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The MILAGRO Campaign: Working toward Cleaner Air

Clean air, a miracle?

Gertrudis Uruchurtu


Instrumentos dentro del avión NCAR/NSF C-130.

Four hundred fifty scientists and technicians participated in an unprecedented international project paving the way to reducing atmospheric pollution in megacities.

Every day for a month, Tim Onasch and Scott Herndon of Aerodyne Research Incorporated (ARI), and Miguel Zavala of the Massachusetts Institute of Technology, as well as several other scientists, got in a white vehicle that looked somewhat like a delivery van and ventured out into 7am traffic. The van, however, was equipped with the most complete and sophisticated instruments to measure the different types of gas, dust and aerosols emitted by car exhausts. Each day they would drive to places that Mexico City inhabitants would try to avoid: freeways with bumper to bumper traffic and bottlenecked traffic jams. Their aim was to absorb emissions from nearby vehicles through special tubes that were connected directly to the analyzers.

The work conducted by Onasch and his team was part of the **MILAGRO Campaign**: **M**egacity **I**nitiative: **L**ocal **a**nd **G**lobal **R**esearch **O**bservations that took place during the past month of March. The goal of the Campaign was to collect as much data and information as possible about the atmospheric pollutants breathed daily by the population of the Mexico City Metropolitan Area (MCMA), which includes municipalities of the State of Mexico and Hidalgo. The network of instruments to monitor atmospheric pollution included sondes and balloons (both tethered and free), six airplanes and three specialized satellites, all of which conducted measurements non-stop 24 hours a day. Ground sensors were strategically placed throughout the region from the Valley of Mexico to Veracruz. The central sites were located at the Mexican Petroleum Institute (IMP) north of Mexico City, at the Technological University of Tecamac in the State of Mexico, and at the Rancho La Biznaga, in Hidalgo.

The data and information collected during the month of March will help MILAGRO scientists to determine the composition of atmospheric pollutants, locate their sources and map out their trajectories. This will help to understand the effects pollutants have both globally and locally


Lanzamiento de globo en Tecámac.

given their propensity to transport across distances covering thousands of kilometers. Another aspect analyzed by the scientists was the chemical and physical transformation of pollutants once they are airborne, their reactions with atmospheric elements and with other pollutants. MILAGRO is the first campaign of this magnitude in the world. Once the results have been incorporated they will provide a valuable database for the development of governmental policies oriented toward improving the air quality of the Mexico City Metropolitan Area.

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450 scientists and technicians from different nationalities and institutions specialized in atmospheric sciences, participated in the project. MILAGRO was sponsored by Mexico, through the Metropolitan Environmental Commission (CAM), the National Institute of Ecology of the Secretariat for the Environment and Natural Resources (INE-SEMARNAT), the National Council for Science and Technology (CONACyT) and PEMEX, and by the United States, through the National Science Foundation (NSF), the Department of Energy (DOE) and NASA. The scientific equipment was provided by different universities and research centers.

MILAGRO's three-year planning phase and the campaign itself were coordinated by Dr. Luisa Tan Molina of the Molina Center for Energy and the Environment (MCE2) and of the Massachusetts Institute of Technology (MIT). The lead scientists of the campaign were: the above-mentioned Dr. Luisa T. Molina, Dr. Jeff Gaffney of the Argonne National Laboratory (ANL), and Dr Sasha Madronich of the National Center for Atmospheric Research (NCAR).

Gas Mixtures

The daily activities of MILAGRO began at the center of operations located in Veracruz and at the "supersites" in the MCMA. The teams would go over the logistical activities of the day as well as the problems and accomplishments from the previous day. Meteorologists presented their weather forecasts based on computerized models that considered the altitude, velocity and direction of the wind and the concentration of pollutants. This data would be essential for all work teams, as well as for ground and aerial laboratories.

Meanwhile, in the white van, the Onasch team would be busy registering pollutant emissions such as carbon dioxide (CO_2), which is the main indicator of an increase in traffic and is emitted every time an organic compound is burned. Other common pollutants are carbon monoxide (CO), which results from incomplete fuel combustion and unburned fuel remains. Also, fossil fuels usually come with impurities from organic compounds that contain sulfur (S) and nitrogen (N), and when fuel is burned in the presence of oxygen these two elements form nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). All of these gases are "primary" pollutants that are toxic

and cause irritation. But the biggest problem in terms of pollution happens when NO_2 reacts with unburned gasoline and forms ozone (O_3). Luminous energy is required for this reaction to take place. Therefore, as luminosity increases during the day, ozone concentrates in greater quantities in the atmosphere. Ozone causes extreme irritation and oxidation in tissues.

