THE MILAGRO CAMPAIGN

Megacity **I**nitiative:
Local **a**nd **G**lobal **R**esearch **O**bservations

Background

Air pollution in megacities

Air pollution is one of the main environmental problems in urban areas, particularly in megacities (cities with more than 10 million residents). Population growth and increasing industrialization have inevitably resulted in a higher demand for energy, greater use of fossil fuels, and more emission of pollutants into the atmosphere. As a result, air pollution has become not only one of the central environmental problems of the century, but also presents serious health consequences to people and economic costs to society.

The main pollutants emitted into the atmosphere in megacities are sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), metal oxides, and atmospheric particles (aerosols) mostly consisting of soot or black carbon, sulfates, nitrates, and organic matter. Currently, the use of fossil fuels in transportation, the generation of electricity, and industrial processes represent the primary sources of pollutant emissions.

The air pollution problem in megacities is influenced by several factors that include the topography, meteorology, demographic growth, industrial growth and urban expansion. The Mexico City Metropolitan Area (MCMA) – the second largest megacity in the world - has an estimated population of 18 million people and covers an urbanized area that totals 1,500 km^2, encompassing the 16 delegations of the Federal District, 37 municipalities of the State of Mexico and 1 municipality of the State of Hidalgo. In the MCMA, emissions of pollutants reach millions of tons per year, and atmospheric concentrations of pollutants routinely exceed the standards recommended by the World Health Organization. As a result, there has been an increase in diagnosed incidences of chronic bronchitis, asthma, reduction of pulmonary capacity, and in premature mortality rates among the citizens.

Regional and global effects of pollution in megacities

Once released into the atmosphere, pollutant gases and aerosols are mixed into and transported throughout the atmosphere without regard to geopolitical frontiers, until they are removed by physical and chemical processes. In many cases, the pollutants can undergo chemical and physical transformations that are driven by sunlight leading to the formation of oxidants and secondary aerosol species, including acidic gases and aerosols. The length of time that the pollutants remain in the atmosphere determines the range of their impacts. In some cases, the air

pollutants are removed rapidly as they are water soluble and can be washed out by wet deposition processes. In other cases, some types of compounds remain for long periods of time, even decades, until they reach the upper layers of the atmosphere

These exported primary pollutants and their reaction products have the potential to affect human health and ecosystems on large geographic scales, and additionally can affect atmospheric visibility, weather systems and precipitation, and global climate. Tropospheric ozone, a product of VOC-NOx chemistry, is also a highly effective greenhouse gas. Suspended particles (sometimes seen as regional haze episodes) reflect or absorb sunlight, deteriorating visibility and altering the atmospheric energy budgets that affect climate. Some types of compounds (such as methane, carbon dioxide, and many halogenated organics) remain in the atmosphere for many years, and are therefore spread around the entire globe. Many of these very long-lived compounds play an important role in greenhouse warming. They eventually also reach the upper layers of the atmosphere where, in the case of the chlorine and bromine containing compounds, they can adversely affect the stratospheric ozone layer.

The geographic re-distribution of pollutants, the evolution of their chemical, physical, and optical properties, and the mechanisms for their eventual removal from the atmosphere are very complex and obviously important, yet only partly understood at the present time.

The MILAGRO Campaign

The **M**egacity **I**nitiative: **L**ocal **a**nd **G**lobal **R**esearch **O**bservations (**MILAGRO)** Campaign will bring an international research team including hundreds of scientists and students to the Mexico City area and to Veracruz in March 2006. They will be joined by a large group of Mexican investigators and collaborate with Mexican government agencies. The goal of MILAGRO is to conduct measurements of pollutants and other trace gases, aerosol particles, and to study the atmospheric processes leading to the formation of secondary aerosols from precursor gases, and the transport and transformations of these gases and aerosols on local, regional, and global scales. This will be accompanied by modeling studies that will integrate this vast amount of information into new insights on the chemistry of the atmosphere in a large urbanized region, as well as the impact of these on larger geographical scales.

