



Renewable Energy and Climate Science for the Americas:  
Metrology and Technology Challenges

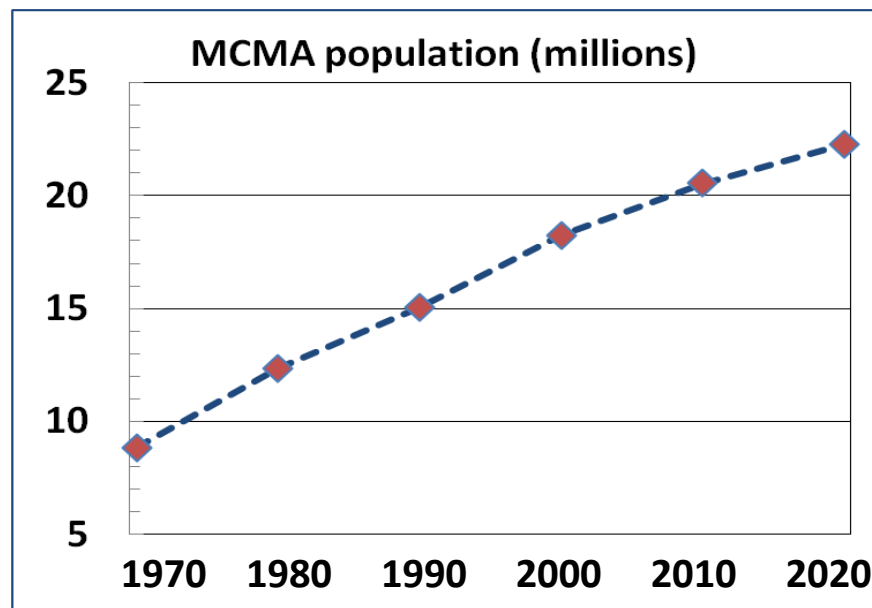
CENAM, Querétaro, México  
October 8-9, 2013

***Air Quality Monitoring Activities  
in  
Mexico City***

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## Air quality in Mexico City at a glance

- In the 70's the population in the Mexico City Metropolitan Area (MCMA) broke the 10 million mark, and 15 million in the 90's. Today it is over 20 million.
- The area was the focus of industrial, service and cultural activities in the country; transport and urban sprawling were growing at unprecedented rates.
- In 1986 air quality deterioration was evident, and preliminary measurements indicated that human health and life quality were seriously compromised.
- The Automatic Atmospheric Monitoring Network (RAMA, for its Spanish name) was installed in 1986 with 25 monitoring stations



**Three air quality integrated studies, related to the MCMA  
will be described**

**EGCA – MARI (1990-1994)**

Estudio Global de la Calidad del Aire  
Mexico City Air Quality Research Initiative  
Joint Los Alamos National Laboratory - Instituto Mexicano del Petróleo

**IMADA – AVER (1995-1998)**

Investigación sobre Materia Particulada y Deterioro Atmosférico  
Aerosol and Visibility Environmental Research  
DOE Laboratories - Instituto Mexicano del Petróleo

**MILAGRO (2006-2009)**

Megacity Initiative, Local and Global Research Observation  
International collaborative project; IMP in coordination with the MCE2 (Molina  
Center for Energy and the Environment)

## EGCA – MARI

Pioneering comprehensive study sponsored by DOE and PEMEX

### The problem

By the end of the 80's, the air pollution problem in Mexico City was growing at a distressing rate

- Mexico City's unique combination of terrain, climate, and altitude were to add a significant degree of difficulty to the task of finding a solution.
- Applying a systems approach and modern decision support techniques, the bilateral team leveraged money, people, and scientific and technology resources with tremendous efficiency.
- The synergy between the cooperating team members, more than anything else, was responsible for the success of the project.
- The goal set by the Bilateral Technical Team was the creation of comprehensive decision support tools that policy makers could use with confidence to set informed air pollution reduction policy.
- The initiative was divided into three tasks.
  - Task 1. Modeling and simulation
  - Task 2. Characterization and measurement
  - Task 3. Strategic Evaluation



## Task 1. Modeling and simulation

### The goal

- To predict the effects, by time of day and area of the city, that various strategies would have on air pollution.
- To provide the appropriate models, adapted to the MCMA, that would be the basis for the analysis of air quality improvement options.
- To simulate meteorology, transport and dispersion of pollutants, and air chemistry resulting from pollutant exposure to sunlight (compounded by Mexico City's altitude and latitude).

