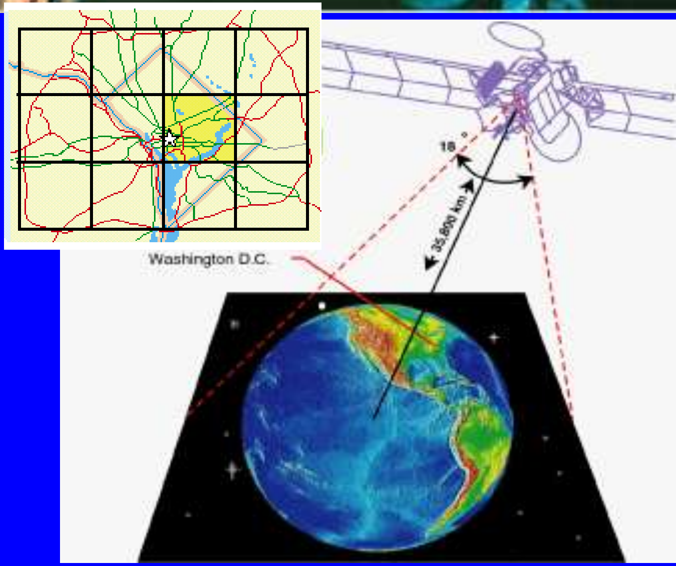


# Geostationary satellite mission for air quality and coastal ecosystems

**One of 15 missions recommended to NASA for the next decade by the U.S. National Research Council**

**Atmospheric GEO-CAPE Workshop at Columbia, MD**
**22 September 2009**

**Atmospheric Planning Team:** J. Al-Saadi, K. Chance, R. Chatfield, S. Christopher, J. Crawford, B. Duncan, D. Edwards, A. Eldering, J. Fishman, S. Kondragunta, D, Jacob, L. Iraci, R. Kawa, X. Liu, D. Neil, M. Newchurch, K. Pickering, J. Rodriguez, R. Scheffe, J. Szykman, O. Torres, J. Wang

**Atmospheric Variability sub-team:** Fishman & Newchurch Co-chairs, Al-Saadi, Chatfield, Crawford, Christopher, Duncan, Kawa, Pickering, Scheffe.

# PURPOSE: Defining the spatial and temporal scale requirements for GEO-CAPE to

# 1) characterize emission patterns and

# 2) observe the spatio-temporal evolution of pollution processes.

**The critical precursors and pollutants are: O3, CO, NO2, SO2, HCHO, H2O2, PAN, HNO3, HNO4, acetylene, HCN, glyoxol, and formic acid.**

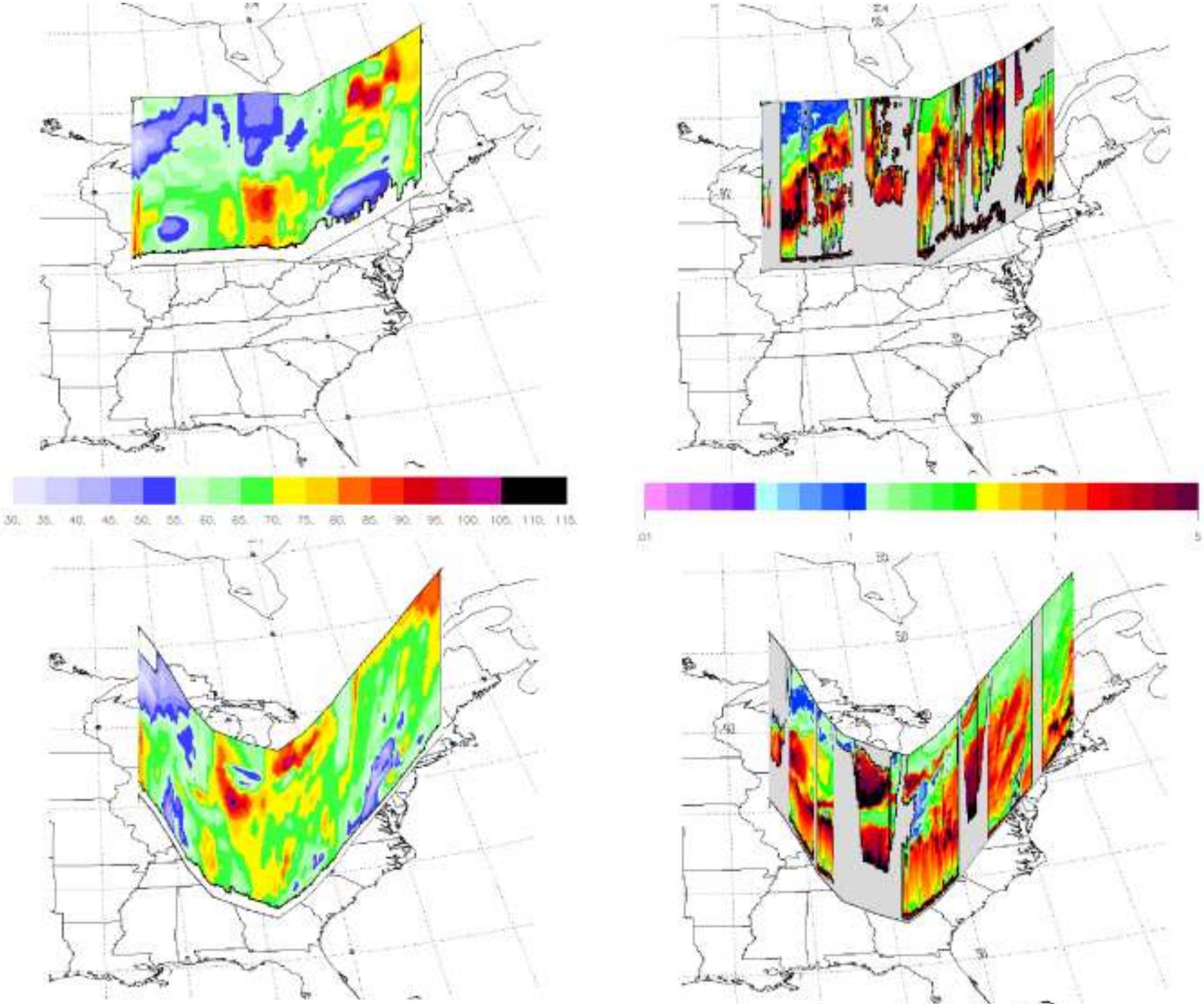
**The critical processes are biomass burning, lightning, biogenic VOC emission, dust events, and surface carbon flux.**

**The critical time frames range from hourly to multi-day episodic.**

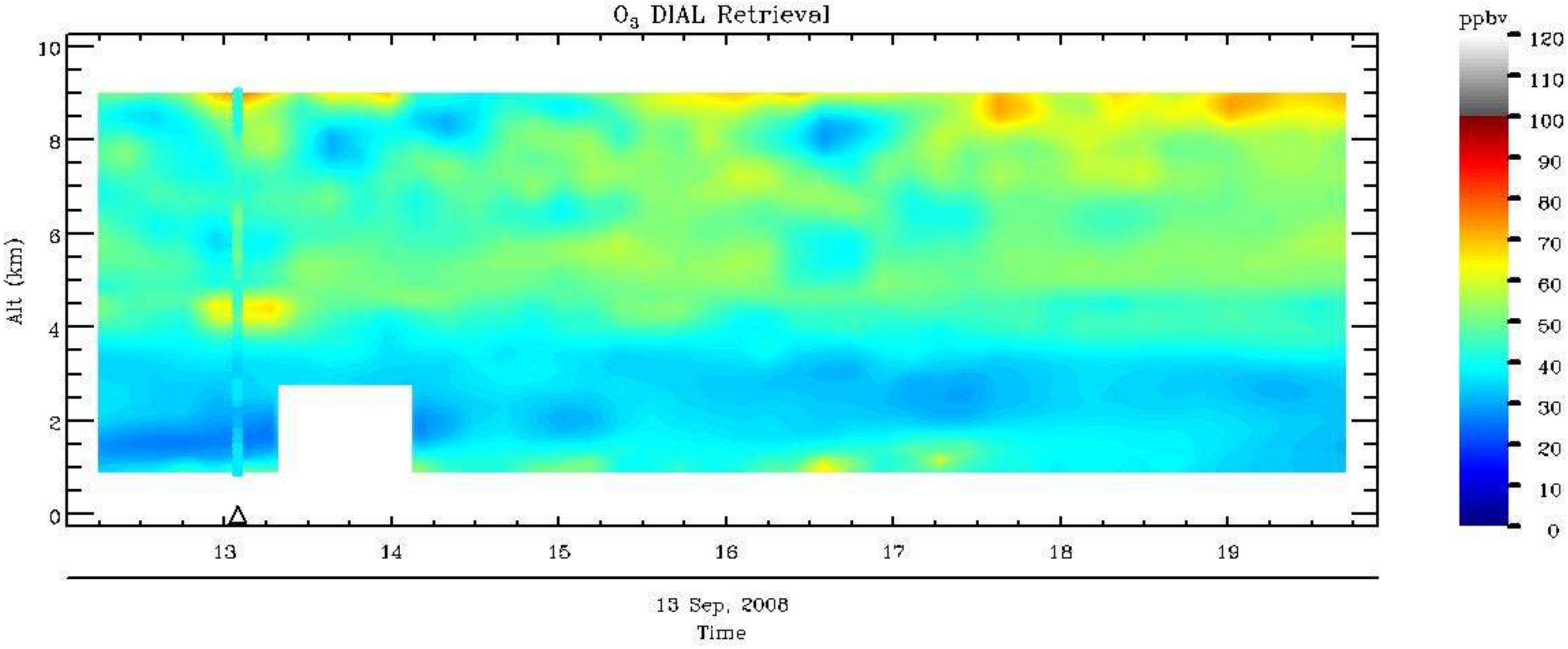
Data Sources and analyses methods for Atmospheric Variability:

- Space-borne observations of columns and profiles (O3-, NO2, CO, HCHO, CHOCHO, aerosols)
- EPA and USDA nets (CO, O3, NO2, SO2, aerosols)
- Lidar observations (O3 and aerosols)
- McDermid/LeBlanc: mid- & upper-trop DIAL O3 at TMF
- Ozonesonde observations
- Nested resolution WRF-chem (define regions and dates)
- Global GEOS-chem
- Univariate statistical climatologies
- Calculated variability: data and models (variograms)
- Pattern recognition
- Production/Destruction rate calculations
- Horizontal Variability of Trace Gases over the Eastern United States
- Spatial autocorrelation (vertical, horizontal, cross species)
- Vertical Autocorrelations of O3 from the Ozonesonde Record
- EOF and SVD analyses

# Aerosol backscatter (right) and ozone (left) profiles from a/c DIAL

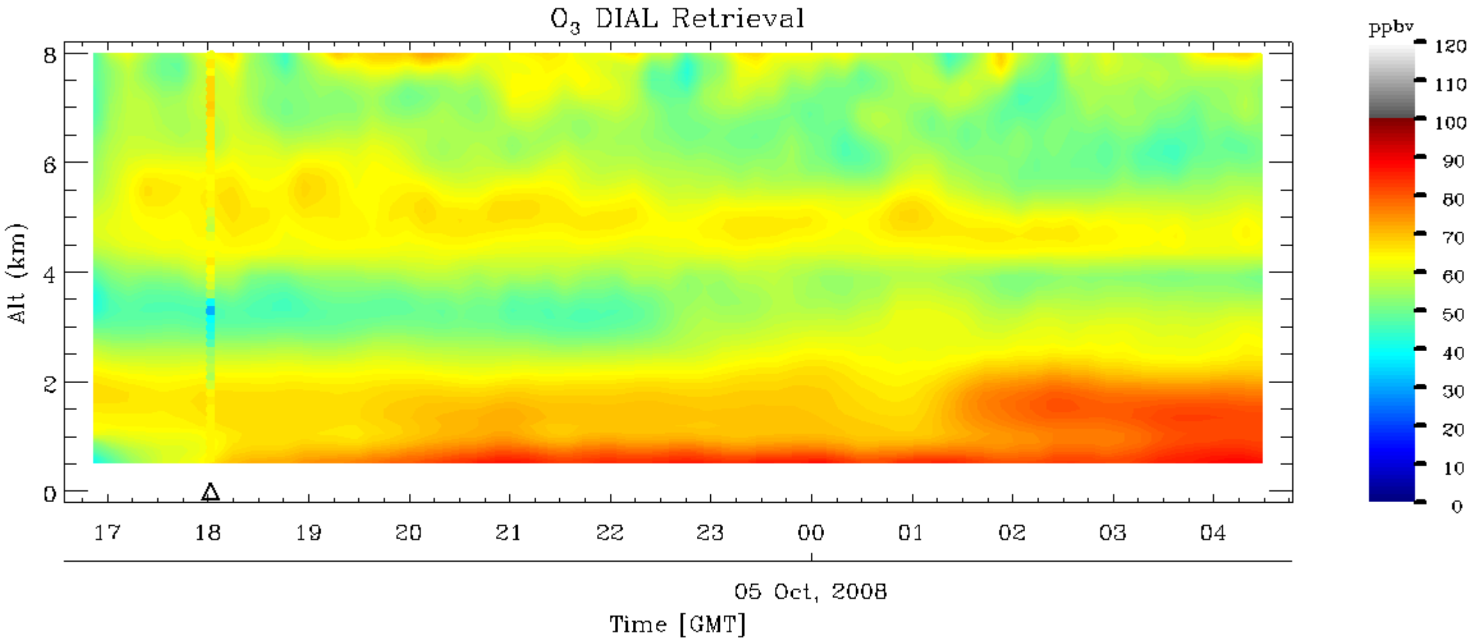


# 13 September 2008
# Huntsville, AL



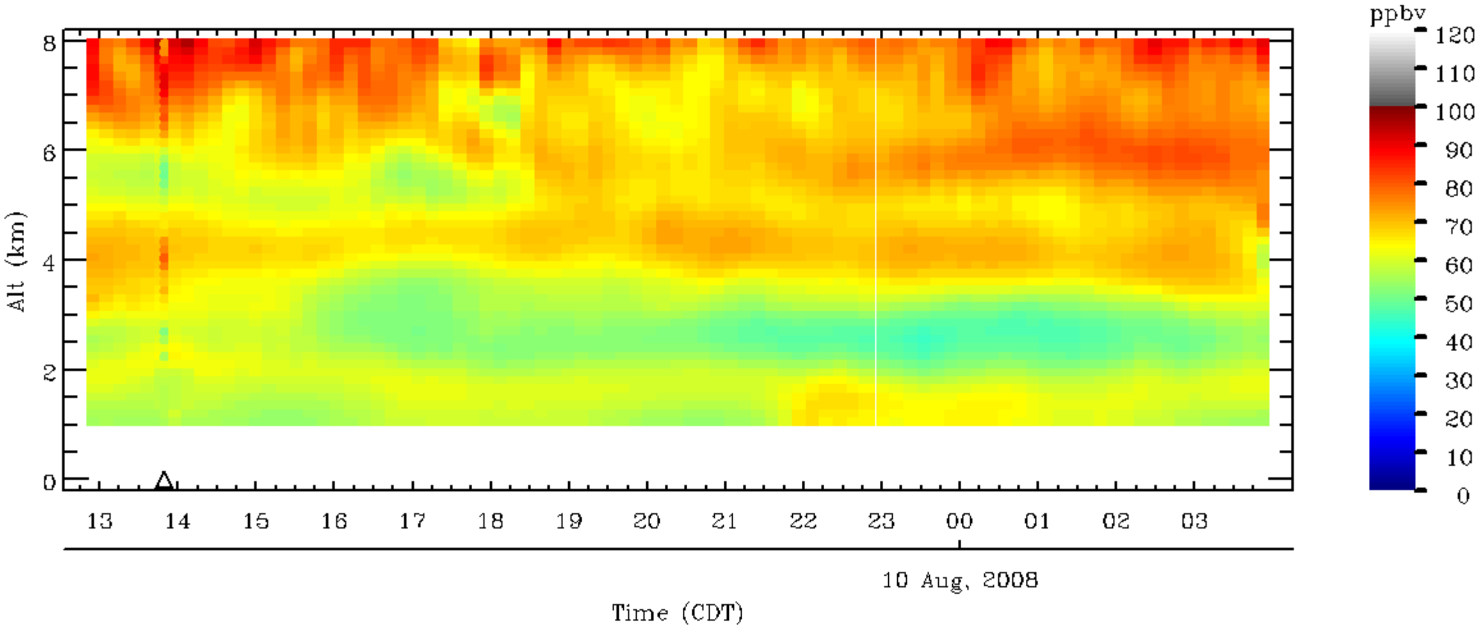
ToC

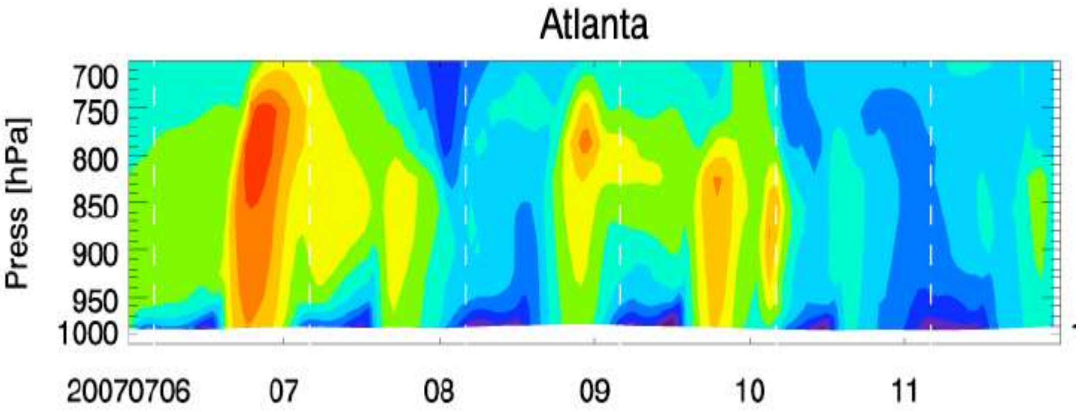
# 4 October 2008
# Huntsville, AL



ToC

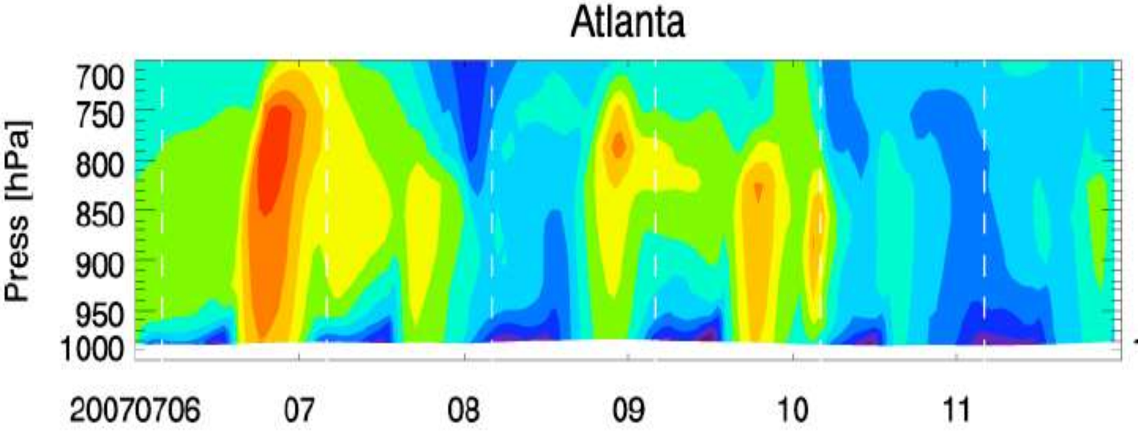
# 10 August 2008
# Huntsville Ozone DIAL



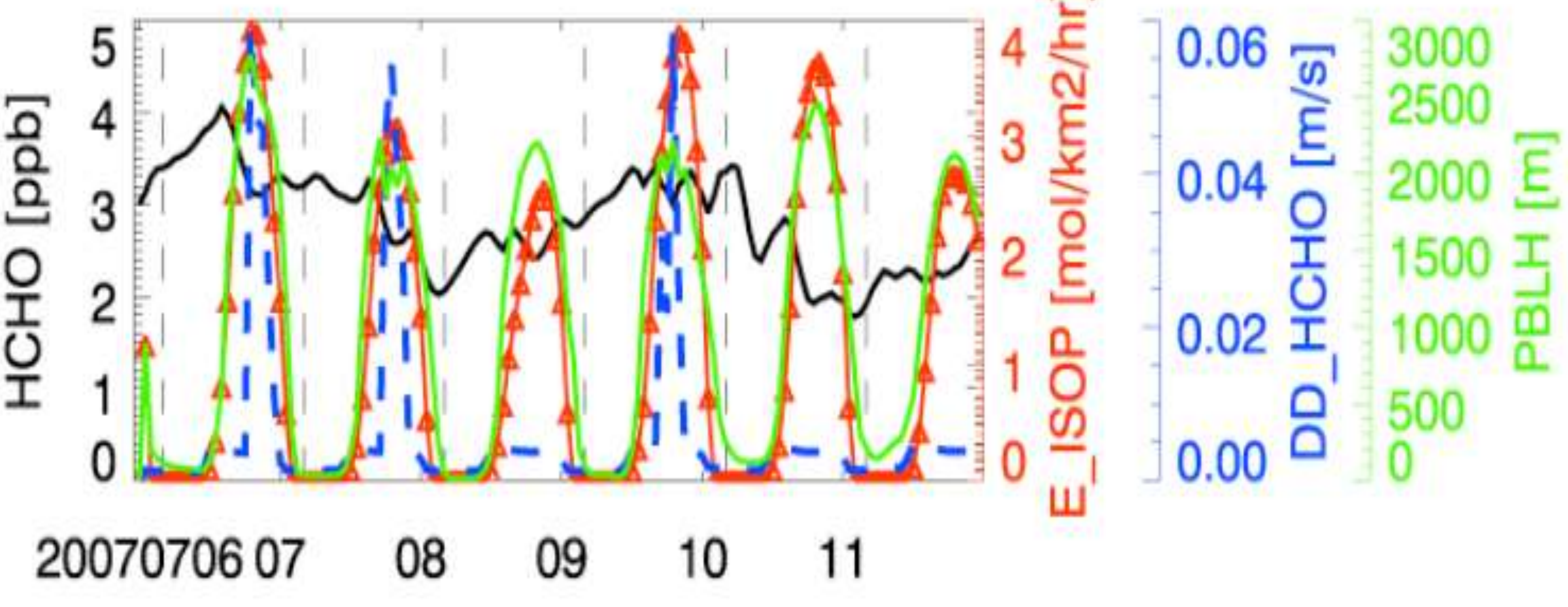


WRF calculation,
Pickering et al.

# Diurnal processes



WRF calculation,
Pickering et al.



