# Linking ozone pollution and climate change: The case for controlling methane

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<td>Published Version</td>
<td>doi:10.1029/2002GL015601</td>
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Linking ozone pollution and climate change: 
The case for controlling methane

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Received 4 June 2002; revised 8 August 2002; accepted 13 August 2002; published 8 October 2002.

[1] Methane (CH4) emission controls are found to be a powerful lever for reducing both global warming and air pollution via decreases in background tropospheric ozone (O3). Reducing anthropogenic CH4 emissions by 50% nearly halves the incidence of U.S. high-O3 events and lowers global radiative forcing by 0.37 W m−2 (0.30 W m−2 from CH4, 0.07 W m−2 from O3) in a 3-D model of tropospheric chemistry. A 2030 simulation based upon IPCC A1 emissions projections shows a longer and more intense U.S. O3 pollution season despite domestic emission reductions, indicating that intercontinental transport and a rising O3 background should be considered when setting air quality goals. INDEX TERMS: 0325 Atmospheric Composition and Structure: Evolution of the atmosphere; 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry. Citation: Fiore, A. M., D. J. Jacob, B. D. Field, D. G. Streets, S. D. Fernandes, and C. Jang, Linking ozone pollution and climate change: The case for controlling methane, Geophys. Res. Lett., 29(19), 1919, doi:10.1029/2002GL015601, 2002.

1. Introduction

[2] There is growing interest in linking air quality and climate change mitigation objectives in the design of emission control strategies. Tropospheric O3 deserves particular attention as both the primary constituent of smog [National Research Council (NRC), 1991] and a significant greenhouse gas [Prather et al., 2001]. Ozone is produced in the troposphere by photochemical oxidation of volatile organic compounds (VOC) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx). While O3 production on global and regional scales is sensitive to NOx emissions from fossil fuel combustion [NRC, 1991; Wang and Jacob, 1998], reducing these emissions may increase greenhouse warming if the positive forcing from increased CH4 concentrations offsets the negative forcing from decreased O3 concentrations [Wild et al., 2001].

[3] Methane is a known major source of the tropospheric O3 background, but is not generally considered a precursor to regional O3 pollution episodes in surface air because of its long lifetime (8–9 years). Recent recognition that intercontinental transport may contribute to these pollution episodes [Jacob et al., 1999; Yienger et al., 2000; Wild and Akimoto, 2001; Fiore et al., 2002; Li et al., 2002] raises the profile of CH4. The present-day U.S. O3 standard is based upon a 0.08 ppmv (8-hour average), not to be exceeded more than three times per year. If this standard becomes more stringent, as it is in European countries (55–65 ppbv), the relative contribution of the background component to exceedances of the standard will increase. We show that reductions in CH4 emissions deserve consideration as a means to meet air quality standards while simultaneously lessening radiative forcing.

2. Model Description

[4] We apply GEOS-CHEM (v4.16), a 3-D global model of tropospheric O3-NOx-CO-VOC chemistry [Bey et al., 2001], to investigate the response of U.S. pollution episodes and global O3 and CH4 to (1) 50% reductions in various anthropogenic precursor emissions relative to a 1995 base year and (2) projected 2030 emissions from the IPCC A1 and B1 scenarios [Prather et al., 2001], which project relatively pessimistic and optimistic futures, respectively. All simulations were spun up for 6 months, long enough to remove the effects of initial O3 concentrations on the results. Our simulations use assimilated observations of meteorological fields from NASA GEOS-1 with 20 vertical sigma layers and a 4° × 5° horizontal resolution; comparison with 2° × 2.5° resolution shows no significant bias [Fiore et al., 2002].

[5] The coarse resolution precludes the model from capturing the local O3 maxima that determine compliance with the national O3 standard. These maxima, however, typically occur under regionally stagnant conditions that are conducive to the formation of elevated O3 levels spanning large spatial scales (>600,000 km2) [Logan, 1989] resolved by the model. During the summer of 1995, these stagnation episodes occurred more frequently than would be predicted by climatological averages [McNider et al., 1998]. We have previously shown that GEOS-CHEM captures these regional high-O3 events, as well as the frequency distribution of O3 at U.S. sites [Fiore et al., 2002]. We compare here simulated June–August daily afternoon (1–5 p.m. local time) mean O3...
(pregnant) O3 burden (Tg) 321 294 300 317 297 317 269 394

CH4 for CH4.
computed OH concentrations by assuming the same CH4 source as in the 1995 base case simulation.