### Meteorological Model

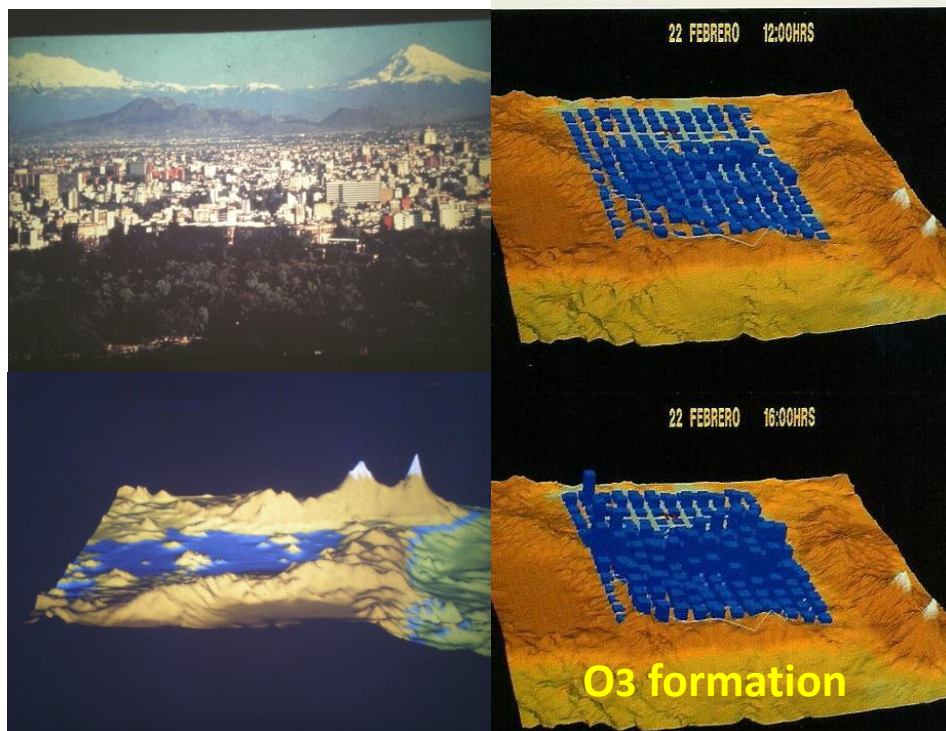
- HOTMAC. Higher-Order Turbulence Model for Atmospheric Circulation.
- Local meteorology, three-dimensional, time-dependent winds, atmospheric stabilities, and turbulence for use with other models.

### Dispersion Model

- RAPTAD. Random Particle Transport and Diffusion Model.
- Transport and dispersion of pollution by moving parcels of contaminated air (with average and turbulent winds from the meteorological model).

### Photochemical Models

- Trajectory Model . Chemistry occurring in a parcel of air moving across the city.
- CIT 3-D Airshed Model. Chemistry, emissions, transport, and mixing of polluted air.



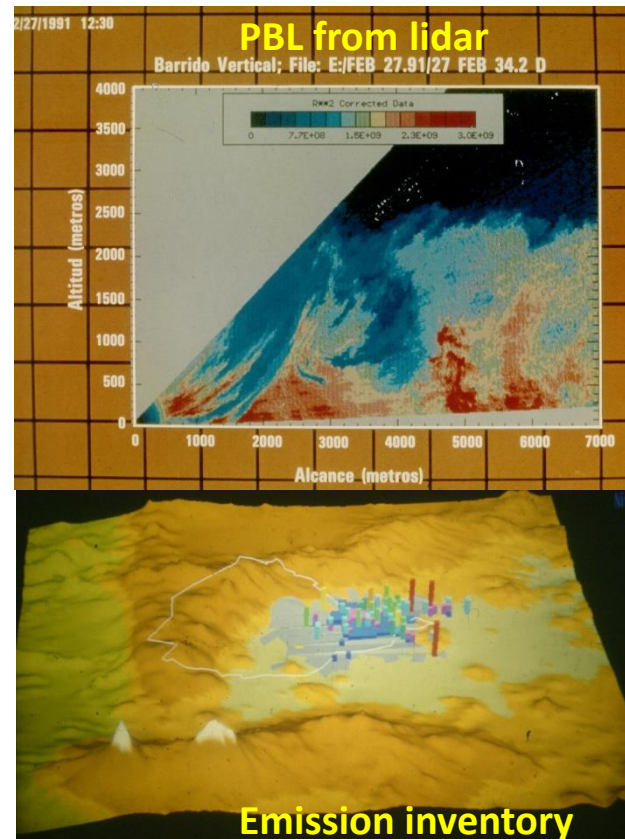
## Task 2. Characterization and measurement

### The goal

- To characterize the meteorology, emissions, and ambient air quality for use in validating the task 1 models and/or providing specific data.
- The task involved routine monitoring, including long-term measurements; 3 short-term, intensive field expeditions; and analysis of the data collected.

