Current Satellite Capabilities for Studying Air Quality: The Relationship between Satellite and Surface Measurements

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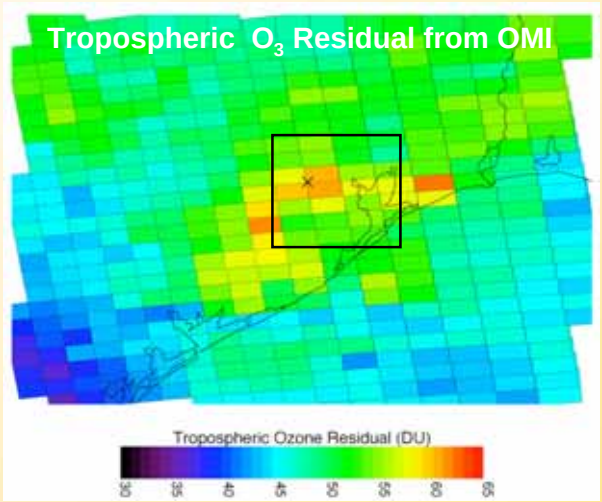
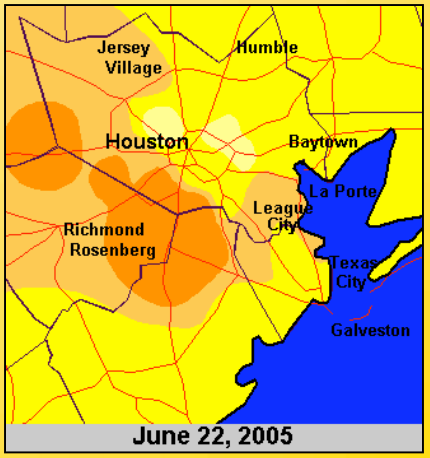


CEOS Atmospheric Composition Constellation Meeting

ESA/ESRIN
Frascati, Italy

16 June 2009



Fundamental Question:

How do we know what we are measuring relates to anything in the atmosphere?

- Validation studies must consider scale

- Previous validation studies examine total tropospheric column

- Temporal consideration:
  - climatological
    - * global distribution
    - * interannual variability
    - * trends

} "Science"

Another Fundamental Question:

How do we know what we are measuring relates to concentrations at the surface?

Spatial consideration

- regional
  - * air pollution episodes
  - * impact on crops and forests
- urban
  - * air quality: surface concentrations

"Applications"

Some Historical Perspective

First Study Showing Surface Ozone Contributes to TOMS Total Ozone Signal

The Characterization of an Air Pollution Episode Using Satellite Total Ozone Measurements

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(Manuscript received 5 January 1987, in final form 2 May 1987)

Published in J. Climate and Appl. Meteor., 1987

Key to Analysis was Ability to Derive "Synoptic" Scale Distribution from Surface Measurements

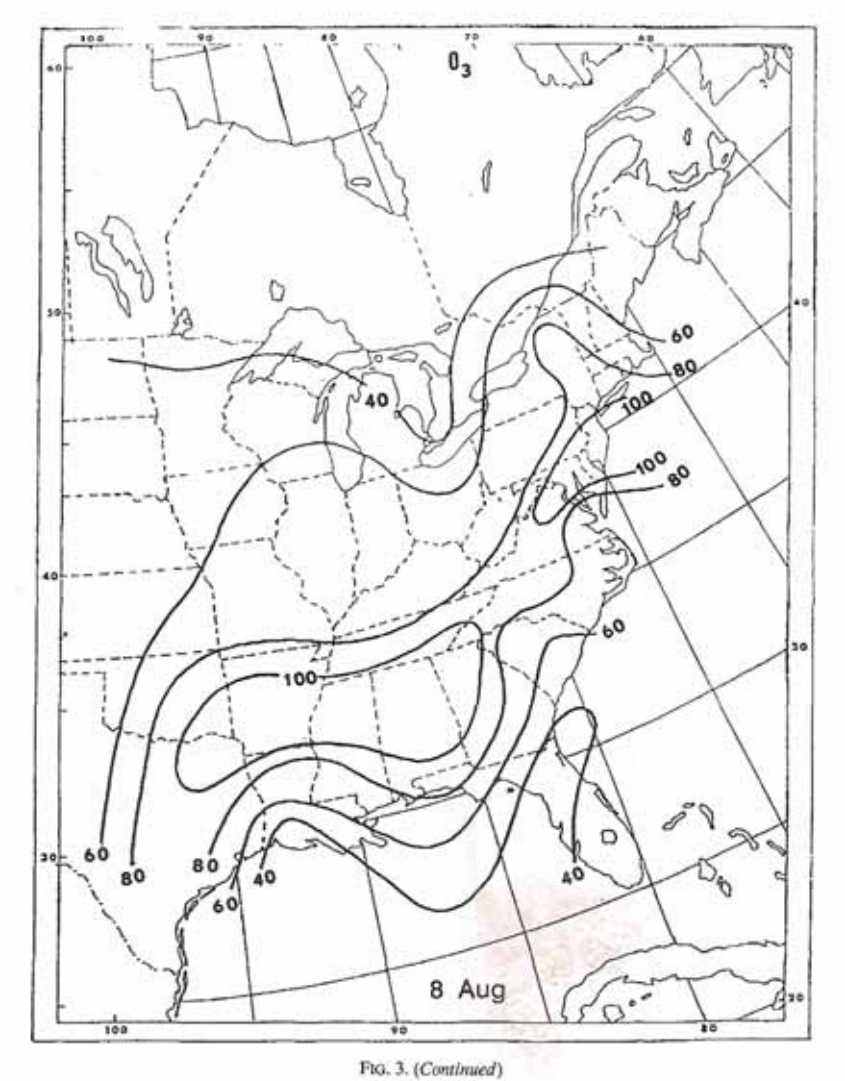
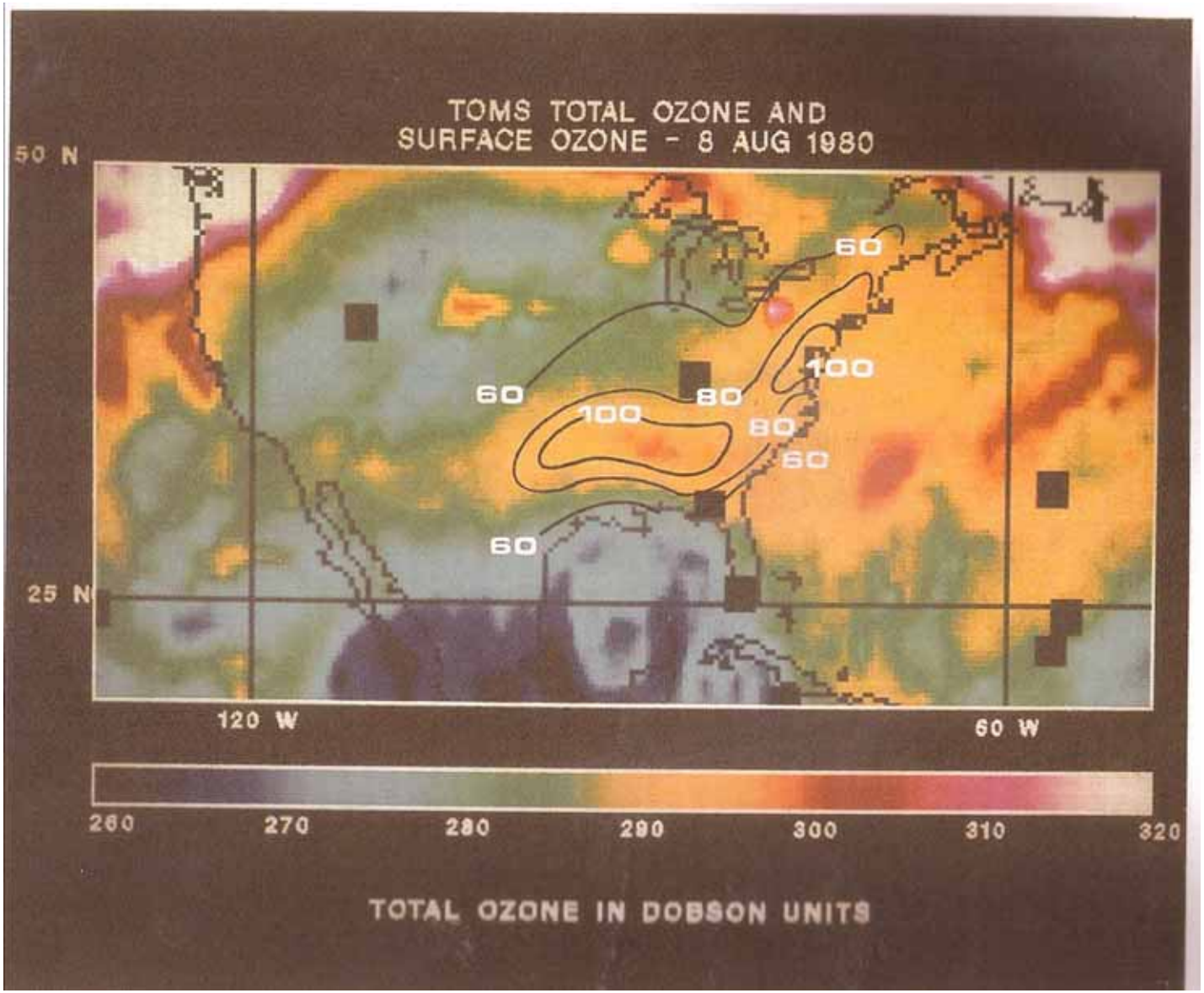


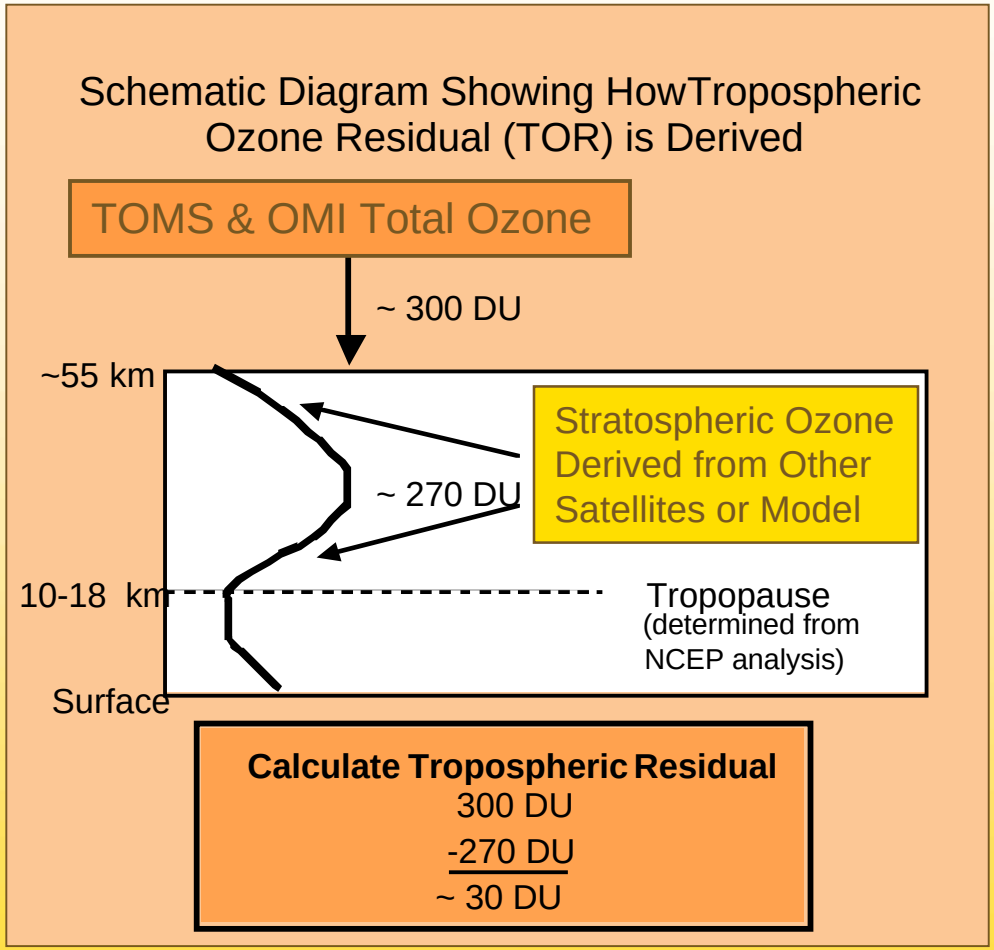
FIG. 3. (*Continued*)

Vukovich (in 1985 study) "…used data from individual sites that were carefully screened to avoid using measurements that might represent local pollution."

Total Ozone Distribution Influenced by What was Present at Surface



How Can Ozone in the Troposphere Be Separated from the Total Ozone Signal?



TOMS Total Ozone back to 1979

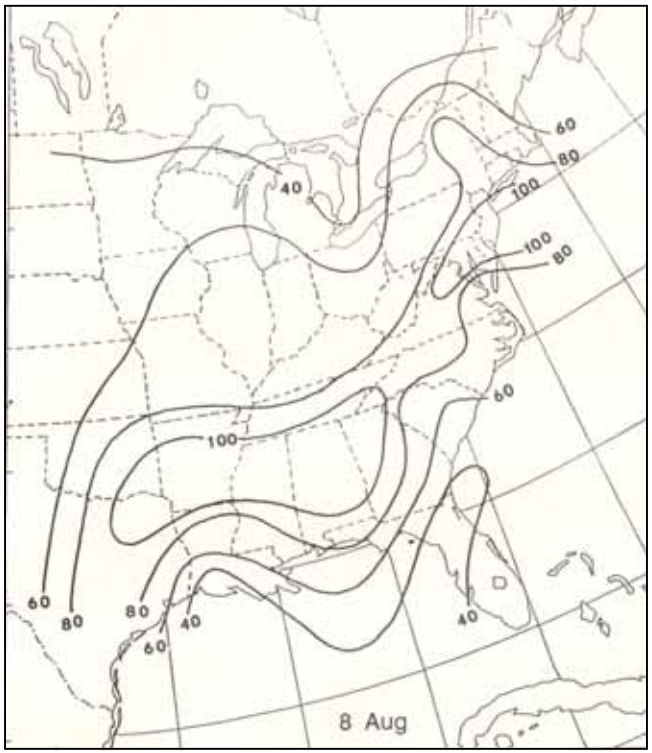
Stratospheric Ozone Columns Determined from SAGE, SBUV and GFS Model Output

