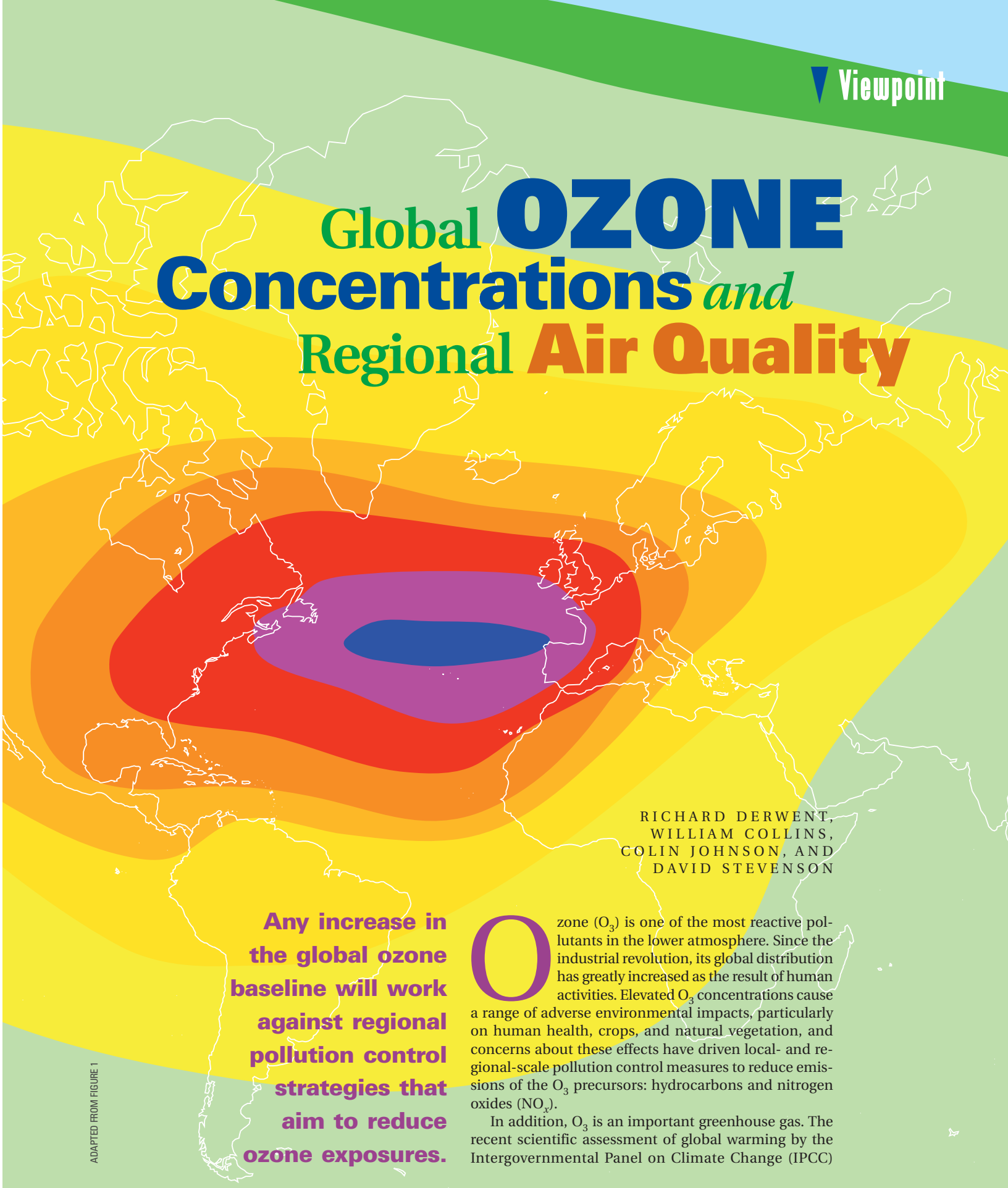
Global OZONE Concentrations *and* Regional Air Quality



ADAPTED FROM FIGURE 1

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Any increase in the global ozone baseline will work against regional pollution control strategies that aim to reduce ozone exposures.

