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Review

Air quality progress in North American megacities: A review

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ABSTRACT

Air quality progress in the North American megacities of Los Angeles, New York, and Mexico City is reviewed, compared, and contrasted. Enormous progress made in North America over the last 5 decades provides a template for other megacities of the world, especially in developing countries, attempting to achieve rapid economic growth without compromising air quality. While the progress to date has been impressive, many challenges remain including the need to improve air quality while simultaneously mitigating climate change. The impact of pollutant emissions from megacities is felt long distances away from the local sources but no policy mechanisms currently exist to mitigate air quality impacts resulting from such pollution transport.

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1. Introduction

Over the last 50 years, the world's urban population has grown faster (2.7% yr^{-1}) than the total population (1.8% yr^{-1}) and is estimated to reach 5 billion by 2030. For the first time in human history the world now has more urban than rural residents with many environmental consequences (Crutzen, 2004; Bell et al., 2007). An offshoot of this rapid urbanization is the emergence of megacities (population >10 million) with a combined worldwide population of nearly 300 million. Megacities are dense centers of population, economic activity, and pollutant emissions and at the same time areas where effective pollution control strategies could realize maximum benefit (Molina and Molina, 2004; Gurjar and Lelieveld, 2005; Chan and Yao, 2008). By 2015 eight of the ten largest megacities will be in developing countries. Here we review and assess the progress in achieving cleaner air that has been made in the megacities of North America with the hope that lessons learned in North America will be valuable in achieving air quality goals in the developing world undergoing rapid economic growth.

North American megacities include Mexico City, perhaps the second largest metropolitan area in the world, and Los Angeles and New York City in the United States, two of the ten largest metropolitan areas. Differences in topography, meteorological conditions, and pollutant emission characteristics lead to marked differences in the air quality considerations in these megacities as well as their impacts on the larger troposphere. This review discusses these differences, as well as similarities. The greater Houston, Texas urban area in the United States is also discussed as an additional contrast; with a population approaching 6 million, this area is not generally considered a megacity, but it is a large urban center of particular interest since it is home to a large fraction of the petrochemical industrial facilities of the United States, which leads to a unique mix of anthropogenic emissions.

2. Los Angeles megacity: an environmental success story

The Los Angeles megacity, here defined as the South Coast Air Basin (SoCAB), is located at 34°3′N and 118°14′W with a population approaching 17 million inhabitants. Summertime photochemical smog was first recognized as a severe environmental problem in Los Angeles and has been the subject of extensive air pollution control efforts since the 1950's (Haagen-Smit, 1952; Cox et al., 2009). California was the first to set motor vehicle emission standards in 1966 and has led the nation in enforcing policies requiring catalytic converters in cars, cleaner unleaded fuels, and zero emission vehicle fleets. Between 1970 and the present, SoCAB VOC and NO_x emissions have declined markedly despite a substantial increase in commerce and vehicle traffic (Cox et al., 2009). Peak O_3

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levels that exceeded 600 ppbv in the 1960's have not reached 200 ppbv since 1998. First stage smog alerts have been reduced from some 200/year in 1970s to about 10/year today. SoCAB is an excellent example for the benefits of implementing emission control strategies in a growing megacity that can be followed in many parts of the developing world.

The improvement in air quality has been accomplished despite several unfavorable conditions that make SoCAB particularly susceptible to high air pollution concentrations. The large population lives in a basin bounded by the Pacific Ocean on the west and by mountains on the other three sides, which prevent efficient horizontal ventilation of the area. Low inversion heights associated with a persistent high pressure system and the adjacent Pacific marine environment limits the vertical mixing within the basin, and the land-sea breeze system re-circulates polluted air within the basin. These topographic and meteorological features allow emissions to accumulate over several days during episodes of relatively stagnant airflow. During the summer ozone season, May through October, clear skies and high temperatures dominate, which speed photochemical production of O_3 and other photochemical products. Private automobiles on extensive freeway systems provide the primary transportation in the area. This transportation system accounts for a large fraction of the emissions in the urban area. Technological solutions involving the development of catalytic converters and more efficient car engines along with the implementation of better traffic management systems have been central to the success of air pollution control strategies.

2.1. *Air quality trends*

Over the past four decades ambient concentrations of key pollutants in the SoCAB region have decreased substantially despite a doubling of the population and tripling of vehicle use. Fig. 1 compares the temporal trends of four pollutant concentrations. These data are presented in units that correspond to U.S. EPA National Ambient Air Quality Standards (NAAQS) [http://www.epa.gov/air/criteria.html], which are presently: O_3 – 75 ppbv (8-hr); CO – 9 ppmv (8-hr); NO_2 – 53 ppbv (1-yr); $PM_{2.5}$ – 35 μg/m^3 (24-hr); SO_2 – 75 ppbv (1-hr); Pb – 1.5 μg/m^3 (3-mo). The numbers in parentheses give the averaging period. The O_3 data are 3-yr averages of the 4th highest annual maxima, the CO data are annual maxima, and the $PM_{2.5}$ are annual 98th percentiles. It is

