Air-quality implications of widespread adoption of cool roofs on ozone and particulate matter in southern California

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Outline

Introduction

Materials and Methods

Results and Discussion

Introduction

Reasons for this research

The South Coast Air Basin of California, a region of 16.8 million people, is among the most polluted air basins in the United States.

A multidecadal effort to attain federal air-quality standards has led to significant progress, but much more work remains.

Because the air-quality effects of urban surface modification by cool roofs are complex and nonlinear, comprehensive emissions processing, meteorological, and chemical transport models are needed to accurately determine potential impacts on air quality for policy-making purposes.

Introduction

Research purposes

Rigorously evaluate the air quality effects in the SoCAB of current cool-roof installation policies in California Title 24 Building Energy Efficiency Standards (Title24).

Materials and Methods

Projecting Future SR

Protecting UVR for Chemical Transport Modeling

Emission Processing

Meteorological and Chemical Transport Modeling

Materials and Methods

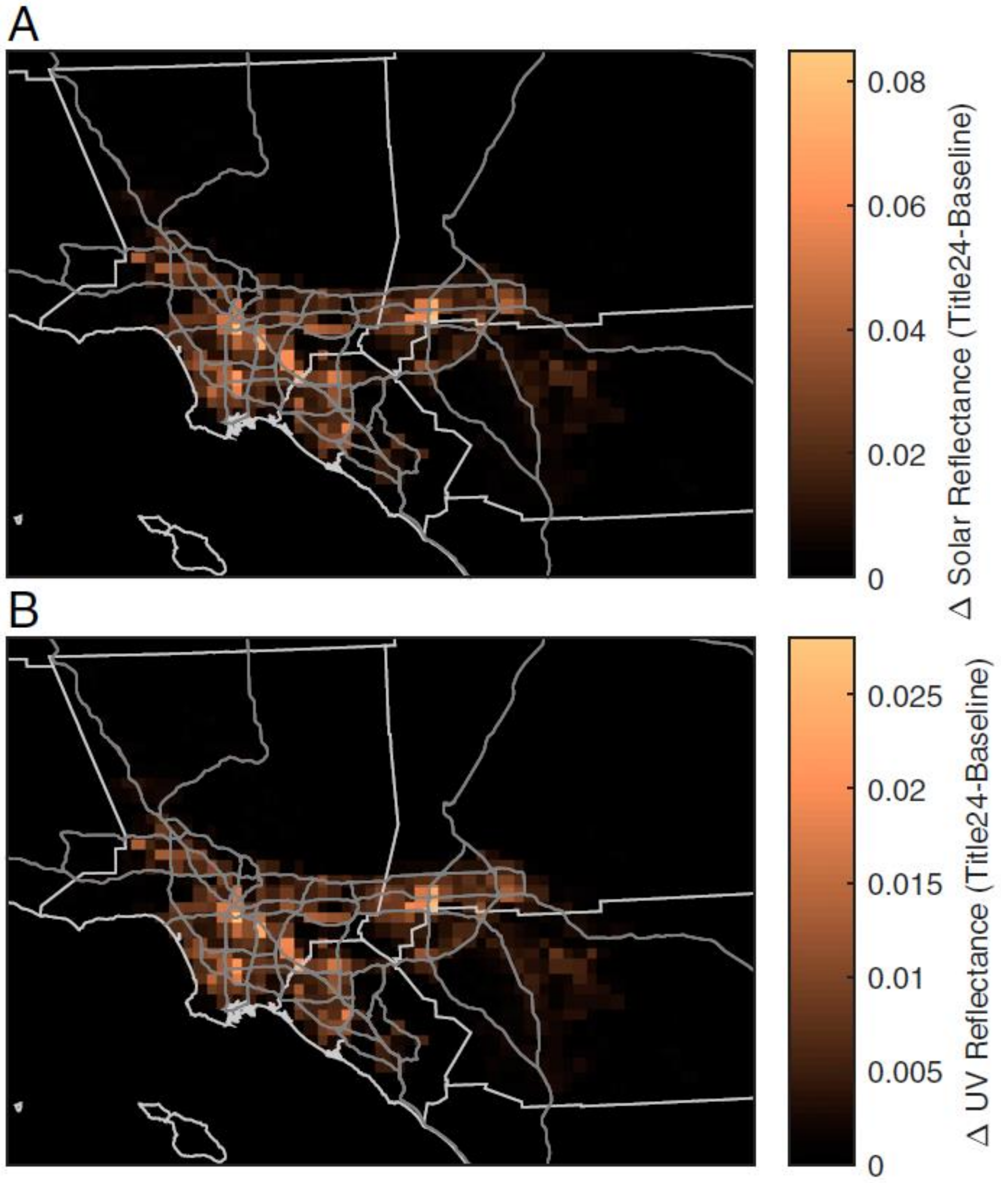

Fig. 1. (*A*) Change in SR (Title24 – baseline) used for WRF simulations. (*B*) Maximum possible change in UVR (Title24 – baseline) used for CMAQ simulations.