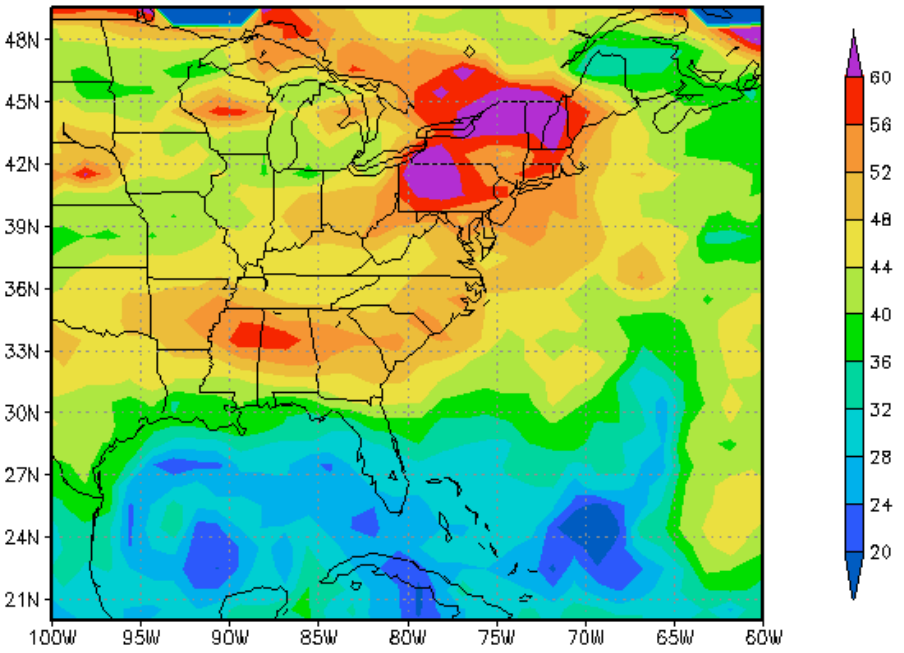
Current Data Record: 1979-2006

Monthly Averages Available at:
http://asd-www.larc.nasa.gov/TOR/data.html

Comparison of Calculated TOR and Surface O_3

August 8, 1980



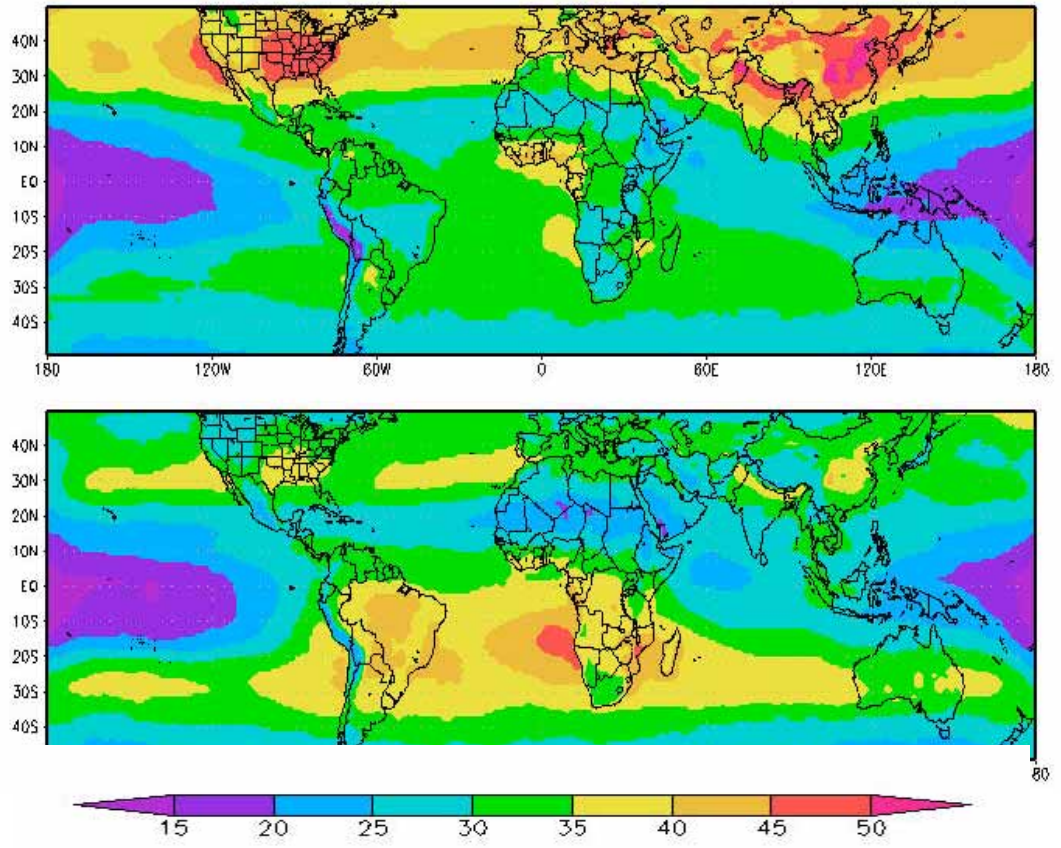


From Fishman et al. (ACP, **3**, 2003)

Satellite Distribution of Tropospheric Ozone Demonstrates Extent of Global Pollution

- Summer smog dominant feature during NH summer

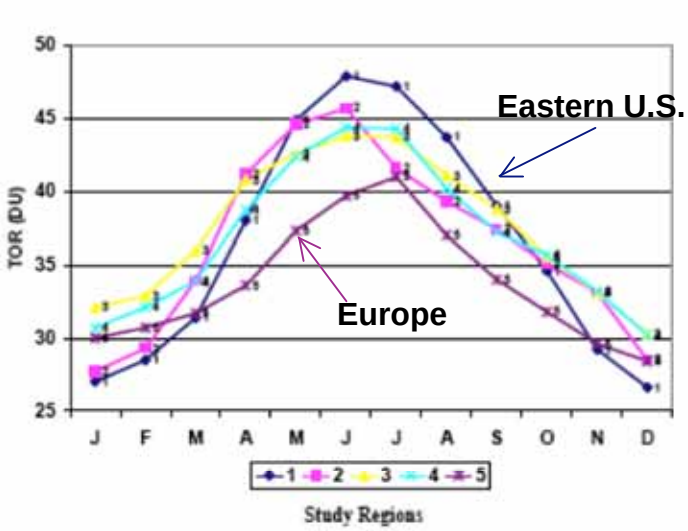
- African and South American biomass and savanna burning generate massive pollution plume during austral spring (Sep-Nov)



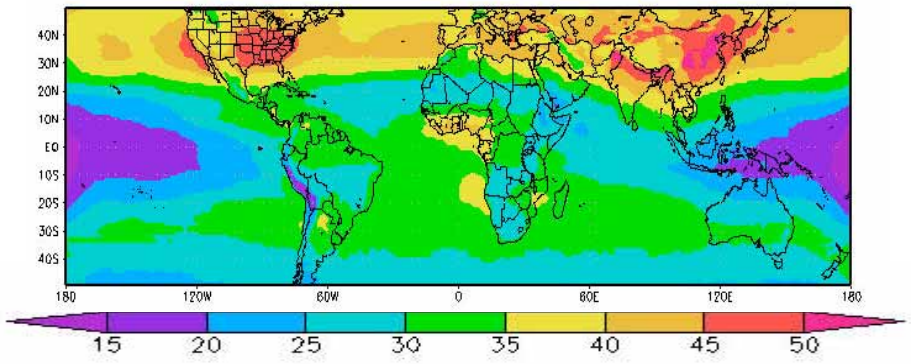
Integrated Tropospheric Ozone (Dobson Units)

How do we validate the accuracy of these distributions?

In addition to the absolute accuracy, we also want to validate the observed gradients



June-August Climatology



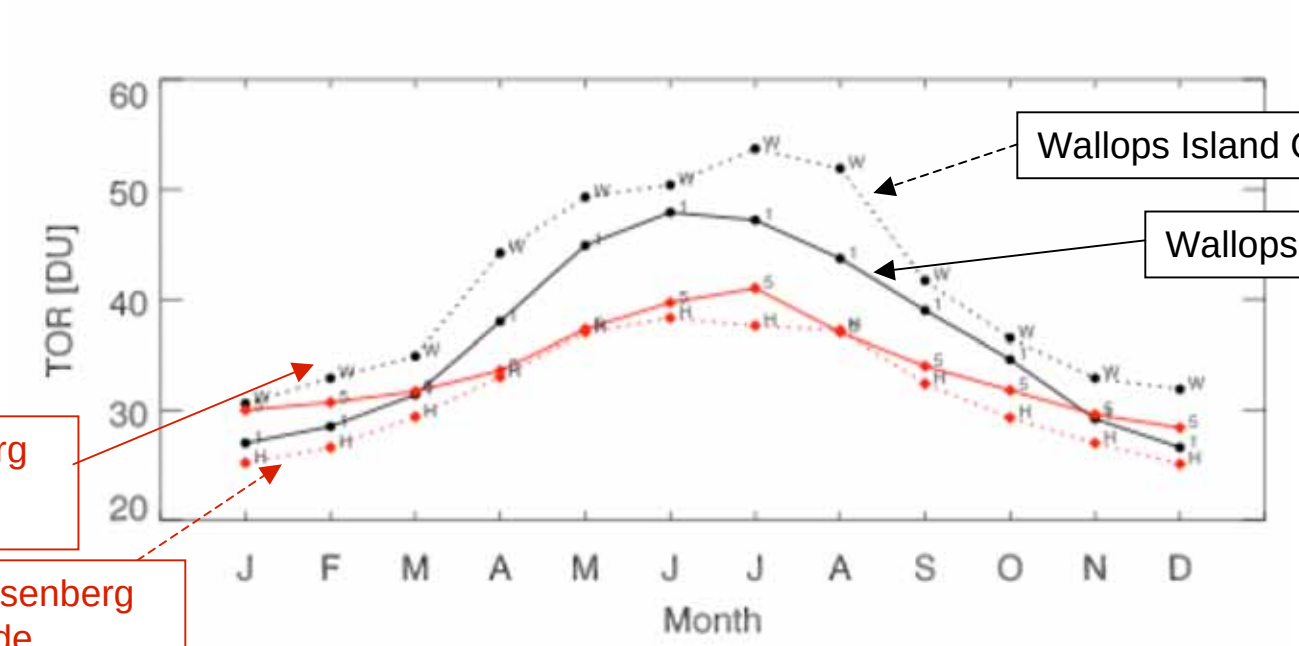
Integrated Tropospheric Ozone (Dobson Units)

Observed gradients vary both spatially and seasonally

Focus on the sites with the longest and most complete data record: Wallops Island and Hohenpeissenberg

Standard Validation Technique

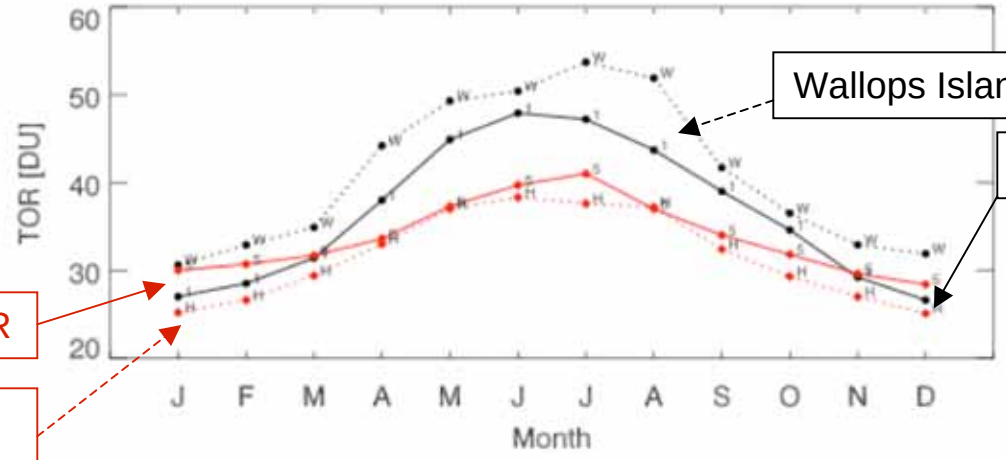
Comparison of Satellite TOR with Ozonesonde Measurements at two Mid-latitude Sites



TOR data are from 9° latitude by 11° longitude boxes (81 grid points) centered near the two sites [Creilson et al., 2003]

How do we validate TOR measurements?

Comparison of Satellite TOR with Ozonesonde Measurements at two Mid-latitude Sites



Wallops Island Ozonesonde

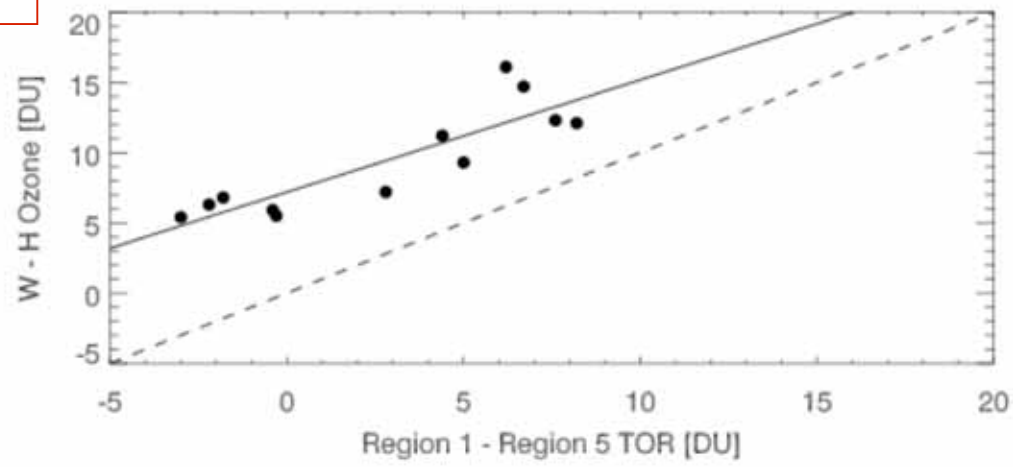
Wallops Island TOR

R = 0.98

Hohenpeissenberg TOR

Hohenpeissenberg Ozonesonde

R = 0.96



Regression of Ozonesonde and TOR Monthly Difference

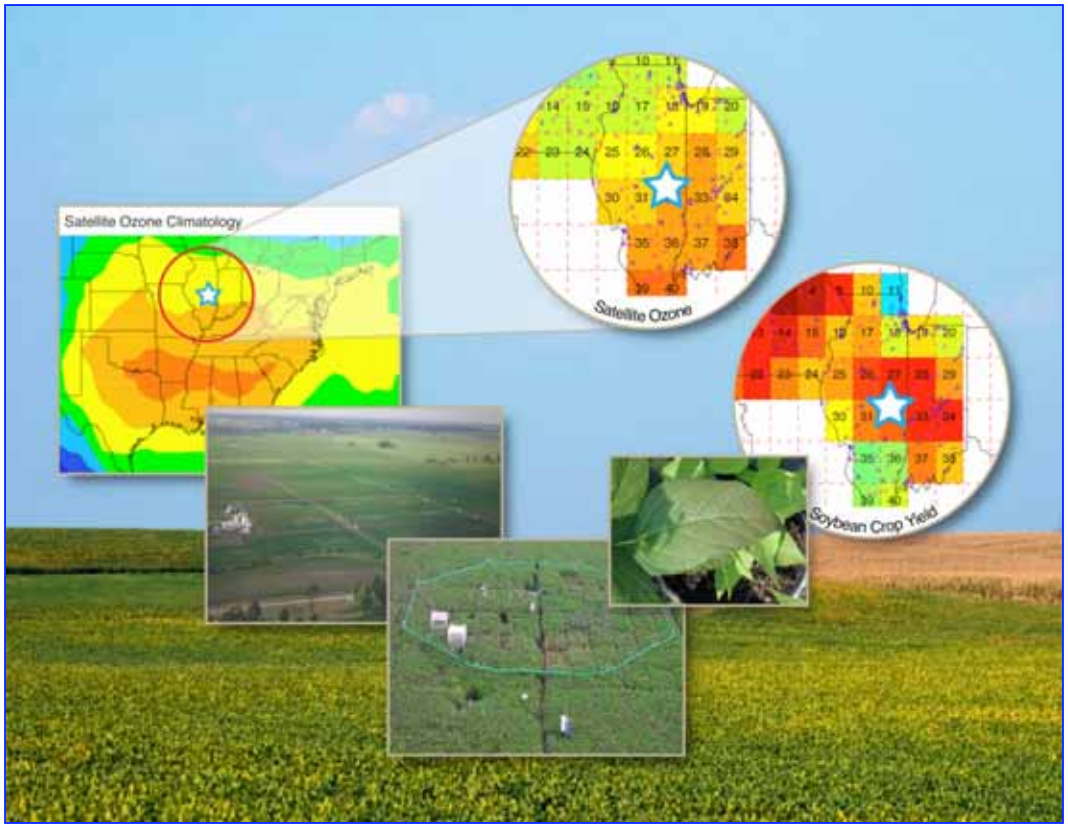
R = 0.87

slope = 0.81

Transitioning Studies from Hemispheric to Regional:

Satellite Studies over the U.S. Midwest to Examine Regional and Interannual Variability

An Application to Soybean Crop Productivity

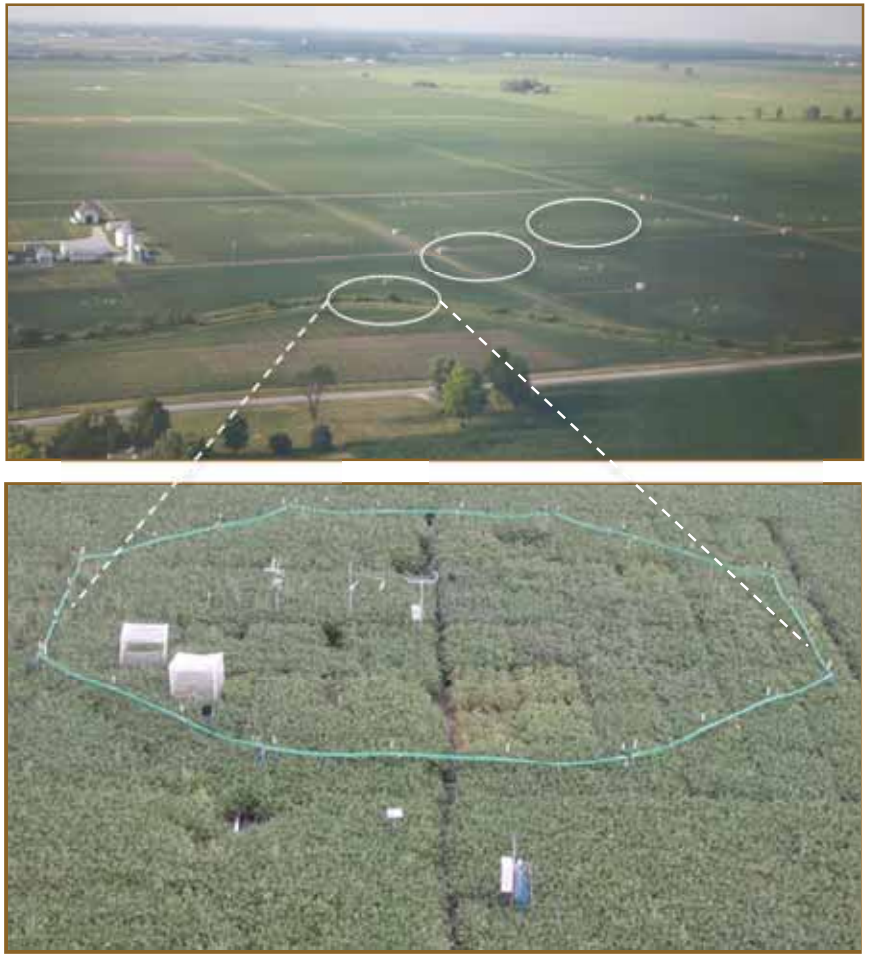


Injury to Plants Performed in Outdoor Laboratories where Excess Ozone Can be Added

Outdoor "Chambers"

- Outdoor chamber studies have been the traditional method of quantifying crop damage, but the enclosed nature of the chambers can influence results
- SoyFACE (Free Air Concentration Enhancement) at Illinois does not intrude on natural setting
- Sensors monitor wind speed and direction and a computer program determines how much and where on the perimeter ozone should be injected

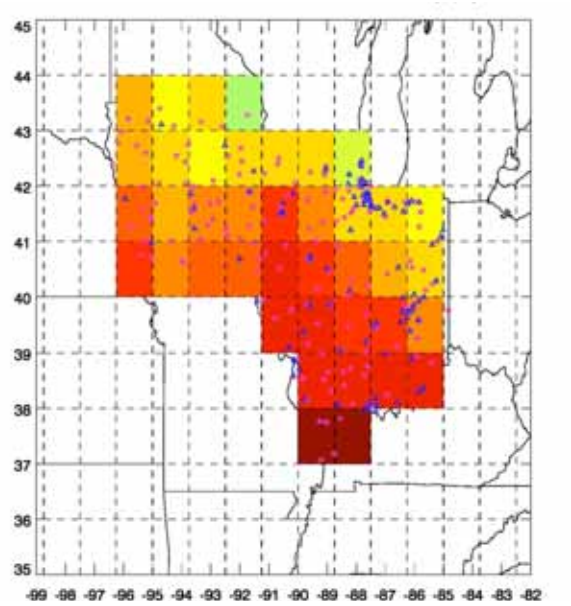
SoyFACE Facility at University of Illinois

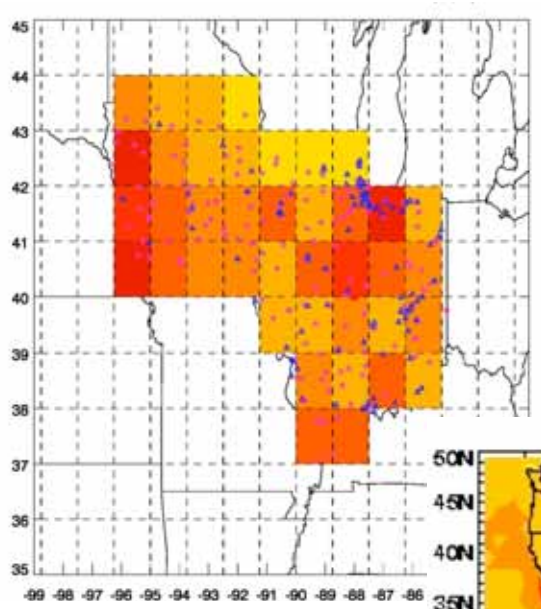


- SoyFACE facility comprised of 32 rings
- Ozone is released through micropores in pipes around the perimeter of each plot

Temporal and Spatial Variability: Monthly and Seasonal

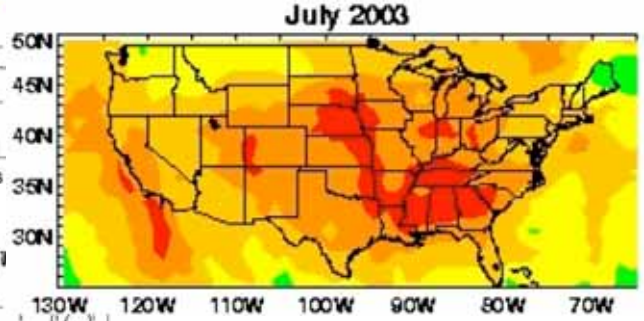
July 2002



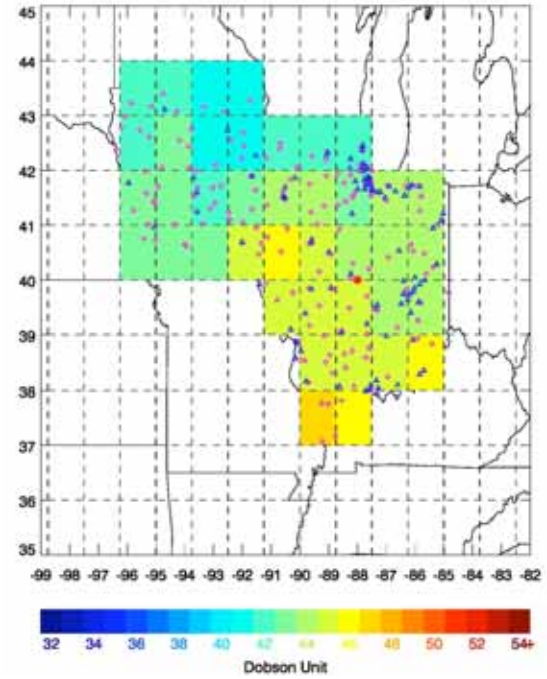


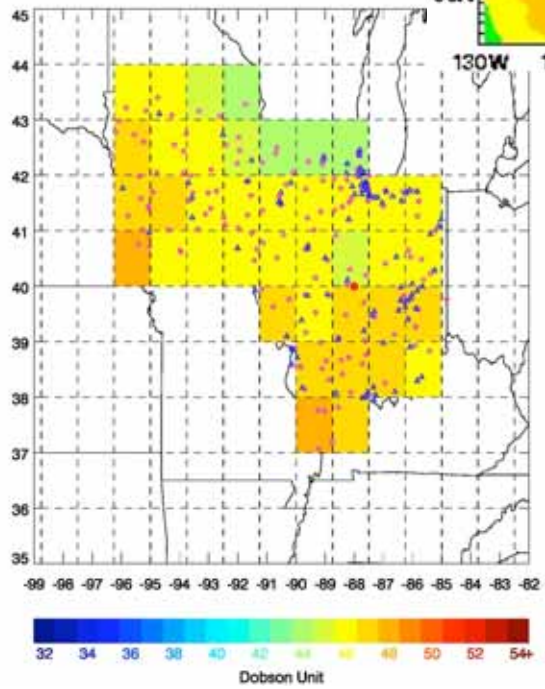
July 2003

Insight into relationship with surface values performed using monthly averaged surface concentrations



June-Aug 2002

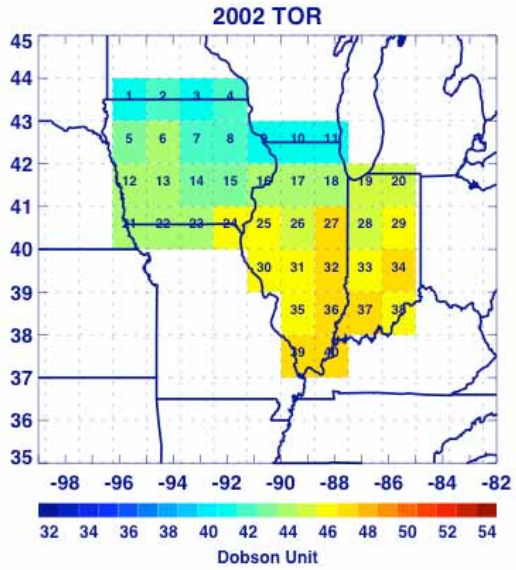


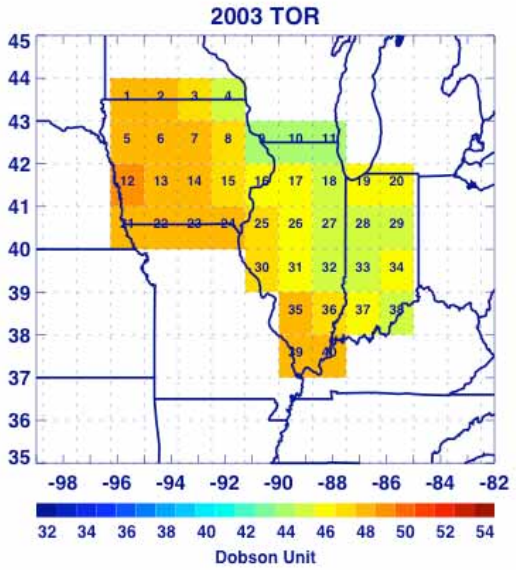


June-Aug 2003

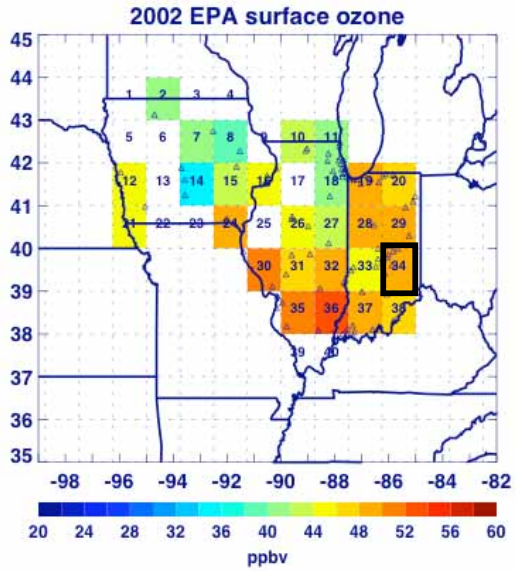
Integrated values throughout entire season should impact crop productivity

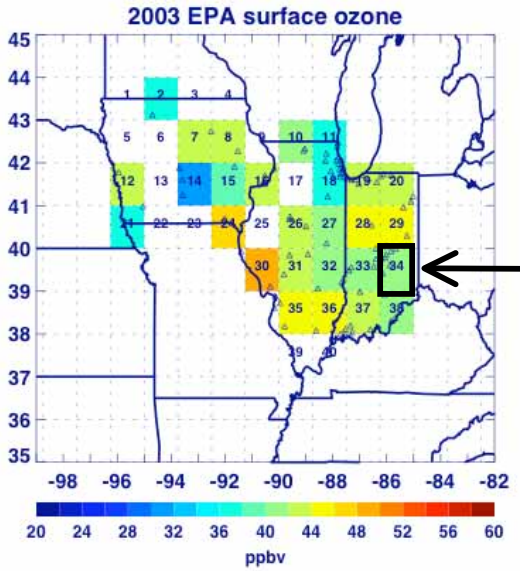
Comparison of Satellite TOR and Surface O_3 over Regional and Seasonal Scales





