Air quality, weather and climate in Mexico City

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The Mexico City Metropolitan Area (MCMA) is one of the world's largest megacities with an estimated 20 million inhabitants living on the dried bed of the elevated lake Texcoco and its surroundings. The inland basin is at an altitude of 2 240 msl and is surrounded on three sides by mountains and volcanoes, with an opening to the Mexican Plateau to the north and a mountain gap to the south-east. With a diameter of around 50 km and limited room for expansion, MCMA has a high density of population as well as of industrial and commercial activities (Figure 1). It represents around 20 per cent of Mexico's population and 9 per cent of its greenhouse gas emissions, with emissions of 60 million tonnes of carbon dioxide equivalent per year.

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Figure 1 — Aerial photo of Mexico City

Air quality management strategies and trends

During the 20th century, Mexico City experienced a huge increase in population and urbanized area as it attracted migrants from other parts of the country and industrialization stimulated economic growth (Figure 2). Population growth, increasing motorization and industrial activities, a constrained basin and intense solar radiation combined to cause intense air-quality problems of both primary and secondary pollutants. The automatic air-quality monitoring network, established in the late 1980s, revealed high concentrations of all criteria pollutants: lead, carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone and particulate matter (PM). Ozone exceeded the air quality standards more than 90 per cent of days and peaked above 300 parts per billion (about three times the standard) 40-50 days a year, among the worst in the world (Molina and Molina, 2002).

Both the Mexican Government and the citizens of Mexico City have recognized air pollution as a major environmental and social concern since the mid-1980s. In the 1990s, comprehensive air quality management programmes were developed and implemented. Specific actions included removal of lead from gasoline and the implementation of catalytic converters in automobiles, reduction of sulphur content in diesel transportation fuel;

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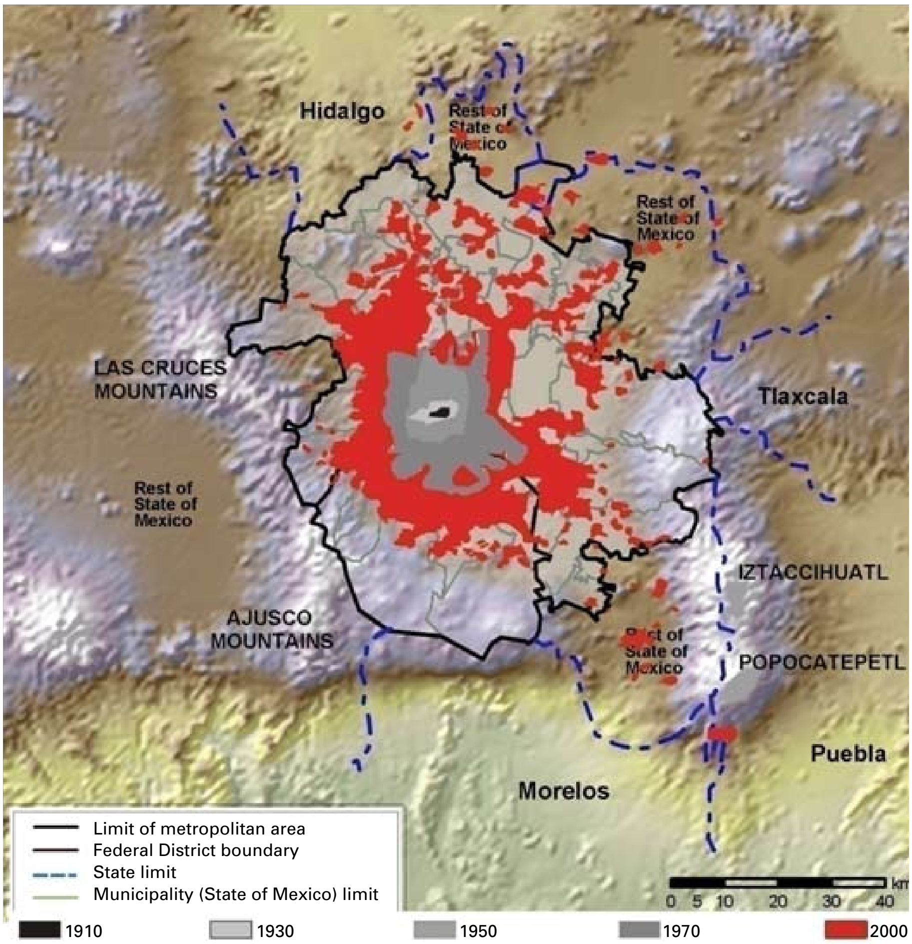