# Variability Statistics Based on CMAQ 1.5-km Horizontal Resolution Simulation

**Ken Pickering, NASA/GSFC**

**Melanie Follette-Cook, UMBC/GEST**

**Yasuko Yoshida, UMBC/GEST**

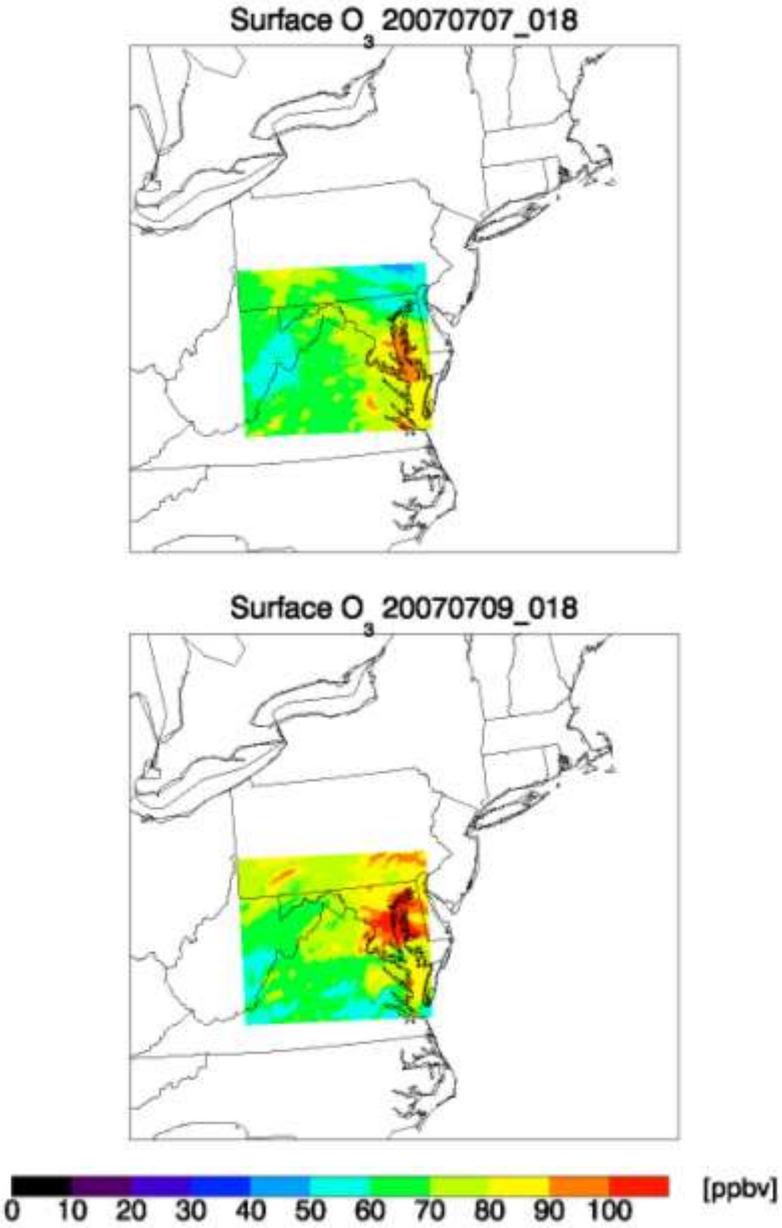
**Chris Loughner, Univ. of MD**

# CMAQ 1.5 km run results

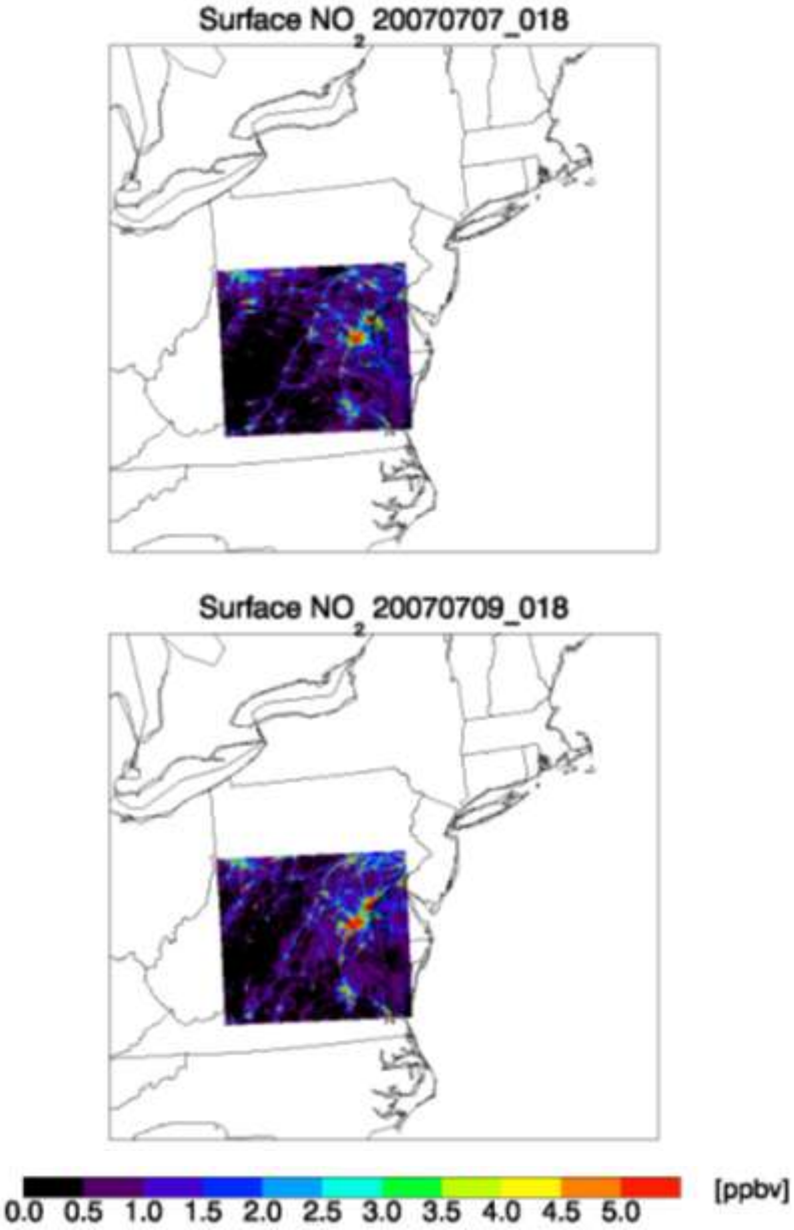
- 1.5 km domain covering the Baltimore/Washington area and upwind regions, nested within a 4.5 km domain, nested within a 13.5 km domain
- 30 levels in the vertical, up to 90 hPa
- Spatial analysis at 18 UTC to correspond with Aura overpass time. Temporal analysis from 13 -23 UTC.
- Data analyzed for a low pollution day – July 7th, 2007, and a high pollution day – July 9th, 2007
- All plots have two lines on them
  - Dashed line is r = 0.7 contour, indicating ~50% of variance explained

    by neighboring grid cell
  - Solid line is r = 0.87 contour, indicating ~75% explained variance
  - Also some results for r = 0.95, indicating ~90% explained variance

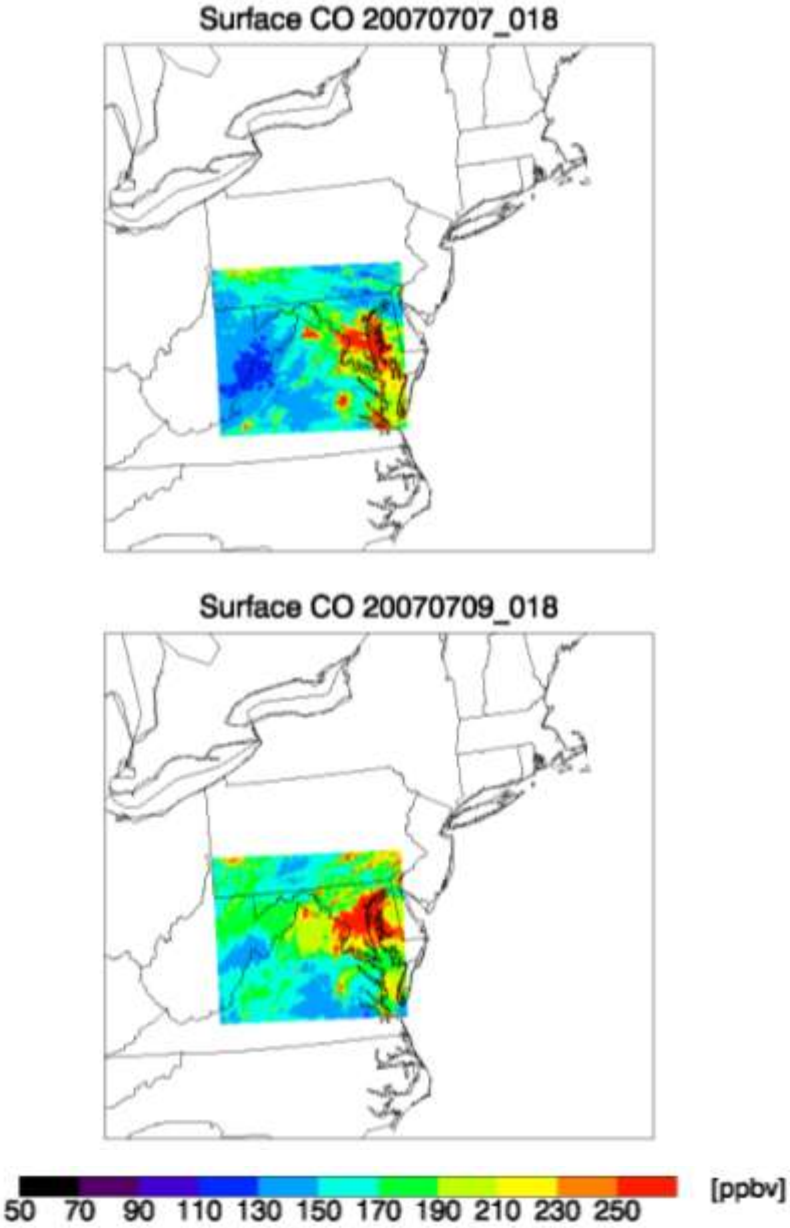
# CMAQ 1.5 km domain – surface ozone



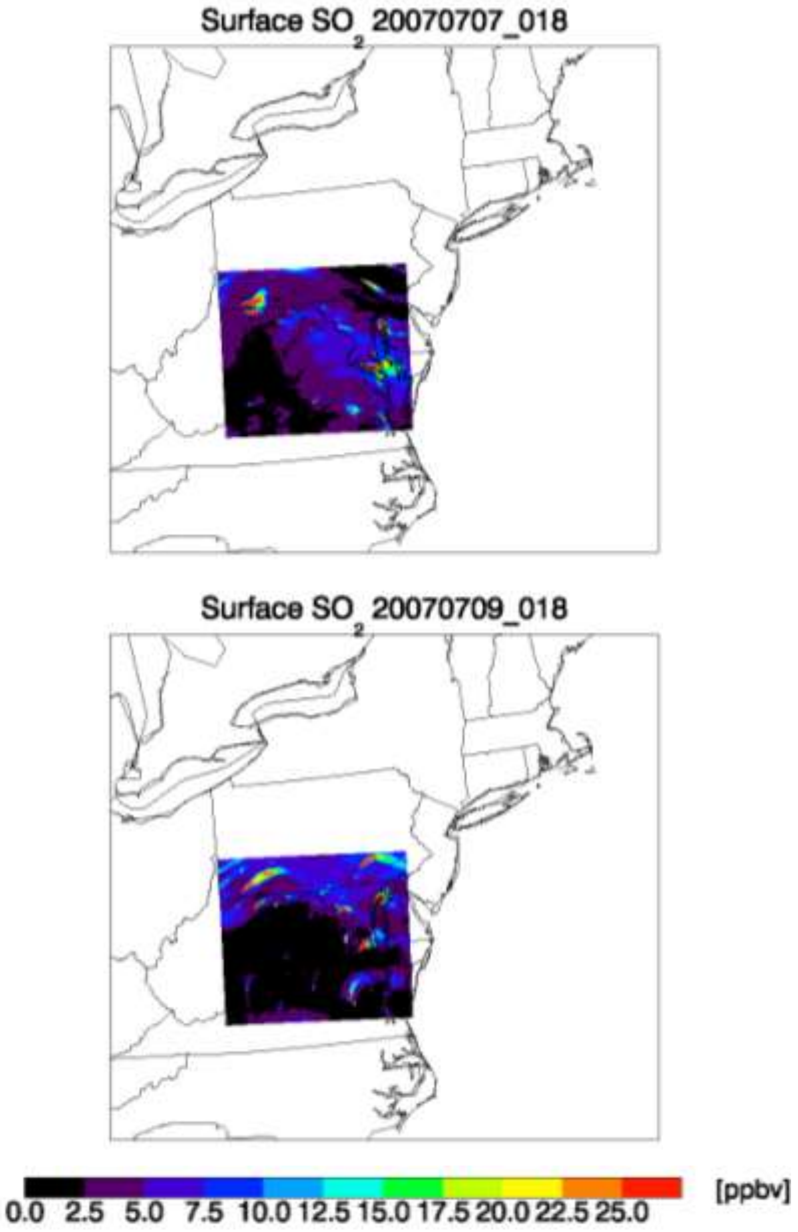
# CMAQ 1.5 km domain – surface $NO_2$



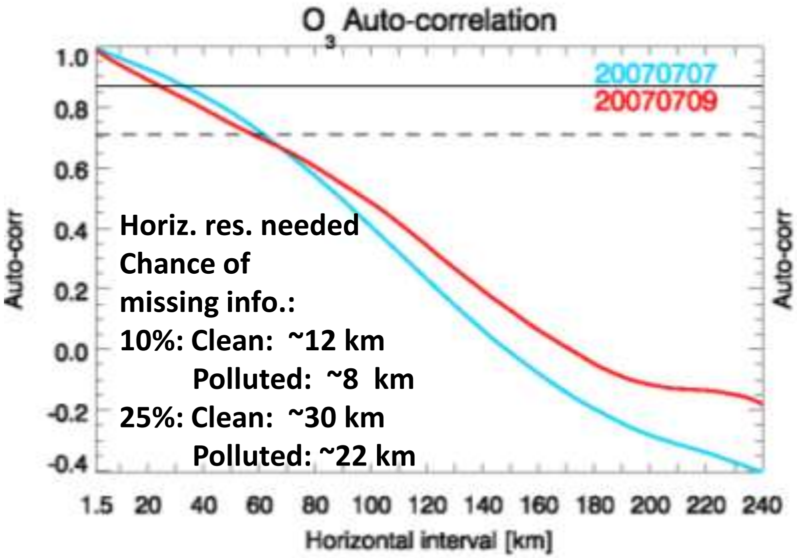
# CMAQ 1.5 km domain – surface CO



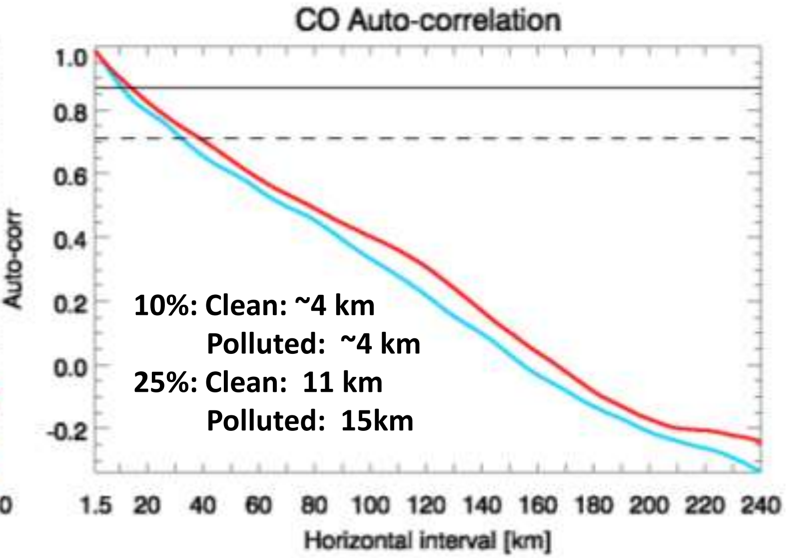
# CMAQ 1.5 km domain – surface $SO_2$



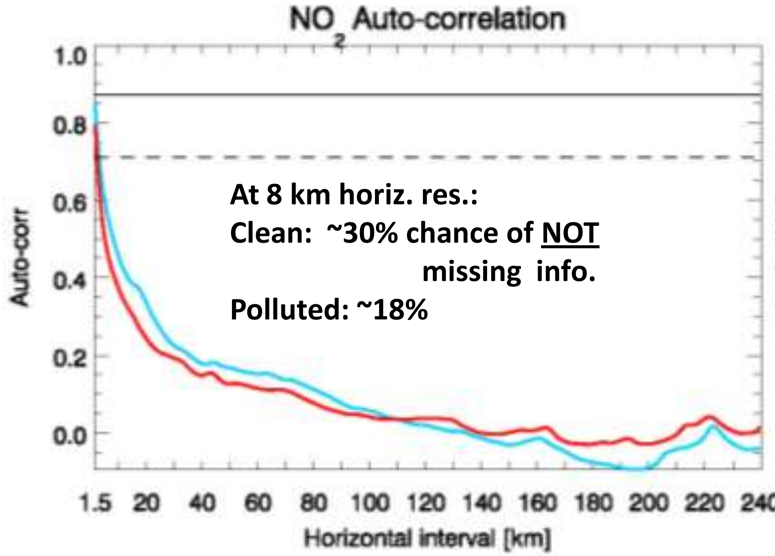
# Decay of horizontal autocorrelation of the tropospheric column



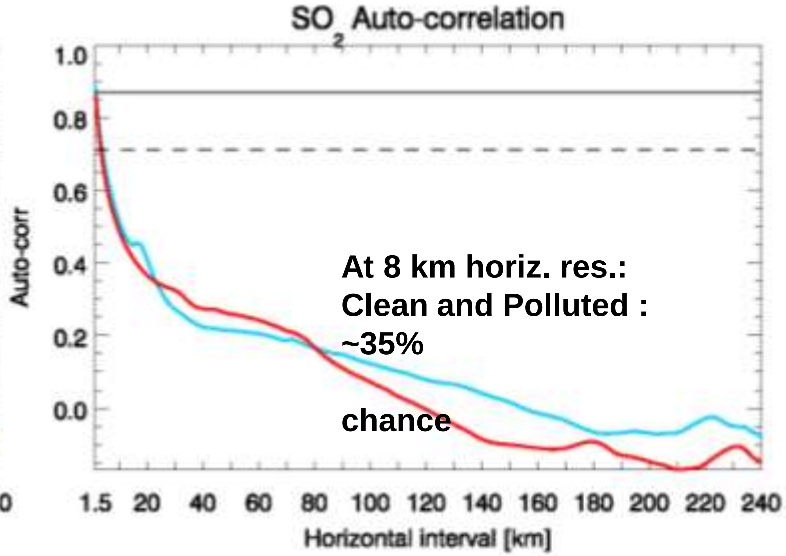
Horiz. res. needed
Chance of
missing info.:
10%: Clean: ~12 km
Polluted: ~8 km
25%: Clean: ~30 km
Polluted: ~22 km