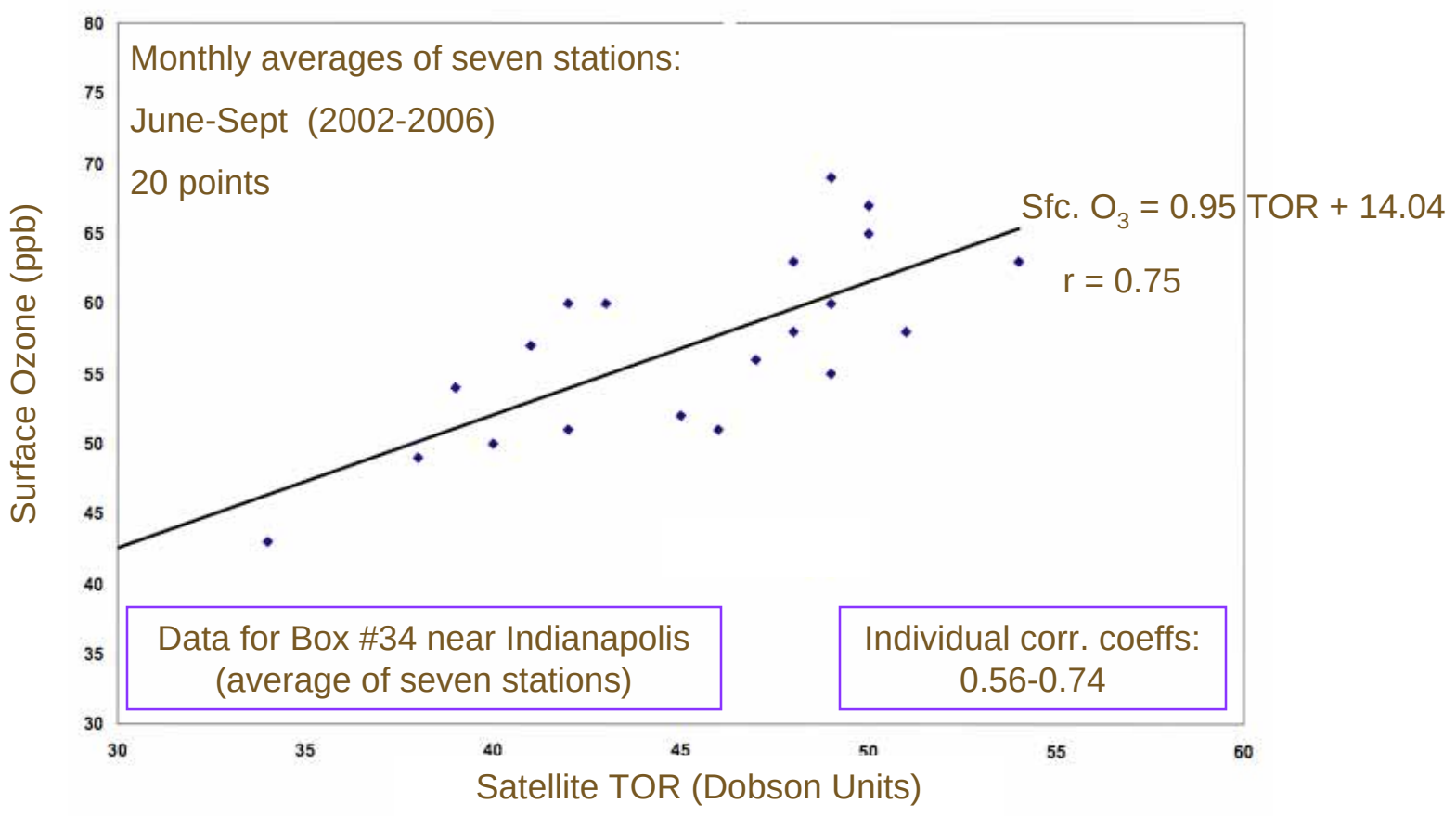
Each of the 27 boxes was positively correlated over the 5 years studied





Highest correlation found in grid box near Indianapolis (seven monitoring stations in Box #34)

Relationship between Surface O_3 and Satellite TOR Using Monthly Averages

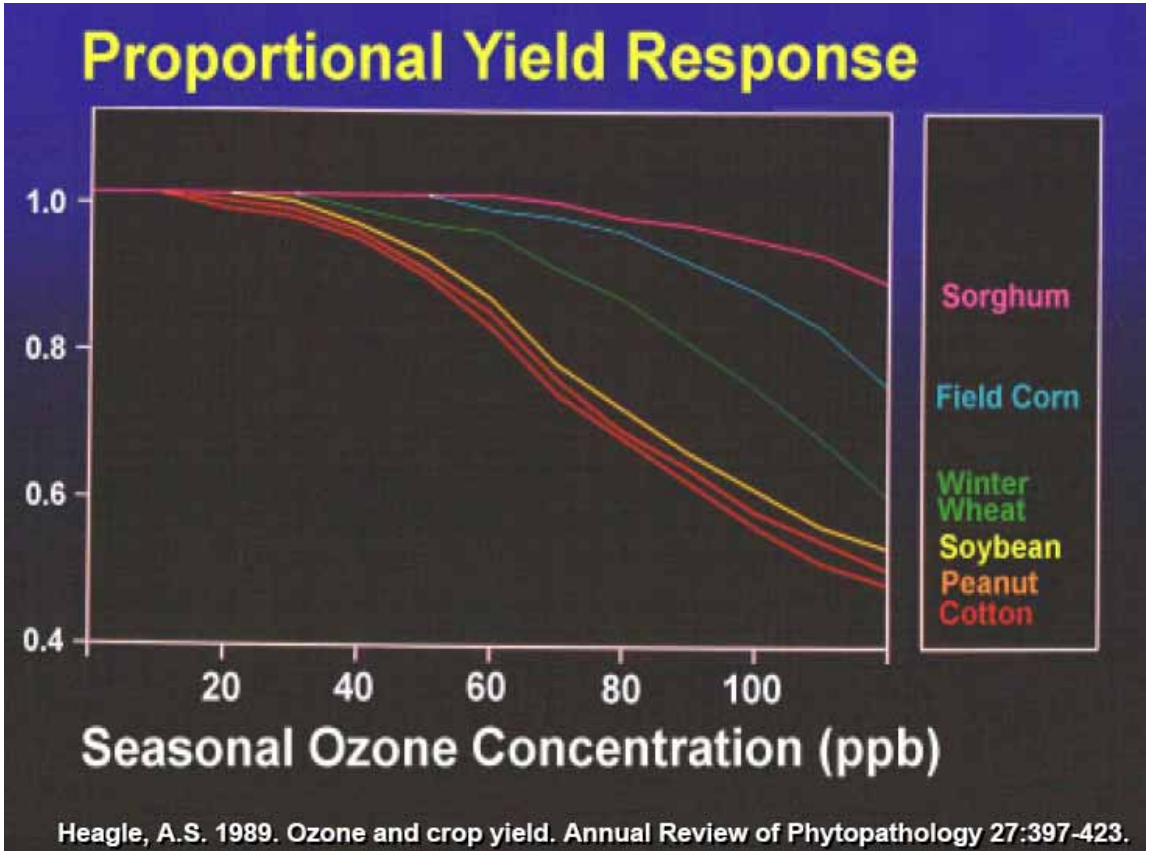


TOR measurements screened to include only observations during clear-sky conditions

Above a Threshold Level Ozone Damage to Plants is Significant

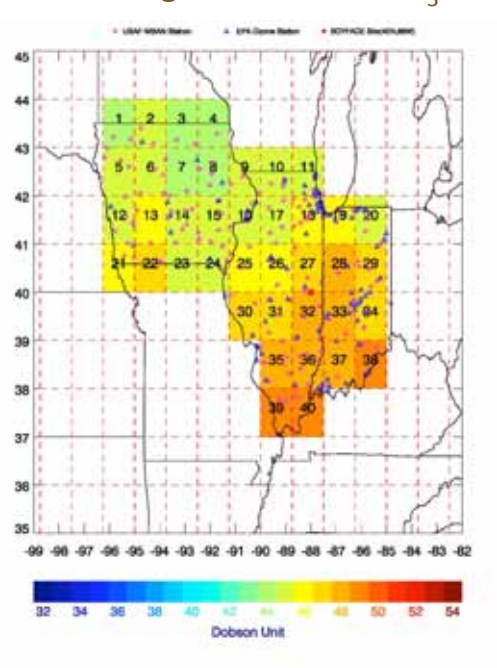
Can the effects on soybean crop yield over entire growing season be related to ambient ozone concentrations?

Damage Threshold for Many Plants is ~40 ppbv

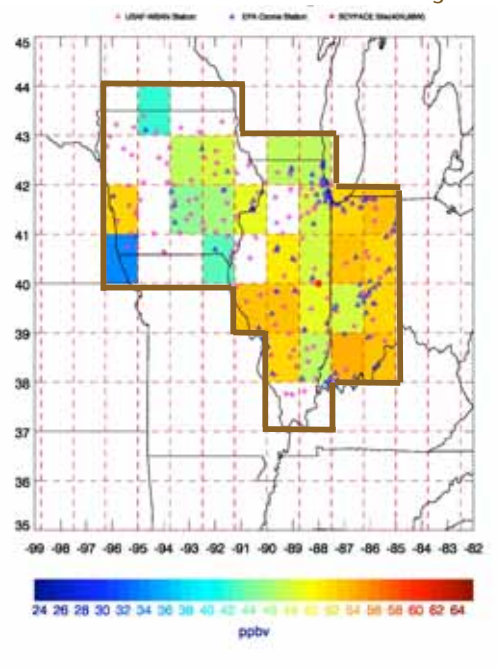


Significant Regional Variability within 3-State Study Area for Any Specific Year

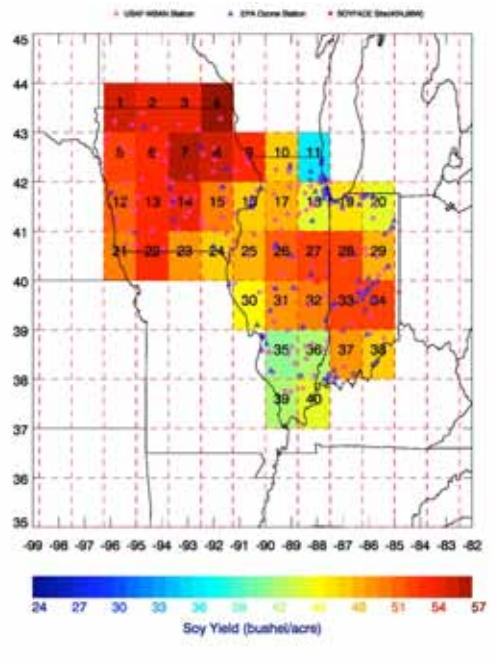
Jun-Aug 2005 Satellite O_3



Jun-Aug 2005 Surface O_3



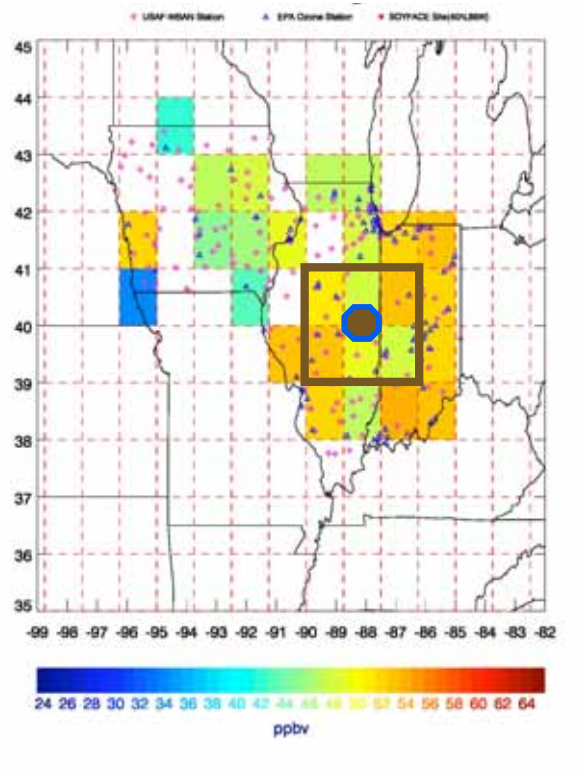
2005 Soybean Crop Yield



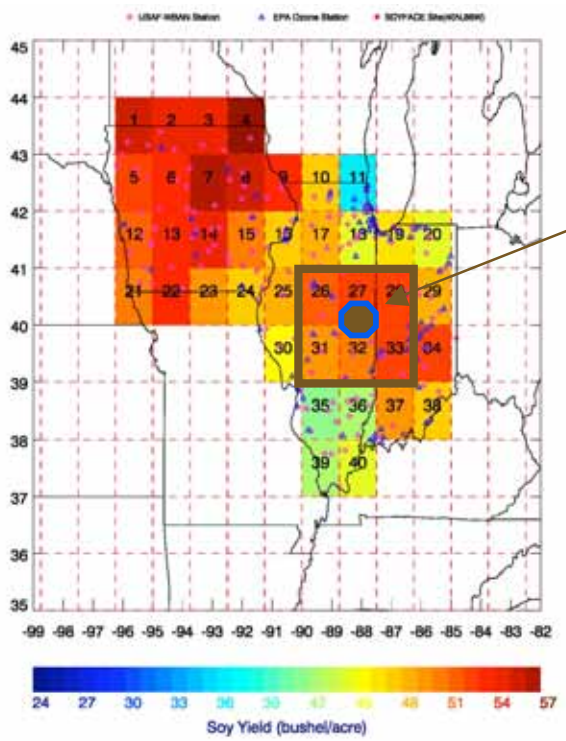
- Satellite Data Provide Uniform Coverage over Entire Study Area

Comparison of Effects near SoyFACE Facility

Jun-Aug 2005 Surface O_3



2005 Soybean Crop Yield



Calculate O_3 loss in region surrounding SoyFACE location:

Use data from 6-box region (200 x 375 km) centered on SoyFACE from 2002-2006

Morgan et al. (2006): -15% in 2002 when increased from 62 to 73 ppbv
-25% in 2003 when increased from 50 to 63 ppbv

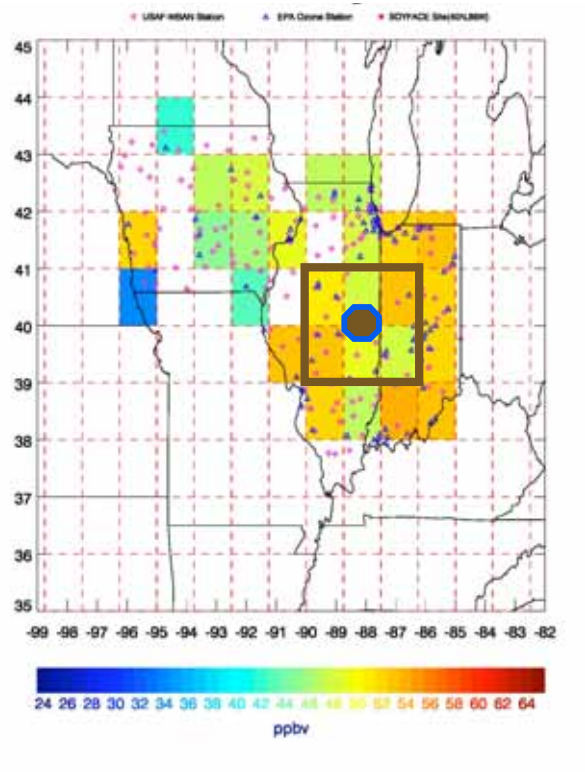
-1.64 ± 0.28% $ppbv^{-1}$

MLR Model (using surface O_3 data): 0.59 ± 0.29 bushels $acre^{-1}$ $ppbv^{-1}$
average yield (2002-2006) = 48.9 bushels $acre^{-1}$