The MILAGRO Campaign will be a close collaboration of four simultaneous measurement campaigns, each focusing on somewhat different objectives and spatial scales:

- **MCMA-2006** (The Mexico City Metropolitan Area – 2006 Experiment) will focus on air quality issues of the MCMA, including the evaluation and design of policies intended to reduce pollutant levels.
- **MAX-Mex** (The Megacity Aerosol Experiment) will focus on aerosols (atmospheric particulates), especially their transport, transformation, and chemical and optical properties. Aerosols can have important effects on human health, climate, and can affect the photochemistry of the atmosphere.

- **MIRAGE-Mex** (Megacity Impacts on Regional and Global Environments) aims to characterize the chemical/physical transformations of the gaseous and particulate pollutants exported from a megacity, and to evaluate their effects on regional and global atmospheric composition and climate.
- **INTEX-B** (Intercontinental Chemical Transport Experiment–B) will focus on the long-range transport of pollution, global atmospheric photochemistry, and the effects of aerosols and clouds on radiation and climate.

MILAGRO measurements will take place **March 1 - 30, 2006**. The measurements will be conducted with a wide range of instruments at ground sites, on aircraft, and satellites. Three main ground locations are: one site within the MCMA located at the Instituto Mexicano del Petróleo ("**T0"**), another at the Universidad Tecnológica de Tecámac in the State of Mexico ("**T1"**) and a third in Rancho La Bisnaga, north of Tizayuca in the State of Hidalgo ("**T2"**). The designations "T0", "T1", and "T2" refer to transport of the urban plume to different points in space and time. Ground sites are ideal for continuous detailed measurements of a large number of species and properties. At each of the sites, standard monitoring and specialized equipment will be installed. At some sites sondes and balloons with instruments to measure meteorological parameters, ozone, and hydrocarbons, will be used. The measurements will be made over a period of 30 days, 24 hours a day.

Additional platforms in or near Mexico City include mobile vans containing scientific laboratories, as well as mobile and stationary upward-looking lasers (lidars). Six instrumented research aircraft will participate in MILAGRO: five will be based in Veracruz, Mexico, and one in Houston, Texas. These airborne measurements will provide information about the atmosphere over a large region, and at various altitudes. Satellite-based instruments will peer down into the atmosphere to provide even larger geographical coverage.

MCMA-2006

The Mexico City Metropolitan Area – 2006 (**MCMA-2006**) campaign is led by Dr. Luisa T. Molina of the Molina Center for Energy and the Environment (MCE^2) with funding from NSF, DOE, several Mexican and European research agencies, and will examine emissions and boundary layer concentrations within the Mexico City Basin. The required data on aerosols, VOCs and other gases, meteorology, and solar radiation will be gathered at the supersite at the Instituto Mexicano del Petróleo and a flux tower located at the city center, in combination with a highly capable mobile laboratory (from Aerodyne Research Inc.) and several fixed units deployed throughout the MCMA at representative urban and boundary sites.

The overall purpose of the **MCMA-2006** is to strengthen the scientific base for the design and evaluation of policies intended for the improvement of air quality in the MCMA by developing scientific information that helps to better understand the generation processes of pollutants in the MCMA, their dispersal, transport and transformation in the atmosphere, the exposure patterns of the general population to these pollutants, and the effects on human health. Similar to previous campaigns, the findings relevant to the design of policies will be identified and presented to the representatives of the Mexican government.

MAX-Mex

The Megacity Aerosol Experiment (**MAX-Mex**) is led by Dr. Jeffrey Gaffney from Argonne National Laboratory, operated by the U.S. Department of Energy (DOE), and is funded by the DOE Atmospheric Science Program (ASP). The ASP program is focused on understanding the role of aerosols in the radiative forcing of the atmosphere and is part of the DOE's Climate Change Research Division efforts to reduce uncertainties in global climate modeling. The MAX-Mex campaign will characterize aerosol formation and changes in aerosol composition, size distribution, light scattering coefficient, absorption coefficient, optical depth, soot-specific absorption, and radiative fluxes at selected vertical and horizontal locations in the outflow from a well-characterized urban core. The planned field study will focus on chemical, physical, and optical characterization of the aerosols, on aerosol transformations including aging of the black carbon during outflow into the region, and on the effects of the megacity aerosol plume on the regional radiative balance in and near this megacity source.

