Overview: Megacity Aerosol Experiment-Mexico City (MAX-Mex)

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University of Arkansas at Little Rock

Second MILAGRO Science Team Meeting
Mexico City, Mexico, DF
Tuesday May 15, 2007
Megacity Initiative - Local and Global Research Observations

**MCMA-2006** – *Mexico City Metropolitan Area* – 2006
- Lead Scientist – Luisa Molina (Molina Center for Energy and Environment, MIT)
- Adrian Fernandez – Instituto Nacional de Ecologia

**MAX-Mex** – *Megacity Aerosol Experiment* – *Mexico City*
- DOE: Lead Scientist, Jeff Gaffney (ANL, UALR)
- Program Manager, Rickey Petty

**MIRAGE-Mex** – *Megacity Impacts on Regional and Global Environments* – *Mexico City*
- NSF: Lead Scientist, Sasha Madronich (NCAR)
- Program Manager, Anne-Marie Schmoltner

**INTEX-B** – *Intercontinental Chemical Transport Experiment (NASA, NSF)*
- NASA: Lead Scientist, Hanwant Singh
- Program Manager, Bruce Doddridge
Radiative Forcing by Tropospheric Aerosols
Uncertainties in Global Climate Predictions

Global Mean Radiative Forcing of the Climate System for the Year 2000, Relative to 1750

Largest uncertainties associated with aerosols and clouds (IPCC 2001)
Objectives of ASP

http://www.asp.bnl.gov

Aerosol radiative forcing of climate:

• Enhance scientific knowledge needed to represent radiative forcing and other climatic influences of aerosols in climate models

Characterize, understand, and develop model representation of:

• Sources of particles and gaseous precursors
• Aerosol transformations
• Local and regional transport of particles and gaseous precursors
• Concentrations of gas-phase aerosol precursors
• Chemical, optical, microphysical, and cloud nucleating properties of aerosols
• Aerosol influences on atmospheric radiation
Aerosol Influences on Radiation and Climate

*Direct Shortwave Radiative Effects (Clear air)*
- Light scattering – Cooling influence
- Light absorption – Warming influence, depending on surface

*Indirect Shortwave Radiative Effects – Aerosols influence cloud properties*
- More droplets – Brighter clouds
- More droplets – Enhanced cloud lifetime
- More droplets – Broadening of drop distribution – warming

*Semi-Direct Shortwave Radiative Effect*
- Absorbing aerosol heats air and evaporates clouds

*Longwave Radiative Effect (Clear sky)*
- Greenhouse effect of aerosol particles

*Hydrological Effects*
- Suppressed surface evaporation - spinning down the water cycle
- Displaced precipitation - clouds last longer or evaporate
Megacities

**Megacities**

*Population >10 Million*

- 1950 – 1 (NYC)
- 1995 – 14
- 2015 – 21

**Mini – Megacities**

*5 Million – 10 Million*

- 1995 – 7
- 2015 – 37

**Asia – Africa**

2/3 rural to 1/2 urban by 2025

*National Geographic*
Megacities and mini-megacities are major sources

Need to better characterize aerosol properties and evolution for models.

- Size, composition, size dependent composition, optical properties, cloud-nucleating properties.

*High concentrations of aerosols and precursors*

- **Carbonaceous aerosols**: organic and black carbon; primary and secondary; fossil, biofuel, and biogenic; fossil and biogenic precursors

- **Inorganics**: sulfate, nitrate and precursors $\text{SO}_2$, $\text{NO}_x$.

These sources will be changing over time as cities develop and technologies evolve.
Mexico City

Ideal Field Study Opportunity

- World’s 2\textsuperscript{nd} largest megacity
- Largest megacity in North America
- Basin meteorology - complex terrain
- Infrastructure connections!
- Size reasonable for aircraft and ground study
- Preliminary ground field studies - 1997 & 2003
Characterize aerosol size-dependent composition

   Internal mixture vs external mixture
   Water uptake dependence on relative humidity

Characterize aerosol optical properties and dependence on controlling variables

   Composition, size dependence, size-dependent composition, humidity
   Effects of chemical processing/aging
   Contribution of BC and species other than BC to absorption