10%: Clean: ~4 km
Polluted: ~4 km
25%: Clean: 11 km
Polluted: 15km



At 8 km horiz. res.:
Clean: ~30% chance of NOT missing info.
Polluted: ~18%

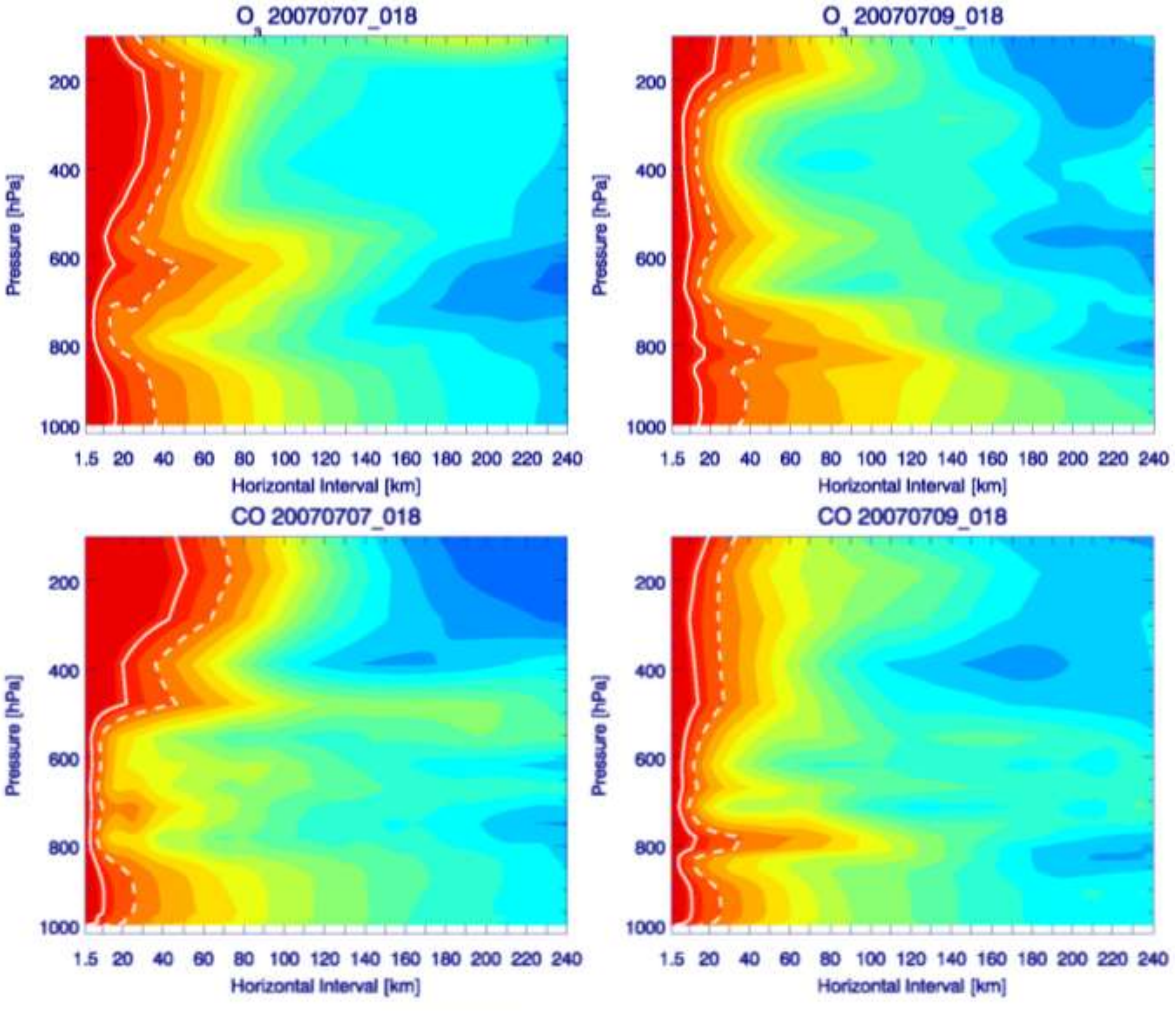


At 8 km horiz. res.:
Clean and Polluted : ~35%

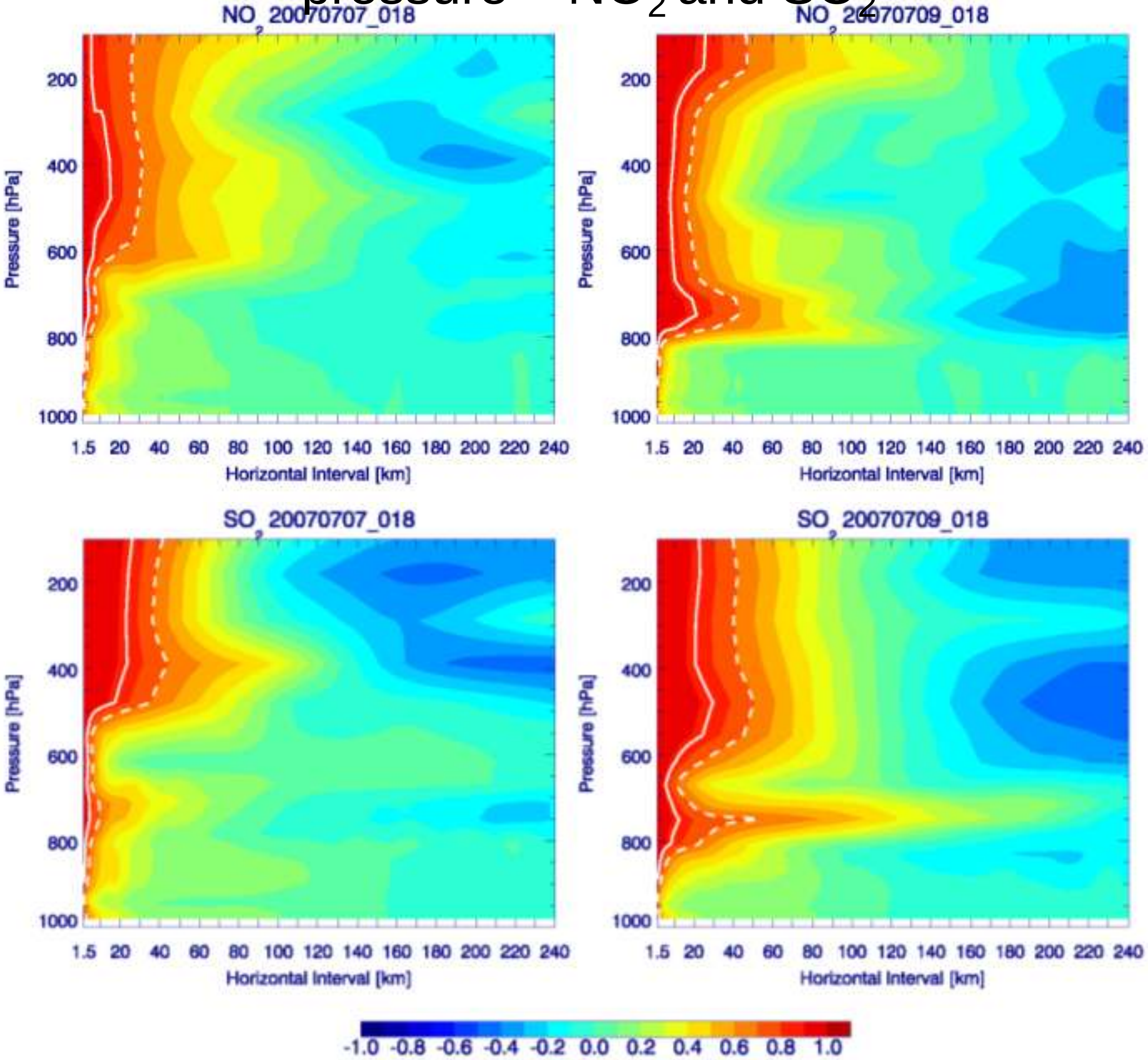
chance

# Decay of horizontal autocorrelation as a function of pressure

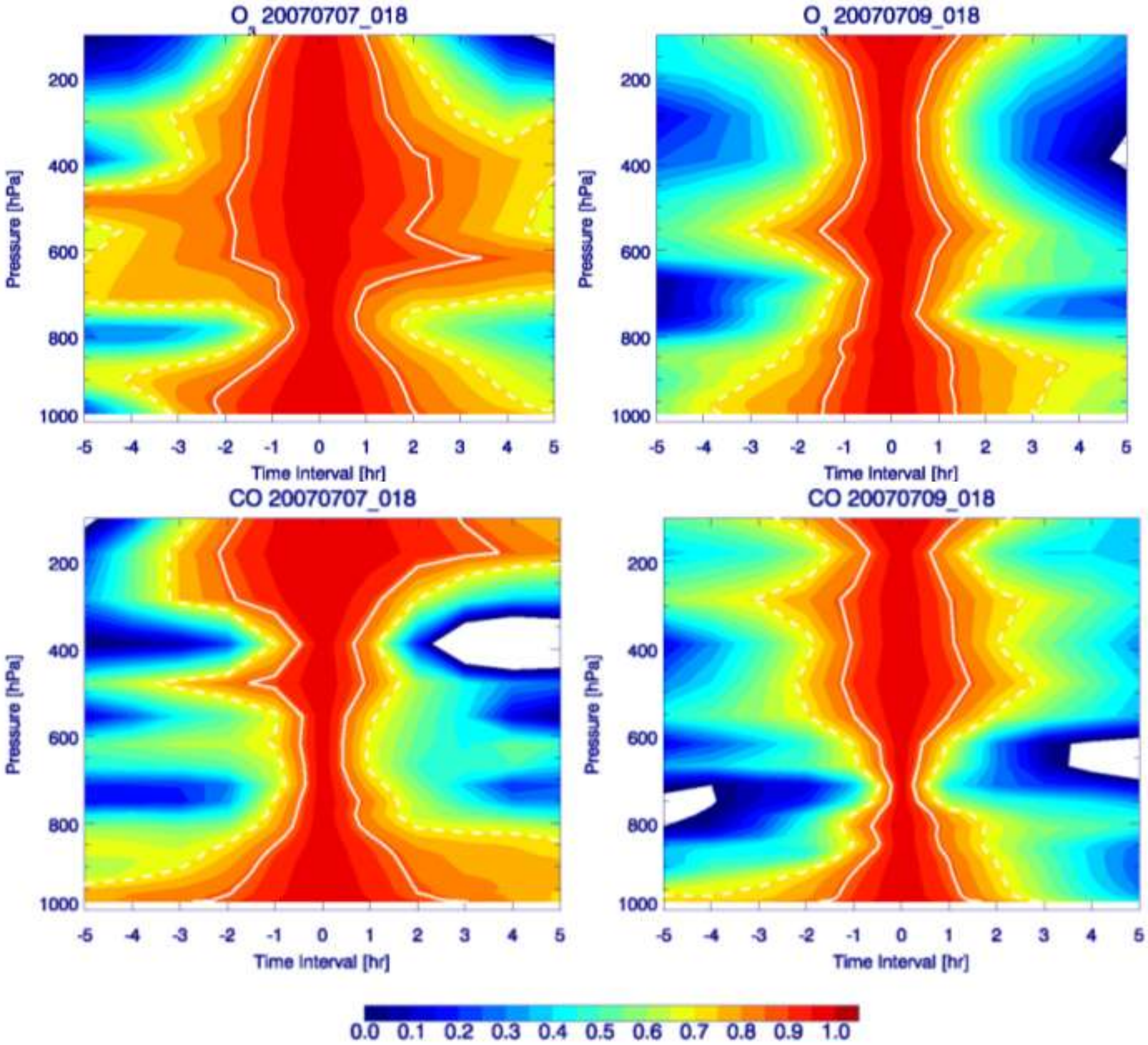
## $O_3$ and CO



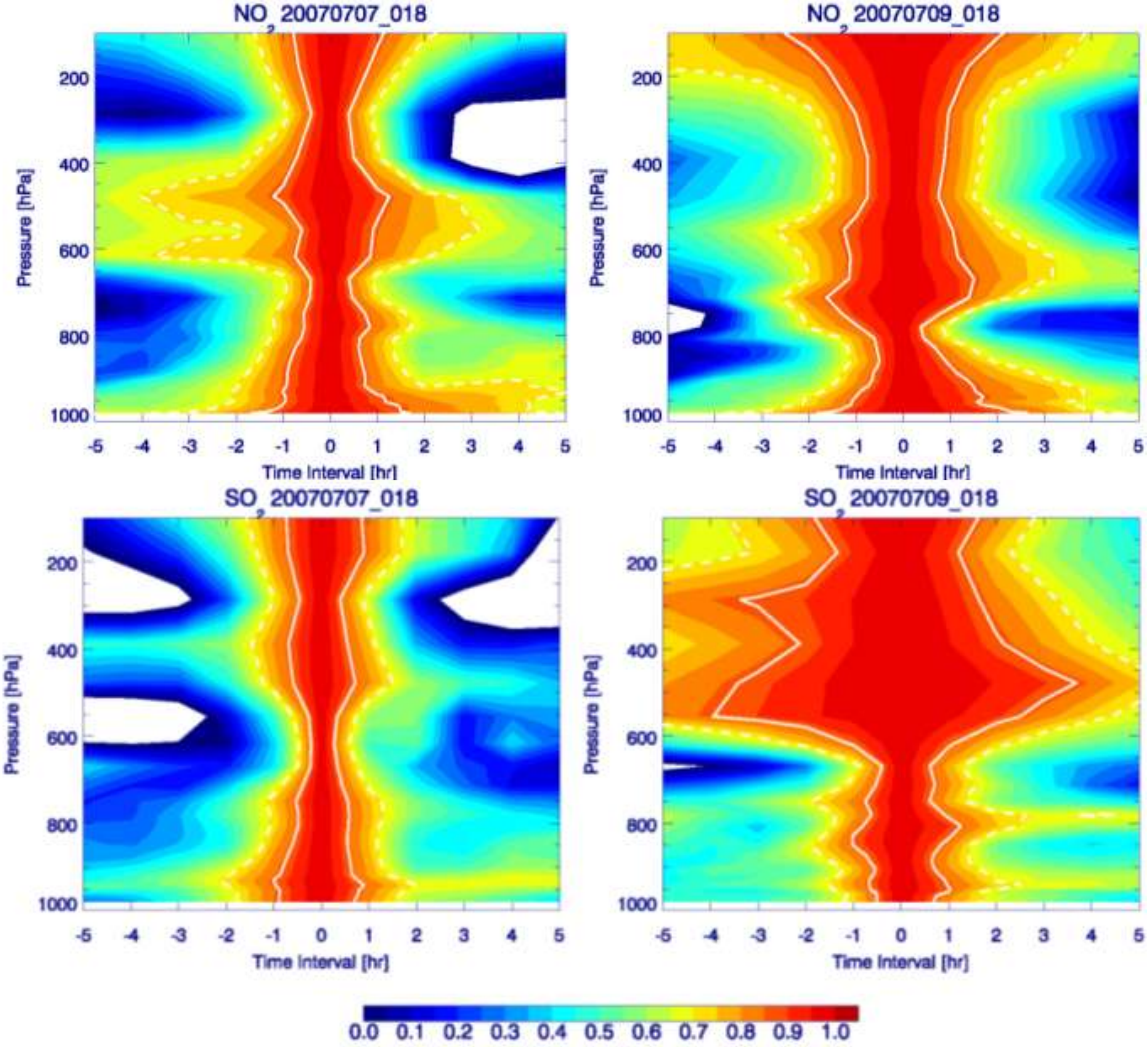
# Decay of horizontal autocorrelation as a function of pressure – $NO_2$ and $SO_2$



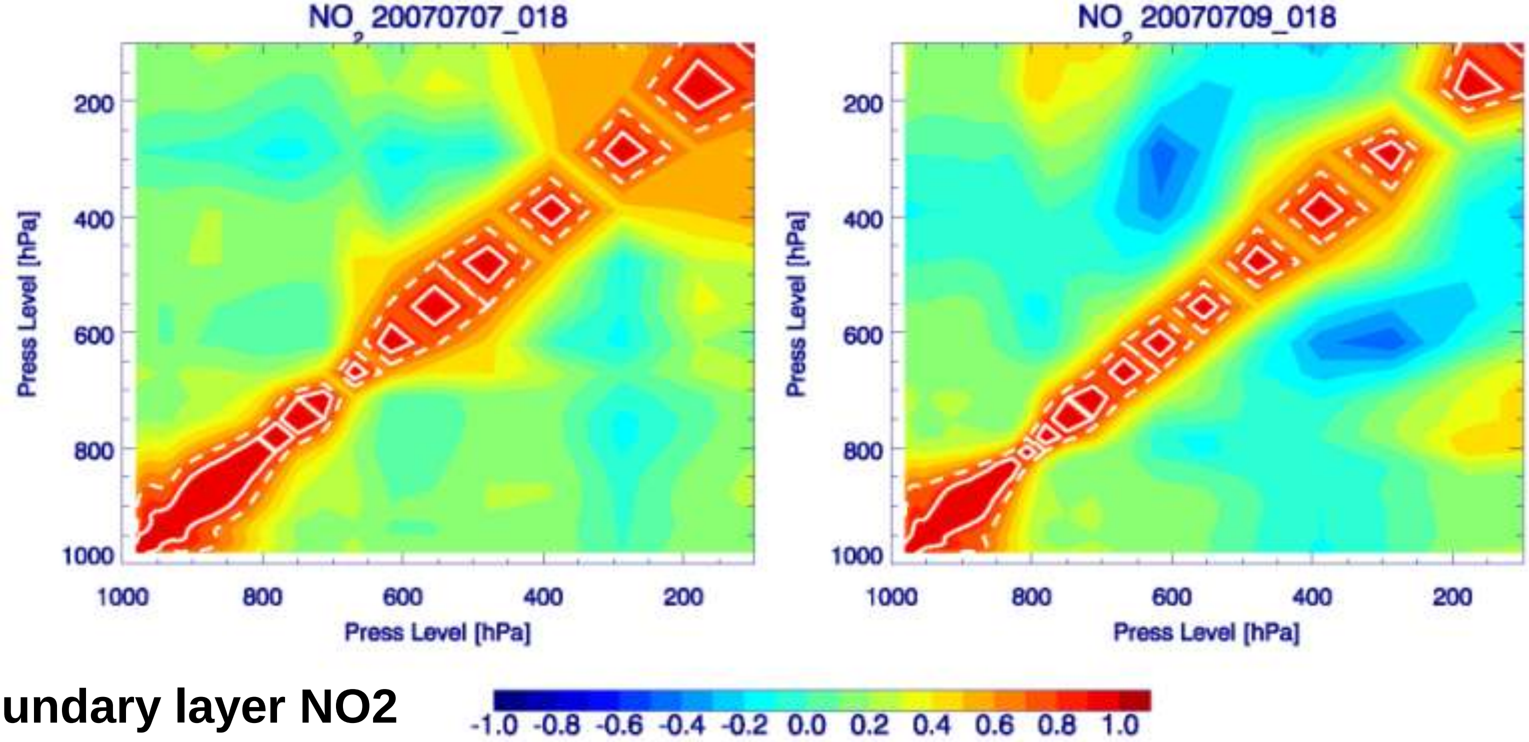
# Decay of temporal correlation as a function of pressure $O_3$ and CO



# Decay of temporal correlation as a function of pressure $NO_2$ and $SO_2$

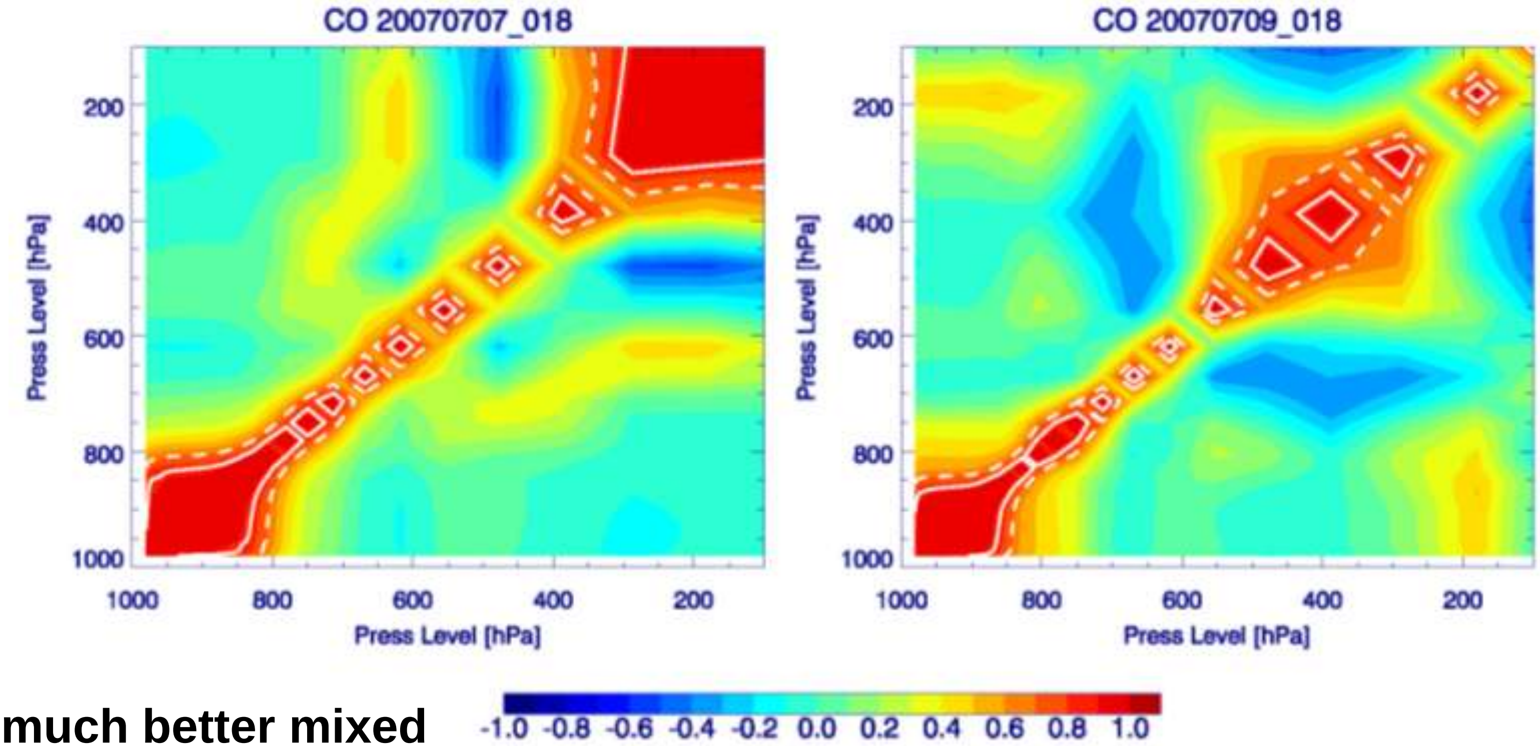


# Decay of vertical correlation as a function of pressure – $NO_2$



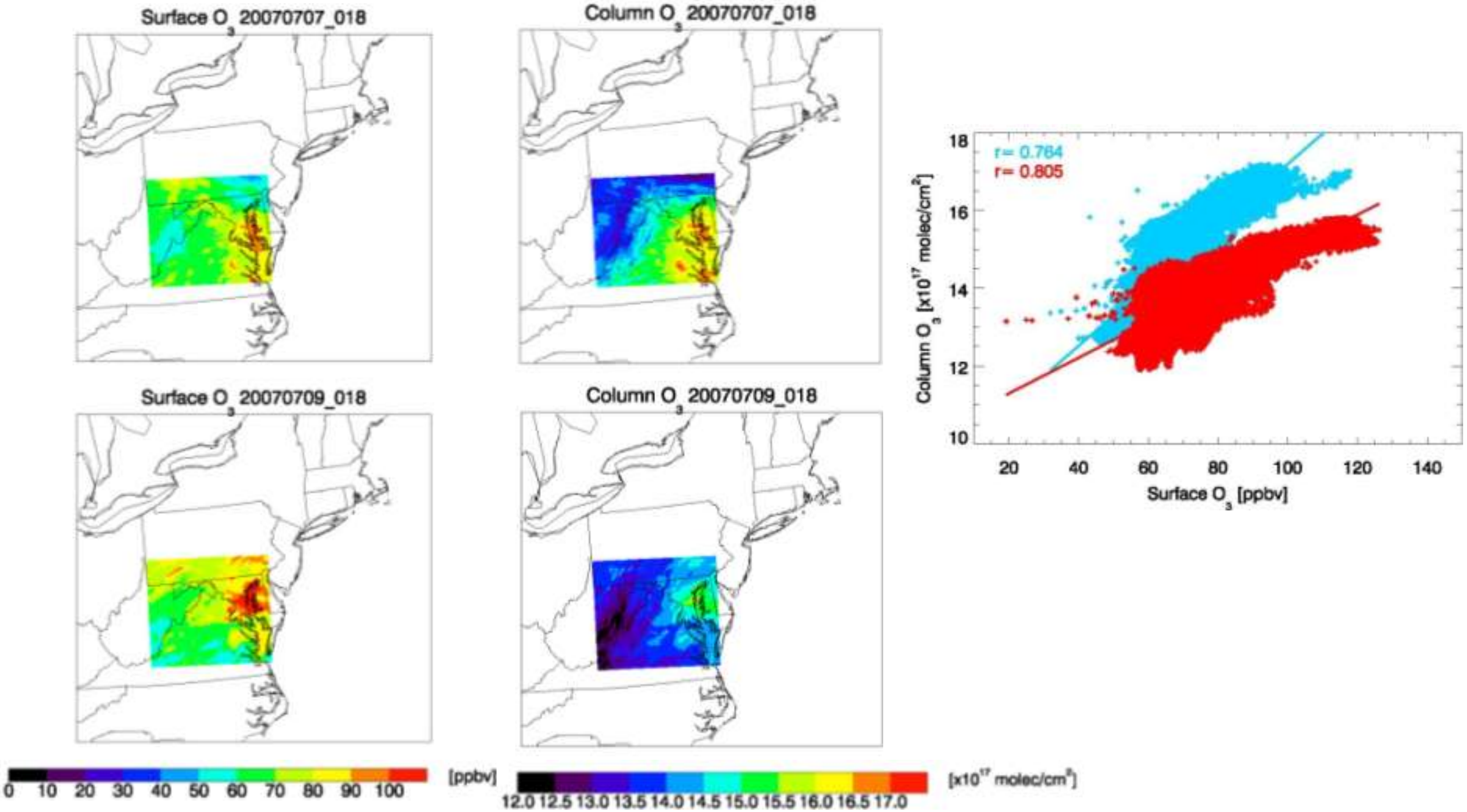
**Boundary layer NO2 not very well mixed. Correlations decay rapidly.**

# Decay of vertical correlation as a function of pressure – CO



**CO much better mixed in BL than NO2.**

# Correlation of surface ozone and tropospheric column ozone

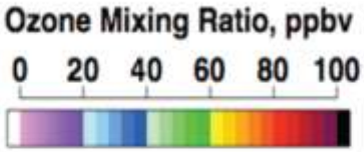


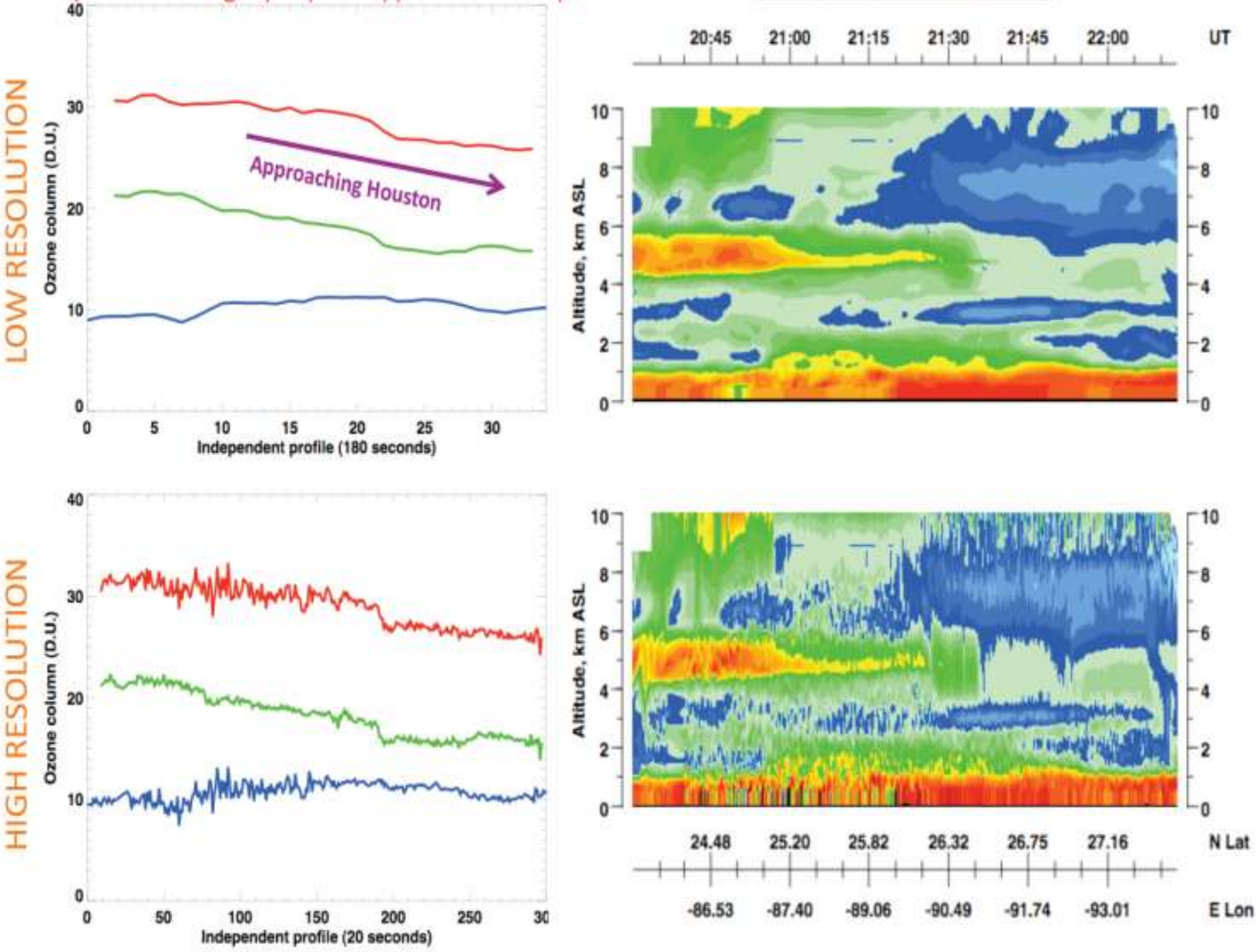
# INTEX-B Flight 3 20:30-22:13 UT

Browell et al. data
Presented by
Fishman

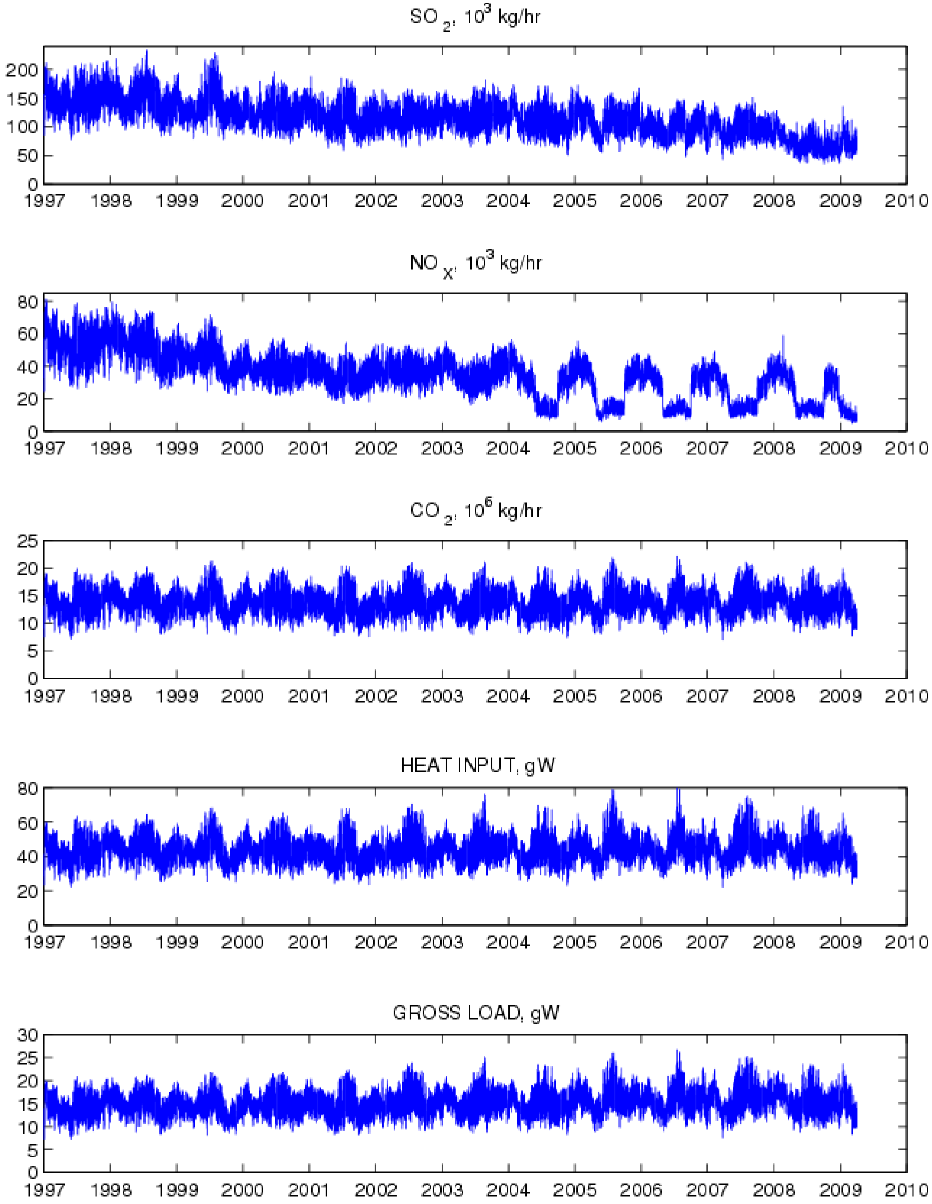
Primary Finding:

