

**MIRAGE-Mex**  
**Megacities Impacts on**  
**Regional And Global Environments**  
**Mexico City case study**

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*Atmospheric Chemistry Division*  
*National Center for Atmospheric Research*  
*Boulder, Colorado USA*

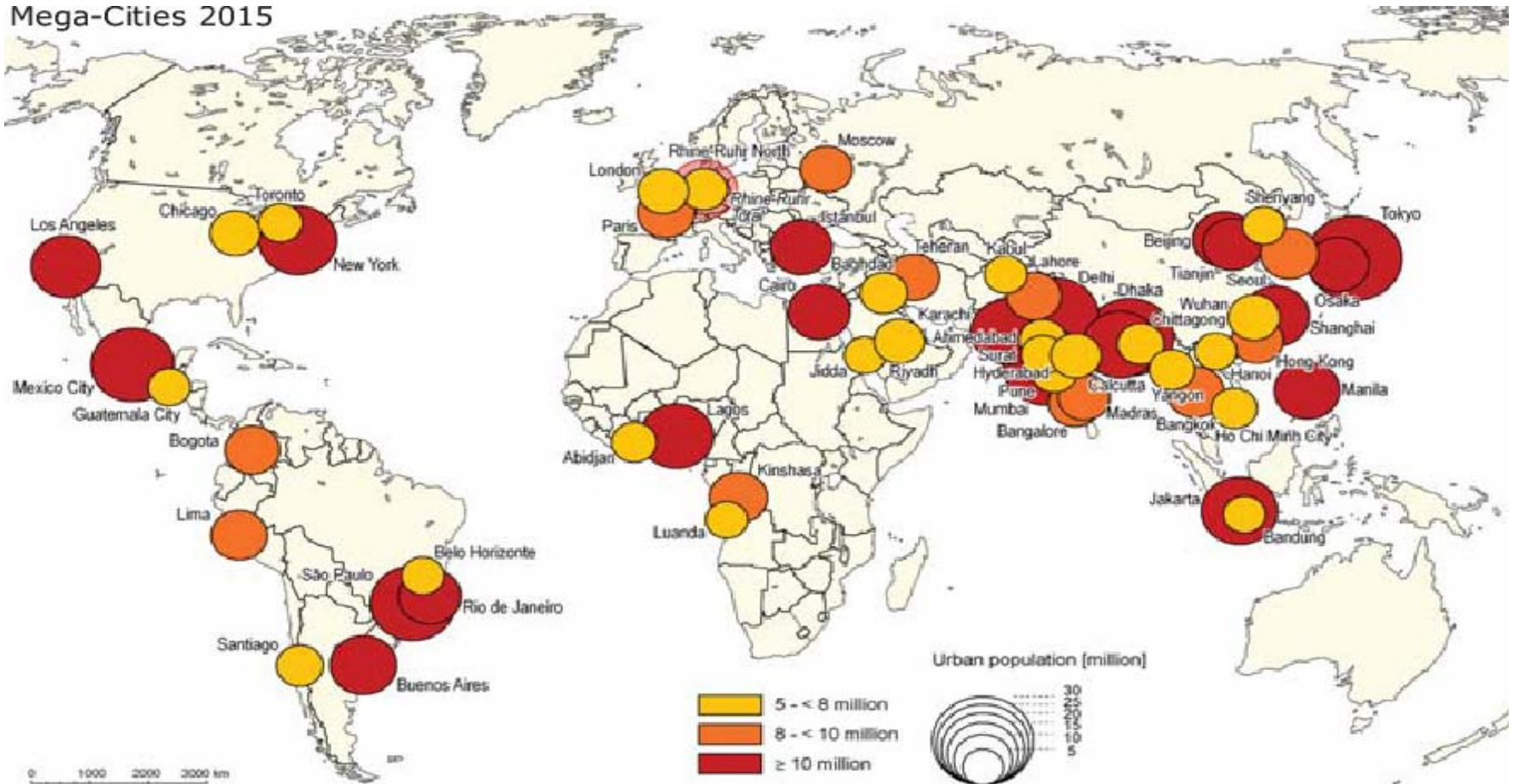
*2<sup>nd</sup> MILAGRO Science Meeting, Mexico City, 15 May 2007*



**NCAR**

# Global Urbanization

Mega-Cities 2015



Source: UN 2002; Draft: F. Kraas; Cartography: R. Spohner

# FUNDAMENTAL HYPOTHESES

- The polluted outflow from a **single megacity** is sufficiently reactive to affect the regional atmosphere and environment.
- The polluted outflow from **all urban areas**, taken together, affects the global atmosphere and environment, and will do so increasingly in the future.

# ENVIRONMENTAL CONCERNS

## ➤ **Regional and global air quality**

- Human health
- Impacts on agriculture and natural ecosystems
- Deteriorating visibility

## ➤ **Climate change**

- Increases in tropospheric O<sub>3</sub>
- Direct radiative effects of aerosols
- Indirect aerosol effects on clouds and precipitation

## ➤ **Tropospheric self-cleaning (oxidizing) capacity**

- Changes in atmospheric residence times of other climatically important gases (CH<sub>4</sub>, HCFC's...)
- Changes in spatial distributions (SO<sub>2</sub>, NO<sub>x</sub>, ...)

# SCIENCE OBJECTIVES ... quantify:

## 1. Geographical extent and temporal persistence of the urban plume:

- characterization of regional air quality
- comparisons to background air
- unique chemical signatures?

## 2. Regional oxidants production:

- O<sub>3</sub>, peroxides, acids, radicals
- Alterations of photochemistry by aerosol heterogeneous and radiative processes

# SCIENCE OBJECTIVES ... quantify:

## 3. Hydrocarbon oxidation products:

- Evolution of long-lived intermediates, e.g. acetone
- Impacts on regional HOx and NOx partitioning and budgets
- Secondary organic aerosol formation
- Removal mechanisms

## 4. Reactive nitrogen:

- Lifetime of NOx
- Differential fate of reservoirs:
  - o *HNO<sub>3</sub> – soluble, sensitive to aerosols and clouds*
  - o *PANs – thermally decomposed, sensitive to temperature*
  - o *Alkyl nitrates – long-lived, potentially important to global NOx*

# SCIENCE OBJECTIVES ... quantify:

## 5. Gas-aerosol chemical processes:

- New particle formation
- Condensation from gas phase
- Oxidation
- Microphysical properties, effects on clouds
- Feedbacks on gas phase (removal, photolysis)

## 6. Aerosol radiative properties:

- Evolution of optical properties, absorption vs. scattering
- Internal vs. external mixture
- Vertical radiation profiles

## 7. Regional surface-atmosphere interactions:

- Background air composition
- Urban plume + fire emissions
- Urban plume + biogenic emissions

# MIRAGE-Mex Measurement Strategy

- **Coordination with other programs**
  - RAMA, MCMA-2006, MAXMex, INTEX-B, satellites
- **Surface measurements near Mexico City**
  - T1 (U. Tecamac), mobile labs
- **Aircraft measurements 0-500 km downwind**
  - NSF/NCAR C-130
- **Aircraft measurements near fires**
  - NSF/USFS Twin Otter
- **Modeling**
  - Process models
  - Regional and global models



# Measurements at T1 Supersite

**Gases:** O<sub>3</sub>, H<sub>2</sub>O<sub>2</sub>, NO, NO<sub>2</sub>, NO<sub>x</sub>, NO<sub>y</sub>, HNO<sub>3</sub>, total RONO<sub>2</sub>, total PANs, OH, HO<sub>2</sub>+RO<sub>2</sub>, NH<sub>3</sub>, SO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub>, H<sub>2</sub>, CO, CO<sub>2</sub>, speciated HCs, CH<sub>2</sub>O, carbonyls, OVOCs, Hg, O<sub>3</sub> sondes

**Aerosols:** PM<sub>10</sub>, PM<sub>2.5</sub>, size distributions, ions, BC, OC/EC, speciated organics, bulk soluble organics, HULIS, PAHs, Hg, radionuclides; size-resolved non-refractory composition, absorption and scattering, size-resolved hygroscopicity, volatility, and mixing state, lidar profiler, surface tension, morphology, optical depths

**Physical:** Surface met, sensible and latent heat fluxes, wind profiler, rh and T soundings, spectral actinic flux, filter radiometers, trajectory-following balloons

# NSF/NCAR C-130

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Base en Veracruz. Mediciones de gases, partículas, radiación



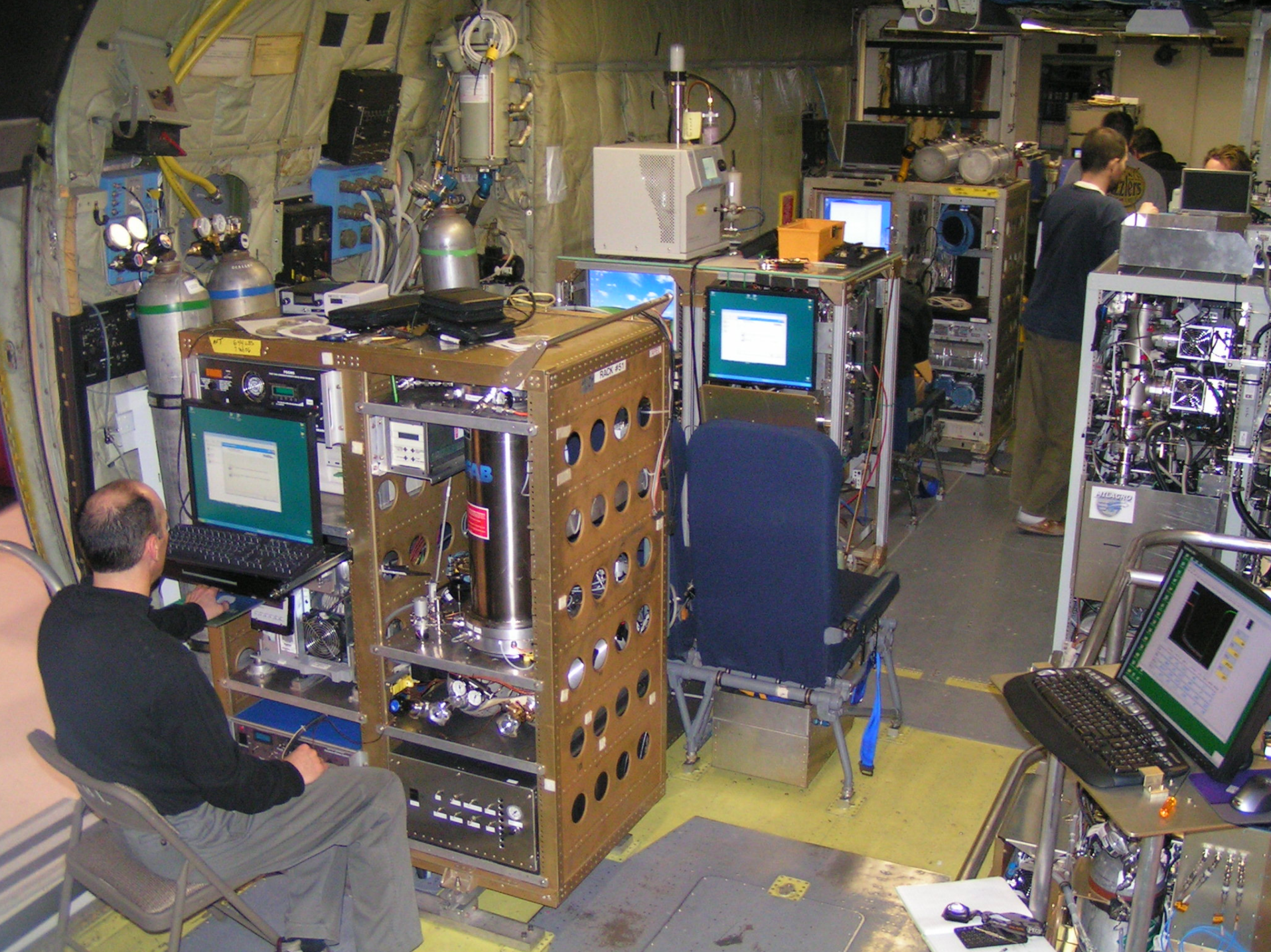


# MEASUREMENTS FROM C-130

**Gases:** H<sub>2</sub>O, O<sub>3</sub>, H<sub>2</sub>O<sub>2</sub>, NO, NO<sub>2</sub>, NO<sub>y</sub>, HNO<sub>3</sub>, HNO<sub>4</sub>, RONO<sub>2</sub>, total PANs, OH, HO<sub>2</sub>+RO<sub>2</sub>, NH<sub>3</sub>, SO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub>, DMS, OCS, MSA, H<sub>2</sub>, CO, CO<sub>2</sub>, speciated HCs, MtBE, halogenated organics, CH<sub>2</sub>O, OVOCs, CH<sub>3</sub>OOH, organic acids, HCN

**Aerosols:** size distributions, CN, CCN, bulk soluble organics, size-resolved non-refractory composition, absorption and scattering, size-resolved hygroscopicity, volatility, and mixing state, single particle soot mass, organic filters, morphology

**Physical:** Lat, lon, z, P, T, RH, IR, VIS, UV-A, spectral actinic flux, aerosol lidar



# DATA QUALITY: In-flight Intercomparison of measurements



**C-130**



**DC-8**



**C-130**



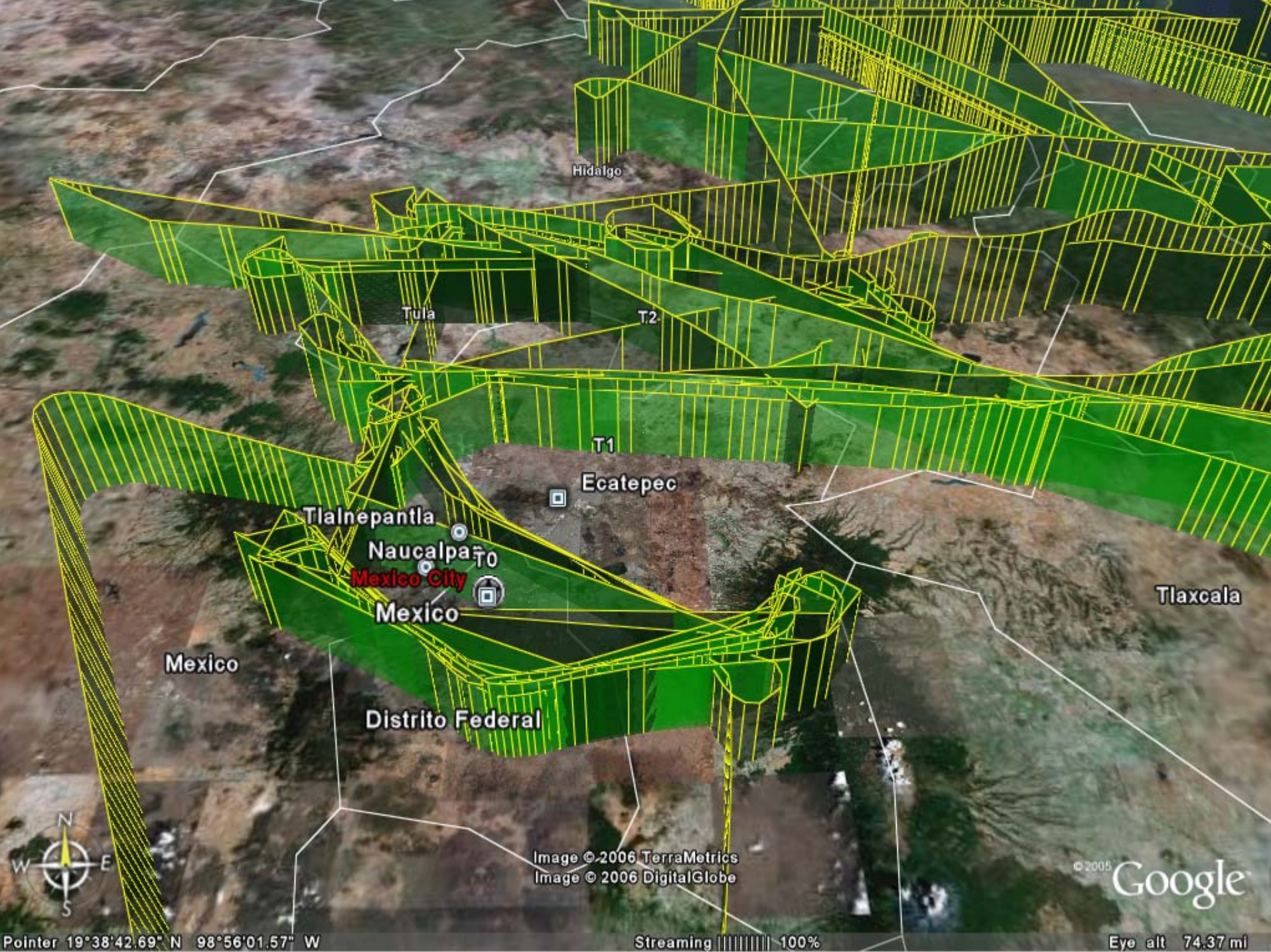
**G-1**

# C-130 FLIGHTS



Image © 2006 TerraMetrics  
Image © 2006 NASA

© 2005 Google



Hidalgo

Tula

T2

T1

Ecatepec

Tlaxcala

Tlalnepantla

Naucalpan

Mexico City

Mexico

Mexico

Distrito Federal

Image © 2006 TerraMetrics  
Image © 2006 DigitalGlobe

© 2005 Google



Pointer 19°38'42.69" N 98°56'01.57" W

Streaming 100%

Eye alt 74.37 mi

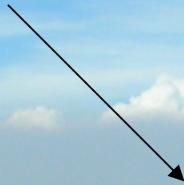
Inside México City  
Benito Juárez Airport



