality than the moderate increases in cover.

Another aspect related to the UAM simulations involved examination of the dry deposition of ozone and NO_2 as a result of increasing the vegetative cover. The simulations indicate that on a daily basis (e.g. August 27) and in the moderate vegetation increase case, about 1% of the mass of ozone in the mixed layer is scavenged by the additional vegetation (dry-deposited). In addition to this amount of ozone being scavenged directly from the atmosphere, there is 0.6% less ozone formation in the mixed layer due to the fact that vegetation also scavenges NO_2, an ozone precursor. The total effect of increased deposition by the additional vegetation is thus to decrease atmospheric ozone in the mixed layer by 1.6%. In the high vegetation cover increase case, 3.6% of the mass of ozone in the mixed layer is scavenged by the additional vegetation. The total effect of increased deposition (O_3 and NO_2 deposition) in this case is to decrease atmospheric ozone in the mixed layer by about 4.5% [2].

Using the definition of population-weighted basin-wide exposure given by Eq. (6), we calculate the change in exposure corresponding to the vegetation increase cases. For the hour at 3 p.m. on August 27, the simulated population-weighted domain-wide exceedance exposure to ozone above the California Ambient Air Quality Standard (CAAQS) for the moderate and high vegetation increase cases is 5% and 14% lower than its original value, respectively. Exceedance exposure above the National Ambient Air Quality Standard (NAAQS) is decreased by 11% and 22%, respectively. Exceedance exposure above the Stage-I alert level is small and almost completely offset with the moderate and high increases in low emitting vegetation. In a case with medium increases in tree cover using medium emitters, the deterioration in air quality is significant (increases of 30% and 50% with respect to CAAQS and NAAQS, respectively).

For daytime hours on August 27, the decreases in exceedance exposure for the moderate and high increases in low emitting trees are 4% and 12% with respect to the CAAQS and 10% and 20% with respect to the NAAQS. With respect to the Stage-I alert, exceedance exposure in the base case is small and gets close to zero in the modified cases. For moderate increases in medium emitting species, the exceedance exposure is increased by 25% and 50% with respect to CAAQS and NAAQS, respectively.

9. Impacts of simultaneous albedo–vegetation changes

A combined case in which both albedo and low emitting vegetation were simultaneously increased each by a moderate (feasible) amount was also simulated. The temperature changes in this case are approximately equal to or slightly greater than those for the high albedo modification case. The largest depression in air temperature in this case is 5°C in the west basin with an average decrease of 2°C elsewhere in the domain. The impacts of simultaneous changes in albedo and vegetation on the wind field are similar to those discussed in the separate albedo and vegetation modification cases. Impacts on mixing heights and specific humidity are, again, similar to those in the previous cases.

In terms of ozone air quality changes, this case is equivalent to or slightly better than the high (extreme) albedo increase case. The largest depressions in ozone concentrations of over 50 ppb are found mostly in the west basin. A decrease of 30 ppb is characteristic of much of the rest of the domain but increases of about 10–15 ppb occur in some areas. Percent exceedance exposure to ozone in this case is reduced by 17% and 22% with respect to CAAQS and NAAQS, respectively, from base case exposure at 3 p.m. on August 27. Thus, the moderate but simultaneous increases in albedo and vegetation have the same effect as the high increase in vegetation and are slightly more effective than the high albedo increase case at this hour. In terms of daytime exceedance exposure, the reductions are 16% and 20% with respect to CAAQS and NAAQS, respectively.

10. Impacts of reductions in motor vehicle emissions

As mentioned earlier in this paper, decreased temperatures can lower the evaporative losses emission and other emis-

sions from mobile and stationary sources. The impacts of temperature decreases, resulting from increases in albedo and vegetation cover, on mobile source emissions were estimated by Fieber and Haney [18] using the EMFAC7F and DTIM-2 models [19]. Two cases were tested; one base case and one combined albedo–vegetation increase case (using low emitting tree species). For August 27, domain-wide daily total organic compounds (TOG) emissions from mobile sources would be reduced by about 1% (a decrease of 20 tpd) whereas NO_x and CO emissions would not change.

The base case and modified mobile source emission inventories were used in two sets of UAM simulations to analyze the impacts on ozone air quality. Population-weighted percent exceedance exposure at 3 p.m. is reduced by 5%, 7%, and 45% from its base case value with respect to CAAQS, NAAQS, and Stage-I levels. The daytime reductions are 3%, 6%, and 57%, respectively.

11. Impacts on emissions from power plants

The strategies of increased albedo and vegetation can reduce the need for building cooling energy and, thus, lower the demand for electricity from utilities in the SoCAB. In theory, if the demand is reduced, electric utilities, in turn, may change the dispatch of power plants which may reduce the amount of emissions.

Based on conservative assumptions, Fishman et al. [20] estimate that an average of up to 9% in peak savings are possible in the Los Angeles Department of Water and Power (LADWP) service territory following simultaneous moderate increases in albedo and vegetation. For the Southern California Edison Company's service territory (SCE), the savings are close to 8.5%. These results assume only 50% eligibility of buildings for high-albedo materials and vegetation modifications. The reduction in cooling load in the SoCAB would reduce emissions from the following SCE power plants: Alamitos, El Segundo, Etiwanda, Highgrove, Huntington Beach, Redondo Beach, San Bernardino, Long Beach, AEHM, Vernon Diesel and Anaheim gas turbine. For the LADWP system, affected power plants include: Harbor, Valley, Scattergood, and Haynes.