### Field Objectives

- Field measurements to fulfilled three functions:
  - 1) Increasing the understanding of Mexico City meteorology, air pollution, and atmospheric dynamics.
  - 2) Providing a baseline for the models using simultaneously obtained measurements to assure a common time period for input and validation.
  - 3) Providing a comprehensive and extensive set of air quality and meteorological data that afforded a unique opportunity to check the performance of the models against actual conditions.
- First campaign, September 1990. To obtain parameters important for initial modifications to the dispersion models to adapt them to Mexico City's unique conditions.
- Second campaign, February 1991. To measure parameters to initialize the models and to provide base-case scenarios for verification and data for understanding and modeling the atmospheric and pollution dynamics.
- Third campaign, March 1992. Additional measurements to provide verification of model results, particularly hydrocarbon concentrations and 3-D slope winds.

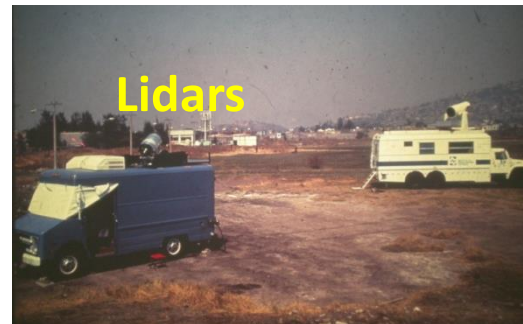
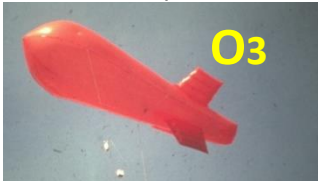


## Routine measurements

- The Air Quality Monitoring Network (RAMA, since 1986) provided a record of prevailing winds during acute episodes and identified cold air drainage from the mountains and areas of pollutant concentration.
- Twice-daily rawinsonde flights (free flying balloons, routinely launched from the Mexico City airport) provided a vertical “snapshot” of local meteorology.

## Measurement methods

- Tethersonde, ozonesonde, rawinsonde, and the NCAR instrumented aircraft were used to measure temperature, humidity wind direction, wind speed, atmospheric pressure, pollutant concentration and aerosol size distribution, surface temperature, and UV intensity
- Satellite spectrometry was used to obtain land-use patterns for solar radiation effects.
- Doppler sodar, SO<sub>2</sub> DIAL, elastic-scattering lidar, and laser ceilometry were used to obtain the atmospheric structure and winds, one-, two-, and three-dimensional profiles of aerosol distribution, plume dynamics, identification of sources of pollution containing particulates and aerosols, and spatial distribution of specific pollutants.
- Canister sampling and characterization of atmospheric VOC's.
- The FEAT (Fuel Efficiency Automotive Test) was used to make over 30,000 tailpipe measurements.



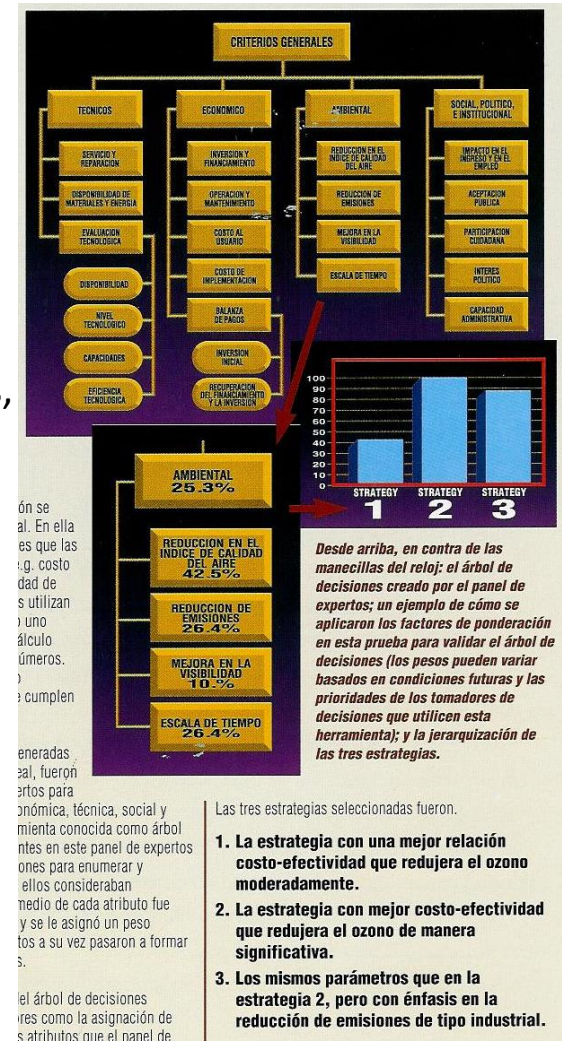
## Task 3. Strategic Evaluation

### The goal

- To develop a general methodology for Mexico City's decision makers to use in ranking air quality improvement strategies.
- The methodology included means to evaluate specific options and combine them into strategies.