Projecting Future SR

We developed a high-resolution database of building rooftop areas classified by land-use category to project future SR after full implementation of Title24 standards in the SoCAB.

Protecting UVR for Chemical Transport Modeling

0-0.027

Materials and Methods

Emission Processing

Annual hourly emissions profiles were developed as a function of the baseline and Title24 meteorological fields for the 2012 base year.

Within the SoCAB, on average during the O3 season, VOC emissions are reduced by 0.1% (0.75 tons per day) and NOx emissions are reduced by 8×10^{-4}% (0.004 tons per day) in the Title24 scenario.

Meteorological and Chemical Transport Modeling

A base case using the MODIS-derived SR fields.

A Title24 case using the modified SR fields detailed above assuming that all buildings in the SoCAB meet Title24 rooftop SR requirements.

Scenario name	WRF SR	Emissions	Reflectance used to drive chemistry
I	Baseline	Baseline	Baseline
II	Baseline	Baseline	Enhanced vis/IR, no UV increase
III	Baseline	Title24	Enhanced vis/IR, no UV increase
IV	Title24	Title24	Enhanced vis/IR, no UV increase
V	Title24	Title24	Enhanced vis/IR, maximum UV increase

Results and Discussion

Changes in Meteorology

Changes in $PM_{2.5}$ Concentrations

Changes in Ozone Concentrations

Policy Implications

Results and Discussion

Changes in Meteorology

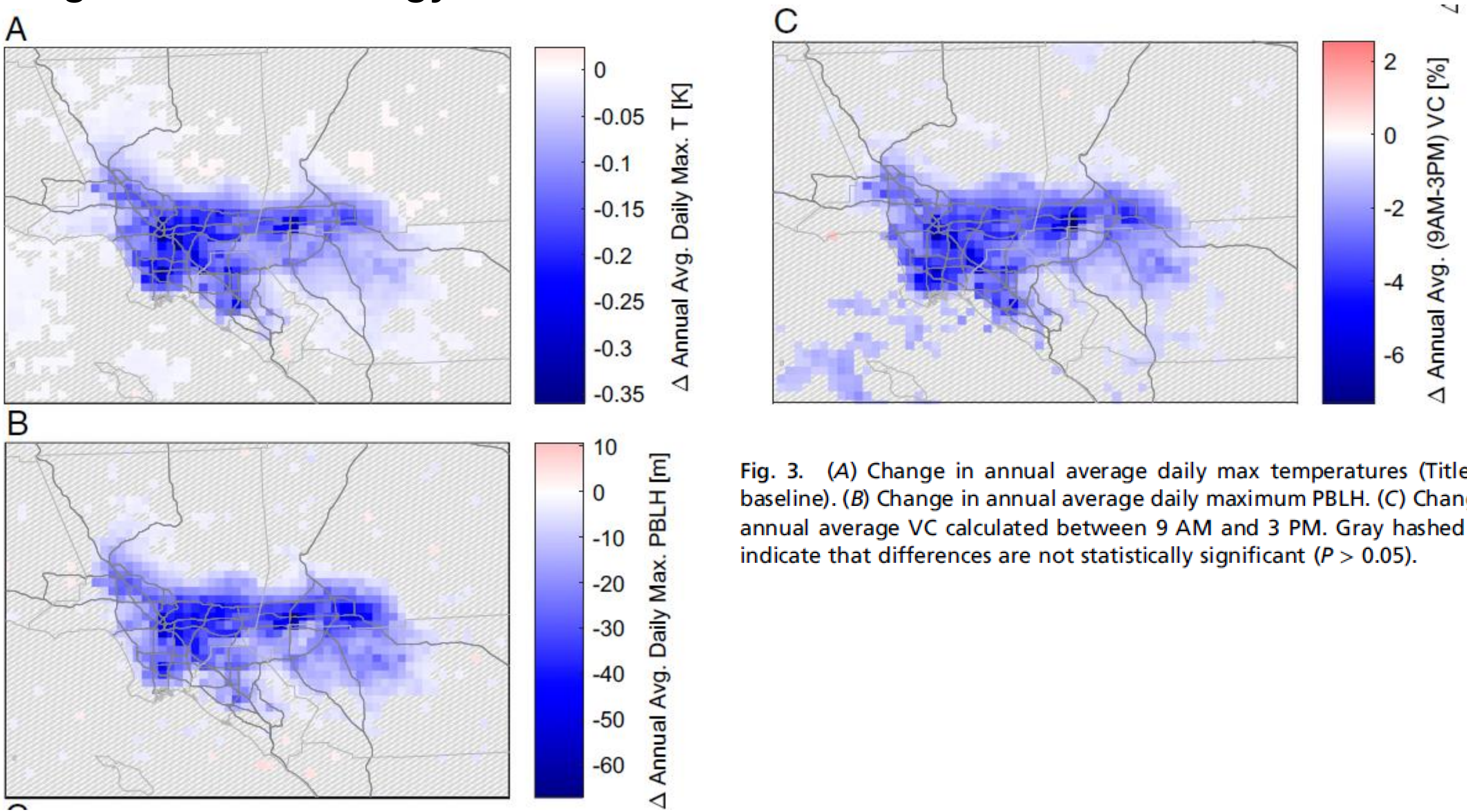

Fig. 3. (*A*) Change in annual average daily max temperatures (Title24 – baseline). (*B*) Change in annual average daily maximum PBLH. (*C*) Change in annual average VC calculated between 9 AM and 3 PM. Gray hashed cells indicate that differences are not statistically significant ($P > 0.05$).

Results and Discussion

Changes in $PM_{2.5}$ Concentrations

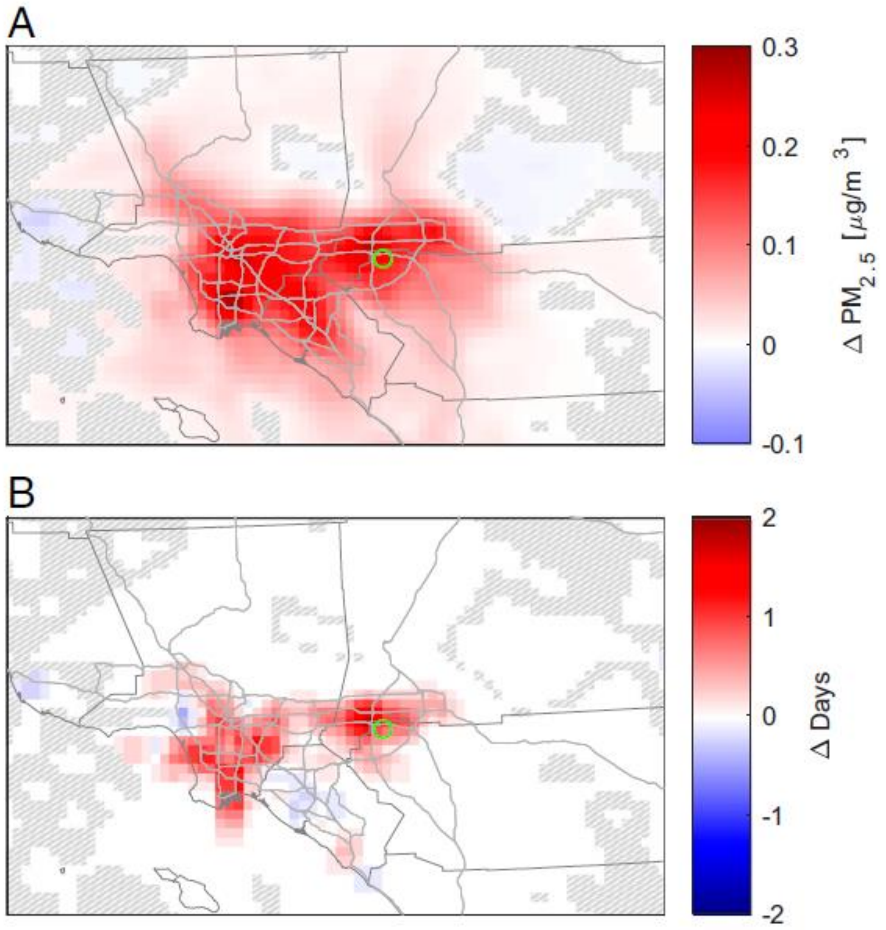

Fig. 4. (*A*) Change in annual average $PM_{2.5}$ concentrations (scenario IV – scenario 1). The green circle indicates the location of the highest annual $PM_{2.5}$ measured DVs in the basin. Seasonal differences in $PM_{2.5}$ are presented in *SI Appendix*, Fig. S34. (*B*) Change in the number of 24-h $PM_{2.5}$ federal standard (35 $\mu g \cdot m^{-3}$) exceedance days in a year (scenario IV – scenario 1). Gray hashed cells indicate that differences are not statistically significant ($P > 0.05$). Image represents 3- × 3-cell moving average.