Figure 2 — Topographical map of the Mexico City Metropolitan Area showing urban expansion

substitution of fuel oil in industry and power plants with natural gas; reformulation of liquified petroleum gas used for heating and cooking. The government also strengthened the vehicle inspection and maintenance programme; vehicles were required to be inspected in a centralized system and more frequent inspections were required for higher emitting vehicles as incentives to promote fleet turnover and help ensure the proper maintenance of vehicles. In addition, the "no driving day" (*Hoy no circula*), which stopped private vehicles from circulation one day a week, have been effective in modernizing the vehicle fleet by exempting low-emitting vehicles from the "no driving day" rule.

As a result of these regulatory actions, combined with technology change, concentrations of criteria pollutants have been decreasing over the past decade, despite the continuing increase in population and economic activity (Figure 3). Mexico City's levels for particulate matter and ozone, however, still exceed standards recommended by the World Health Organization.

The Metropolitan Environmental Commission (CAM), an interagency body that consists of environmental authorities in federal government, the State of Mexico and the Federal District was created in the mid-1990s to coordinate the policies and programmes that are implemented in the metropolitan area. The current air-quality management programme, PROAIRE 2002-2010, includes a series of new measures to further improve air quality and calls for more extensive observation data to improve the MCMA emissions inventory (Molina and Molina, 2002; CAM 2002). A large field measurement campaign, supported by CAM, was carried out in 2003 (Molina et al., 2007). In 2006, Mexico City was selected as the case study of MILAGRO (Megacity Initiative: Local And Global Research Observation), an international scientific project to investigate the outflow of emissions from a megacity (Molina et al., 2008). These field studies have provided comprehensive datasets for updating and improving the emissions inventory, the chemistry, dispersion and transport processes of the pollutants emitted to the MCMA atmosphere and their regional and global impacts.

One of the important PROAIRE 2002-2010 measures is in the transportation sector, the most important source of pollutants emitted to the MCMA atmosphere. Mexico City has recently adopted the bus rapid transit system, designed initially in the city of Curitiba, Brazil, and successfully adopted in Bogotá, Colombia, where prime road space was allocated to low-emission, high-capacity buses. A recent study conducted by researchers at INE/SEMARNAT showed that commuters' exposure to carbon monoxide, hydrocarbons and particulate matter was reduced by about 50 per cent when the popular 22-seater gasoline minibuses were replaced by modern diesel buses (Metrobus) running in a confined or dedicated lane (Wöhrnschimmel et al., 2008). This study corroborated Bogotá's findings that the bus rapid transit system can simultaneously reduce criteria pollutant and greenhouse-gas emissions, commuters' exposure levels and travel time.

The Government has also increased its efforts to encourage public participation and stakeholder input. Information on air-quality levels and new initiatives are available on line (www.sma.df.gob.mx/simat/) and published in news media.

Meteorology

Aside from air pollution, the Mexico City Metropolitan Area has an ideal climate: a cool dry season from November to February, followed by

