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An urban-forest control measure for ozone in the Sacramento, CA Federal Non-Attainment Area (SFNA)

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ABSTRACT

Urban forest strategies of gradually replacing high emitters of biogenic volatile organic compounds (BVOC) with low-emitting species are being considered as voluntary or emerging control measures for maintenance of the 8-h ozone standard in the Sacramento Federal Non-Attainment Area (SFNA). We describe a regulatory modeling study demonstrating the air-quality impacts of such measures as well as of strategies that increase net canopy cover.

The results indicate that changing the mix of urban trees can improve air quality. The daily reductions in ozone resulting from species replacement alone reach up to 0.50 ppb. With a more geographically-targeted replacement, the daily reductions increase to 3 ppb. Population-weighted exposure to ozone is reduced by up to 34% relative to the NAAQS (120 ppb) and 12% relative to the CAAQS (90 ppb). The 8-h average peak ozone is reduced by 2%. If, in addition to species replacement, the net canopy cover is increased, the reductions in ozone become much larger but increases in ozone also occur. In some scenarios, the air-quality impacts are 10 times as large as those of only replacing 650,000 trees (control measure). Furthermore, because of the canopy growth (including the replacement trees) relative to 2000–2005, the SFNA is cooled by up to 1.2 °C by 2018 and 1.6 °C by 2023.

1. Introduction

Among several ozone air-quality improvement strategies, the Sacramento, CA region Air Districts are considering the use of urban forests to help the area maintain the 8-h standard. Under the current federal regulatory framework, an urban-forest strategy is considered a voluntary or emerging control measure. To include such a strategy in the area's State Implementation Plan (SIP), the air districts must quantify the benefits using best available science and technology, e.g., via meteorological, emissions, and photochemical modeling. This paper summarizes modeling performed to support the development of an urban-forest control measure for the SFNA. Two main scenarios and combinations thereof were examined:

(1) Replacement of 650,000 current-mix species (~3% of trees in the region) with lower emitters (control strategy).
(2) Net increase in canopy cover in newer *urbanizing* areas where forest cover will increase to match that in *urbanized* areas (auxiliary benefits).

The first scenario involves minimal impact on the region's meteorology or pollutant-deposition rates because no significant differences in vegetation cover, energy, and water balance of the replacement canopy are anticipated, nor changes in thermo-physical properties. In this case, only chemistry impacts resulting from reductions in emissions of biogenic volatile organic compounds (BVOC) can be expected. The second approach involves *both* meteorology and chemistry effects as well as changes in deposition rates.

Urban forests can impact air quality via several pathways, e.g., meteorological, deposition, emissions, and chemical. *Replacing* the

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current mix with low emitters (i.e., the control measure) is mostly a chemistry effect and results in decreased ozone concentrations. This is because the abundance of BVOC in the atmosphere allows ozone to accumulate via their reaction with nitric oxide (NO), reducing titration of ozone. Thus a control measure that can reduce VOC in the atmosphere, such as reducing BVOC from urban forests, can help reduce ozone accumulation.

However, *increasing* the canopy cover can impart both positive (beneficial) and negative (inadvertent) effects on air quality. Previous studies (e.g., Taha, 1996, 2005) have shown that the relative benefits and disbenefits differ from one region to another and that it is possible to maximize the potential benefits on a region-specific basis by locally optimizing the control strategies. These studies also showed that it is not possible to generalize the findings or extrapolate results from one area to another.

McPherson (1998) and Simpson and McPherson (2007) estimate that the regional urban forest in the Sacramento area consists of ~7 million trees from over 100 different species made up of 61% low emitters, 28% medium-emitting, and 11% high emitters. Through a combination of community education and policy change over a period of 10 years, the proposed control measure will cause 650,000 medium- and low-emitting trees to be planted that otherwise would have been higher emitters. This shift will reduce BVOC emissions by a quarter of a ton per day or more in the SFNA. In addition, the Sacramento Urban Forest Ecosystem Study (McPherson, 1998) concludes that the existing regional canopy in the Sacramento region is 14% in developed (urbanized) areas and 5% in undeveloped (urbanizing) areas slated for development. Thus another set of scenarios examined in this study includes increasing canopy cover in *urbanizing* areas from 5% to 14% to maintain the overall target cover in the region.