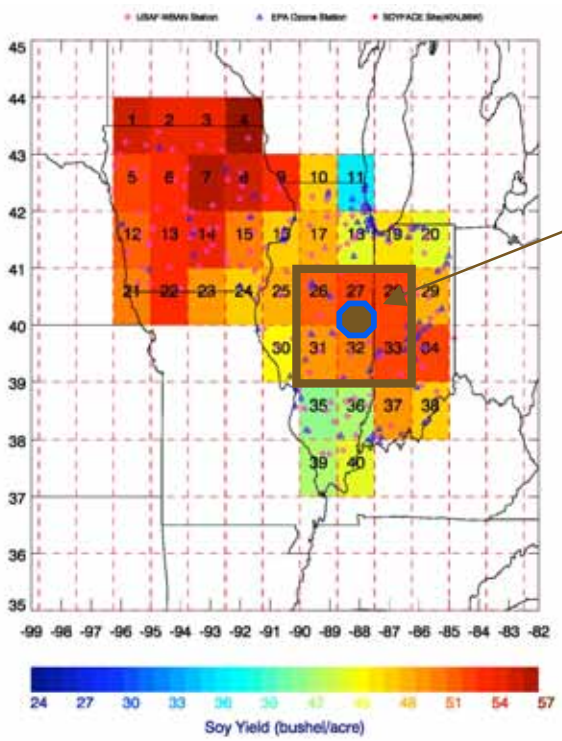
-1.21 ± 0.58% $ppbv^{-1}$

Comparison of Effects near SoyFACE Facility

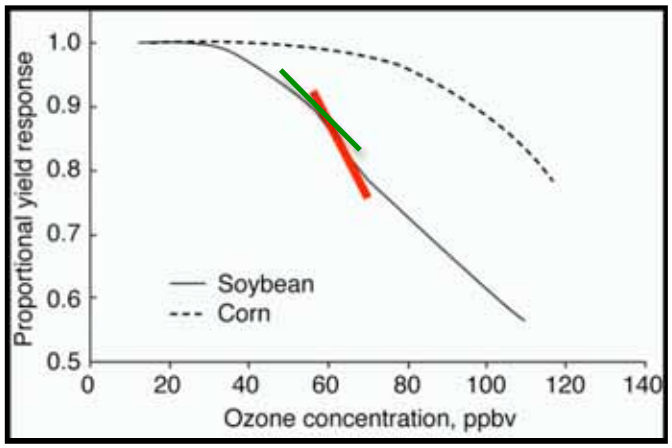
Jun-Aug 2005 Surface O_3



2005 Soybean Crop Yield



Because of the difference in units, the only quantity that can actually be measured is the proportional yield decrease as a function of concentration



SoyFACE Experimental Result:

-1.64 ± 0.28% $ppbv^{-1}$

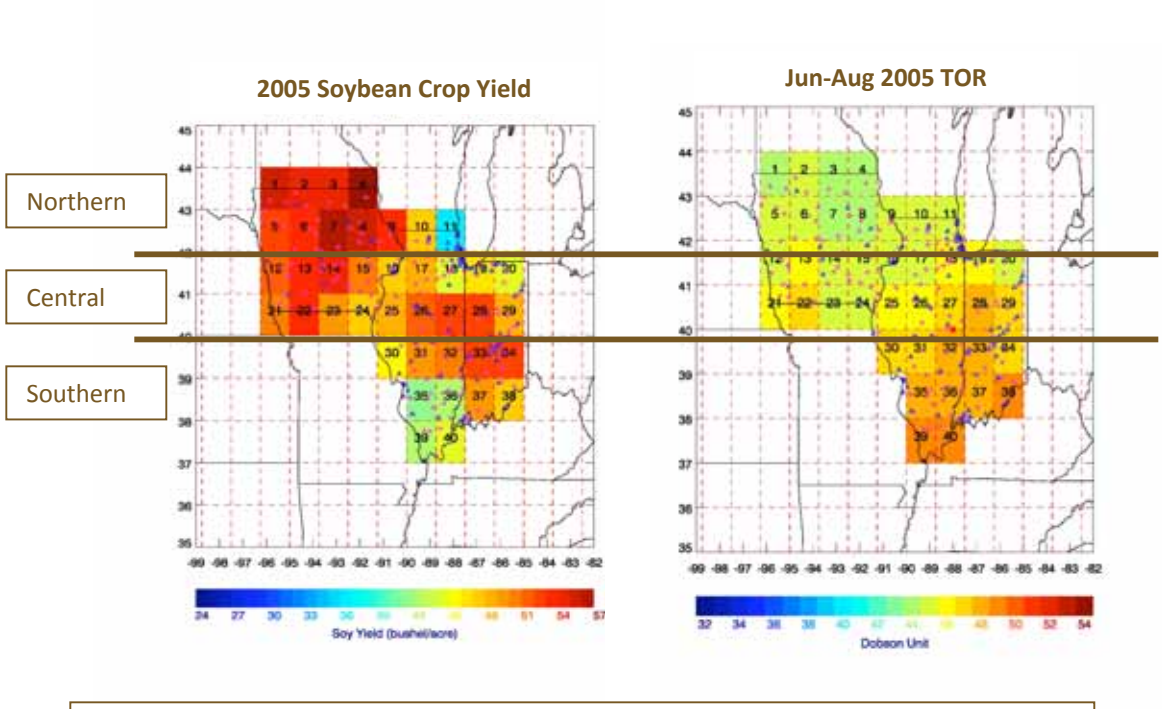
Result from Surface Ozone Monitors:

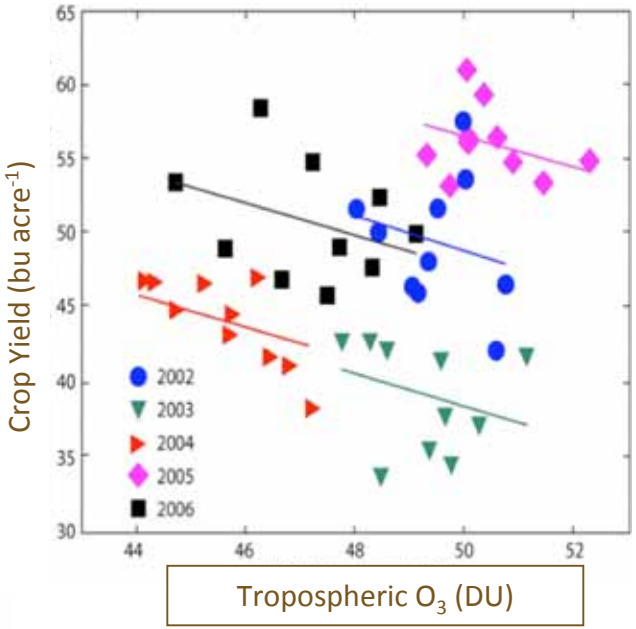
-1.21 ± 0.58% $ppbv^{-1}$

Both calculations in good agreement with laboratory findings

Quantifying Impact of Ozone on Crop Yield:

Statistically Significant Only for Southern Region of Study Area





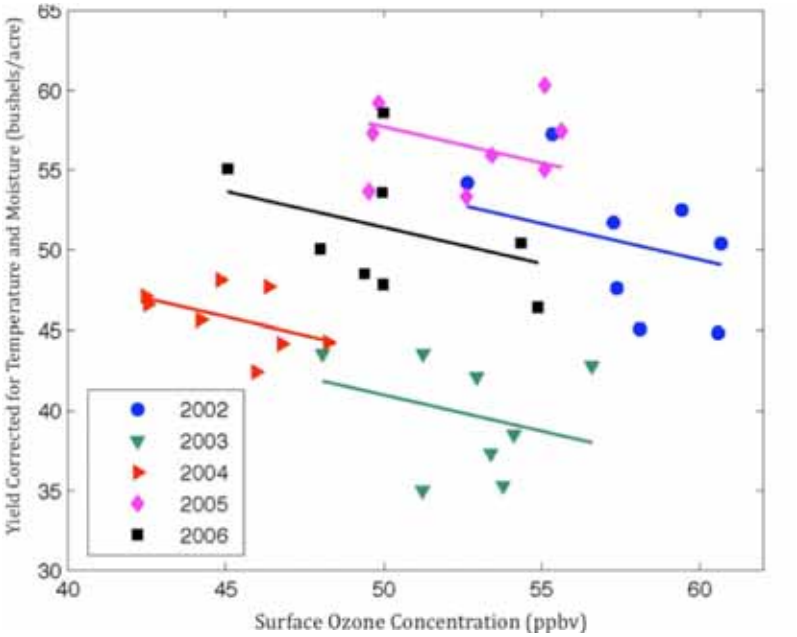
- Regression most significant for Southern region
- Crop damage only occurs when concentrations are above threshold
- Southern region >60 ppbv 24% of days

(central: 13%; northern 9%)

- Average concentrations:
  - northern: 45 ppbv
  - central: 49 ppbv
  - southern: 54 ppbv

Comparison of Crop Loss Using Surface O_3 and Satellite TOR

Crop Yield vs Surface O_3



m = -0.45 bushels acre^{-1} ppbv^{-1}

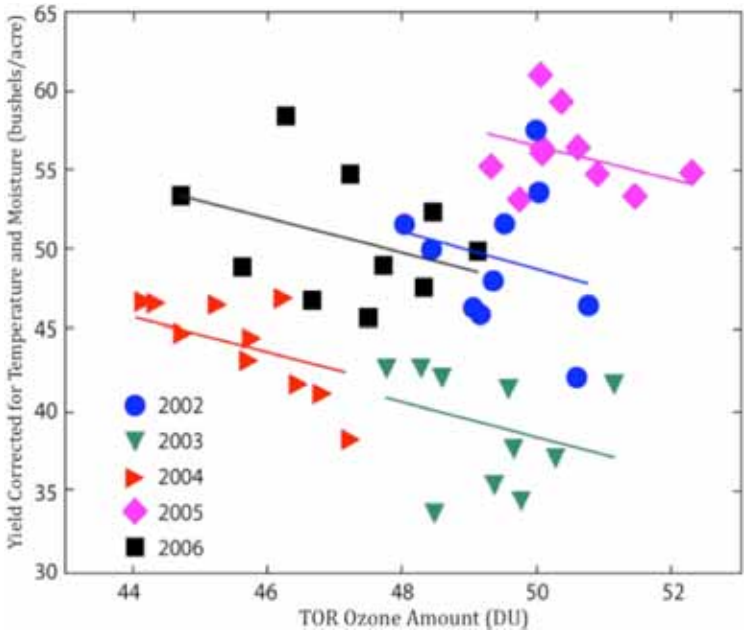
yield = -0.90% ppbv^{-1} (2002-2006)

SoyFACE Measurment:

yield = -1.64% ppbv^{-1}

(2002-2003; Morgan et al., 2006)

Crop Yield vs Satellite O_3



m = -1.09 bushels acre^{-1} DU^{-1}

Relationship between Sfc O_3 and TOR:

Sfc O_3 = 0.84 TOR + 11.70 (r=0.64)

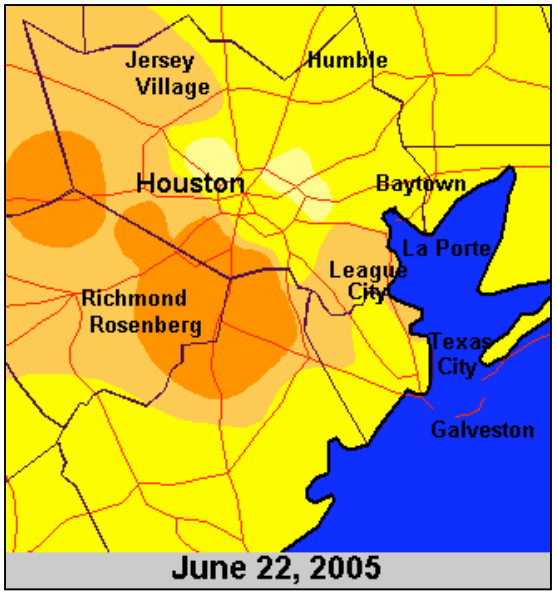
[data from 37°-40°N]

yield = -1.86±0.99% ppbv^{-1} (2002-2006)

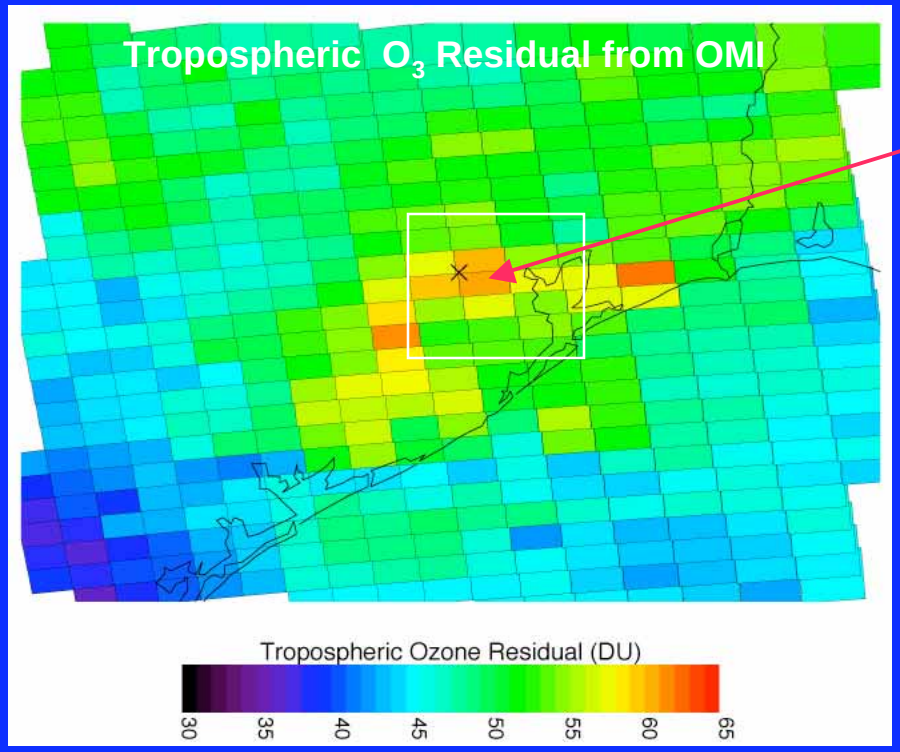
Transitioning Studies from Regional to Urban:

Pilot Studies Intermittently Capture Urban Pollution

A Case Study Over Houston



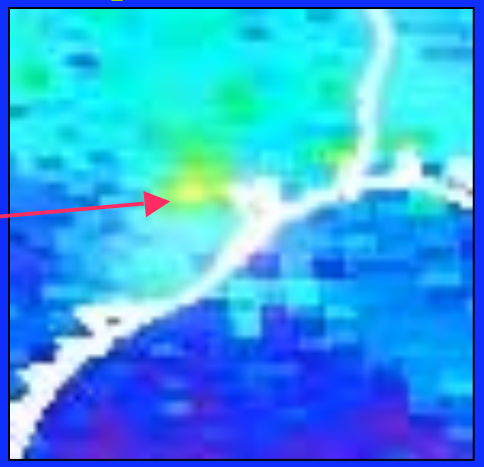
OMI Measurements Capture Pollution Event In Houston Area for June 22