18 March 2006

# Looking toward México City from the south

urban pollution



clean air



18 March 2006



Fires in the hills just south of México City



dust



18 March 2006

# Pollution layer over the Gulf of México

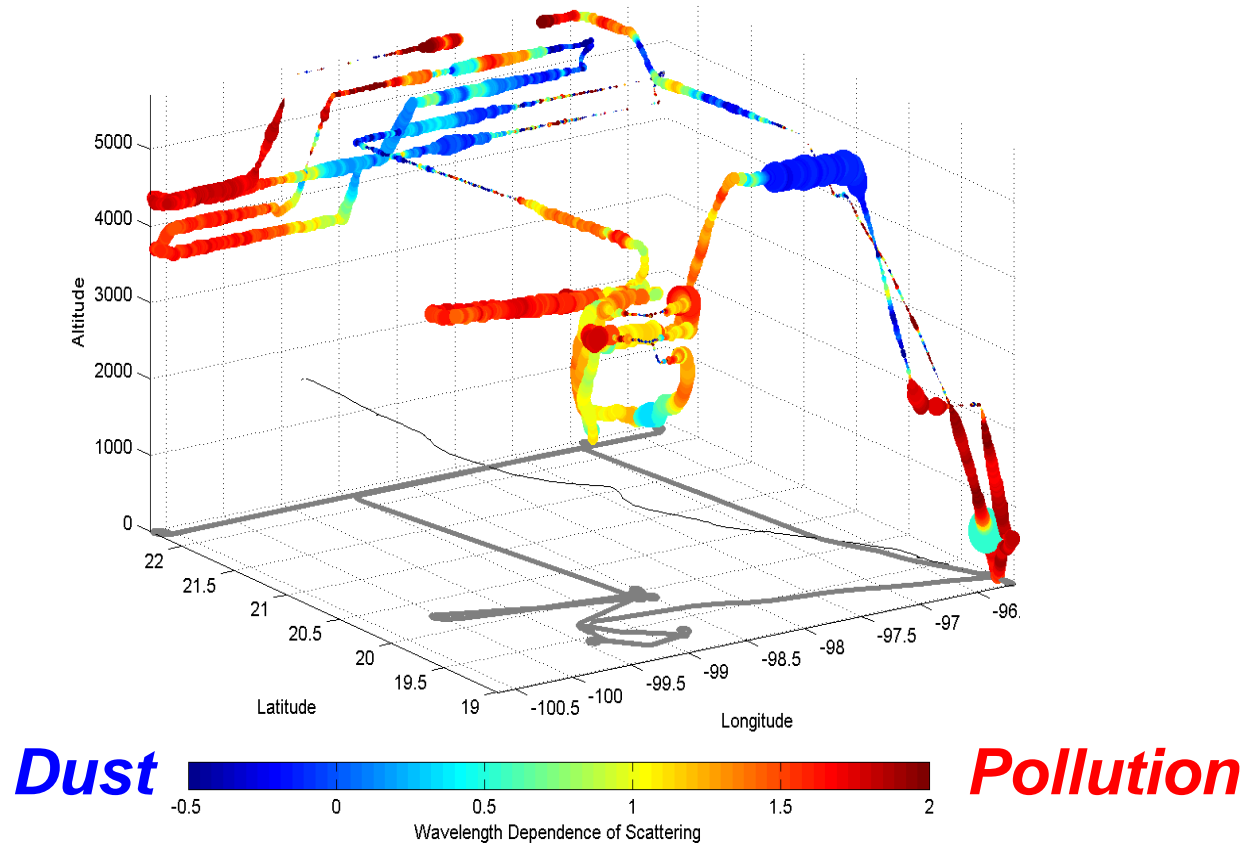


18 March 2006

# Aerosol Optical Properties

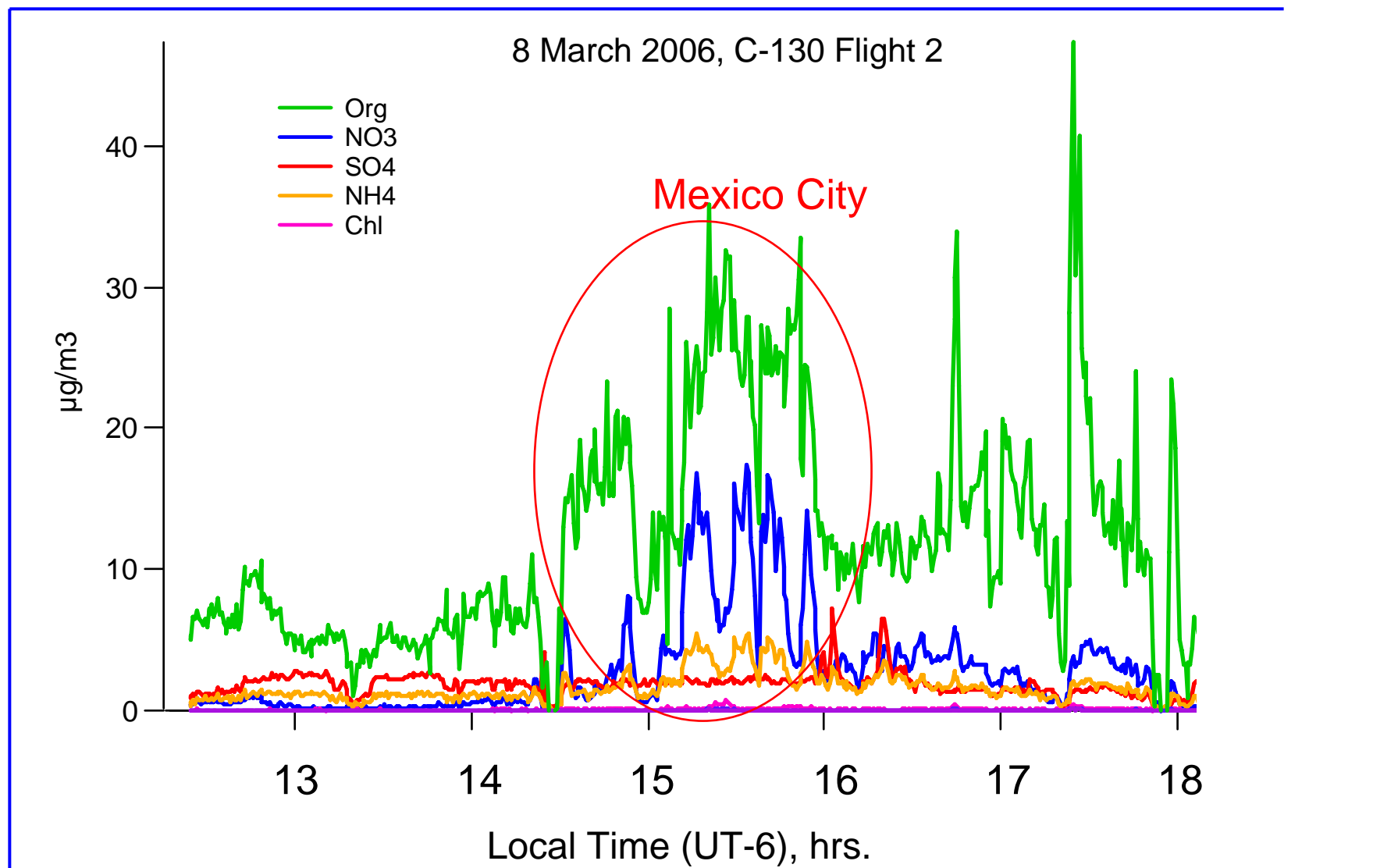
18 March 2006 C-130 Flight 6

Wavelength  
dependence  
of scattering



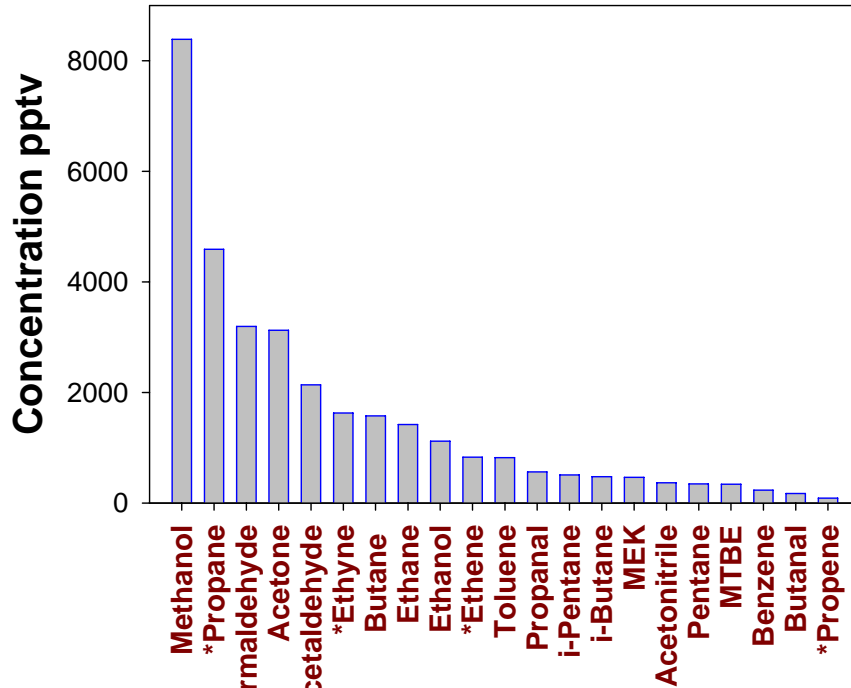
MIFlight06\_200603183d2dfiightrackwormscav2\_noinserf.fig, proplot3d2dfiightrackwormscav2.m, Yohei, 2007-04-19

# Organics Dominate Aerosol Chemistry



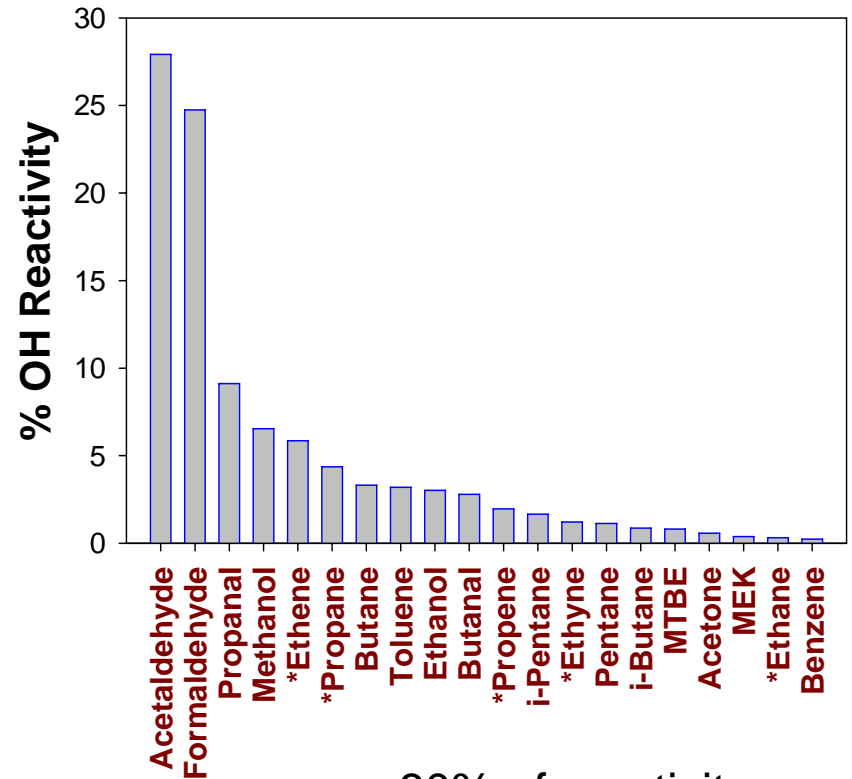
# VOC Abundance and Reactivity in Mexico City C-130 Overflights

## VOC Abundance



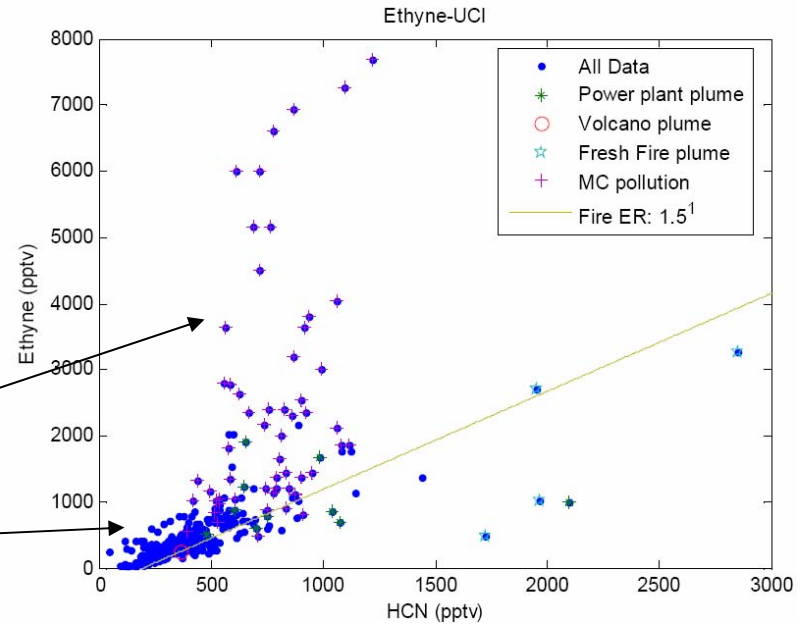
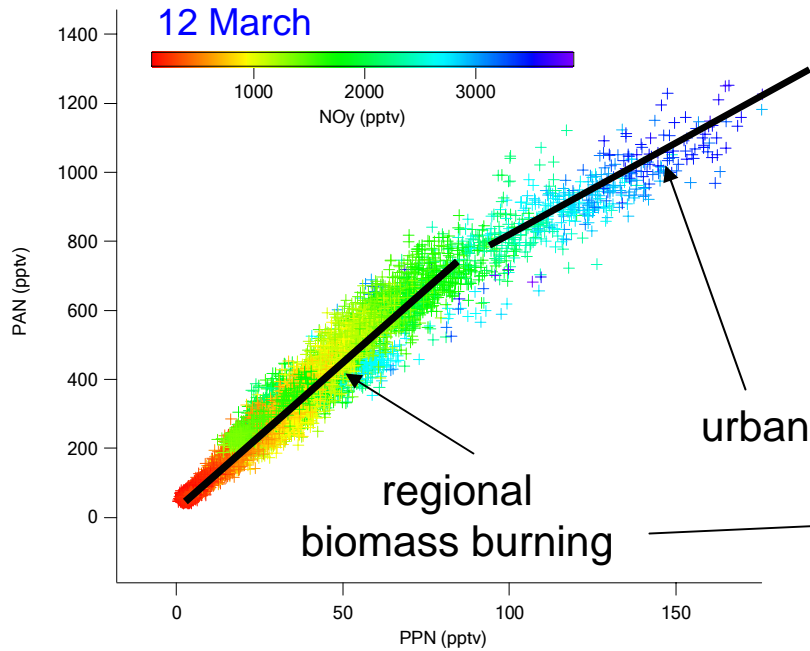
high methanol

