It is time for a new intensive air quality field campaign in Mexico City

Erik Velasco[1], Armando Retama[2], Miguel Zavala[3], Marc Guevara[4], Bernhard Rappenglück[5], Luisa T. Molina[3]

[1] Independent Research Scientist, Singapore 118719, Singapore.
[2] Independent Research Scientist, Mexico City 11800, Mexico.
[3] Molina Center for Energy and the Environment, La Jolla, CA 92037, USA.
[4] Earth Sciences Department, Barcelona Supercomputing Center, Barcelona 08034, Spain.
[5] Department of Earth and Atmospheric Sciences, University of Houston, Houston, TX 77204, USA.

Corresponding author: Erik Velasco (evelasco@mce2.org)

Key Points:

- Intensive field measurement campaigns are needed to support air quality policies.
- The design of a focused intensive field campaign must be based on a set of policy-relevant questions.
- The cost of a comprehensive field study, for example in Mexico City, represents < 0.5% of the annual air pollution’s health-expenses.

Abstract

Cutting-edge science is needed to face the air quality threat posed by current urbanization under a changing climate, especially in cities from developing nations. Air quality policies based on scientific information have proved to be effective for controlling air pollution and protecting public health. Intensive field studies provide knowledge that combined to data from emission inventories and air quality monitoring allows to understand the causes that trigger air pollution and catalyze the design of effective control measures. We review the case of Mexico City, where past international collaborative studies were fundamental to improve air quality, but a null progress and a possible reversal to high air pollution levels in recent years suggest that a new dedicated field measurement campaign is urgently needed.

It has been over 14 years since the Megacity Initiative: Local and Global Research Observation (MILAGRO) 2006 field measurement campaign (Molina et al., 2010). MILAGRO was an international, multi-agency, collaborative initiative that involved more than 400 researchers to evaluate the local and regional air pollution impacts from a megacity (an urban area with population larger than 10 million). With over 21-million inhabitants, the Mexico City Metropolitan Area (MCMA) was selected as the case study, a megacity that has experienced annual economic growth (2.3-3.3 %; IMCO, 2017) and population increase (0.8 %; SEDATU et al., 2018) during the last decade, while overcoming severe air pollution.

Mexico City has robust infrastructure and air quality management tools. Its biannually updated emissions inventory, extensive air quality monitoring network and forecasting system to alert the public of high pollution events 24-hour in advance (http://www.aire.cdmx.gob.mx/) demonstrate how a megacity with limited resources can incorporate scientific information and air quality management tools to improve its air quality and protect the health of its inhabitants.

The atmospheric pollution of Mexico City has been probably one of the best-case studies among cities from developing nations. The MILAGRO campaign was conducted in March 2006 during the dry season, a period in which the worst air pollution episodes generally occur. High-pressure synoptic systems bring frequently clear skies and create atmospheric stability during this time of the year. The solar radiation is intense and enhances the photochemical activity, while the wind outflow is weak and promotes the pollutants accumulation within the basin (SEDEMA, 2018a). This is in contrast to days when the basin-mountain circulation ventilates the MCMA basin (2240 m a.s.l.) effectively (de Foy et al., 2006). Analysis of the comprehensive data obtained from the deployment of a wide array of state-of-the-art instrumentation within the urban core and boundary sites, and onboard instrumented research aircraft, together with the support of meteorological and chemical forecasting models, had improved significantly the understanding of the emission characteristics, and the physics and chemistry of the processes contributing to the formation of ozone (O_3), secondary aerosols and other pollutants, and the meteorological conditions favoring the accumulation of pollutants within the MCMA's basin. The scientific findings and policy implications provided the groundwork for the current air quality management program (PROAIRE 2011-2020; CAM, 2011). The program is expected to be updated in 2020 using new scientific information for its elaboration.

The information obtained from MILAGRO and two smaller previous studies, IMADA-AVER 1997 (Doran et al., 1998) and MCMA 2003 (Molina et al., 2007) provided the scientific basis to build the current air quality management program and formulate effective policies to control severe air pollution. Mexico City went from being one of the most polluted cities in the world during the eighties to become an example for other cities struggling to reduce pollution (Parrish et al. 2011). Current concentrations of criteria pollutants, such as sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and lead (Pb) are below the Mexican air quality standards for health protection (SEDEMA, 2018a). But secondary pollutants generated by atmospheric chemical reactions, such as O_3 and secondary particles, which constitute a significant fraction of particles smaller than 2.5 µm in size ($PM_{2.5}$), have not shown further reductions since about 2010 and are still above air quality standards (Molina et al., 2019). Similar to other urban areas in the world, after decades of important decreases in O_3, little additional progress has been achieved in recent years (e.g., Yan et al., 2018; Li et al., 2019). In addition, recent severe air pollution episodes suggest that the production of secondary pollutants may have started to rebound under an expanding urban sprawl (350 ha year^{-1} over a current urbanized area of 7866 km^2, Juárez-Neri and Pérez-Corona, 2019), increasing motorization trend (580,000 vehicles year^{-1} from 2005 to 2015, INEGI, 2019) and changing climate (Velasco and Retama, 2017; Osibanjo et al., 2020). Current environmental policies need to be redesigned to be more effective in reducing photochemical airborne pollution. Changes in emissions and atmospheric chemistry within and outside the MCMA's basin, coupled with meteorological flows induced by complex terrain, and likely modified by increasing built-up surface may contribute to the beginning of a possible reversal to high air pollution levels.