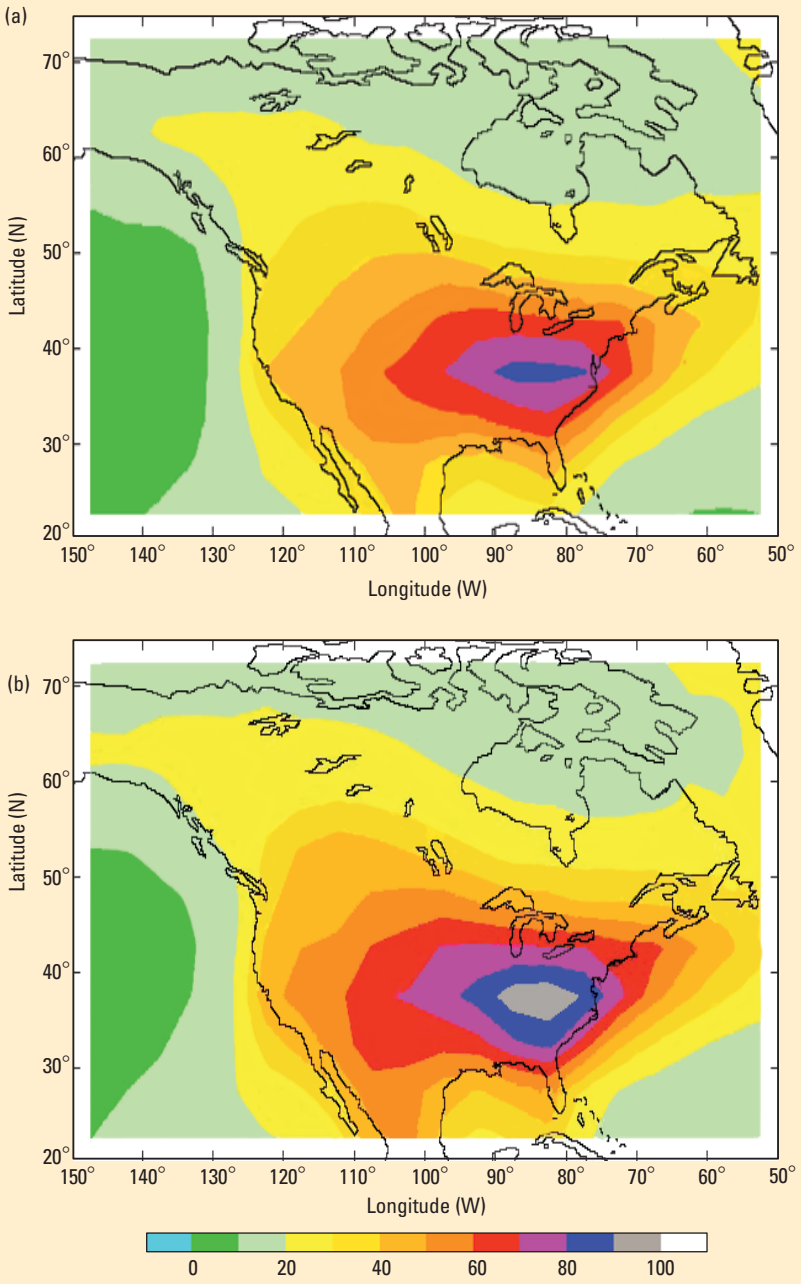
Ozone (O_3) is one of the most reactive pollutants in the lower atmosphere. Since the industrial revolution, its global distribution has greatly increased as the result of human activities. Elevated O_3 concentrations cause a range of adverse environmental impacts, particularly on human health, crops, and natural vegetation, and concerns about these effects have driven local- and regional-scale pollution control measures to reduce emissions of the O_3 precursors: hydrocarbons and nitrogen oxides (NO_x).