Characterize aerosol cloud nucleating properties and dependence on controlling variables

   Composition, size dependence, size-dependent composition, humidity
   Effects of chemical processing/aging
Characterize and quantify secondary aerosol formation and aerosol evolution

- New particle formation vs condensational growth
- Role of coagulation in modifying size and composition distribution
- Mechanism(s) of new particle formation and responsible species
- Dependence on gas-phase precursors

Urban vs regional vs global impacts – Effects of transport and scale for aerosol forcing

- Spatial Impacts – Horizontal and Vertical – Temporal
Operational rawinsondes (NSF): supplemented to 4 per day at Veracruz and Mexico City and 2 per day at Acapulco

Aircraft operations: Veracruz – NASA at Houston

Radar wind profilers: T0, T1, T2, Veracruz

Microwave radiometer: T0

GPS radiosondes: T1, T2

Tethersonde: T1

Micropulse Lidar: T1

J. Fast, PNNL
Geographic Relation of Projects

- DC-8
- C-130
- G-1 (DOE)
- King-Air
- J-31

Intercontinental Scale
- INTEX-B
- MIRAGE-Mex
- MAX-Mex
- MCMA

Local Scale
- Houston Operations Center
- Veracruz Operations Center

250 km

terrain height (meters)

J. Fast, PNNL
<table>
<thead>
<tr>
<th>Institution/Location</th>
<th>Instrumentation</th>
<th>Description</th>
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<tr>
<td>UALR/ANL</td>
<td>Aethalometer (7 channel)</td>
<td>BC Aerosol absorption</td>
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<tr>
<td>UALR/ANL</td>
<td>Multi-angle Absorption</td>
<td>BC Aerosol absorption</td>
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<tr>
<td>UALR/ANL</td>
<td>Nephelometer 3 wavelength</td>
<td>particle scattering</td>
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<tr>
<td>UALR/ANL</td>
<td>Nephelometer 1 wavelength dry</td>
<td>dry particle scattering</td>
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<tr>
<td>UALR/ANL</td>
<td>Nephelometer 1 wavelength wet</td>
<td>wet particle scattering</td>
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<td>UALR/ANL</td>
<td>Filter Sampler</td>
<td>OC/EC, humic like substances</td>
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<td>UALR/ANL</td>
<td>Open path NIR TDLAS</td>
<td>NH3</td>
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<td>UALR/ANL</td>
<td>Filter Sampler</td>
<td>14C, 40K, 210Pb, 7Be, 210Po, 210Bi,</td>
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<td>UALR/ANL</td>
<td>RB Meter</td>
<td>UVB</td>
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<tr>
<td>UALR/ANL</td>
<td>Weather Station</td>
<td>wind speed/dir., rain, temp, press, RH</td>
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<td>BNL</td>
<td>CCN Counter</td>
<td>cloud condensation nuclei</td>
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<tr>
<td>BNL</td>
<td>Scanning Mobility Particle Sizer</td>
<td>aerosol size distributions</td>
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<td>DRI, U of Nev, Reno</td>
<td>Photoacoustic Spect.</td>
<td>aerosol absorption</td>
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<td>PNNL</td>
<td>MFRSR</td>
<td>radiation, aerosol optical depth</td>
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<td>PNNL</td>
<td>Solar Tracker</td>
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<td>PNNL/EMSL</td>
<td>DRUM Aerosol Sampler</td>
<td>sampling for PIXE/PESA/STEM</td>
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<td>PNNL/EMSL</td>
<td>TRAC Aerosol Sampler</td>
<td>sampling for TEM, SEM/EDX analysis</td>
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<tr>
<td>Aerodyne Res. Inc.</td>
<td>ARI H.R. TOF-AMS/soft ions</td>
<td>non-refractory fine PM size &amp; comp.</td>
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<td>University of Colorado</td>
<td>High Res. TOF-AMS</td>
<td>aerosol size and composition</td>
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<td>University of Colorado</td>
<td>Thermal Denuder</td>
<td>aerosol volatility before AMS</td>
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<td>University of Colorado</td>
<td>Aerosol Concentrator</td>
<td>aerosol concentration before AMS</td>
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<tr>
<td>University of Colorado</td>
<td>Optical Particle Counter</td>
<td>aerosol size, number (Grimm 1.109)</td>
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<td>University of Colorado</td>
<td>TSI SMPS</td>
<td>particle size distribution</td>
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<td>University of Colorado</td>
<td>TSI nano-SMPS</td>
<td>nanoparticle size distribution</td>
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<tr>
<td>University of Colorado</td>
<td>TSI DustTrak</td>
<td>aerosol concentration</td>
</tr>
</tbody>
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ASP G-1 Research Aircraft Facility Layout