Air quality studies are needed to support emission-based control policies. However, since 2006 MILAGRO campaign relatively few field measurements and modeling studies have been conducted in the MCMA. In a recent review paper about MCMA's air quality management, Molina et al. (2019) found that new and updated scientific information is needed to efficiently address the current air quality challenges. In such context, a new focused intensive field campaign can help to understand the emerging drivers in the MCMA atmospheric physics and chemistry, and update or redesign current environmental air quality programs for attaining clean air.

The Megalopolis Environmental Commission (CAMe) was created in 2013 to coordinate efforts to address regional environmental problems in Mexico City and the contiguous municipalities of five surrounding states (Puebla, Tlaxcala, Morelos, Hidalgo and Mexico) (DOF, 2013). In concert with federal and state authorities, CAMe is in the process of enacting a new air quality management program in 2020 for the 16 townships of Mexico City and 60 contiguous municipalities that form MCMA. In the absence of updated scientific information on the local air pollution processes, the actions and policies outlined by the new air quality management program could be ineffective or even counterproductive. This suggests that a new dedicated field measurement campaign is urgently needed.

CAMe will have to make the best use of available scientific and technological knowledge to develop a set of policies to update and improve the current air quality program. The recommendations drawn from a workshop held in September 2018, sponsored by the Mexico City government and attended by local authorities, scientists and relevant stakeholders to evaluate the progress of the current air quality management program (SEDEMA, 2018b) could be used also as a basis to identify the scientific needs. Ideally, the new air quality management program should have a span no longer than five years. With the data obtained from a new dedicated field campaign during such period, the environmental authorities would be able to fill the knowledge gaps to develop effective policies responding to changes experienced in the city's atmosphere since MILAGRO.

The first year should be used to prepare a white paper for such intensive field campaign and invite the national and international scientific community to participate. Previous studies in Mexico City and other large cities have demonstrated that international collaboration is an effective way to promote the scientific research needed to understand the causes that trigger air pollution, and catalyze the design of effective control measures (e.g., APHH-Beijing, Shi et al., 2019; KORUS-AQ, Peterson et al., 2019; MEGAPOLI and PARTICULES, Beekmann et al., 2015).

The economic resources for the study should also be procured during the first year. MILAGRO had an approximated cost of 20-million US dollars, with large proportion provided by international sponsors, while the preceding and smaller study MCMA-2003 amounted to almost 3-million US dollars. Under the current financial scenario, a study of similar dimensions to MILAGRO might not be feasible, but a study of similar scope to MCMA-2003 should be possible considering the economic and social costs associated with poor air quality. Air pollution entails economic losses of 2.8% of the gross domestic product (GDP) at the national scale (INEGI, 2018; Roy and Braathen, 2017). Roy and Braathen (2017) stated that future costs are likely to be higher because of an increasing trend of premature deaths (15% from 2010 to 2015) from particle pollution. Assuming similar percentage loss at the local scale, air pollution could have an annual cost of about 4.8 billion US dollars in Mexico City. Thus, a study such as MILAGRO would represent a small percentage (~0.4%) of the annual health-related cost associated with air pollution in the city, while the cost of a study similar to MCMA-2003 would be negligible (~0.06%).

The field campaign should take place along 4-6 weeks between March and May at the height of the photochemical season in Mexico City of the second year. A smaller winter campaign focused on aerosols chemistry should be considered also to address the seasonal variability of the particulate pollution regarding composition and sources. The data analysis should be completed during the following 18-24 months, along with the application of numerical models to characterize the physical and chemical processes driving air pollution, so that the results could be incorporated into the design of the new control measures during the fourth year. This would provide over one year to finalize and release a new air quality management program for the next ten years before the end of the current political administration in 2024.

The design of an air quality management program should also consider urban planning programs and climate change mitigation efforts in place, as well as mobility initiatives, public health policies and prospects of the economy growth. The data provided by the proposed field campaign will add to the existing information of relevance for the city's governance. In addition, the government must allocate resources to incorporate continuous measurements of key compounds, such as volatile organic compounds (VOCs) and PM, into the current air quality monitoring program, in order to assess the impact of management actions on the chemical composition in the MCMA's atmosphere.

The field campaign needs to be designed to address key scientific questions to support the planning of new air quality policies, and address potential changes in emissions of primary pollutants and in atmospheric processes controlling the formation of O_3 and secondary aerosols in the MCMA. An improved understanding of the atmospheric reactivity is needed to determine the sensitivity of secondary pollution to VOCs and NO_x. A comprehensive characterization and source apportionment assessment of the VOCs budget and nitrogen-containing compounds will be critical to find missing or emerging emission sources. For instance, the use of volatile chemical products for cleaning and personal care have emerged as an important source of VOCs in photochemical processes, particularly in the formation of secondary organic aerosols (SOA) in cities where environmental actions have succeeded in controlling major emission sources such as mobile emissions (e.g., McDonald et al., 2018). Similarly, the background contribution of primary and secondary pollutants needs to be quantified for a thorough local management (e.g., Pay et al., 2019).