Overall tropospheric column increases during flight leg as plane approaches Houston, a result of larger scale structure in free troposphere even though values in pbl increase slightly as plane approaches metropolitan area

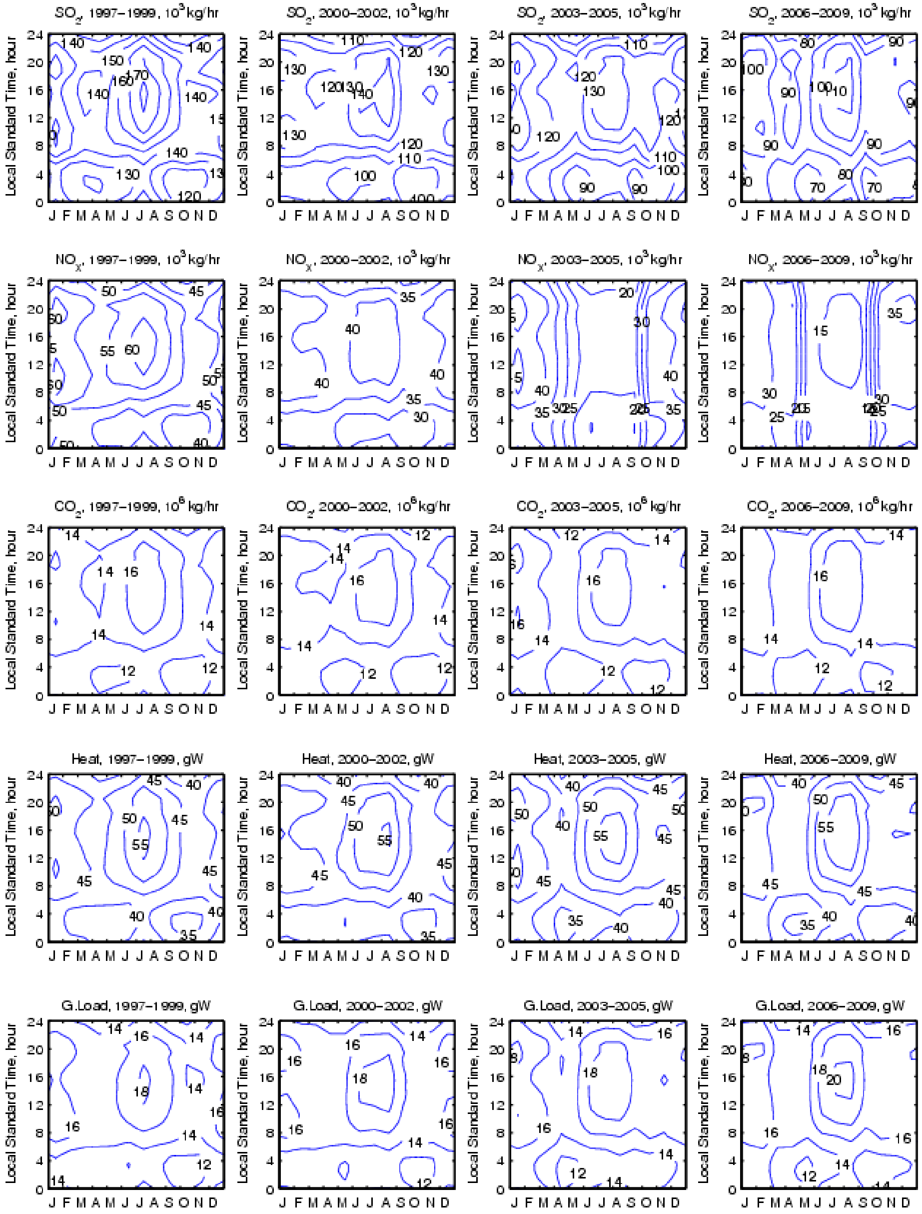




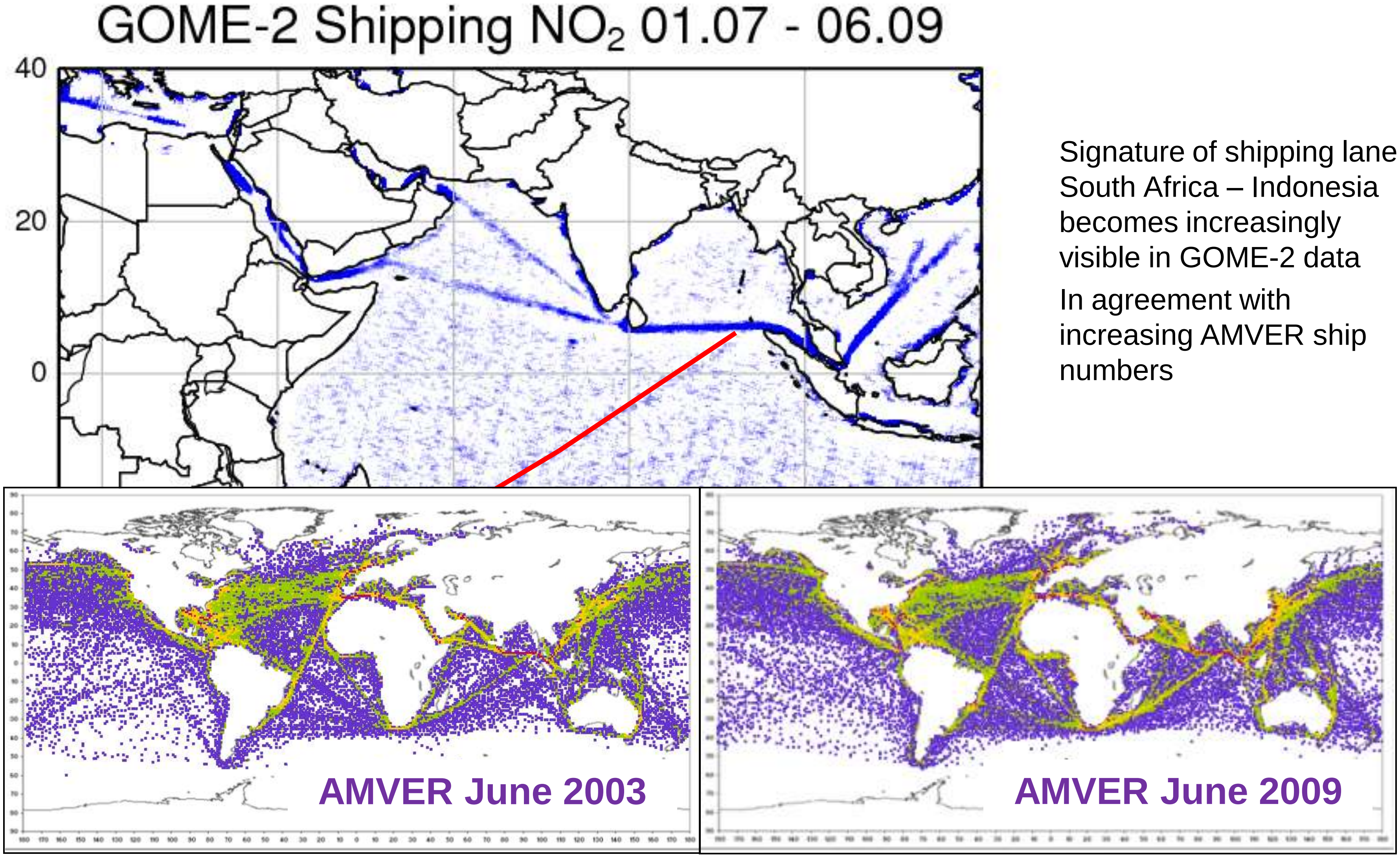
OHIO POWER PLANTS EMISSIONS



OHIO POWER PLANTS EMISSIONS



Courtesy of Kostya Vinnikov



GOME-2 Shipping $NO_2$ 01.07 - 06.09

AMVER June 2003

AMVER June 2009

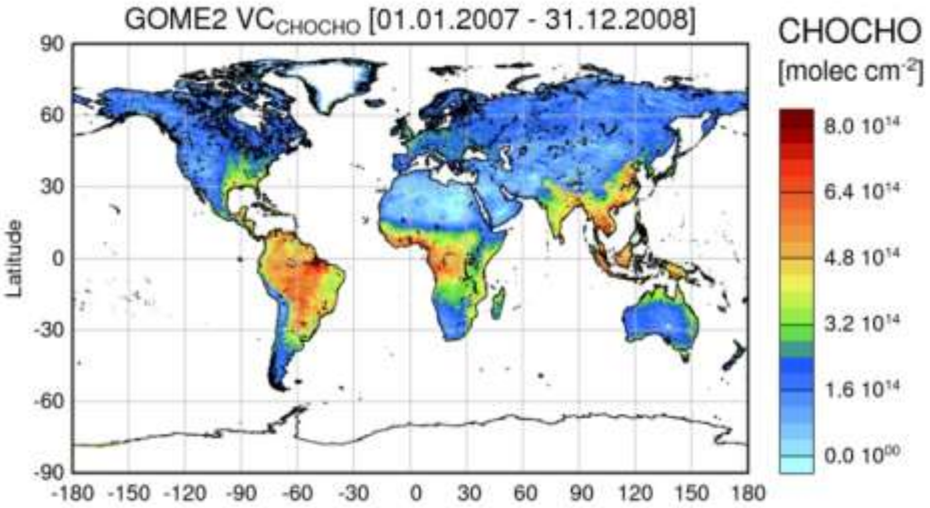
Signature of shipping lane South Africa – Indonesia becomes increasingly visible in GOME-2 data

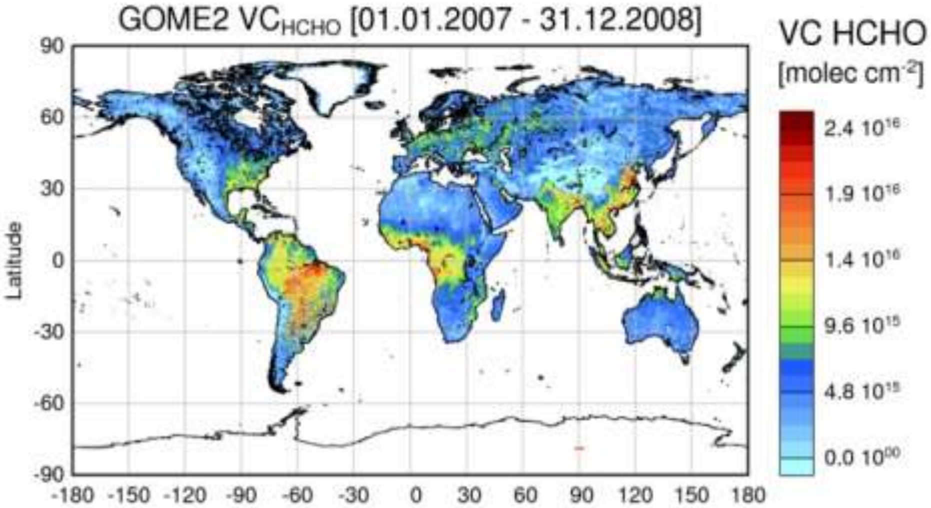
In agreement with increasing AMVER ship numbers

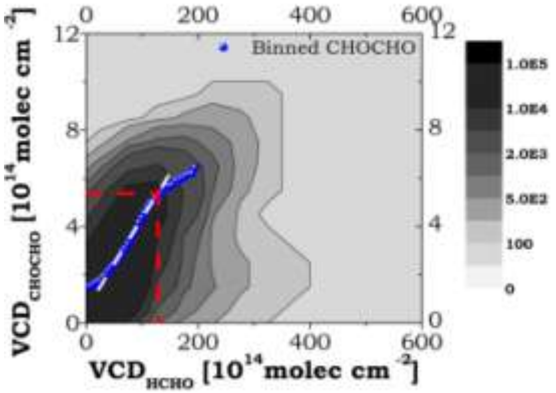
http://www.amver.com/density.asp

# GOME-2 HCHO and CHOCHO

- Glyoxal and formaldehyde fields are very similar
- Good agreement with SCIAMACHY data
- Ratio CHOCHO / HCHO depends on sources







Vrekoussis et al., GOME-2 observations of oVOCs: What can we learn from the ratio CHOCHO to HCHO on a global scale, *paper in preparation*, 2009

# TES Observations of Tropospheric Ammonia

**Karen E. Cady-Pereira, Mark W.Shephard, Vivienne H. Payne**

*AER, Inc.*

**Ming Luo, Reinhard Beer, + JPL TES Science Team**

*JPL*

**Daven Henze**

*University of Colorado*

**Robert W.Pinder, John Walker**

*US EPA-ORD*

**Curtis P. Rinsland**

*NASA Langley*

**Lieven Clarisse**

*Universite Libre de Bruxelles*

*AURA, Sept 14-18, 2009, Leiden, The Netherlands*

# Why Measure Ammonia from Space?

**Lack of direct $NH_3$ obs. to help with large uncertainties in modeled emissions**

- ***In situ*** **(mostly surface) measurements are sparse**
- **Uncertainty in the seasonal and spatial variability**
  - **CMAQ (regional) : peak emissions during fertilization application in spring (April)**
  - **GEOS-Chem (global) : peak emissions with high temperatures in summer (July)**

**Satellite measurements have potential to constrain the $NH_3$ emissions**

**US EPA Monitoring Network**

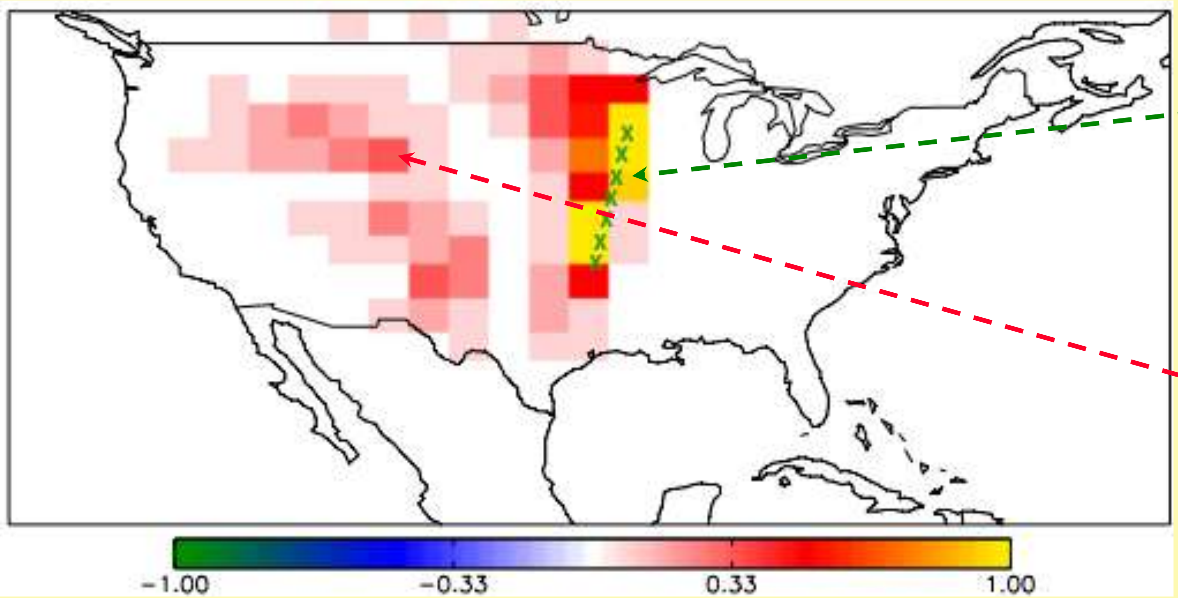
**(Gary Lear)**

# Sensitivity Tests

## How sensitive are TES measurements to changes in $NH_3$ emissions?

- **Map shows the sensitivity of TES measurements (marked by X) to $NH_3$ emissions from any model grid box (from up to a week prior)**
  - – relative to the influence of the $NH_3$ directly underneath the TES track

**Sensitivity of TES obs in the track to $NH_3$ emissions from the week prior**



**Sensitivities scaled relative to the maximum values (yellow)**

**TES Obs are most sensitive to $NH_3$ emissions directly underneath the track (X)**

**TES is sensitive to $NH_3$ emissions away from obs.**

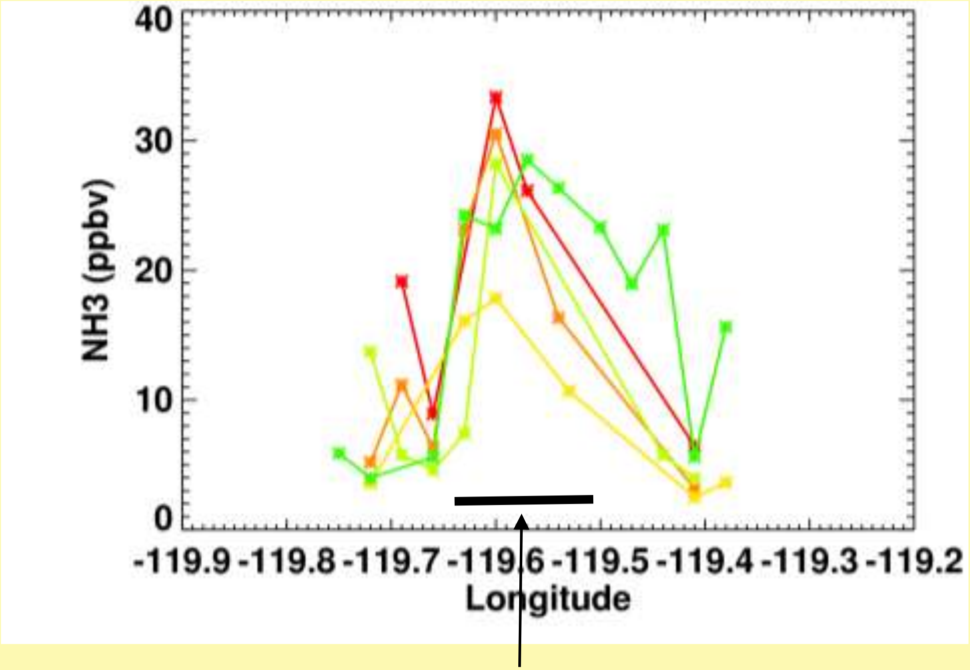
- e.g. TES is ~40% as sensitive to emissions here compared with directly beneath **(X)**

**$NH_3$ lifetime increased :**

- $NH_3$ (gas) -> $NH_4$ (aerosol-phase)
- Bi-directional flux (biosphere and atmosphere)

# $NH_3$ Spatial Gradients and Seasonal Variability: San Joaquin Valley -2008

## July-August Transects

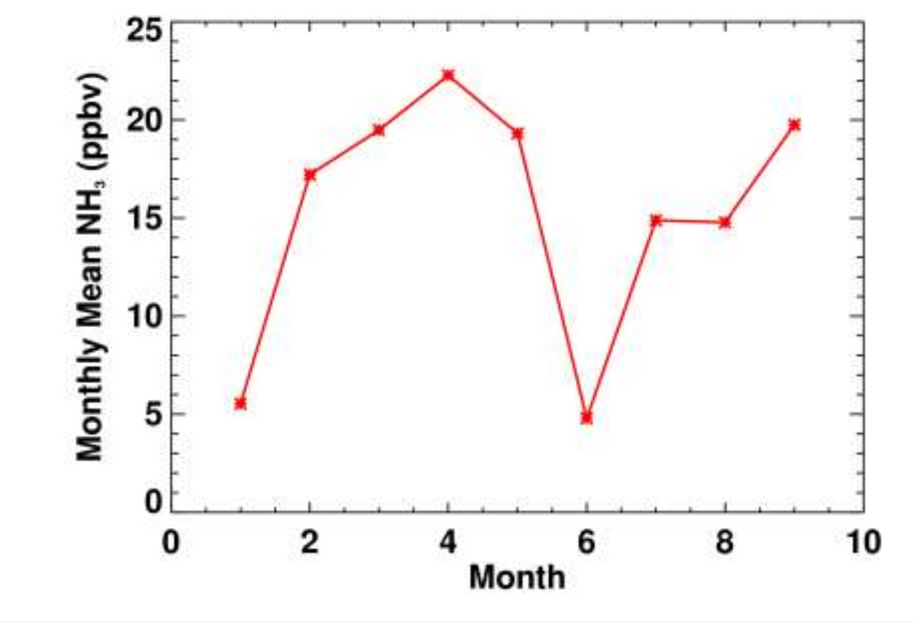


San Joaquin Valley

**TES captures spatial gradient**

- **High values (40 ppbv): much greater than GEOS-Chem**

## Monthly Mean values

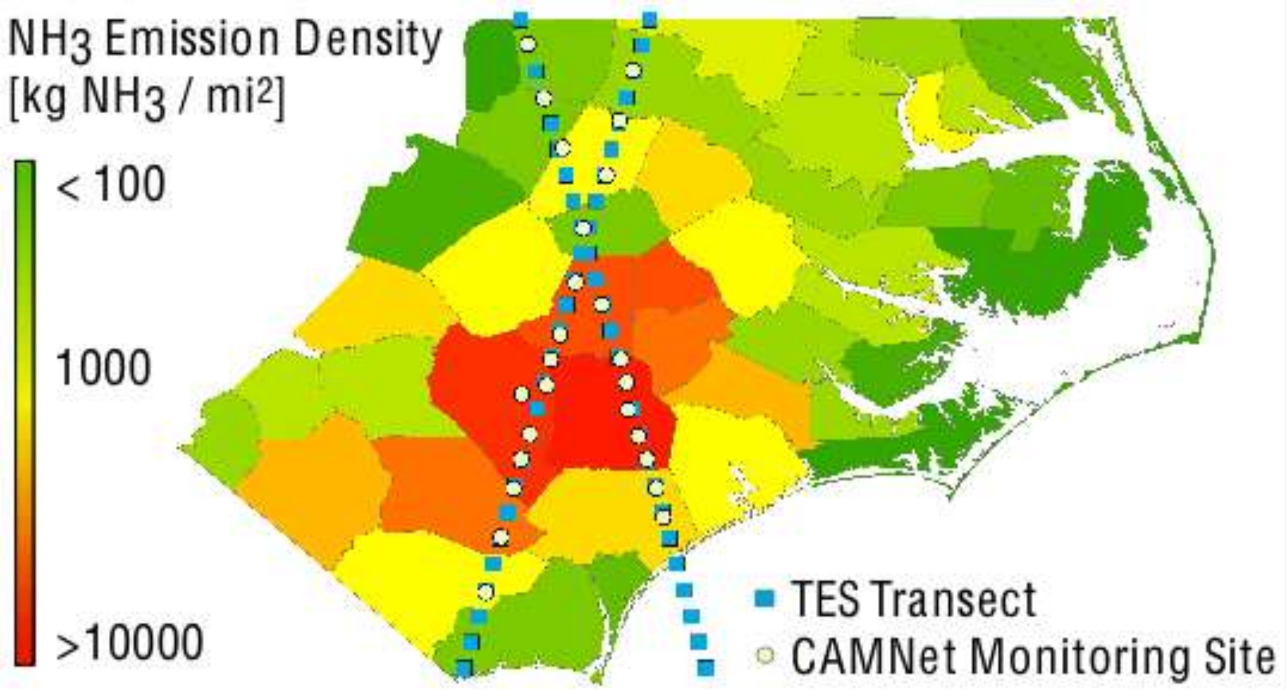


**Seasonal variability**

- **Peaks in April and September**
  - **Typical of farming with fertilizer application?**
  - **Will compare with in situ datasets where available**