Table 2. Impacts of Perturbations to Anthropogenic Emissions

<table>
<thead>
<tr>
<th>Selected Diagnostics</th>
<th>Base Case 1995</th>
<th>50% CH4</th>
<th>50% NOx</th>
<th>50% VOC</th>
<th>50% NOx &amp; VOC</th>
<th>50% CO</th>
<th>50% All</th>
<th>A1 2030</th>
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<tbody>
<tr>
<td>Tropospheric O3 burden (Tg)</td>
<td>321</td>
<td>294</td>
<td>300</td>
<td>317</td>
<td>297</td>
<td>317</td>
<td>297</td>
<td>394</td>
</tr>
<tr>
<td>global CH4 conc. (ppbv)</td>
<td>1700</td>
<td>1000</td>
<td>1867</td>
<td>1685</td>
<td>1846</td>
<td>1643</td>
<td>1040</td>
<td>2431</td>
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<tr>
<td>OPE</td>
<td>33</td>
<td>30</td>
<td>43</td>
<td>32</td>
<td>42</td>
<td>32</td>
<td>38</td>
<td>27</td>
</tr>
<tr>
<td>CH4 lifetime</td>
<td>8.5</td>
<td>7.2</td>
<td>9.4</td>
<td>8.5</td>
<td>9.3</td>
<td>8.3</td>
<td>7.5</td>
<td>9.3</td>
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Mean U.S. summer afternoon surface O3 (ppbv) 51 48 42 50 41 50 38 55
Background 23 21 21 23 21 23 18 29

3. Impacts on Global Chemistry and Climate

Table 2 summarizes the important results from our simulations. We find that the CH4 lifetime is longer when NOx emissions are decreased and shorter when VOC or CO emissions are decreased, consistent with our understanding of the effect of these emissions on global OH [Wang and Jacob, 1998]. The 2030 A1 simulation yields a CH4 lifetime that is 10% longer than in 1995. The global O3 production efficiency (OPE), the number of tropospheric O3 molecules produced per molecule of NOx emitted [Liu et al., 1987], increases with decreasing NOx emissions and decreases with increasing VOC or CO concentrations (Table 2), again as expected [Wang and Jacob, 1998]. The OPE decreases in the A1 simulation, due to the large increase in global fossil fuel NOx emissions.

We find that 50% reductions in anthropogenic CH4 emissions have more influence on the tropospheric O3 between CH4 emissions and concentrations (assuming an OH feedback factor of 1.6) determined by Prather [1996] to translate a 50% decrease in anthropogenic CH4 emissions into a steady-state concentration of 1000 ppbv for the corresponding troposphere.

[7] Emissions for the A1 and B1 2030 scenarios were generated by scaling 1995 emissions by regional growth factors derived from emissions in the IMAGE socioecono
d model [IMAGE Team, 2001] for each anthropogenic source and biomass burning. The IMAGE model gives projections consistent with those of the IPCC reference models. Due to space restrictions, we focus here on the A1 scenario. Emissions increase globally (Table 1) from 1995 to 2030, but the distribution shifts. In the developed world (Europe, North America, Japan, etc.), anthropogenic NOx emissions decline by 10%, but they increase by 130% in the developing world (South America, Africa, Asia, etc.). U.S. anthropogenic emissions of O3 precursors decline by 20–40%, IMAGE projects a 43% increase in CH4 emissions from 1995 to 2030, which we apply to the CH2 concentration assuming constant OH. In the 2030 A1 simulation, CH4 actually increases by 31% (as implied by mass balance) because OH concentrations decrease. Thus our CH4 increase is conservative. The IPCC A1 scenario does not include aircraft NOx emissions; we use projections from the Environmental Defense Fund [Henderson et al., 1999] to determine a growth factor of 2.26.

[8] Table 2 summarizes the important results from our simulations. We find that the CH4 lifetime is longer when NOx emissions are decreased and shorter when VOC or CO emissions are decreased, consistent with our understanding of the effect of these emissions on global OH [Wang and Jacob, 1998]. The 2030 A1 simulation yields a CH4 lifetime that is 10% longer than in 1995. The global O3 production efficiency (OPE), the number of tropospheric O3 molecules produced per molecule of NOx emitted [Liu et al., 1987], increases with decreasing NOx emissions and decreases with increasing VOC or CO concentrations (Table 2), again as expected [Wang and Jacob, 1998]. The OPE decreases in the A1 simulation, due to the large increase in global fossil fuel NOx emissions.