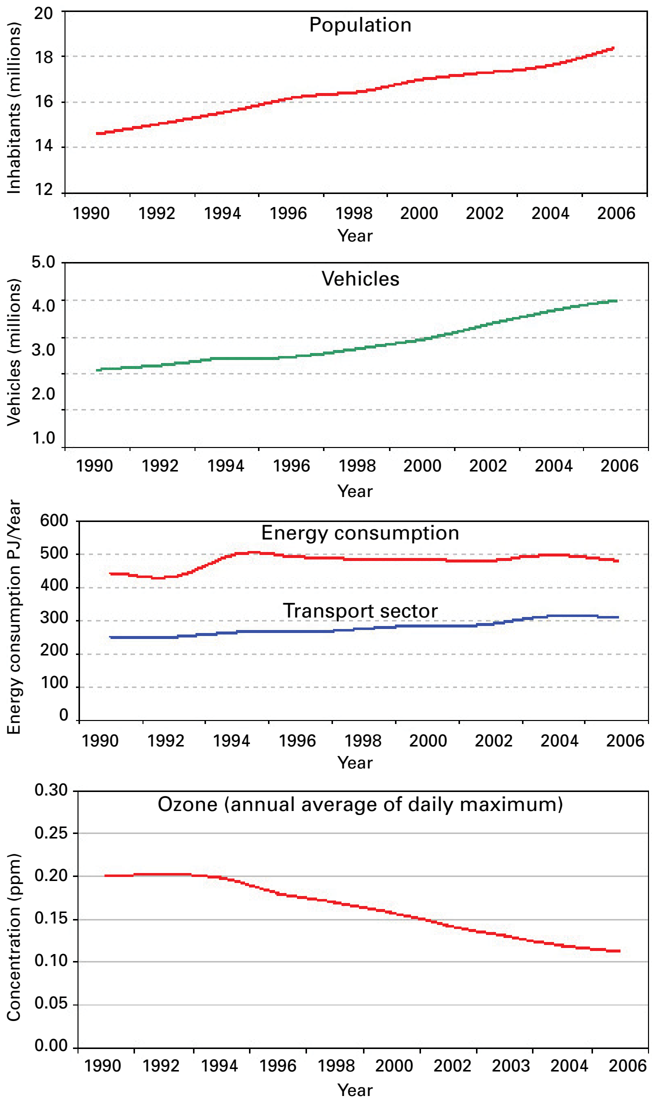


Figure 3 — Trends in population, vehicular fleet, energy consumption and ozone concentration in the Mexico City Metropolitan Area (1990-2006)

a warm dry season until April and a rainy season from May to October. Temperatures are moderate and humidity is low. With mountain shielding on most sides, winds are weak inside the basin. In terms of air pollutants, the cool season has strong surface inversions and higher peaks of primary pollutants in the morning. The warm season has more ultraviolet radiation and hence more smog. Drier conditions cause increased aerosol loadings due to dust and biomass burning. The rainy season has lower PM_{10} and carbon monoxide but continues to have high ozone due to intense photochemistry before the afternoon showers. Air quality is therefore a year-round concern.

Part of the problem lies with meteorology. Weak winds and strong temperature inversions at night lead to high primary pollutant concentrations during rush hour and into the morning. Being at low latitudes (20°N), synoptic forcing is weak and the weather is strongly influenced by the mountain-valley winds in the basin. A typical warm-season circulation starts with weak drainage winds into the basin. This is followed by very rapid boundary layer growth to maximum heights of 2-4 km in the early afternoon. A gap flow enters the basin from the south-east and creates a convergence line across MCMA (see Figure 4). The timing of the gap flow determines the location and magnitude of maximum ozone concentrations (de Foy et al., 2008).

With such weak winds and intense smog, it is tempting to compare MCMA with Los Angeles. In Los Angeles, stable high-pressure systems with subsidence aloft lead to multi-day accumulation of pollutants and peak smog episodes. In MCMA, simulations of particle trajectories show that the rapid growth of the boundary layer leads to efficient vertical mixing. When the convergence line moves north-east, the air mass is vented from the basin by the winds aloft. There is therefore limited recirculation and day-to-day carry-over in the basin. In fact, MCMA is more similar to Houston, where a polluted airmass is vented out to sea in the morning and transported back over the city by the afternoon sea breeze (Banta et al., 2005).

From the climate point of view, a 100-year time series of temperature from the meteorological observatory shows a slight decrease in the first half of the century followed by a marked increase up to the present of 2 to 4 °C. There has also been an increase in the number and duration of heat waves in MCMA. Modelling studies of land use change suggest that up to three quarters of this may be attributed to the urban heat island and the remainder to climate change. Studies of the urban heat island show that it may interact with the mountain-valley winds and influence night-time drainage flows and afternoon ventilation.

Rainfall had an even more pronounced trend over the last century than temperature (see Figure 5). Annual rainfall at the observatory has increased by 50 per cent. Whereas there used to be 0-3 days per year with extreme events (> 30 mm/day) at the beginning of the century, there are routinely 5 to 10 days per year in more recent decades. It is still unclear how much of the change can be attributed to the urban heat island and how much to climate change.