The MAX-Mex program will use two aircraft: A well instrumented airplane, the DOE Gulfstream aircraft (G-1), to measure aerosol properties and precursor gas contributions. An additional aircraft (King Air) will deploy a lidar and provide two-dimensional (height-distance) information on aerosol distribution and plume extents. In addition, different types of equipment will be installed at the three ground-based supersites, again focusing on aerosol emission and formation, properties, chemical and physical transformations, and effects on climate.

MIRAGE-Mex

The Megacity Impacts on Regional and Global Environments (MIRAGE) program is a multidisciplinary activity led by Dr. Sasha Madronich of the National Center for Atmospheric Research (NCAR). The project is primarily funded by the U.S. National Science Foundation (NSF) with additional support from NASA, Mexican Government agencies, and other sources. The overall goal of MIRAGE is to increase the understanding of how the world's megacities affect regional and global air chemistry, and how this in turn can influence weather and climate.

By using Mexico City as a case study (**MIRAGE-Mex)**, the researchers aim to:

1) Quantify the spatial extent and temporal persistence of the polluted plume exiting Mexico City;
2) Identify and quantify the chemical and physical transformations of the gases and aerosols in the plume, especially the processes that lead to the removal of these pollutants from the atmosphere;
3) Quantify the effects of the plume on regional oxidants and atmospheric radiation budgets, and ultimately on climate; and
4) Examine the interactions of the urban plume with background air, as well as pollutants from other sources, including regional anthropogenic pollutants, biomass fires, and vegetative emissions.

To achieve these objectives, an extensive series of observations of the chemical and physical state of the atmosphere in the region surrounding México City will be made during MILAGRO. The NSF C-130 aircraft will carry a payload of state-of-the-art scientific instruments and, flying from its base in Veracruz, will sample air at different distances from Mexico City to measure how gases and particles "age" during transport, specifically tracking those chemical, physical, and optical properties that have the potential to affect air quality, weather, and climate on large geographic scales. An additional aircraft (Twin Otter, also based in Veracruz) will conduct studies of fires and their effect on the local and regional composition of the atmosphere. Other MIRAGE-Mex researchers will be located at the T1 site at Tecámac, located on the northern boundary of Mexico City, to examine the chemistry and physics of air as it first exits México City.

INTEX-B

The Intercontinental Chemical Transport Experiment – Phase B (**INTEX-B**) is led by Dr. Hanwant Singh of the U.S. National Aeronautics and Space Administration (NASA). The project is funded by NASA with additional support and contributions from NSF and international partner countries. The INTEX-B campaign will emphasize the regional-to-global aspect of MILAGRO with observations from two aircraft, a DC-8 and a J-31, as well as satellites. The larger DC-8 aircraft will provide comprehensive observations of chemistry and aerosols using both direct air sampling and laser remote sensing while the smaller J-31 will focus exclusively on aerosols and their radiative impacts. Operating from Houston, Texas, the DC-8 will interact with other MILAGRO aircraft to locate and sample pollution associated with the Mexico City Metropolitan Area and will then extend observations well downstream over the Gulf of Mexico. Operating from Veracruz, the J-31 will seek to examine the impact of aerosols closer to Mexico City pollution sources. The DC-8 and J-31 will fly in coordination with NASA satellites (Aura, Aqua, and Terra) to provide ground truth as well as to provide a bridge between the wealth of detail offered by the MILAGRO observations and the broad regional-to-global perspective provided by satellites.