[9] We find that 50% reductions in anthropogenic CH4 emissions have more influence on the tropospheric O3...
forcing can be assessed using the standard concept of radiative change in radiative forcing from CH₄ directly from the Earth system resulting from the perturbation. We calculate instantaneous global change in the radiative balance of the system.

Budget, whereas the homogeneity of CH₄ permits anthropogenic NOx emissions to be equally effective. The decreases in NOx and CH₄ emissions, however, are equally effective at lowering background O3 concentrations (2 ppbv in the mean). Decreases in CO or VOC emissions have little impact. For the A1 2030 simulation, mean afternoon surface O3 increases by 4 ppbv while background concentrations rise by 6 ppbv. Even in the more optimistic B1 scenario, higher global CH₄ emissions contribute to elevating U.S. background O3 levels by 2 ppbv, partially offsetting air quality gains achieved through domestic emissions controls.

We use a threshold of 70 ppbv as a metric to gauge changes in the frequency of O3 pollution events in our simulations. Figure 1 (bottom panel) shows the number of U.S. grid-square days in June–August 1995 where simulated afternoon average (1–5 p.m. local time) O3 levels exceed 70 ppbv. Reducing anthropogenic NOx emissions by 50% nearly eliminates the occurrence of grid-square days in excess of 70 ppbv (Figure 1). Because of subgrid variability in O3, this result does not mean that local exceedances of 70 ppbv would be as drastically reduced, but it does point to significant improvement in air quality. When anthropogenic CH₄ emissions are reduced by 50%, the incidence of O3 concentrations in excess of 70 ppbv (Figure 1) declines by 45% (for an 80 ppbv threshold that statistic is 54%).

The U.S. has aggressive emission controls to abate future O3 pollution. Although fossil fuel emissions in the U.S. for NOx, CO, and VOC decline in the IPCC A1 2030 scenario relative to 1995 by 27%, 45%, and 30%, respectively, we find that the number of grid-square summer days over the U.S. with O3 > 70 ppbv increases relative to 1995. Efforts to improve U.S. air quality are thus thwarted by the rise in global background O3 levels due to increased emissions outside U.S. borders. These results are consistent with the modeling study of Collins et al. [2000] who found
that European efforts to improve air quality via domestic emissions reductions may be offset by a rise in emissions from developing nations by 2015. These simulations underscore the need to consider regional air quality in a global context.

Another adverse impact of rising global emissions on U.S. air quality is a longer U.S. O3 pollution season, as diagnosed by exceedances of a 70 ppbv threshold. Intercontinental transport makes a larger contribution to U.S. O3 pollution in spring and fall than in summer because of the longer O3 lifetime [Jacob et al., 1999]. Figure 2 shows the larger numbers of exceedances of the 70 ppbv threshold in March through November in the A1 2030 simulation; results are similar for an 80 ppbv O3 threshold.

5. Conclusions

Our global 3-D model analysis shows that reducing CH4 emissions enables a simultaneous pursuit of O3 air quality and climate change mitigation objectives. Whereas reductions in NOx emissions achieve localized decreases in surface O3 concentrations, reductions in CH4 emissions lower the global O3 background and improve surface air quality everywhere. Simulation of a 2030 (IPCC A1) scenario where anthropogenic U.S. emissions of O3 precursors decrease but global emissions (including CH4) increase indicates a greater incidence of O3 pollution episodes and a longer U.S. O3 season, stressing the need for a global perspective in the design of future regional pollution control strategies.

Acknowledgments. The authors would like to thank Loretta Mickley and Mat Evans for helpful conversations, and to acknowledge the support of the U.S. EPA Office of Air Quality and Planning Standards, the National Science Foundation, and the Atmospheric Chemistry Modeling and Analysis Program of NASA.

Figure 2. Number of U.S. model grid-square days per month with afternoon (1–5 p.m.) O3 concentrations in surface air above a 70 ppbv threshold for the 1995 base case (white bars) and 2030 A1 (black bars) simulations. The A1 simulation reveals a longer O3 pollution season. Results are similar for an 80 ppbv O3 threshold.

References


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