### A new approach

- Applying a systems approach and modern decision support techniques, the bilateral team proposed a multi-attribute decision making tool.
- The selection of attributes, assignment of weights, and development of scoring procedures was performed by an Experts Panel comprising representatives from organizations responsible for MCMA air quality.
- All options for reducing air pollution were collected and fed into a "what if" linear program.
- The linear program was requested to provide strategies that met specific conditions, such as minimum cost for a particular air quality improvement.
- Test strategies were generated and passed to the Experts Panel to be evaluated in four aspects: **environmental, economic, technical, and socio-political**.







### Some key findings and accomplishments

#### The team\*:

- Modeled the air quality impacts from remote sources beyond the periphery of the MCMA that could not be assessed with simpler models.
- Improved the model of the mixing-layer heights based on the fluctuations in the vertical wind component. Previous models have considered only temperature profiles.
- Developed better techniques for extracting wind velocities from cross-correlation of elastic scattering lidar.
- Improved the emission inventories for the MCMA, showing that the hydrocarbons were severely underestimated.
- Found the average emissions of the cars in Mexico City were about three times higher than those measured in the US.
- Performed first-time measurement of the composition of the atmosphere over Mexico City, revealing that the hydrocarbon profile –previously unknown– was significantly different from the characteristic profiles of US cities.

#### \*The team

LANL, DOE, DOS, EPA, NCAR, NOAA, U of Denver, U of Utah, Carnegie Mellon U, U of Illinois, IBM.  
IMP, PEMEX, SEDESOL, DDF, EDOMEX, SSA, CAM, INE, CFE, UNAM, IIE, ININ, ITAM, IPN, SMN,  
SENEAM, CINVESTAV.

## IMADA – AVER

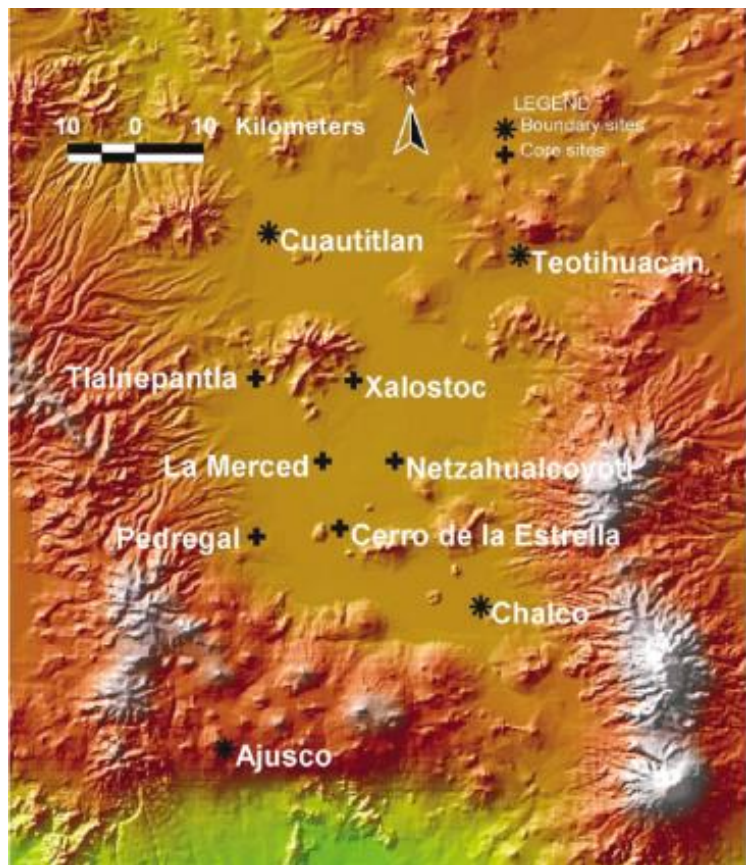
### Main Goals:

- To provide comprehensive information to explain the nature and causes of particulate concentrations and visibility impairment in and around Mexico City.
- To study spatial distribution, temporal variation, and intensity of PM<sub>2.5</sub> and PM<sub>10</sub> concentrations.
- To further characterize the major sources contributing to significant chemical components of PM<sub>10</sub>, PM<sub>2.5</sub>, and light extinction, including sources that directly emit particles and those that emit precursor gases for secondary aerosol formation.
- To measure and characterize the structure and evolution of the boundary layer and the nature of regional circulation patterns that determine the transport and diffusion of atmospheric contaminants in the Valle de Mexico.