## VOC K<sub>OH</sub> Reactivity



60% of reactivity  
from aldehydes

# BIOMASS BURNING vs. URBAN



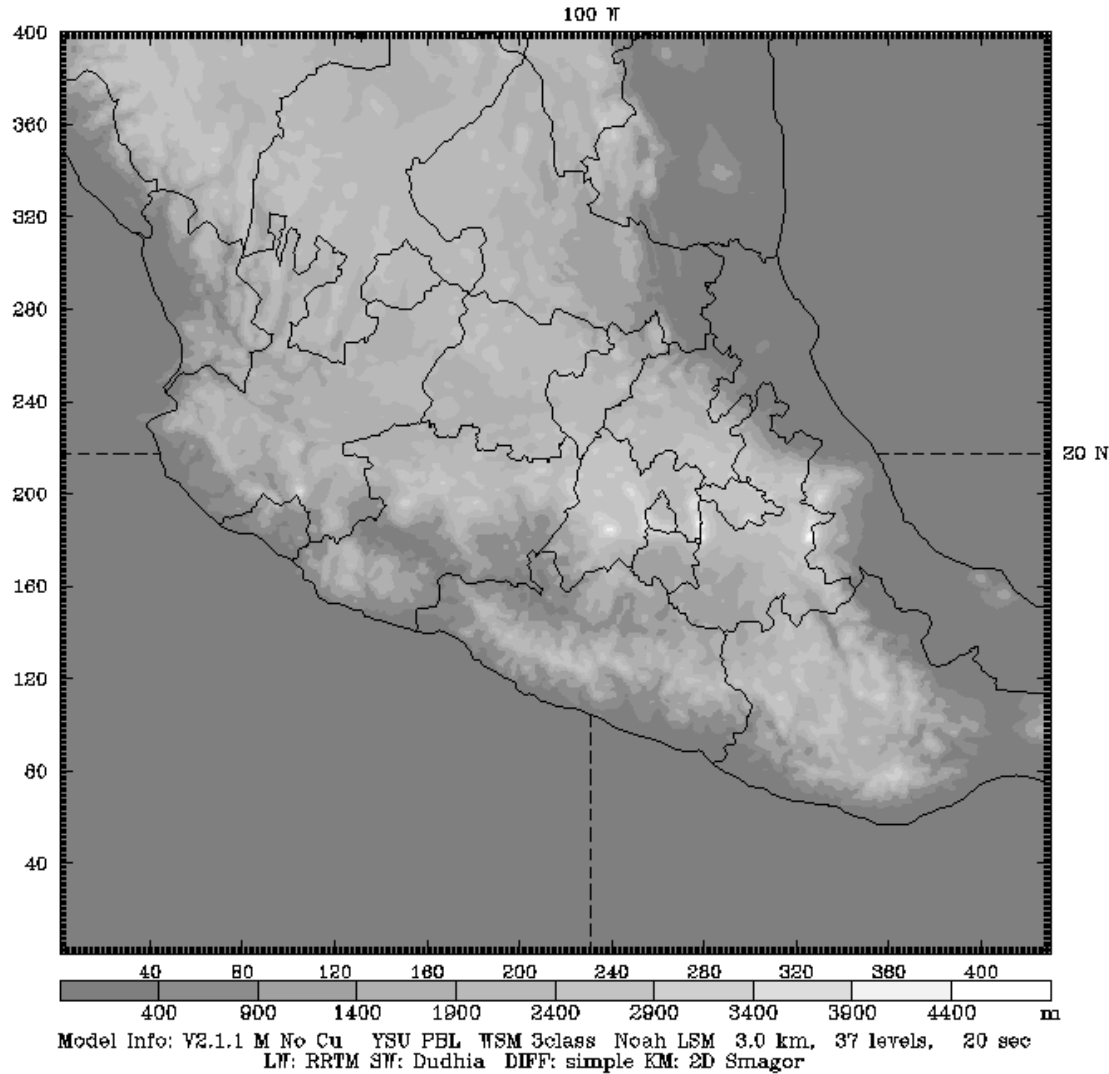
*F. Flocke, W. Zheng*

*J. Crouse, D. McCabe, P. Wennberg,  
E. Atlas, D. Blake*

Dataset: dom2 RIP: dom2  
Fest: .00 h  
Terrain height AMSL  
Mass weighted c1 integral

Init: 0000 UTC Sat 18 Mar 06  
Valid: 0000 UTC Sat 18 Mar 06 (1700 MST Fri 17 Mar 06)

2006  
17 March  
18:00



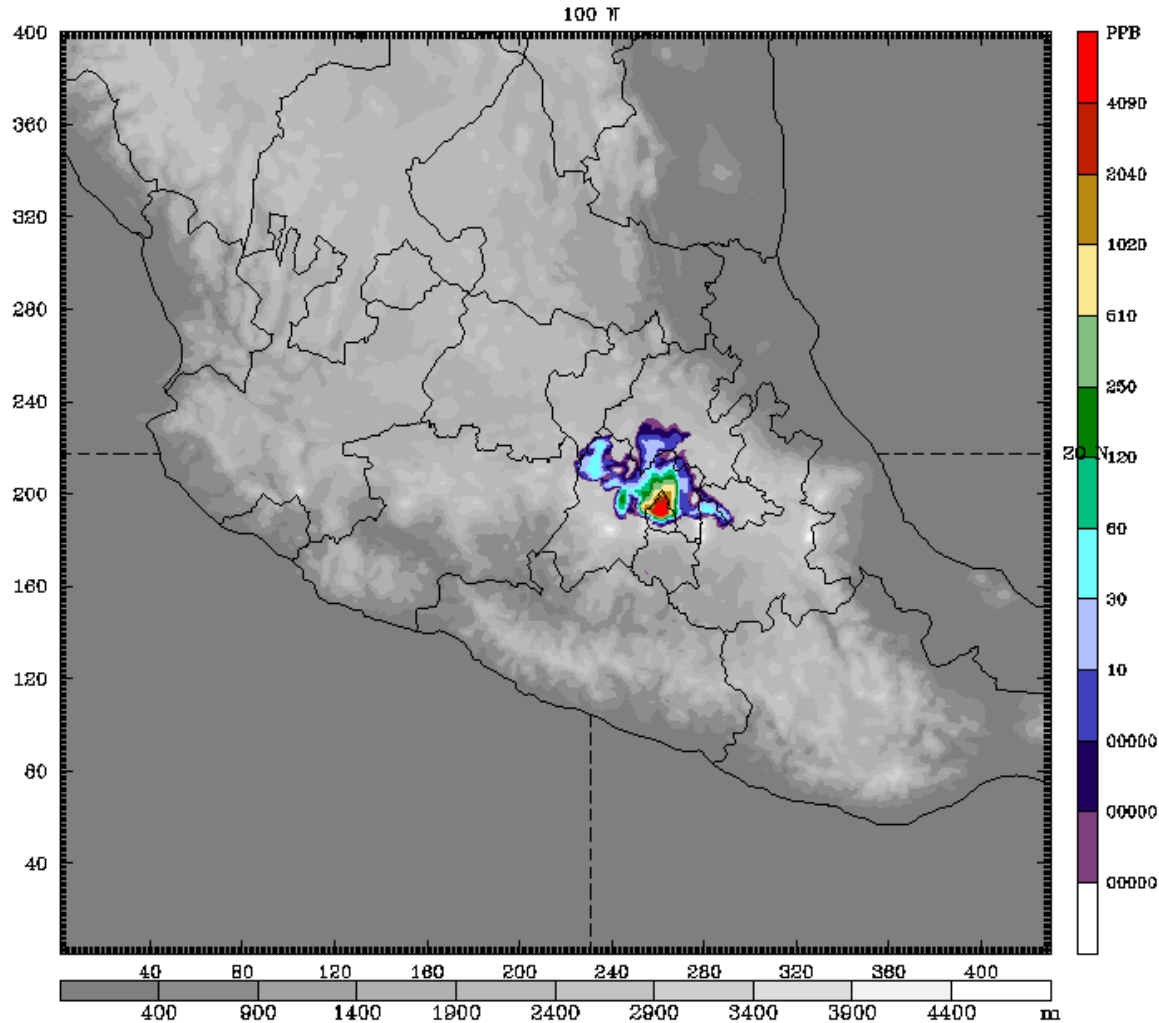
WRF model – 3 km resolution

*Skamarock et al.*

Dataset: dom2 RIP: dom2  
Fest: 3.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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2006  
17 March  
21:00

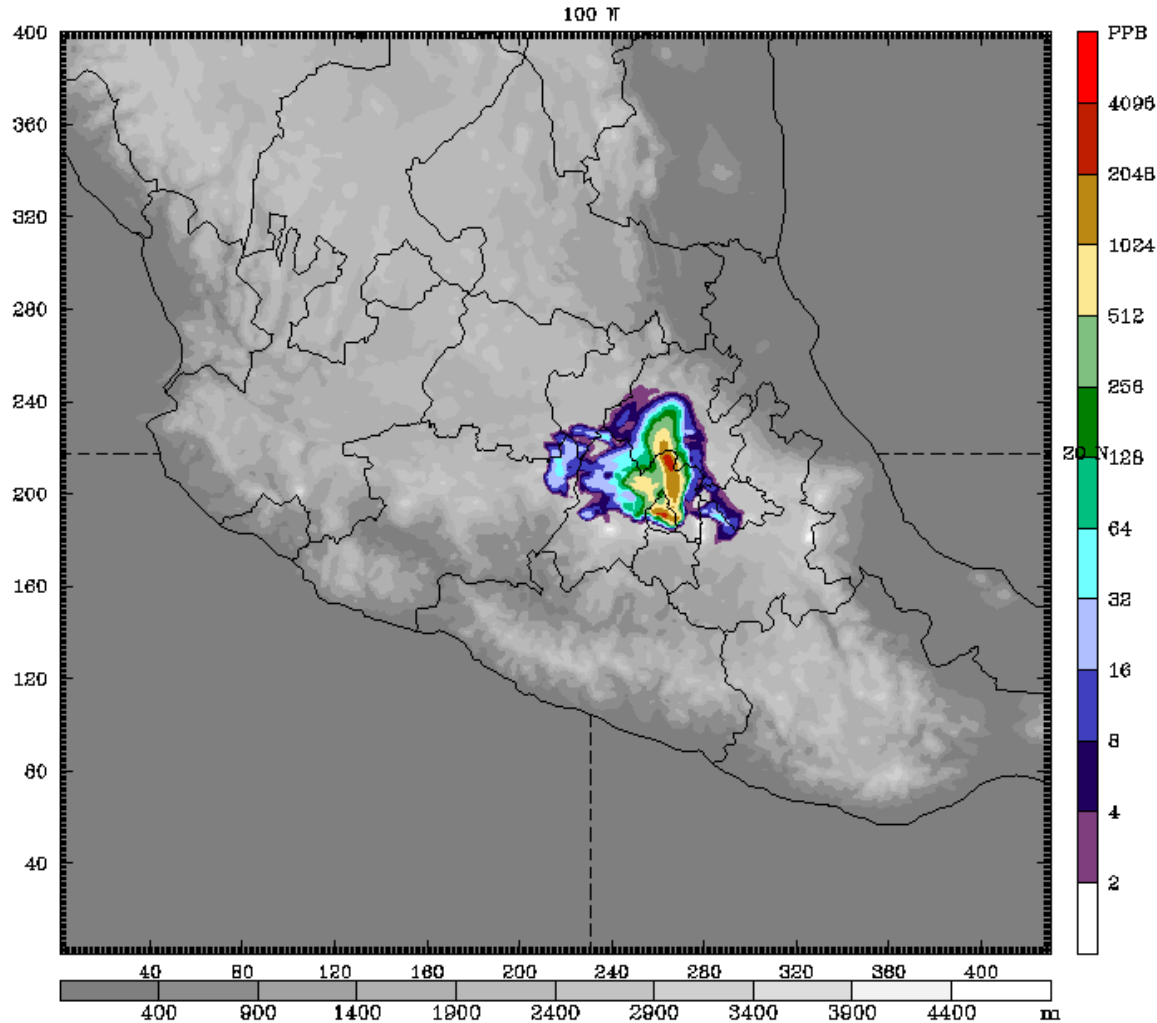


Model Info: V2.1.1 M No Cu YSU PBL WSM 3class Noah LSM 3.0 km, 37 levels, 20 sec  
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Dataset: dom2 RIP: dom2  
Fest: 6.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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18 March  
00:00

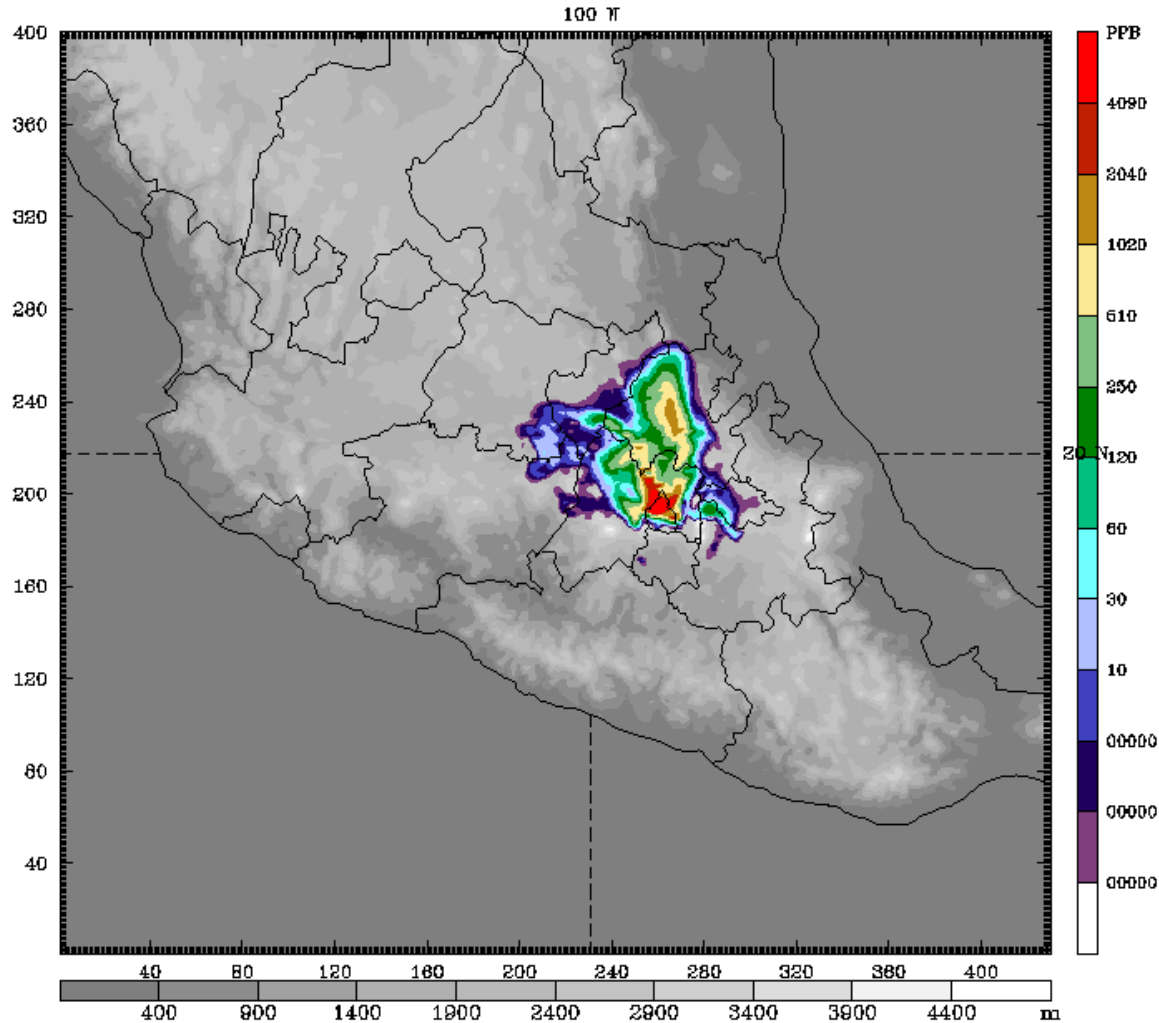


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Dataset: dom2 RIP: dom2  
Fest: 9.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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2006  
18 March  
03:00