At times, the van would stay parked for 24 hours at certain strategic sites, such as the *Pico de Tres Padres* or areas neighboring the Tula refinery. During these intervals the daily content and evolution of gas mixtures coming from the city were analyzed. One early morning, scientists detected very high levels of sulfur dioxide. They determined it couldn't have been caused by fuel combustion since it was not accompanied of a CO2 elevation. It turns out this gas came from a giant fumarole emitted by the Popocatépetl volcano that morning.

Scientists on the roof

Meanwhile, at another site, the team of Beatriz Cárdenas and Claudia Márquez from the National Institute of Ecology (INE) would arrive to the premises of the Mexican Petroleum Institute (IMP) at three in the morning in order to calibrate the instruments that would subsequently be elevated, by way of a balloon, to an altitude of 4000 meters to capture and register the concentration of hydrocarbons and ozone during the day. Balloons such as these would be launched at different monitoring sites, both tethered and free, four times a day and sometimes during the night as well. Free flight meteorological balloons were launched that would stay in the air between one and three days and could reach an altitude of 5500 meters. Other types of balloons were the ozonesondes and the radiosondes that are used to provide data on temperature, pressure and relative humidity.


Foto: Luisa Tan Molina

Torre Flux vista desde el edificio de la Red Automática de Monitoreo Atmosférico.

Simon Paech, an Australian from the University of Alabama, would go up to the roof of the IMP every day. Wearing his dark glasses and a canvas hat drawn down over his ears, he worked most of the day under the glaring rays of the sun analyzing the radiometer and the wind profiler there installed. The radiometer was used to register water vapor and temperatures in an atmospheric column 10 kilometers high; it would transmit an upward-looking microwave that would later be reflected back to earth. The data it collected went straight to the computers located in the next room. The


Foto: Luisa Tan Molina

Lanzamiento de globo en el Instituto Mexicano del Petróleo.

wind profiler, which looks like an enormous bathtub, has the capacity of measuring the physical characteristics of wind movement.

Other "roof" scientists collected data on the concentrations of sodium and potassium in the atmosphere using a mass spectrometer. Because they are produced by biomass fires (forests, pastures and certain types of organic trash), these two elements are used as fire indicators.

MILAGRO Project

MILAGRO is an acronym for "**M**egacity **I**nitiative: **L**ocal **a**nd **G**lobal **R**esearch **O**bservations". It is integrated by four atmospheric research campaigns:

- **MCMA-2006** – Mexico City Metropolitan Area- 2006 Experiment, focused on conducting measurements to study the air quality in the MCMA, the exposure patterns and effects on the health of the population, and the design and evaluation of measures to reduce the levels of pollutants.
- **MAX-Mex**: Megacity Aerosol Experiment. This study focuses on the evolution of suspended particles in the atmosphere, their transport and transformation, and chemical and optical properties.
- **MIRAGE-Mex:** Megacity Impacts on Regional and Global Environments, which studies the chemical and physical transformation of gases and pollutant particles emitted by a megacity, as well as its regional and global effects on the composition of the atmosphere and the climate.
- **INTEX-B:** Intercontinental Chemical Transport Experiment-B. This experiment aims to characterize long-term distribution of pollution, global atmospheric photochemistry and the effects of aerosols in clouds and the weather.

Every day, Dara Salcedo, from the Autonomous University of Morelos (UAM), would register on her computer the aerosols captured through an entrance gas pipe located on the roof of the IMP building. A special instrument separated the aerosols according to their volatility and size before sending them to the spectrometer than would then analyze their composition. Aerosols are solid or liquid particles suspended in the atmosphere that measure less than 10 micrometers (one thousandth of a millimeter). Those measuring more than 10 micrometers tend to drop due to gravity. Some aerosols have natural origins, such as dust and particles that come from volcanic emissions and forest fires. However, most aerosol particles are the result of human activities which involve burning fossil fuels for transportation and industrial purposes. Suspended particles have the potential to cause great harm. The smaller the particle, the longer it will remain suspended in the air making it easier for people to inhale it when they breathe, allowing it to penetrate the respiratory system.

