Fresh air in the 21st century?

Michael Prather,1 Michael Gauss,2 Terje Berntsen,2 Ivar Isaksen,2 Jostein Sundet,2 Isabelle Bey,3 Guy Brasseur,4 Frank Dentener,5 Richard Derwent,6 David Stevenson,6 Lee Grenfell,7 Didier Hauglustaine,8 Larry Horowitz,9 Daniel Jacob,10 Loretta Mickley,10 Mark Lawrence,11 Rolf von Kuhlmann,11 Jean-Francois Muller,12 Giovanni Pitari,13 Helen Rogers,14 Matthew Johnson,14 John Pyle,14 Kathy Law,14 Michiel van Weele,15 and Oliver Wild16

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1 Ozone is an air quality problem today for much of the world’s population. Regions can exceed the ozone air quality standards (AQS) through a combination of local emissions, meteorology favoring pollution episodes, and the clean-air baseline levels of ozone upon which pollution builds. The IPCC 2001 assessment studied a range of global emission scenarios and found that all but one projects increases in global tropospheric ozone during the 21st century. By 2030, near-surface increases over much of the northern hemisphere are estimated to be about 5 ppb (+2 to +7 ppb over the range of scenarios). By 2100 the two more extreme scenarios project baseline ozone increases of >20 ppb, while the other four scenarios give changes of –4 to +10 ppb. Even modest increases in the background abundance of tropospheric ozone might defeat current AQS strategies. The larger increases, however, would gravely threaten both urban and rural air quality over most of the northern hemisphere. INDEX TERMS: 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 0365 Atmospheric Composition and Structure: Troposphere—composition and chemistry; 1610 Global Change: Atmosphere (0315, 0325). Citation: Prather, M., et al., Fresh air in the 21st century?, Geophys. Res. Lett., 30(2), 1100, doi:10.1029/2002GL016285, 2003.

1. Introduction

The air we breathe can contain noxious substances in the form of trace gases and aerosols. Ozone (O₃) is identified as one of the more serious of these air pollutants, and the large abundances of O₃ observed within and downwind of metropolitan regions are clearly identified with emissions of ozone precursors, specifically, oxides of nitrogen (NOₓ), carbon monoxide (CO) and volatile organic compounds (VOC), by the industrial and transportation sectors [Haagen-Smit, 1951]. Breathing ozone, even at relatively low abundances, is correlated with pulmonary damage and asthma attacks [e.g., Peden, 2001; Desqueyroux et al., 2002; Mortimer et al., 2002]. Ground-level O₃ damages agricultural crops and natural ecosystems [e.g., Mauzerall and Wang, 2001; Oksanen and Holoapainen, 2001] and reacts with environmental compounds to produce other toxic substances [e.g., Morrison and Nazaroff, 2002].

Ozone is an air quality problem today for much of the world’s population. For example, in the U.S. the 8-hour ozone standard of 80 ppb (all abundances are mole fraction, ppb = 10⁻⁶) was exceeded over the last decade by an average 28 days per year for New England, where “serious” to “severe” non-attainment areas cover the populous regions [U.S. Environmental Protection Agency, Region 1: New England, http://www.epa.gov/region01/eco/ozone/]. In Europe, more than half the urban population is exposed to ozone above the 8-hour standard of 55 ppb for more than 30 days per year [EEA, 2002]. Some developing countries like India have air quality standards (AQS) for SO₂, NO₂, aerosols, but not O₃. The impacts of O₃ pollution on vegetation and in developing countries is only recently being assessed [e.g., Emberston et al., 2001; Taylor, 2001]. The global damages caused by increasing O₃ levels have not been fully evaluated.

Strategies to abate urban O₃ originally focused on local or regional solutions such as the State of California’s Air Quality Management Districts (http://www.qamd.gov/). The 1979 Geneva Convention on Long-Range Transboundary Air Pollution (http://www.unece.org/env/lrtap/) now has Protocols that consider continental-scale transport of O₃ and its precursors. Recent studies have shown that transport, intercontinental transport of O₃ and related pollutants couples the major continents of the northern mid-latitudes [Tarrason and Iversen, 1998; Wild and Akimoto, 2001; Li et al., 2002] and hint that the O₃ AQS may be a global problem. Still, the typical scientific study to aid policy decisions on future O₃ AQS [e.g., Jensen et al., 2001] does not consider global-scale changes in tropospheric O₃ that are anticipated during the 21st century.

More than a dozen research groups analyzed the changes in atmospheric chemistry projected for the 21st century as part of the OxComp workshop of the Third Assessment Report of the Intergovernmental Panel on...
Three-dimensional global models were used to project the changes in greenhouse gases resulting from changing anthropogenic emissions based on the Special Report on Emissions Scenarios (SRES) [Nakicenovic et al., 2000]. The IPCC/TAR reported tropospheric O₃ column as a climate forcing and only noted briefly that surface O₃ increases by 2100 might be “threatening attainment of air quality standards over most metropolitan and even rural regions...” Surface maps and seasonality of these projected O₃ changes are presented and discussed here for the first time.

2. Results

The increases in near-surface O₃ projected from year 2000 to year 2100 for one of the extreme SRES scenarios are shown in Figure 1 as January and July monthly averages. The largest increases typically occur in the tropics.