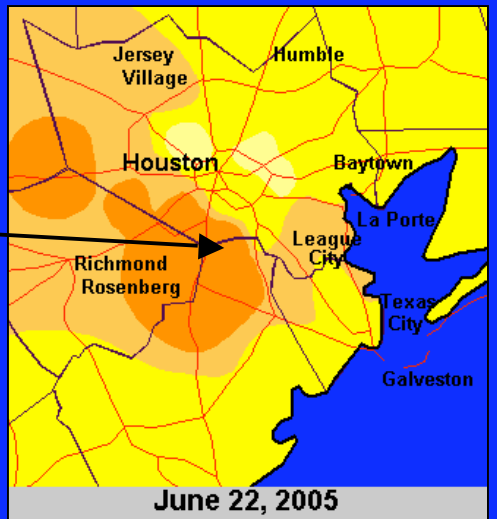
Elevated TOR from OMI

Elevated NO_2 from OMI

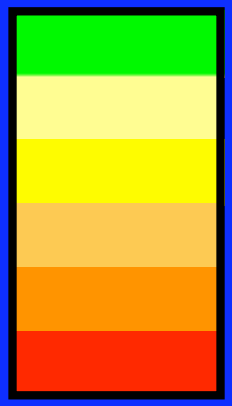
NO_2 Column from OMI



Elevated Surface O_3 from EPA Sites



Surface O_3 Concentrations



0-60 ppb

61-79 ppb

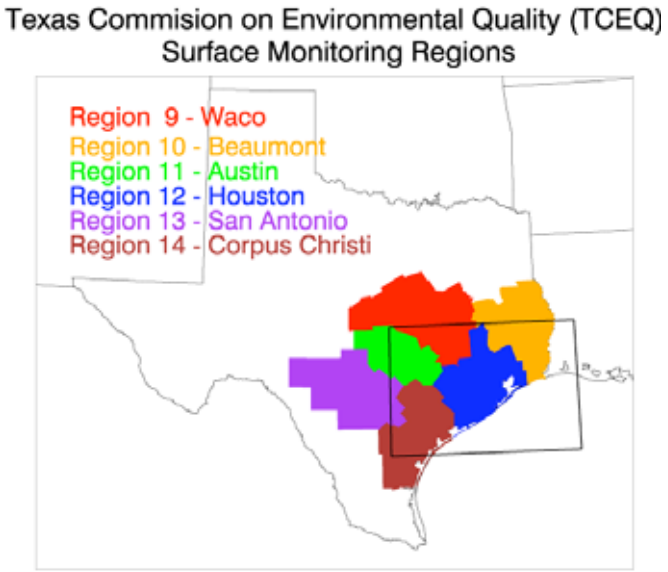
80-99 ppb

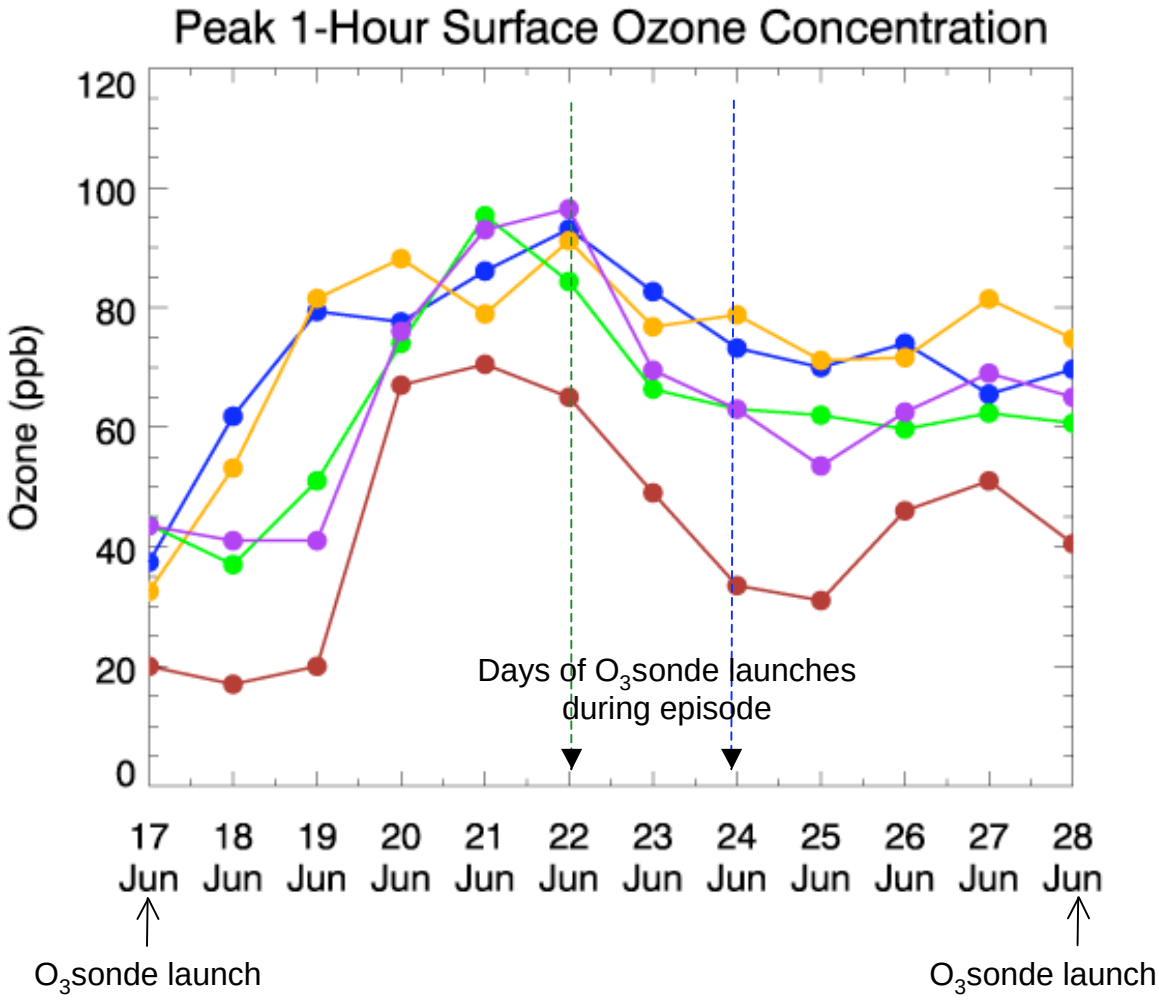
100-110 ppb

111-124 ppb

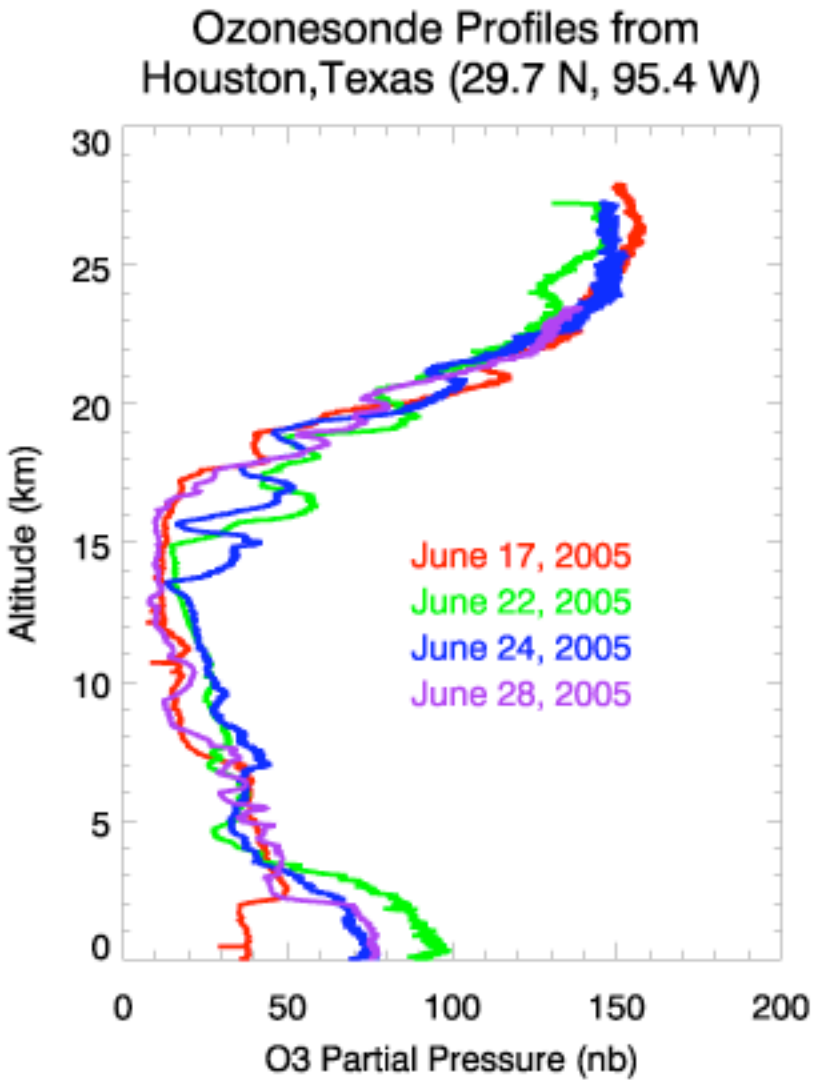
125+ ppb

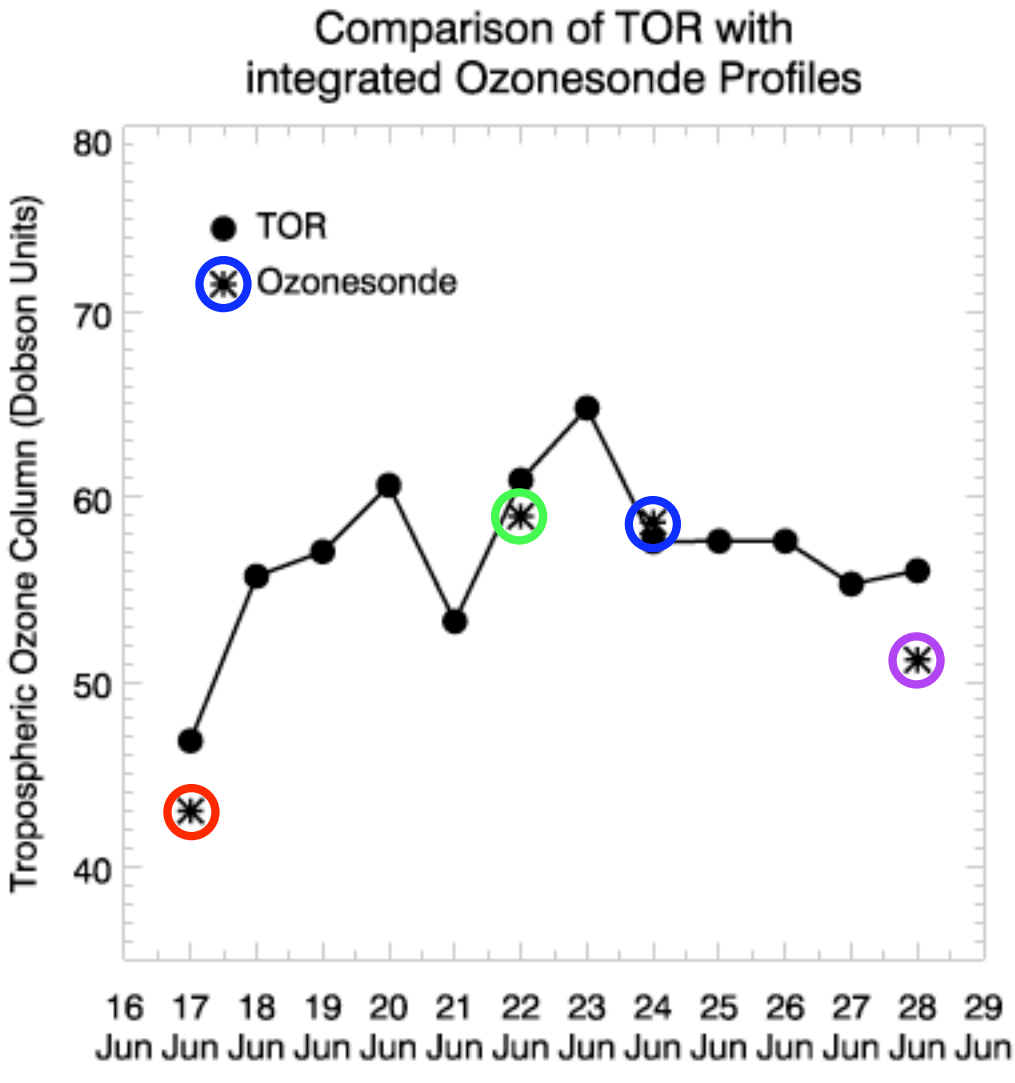
Regional Ozone Pollution Episode over Southeast Texas during late June 2005