2. Models

2.1. Meteorological models

The MM5 mesoscale model and a variant of the fine-resolution UCP MM5 (uMM5) were used in this study. There were two reasons for this choice: (1) compatibility with regulatory modeling in California that was done with MM5 during 2005–2010, and (2) facilitate the coupling between the MM5 and the uMM5, a highly urbanized model, which would have been more difficult to achieve with other models. In this study, the uMM5[1] meso-urban meteorological model (Dupont, Otte, & Ching, 2004; Taha, 2008a,b,c) was used, along with the sub-mesoscale soil model (SM2-u) of Mestayer et al. (2004) to improve the characterization of urban heat islands, canopy-layer meteorology, vegetation canopy water and energy balance, and flow divergence/convergence in the urban canopy and boundary layers. The model, its application, and model-specific input are discussed in Dupont et al. (2004) and Taha (2007, 2008a,b,c).

It is to be noted that other models exist that are also dedicated to fine-scale urban modeling including the Town Energy Balance model (TEB) of Masson (2000) and several recent additions to the WRF model (Skamarock, Klemp, & Dudhia, 2008). These updates include the urban parameterizations of Martilli, Clappier, and Rotach (2002), which are also implemented in the uMM5, and those of Salamanca, Martilli, Tewari, and Chen (2011). The uMM5 is similar in features and capabilities to the urban WRF models but its configurations, data input development, and applications are different and more site-specific.

The MM5 is described in detail in several papers and technical notes. For information, the reader is referred to Dudhia (1993), Grell, Dudhia, and Stauffer (1994), Seaman, Kain, and Deng (1996), Hong and Pan (1996), Hsie and Anthes (1984), Tao and Simpson (1993), Schultz (1995), Reisner, Rasmussen, and Bruintjes (1998), Anthes (1977), Kain and Fritsch (1993), Grell, Kuo, and Pasch (1991), Betts and Miller (1986), Pan and Mahrt (1987), Chen and Dudhia (2001), and Stauffer and Seaman (1990).

2.2. Emissions model

Biogenic emissions modeling was carried out with the SMOKE/BEIS3 models as discussed in Section 6.

2.3. Photochemical model

The CAMx photochemical model (Environ, 2003) was used after some modifications were made to input, dry deposition calculations, and other aspects as needed in this study to simulate the effects of urban forests in support the proposed control measure. CAMx and its required input are discussed in Yarwood, Morris, Yocke, Hogo, and Chico (1996) and Environ (2003).

3. Modeling episodes and domains

Two regulatory episodes used by the California Air Resources Board (ARB) and Air Districts were modeled. These are 27 July–4 August 2000, 5–14 July 1999, and future-year projections of the episodes (2018 and 2023). The horizontal meteorological modeling domains are shown in Fig. 1. Both episodes were modeled with 36, 12, and 4-km grids (the 36-km grids differ). This study also adds a fourth, 1-km grid (D04) for fine-resolution meteorological simulations with the uMM5 that are subsequently used to drive the fine-resolution (1-km) photochemical simulations. Model details, horizontal and vertical domain attributes, periods, and other information are discussed in Taha, Wilkinson, and Bornstein (2011).

The photochemical (CAMx) modeling domains were defined such that the 4-km grid was inscribed within the 4-km MM5 grid whereas the 1-km grid was inscribed within the uMM5 domain. The coarse (4 km) CAMx simulations were driven by the mesoscale MM5 fields whereas the fine (1 km) grid simulations were driven by the uMM5.

4. Surface characterization

This study applies different models at different scales and, thus, different parameterizations and corresponding surface characterizations are used in each domain. In the 36- and 12-km grids, surface characterization generally follows the standard procedure in the MM5 using pre-assigned properties except that some parameters were updated as discussed in Taha (2007) and Taha et al. (2011) mainly to reduce soil moisture in urban land use[2].

In the SFNA domain, a modified approach (Taha, 2005, 2007) is followed. This employs more recent and location-specific surface data, e.g., from updated land-based surveys, remote-sensing platforms, LiDAR, or aerial photography, and, in this case, more recent and more resolved land-use and land-cover (LU/LC) data (Xiao & Wu, 2008; Xiao, Wu, Simpson, & McPherson, 2009). Note that whereas the standard MM5 approach characterizes the surface physical properties based on LU information, this study's surface characterization is based on both LU and LC. Furthermore, both LU and LC characterizations in the SFNA were updated in this project.

[1] The term "uMM5" is used here to refer to modifications and updates by Taha (2007, 2008a,b,c) to the UCP MM5 of Dupont et al. (2004) resulting in an updated version of the model.

[2] In general, urban soil moisture was over-estimated in some prior modeling efforts.