Average PM2.5 concentrations increase.

Los Angeles region and Long Beach, annual PM2.5 concentrations are projected to increase by approximately 0.3 μg·m−3.

These changes are location-dependent, with increases in Los Angeles and the Inland Empire where PM2.5 is typically highest.

Results and Discussion

Changes in $PM_{2.5}$ Concentrations

Table 2. Simulated changes in $PM_{2.5}$ and O_3 at polluted locations

Scenario name	WRF SR	Emissions	Reflectance used to drive chemistry	Δ Annual average $PM_{2.5}$ at Mira Loma, $\mu g{\cdot}m^{-3}$	Δ Daily maximum 8-h O_3 at Redlands, ppb	Δ Daily maximum 1-h O_3 at Fontana, ppb	Δ Basin maximum annual $PM_{2.5}$ DV, $\mu g{\cdot}m^{-3}$	Δ Basin maximum 24-h $PM_{2.5}$ DV, $\mu g{\cdot}m^{-3}$	Δ Basin maximum 8-h O_3 DV, ppb	Δ Basin maximum 1-h O_3 DV, ppb
I	Baseline	Baseline	Baseline	0	0	0	0	0	0	0
II	Baseline	Baseline	Enhanced vis/IR, no UV increase	0.00 ± 0.000**	0.00 ± 0.000**	0.01 ± 0.000**	0	0	0	0
III	Baseline	Title24	Enhanced vis/IR, no UV increase	0.00 ± 0.000**	−0.01 ± 0.000**	−0.01 ± 0.001**	0	−0.07	0	0
IV	Title24	Title24	Enhanced vis/IR, no UV increase	0.19 ± 0.007**	0.04 ± 0.013**	−0.040 ± 0.023*	+0.23	+0.62	+0.3	−0.4
V	Title24	Title24	Enhanced vis/IR, maximum UV increase	0.20 ± 0.008**	0.66 ± 0.015**	0.96 ± 0.026**	+0.22	+0.65	+1.3	+1.9

Average concentrations are reported as nine cell averages (cell including station + eight adjacent cells). Uncertainty ranges represent the standard error. Δ indicates that the results of the baseline scenario were subtracted from the scenario indicated on each row. An additional scenario where UVR is increased to one-half of its maximum value is presented in *SI Appendix*, Table S2. *$P = 0.004$; **$P < 0.0001$.