Using the Elfin model [21], Hall and Hall [22] estimate that for the major LADWP power plants in the SoCAB, weekday emission of NO_x would be reduced by 2.42 tpd for a case with moderate, simultaneous increases in albedo and vegetation. ROG emissions would be reduced by 0.05 and CO by 0.02 tpd. For the major SCE power plants in the SoCAB, the modified case would cause the following reductions (tpd) in emissions: 4.74 of NO_x, 0.2 of PM10, 0.15 of ROG, and 1.1 of CO. These reductions are small and the UAM simulations suggest that their impacts on ozone air quality and population-weighted exposure to this pollutant are similarly small. However, these findings need to be examined in more detail in the future.

12. Conclusions

Some possible impacts of large scale increases in surface albedo and vegetation cover on the meteorology and ozone air quality in California's South Coast Air Basin (SoCAB) were simulated. For that purpose, mesoscale meteorological and photochemical (air quality) modeling of the SoCAB was performed. In preparation for the simulations, an extensive surface characterization task was undertaken. The outcome of that task included gridded albedo, vegetation biomass, and biogenic emission factors. These gridded data, in addition to other information, were used as input into the meteorological and photochemical models.

Using this information, base case and modified-case simulations were performed. The results indicate that the impacts of increased albedo and/or vegetation cover in the SoCAB can be locally positive or negative, depending on location-specific conditions. However, the net overall effect is a decrease in near-surface ozone concentrations and population exposure to ozone.

In the moderate albedo increase scenario, the largest simulated decrease in ozone concentrations at 3 p.m. on August 27 was 34 ppb whereas the largest increase was 25 ppb. In the high albedo increase scenario, these figures were 50 and 20 ppb, respectively. The base case simulation results indicate that 34% of the population-weighted exceedance exposure at 3 p.m. was over the CAAQS. The corresponding values for the moderate and high albedo increase cases were 32% and 30%, respectively. In terms of the NAAQS, the base case simulation results indicated 18% exposure over the standard. In the moderate and high albedo cases, this percentage dropped to 16% and 15%, respectively.

In terms of total daytime population-weighted exposure to ozone on August 27, the effects of the albedo increases strategies were to reduce the total daytime exceedance exposure above CAAQS by 4% and 12% from the base case exposure, respectively. For a threshold of 120 ppb (NAAQS), the effectiveness of the moderate and high albedo increases were to reduce the exceedance exposure by 5% and 10%, respectively.

The impacts of increasing vegetative cover are similar in magnitude to those of increasing albedo if low emitting tree species are introduced in the basin. Introduction of medium emitter trees results in a significant increase in ozone concentrations (up to 50 ppb in some locations). This is because introducing medium emitters into the basin, according to this study's assumptions, has the effect of increasing the biogenic ROG inventory from 340 to 460 tpd. High emitting species would likely further degrade the air quality. In the case of large increases in low emitting vegetation, the largest reductions in concentrations are on the order of 40 ppb whereas the largest increases are on the order of 10 ppb. The UAM simulations suggest that large increases in vegetation cover have greater net beneficial impacts on ozone air quality than the moderate increases in vegetation cover.

Increasing the tree cover in the SoCAB may also increase the deposition of pollutants, including ozone. In the moderate vegetation increase case, the simulations indicated that there could be 1.6% less ozone in the mixed layer because it is either directly scavenged by the additional vegetation or prevented to form because of NO_2 deposition. In the large vegetation increase scenario, the corresponding number was 4.5%.

At 3 p.m. on August 27, the simulated population-weighted exceedance exposure to ozone above the California Ambient Air Quality Standard (CAAQS) for the moderate and high vegetation increase cases is 5% and 14% lower than its original value, respectively. Simulated exceedance exposure above the National Ambient Air Quality Standard (NAAQS) is decreased by 11% and 22%, respectively. Exceedance exposure above the Stage-I alert level is small and almost completely offset with the moderate and high increases in low emitting vegetation. In terms of total daytime exceedance exposure on August 27, the decreases for the moderate and high increase scenarios are 4% and 12% with respect to the CAAQS and 10% and 20% with respect to the NAAQS.

A combined case in which both albedo and low emitting vegetation cover were simultaneously increased each by a moderate amount was also simulated. In terms of ozone air quality changes, the simulated impacts corresponding to this case are equivalent to or slightly more beneficial than those corresponding to the high albedo case. Depressions in ozone concentrations of over 50 ppb are found in some areas of the west basin. A decrease of 30 ppb is characteristic of much of the rest of the modeling domain but increases of about 10–15 ppb occur in some locations.

To determine the relative importance of these findings compared to the impacts of other strategies, like mobile source emission control, on reducing exposure to ozone, a standard UAM test was performed in which the same episode was simulated with and without motor vehicles in the SoCAB. Although the results need further investigation, the current findings indicate that the effects of the albedo and/or vegetation increase strategies are of the same order of magnitude as the effects of removing motor vehicles from the SoCAB. Of course, the relative effectiveness of albedo and vegetation increase strategies will change under different emission inventories, episodes, locations, or meteorological conditions. One should also bear in mind the uncertainties associated with the simulation results and, in particular, the current emission inventories. Specifically, current estimates of mobile source emissions may be grossly underestimated.

Results from these simulations are episode and location specific. They are not transferable to other meteorological conditions or other airsheds. A case-by-case modeling study should be performed if an assessment of the impact of these strategies in other basins or other weather conditions are sought. When improved emission inventories become available, these simulations should be repeated to get hopefully more accurate and reliable results. Finally, this study has been a first in attempting at correlating ozone air quality to changes in surface albedo and vegetation and, thus, intercomparison with findings from others has not been possible so far.

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