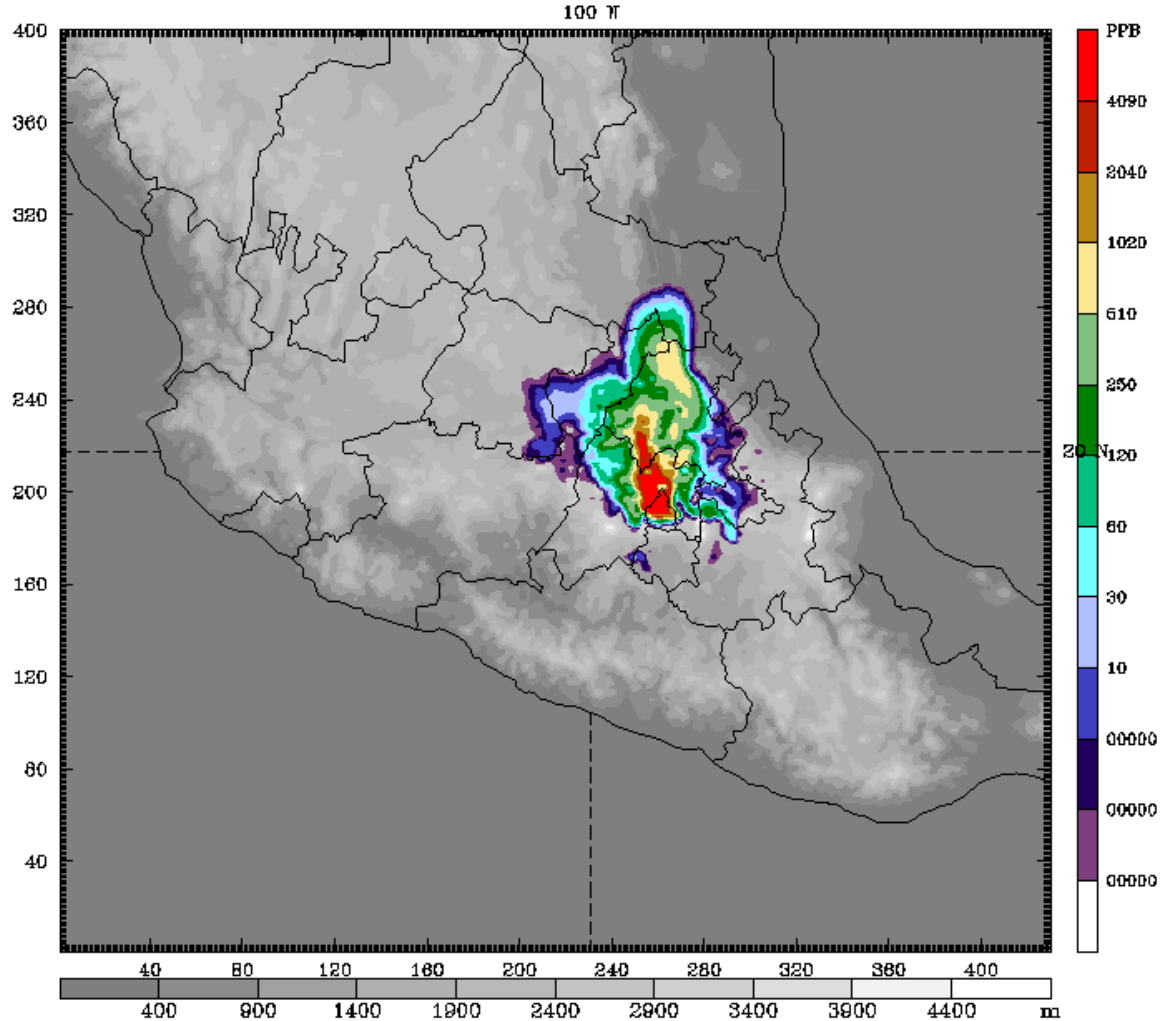


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Dataset: dom2 RIP: dom2  
Fest: 12.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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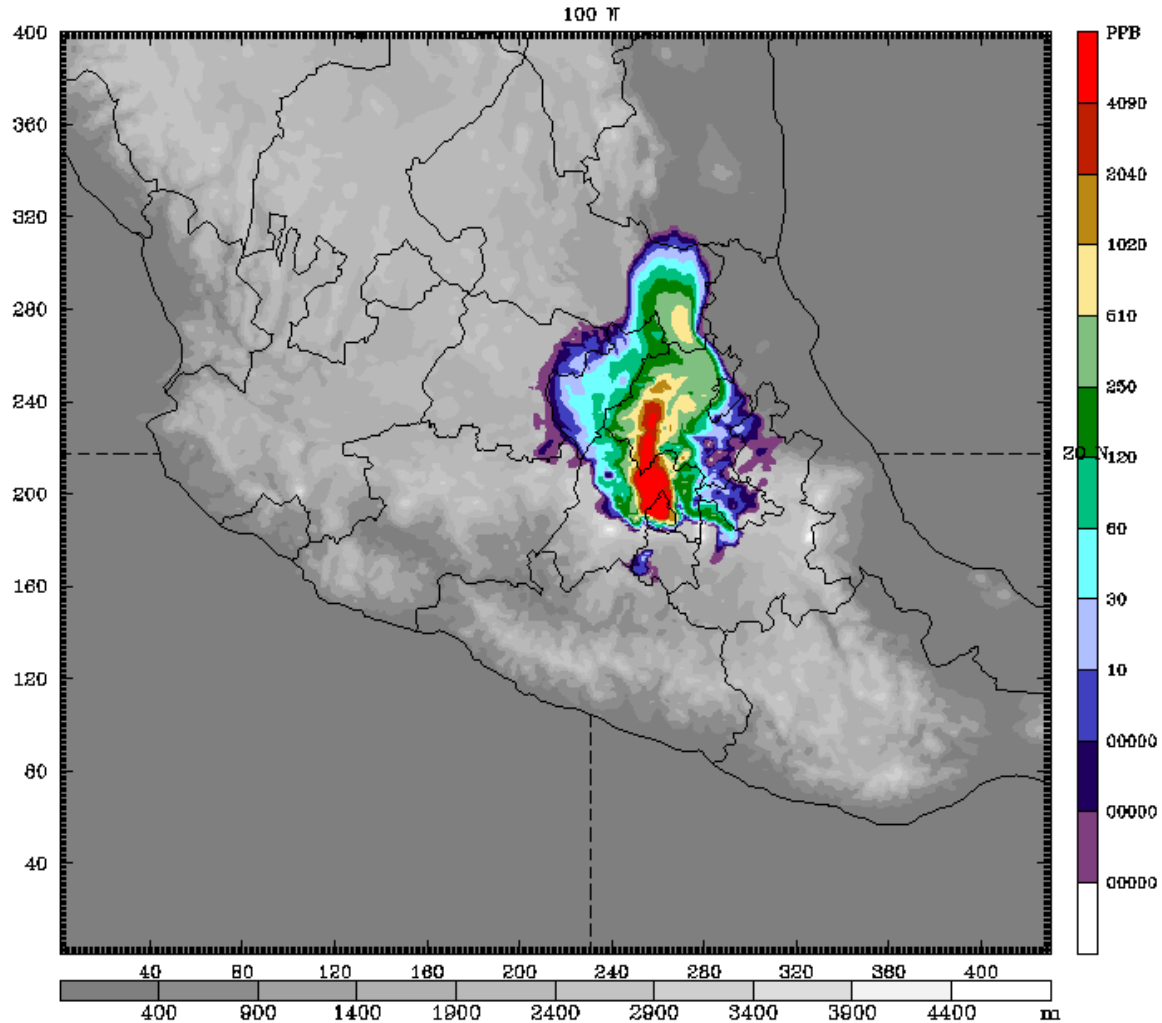


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Dataset: dom2 RIP: dom2  
Fest: 15.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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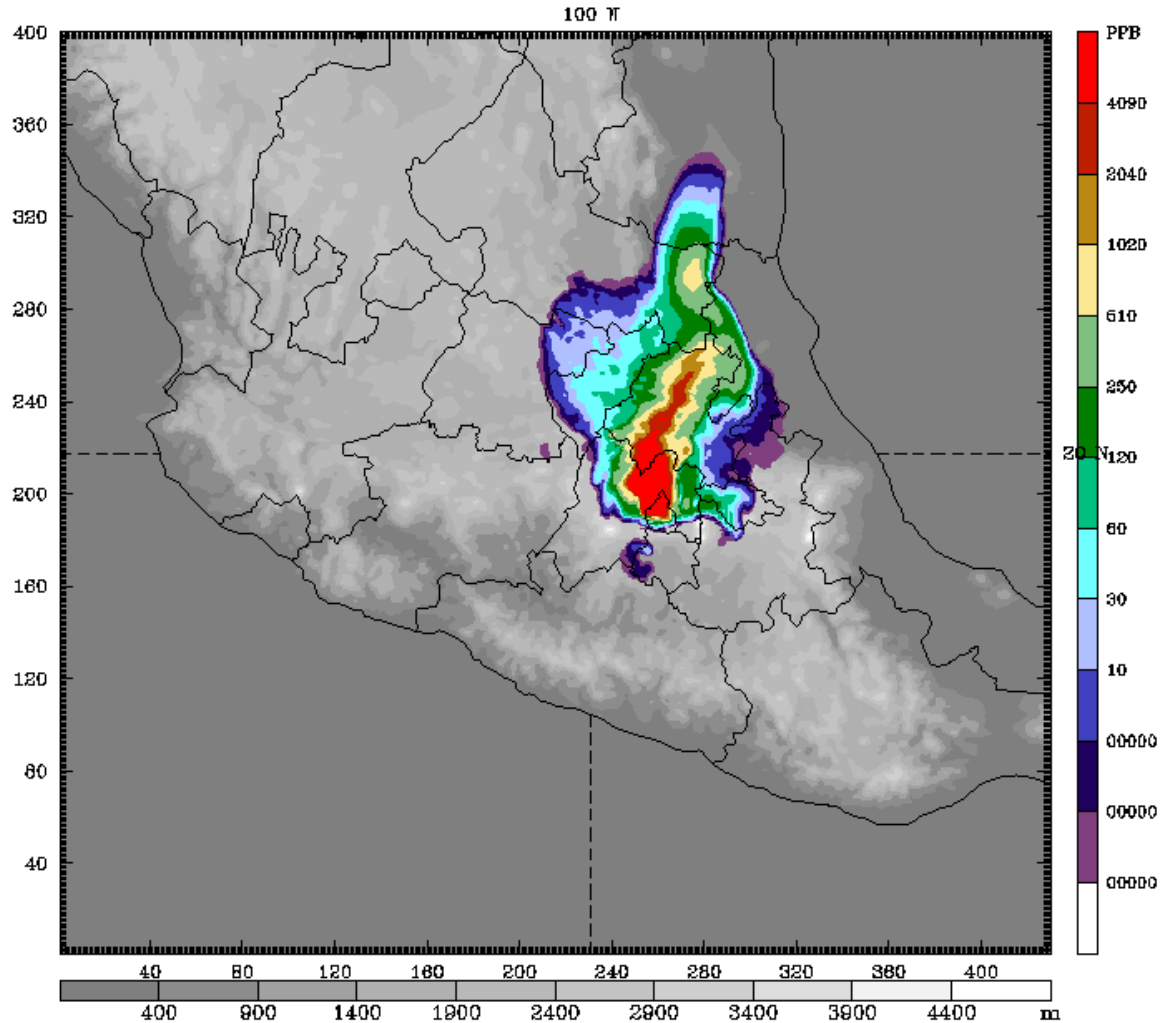


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Terrain height AMSL  
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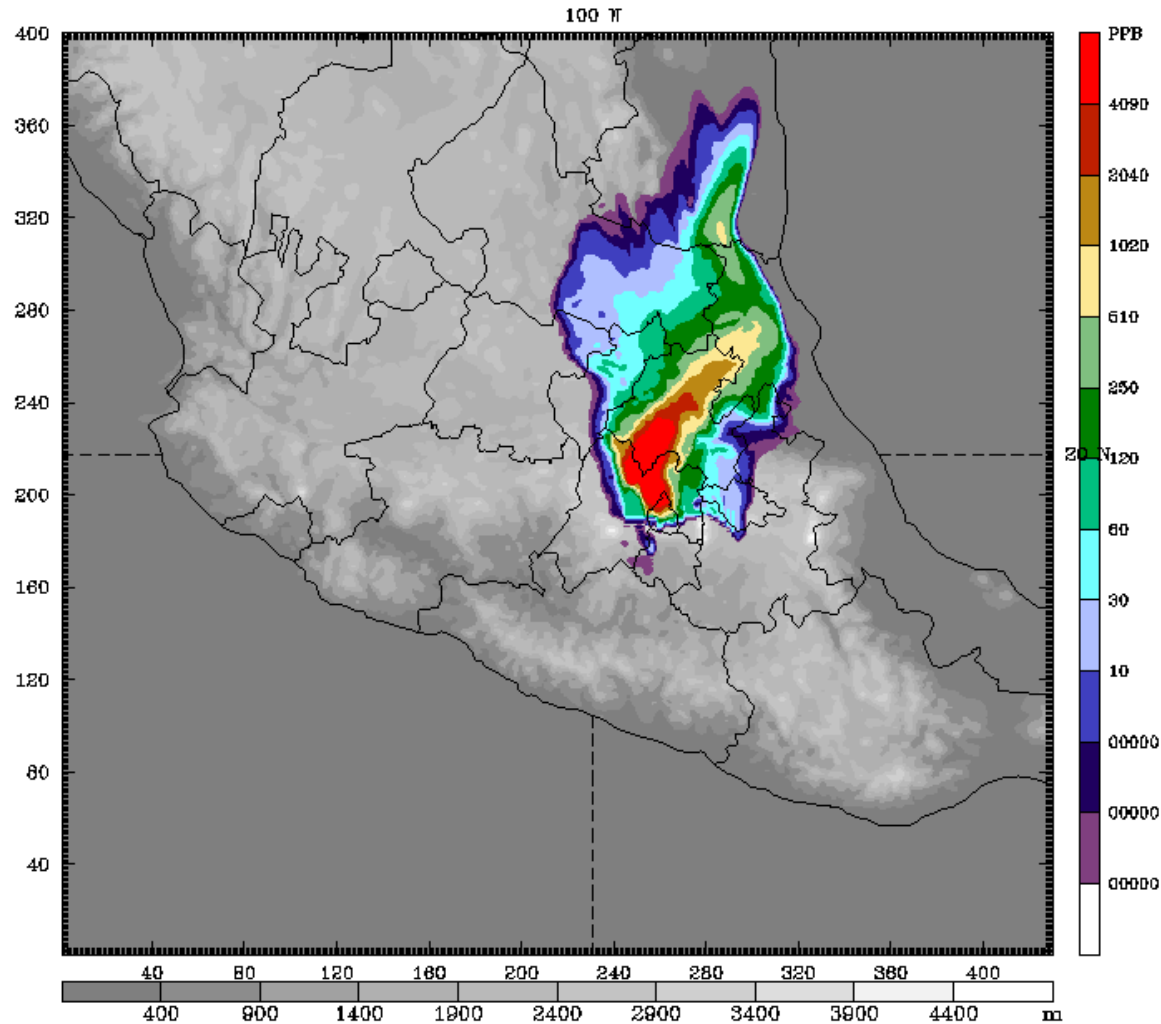
2006  
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Dataset: dom2 RIP: dom2  
Fest: 21.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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18 March  
15:00