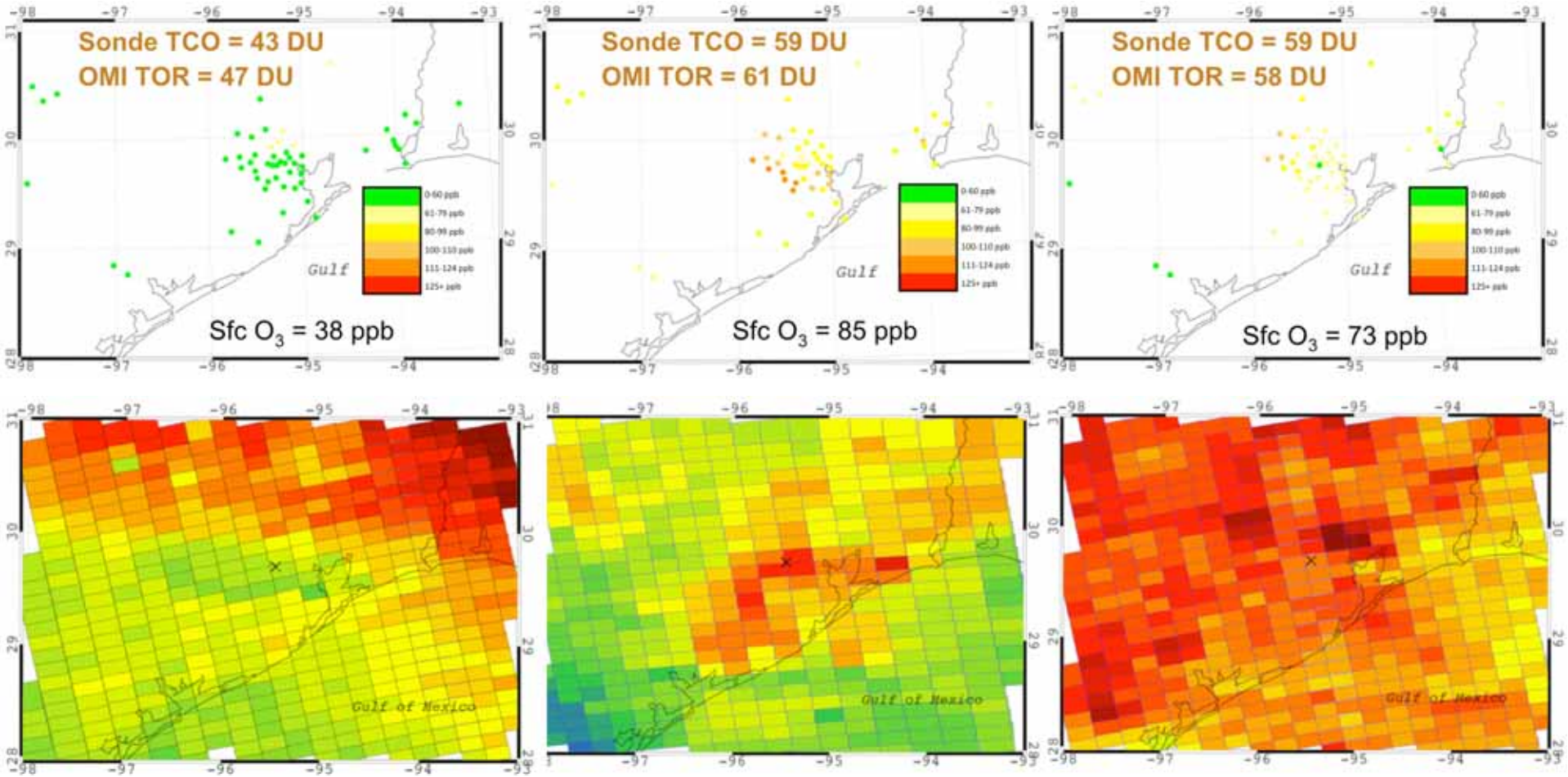


Good Agreement with Few Available Ozonesonde Measurements





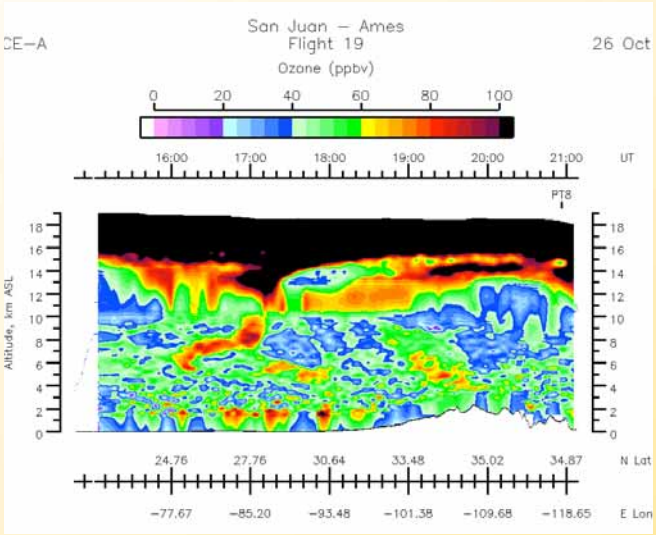
Surface O_3 and TOR Over Houston



Studies at NASA Langley Research Center to Define Science Requirements for GEO-CAPE

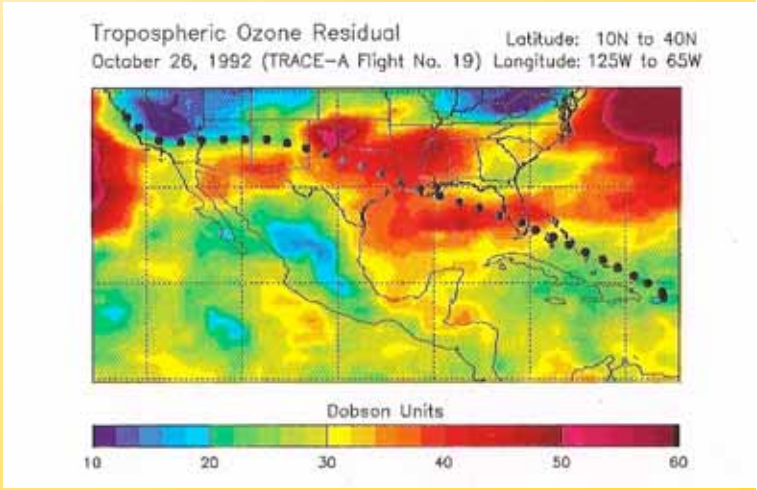
(One of Two Tasks)

Analysis of Existing Aircraft Datasets to Capture Column Variability in the Troposphere



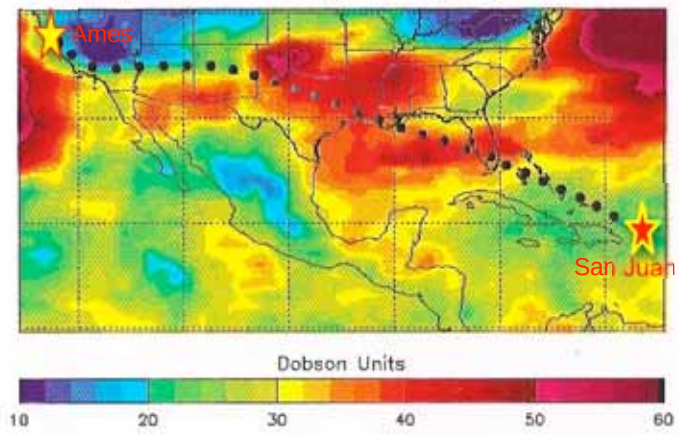
UV-DIAL Ozone Cross Sections

TOR Measurements

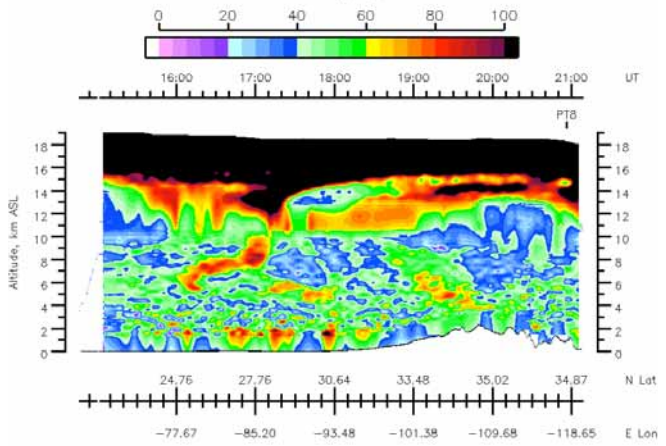


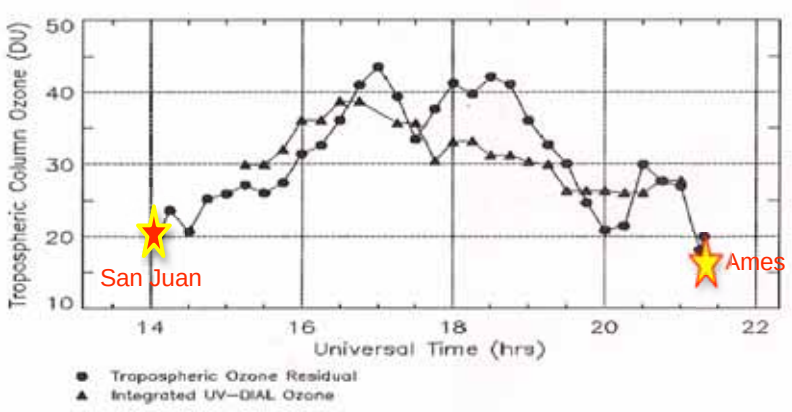
Transit Flight during TRACE-A Provided Unique Opportunity to Validate Satellite TOR

TOR Distribution – Oct. 26, 1992

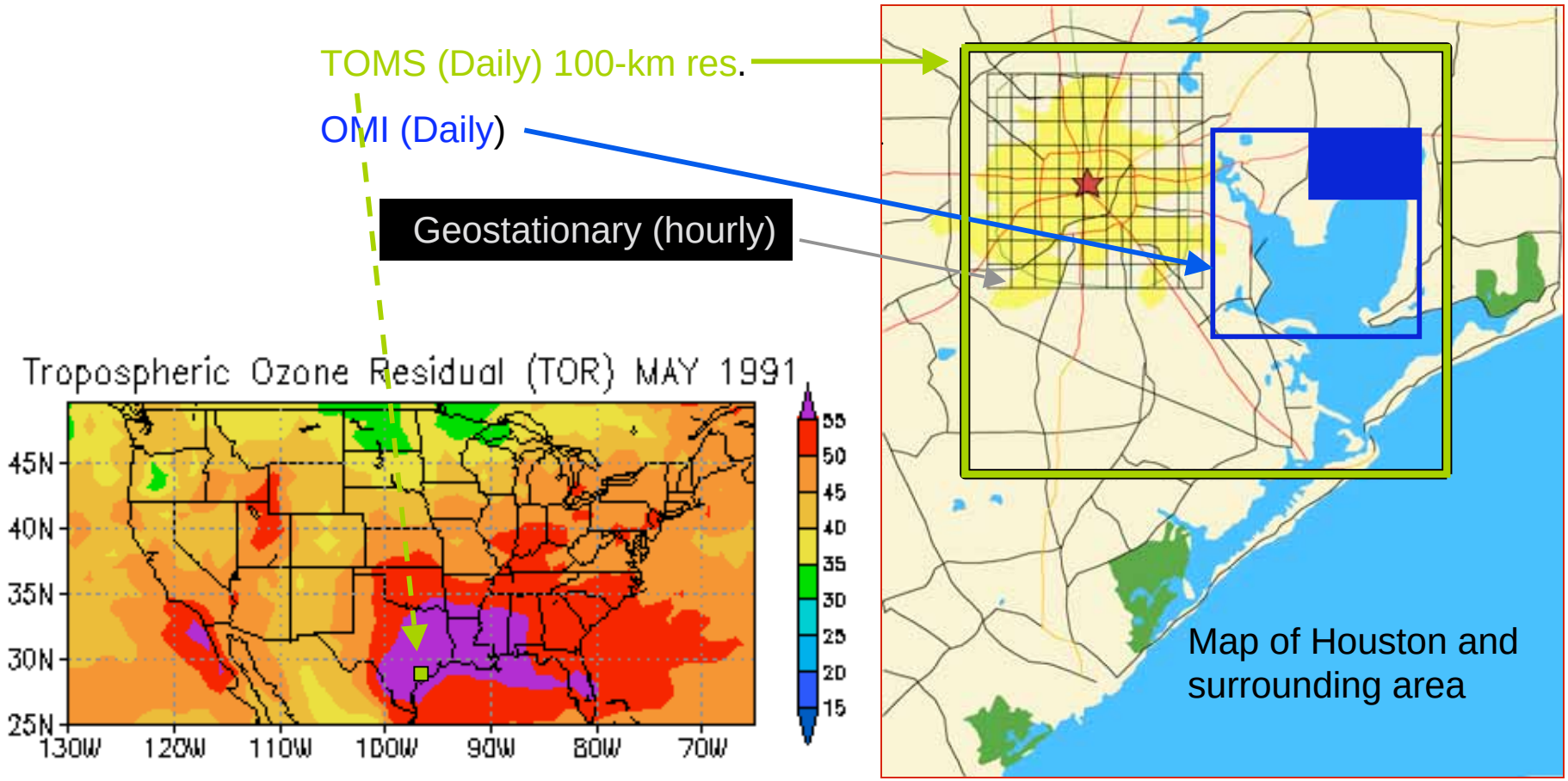


UV-DIAL Ozone
San Juan – Ames: Oct. 26, 1992





Best Method to Observe Pollution is from Geostationary Orbit

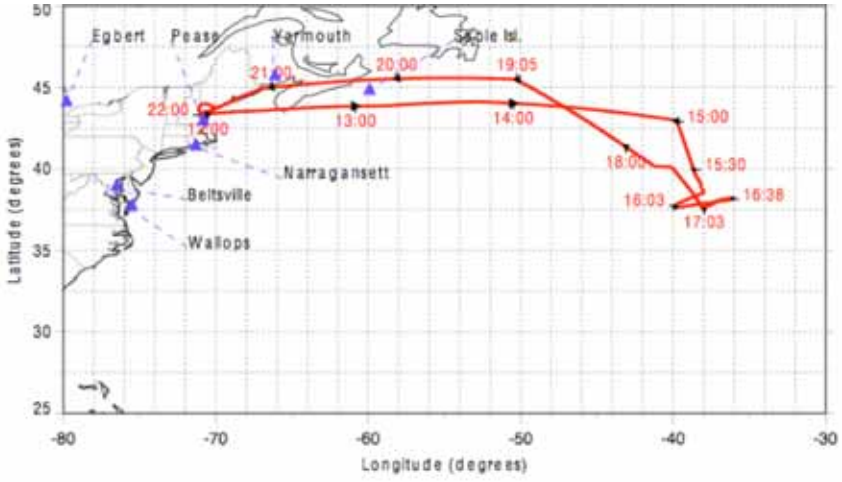


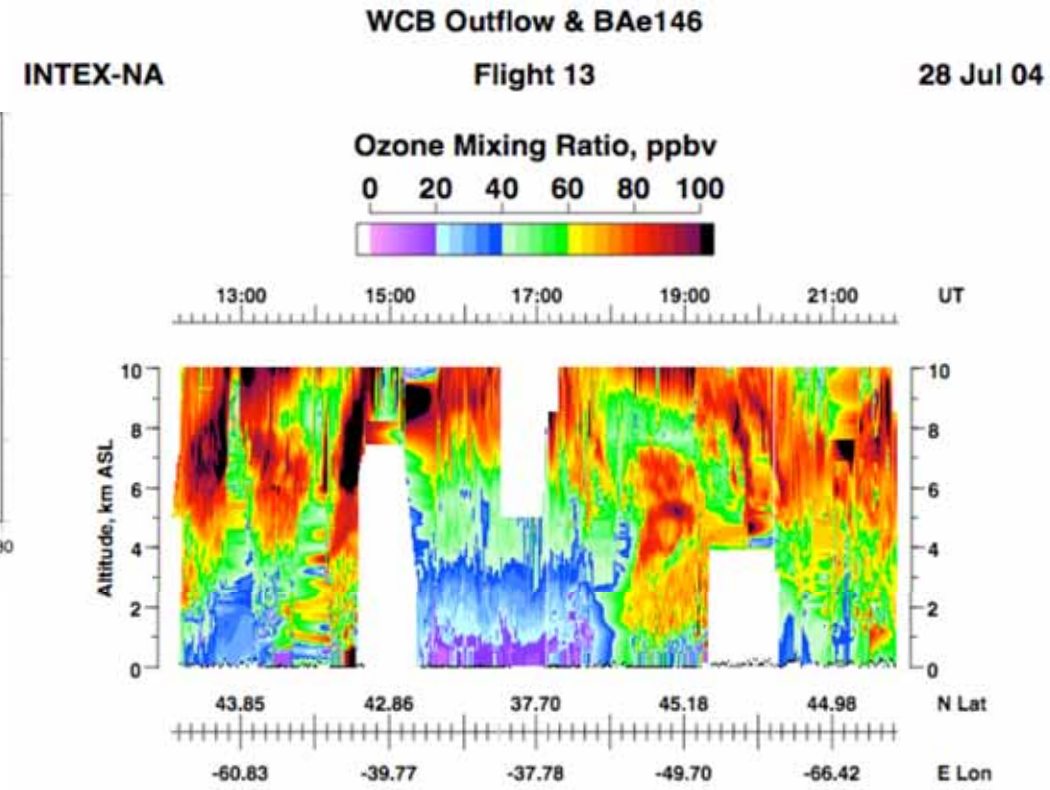
Purpose of the present study is to examine how much variability exists in the tropospheric ozone column at a 4-km resolution and to see if this variability is from the boundary layer or the free troposphere