Climate Change Action Plan

The MCMA's Climate Change Action Plan (Acción Climática), designed for 2008-2012, consists of 26 emission-reduction measures, 12 adaptation measures and six communication and education measures with a total

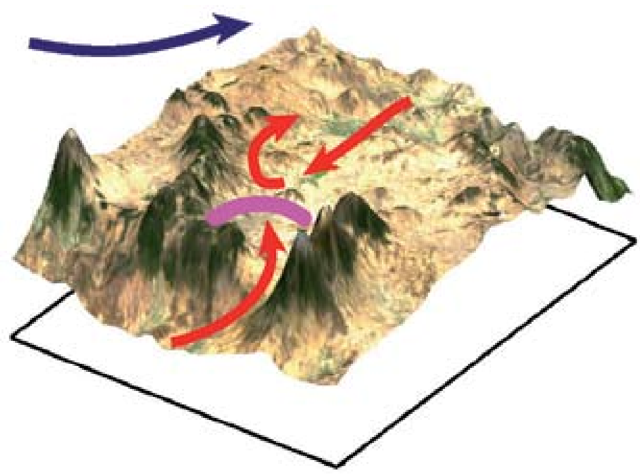


Figure 4 — Conceptual circulation model for a warm-season day. Surface winds from the north meet the gap flow from the south (red) and form a convergence line (pink). Vertical mixing leads to basin venting due to westerlies aloft (blue). MODIS true colour image projected on terrain elevation model (vertical scale exaggerated).

budget of nearly US$ 5.955 billion. It was initiated with World Bank support, developed with analysis of costs, benefits, barriers and impacts and concluded with public consultation and consensus-building between 32 governmental organizations. The aim is to reduce greenhouse-gas emissions by 7 million tonnes of carbon dioxide equivalent for the period from 2008 to 2012 and to have an adaptation plan ready for 2012.

The largest emission-reduction measures are for biogas capture projects and waste-management projects. Next come the transportation sector with public transport for school children, a new Metro (subway) line, up to 10 new Metrobus lines and special transport corridors. These are complemented by fleet renewal projects for taxis and medium-capacity buses, inspection and maintenance measures and modernization of fleet transfer and renovation stations. In the residential sector, efficient lighting for homes is particularly cost-effective. Additional measures will address residential energy and water use and sustainable housing development. Energy efficiency will be promoted through targeted projects in government agencies and public utility sectors. Further measures include renewable energy generation projects and recycling centres.

Adaptation to increased rain and extreme events will consist of improved flood management by developing flood gates and alert systems. Rural development projects will promote soil and water conservation, reforestation and crop protection projects. These will further include monitoring of genetically modified crops, promotion of organic agriculture, planting of climate- change-resistant tree species and the promotion of green roofs. Adaptation to increased temperature will focus on remote-sensing and monitoring of forest fires and an epidemiological monitoring system for vulnerable populations.

Education and communication projects include a permanent education program for climate change, education for resource-efficient housing, water conservation, public understanding campaigns and integrated waste management campaigns. The focus is on raising awareness, understanding risks and promoting adaptation and mitigation measures.

Results to date include a "solar standard" being promoted for solar collectors for hot water provision. This has already been adopted by 30 per cent of swimming pools (6 957 m^2 installed) where it has a 1.5 year pay back period. Installation will continue with 6 500 new housing projects by 2012, as well as adoption by hotels and other commercial partners.

The Metrobus system is a resounding success with one of the most highly used lines in the world carrying 265 000 passengers per day. This is the first project in the world to sell emission reductions as part of its financing. For the period from 2005 to 2007, there was reduction of about 67 400 tonnes carbon dioxide equivalent, which sold for 281 600 euros. New lines are being developed and 10 new transport corridors will be installed by 2012 leading to a reduction of 369 500 tonnes of carbon dioxide equivalent along with an improved urban environment.