Building on an earlier study: the MCMA-2003 Measurement Campaign

During the past four years, a group of scientists, engineers, economists and experts in the political and social sciences from Mexico, the United States and other countries have carried out an integrated assessment of the air quality of the Mexico City Metropolitan Area with the support of the Metropolitan Environmental Commission (CAM). This case study has been a collaborative research and education program of the Integrated Program on Urban, Regional, and Global Air Pollution initiated by Dr. Luisa T. Molina and Dr. Mario Molina at the Massachusetts Institute of Technology (MIT) in 1999. This program has used a coordinated and interdisciplinary approach to analyze the air pollution problems derived from human activity in large cities and its impact on the health of the population, climate, and ecosystems. The MCMA-2003 measurement campaign led by Dr. Luisa T. Molina was carried out within the framework of that program. The objective of the MCMA-2003 field measurement campaign was to improve the understanding of air quality problems in megacities by conducting measurement and modeling studies of atmospheric pollutants in the MCMA.

The campaign was designed to cover the height of the annual photochemical season just prior to the onset of the rainy season, and involved a highly instrumented supersite located at the Centro Nacional de Investigación y Capacitación Ambiental (CENICA), a component of the Instituto Nacional de Ecología (INE), located on the campus of the Metropolitan Autonomous University (UAM) - Iztapalapa. The fixed supersite capability at CENICA was enhanced with state-of-the-art instrumentation contributed by many US and European teams. A mobile laboratory (from Aerodyne Research Inc.) was deployed for measurements at various locations in Mexico City. When not involved in mobile off-site experiments, the mobile lab was sited at CENICA and its instrument suite contributed to the supersite's database. In addition, extensive meteorological data and a wide range of chemical data were collected by collaborating Mexican research groups. A complete description of the campaign, instruments and measurements can be found at: http://mce2.org/megacities/fc03/overview/welcome.html.

The MCMA-2003 study provided scientific information that was fundamental in the planning of the larger MILAGRO Campaign. Specifically, it showed that the atmosphere of the MCMA is extremely active photochemically and is ideally suited for understanding the atmospheric chemistry of tropical megacities. MILAGRO will provide even more comprehensive measurements inside the metropolitan area, as well as the first ever measurement of how much pollution extends outside the MCMA.

Education and Outreach activities of the MILAGRO Campaign

The MILAGRO Campaign recognizes the need to contribute to the education and training of young investigators, to raise social awareness toward atmospheric pollution problems, and to disseminate the results of the measurement campaign to the scientific community as well as policy makers and the general public. With this in mind, the MILAGRO organizers have set up a series of education and outreach activities to be carried out in parallel to the scientific activities by Mexican and foreign researchers working at the field sites.

The objectives of the Education and Outreach program are:

1) To foster communication between scientists of the MILAGRO campaign and students, other investigators, and the public in general.
2) To contribute to the education and training of students in the technical and scientific aspects related to atmospheric pollution in megacities and their impact on a regional and global scale.
3) To promote greater interest in science and scientific careers among K-12 students through the participation of teachers in the field and in the outreach activities, including web-based bilingual reports and information.
4) To publish and disseminate the results and impacts of the MILAGRO campaign to the general public and to create awareness among the people of the Mexico City Metropolitan Area regarding the problems of air quality and its possible effects and solutions.

The following are a few of the activities that have been organized:

1) Exhibits

2) Scientific workshops on the function and use of the equipment being used in MILAGRO
3) Presentations and talks with students, professors and the general public
4) Guided tours of the monitoring sites
5) Web-based information and outreach in English and Spanish

Contact Information for the MILAGRO Campaign

MCMA-2006
Mexico City Metropolitan Area – 2006
Lead Scientist: Dr. Luisa T. Molina,
Molina Center for Energy and the Environment (MCE^2)
http://mce2.org/megacities/fieldcampaign2006/

MAX-Mex
Megacity Aerosol Experiment – Mexico
Lead Scientist: Dr. Jeff Gaffney,
Argonne National Lab/Department of Energy (ANL/DOE)
http://www.asp.bnl.gov/MAX-Mex.html