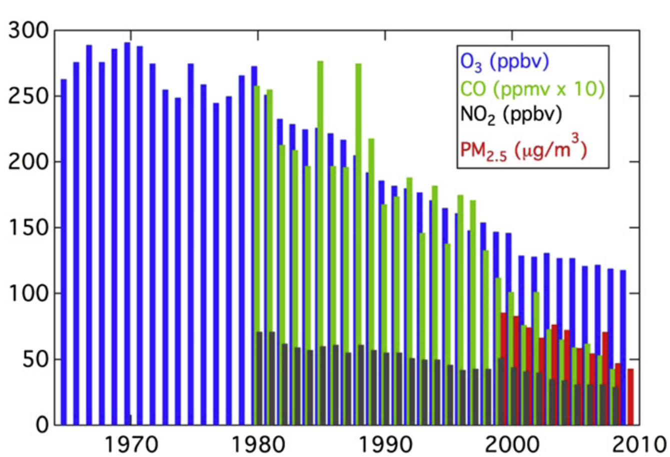

Fig. 1. Air quality trends in the Los Angeles urban area of California. As per national standards, the O_3 data (8-h average) are 3-yr averages of the 4th highest annual maxima, the CO data (8-h average) are annual maxima, the NO_2 data are annual averages, and the $PM_{2.5}$ data (24-h average) are annual 98th percentiles. Data are derived from monitoring stations in the SoCAB region (Alexis et al., 1999; Cox et al., 2009; http://www.arb.ca.gov/adam/cgi-bin/db2www/polltrendsb.d2w/Branch).

evident that there has been an impressive decline in ozone concentrations as well as other air pollutants over the nearly five decades of pollutant monitoring. Although it still violates the NAAQS for O_3 and $PM_{2.5}$, the Los Angeles basin is in compliance with the NAAQS for nitrogen dioxide, carbon monoxide, sulfur dioxide, and lead. It is fair to say that this megacity has gone from being one of the most polluted in the world 50 years ago to presently one of the "least polluted" cities of its size. Estimates are that many thousands of lives have been saved from improvements in air quality (Hall et al., 2008).

The relative temporal trends of the primary pollutants, NO_2 and CO, reflect the history of the air quality control strategy adopted in the United States. Initially, the control focus was upon VOCs and CO, notably including the introduction of catalytic converters on automobiles in the mid-1970s. The focus later shifted to include NO_x emission controls. Fig. 1 shows that this control emphasis has led to a significantly larger decrease in ambient CO concentrations (factor of 5.2) than that for the ambient NO_2 concentrations (factor of 2.3) from 1980 to 2008. SO_2 emissions have also decreased substantially over the last three decades, primarily due to reduced sulfur content of fuels utilized in mobile (as of 2006 15 ppm by mass for on-road diesel) and point sources, and to scrubbing of sulfur from flue gases emitted by point sources.

It is important to recognize that significant problems remain. The region still violates the ozone standard and indeed despite continued emission reductions little improvement in O_3 air quality has been observed since 2000. During 2005–2008 the 8-h O_3 exceeded the NAAQS on 110–120 days each year. The current peak O_3 levels are roughly double the accepted levels set to protect the most vulnerable populations. Several difficulties exist in achieving air quality goals. Due to the extremely non-linear nature of VOC–NO_x–O_3 chemical system, it is possible that VOC/NO_x ratios over time have shifted to a regime where further VOC reductions are only minimally effective (Sillman, 1999). There is also evidence to support the view that background O_3 concentrations transported into California constitute a significant fraction of the NAAQS, and are increasing, possibly in response to increasing Asian emissions of O_3 precursors (Parrish et al., 2009a, 2010). Such an increase can negate some of the local pollution control progress (Jacob et al., 1999; Lin et al., 2008). Controlling emissions from heavy-duty diesel trucks has been far more difficult than passenger cars as the turnover time for this fleet (25–30 years) greatly exceeds that for the passenger fleet (7–10 years). A relatively small fraction of the total motor vehicle fleet, currently 10 million vehicles in the Los Angeles basin, accounts for a very large fraction of the total mobile source emissions. A related problem is the emergence of the ports of Los Angeles and Long Beach as dominant point sources of diesel-related pollution in the Los Angeles Basin due to a tripling of goods movement from Asia through these ports over the past 15 years. Future progress is anticipated from a greater use of plug-in hybrids, electric cars, alternate fuels and better control technology. Current targets call for on-road emission reductions of VOC, NO_x, SO_x, and $PM_{2.5}$ by respectively 70%, 70%, 50% and 12% between 2007 and 2020 (Cox et al., 2009).

2.2. *Air quality and climate change*

Megacities contribute significantly to the burden of Green House Gases (GHGs) in the atmosphere. In the past, air quality control strategies have been based largely on health implications with little consideration for the associated climate change consequences. An added complication for future control strategy development is the need to mitigate climate change impacts while improving air quality (Bell et al., 2007). Although uncertainties remain, a warmer climate, with increasingly hotter days, is also