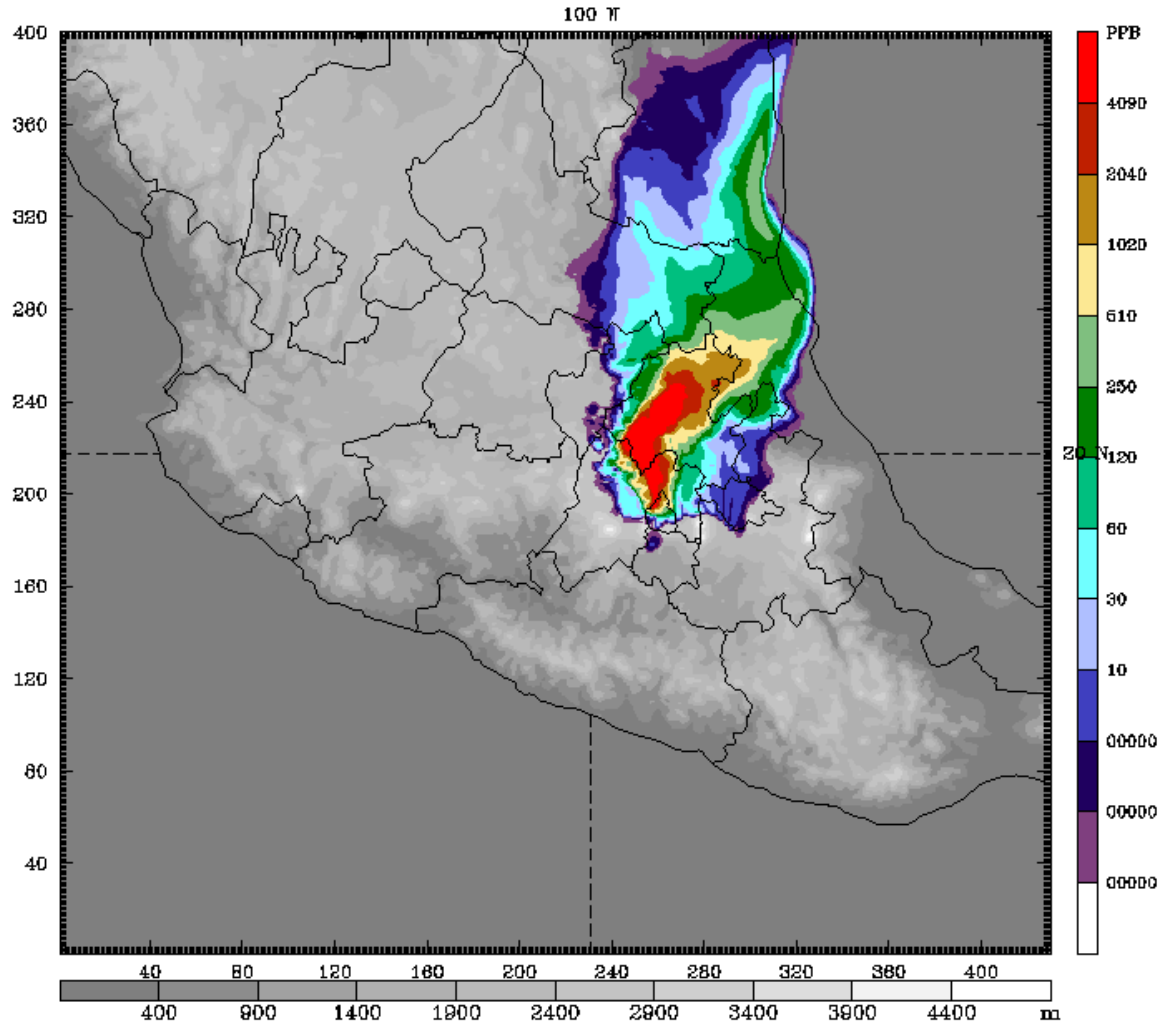


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Dataset: dom2 RIP: dom2  
Fest: 24.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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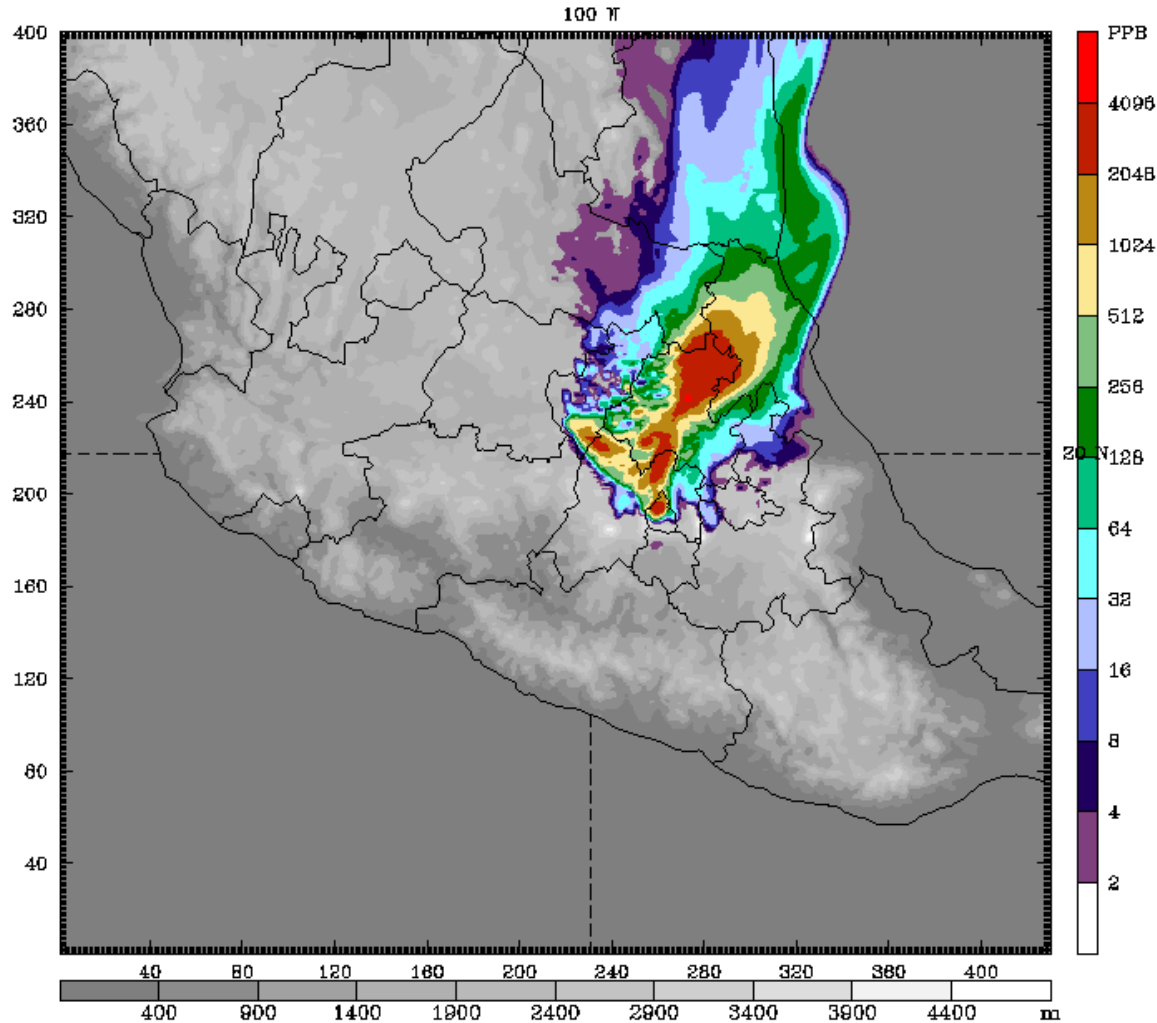
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18 March  
18:00



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Terrain height AMSL  
Mass weighted c1 integral

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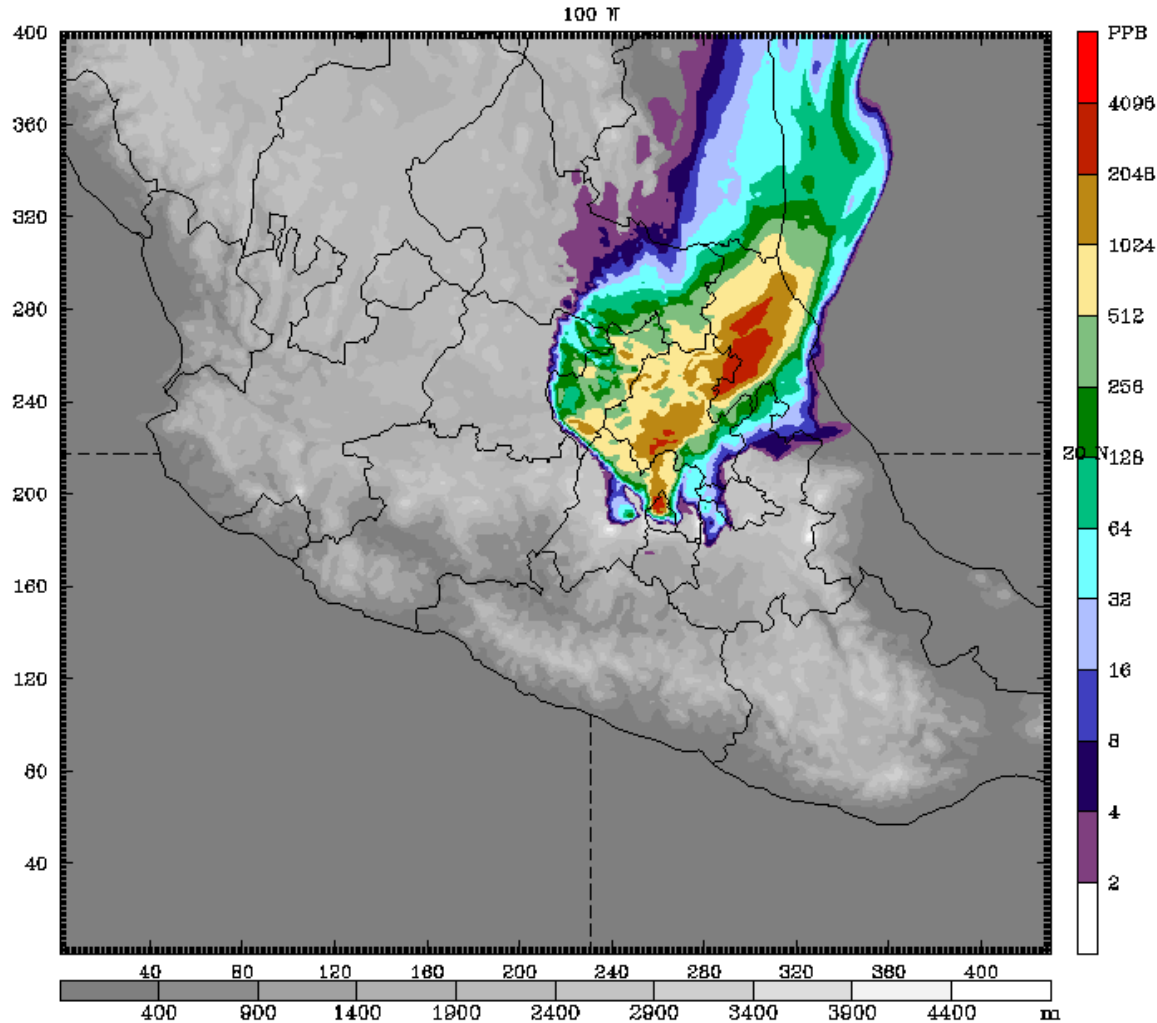


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LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Dataset: dom2 RIP: dom2  
Fest: 30.00 h  
Terrain height AMSL  
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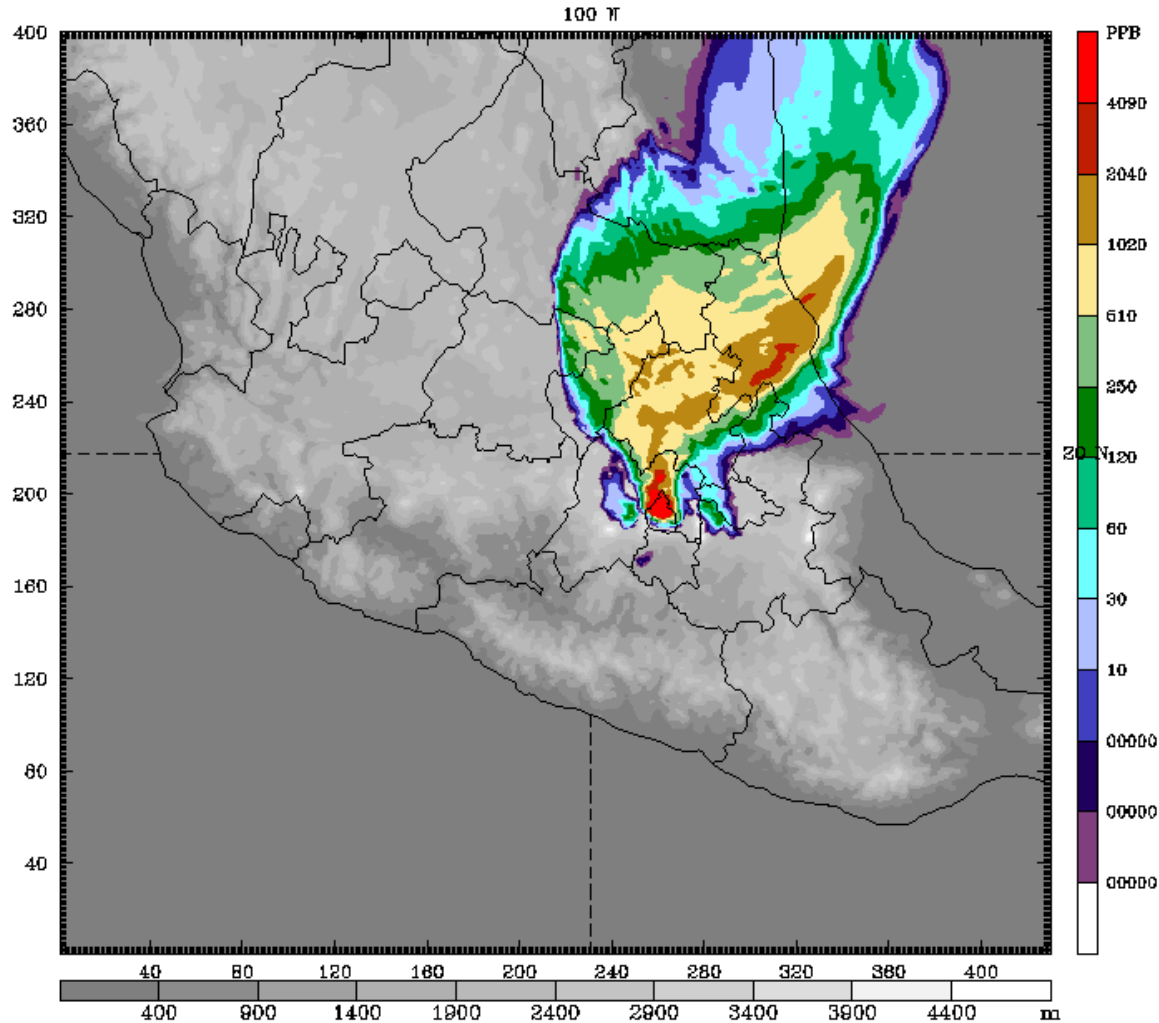


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Dataset: dom2 RIP: dom2  
Fest: 33.00 h  
Terrain height AMSL  
Mass weighted c1 integral

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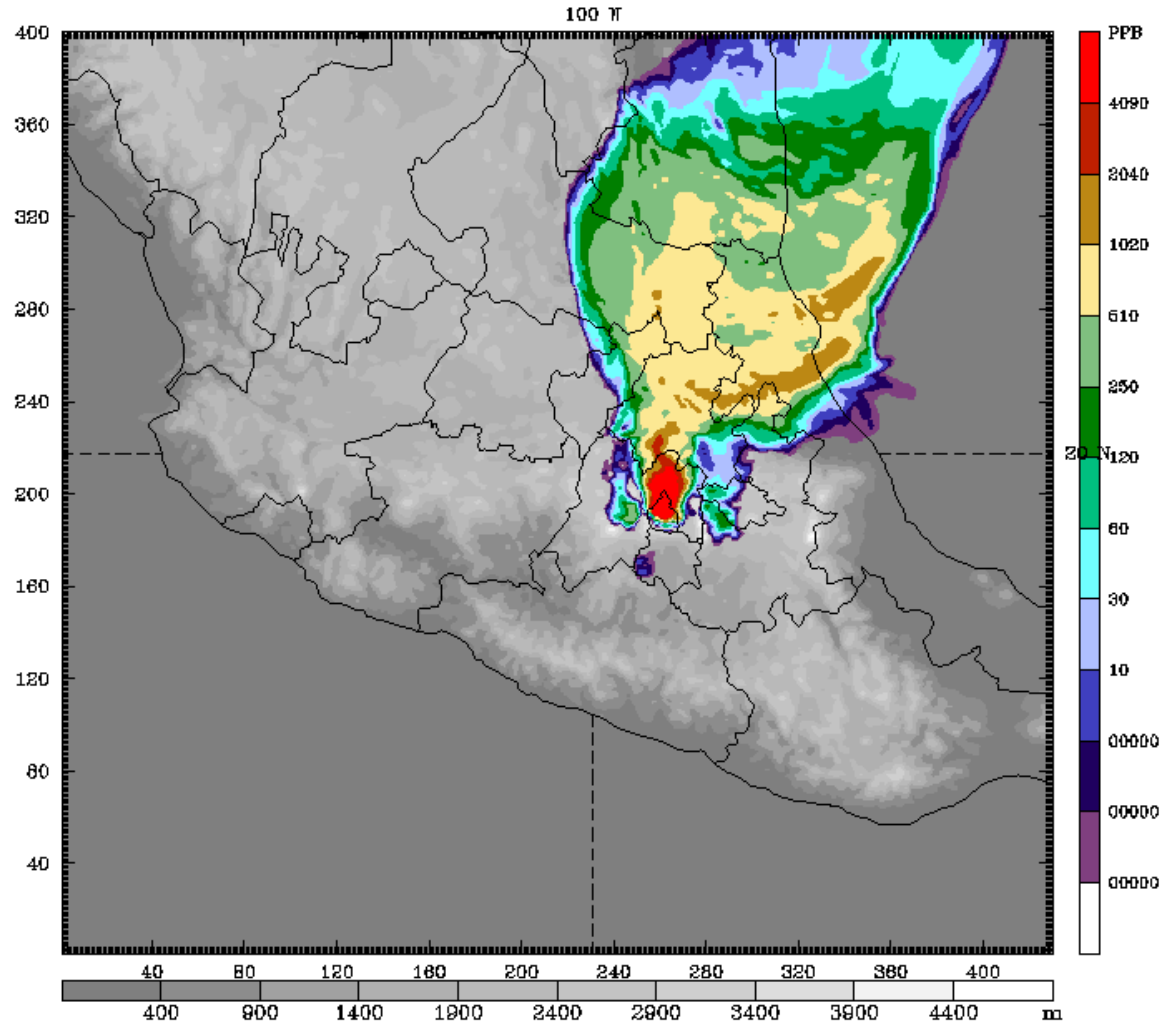