MIRAGE-Mex
Megacity Impacts on Regional and Global Environments-Mexico
Lead Scientist: Dr. Sasha Madronich,
National Center for Atmospheric Research/National Science Foundation (NCAR/NSF)
http://mirage-mex.acd.ucar.edu/

NASA-INTEX-B
Intercontinental Chemical Transport Experiment – Phase B
Lead Scientist: Dr. Hanwant Singh,
National Aeronautics and Space Administration/Ames Research Center (NASA/ARC)
http://www.espo.nasa.gov/intex-b

MILAGRO Website
http://www.joss.ucar.edu/milagro/

Participants

More than 50 academic and research institutions and over 300 US and international investigators will participate in the MILAGRO campaign.

The Mexican participating institutions include:
Agencia de Protección al Medio Ambiente y Recursos Naturales –Gobierno del Estado de Nuevo León (APMARN)
Centro Mario Molina (CMM)
Centro Nacional de Investigación y Capacitación Ambiental (CENICA-INE)
Centro de Investigación en Materiales Avanzados, S.C. (CIMAV)
Centro de Educación y Capacitación para el Desarrollo Sostenible (CECADESU-SEMARNAT)
Colegio Alemán
Comisión Ambiental Metropolitana (CAM)
Comisión de Recursos Naturales y Desarrollo Rural-Gobierno del Distrito Federal (CORENA)
Consejo Estatal de Ecología (Estado de Hidalgo)
Consejo Estatal de Protección al Ambiente (Estado de Veracruz)
Consejo Nacional de Ciencia y Tecnología (CONACyT)
Dirección de Ecología-Presidencia Municipal de Salamanca- Gobierno del Estado de Guanajuato
Dirección General de Aeronáutica Civil (DGAC –SCT)
Fuerza Aérea Mexicana (FAM –SEDENA)
Fundación México-Estados Unidos para la Ciencia (FUMEC)
Gobierno del Estado de México, Secretaria de Medio Ambiente (SEGEM)
Instituto de Investigaciones Eléctricas (IIE)
Instituto Mexicano de Tecnología del Agua (IMTA)
Instituto Mexicano del Petróleo (IMP)
Instituto Nacional de Cancerología (INC)
Instituto Nacional de Ecología (INE)
Instituto Nacional de Estadística, Geografía e Informática (INEGI)
Instituto Nacional de Investigaciones Nucleares (ININ)
Instituto Nacional de Salud Pública (INSP)
Instituto Tecnológico de Estudios Superiores (Campus Monterrey y Estado de México)
Petróleos Mexicanos (PEMEX)
Secretaría de Comunicaciones y Transporte (SCT)
Secretaría de Educación Pública (SEP)
Secretaría de Gobernación (SEGOB)
Secretaría de Hacienda y Crédito Público (SHCP) – Administración General de Aduanas (AGA)
Secretaría de la Defensa Nacional (SEDENA)
Secretaria de Desarrollo Sustentable-Gobierno del Estado de Querétaro
Secretaría de Marina (SEMAR)
Secretaria de Medio Ambiente del Gobierno del Distrito Federal (SMA-GDF)
Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)
Secretaría de Relaciones Exteriores (SRE)
Servicio Meteorológico Nacional (SMN)
Servicios a la Navegación en el Espacio Aéreo Mexicano (SENEAM)
Sindicato Nacional de Telefonistas de la República Mexicana