# TES NH3 Validation Example : Transects over North Carolina USA

- **Started in early February 2009**
- **Will run at least through Dec. 2009**
- **CAMNet $NH_3$ monitoring sites match-up with TES overpass**
- **Will allow detection of spatial variability and seasonal trends**



# Observing the troposphere with IASI:

## Emission, chemistry and transport

**Pierre Coheur** SPECAT/ULB and CNRS/LATMOS team

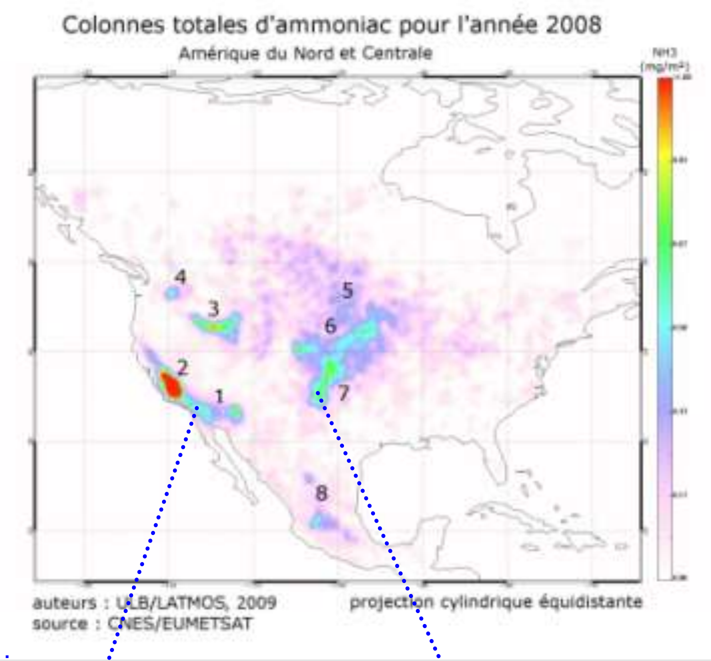
# Products / Applications

## Tropospheric sources

## → Ammonia

***Clarisse et al.***, Nature Geo, 2009

**The link to agriculture**

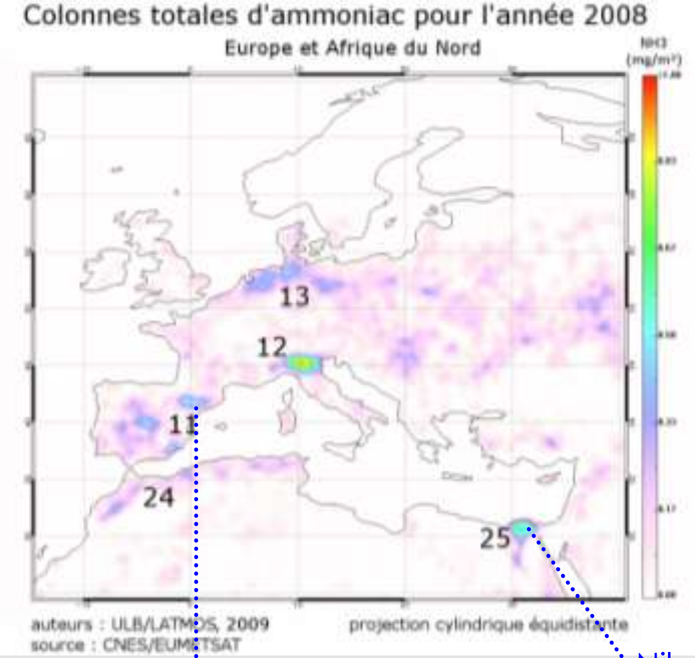


Colonnes totales d'ammoniac pour l'année 2008

Amérique du Nord et Centrale

auteurs : ULB/LATMOS, 2009
source : CNES/EUMETSAT

projection cylindrique équidistante



Colonnes totales d'ammoniac pour l'année 2008

Europe et Afrique du Nord

auteurs : ULB/LATMOS, 2009
source : CNES/EUMETSAT

projection cylindrique équidistante

Inland empire

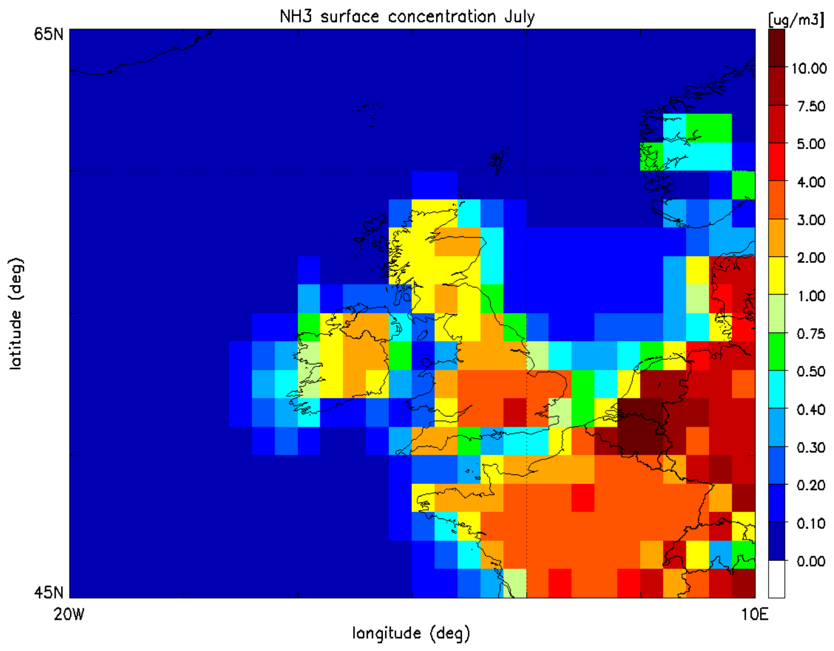
High Plains Aquifer

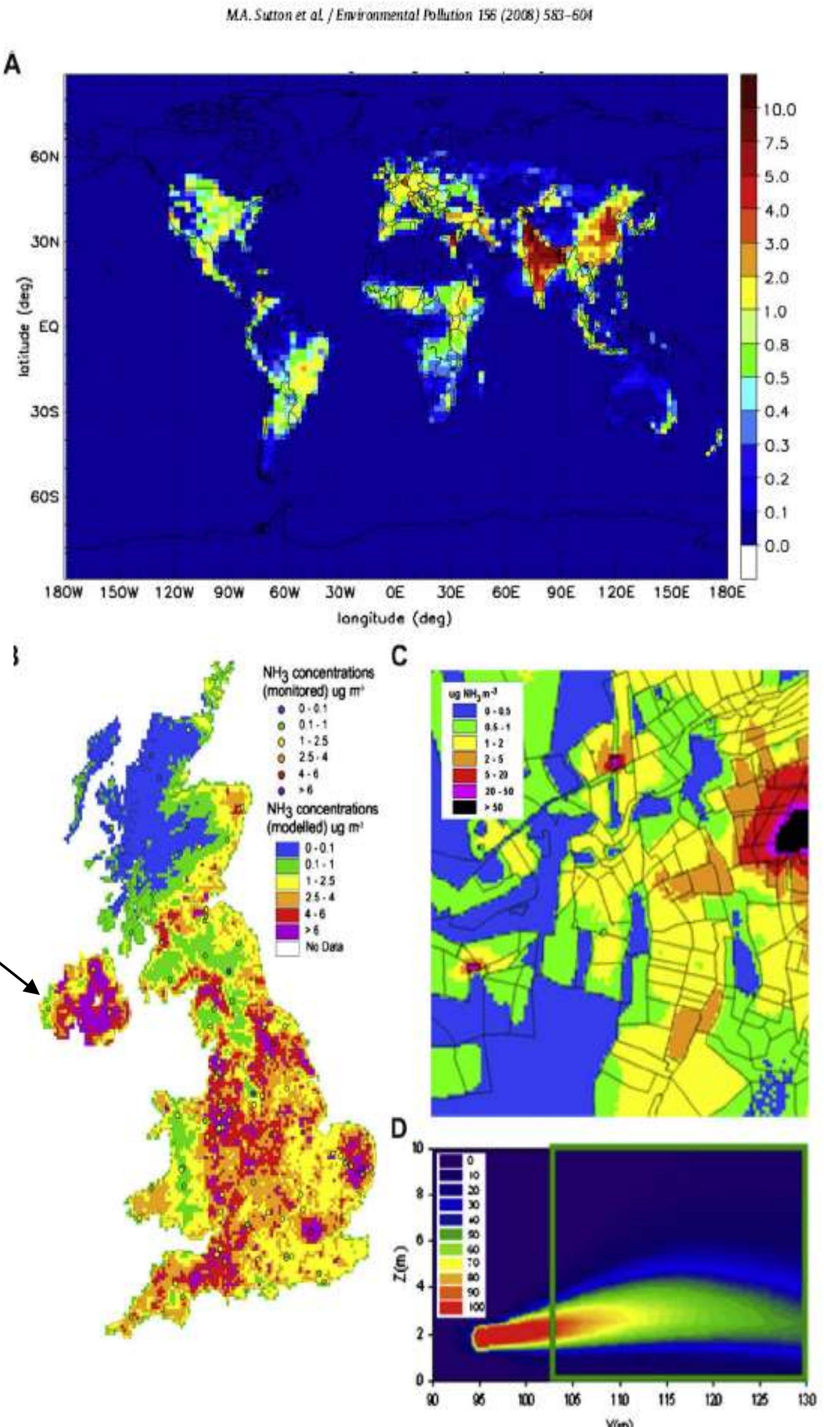
Ebro valley

Nile Delta

# Global Modelling of $NH_3$ and the first comparison with satellite observations

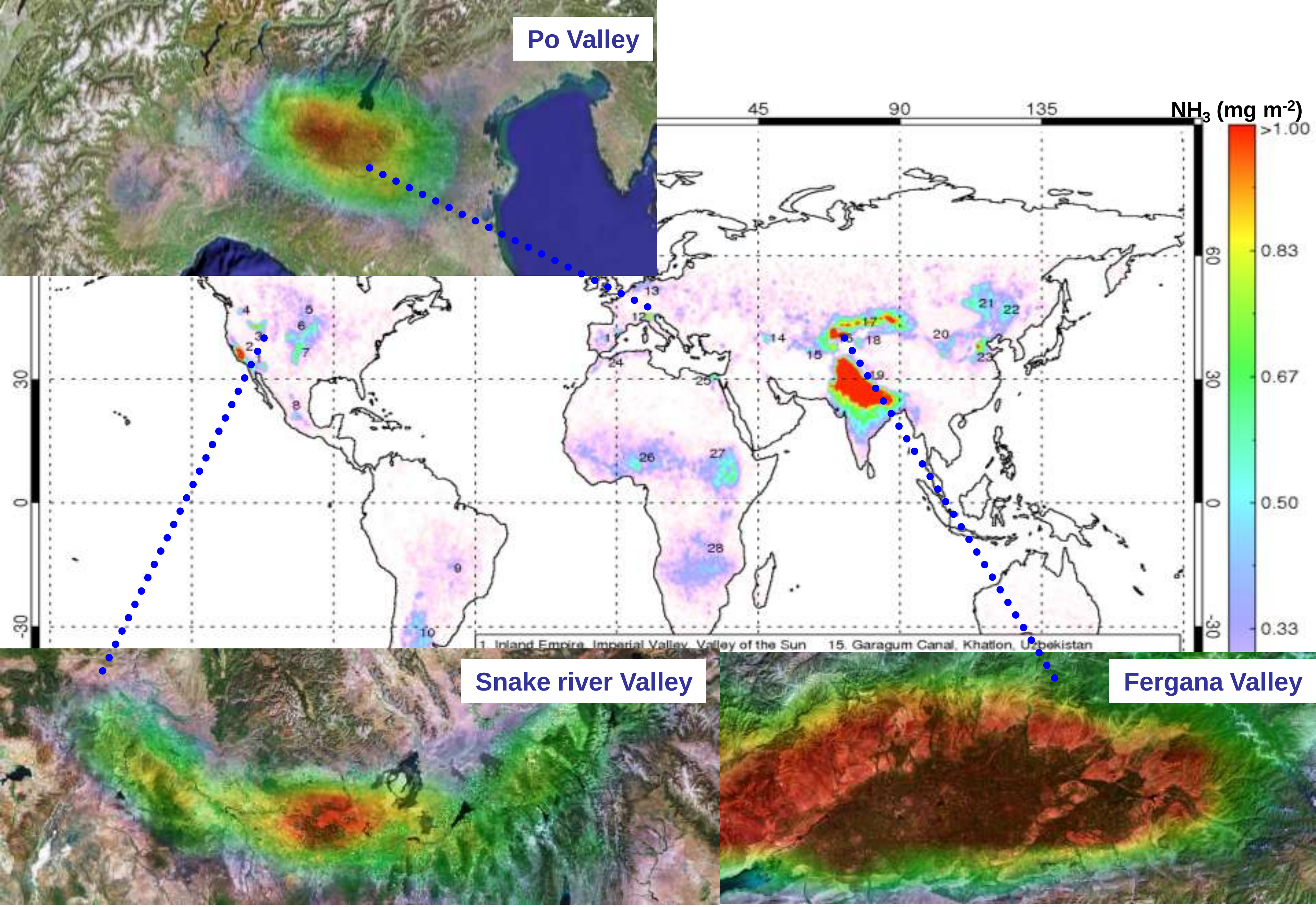
**Frank Dentener**
**Lieven Clarisse**





## Comparison of NH$_3$ on global, country and urban scale

Sutton et al, 2008



Clarisse et al, [2009]

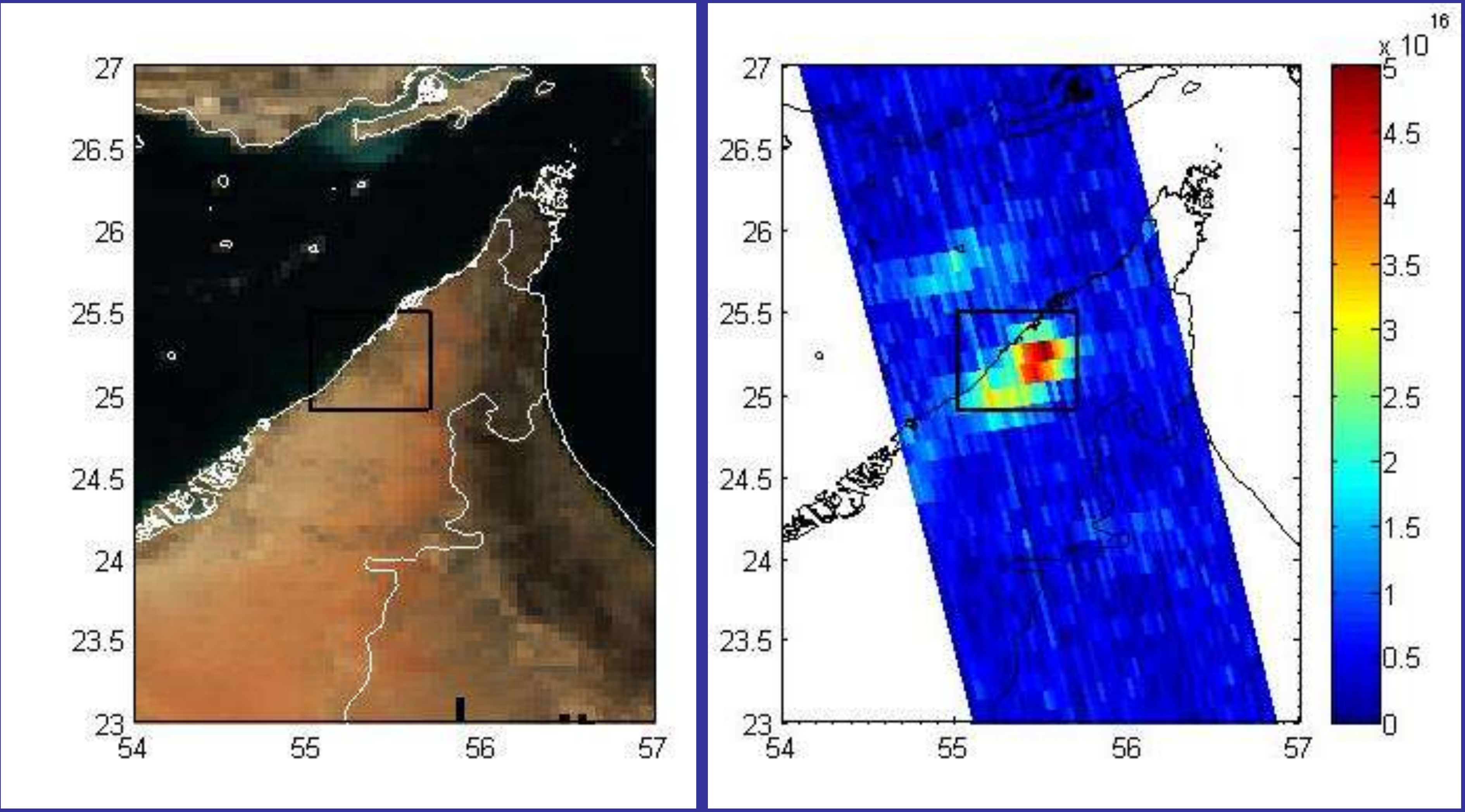
# Some new uses of OMI $NO_2$ observations

- Spatial Resolution
- Fires
- Farms

**R.C. Cohen**
**UC Berkeley**

$$ NASA

# 11/21/2004: Unbinned 3km wide pixels



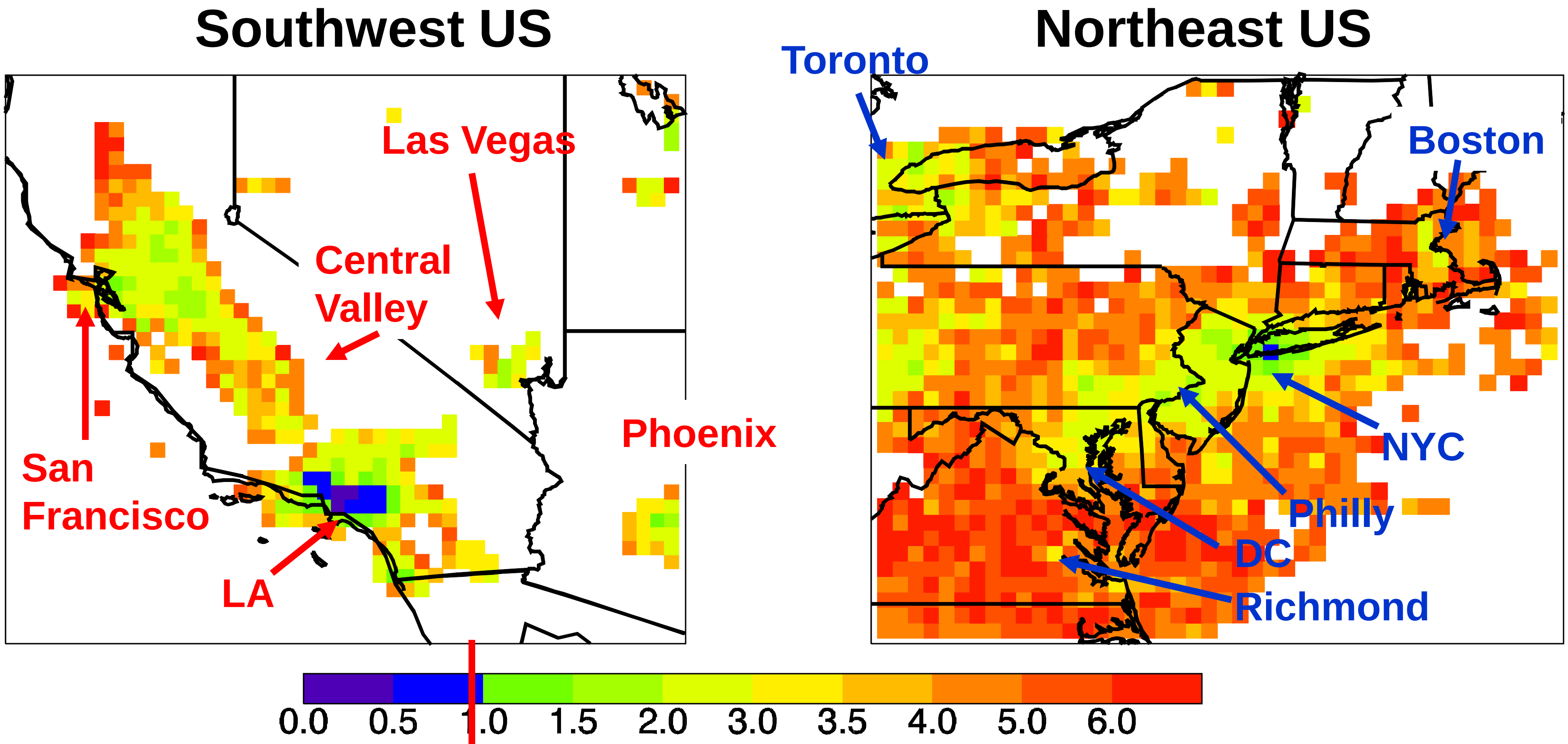
# The Sensitivity of U.S. Surface Ozone Formation to $NO_x$ and VOCs as Viewed from Space

Bryan Duncan[1], Yasuko Yoshida[1], Jennifer Olson[2],
Sandy Sillman[3], Christian Retscher[1], Ken Pickering[1],
Randall Martin[4], Ed Celarier[1], Jim Crawford[2]

[1]NASA Goddard Space Flight Center
[2]NASA Langley Research Center
[3]University of Michigan
[4]Dalhousie University