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Dataset: dom2 RIP: dom2  
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Terrain height AMSL  
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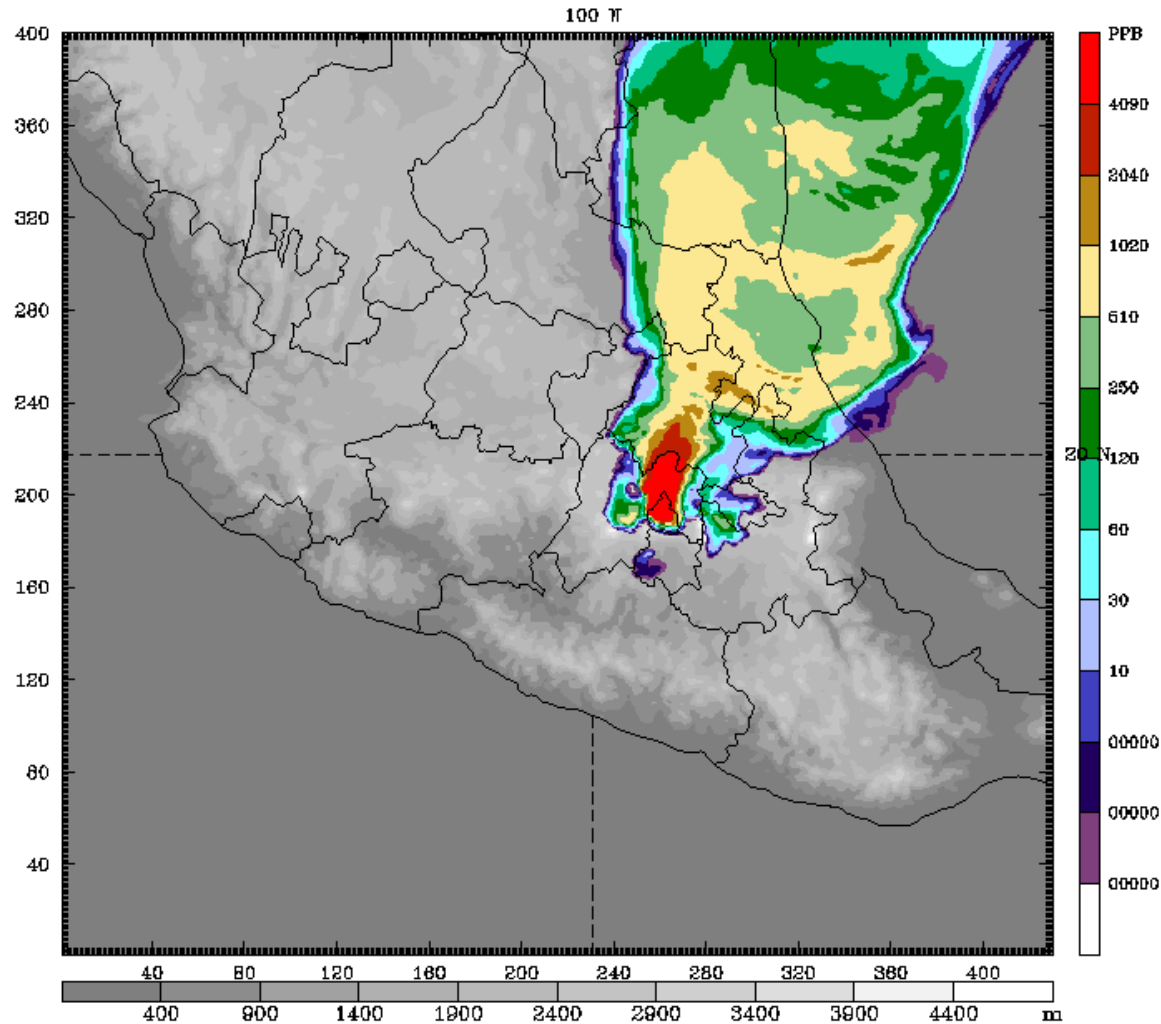
2006  
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06:00



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Terrain height AMSL  
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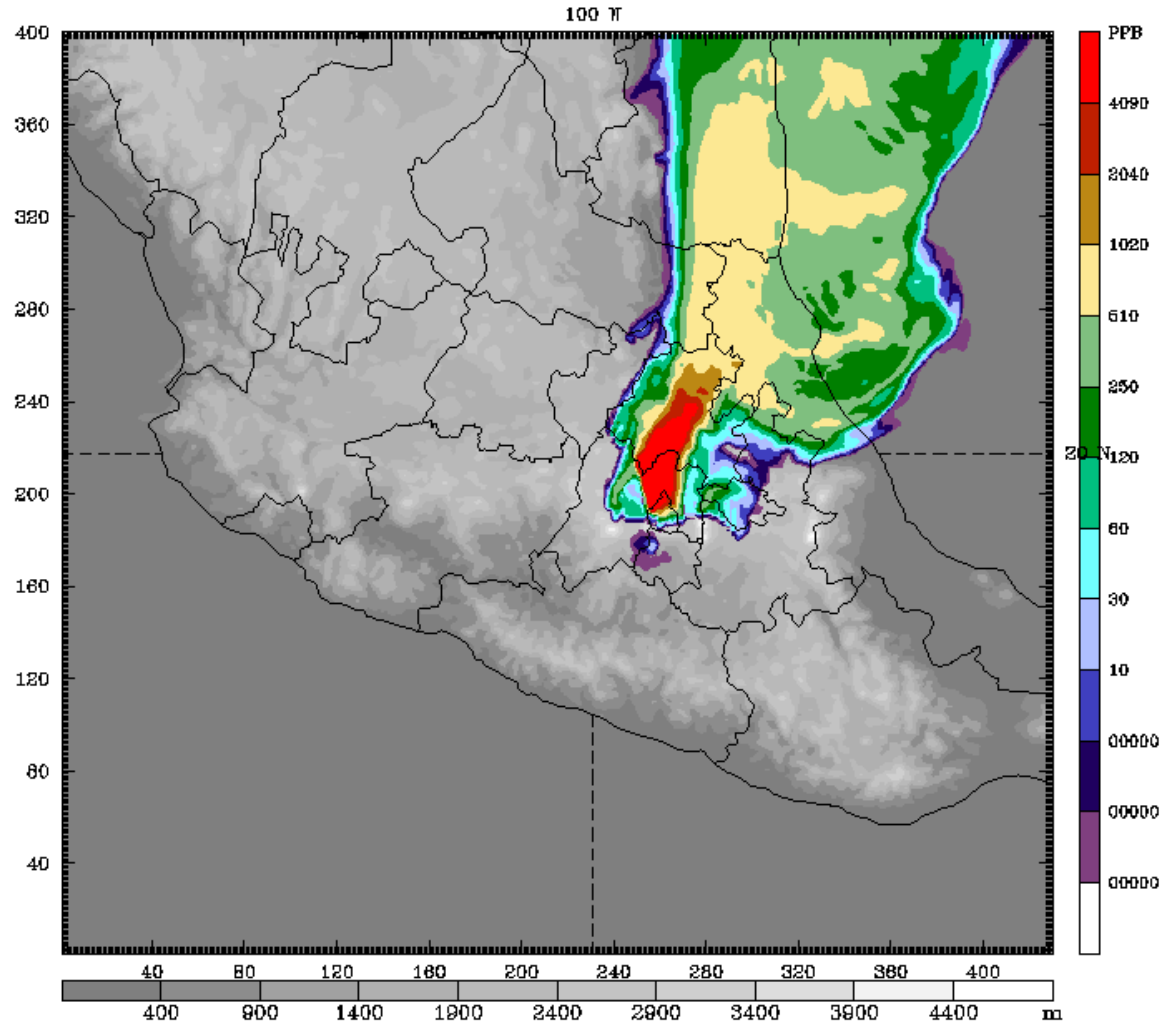


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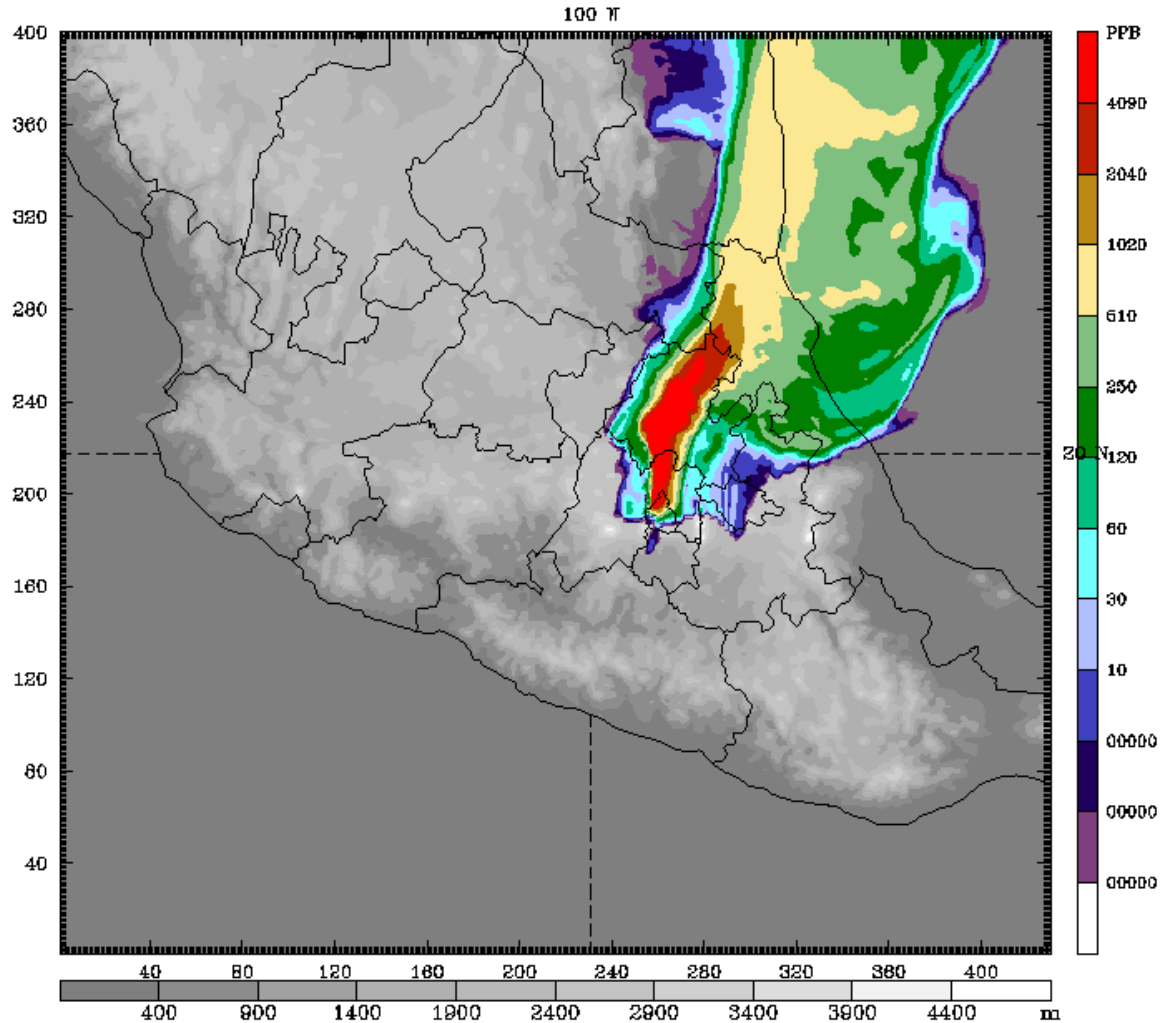


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LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Dataset: dom2 RIP: dom2  
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Mass weighted c1 integral

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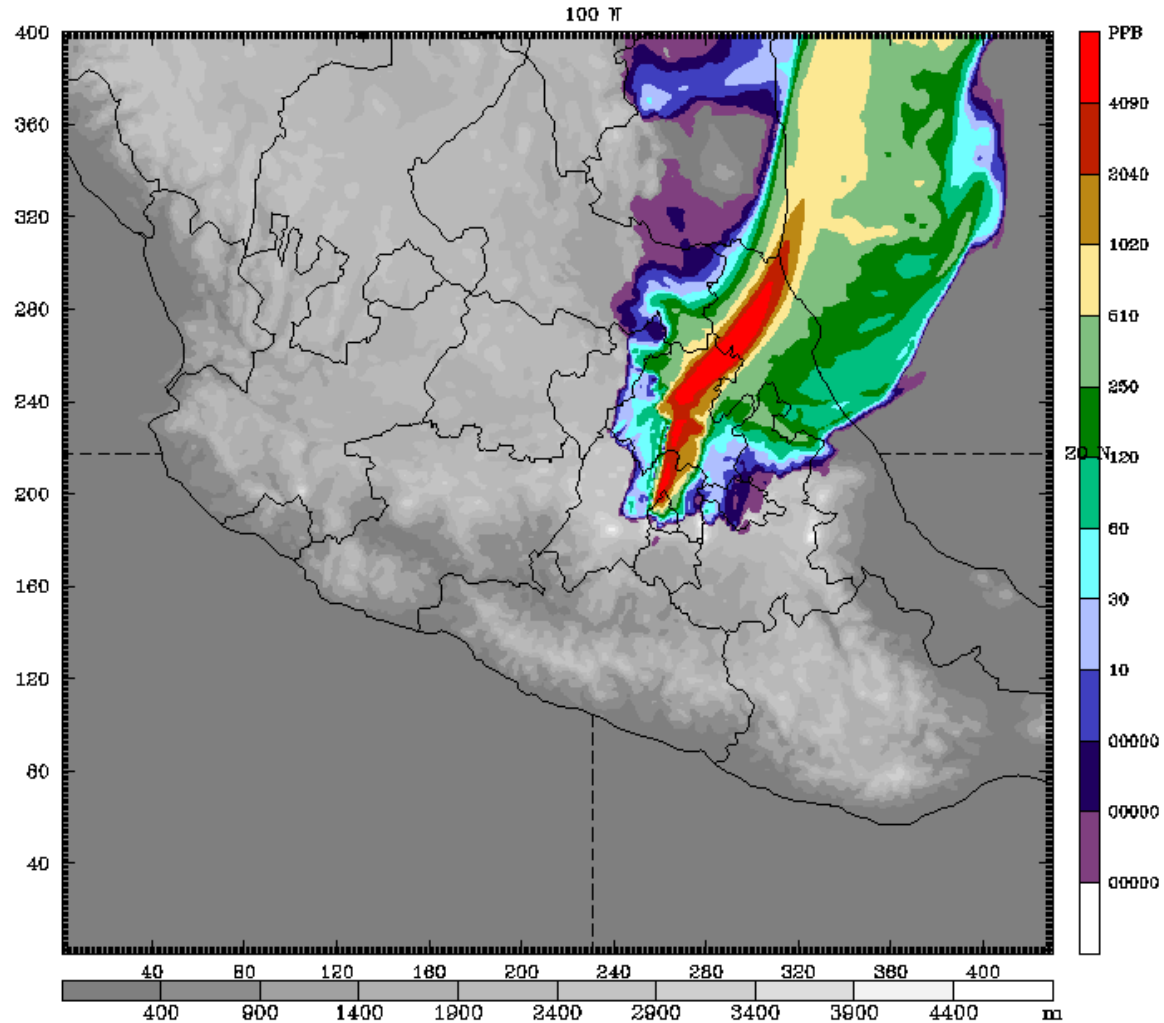
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Terrain height AMSL  
Mass weighted c1 integral