In addition, O_3 is an important greenhouse gas. The recent scientific assessment of global warming by the Intergovernmental Panel on Climate Change (IPCC)

FIGURE 1

Surface ozone concentrations over North America

Surface ozone concentrations over North America during July are projected under an Intergovernmental Panel on Climate Change's scenario to increase between the years (a) 2000 and (b) 2030. Values are in parts per billion; mean value is 28.1 ppb in 2000 and increases to 32.6 ppb by 2030.



quantified the impacts of a wide range of radiative forcing agents, including greenhouse gases and aerosols, and other forcing mechanisms. The panel found that, after carbon dioxide (CO_2) and methane (CH_4), O_3 is the most important driver of human-induced climate change through 2100 (*1*).

In this viewpoint, we review the IPCC findings, look at how O_3 forms, and describe how understanding weather systems is important to predicting the pollutant's global transport.

Activity in the troposphere

O_3 is not emitted directly into the atmosphere but is instead formed in situ by chemical reactions driven by sunlight, which involve the oxidation of carbon monoxide (CO), CH_4, and organic compounds in the presence of NO_x. O_3 is present throughout the atmosphere, but it contributes most to global warming in the lower atmosphere—mainly in the middle and upper troposphere in the 5–15-kilometer altitude range—because this region is one of the coldest in the atmosphere.

Because CO, CH_4, organic compounds, and NO_x have important anthropogenic sources, emissions of these O_3 precursors are expected to continue to grow following the scenarios outlined in the IPCC assessment (*1*). The elevated O_3 produced in the cold regions of the middle and upper troposphere will thus induce additional global warming. Because the United Nations Framework Convention on Climate Change does not include O_3 in its basket of greenhouse gases, no global-scale emission controls are envisioned to address its buildup.

A surprising conclusion from the IPCC analysis is that surface O_3 concentrations are also expected to increase through the year 2100 (*1*). Surface O_3 concentrations during the summer months over the continental landmasses currently average about 30–40 parts per billion (ppb). In two of the emission scenario families outlined by IPCC (*2*), the corresponding values become 45–50 ppb in 2030, 60 ppb in 2060, and 70 ppb in 2100 (*1*). These concentrations are well above the internationally accepted environmental criteria values set at about 40–50 ppb to protect human health, sensitive crops, and vegetation (*3*). This prediction covers the entire continental northern hemisphere, despite the strenuous measures being taken to improve urban- and regional-scale O_3 air quality in North America and Europe. The O_3 level predictions in the other IPCC scenarios are not as bleak in each scenario family, but they project increased levels of tropospheric O_3 (*1*). Indeed, of the 10 scenarios considered by the IPCC, only one had O_3 decreasing below present-day levels (*1*).

Understanding the mechanisms

The mechanisms and processes leading to the anticipated increase in the middle and upper tropospheric O_3 concentrations have steadily been unraveled. Because of low water vapor concentrations in the upper troposphere, ultraviolet photolysis is a

relatively inefficient O_3 destruction process. Therefore, O_3 lifetimes exceed one to two months. Ozone becomes relatively well mixed in the atmosphere around latitude circles at this altitude, so any perturbation arising from human activities rapidly spreads to global proportions. Moreover, with little destruction, O_3 production can proceed with relatively low NO_x concentrations (*4*).

In the upper troposphere, NO_x and hence, O_3 production is controlled by aircraft emissions, convective updrafts bringing biomass burning emissions from the surface, lightning, and downward stratospheric injection (*5*). Human influences grow with increasing aircraft emissions and larger surface and biomass burning emissions through convection. In this context, the rapidly increasing NO_x emissions from Asia have particular significance for surface air quality in the western United States (*6*).

Although the mechanisms underpinning the future global-scale increases of middle and upper tropospheric O_3 have been straightforward to unravel, those involved with the increase in future surface O_3 over the northern hemisphere continents have not. Figures 1–3 present surface O_3 concentrations for the years 2000 and 2030 over North America, Europe, and Asia under the same IPCC scenario. These model surface O_3 concentrations were derived from one example study using the STOCHEM model (*7*) and were included in the IPCC Third Assessment report (*1*).

The moral is that O_3 is not transported efficiently at the surface, but it is in the upper troposphere.

The predicted increases in continental surface concentrations contrast the nearly constant levels over the oceans. Although elevated O_3 concentrations are often found in air masses flowing out of the continents and into oceanic regions during summertime, the levels rapidly decrease as the polluted air masses travel out over the coastline because of NO_x's short lifetime. With increasing travel time, O_3 production rapidly turns into O_3 destruction.