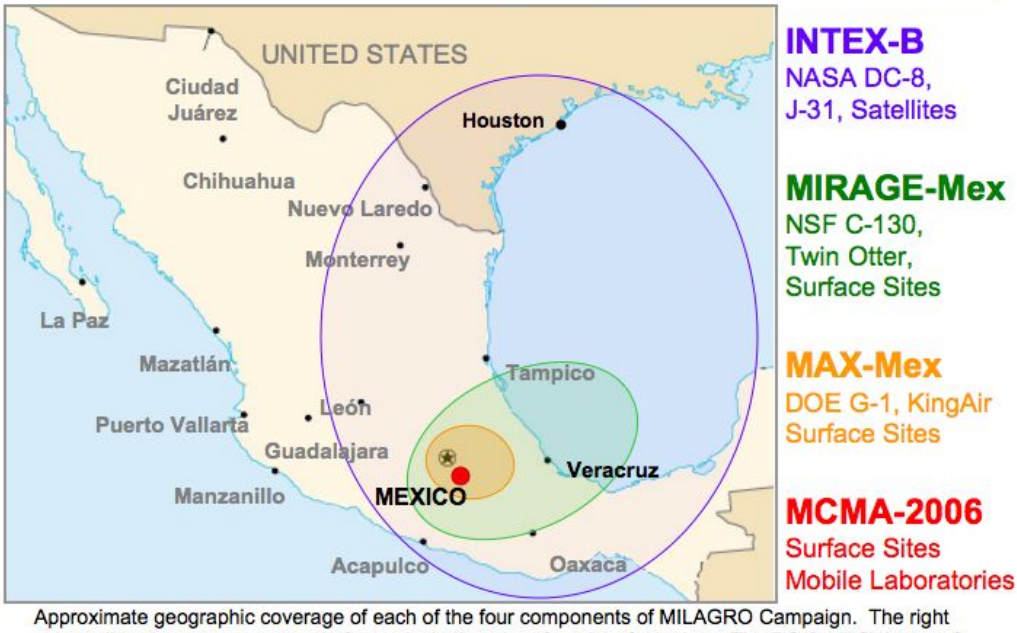
Universidad Autónoma de San Luis Potosí (UASLP)
Universidad Autónoma del Estado de Morelos (UAEM)
Universidad Autónoma Metropolitana (UAM)
Universidad Nacional Autónoma de México (UNAM)
Universidad Tecnológica de Tecámac (Estado de México)
Universidad Veracruzana (Estado de Veracruz)

The non-Méxican* participating institutions include:
(* From United States of America, unless indicated otherwise)
Aerodyne, Inc.
Arizona State University
Bergstrom Aircraft
California Inst. of Technology
Chalmers University (Sweden)
Colorado State University
Columbia University
Consejo Superior de Investigaciones Científicas (Spain)
Department of Energy (DOE)
  DOE/Argonne National Lab.
  DOE/Brookhaven National Lab.
  DOE/Los Alamos National Lab.
  DOE/Lawrence Berkeley National Lab.
  DOE/Pacific Northwest National Lab.
Droplet Meas. Tech., Inc.
Florida State University
Georgia Inst. Technology
Goteborg University (Sweden)
Harvard University
Heidelberg University (Germany)
Massachusetts Inst. of Technology
Molina Center for Energy and Environment (MCE2)
National Aeronautics and Space Administration (NASA)
  NASA/Ames Research Center
  NASA/Goddard Space Flight Center
  NASA/Jet Propulsion Lab.
  NASA/Langley Research Center
National Center for Atmospheric Research (NCAR)
  NCAR/Atmospheric Chemistry Division
  NCAR/Earth Observing Lab.
  NCAR/ Mesoscale & Microscale Meteorology Division
National Science Foundation (NSF)
National Oceanic and Atmospheric Administration (NOAA)
Paul Sherrer Inst. (Switzerland)
Pennsylvania State University
SkyResearch, Inc.
Smith College

SpecTIR, Inc
State University of New York at Old Westbury
Texas A&M University
University of Alabama
University of California/Berkeley
University of California/Irvine
University of California/Los Angeles
University of California/San Diego
University of Colorado
University de Lille (France)
University of Hawaii
University of Houston
University of Indiana
University of Iowa
University of Leipzig (Germany)
University of Manchester (United Kingdom)
University of Maryland
University of Miami
University of Minnesota
University of Montana
University of New Hamsphire
University of Nevada
University of North Dakota
University of Rhode Island
University of Virginia
University of Washington
University of Wisconsin
U.S. Forest Service
Virginia Technology
Washington State University