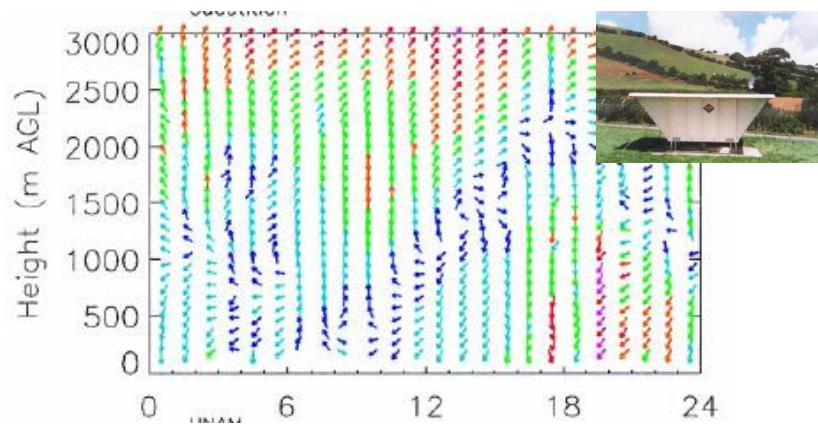
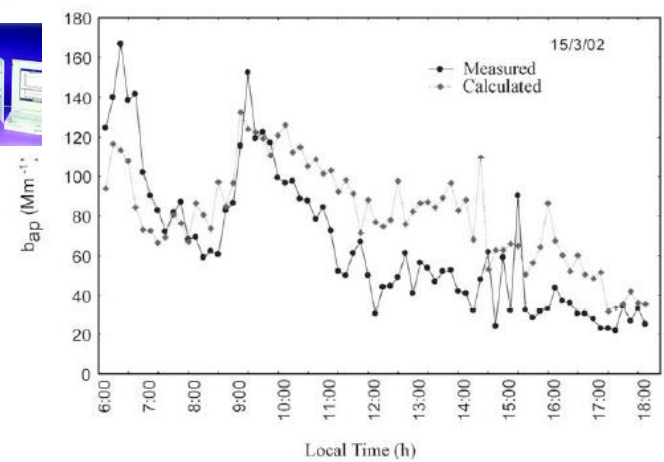
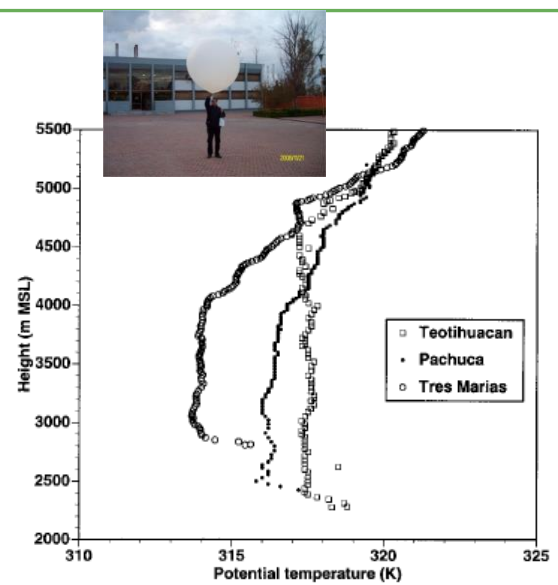
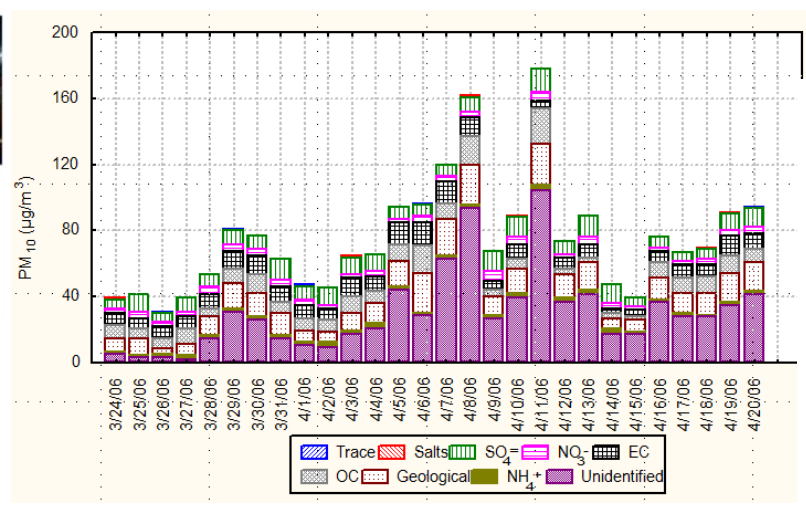
Bi-national collaboration project sponsored by DOE and PEMEX.



- Sampling locations were selected to represent regional, central city, commercial, residential, and industrial portions of the city.
- PM<sub>2.5</sub> and PM<sub>10</sub> were measured over 24-h intervals at six core sites and at 25 satellite sites in and around Mexico City.
- Total mass and chemical composition for PM<sub>10</sub> and PM<sub>2.5</sub> were determined: trace elements, ions (sulfate, nitrate, ammonium, soluble sodium, and soluble potassium), and carbon (organic and elemental).
- Canister samples for light hydrocarbon (C<sub>2</sub>-C<sub>10</sub>) gases
- Measurements of peroxyacetyl nitrate (PAN) were taken at a site north of the downtown area of the city at 30-min intervals
- Meteorological measurements on surface and aloft were deployed at different site locations, in and out the Mexico City: wind profilers, sodars, meteorological stations and rawinsondes.