If the predicted increased surface O_3 concentrations over North America had been driven by the growth in Asian emissions, then this could not have involved increased intercontinental O_3 transport at the surface because the pollutant is destroyed over the Pacific Ocean. Similarly, O_3 destruction over the North Atlantic Ocean would hinder intercontinental transport at the surface from North America to Europe.

FIGURE 2

Surface ozone concentrations over Asia

Surface ozone concentrations were (a) measured during July in 2000 and (b) predicted under an Intergovernmental Panel on Climate Change's scenario for 2030. Values are in parts per billion; mean value is 33.7 ppb in 2000 and 41.0 ppb by 2030.

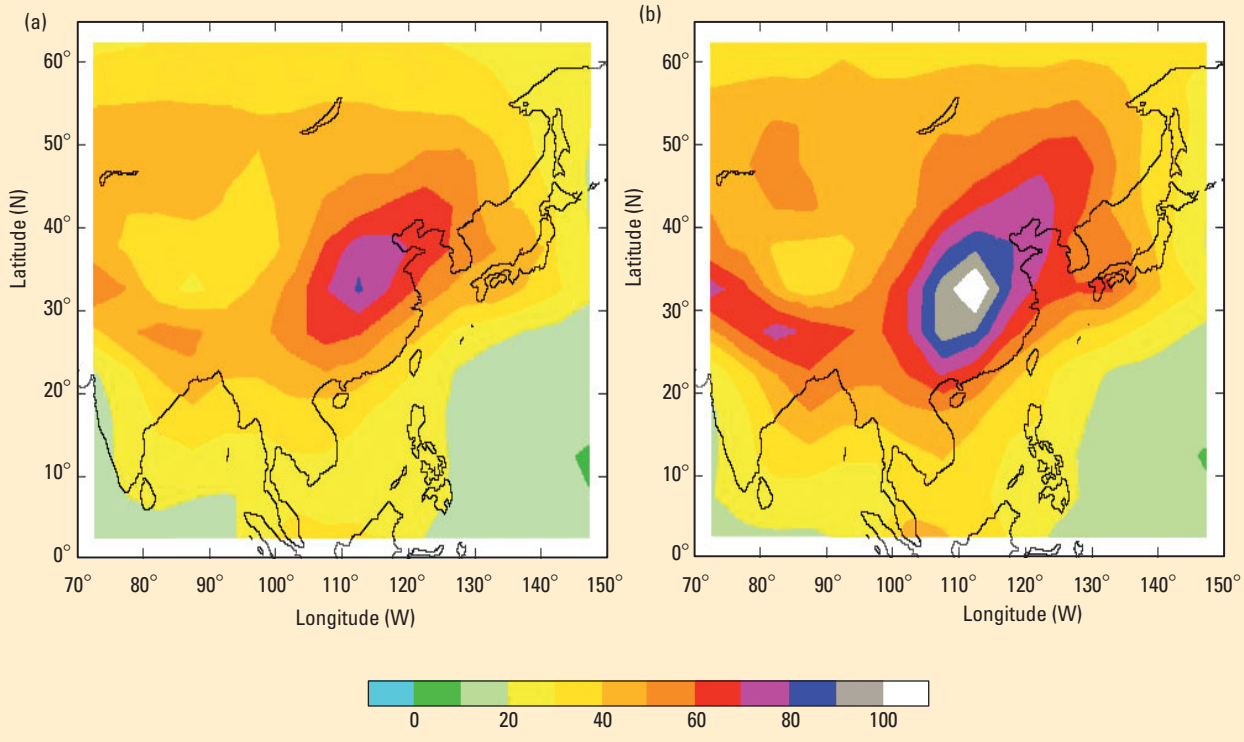
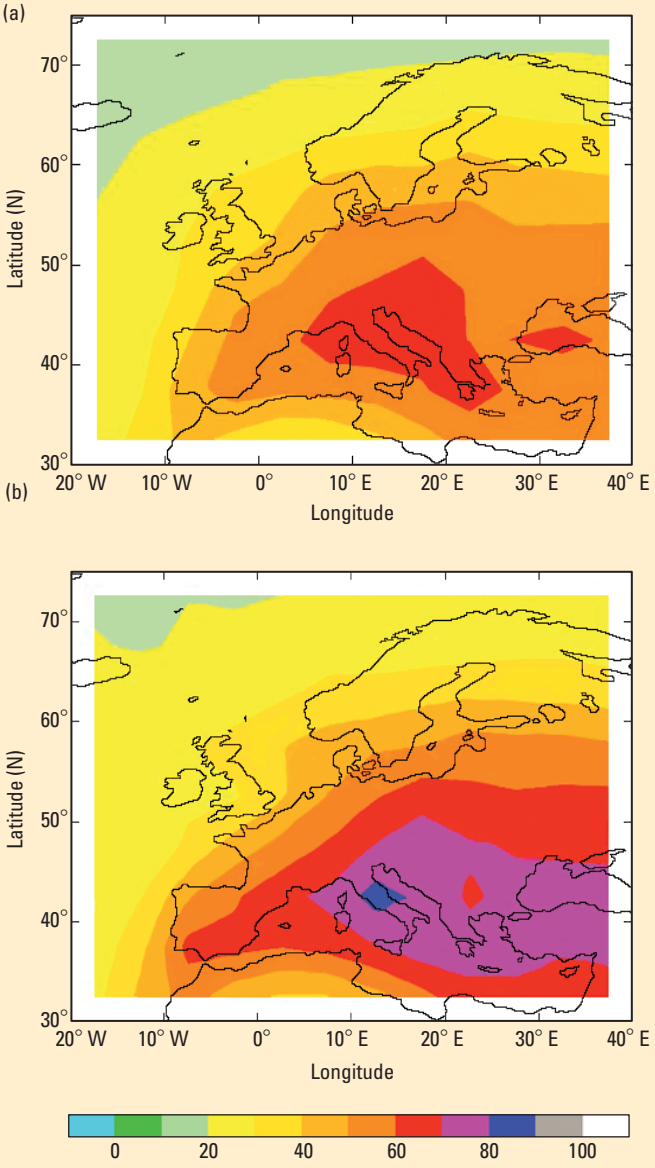