September 16, 2009 Leiden, Netherlands

# OMI HCHO/$NO_2$ : August 2006



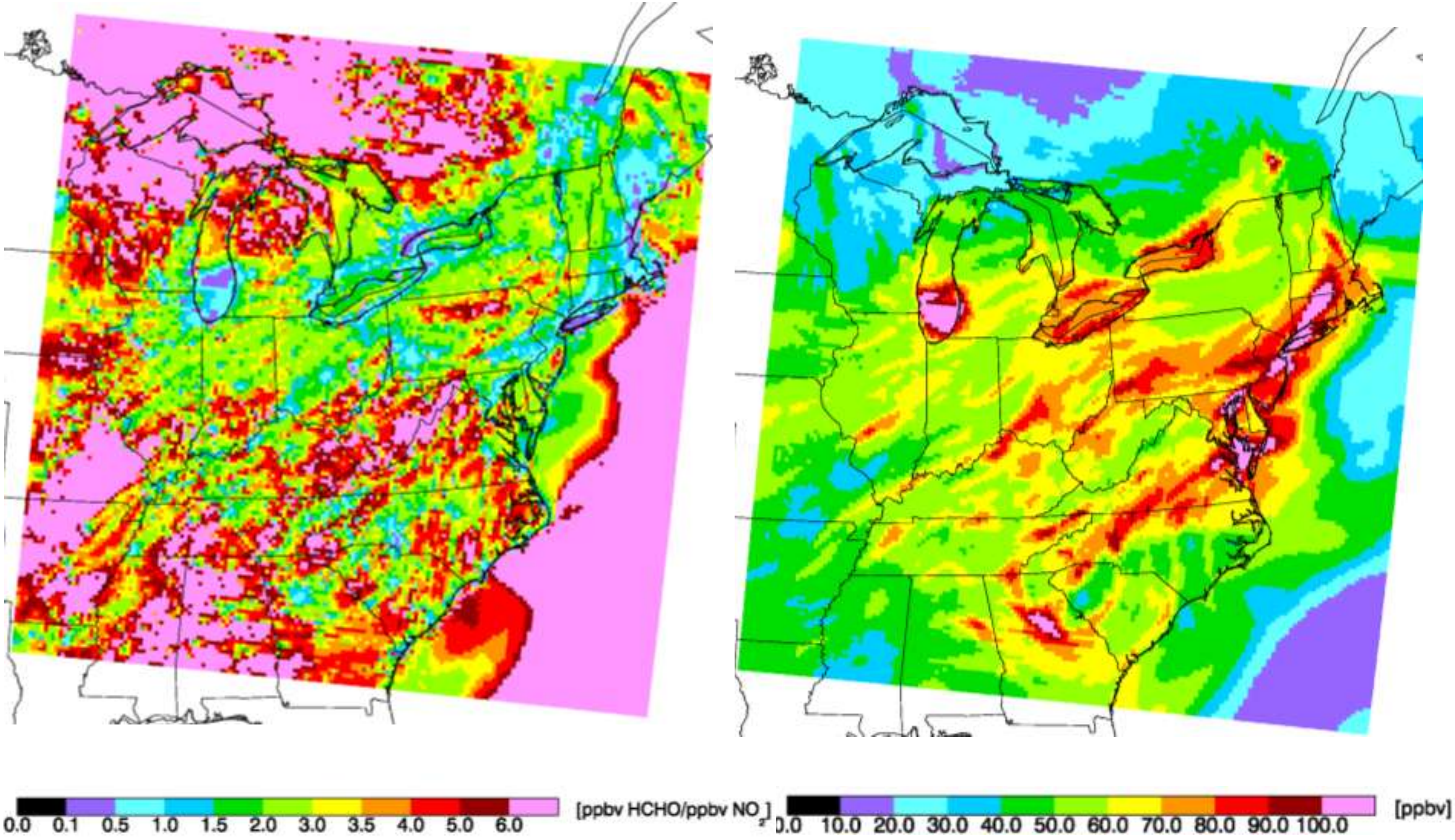
**Southwest US**

**Northeast US**

VOC controls $O_3$ prod. | $NO_x$ controls $O_3$ production →

**OMI captures gradient from downtown to suburbs to rural areas!**

# WRF-Chem: July 9th : 3 pm : Surface



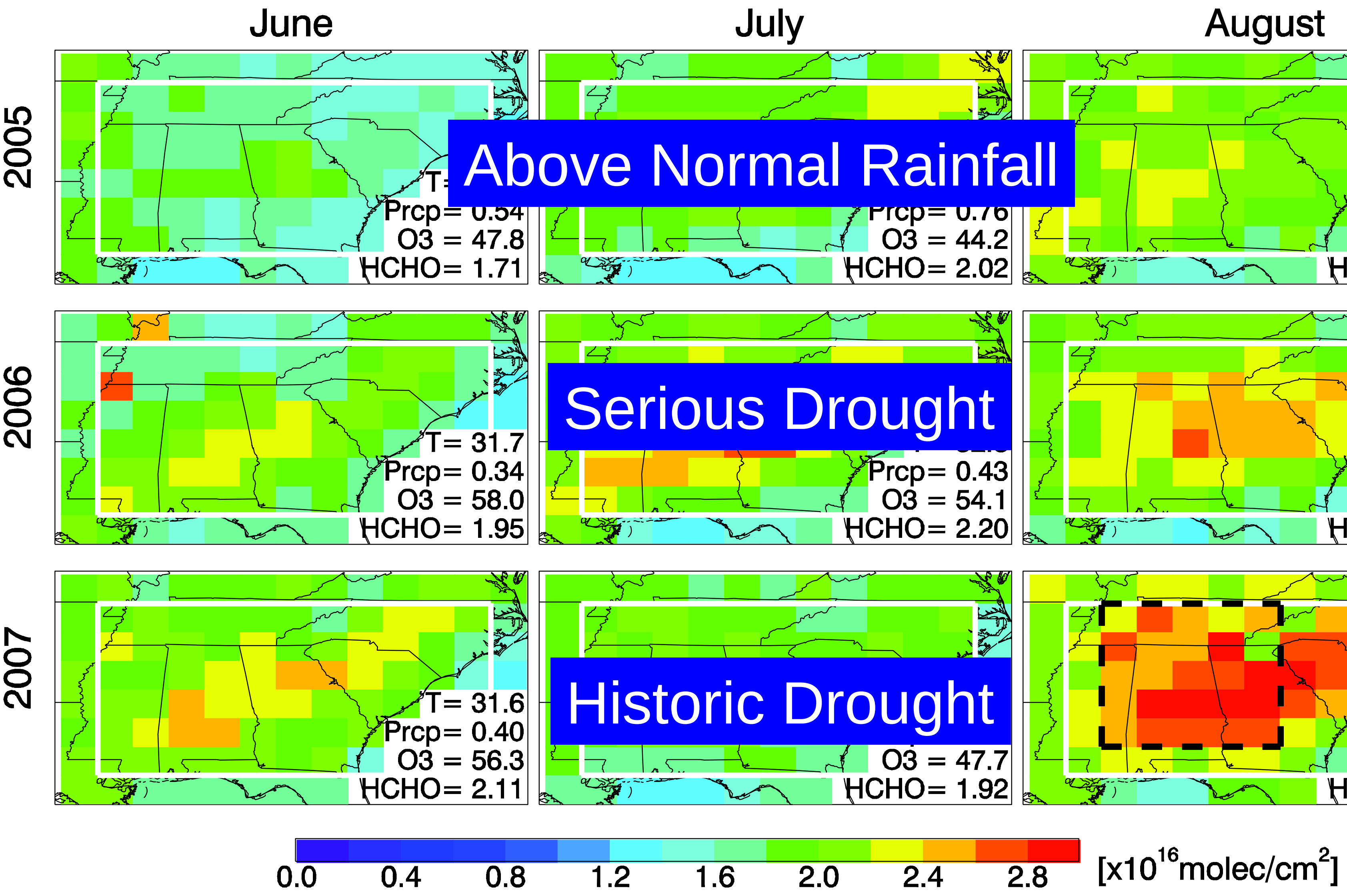
HCHO/$NO_2$

Ozone (ppbv)

# OMI HCHO as Proxy for Variability of Isoprene Emissions

Major player in AQ!

~22% Variation

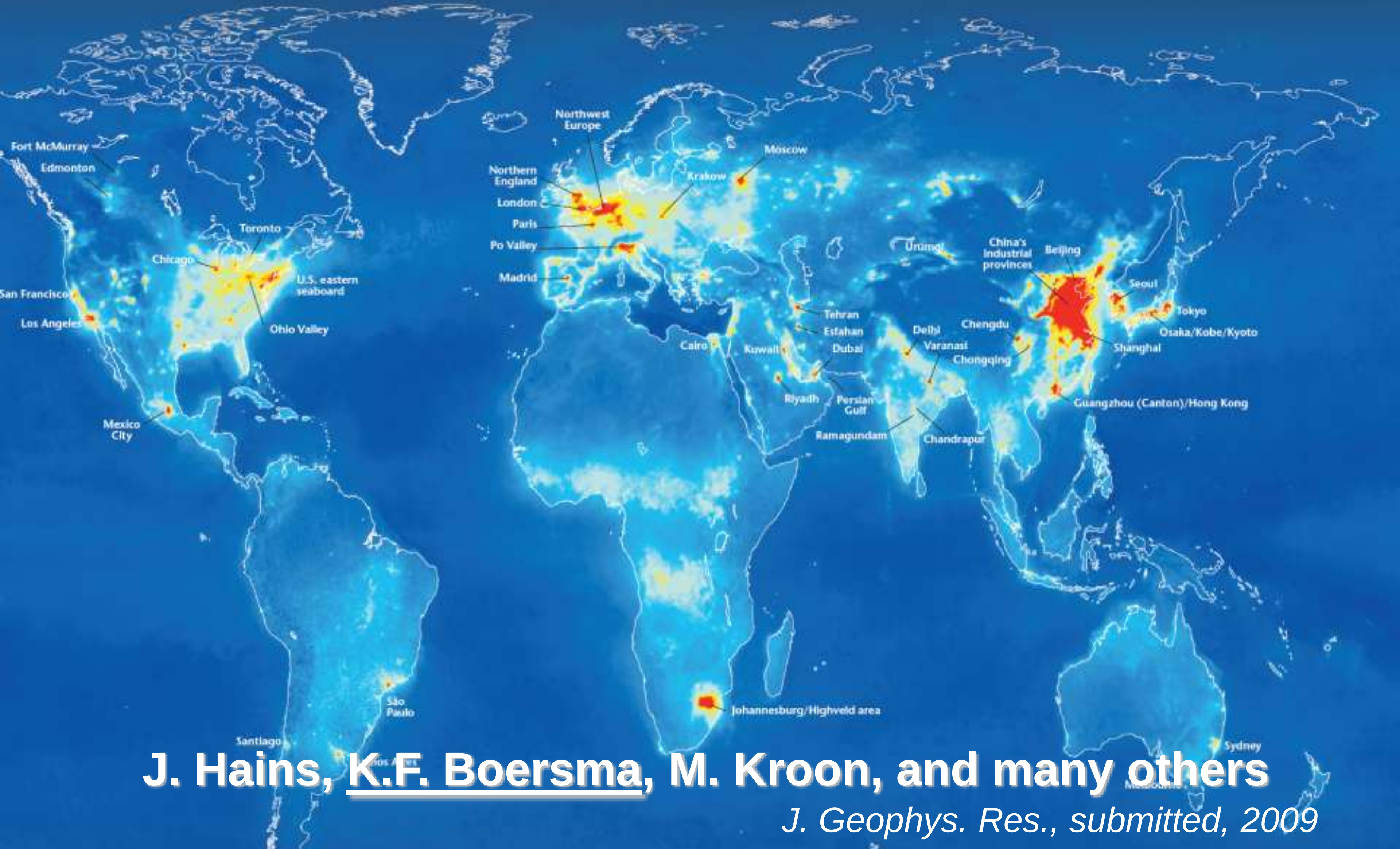


Above Normal Rainfall

Serious Drought

Historic Drought

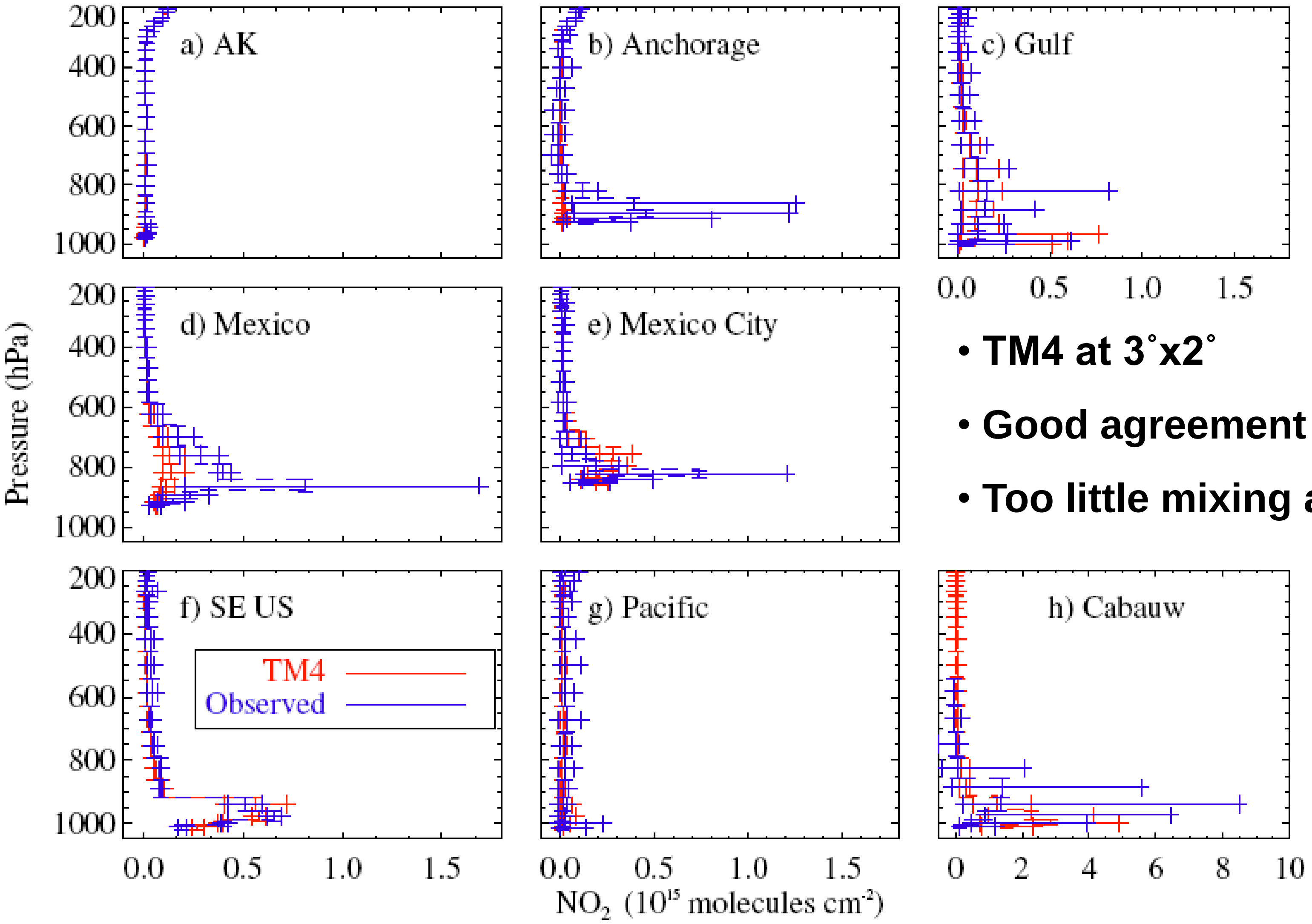
# Testing and improving OMI $NO_2$ using DANDELIONS and INTEX-B data



J. Hains, K.F. Boersma, M. Kroon, and many others

*J. Geophys. Res., submitted, 2009*

# Evaluating TM4 a priori profile shapes



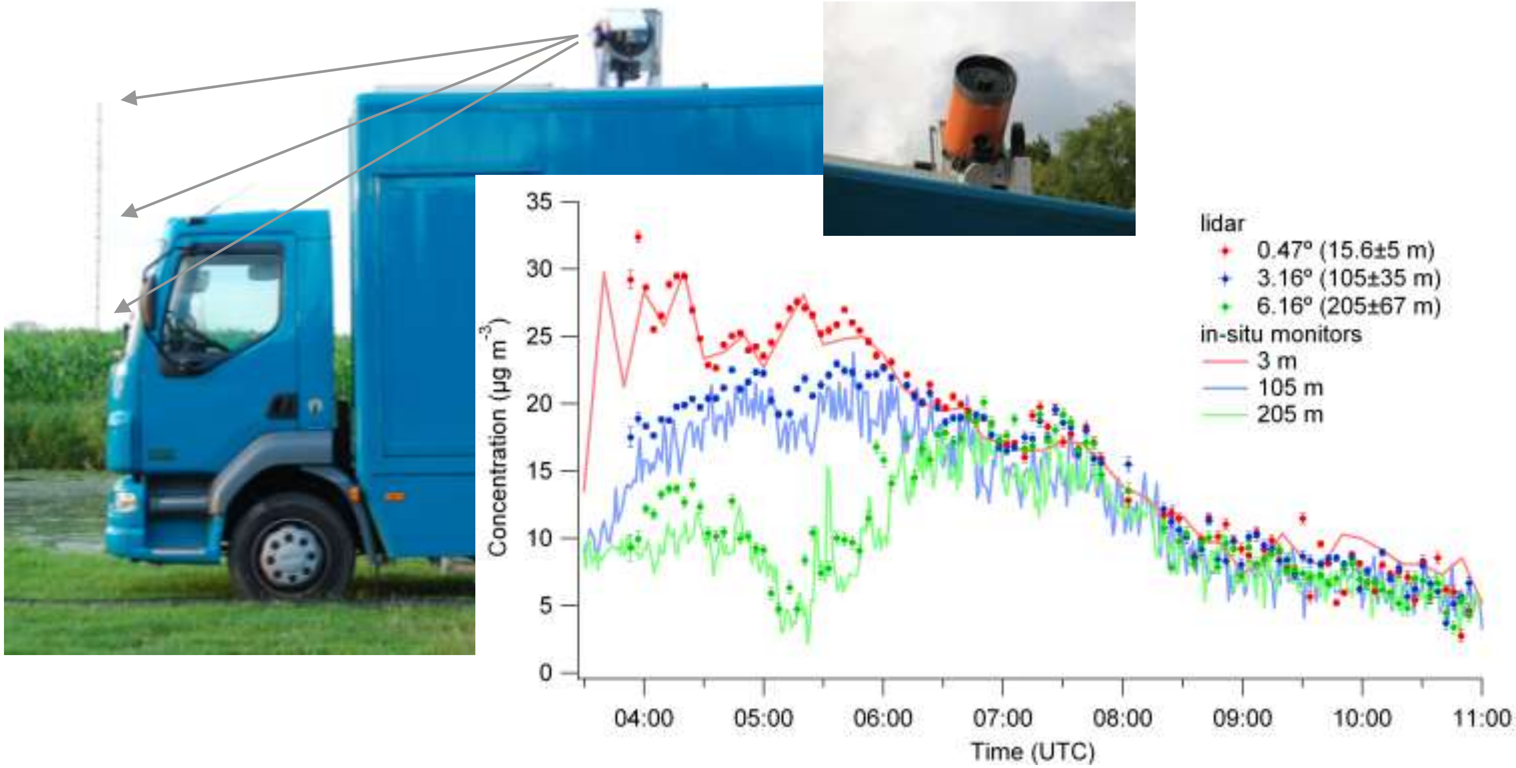
- **TM4 at 3˚x2˚**
- **Good agreement for a, c, f, g**
- **Too little mixing at Cabauw**

# The Cabauw Intercomparison campaign of Nitrogen Dioxide measuring Instruments

*Ankie Piters, KNMI*
*and CINDI Organisation Team*

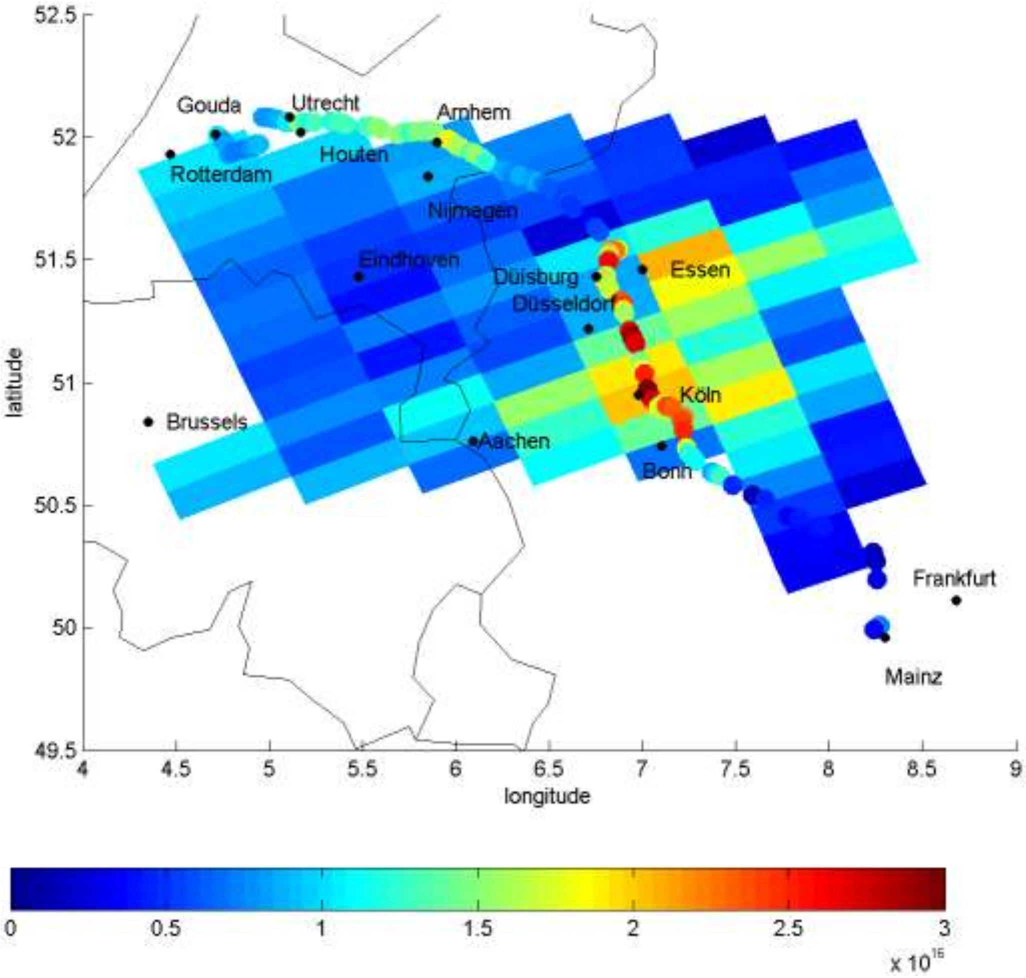
# NO2 gradients <200m measured by lidar

- c) Measuring from a distance towards the tower to validate with the in-situ sensors at different latitude levels

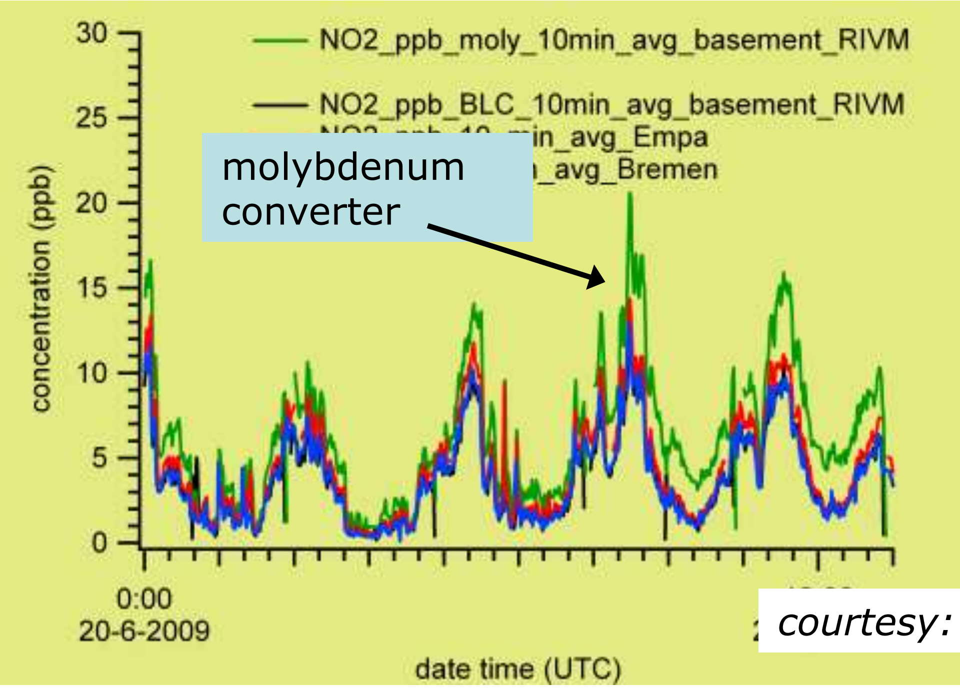


*courtesy: D. Swart, RIVM*

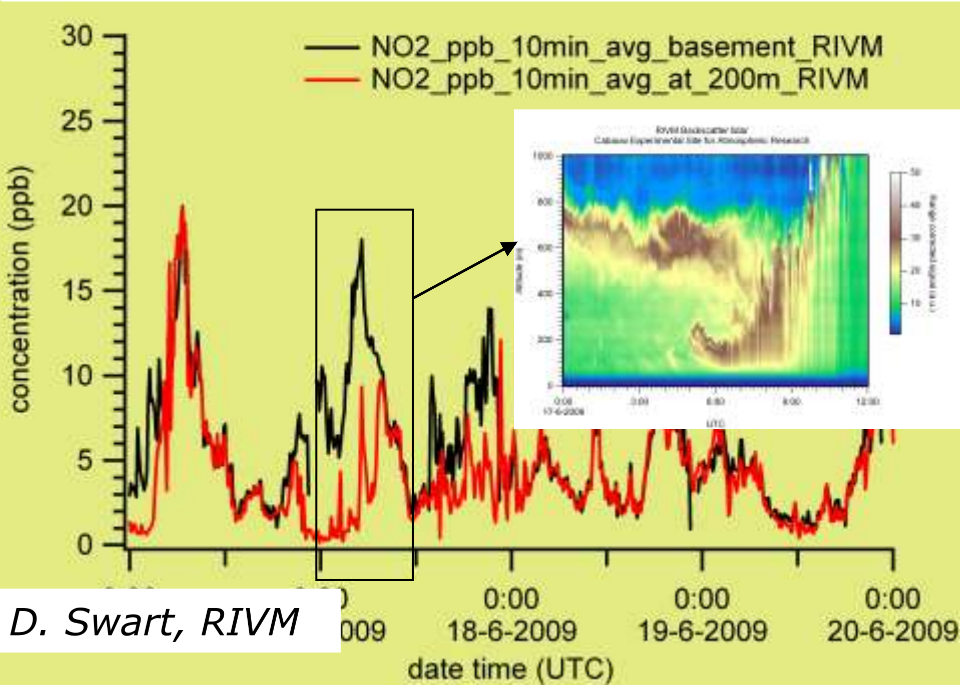
# NO2 surface gradients exceed satellite resolution