Suspended particles form secondary pollutants when they react with other substances that are present in the atmosphere. Such is the case of nitrogen and sulfur oxides, which are also combustion byproducts. These particles happen to be the main component of the yellowish fog floating over Mexico City that the inhabitants of the metropolitan area witness frequently. Robert Osborne from the Texas A&M University did a laboratory study with specific isolated particles in order to better understand the conditions in which they would expand when joining other substances, like in the case of sulfur oxides or water vapor.

The impact on the population

To understand the impact of pollutant particles and gases on the population has been, for many years now, at the very center of the research conducted by Alvaro Osornio of the Environmental University Program (PUMA), and by Horacio Tovalín, from the Zaragoza Faculty of Graduate Studies, both institutions of the UNAM. Together, the scientists compared the results obtained by the MILAGRO Campaign's research teams and correlated them to the impact pollutants have on the inhabitants of the areas located in the emissions pathway going through the states of Mexico and Hidalgo.

The teams registered the concentration of pollutants inside and outside the schools and homes of 600 children and 210 young adults. With specialized equipment they measured the exposure of each one of them to gases and particles. In addition, blood samples were taken to evaluate how the phagocytes in the immunological system and the antioxidant enzymes reacted to the pollutants.

Due to the fact that the incidence of asthma in the population of megacities has increased in an almost parallel manner to the concentration of pollutants, a study is also being conducted to understand if any of the five genes implicated in this ailment has been affected in the inhabitants of this region.

Flying laboratories


Avioneta ultra ligera en el aeropuerto.

Every day, from their base at Veracruz airport, five airplanes equipped with specialized equipment would prepare for take off in order to conduct their scheduled flights. Some would be in charge of taking air samples to analyze gases such as carbon monoxide, dioxide and aerosols. Others would seek out forest or agricultural fires, very frequent at this particular time of year, in order to determine the composition, evolution and trajectory of the smoke. One of the airplanes used laser radar to obtain very detailed aerosol measurements. Another, the J31, had instruments that measured the reactions of aerosol particles in the presence of solar radiation. This data happens to be very important since some particles tend to absorb the radiation while others reflect it. Soot particles, for example, absorb radiating energy, while water molecules in the clouds usually reflect it. This, in turn, affects the planet's weather by cooling or heating the Earth. Furthermore, in Houston, a NASA airplane would be getting ready to begin tracking the intercontinental transport of pollutants at greater altitudes and distances. Three specialized monitoring satellites

named *Aura, Terra* and *Aqua* would help to validate the results from the experiments conducted by the airplanes.

Megacity

Why was the Mexico City Metropolitan Area chosen as case study for the MILAGRO Campaign? Its growing population of more than 20 million people makes it the third most populated city in the world, only surpassed by Tokyo and the New York-Philadelphia area. The MCMA region is representative of the emissions that are typical of cities with developing economies. In addition, its great levels of luminosity during at the time of year when the Campaign took place proved favorable in order to study different photochemical reactions. Another important aspect was the existence of data dating back at least 10 years from measurements of nitrogen oxides, ozone, carbon monoxide and sulfur dioxide, particles, photochemical reactions and aerosols. The 2003 campaign (MCMA-2003) supported by the Metropolitan Environmental Commission (CAM) has provided an important foundation for MILAGRO.

The data and information obtained from the measurement were sent to the University of Colorado in Boulder where it will be studied and analyzed. An integrated result is expected to be released in 2008. A more detailed representation of the results will be provided by modeling computerized studies in approximately two years.

The costs associated to the MILAGRO Project, its impressive technological displays, and the intellectual and physical aptitudes invested in this environmental endeavor, could very well be lost or become obsolete unless an educational campaign is conducted in parallel to make people aware of how vulnerable and fragile our atmosphere and our bodies are when exposed to the pollutants we keep discharging into the atmosphere.

Gertrudis Uruchurtu is a chemical pharmaco-biologist. She has taught high school chemistry for 30 years and is a graduate of the Science Dissemination Seminar (*Diplomado de Divulgación de la Ciencia*) of the DGDC/UNAM.