Fresh air in the 21st century?

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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

[2] 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 Holopainen, 2001] and reacts with environmental compounds to produce other toxic substances [e.g., Morrison and Nazaroff, 2002].

[3] 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.

[4] 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.aqmd.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 transoceanic, 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.

[5] 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

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Climate Change (IPCC/TAR) [Prather and Ehhalt, 2001]. 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) [Nakićenović 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

[6] 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.
3. Discussion

[10] What do projections of global tropospheric $O_3$ mean for AQs in the 21st century? Clearly, these increases are not intended as direct projections of urban $O_3$ change, but rather, they indicate an upward shift in the baseline levels of $O_3$ upon which regional pollution builds. The extreme, high-$O_3$ events as measured in the hourly AQs are driven by local emissions and less likely affected by baseline $O_3$ 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 $O_3$ in developing countries [Mauzerall and Wang, 2001]. In addition, the high $O_3$
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 to +7) ppb over the northern hemisphere would notably impede AQStop 2000 [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 AQStop 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 AQStop 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.

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References


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