The changes observed in recent years of the locations within the basin experiencing the highest O_3 peaks may respond to changes in diurnal patterns, spatial distributions and composition of precursor emissions. The expansion of the urban sprawl, changes in the urban morphology, metabolism and surface materials may also help to explain changes in the formation and dispersion of pollutants. Changes in the energy balance partitioning across the built-up surface may drive significant changes in the local meteorology and boundary layer evolution (Oke et al., 2017).

The application of improved measurement methods and modeling tools to investigate the physicochemical properties of the particles will yield new information on the local and regional heterogeneous chemistry, thus helping to elucidate the particles origin and transformations, as well as shed light on the health risks and on the optical and radiative impacts on urban boundary layer properties. Special attention should be paid to the role of ammonia (NH_3) and other nitrogen compounds in the formation of inorganic aerosols and the particles' acidity. Aerosol acidity influences the nitrate and sulfate formation, gas-particle partitioning of semi-volatile species and organic aerosols properties, affecting the formation, deposition and lifetime of many compounds in the atmosphere (Hennigan et al., 2015). A complete speciation of the organic fraction will allow to explain the particles attribution to different emission sources and chemical processes.

Molina et al. (2019) recently reviewed the policy implications for air quality improvement in the MCMA using key findings from MILAGRO and previous field campaigns, as well as recent studies on the subject as part of a comparison with research activities and policies implemented in Singapore to improve air quality. Based on the lessons learned in both cities, and the authors' experience on the air quality management of Mexico City and their participation in previous major research field studies, an initial list of policy-relevant questions is presented in Table 1. To answer these overarching questions a set of specific science questions are presented next to them. These questions are aiming to initiate scientific discussion in designing the new focused field campaign proposed here, but should not be considered as a definitive list.

The proposed new focused field campaign, if successfully executed, is expected to provide improved scientific knowledge needed to address the current challenges facing the air quality managers of Mexico City. The results would also help to improve the development and performance of emission inventories and air quality models, which are needed to predict air pollution episodes and take appropriate control measures according to prevalent weather and social conditions. Furthermore, the findings would serve as an example for many other megacities struggling with environmental degradation, particularly those in the (sub)tropics, where population and energy consumption are projected to increase the most in the following years (United Nations, 2018).

Acknowledgements

Data were not used, nor created for this research.

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Table 1. Key science questions to support the planning of a new focused intensive field campaign on air quality in the MCMA. The answers are expected to improve the scientific knowledge needed to address the local and regional air pollution problems and support the update and redesign of the current air quality management program.

Policy-relevant questions	**Scientific questions**
Which are the current air pollution driving forces in the MCMA?	What are the physical and chemical factors preventing further reductions in O_3 and fine particles?
	What are the regional contributions of primary and secondary pollutants?
	What are the spatial, temporal and chemical characteristics of the emissions of precursor species across the metropolitan area?
	Are there missing species or species not properly quantified of relevance for photochemical processes due to emerging emission sources?
How has the atmospheric chemistry changed across the city in recent years?	Has O_3 production changed since MILAGRO field campaign? In what sectors of the city is O_3 production in VOC- or NO_x-sensitive regimes? Are there seasonal, weekly and diurnal transitions between chemical regimes?
	How do the OH (hydroxyl) and hydroperoxyl (HO_2) radicals evolve along the diurnal course? Which is the current OH reactivity (i.e. the inverse life-time of the OH radical) within the urban core and at outskirts?
	How relevant is the nighttime atmospheric chemistry for the next day's air quality?
	Which mechanisms control the production of secondary inorganic and organic aerosols?
Are current air quality models capable of reproducing the spatial and temporal variability of O_3, $PM_{2.5}$ and other secondary pollutants?	Do the chemical mechanisms used by current models adequately explain the atmospheric reactivity and production of radicals, intermediate and secondary species?
	What is the most suitable boundary layer parameterization scheme for high-pollution episodes?
	Does the urban canopy parameterization truly reflect the multi-scale urban characteristics of the city?
	Does the emissions inventory integrate accurately local and regional emissions sources of anthropogenic and biogenic origin?
Has the urban expansion experienced in recent years under a changing climate affected the local meteorology and air quality?	Could a potential increase in urban heat island affect the wind-flow and ventilation pattern within the basin, as well as the spatial and temporal distribution of pollutants?
	What is the spatial and temporal variation of the convective daytime boundary layer height, the stable nocturnal surface layer and the residual layer, and their impact on pollutants dispersion and atmospheric chemistry?
	What is the impact of aerosols on the radiative balance? How does the aerosol burden modify the local micrometeorology and the boundary layer evolution?
	Might more frequent and intense large-scale meteorological phenomena trigger air pollution episodes?