*courtesy: T. wagner, MPI Mainz*

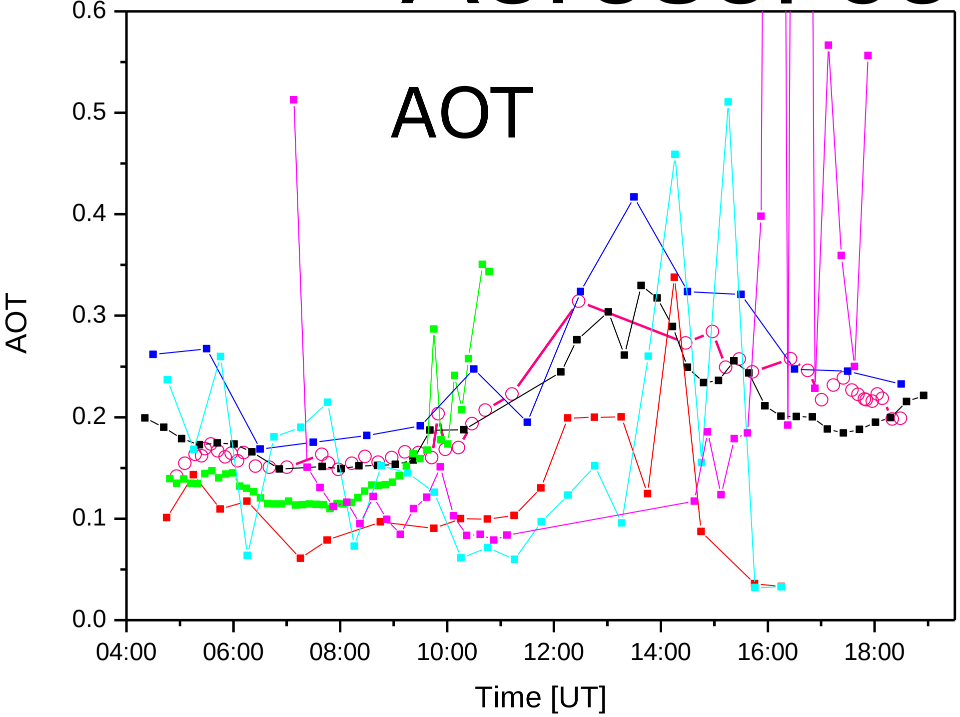


molybdenum converter



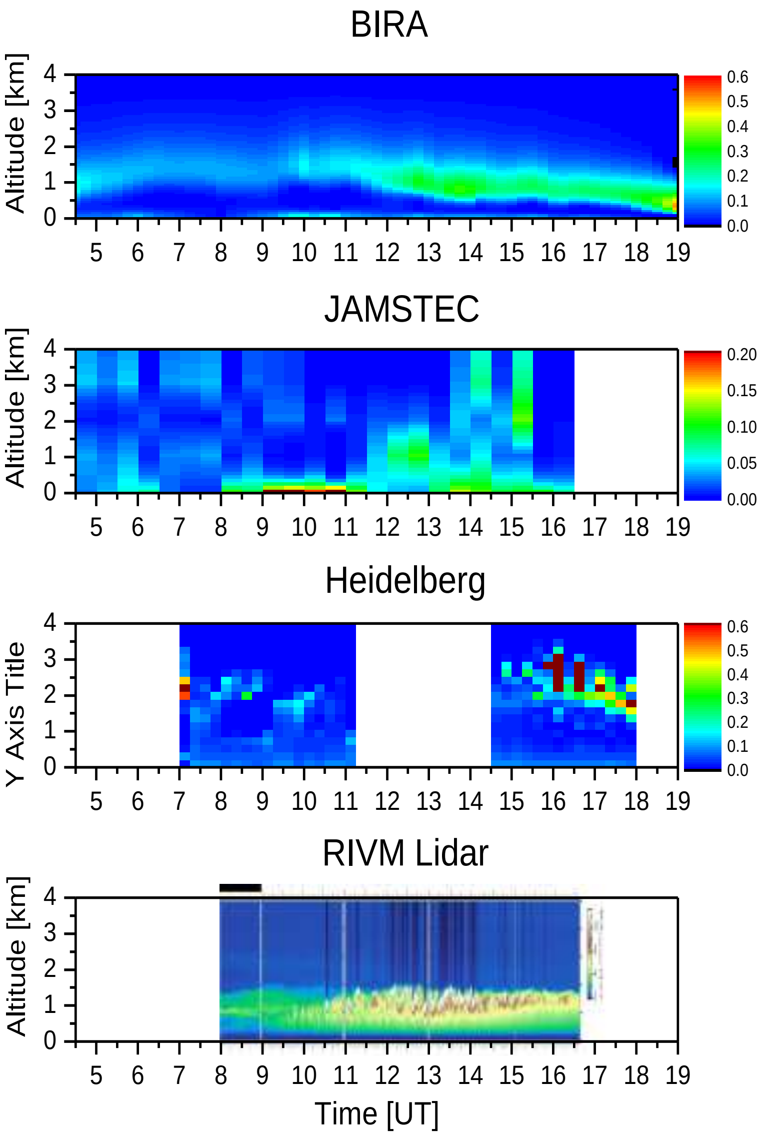
*courtesy: D. Swart, RIVM*

# Aerosol comp



*courtesy: U. Friess, IUP Heidelberg*

aerosol extinction profiles →

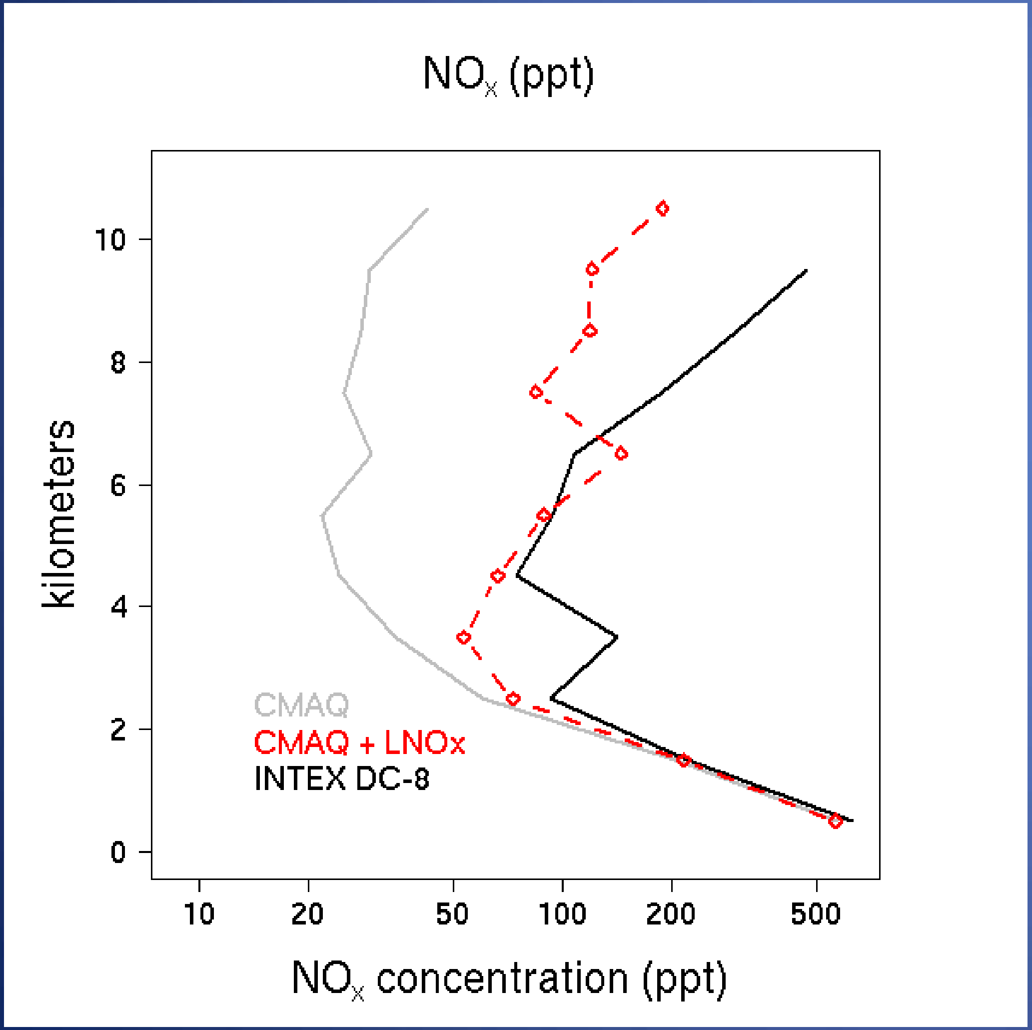


# Use of OMI Data in Monitoring Air Quality Changes Resulting from $NO_x$ Emission Regulations over the United States

K. Pickering[1], R. Pinder[2], A. Prados[3], D. Allen[4], J. Stehr[4], R. Dickerson[4], S. Ehrman[4], E. Celarier[5], J. Gleason[1]

[1] NASA Goddard Space Flight Center
[2] U. S. Environmental Protection Agency
[3] JCET/Univ. of MD Baltimore County
[4] University of Maryland, College Park
[5] GEST/Univ. of MD Baltimore County

# Lightning $NO_x$ Source Being Added to CMAQ



**Lightning flash rates predicted for times and locations of convective precipitation in meteorological model.**

**Flash rates scaled on a monthly basis to the NLDN + IC estimate from Boccippio IC/CG climatology**

**Vertical distribution of LNOx production based on observed climatology and direct function of pressure. Production/flash = 500 moles NO**

**Comparison of CMAQ with INTEX-A aircraft data is good up to ~7 km. Aircraft emissions still needed in CMAQ.**

# *Method*

*Airborne field data are statistically evaluated using a modified variogram technique to examine their spatial variability.*

Classical Variogram Definition (Matheron, 1962)

$$2\gamma(h) \equiv \frac{1}{N(h)} \sum_{N(h)} (Z(s_i) - Z(s_j))^2$$

Where N is the number of data pairs separated by distance h;
Z(s) is the variable of interest at a given location s; and
locations $s_i$ and $s_j$ denote location pairs separated by distance h

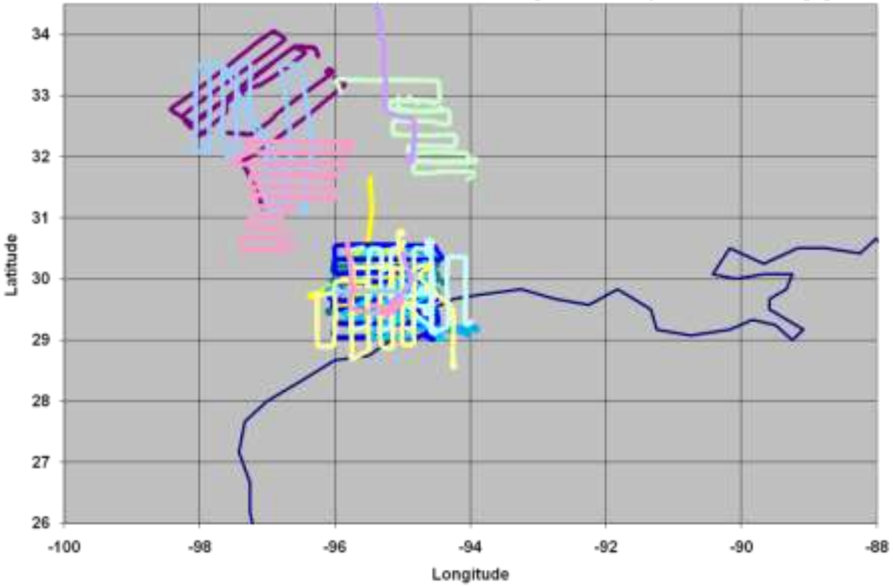
Variogram Definition used for this analysis (also called a semimadogram)

$$\gamma(h) \equiv \frac{1}{N(h)} \sum_{N(h)} |\, Z(s_i) - Z(s_j)\,|$$

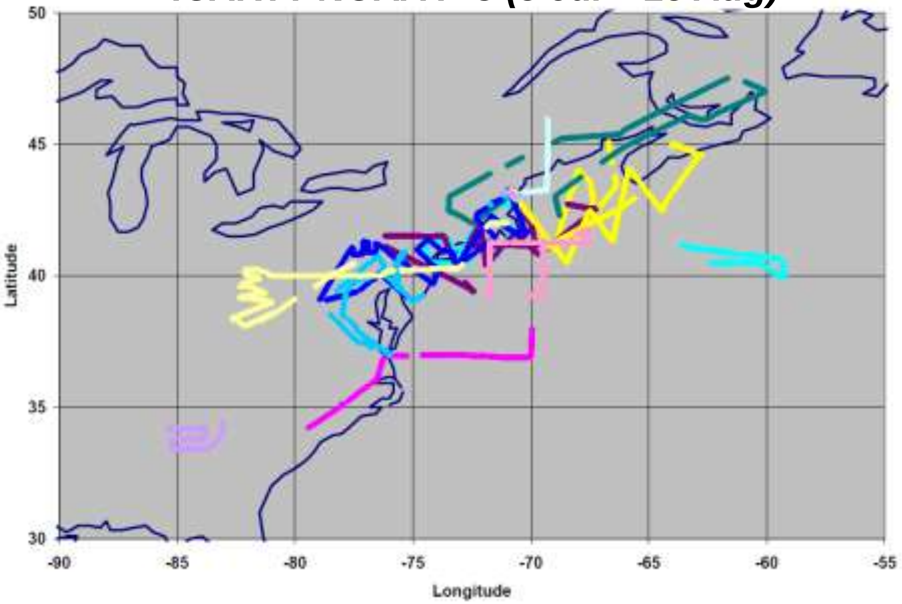
Simply stated, it is the average difference for the variable of interest over a given distance. Future plans may include calculating other statistics (e.g., median and percentiles).

# Distribution of Flight Data Collected in the Boundary Layer (below 2 km)

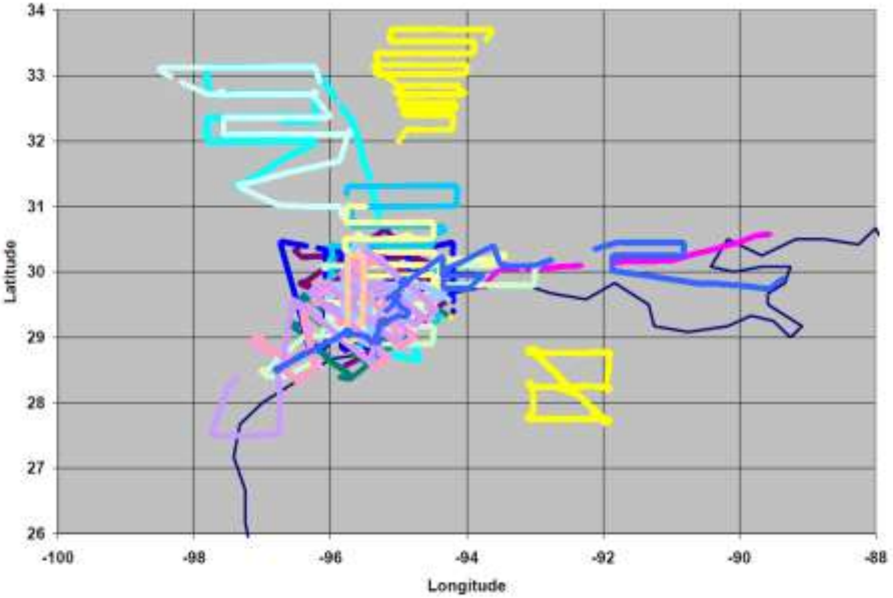
## *TEXAQS 2000 NOAA P-3 (16 Aug – 13 Sep)*



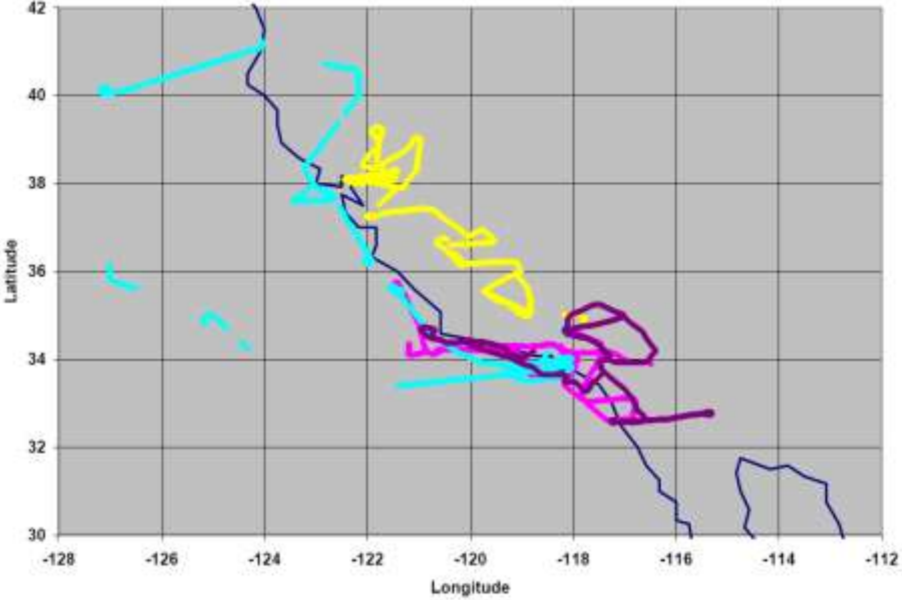
## *ICARTT NOAA P-3 (5 Jul – 15 Aug)*



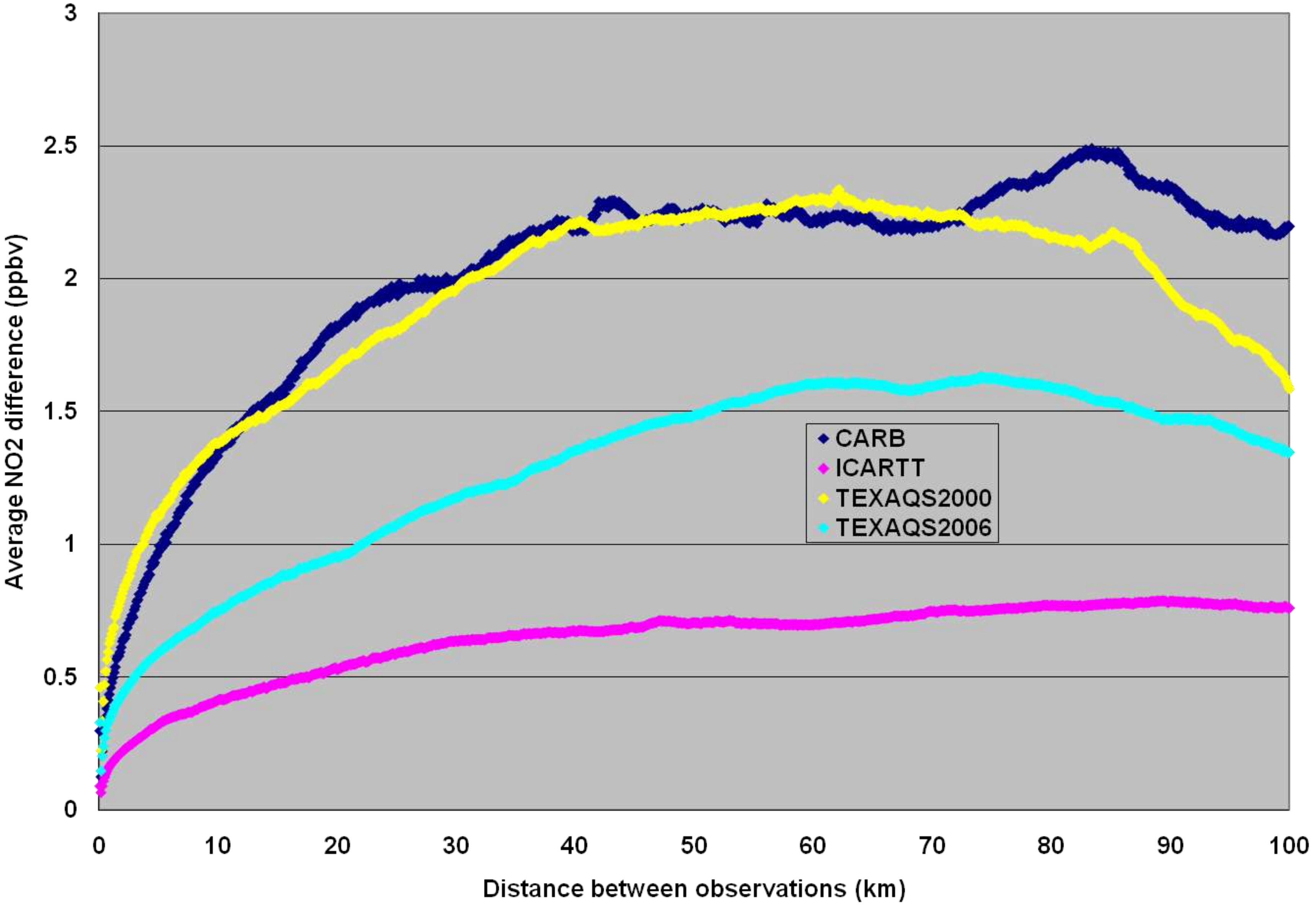
## *TEXAQS 2006 NOAA P-3 (31 Aug - 13 Oct)*



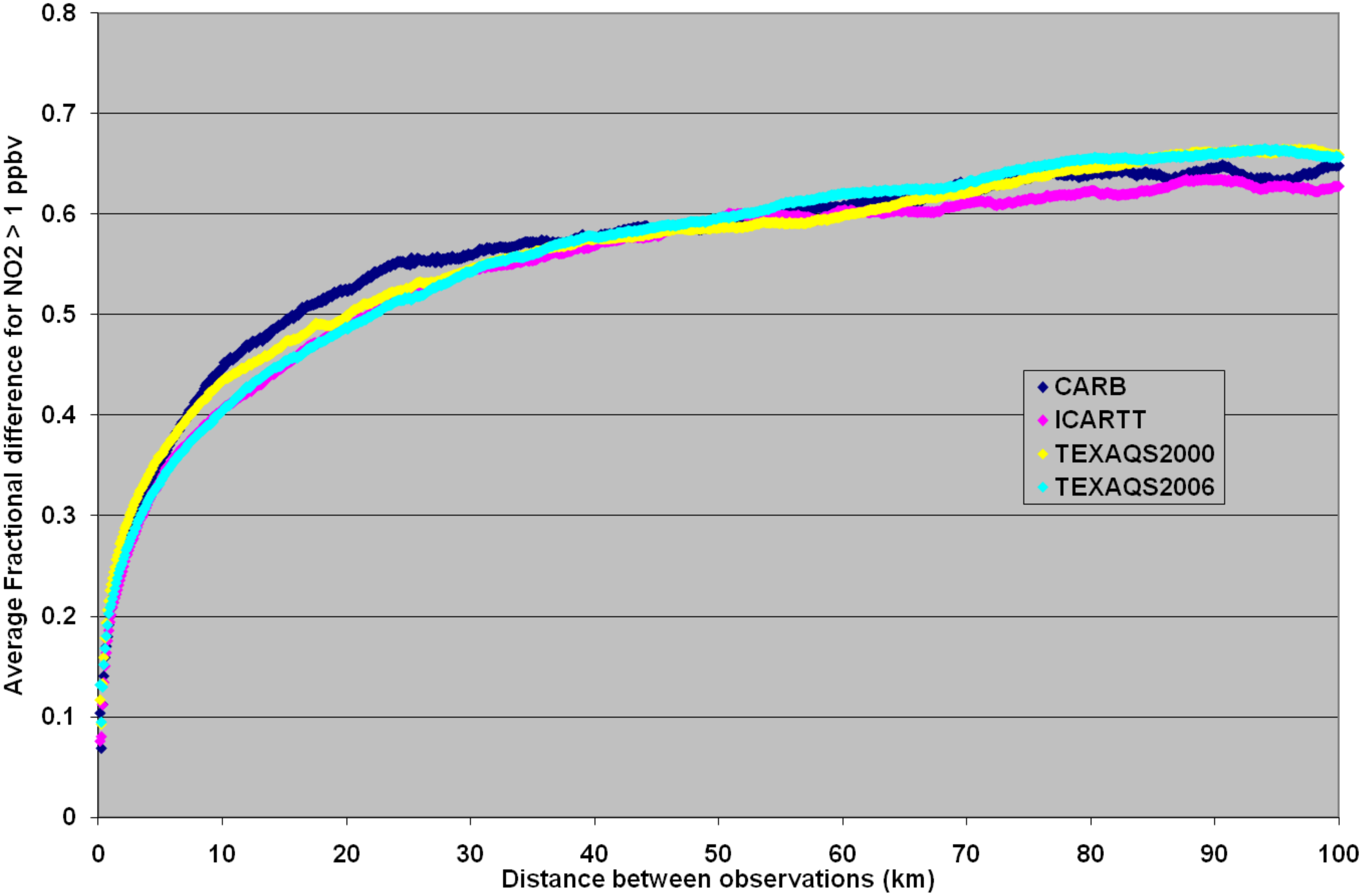
## *ARCTAS CARB NASA DC-8 (18-24 June)*

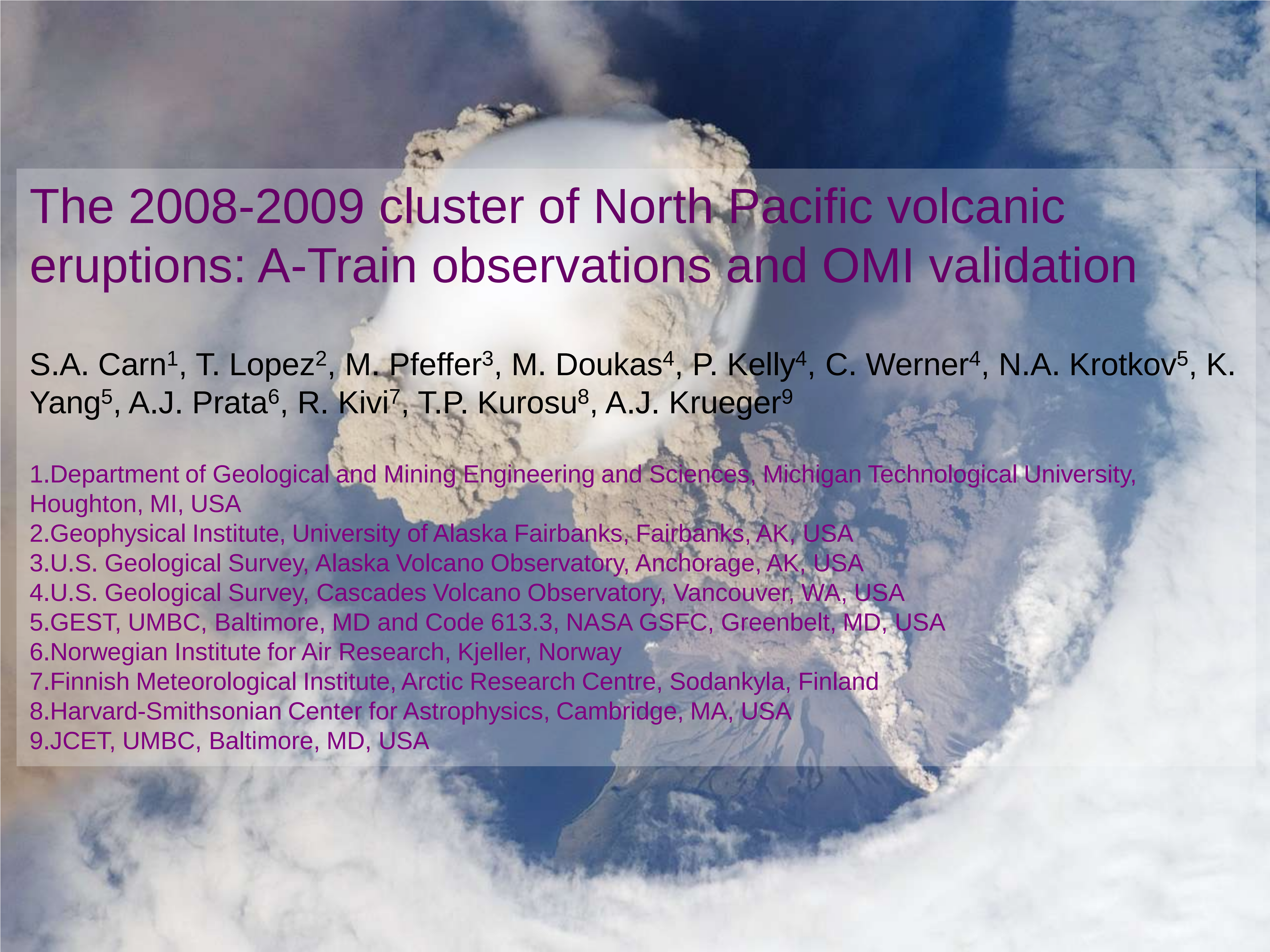


***NO2 Variograms:*** **Basic behavior is similar for all four campaigns, although magnitudes differ. Interpreting magnitude is difficult since it is influenced by both the magnitude of pollution encountered and the fraction of flight time in urban/polluted versus remote areas.**