Results and Discussion

Changes in Ozone Concentrations

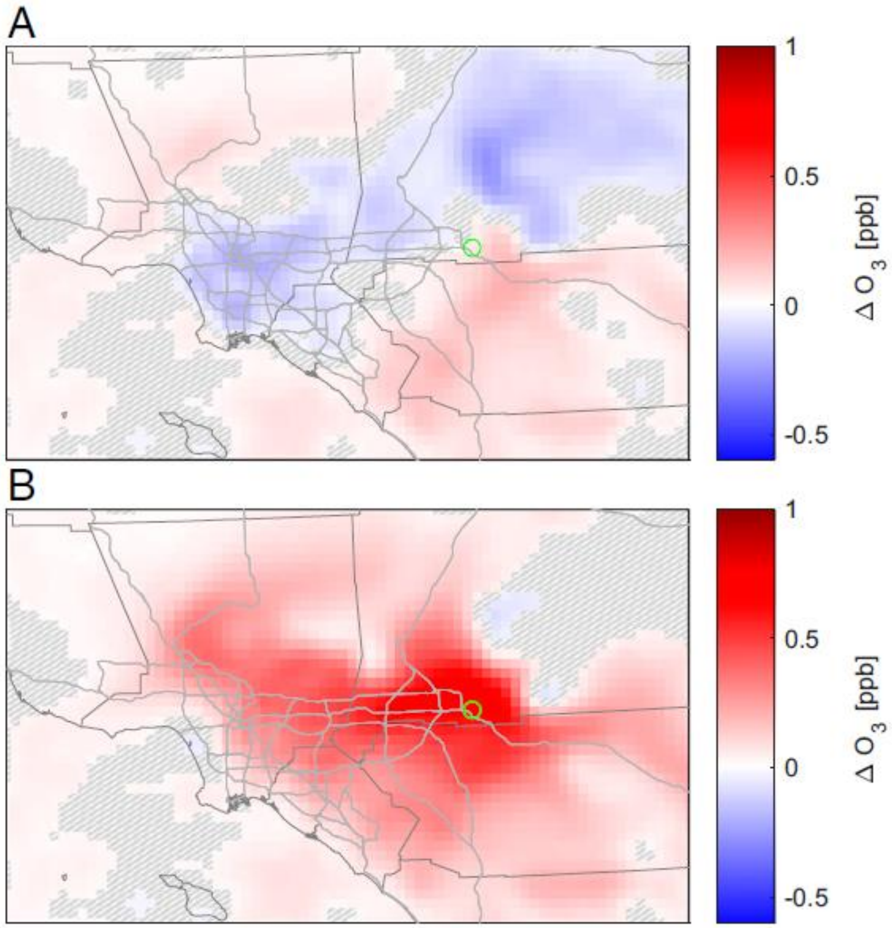

Fig. 5. (*A*) Change in annual average $DM8HO_3$ values (scenario IV) with the assumption that UVR does not change with widespread installation of cool roofs. The green circle indicates the location of the highest 8-h O_3 measured DVs in the basin. (*B*) Change in annual average $DM8HO_3$ values with the assumption that UVR increases are consistent with the maximum possible increase based on roofing products currently available (scenario V). Gray hashed cells indicate that differences are not statistically significant ($P > 0.05$). Image represents 3- × 3-cell moving average.

O_3 concentrations largely decrease, with the exception of the Redlands area

Most residents in the SoCAB live in areas that will experience a decrease in O3

Average DM8HO3 concentrations increase in most of the SoCAB

Results and Discussion

Changes in Ozone Concentrations

Table 2. Simulated changes in $PM_{2.5}$ and O_3 at polluted locations

Scenario name	WRF SR	Emissions	Reflectance used to drive chemistry	Δ Annual average $PM_{2.5}$ at Mira Loma, $\mu g \cdot m^{-3}$	Δ Daily maximum 8-h O_3 at Redlands, ppb	Δ Daily maximum 1-h O_3 at Fontana, ppb	Δ Basin maximum annual $PM_{2.5}$ DV, $\mu g \cdot m^{-3}$	Δ Basin maximum 24-h $PM_{2.5}$ DV, $\mu g \cdot m^{-3}$	Δ Basin maximum 8-h O_3 DV, ppb	Δ Basin maximum 1-h O_3 DV, ppb
I	Baseline	Baseline	Baseline	0	0	0	0	0	0	0
II	Baseline	Baseline	Enhanced vis/IR, no UV increase	0.00 ± 0.000**	0.00 ± 0.000**	0.01 ± 0.000**	0	0	0	0
III	Baseline	Title24	Enhanced vis/IR, no UV increase	0.00 ± 0.000**	-0.01 ± 0.000**	-0.01 ± 0.001**	0	−0.07	0	0
IV	Title24	Title24	Enhanced vis/IR, no UV increase	0.19 ± 0.007**	0.04 ± 0.013**	-0.040 ± 0.023*	+0.23	+0.62	+0.3	−0.4
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Results and Discussion

Policy Implications

Compliance with Title24 cool-roof standards may make attainment of this goal more difficult, even if future UVR increases are small.

Although more realistic UVR increases cannot be projected without knowledge of the individual cool roofing products that are adopted, our analysis indicates that UVR will likely increase when replacing standard roofs with cool roofs.

We estimate that even if UVR increases can be entirely avoided, Title24 could increase the 2031 8-h DV by 0.3 ppb and the 2031 1-h DV by 1.1 ppb.

Results and Discussion

Policy Implications

Author’s suggestions

The O_3 concentration sensitivity to small changes in cool-roof UVR supports the establishment of a standard regulating the UVR of certified cool-roof materials. Furthermore, it is possible that a reduction in UVR below current values will lead to improvements in O_3 air quality throughout the SoCAB.

When assessing the impacts of cool roofs, it is important to consider all environmental and economic consequences. Without a comprehensive analysis of all of the benefits of cool roofs it would be a mistake to discourage this technology solely on the basis of air quality alone.

Results and Discussion

Future studies

Results of this analysis also shed light on the choice of pavement materials and cool pavements, a potentially more important driver of overall urban SR and UVR.

Results and Discussion

Some inspirations

Take the impacts of cool roofs and cool pavements into consideration when analyzing ozone concentration in Lake Taihu Basin with Lake Model.

When analyzing the ozone concentration, in addition to considering the effects of meteorological processes and chemical reactions, the influence of UVR should also be considered.

Thank you