PCASP, CAPS – PNNL, BNL: Senum, Hubbe
State – PNNL: Hubbe
PTRMS - EMSL: Alexander, Ortega
AMS - Aerodyne, EMSL: Alexander, Jayne
Peroxides - SUNY, BNL: Lloyd, Bowerman
VOCs – York: Hubbe, Rudolf
PILS – BNL: Lee

CO, NO, NO₂, NO₃, O₃, SO₂ – BNL: Springston, Senum
PSAP, Neph, CNCs – PNNL: Group
TSEMs – BNL: Wang
MFRs – PNNL: Barnard
SPSP – DMT, CIRPAS: Kok, Jonsson, Senum
Balloons – PNNL: Zaveri, Hubbe
Data – PNNL, BNL: Hubbe, Springston, Senum
Base: Veracruz
Airborne High Spectral Resolution Lidar (HSRL)

NASA King Air
Sampling Strategy a Success

- T1/T2 transport scenario occurred on 4-5 days during March 2006.
- Simulated downwind plume in good agreement with observations.

Strong ambient SW flow aloft decreases during day.

WRF-chem Particulate Volume Prediction
21 UTC 20 March, ~990 m AGL

Wind Profiles and PBL at T1, 20 March

G-1 data provided by Stephen Springston, BNL

G-1 Aircraft Data 20 - 23 UTC

Radar Wind Profiler

Simulated, WRF

J. Fast, PNNL
Aerosol Composition Comparison

Aerosol Mass Spectrometer Measurements from G-1

Eastern U.S. Regional Pollution

Mexico City Urban

- Eastern U.S. episodes - sulfate dominated
- Mexico urban aerosol - organic dominated, with nitrate

L. Kleinman, BNL
**Aerosol Absorption:** Note the day to day variability in the peak absorption, probably due to meteorology.

**Aerosol Scattering:** peaks later in the day than absorption, due to dust, OC, secondary organic aerosol, and inorganics. (W. Patrick Arnott, U. Nev. Reno)
Layering of Aerosols above T1

Aerosols lofted from Boundary Layer into Lower Troposphere

Wind Profiler

Ground-Based Micropulse Lidar
(Lidar return amplitude)

R. Coulter, ANL
Determination of Aerosol Type

Aerosol types inferred from HSRL measurements Over Mexico City (MC) during INTEX-B/MILAGRO

- West side of MC basin
  - High extinction/backscatter ratio, low depolarization: urban pollution

- East side of MC basin
  - Low extinction/backscatter ratio, high depolarization: dust

Hostetler, Ferrare NASA
B200/ HSRL Field Missions in 2006

MAXMex/MILAGRO/INTEX-B
DOE-NSF-NASA-Mexico
March 1-30

15 science flights, 55 flight hr
- 5 flights with J-31
- 6 flights with G-1
- 4 flights with C-130
- 5 MISR coincidences
- 10 MODIS coincidences

Hostetler, Ferrare NASA

CALIPSO Validation
June 14 – Aug 10

10 CALIPSO validation flights
- 6 flights in “Early Phase” starting immediately after CALIPSO configured for science ops (14-30 June)
- 4 flights as part of CCVEX (July-Aug)

TexAQS II/GoMACCS
NOAA-DOE-NASA
Aug 27 – Sep 29

22 science flights, 90 flight hr
- 7 flights with NOAA WP-3
- 6 flights with NOAA Twin Otter
- 7 flights with CIRPAS Twin Otter
- 2 flights over the RHB
- 4 MISR LM coincidences
- 14 MODIS coincidences
Aerosol Intensive Parameters derived from HSRL data