**Normalized NO2 Variograms:** **Here, variograms have been calculated for the fractional difference in NO2 for values in excess of 1 ppbv. The similarity in these curves suggests that despite the differences in magnitude for the campaign-specific variograms, the variability in proximity to pollution plumes is consistent across campaigns.**





# The 2008-2009 cluster of North Pacific volcanic eruptions: A-Train observations and OMI validation

S.A. Carn[1], T. Lopez[2], M. Pfeffer[3], M. Doukas[4], P. Kelly[4], C. Werner[4], N.A. Krotkov[5], K. Yang[5], A.J. Prata[6], R. Kivi[7], T.P. Kurosu[8], A.J. Krueger[9]

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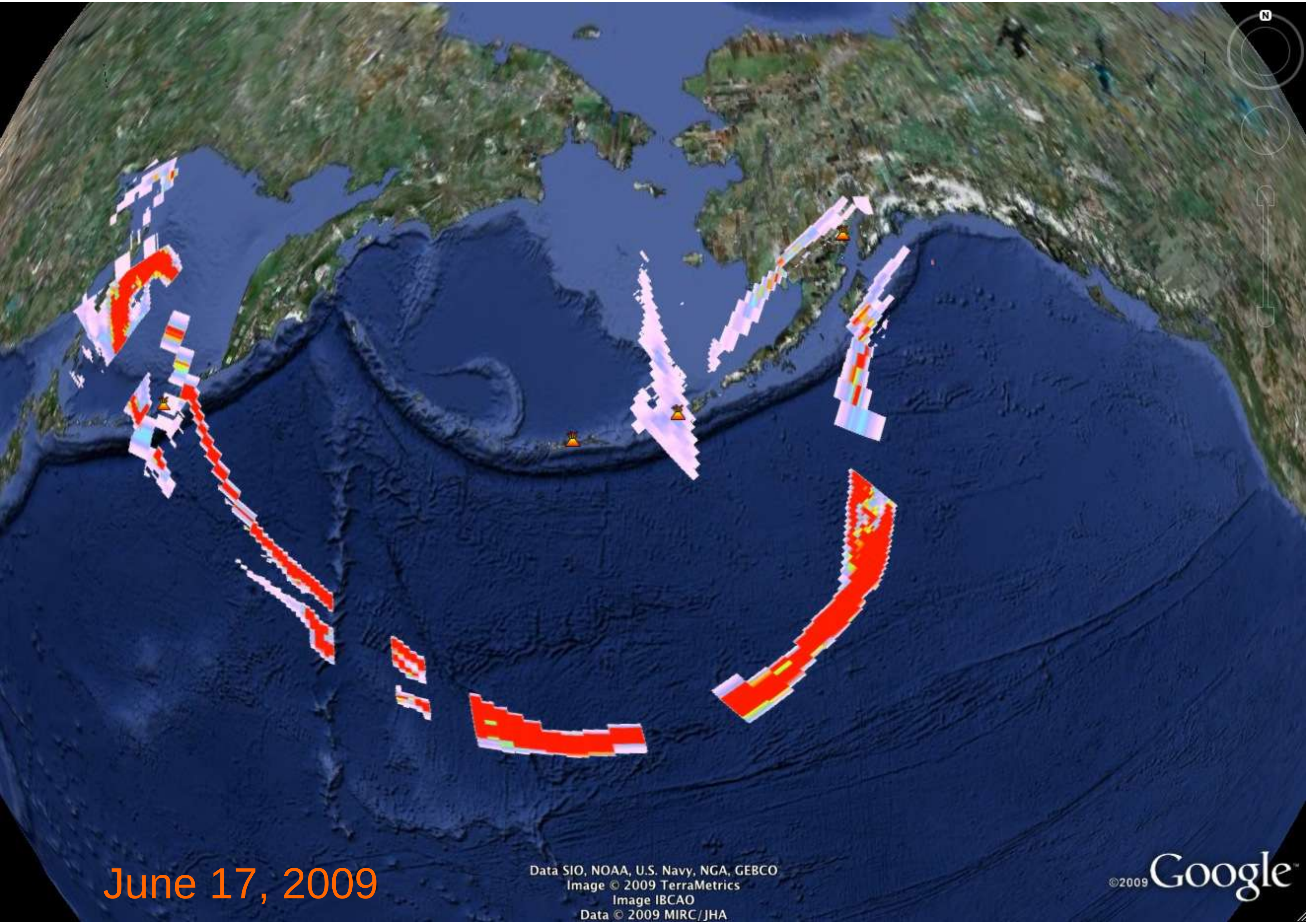
2.Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA
3.U.S. Geological Survey, Alaska Volcano Observatory, Anchorage, AK, USA
4.U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, WA, USA
5.GEST, UMBC, Baltimore, MD and Code 613.3, NASA GSFC, Greenbelt, MD, USA
6.Norwegian Institute for Air Research, Kjeller, Norway
7.Finnish Meteorological Institute, Arctic Research Centre, Sodankyla, Finland
8.Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA
9.JCET, UMBC, Baltimore, MD, USA

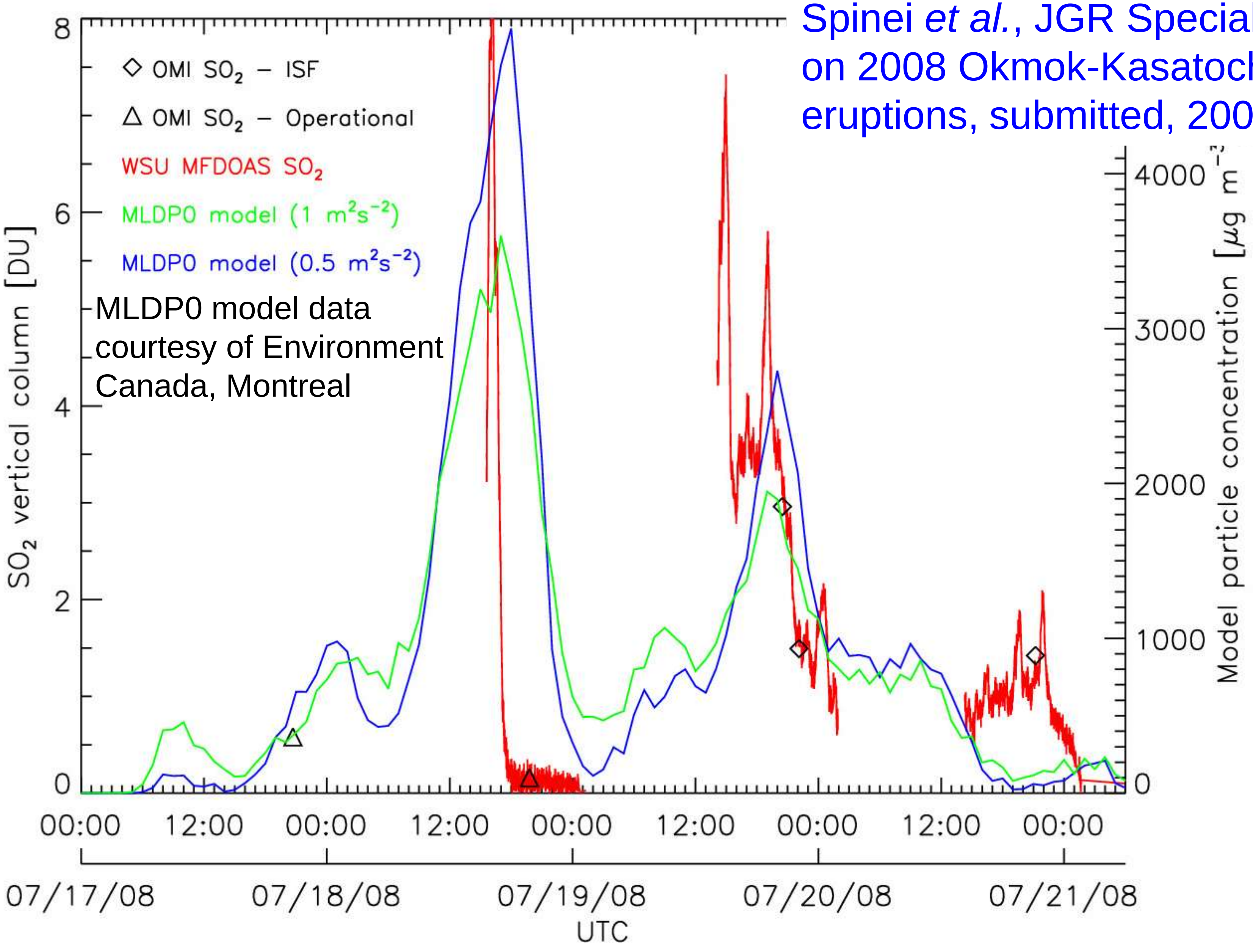


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics
Image IBCAO
Data © 2009 MIRC/JHA
©2009 Google
N

June 17, 2009

# Okmok: $SO_2$ validation with WSU MF-DOAS

Spinei *et al.*, JGR Special Issue on 2008 Okmok-Kasatochi eruptions, submitted, 2009



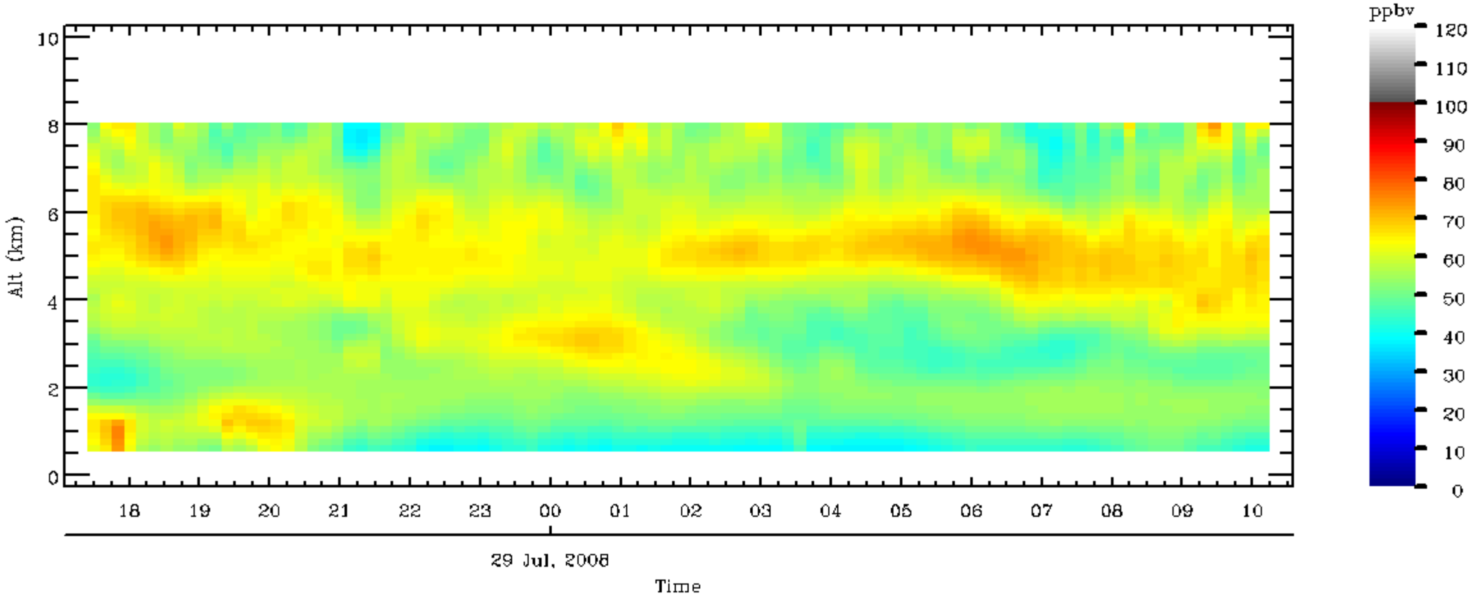
MLDP0 model data courtesy of Environment Canada, Montreal

# Backup

# Conclusions

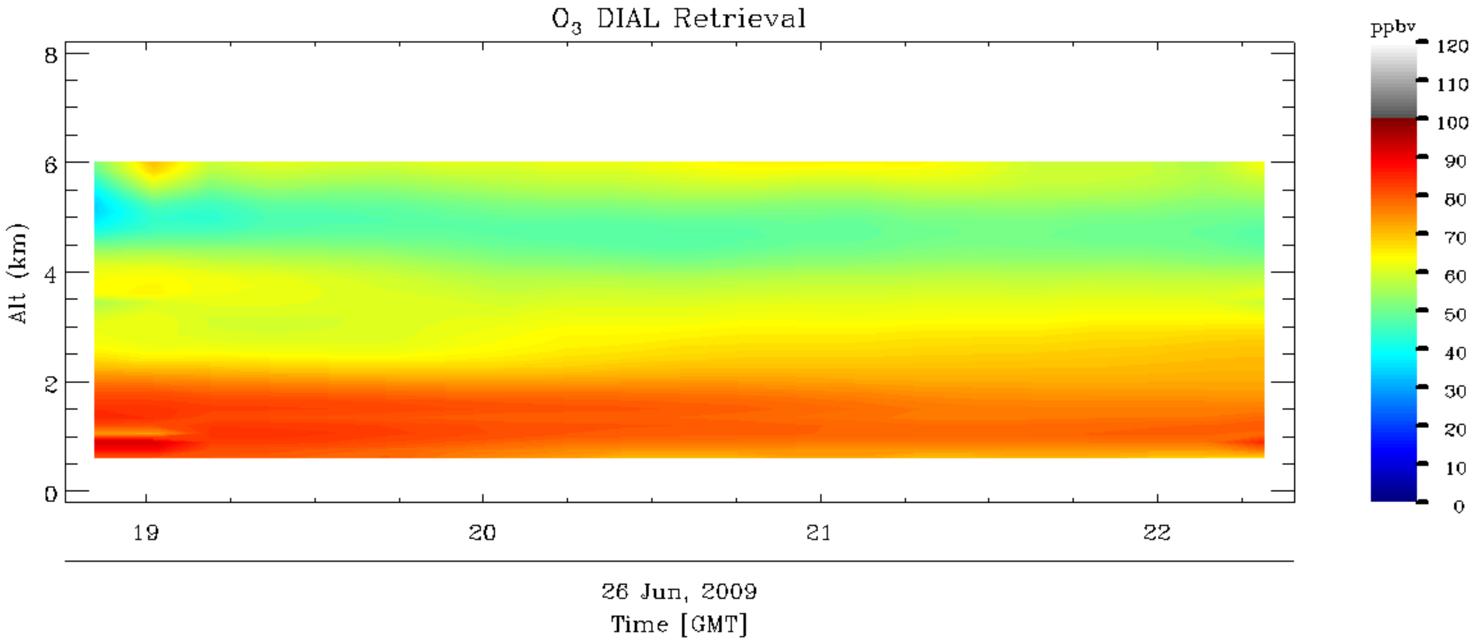
- Multiple species exhibit significant variation in time and space at increasingly finer scales.
- Autocorrelations and cross correlations are strong functions of species, altitude, horizontal distance, and time separation.

# 28 July 2008
# Huntsville, AL



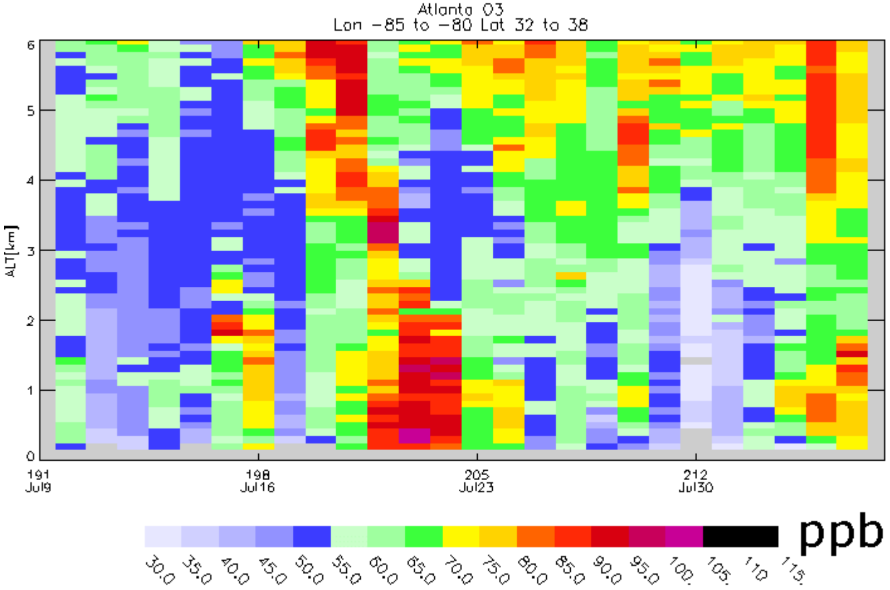
ToC

# 26 June 2009
# Huntsville, AL

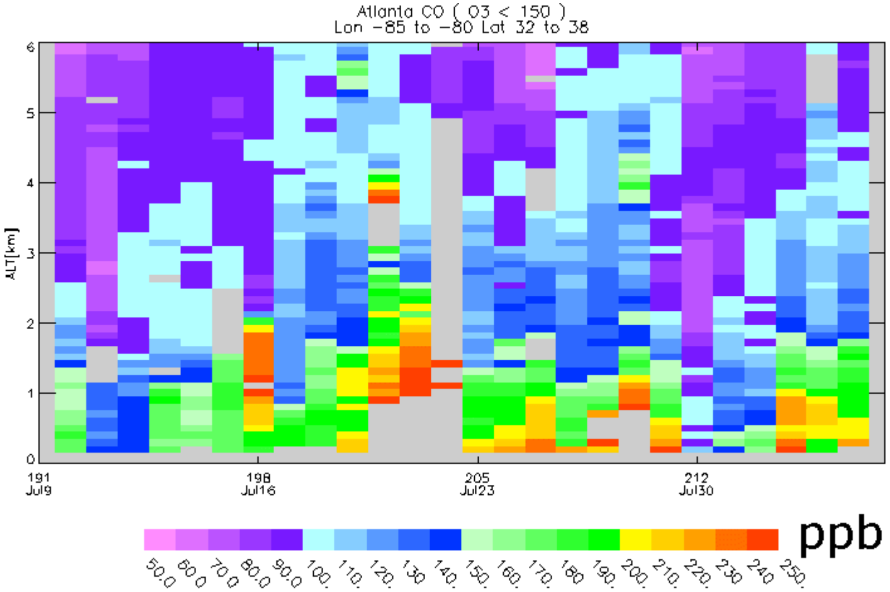


ToC

# Ozone and CO 4 days in Atlanta July

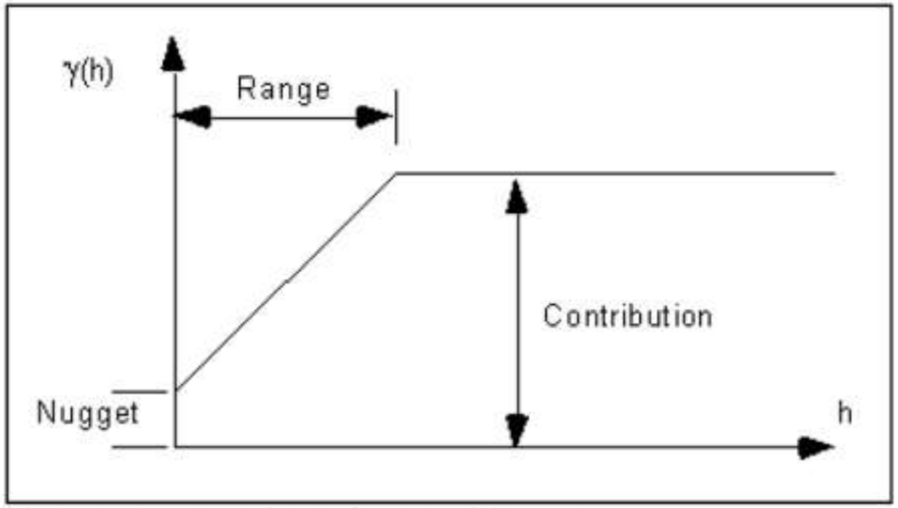


Atlanta O3
Lon −85 to −80 Lat 32 to 38



Atlanta CO ( O3 < 150 )
Lon −85 to −80 Lat 32 to 38

# Basic variogram interpretation (taken from http://www.ems-i.com/gmshelp/Interpolation/Interpolation_Schemes/Kriging/Variogram_Editor.htm)



*The Parameters Used to Define a Model Variogram.*

- The nugget represents a minimum variance. *For this analysis, the nugget is likely dominated by the measurement uncertainty.*
- The contribution (sometimes called the “sill”) represents the average variance of points at such a distance away from the point in question that these is no correlation between the points.
- The range represents the distance at which there is no longer a correlation between the points.

***For the airborne data analysis presented here, the distance (h) is considered to represent satellite resolution and the variogram ($\gamma(h)$= average difference) to be an indication of expected sub-grid variability for a given resolution.***

***Data filtering and assumptions:***

Data assessed for all pairs below 2 km

Data pairs with distances of up to 100 km included

Data pairs must span less than 30 minutes which minimizes differences that may be attributed to chemistry (especially for NO2) and transport.

Assessed variables are measured at 1 hz (roughly 100 m resolution for NOAA P-3 and 150 m for NASA DC-8)

Data pairs are restricted to daylight conditions as defined by solar zenith angles of 70 degrees or less

Data are assumed to be isotropic (i.e., vector direction between data pairs is not important)

Data are assumed to represent a well-mixed boundary layer (i.e., vertical separation between data pairs is not used as a discriminator)

**Normalized NO2 Distributions:** **CARB data shows the broadest distribution which helps corroborate the larger relative NO2 differences observed on the previous slide.**