FIGURE 3

Surface ozone concentrations over Europe

Under an Intergovernmental Panel on Climate Change's scenario, Europe will experience the highest July ozone levels, with steadily rising values beginning in the year (a) 2000 through (b) 2030. Values are in parts per billion; mean value is 42.4 ppb in 2000 and 48.6 ppb in 2030.



So, the moral is that O_3 is not transported efficiently at the surface, but it is in the upper troposphere.

The weather connection

The mechanisms underpinning the potential increases in O_3 concentrations in Figures 1–3 are intimately connected to understanding intercontinental transport. Transport of O_3 is efficient and well understood in the upper troposphere, with transit times around latitude circles at this altitude on the order of several days. Convective processes in tropical and midlatitude regions are important in lofting NO_x into the middle and upper troposphere (*8*). Once there, one molecule of NO_x can catalyze the formation of many O_3 molecules during its lifetime.

Weather systems and their associated fronts in midlatitudes provide another vehicle for transporting surface-emitted pollutants to the middle and upper troposphere (*9*). But the missing element has been the meteorological processes that bring upper tropospheric air laden with O_3 down to the land surfaces. These processes may, in turn, involve convection and the large-scale weather systems that fill midlatitude areas of the troposphere. If the IPCC scenarios are correct that human activities do increase upper tropospheric O_3, a global-scale pool of the pollutant will grow and this, in turn, will increase surface O_3 concentrations in all the northern hemisphere continents through the cycle of constantly changing weather patterns.

Problems associated with these O_3 increases are more directly relevant to long-term exposure levels for crops and vegetation rather than to humans, for whom short bursts of ozone in pollution episodes are more relevant. However, urban- and regional-scale pollution episodes are built on top of these global baseline values. Thus, future increases in tropospheric O_3 may work against regional pollution control strategies designed to reduce exposure levels for both humans and vegetation.

Acknowledgments

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