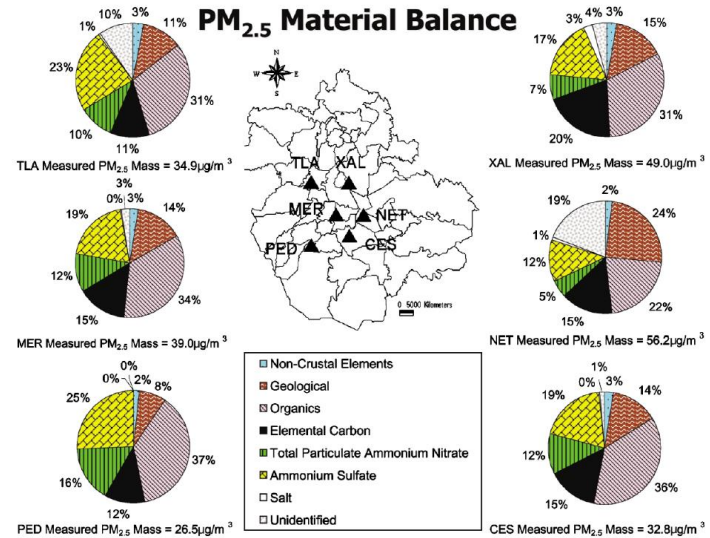
PM (+) and MET (\*) sampling and monitoring sites



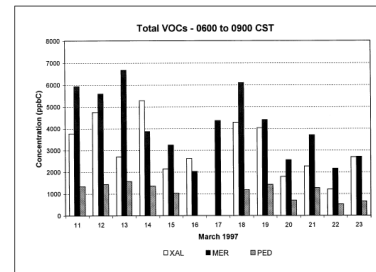
Chemical composition and optical properties of aerosols

Wind and temperature vertical profiles

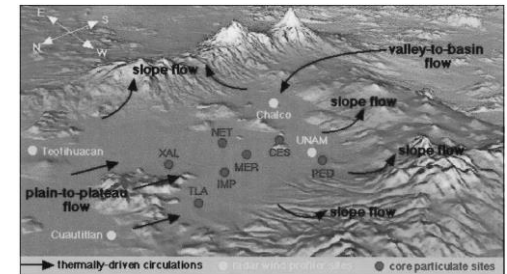
- Light scattering and absorption measurements at the downtown MER and suburban PED sites showed a high correlation with PM<sub>2.5</sub> concentrations and reduced visibility at both sites, particularly during the morning hours (0800–1100).
- The highest VOC concentrations occurred during the morning (0600–0900 CST). Average value 4106ppbC.
- PAN concentrations measured at IMP site were similar to those found in Los Angeles, CA, during the early 1970s. PAN levels exceeded 30 ppb on five of the days sampled and exceeded 10 ppb on all but a few days of the study.
- The IMADA-AVER was the first detailed examination of the planetary boundary layer in the Mexico City basin. Radar wind profilers, radiosondes, sodars, and surface stations were used to obtain a picture of the structure and evolution of the boundary layer.
- Regional flows entering the northern part of the valley had been identified earlier but were measured in far greater detail in this experiment than had previously been possible.



Material balance at the core sites during IMADA-AVER field Campaign.



VOC ambient concentration



Wind flow patterns identified during IMADA-AVER Project

## MILAGRO

- To examine the behavior and the export of atmospheric emissions from a megacity, relevant to the evolution and impacts of pollution from many other megacities.
  - To quantify the spatial and temporal extent of the urban plume
  - To analyze pollutant chemical and physical transformation in the plume
  - To quantify regional impacts of the plume
  - To examine the interaction of the plume with surrounding sources
- Mexico City Metropolitan Area as a Case Study
  - One of the world's largest megacity
  - North America's Most populous city
- MILAGRO encompasses four coordinated components performed simultaneously
  - **MCMA-2006: processes characterization inside the source**
  - **MAX-MEX: regional aerosol transformation downwind**
  - **MIRAGE-Mex: regional transport**
  - **INTEX-B: regional to global transport**
- International collaborative project (150 institutions in 30 countries and 450 scientists)



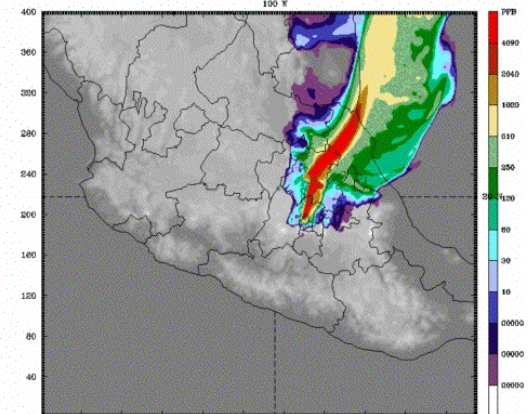
**INTEX-B**  
NASA DC-8  
-31, Satellites  
(NASA)