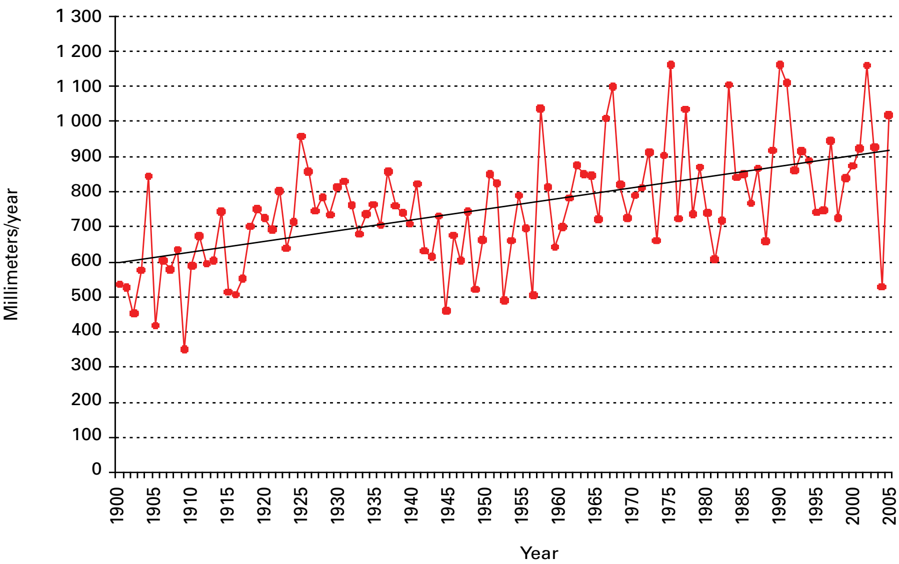
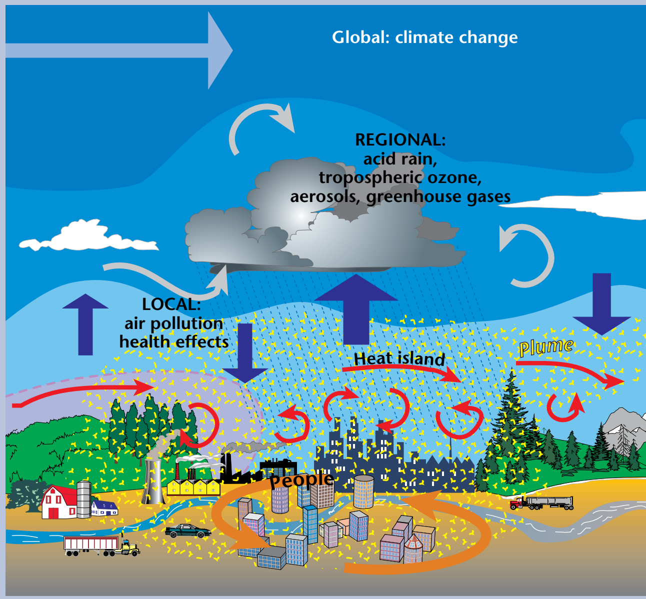


Figure 5 — Historical trends in rainfall at one meteorological observatory in MCMA

Urban meteorology research



WMO Members reacted to the needs to develop meteorological and environmental capabilities in urban areas by establishing the Global Atmosphere (GAW) Urban Research Meteorology and Environment (GURME) project in 1999. The interest arose from the difficulties countries were facing from growing urbanization and related air pollution problems.

Several projects have been undertaken under GURME to assist and facilitate related research activities and consequently in establishing urban applications. These projects include such activities as:

- Studies to understand the formation of local atmospheric pollution;
- Heat island studies;
- Designing, establishing and enhancing both meteorological and air pollution measurement networks;
- Building air-quality modelling and forecasting systems and services;
- Training and capacity-building for air-quality modelling and forecasting;
- Studies on the impact the urban area has on regional air quality;
- Building Web-based communication systems for informing authorities and the public on special weather conditions (such as ice, snow, smoke and haze) and on air pollution.

GURME has concentrated its efforts on air-quality modelling and forecasting—activities needed to support effective environmental management on the urban scale. Expert meetings are conducted to gather up-to-date information on new methods for chemical weather forecasting and to help identify future research needs to improve the forecasts. Training has been offered to Latin American and South Asia regions. Both research and operational sectors have come together in these events.

GURME involves cooperation between organizations and agencies acting in different fields. Working in concert with different authorities is important for the successful carrying-out of the studies, implementation of activities and fostering of improved prevention strategies.

GURME also engages collaboration that extends to regional and global scales. There is growing appreciation that accurately forecasting chemical weather requires consideration of the influence of pollution sources from larger-scale phenomena (such as duststorms and forest fires). The multiscale nature of the issues addressed in GURME necessitate and facilitates collaboration across scales.

Conclusions

Mexico City has been working on improving air quality for a number of years. Much progress has been made in tackling air-pollution problems through comprehensive air-quality management programmes based on scientific, technical, social and political considerations. Yet continuing pressure from increasing urban population and the desire of people to have a better quality of life causes an ongoing need to improve air quality.