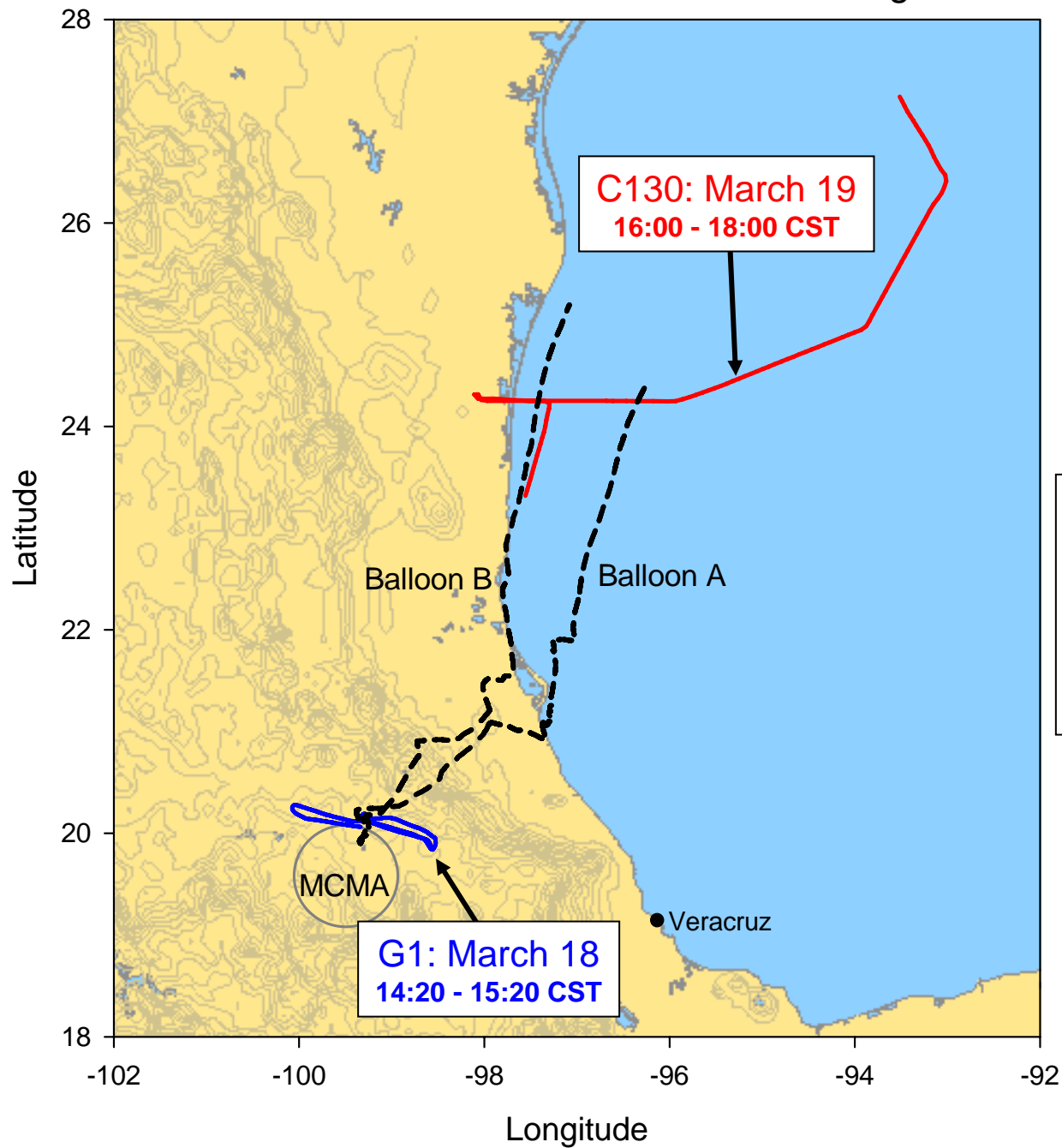
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Model Info: V2.1.1 M No Cu YSU PBL WSM 3class Noah LSM 3.0 km, 37 levels, 20 sec  
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# Coordinated G1 - C130 - CMET Balloon Flights

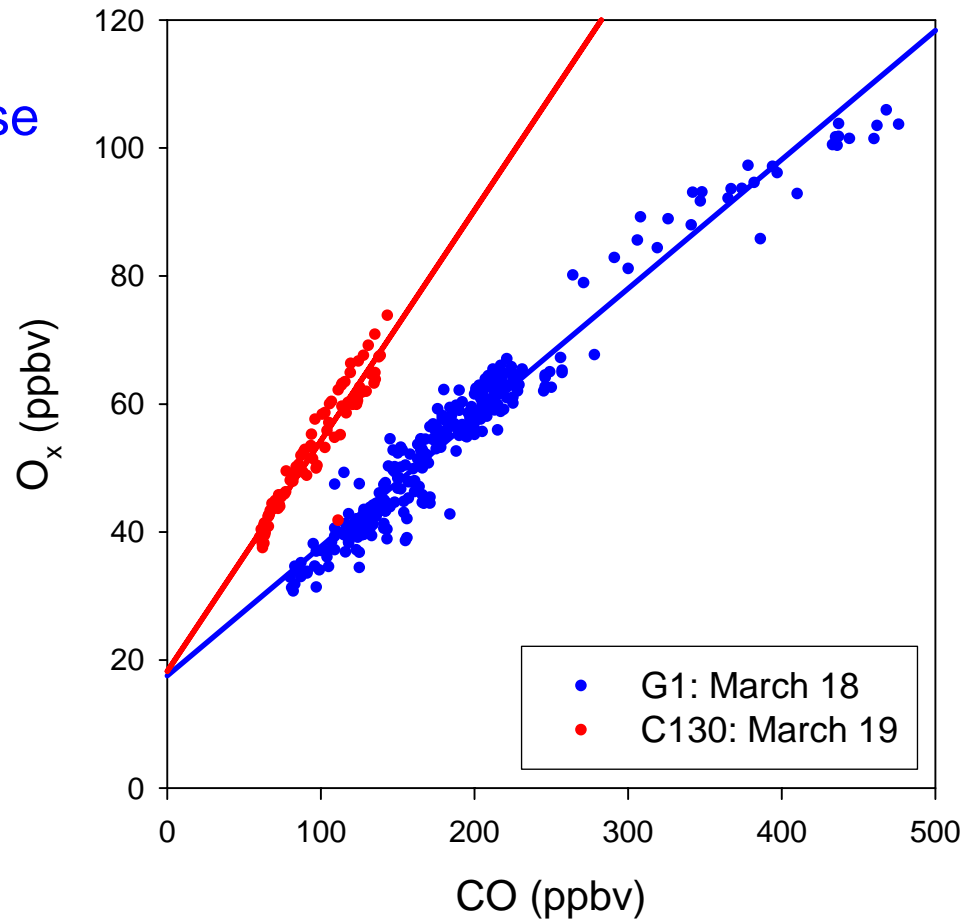


# O<sub>3</sub> Production in Mexico City Plume

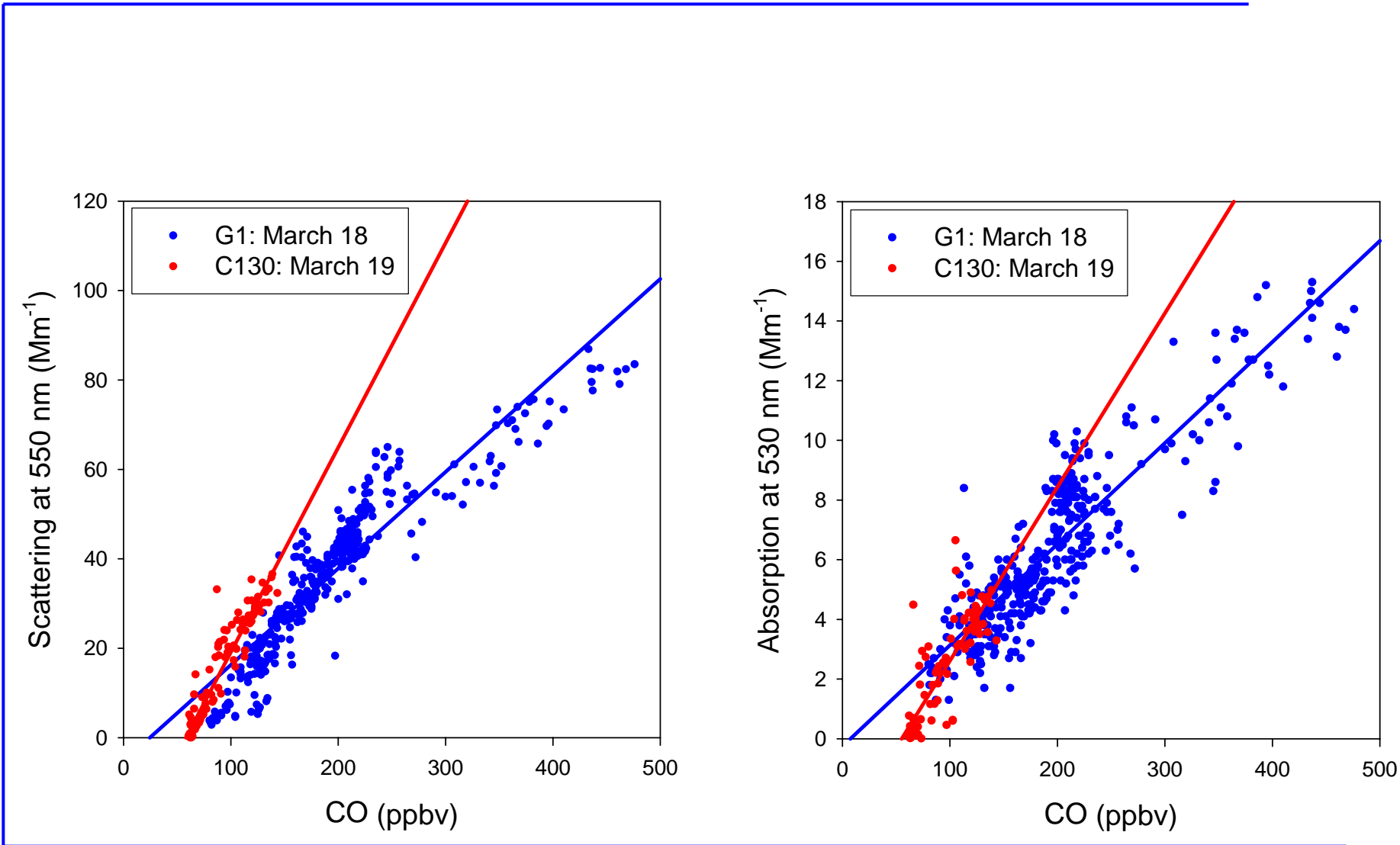
## In 1-day-old plume

CO and Ox (O<sub>3</sub> + NO<sub>2</sub>) decrease because of mixing with cleaner air

but Ox/CO increases, indicating continuing Ox production



# Evolution of Aerosol Optical Properties

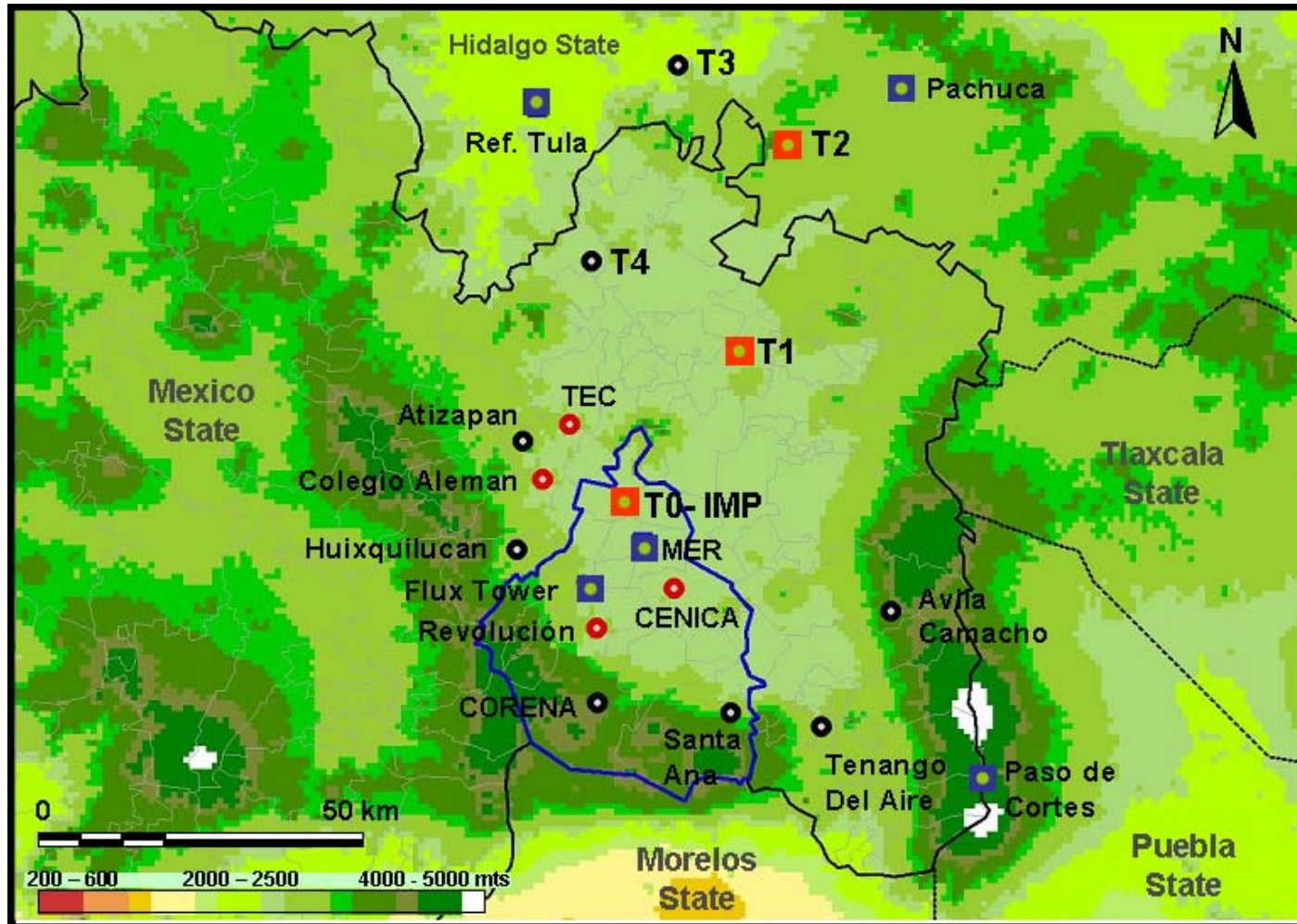


# Some Preliminary MIRAGE-Mex Results

- Very rich data set
- Active regional photochemistry
- Ozone and aerosol production for several days downwind
- OH reactivity dominated by OVOC's and CO
  
- Gas-aerosol interactions, esp. organics and nitrate
- Organic aerosol dominant on both urban and regional scales
- Significant radiative perturbations
- Some contribution from biomass burning
  - More important for aerosols than gases?
  