**MIRAGE-Mex**  
NSF C-130,  
Twin Otter, Supersite  
(NCAR)

**MAX-Mex**  
DOE G-1,  
King Air (2), Supersite  
(DOE-ASP)

**MCMA-2006**  
Supersites,  
Mobile Laboratories  
(MCE2)

Dataset: dom2 RIP: dom2 Init: 0000 UTC Sat 18 Mar 06  
Foot: 48.00 h Valid: 0000 UTC Mon 20 Mar 06 (1700 MST Sun 19 Mar 06)  
Terrain height AMEL  
Mass weighted c1 integral



Model Info: V2.1.1 M Fo Cu YSU PBL WSM Sclass Neat LEM 3.0 km, 27 levels, 20 sec  
LW: RRTM SW: Dudhia IOP: simple EM: ED Stragor

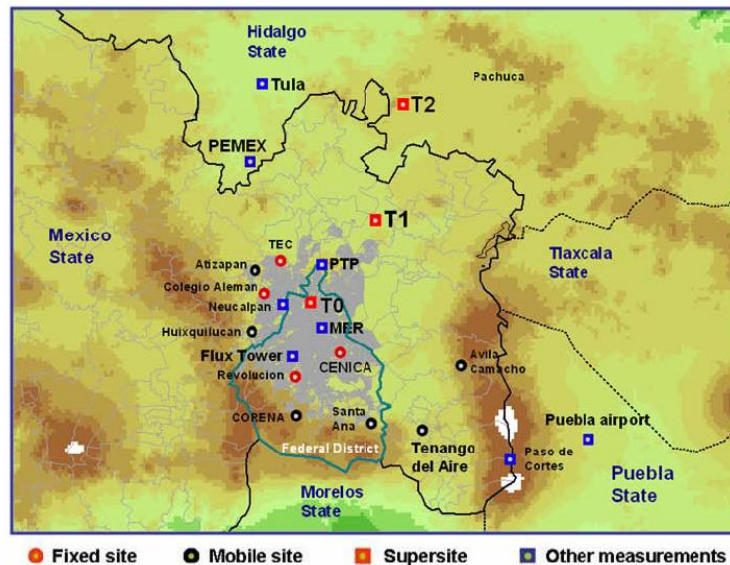
The measurements included a wide range of instruments at ground sites, on aircraft, and satellites.

Three supersites, spaced about 30 km apart to examine the pollutant plume evolution, were set up at:

- T0 (origin): Instituto Mexicano del Petróleo
- T1 (1<sup>st</sup> step): Universidad Tecnológica de Tecamac in the State of Mexico
- T2 (2<sup>nd</sup> step): Rancho La Bisnaga in the State of Hidalgo.

Additional platforms in or near Mexico City included:

- Mobile vans containing scientific laboratories
- Mobile and stationary upward-looking lidars
- Fixed mobile units located at the boundary sites to measure criteria pollutants and meteorological parameters.



**MCMA-2006: Ground-Based Measurement Sites**



Seven instrumented research aircraft participated in MILAGRO:

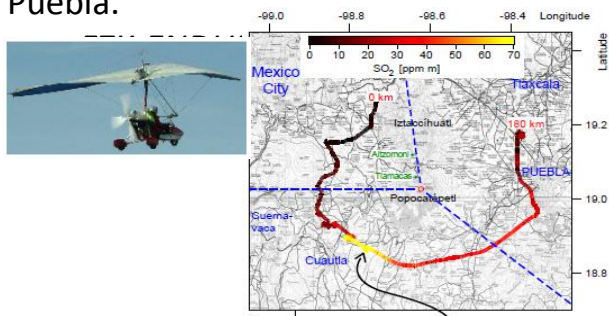
Five were based in Veracruz, Mexico:

- NCAR/NSF C-130
- DOE Gulfstream-1 (G-1)
- US Forest Service Twin Otter
- NASA J-31
- King Air

in Houston, Texas

- NASA DC-8

and at the Hermanos Serdan Airport near Huejotzingo, Puebla.