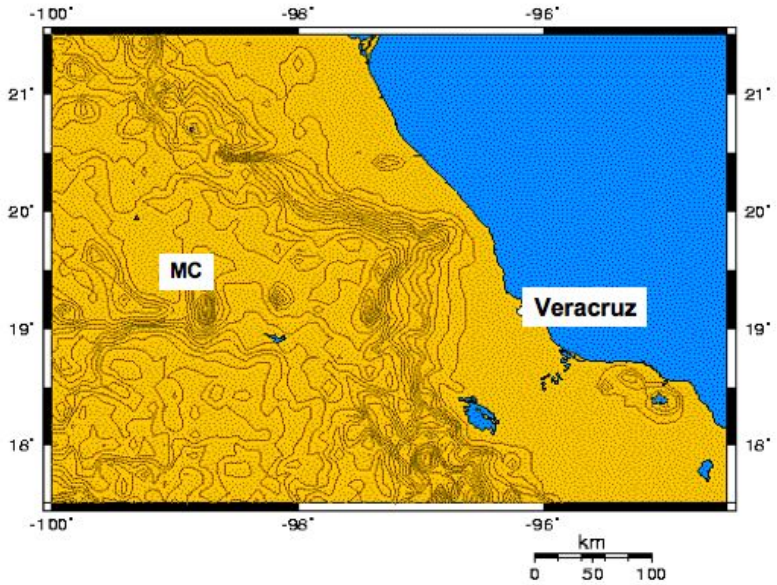
Maps and Photo Gallery

MILAGRO CAMPAIGN: Geographic Coverage

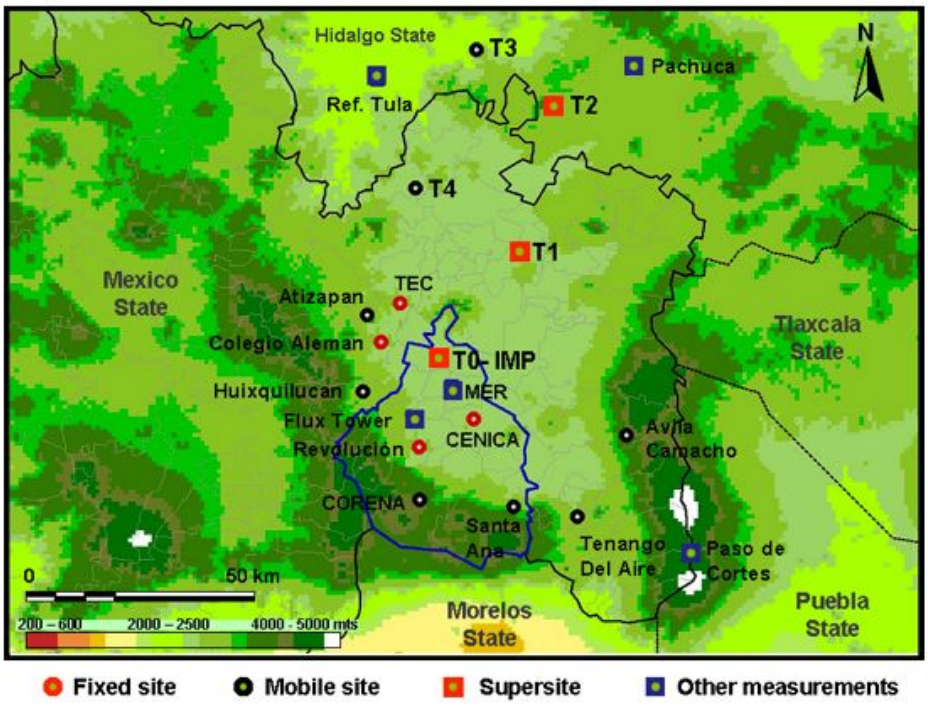


Approximate geographic coverage of each of the four components of MILAGRO Campaign. The right column lists the measurement platforms, including aircraft and surface sites. The DC-8 will flight out of Houston, while the other 5 airplanes will fly out of Veracruz.