The Government has also taken actions to mitigate greenhouse-gas emissions. The aim of the plan is to promote "no-regrets" policies that are beneficial even in the absence of climate change. The plan also seeks to focus on "win-win" strategies that promote social development at the same time as environmental benefits.

There are substantial air-quality co-benefits to mitigating climate change. Integrated assessments evaluating co-benefits of coordinated air pollution and climate mitigation efforts have been conducted for Mexico City. An examination of four megacities (Mexico City, New York City, Santiago de Chile, and São Paulo) by Cifuentes et al. (2001) indicated that greenhouse-gas mitigation would lead to large reductions in ozone and particulate matter concentrations with substantial resulting improvements in public health. McKinley et al. (2005) found that five proposed control measures in Mexico City, estimated to reduce annual particle exposure by 1 per cent and maximum daily ozone by 3 per cent, would also reduce greenhouse gas emissions by 2 per cent for both periods 2003-2010 and 2003-2020. Another study showed that if the current air-quality management programme (PROAIRE 2002-2010) for Mexico City were implemented as planned, they would result in a reduction of 3.1 per cent of projected carbon dioxide emissions in 2010, in addition to substantial local air-pollutant reductions (West et al., 2004). It is therefore important to integrate air-quality and climate-stabilization goals in the design of environmental policy to realize potential synergistic benefits.

References

Banta, R.M., C.J. Seniff, J. Nielsen-Gammon, L.S. Darby, T.B. Ryerson, R.J. Alvarez, S.R. Sandberg, E.J. Williams and M. Trainer, 2005: A bad air day in Houston, *Bul. Amer. Meteoro. Soc.*, 86: 657-669.

Cifuentes, L., V.H. Borja-Aburto, N. Gouveia, G. Thurston and D.L. Davis, 2001: Climate change: hidden health benefits of greenhouse gas mitigation, *Science*, 293, 1257-1259.

De Foy, B., J.D. Fast, S.J. Paech, D. Phillips, J.T. Walters, R.L. Coulter, T.J. Martin, M.S. Pekour, W.J. Shaw, P.P. Kastendeuch, N.A. Marley, A. Retama and L.T. Molina, 2008: Basin-scale wind transport during the MILAGRO field campaign and comparison to climatology using cluster analysis. *Atmos. Chem. Phys.*, 8:1209-1224.

CAM, 2002: Programa para Mejorar la Calidad del Aire en el Valle de México 2002-2010, Comisión Ambiental Metropolitana, Mexico.

McKinley, G., M. Zuk, M. Hojer, M. Ávalos, I. González, R. Iniestra, I. Laguna, M.A. Martínez, P. Osnaya, L.M. Reynales, R. Valdés and J. Martínez, 2005. Quantification of local and global benefits from air pollution control in Mexico City. *Environ. Sci. Technol.*, 39, 1954-1961.

Molina, L.T. and M.J. Molina (Eds.), 2002: *Air Quality in the Mexico Megacity: An Integrated Assessment*, Kluwer Academic Publishers.

Molina, L.T., C.E. Kolb, B. de Foy, B.K. Lamb, W.H. Brune, J.L. Jimenez, R. Ramos-Villegas, J. Sarmiento, V.H. Paramo-Figueroa, B. Cardenas, V. Gutierrez-Avedoy and M.J. Molina, 2007: Air quality in North America's most populous city—overview of the MCMA-2003 campaign, *Atmos. Chem. Phys.*, 7, 2447– 2473.

Molina, L.T., S. Madronich, J.S. Gaffney and H.B. Singh, 2008: Overview of MILAGRO/INTEX-B Campaign, *IGAC Newsletter*, 38, 2-15.

West, J., P. Osnaya, I. Laguna, J. Martínez and A. Fernández-Bremauntz, 2004: Co-control of urban air pollutants and greenhouse gases in Mexico City. *Environmental Science and Technology*, 38:3474-3481.

Wöhrnschimmel, H., M. Zuk, G. Martínez-Villa, J. Cerón, B. Cárdenas, L. Rojas-Bracho and A. Fernández-Bremauntz, 2008: The impact of a rapid bus transit system on commuters' exposure to benzene, CO, $PM_{2.5}$ and PM_{10} in Mexico City. *Atmospheric Environment* (in press).