- **MILAGRO (Mexico)**
  - higher depolarization, smaller color ratio, smaller $S_a$
  - larger, more non-spherical
  - dominated by “dust”

- **GOMACCS (Houston)/CALIPSO (Eastern U.S.)**
  - smaller depolarization, higher color ratio, larger $S_a$
  - smaller, more spherical
  - dominated by “urban/biomass”

Hostetler, Ferrare NASA
Aerosol Venting into Free Troposphere

Lidar measurements confirm earlier DOE / ASP modeling studies

Models are being used to determine the effect of venting on aerosol evolution and radiative forcing

Hostetler, Ferrare NASA; J. Fast, PNNL
Use of Satellite Measurements

Satellite and Aircraft Intercomparisons for Biomass Burning and Dust Events

- Very dry conditions contributed to higher-than-normal biomass burning events.
- Mixing of anthropogenic and biomass burning particles.

- Aircraft measurements permit determination of the height of particles downwind of Mexico City and the relative contribution of anthropogenic and biomass burning sources to aerosol optical depth.

**Fires**

MODIS/Aqua
5 March 2006

**Aerosol Optical Depth**

MODIS/Terra
19 March 2006

provided by Allen Chu, NASA
Aerosol Absorption – Changes due to Secondary Organic Aerosols and Biomass Burning

2003 – Mexico City

Departure from $1/\lambda$ behavior of 370 nm / 880 nm ratios for broadband absorbers. Note changes in aerosol absorption ratio vs time of day:

AM (2400 – 1200) and PM (1200 – 2400)

MODIS satellite image showing wildfires April 18, 2003

- Satellite data MODIS indicated that plumes from Yucatan fires impacted the Valley of Mexico during this time in April 2003.
- $^{14}$C is consistent with transport from Yucatan to Mexico City during same time period.
- $^{7}$Be is produced in upper troposphere. Low levels are consistent with little upper air transport and mixing during this period.
- $^{14}$C contributions could also be from SOA from natural hydrocarbons and from “biomass trash burning”

$^{14}$C results show 70% biogenic carbon in aerosols in Mexico City samples during end of April 2003. 4/21-4/27

Marley/Gaffney UALR
New particle formation was frequently observed. New particles exhibited variable hygroscopicity indicating external mixture.
Publications – Atmospheric Chemistry and Physics (ACPD and ACP) Special Issues

The T1-T2 study: evolution of aerosol properties downwind of Mexico City

A meteorological overview of the MILAGRO field campaigns
Anticipated Further Analyses and Results

- Examination of size-dependent aerosol composition as function of “age” subsequent to emission and chemical processing.
- Attribution of changes in size-dependent composition to specific processes.
- Quantification of secondary organic aerosol production.
- Comparison of properties of biomass burn and urban soot aerosols.
- Examination of dust events and dust interactions with urban aerosol.
- Examination of hygroscopic growth, CCN properties, and precipitation scavenging in relation to aerosol properties.
- Quantitative description of aerosol transport.
- Examination of evolution of composition and optical properties of black carbon and secondary organic aerosol.
- Evaluation of performance of current models.
- Development of new and/or improved treatments of aerosol processes.

VERY RICH DATA SET!
MAX-Mex and MILAGRO Continue

Data: Final Data Sets – March 2007
MILAGRO Science Meeting – October 2006
Publications – Atmospheric Chemistry and Physics (ACPD and ACP)
Special Issues
EGU Symposium – Vienna, Austria (April 16-20, 2007)
MILAGRO Science Team Meeting (Mexico City – May 15-20, 2007)
AGU Symposium – Acapulco, Mexico (May 22-25, 2007)

Acknowledgments
ASP MAX-MEX Science Team
Pilots and ASP Science Support personnel
MILAGRO Participants
Our Mexican Hosts – INE, CENICA, SENEAM, IMP, UT Tecamac

THE PROJECT WAS CARRIED OUT SAFELY WITH NO INCIDENTS.
Albedo:

- Morning rush hour.
  - Large amounts of black carbon aerosol.
- Secondary Organic Aerosol formation (UV+VOCs)
Albedo:

Morning rush hour. Large amounts of black carbon aerosol.

Regional Mixing Increases