MILAGRO CAMPAIGN: Airplane Flight Path (Veracruz Airport to MCMA)



MILAGRO CAMPAIGN: Surface Sites

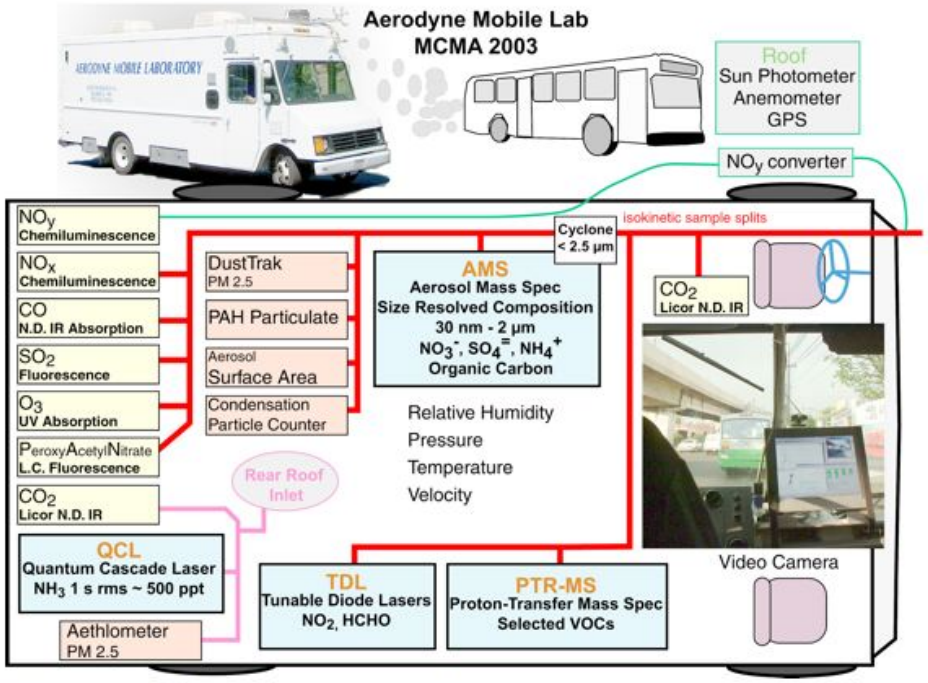


T0: Instituto Mexicano del Petróleo (DF)

T1: Universidad Tecnológica de Tecámac (Estado de México)

T2: Rancho La Bisnaga (near Tizayuca, Hidalgo)

MCMA-2006 Mobile Laboratory



This van was first deployed during the MCMA-2003 Campaign.

DOE G1 Aircraft

Base: Veracruz Jara International Airport

NSF C-130 Aircraft

Base: Veracruz Jara International Airport

NASA DC-8 Aircraft

Base: Houston, Texas

NASA J-31

Base: Veracruz Jara International Airport

NASA KingAir B-200

Base: Veracruz Jara International Airport

The KingAir B-200 aircraft, owned and operated by NASA with funding from DOE, has a downward-pointing LIDAR that will measure the concentrations and properties of aerosols below its flight altitude.

NSF/USFS/U Montana Twin Otter

Base: Veracruz Jara International Airport

The Twin Otter is owned and operated by the US Forest Service. It is funded by NSF to measure the chemical and physical properties of smoke from agricultural and forest fires.

G-1 Aircraft: Aerosol Inlets

G-1 Aircraft: Instruments

LIDAR Systems

Installed in: NSF/C-130, DOE/NASA KingAir, NASA/DC-8

Wind profiler and radiometer

Site: T0 (IMP)

The profiler shown here is from the University of Alabama at Huntsville supported by NSF. This is one of the four profilers that will be used during the MILAGRO Campaign.

Radiosondes

Sites: T1, T2, SMN: Tacubaya, Veracruz, Merida, Acapulco

Tethered Balloons

Sites: T0, T1