- Reactive nitrogen imbalances
- PAN as regional NO<sub>x</sub> source



# Surface Measurements Valle de México



- Sitios fijos
- Sitios móviles
- Supersitios
- Otras mediciones

# MIRAGE Mobile Labs



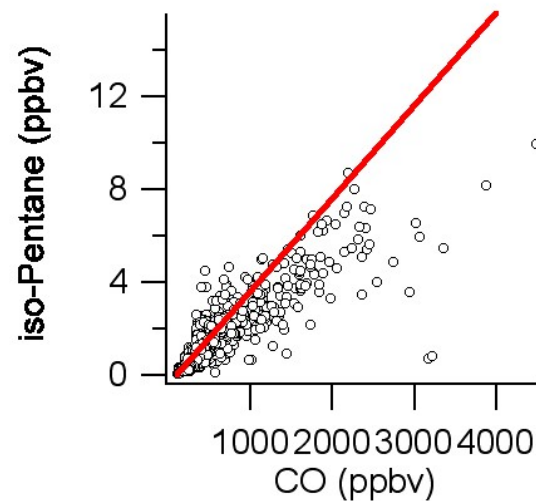
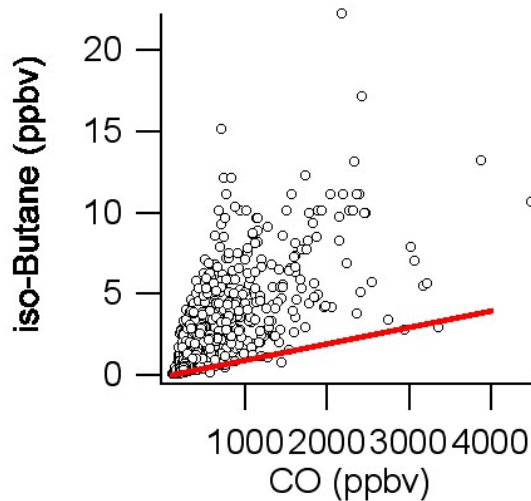
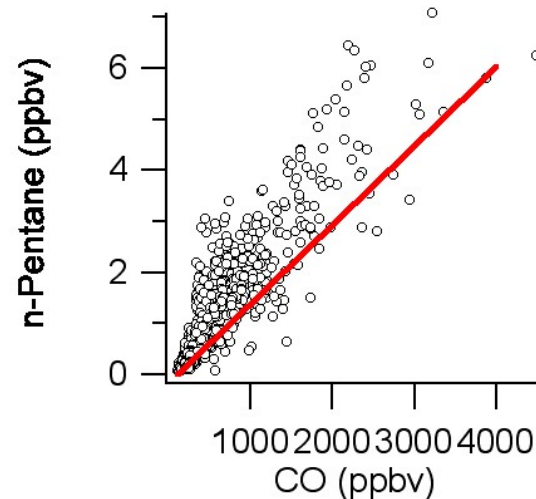
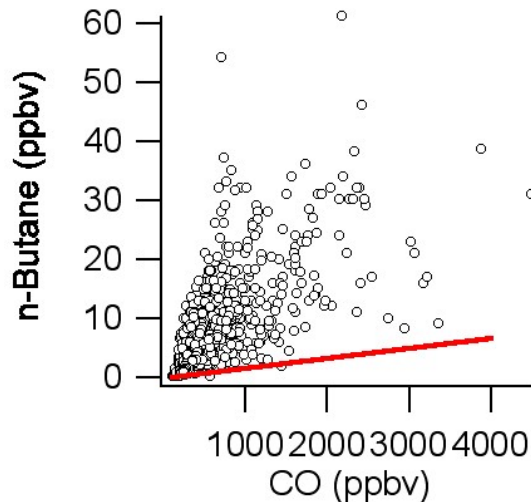
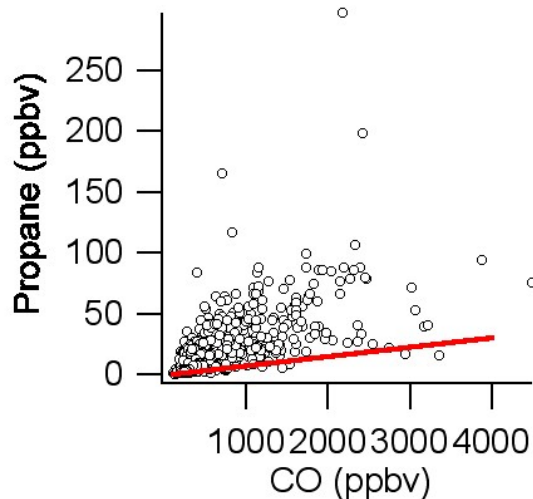
U. Alabama profiler

U. Iowa/LANL LIDAR

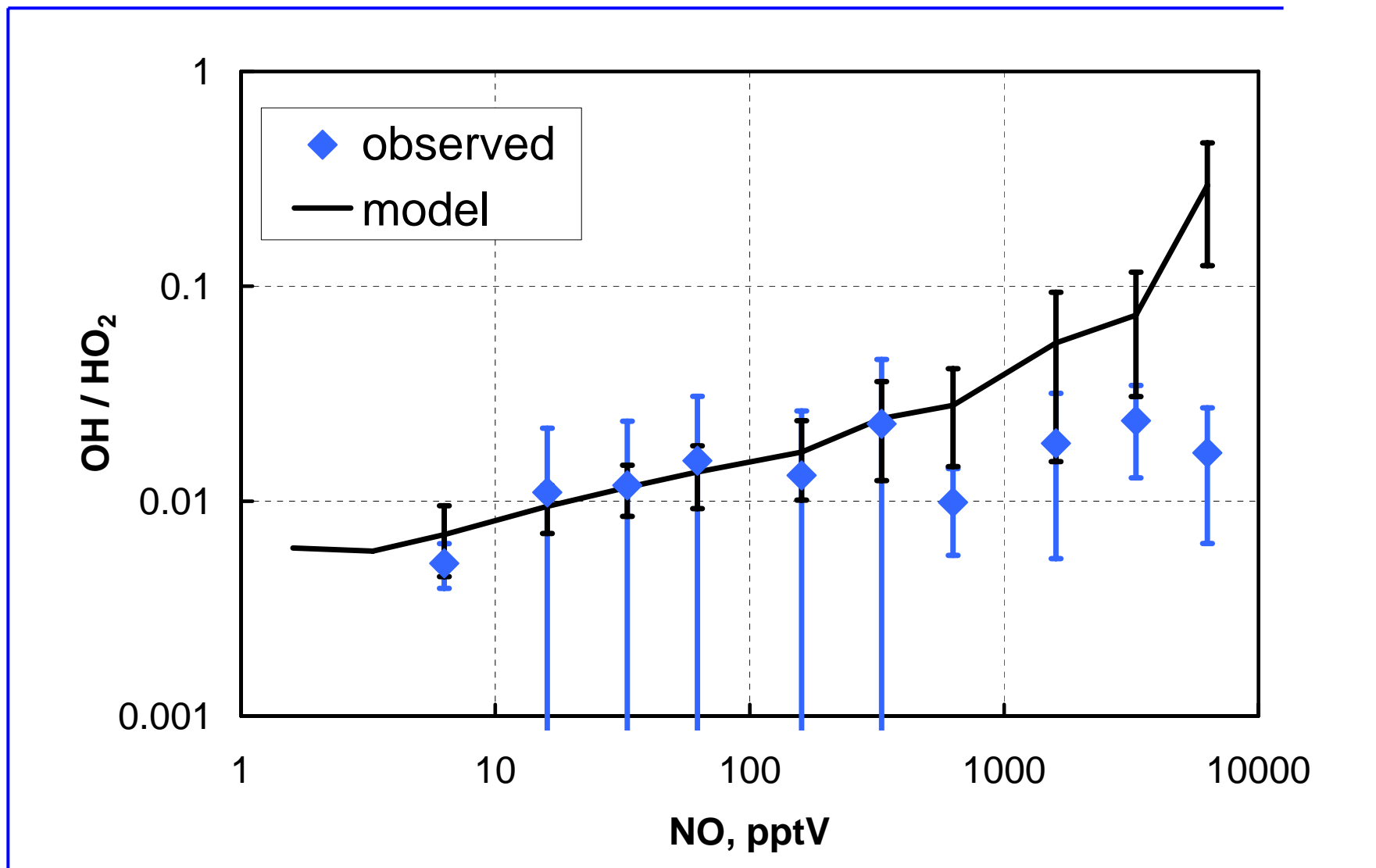
NCAR FTIR



# Comparison of Emissions with U.S.: Alkanes



# C-130



# Méxican Institutions

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, Secretaría 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)

Secretaría de Desarrollo Sustentable-Gobierno del Estado  
de Querétaro

Secretaría de Marina (SEMAR)

Secretaría 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)

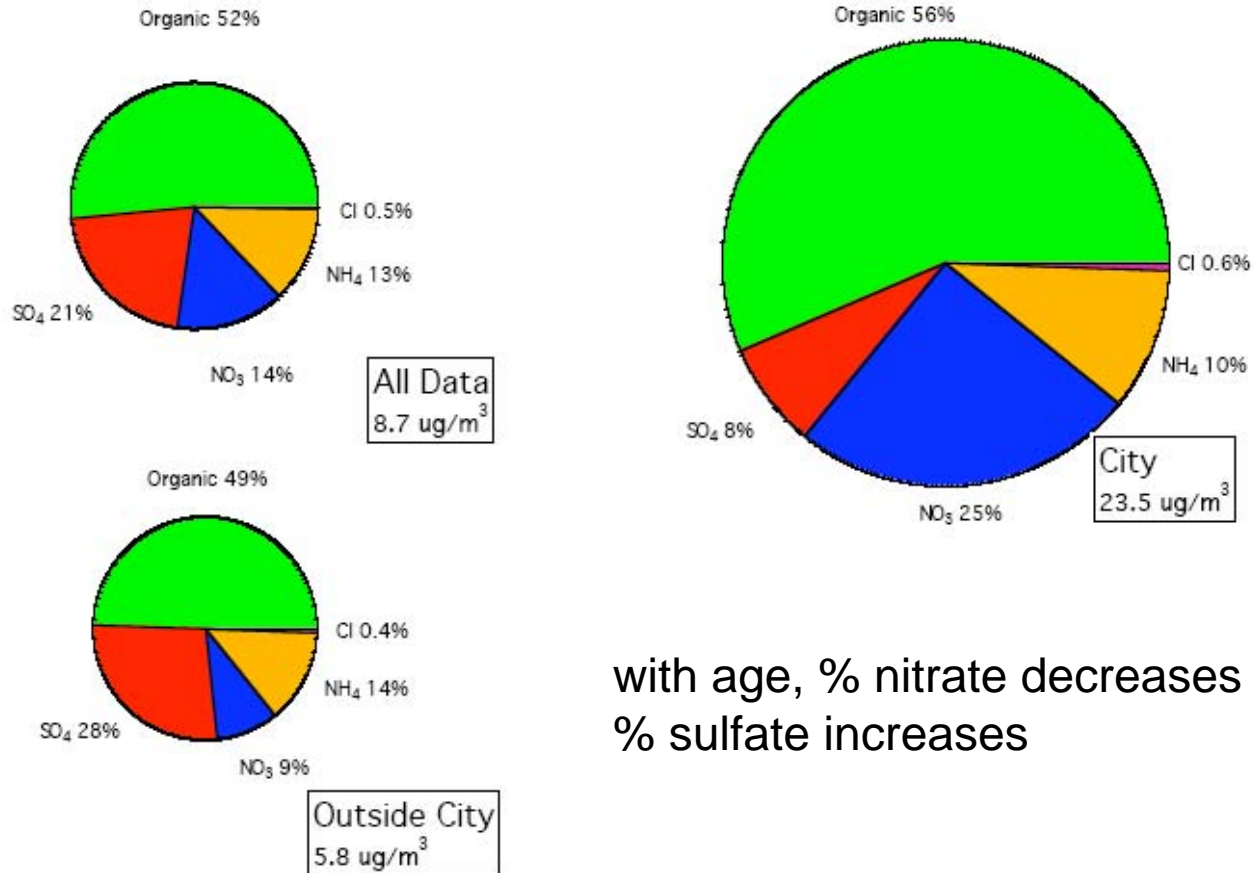
Universidad Veracruzana (Estado de Veracruz)

# Non-Méxican Institutions

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 Measurement Technology, 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 Institute (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 Hampshire  
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

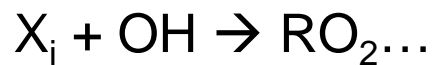
# C-130 Aerosol Mass Spectrometer

## Non-refractory Aerosol Chemistry



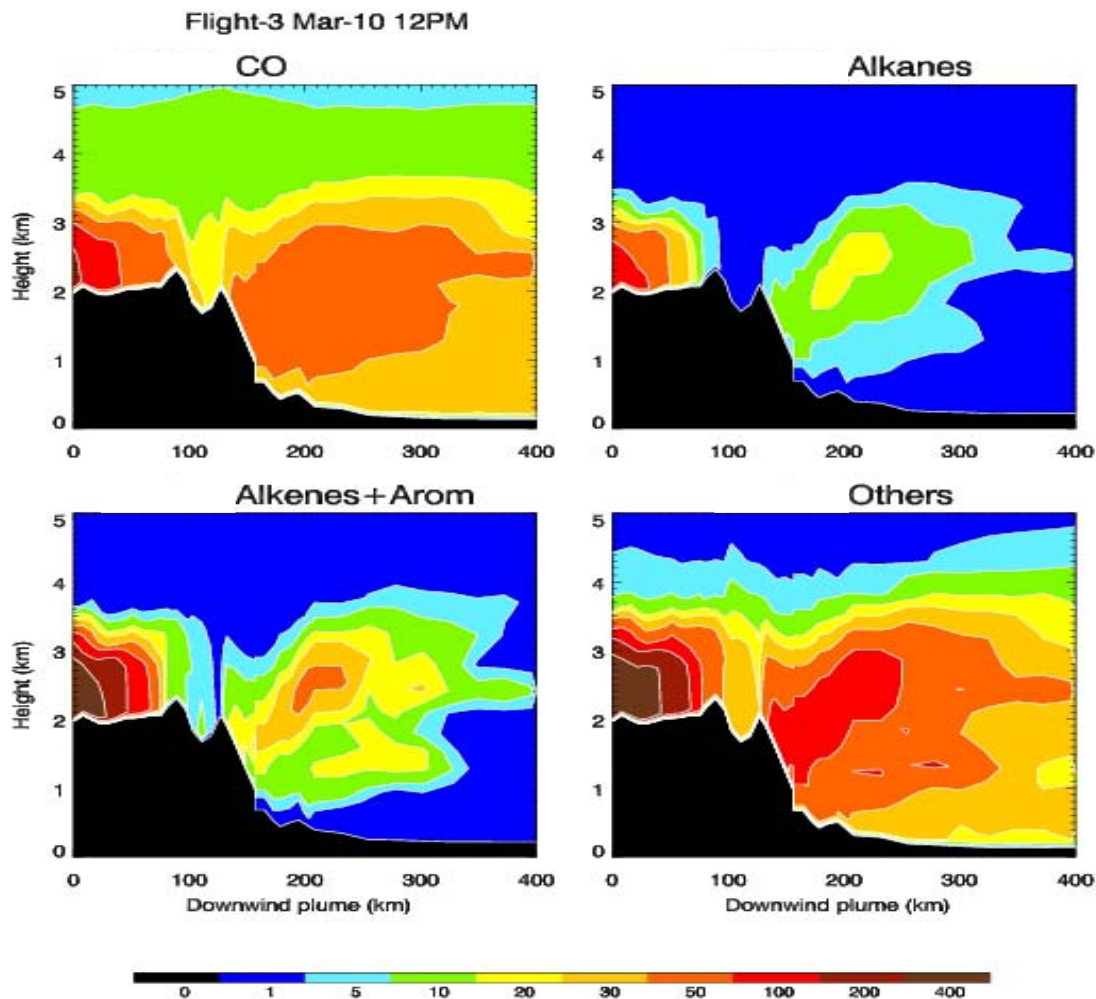
with age, % nitrate decreases and % sulfate increases

# OH Reactivity – WRF-Chem model



$$K_{OH} = \sum k_i [X_i], s^{-1}$$

O<sub>3</sub> production potential



# INTERCOMPARISON OF MEASUREMENTS

## C-130 seen from the G-1



18 March 2006

# RESULTS

## IN PROGRESS:

- 1 September 2006 - Preliminary data submission
- 23-25 October 2006 - First science meeting  
120 posters
- 1 March 2007 - Final data submission
- May 2007 - Second science meeting
- 1 March 2008 - Public access to data
  
- Publication in international scientific journals
- Presentations at scientific conferences

Remote-controlled balloons, funded by the NSF and operated by Smith College

Measurements of temperature, pressure, humidity, and winds (trajectories)



El avion Twin Otter pertenece y es operado por el Servicio Forestal de EEUU, y su uso en MILAGRO fue fundado por la Fundacion Nacional de la Ciencia (NSF) a través la Universidad de Montana

Mediciones de humo de fuegos agricolas y forestales



POPULATION OF CITIES WITH 10 MILLION INHABITANTS OR MORE, 1950, 1975, 2000 AND 2015  
(in millions)

<i>City</i>	<i>1950</i>	<i>City</i>	<i>1975</i>	<i>City</i>	<i>2000</i>	<i>City</i>	<i>2015</i>
1 New York	12.3	1 Tokyo	19.8	1 Tokyo	26.4	1 Tokyo	26.4
		2 New York	15.9	2 Mexico City	18.1	2 Bombay	26.1
		3 Shanghai	11.4	3 Bombay	18.1	3 Lagos	23.2
		4 Mexico City	11.2	4 Sao Paulo	17.8	4 Dhaka	21.1
		5 Sao Paulo	10.0	5 New York	16.6	5 Sao Paulo	20.4
				6 Lagos	13.4	6 Karachi	19.2
				7 Los Angeles	13.1	7 Mexico City	19.2
				8 Calcutta	12.9	8 New York	17.4
				9 Shanghai	12.9	9 Jakarta	17.3
				10 Buenos Aires	12.6	10 Calcutta	17.3
				11 Dhaka	12.3	11 Delhi	16.8
				12 Karachi	11.8	12 Metro Manila	14.8
				13 Delhi	11.7	13 Shanghai	14.6
				14 Jakarta	11.0	14 Los Angeles	14.1
				15 Osaka	11.0	15 Buenos Aires	14.1
				16 Metro Manila	10.9	16 Cairo	13.8
				17 Beijing	10.8	17 Istanbul	12.5
				18 Rio de Janeiro	10.6	18 Beijing	12.3
				19 Cairo	10.6	19 Rio de Janeiro	11.9
						20 Osaka	11.0
						21 Tianjin	10.7
						22 Hyderabad	10.5
						23 Bangkok	10.1

*UN, World Urbanization Prospects  
The 2002 Revision*