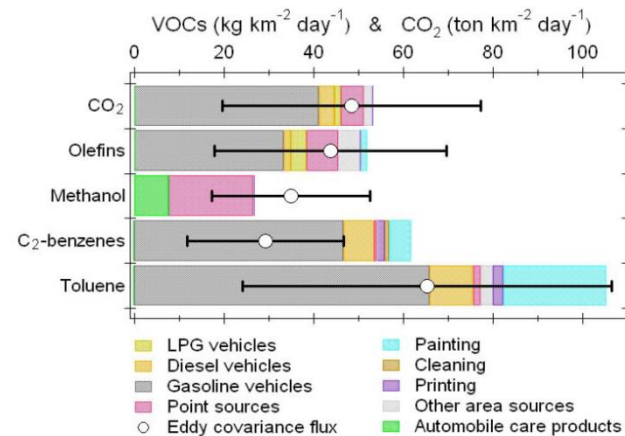
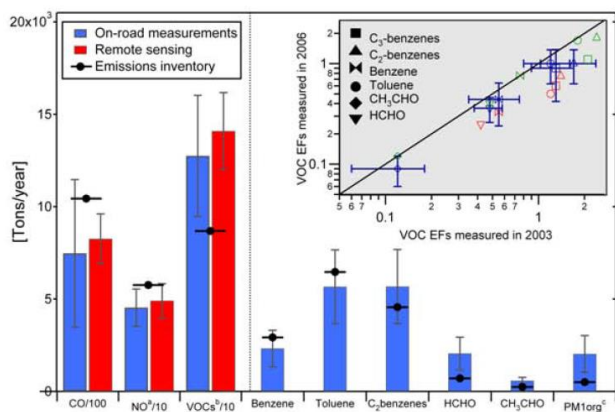
**SO2 measurements on board an ultra-light aircraft around Popocatepetl volcano.**

## Measured variables and processes:

- Meteorology and dynamics
- Emissions of gases and fine particulate matter
- Volatile organic compound: sources and ambient concentrations
- Urban and regional photochemistry
- Ambient particulate matter
- Aerosol optical properties and radiative influences
- Regional plume from INTEX-B flights over Mexico City and the Gulf
- Health studies

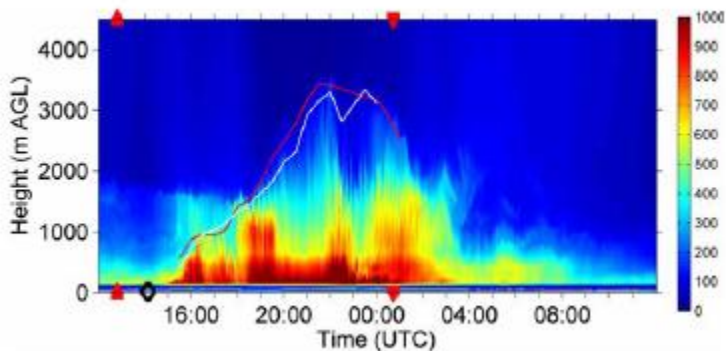




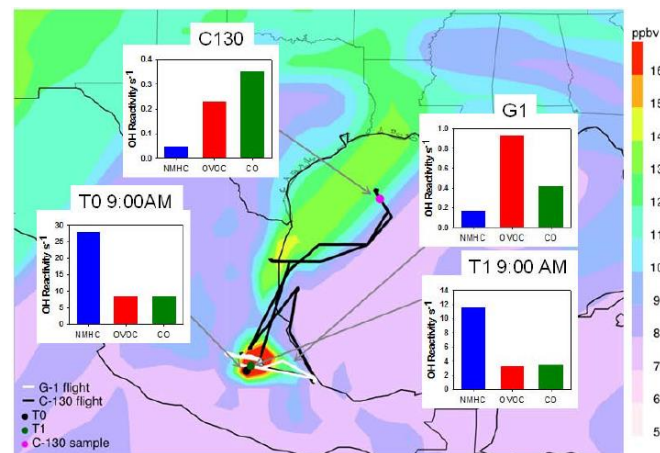


Comparison among LDGV on-road mobile emissions estimated during MILAGRO, remote sensing measurements and emission inventories.

Average fluxes measurements compared to the disaggregated emissions inventory.



Mixing Layer evolution as a backscatter signal on 9 March 2006 for the lidar deployed at the T1 site



CO simulation of the urban plume and carbon-containing compounds speciation measured at G-1 and C130 planes.

- The rate of ozone production from HO<sub>2</sub> radicals and the observed rate of ozone production from all production mechanisms are among the highest observed anywhere.
- Biomass burning was found to have a significant influence on regional chemistry, contributing more than half of the organic aerosol and about one third of the benzene, reactive nitrogen, and carbon monoxide to the regional outflow.
- Aerosol contributions from biomass burning sources contained both black carbon and oxidized organics that yielded enhanced UV absorption. This observation indicated biomass burning activities can have important impacts on the absorption or heating by carbonaceous aerosols in megacity, urban as well as regional scales.
- Surface and airborne lidars, as well as airborne meteorological measurements have shown multiple layers of particulate matter resulting from complex mixing processes over central Mexico
- Many hydrocarbon emissions show greater enhancement ratios to CO in the MCMA than the US due to the widespread use of LPG and higher industrial and evaporative emissions of aromatics in Mexico City.
- The Popocatepetl volcano has very limited impacts on the air quality in the MCMA because of the elevation of the emissions and the vertical stratification in the wind flows. However, these impacts can be larger at regional scales.