![Figure 1](image-url)
Revised and the CH₄ abundances were recalculated to include the emissions of NOx, CO, and VOC. The results are intended as direct projections of urban O₃ change, but rather, they indicate an upward shift in the baseline levels upon which regional pollution builds. The extreme, rather than CO or VOC that drive the other half.

Figure 2. (top) Zonal-mean surface O₃ increase (ppb) from Y2000 to Y2100 as a function of latitude following scenario A2x. See Figure 1. The 4 months shown (Jan, May, Jul, Sep) bound all other months and are labeled at their extrema. The annual average (dashed) is also shown. (bottom) The Jan zonal average (blue, thick solid) and Jul zonal average (red, thick dashed) are shown again with their minima and maxima (thin lines). These min/max are the zonal averages of the extreme model result for each 5° × 5° grid box.

where high sunlight conditions prevail, but the rise in O₃ affects most of the globe, including what are currently thought of as clean-air remote regions. These values are taken from global tropospheric chemistry model simulations for the IPCC/TAR scenario A2x, which was the only scenario analyzed with the full chemistry models [Prather and Ehhalt, 2001]. This projection of anthropogenic emissions is based on the preliminary SRES A2 scenario and a preliminary estimate of the methane (CH₄) abundance. Prior to the completion of the TAR the SRES scenarios were revised and the CH₄ abundances were recalculated to include the emissions of NOx, CO, and VOC.

Figure 2 shows the extreme ranges of all ten model results for Jan (dashed) and Jul (solid), selecting the extreme of all models for each 5° × 5° grid box to average zonally. Thus, based on the range of independent model results, the 2/3-likelihood confidence interval for the zonal mean increase in near-surface O₃ due to these emissions is judged to be less than ±5 ppb. As identified in the OxComp study, the increase in CH₄ abundance from Y1750 ppb to Y4300 ppb drives almost half of this O₃ increase, and it is primarily the increased emissions of NOx rather than CO or VOC that drive the other half.

3. Discussion

What do projections of global tropospheric O₃ mean for AQS in the 21st century? Clearly, these increases are not intended as direct projections of urban O₃ change, but rather, they indicate an upward shift in the baseline levels of O₃ upon which regional pollution builds. The extreme, high-O₃ events as measured in the hourly AQS are driven by local emissions and less likely affected by baseline O₃ increases. Efforts to meet the new 8-hour standards, however, and particularly the European cumulative standards for crops and vegetation (AOT40), would be greatly impacted by baseline increases of 15 to 25 ppb. It is worrisome that the largest baseline increases occur in northern mid-latitudes around continents during summer when air quality is currently at its worst. There are already agricultural concerns about the summertime high O₃ in developing countries [Mauzerall and Wang, 2001]. In addition, the high O₃
regions coincide with increasing aerosol emissions [Penner, 2001], which further exacerbates human health impacts. [11] How representative is this high-end scenario of future O3 increases? Among the six final SRES illustrative scenarios, two (A2 and A1FI) have emissions of O3 precursors as large as the A2x scenario shown here. If we scale the change in near-surface O3 with that of the total tropospheric O3 as reported in the TAR [Prather and Ehhalt, 2001], then these two scenarios would project changes like those illustrated here for the latter decades of the 21st century. On the other hand, the four less extreme SRES scenarios (A1B, A1T, B1, B2) project much lower fossil fuel use and smaller near-surface O3 changes ranging from −4 to +10 ppb by 2100. More immediately, by 2030 all six scenarios would project near-surface O3 increases that range from 9% to 34% (averaging 25%) of those shown here. Such near-term increases of about 5 (+2 to +7) ppb over the northern hemisphere would notably impede AQS attainment [Fiore et al., 2002]. One critical element in these projections is the scenario for emissions of O3 precursors, not just their amount, but their location. A known flaw with the SRES scenarios is that they did not explicitly consider the emergence of new ozone-related air quality regulations in developing countries. A revised and expanded SRES-like effort, one that focuses on the regional emissions of O3 precursors and allows for emerging air quality regulations, is required for AQS planning over the next several decades. [12] What is missing? These projections of 21st century changes in global tropospheric chemistry include only changes in anthropogenic emissions. As noted in the TAR, the response of the climate system to the overall anthropogenic forcing (including carbon dioxide) is expected to be larger than anything observed in the last millennium, and thus we expect natural ecosystems and their emissions of O3 precursors to be altered. Unfortunately, we were unable to evaluate this feedback in the TAR due to a lack of research and publication on this topic. In addition, the physical climate change itself will alter the dynamics, temperature, and humidity of the troposphere, including possibly the occurrence of stagnation episodes that lead to AQS exceedences. One of the OxComp models (UKMO) has shown since the TAR that the 21st century physical climate change driven by the A2 scenario tends to reduce global tropospheric O3 because of the higher humidity and temperature [Johnson et al., 2001], a result consistent with earlier sensitivity studies [Brasseur et al., 1998]. These missing feedbacks represent a major source of uncertainty in projecting near-surface baseline O3 increases. They need to be evaluated within the research of the broader community before the next assessments. [13] Acknowledgments. The authors thank the leadership of Sir John Houghton in Working Group I of the IPCC Third Assessment Report, which made these collaborative model studies possible.

References


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