J. Fishman 09/2003

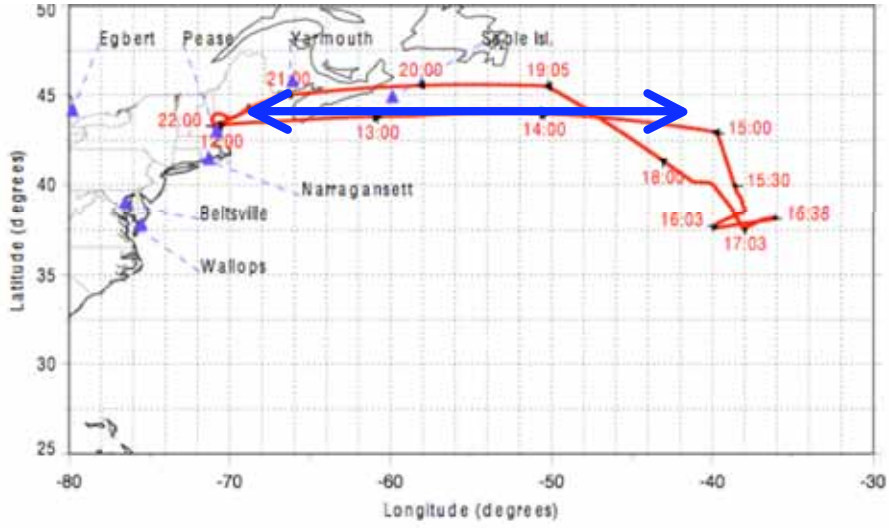
UV-DIAL Ozone Data with 4-km Resolution

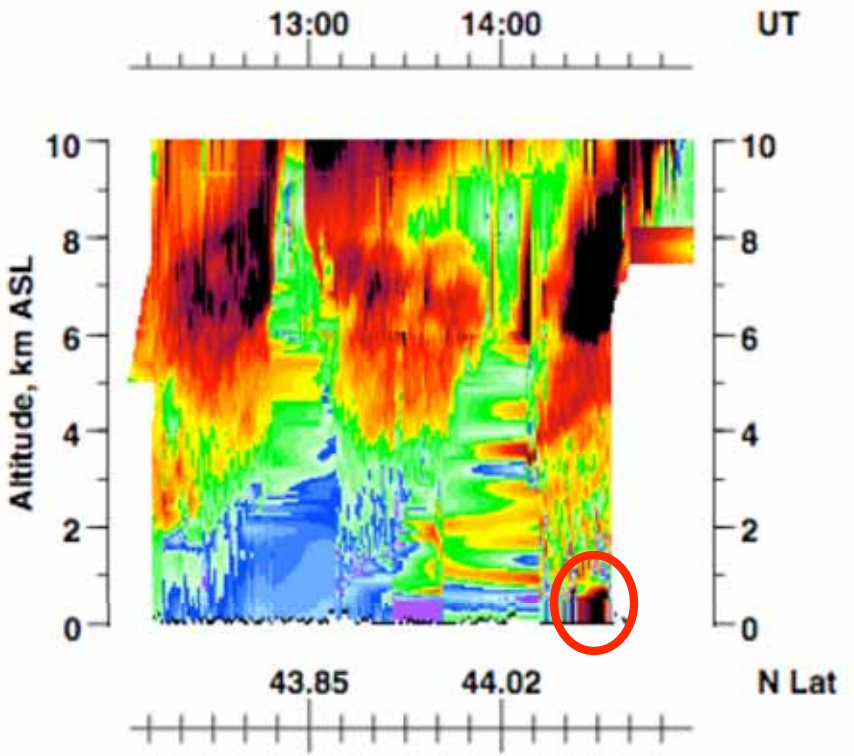
Determine Degree of Column Variability to Help Define Science Requirements for GEO-CAPE

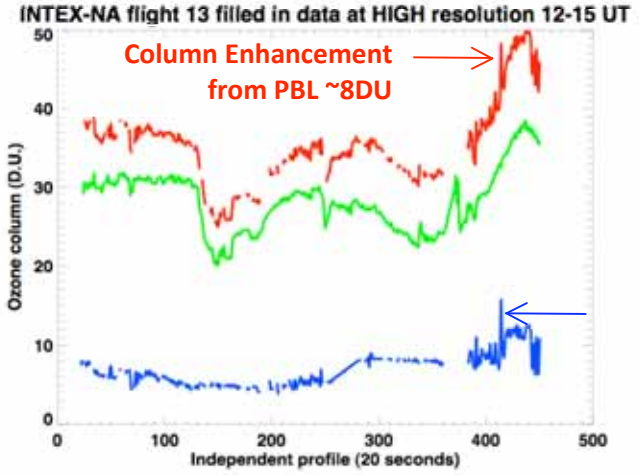




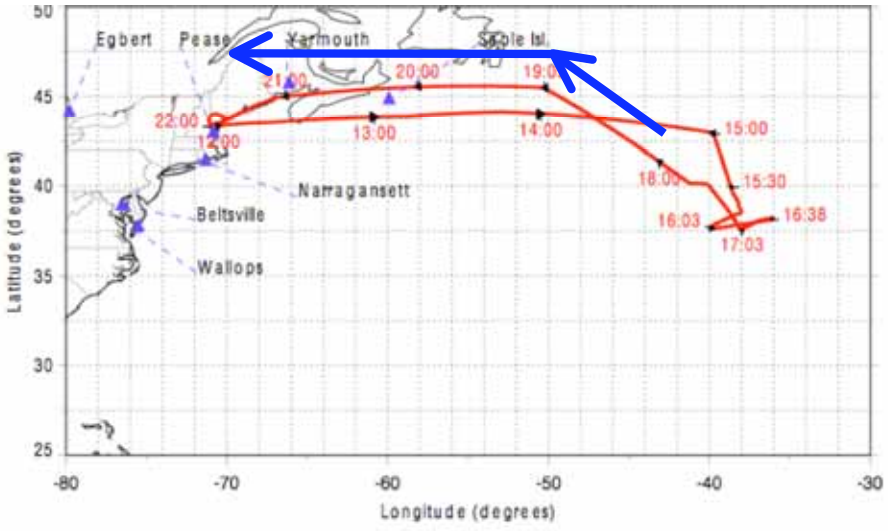
UV-DIAL Ozone Cross Section
INTEX-NA Flight 13
July 28, 2004

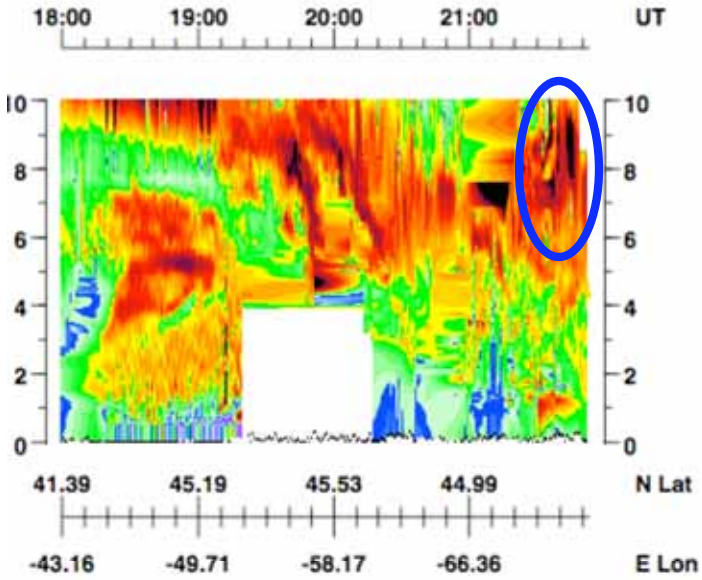




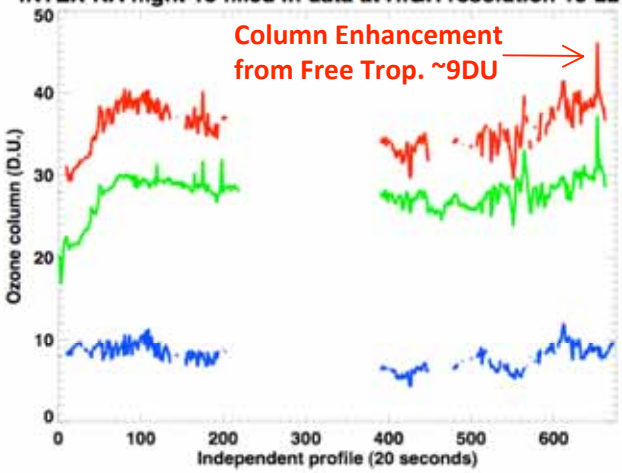


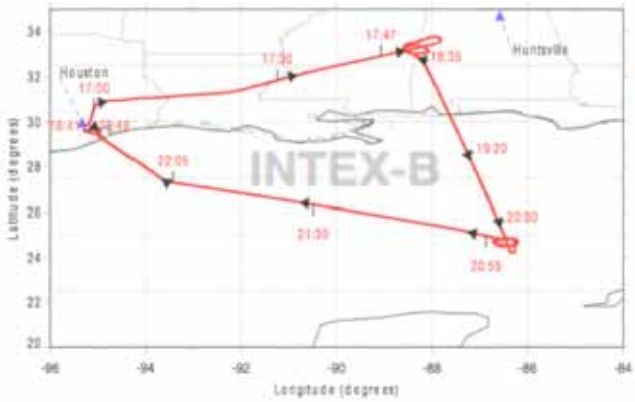
UV-DIAL Ozone Cross Section
INTEX-NA Flight 13
July 28, 2004





INTEX-NA flight 13 filled in data at HIGH resolution 18-22 UT

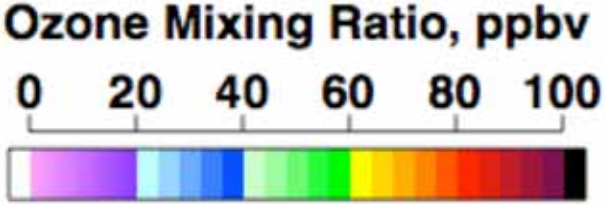


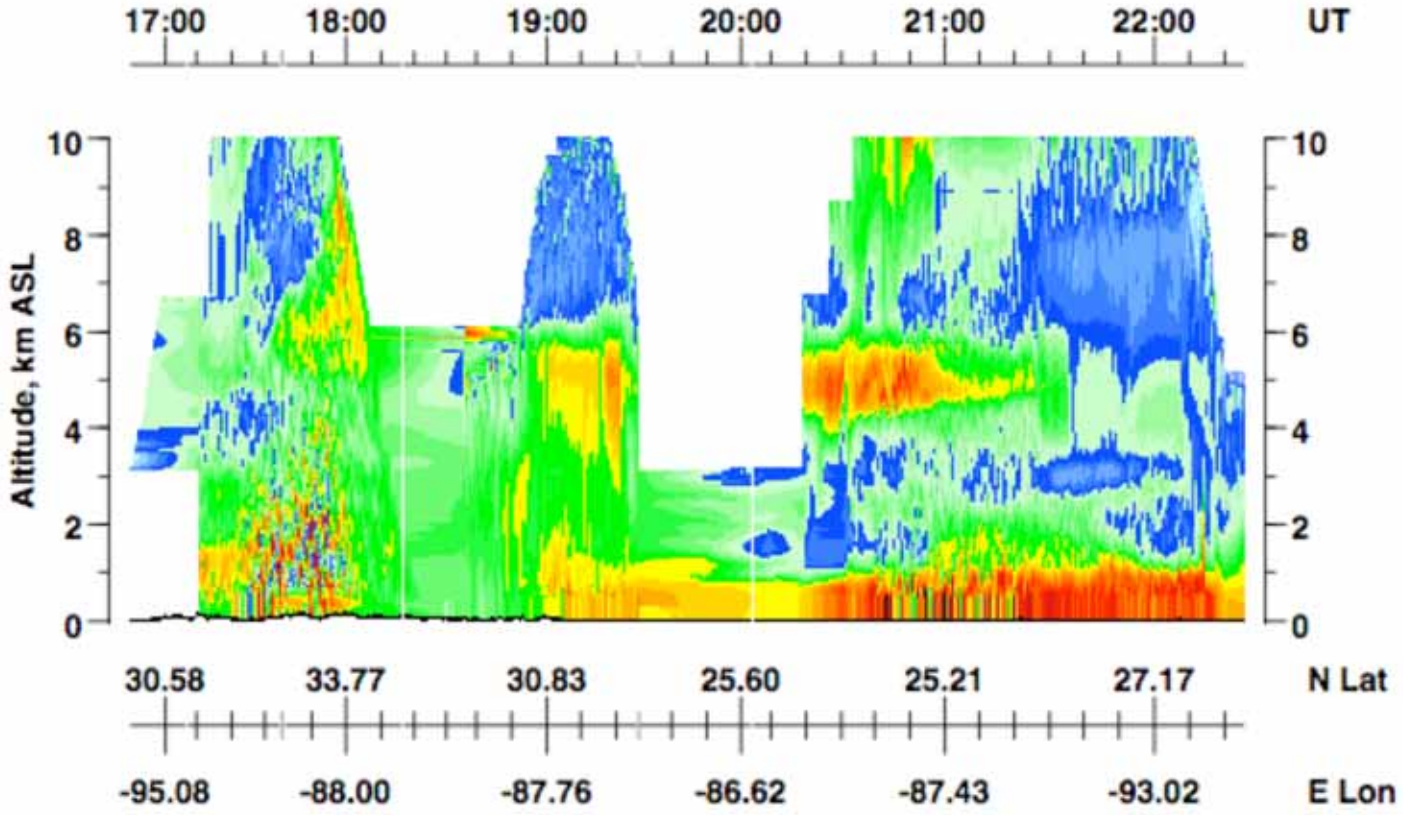


TES & OMI Validation / Smoke Plumes

Flight 3

4 Mar 06

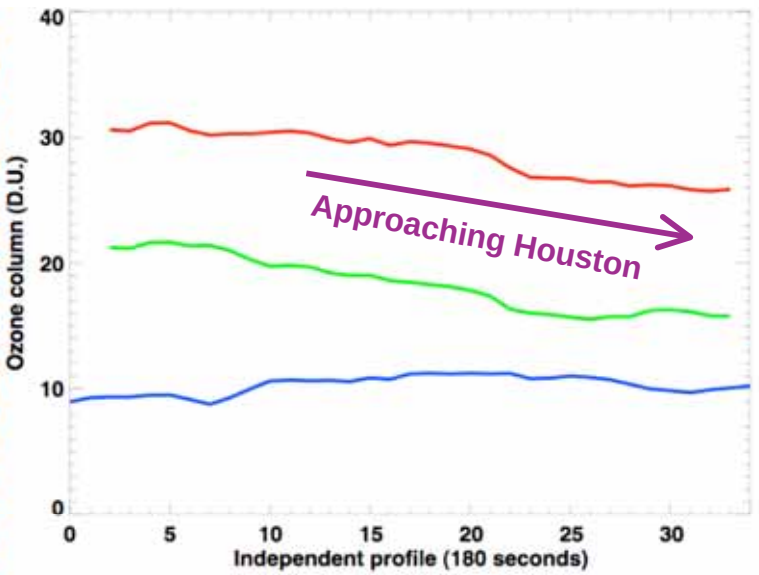


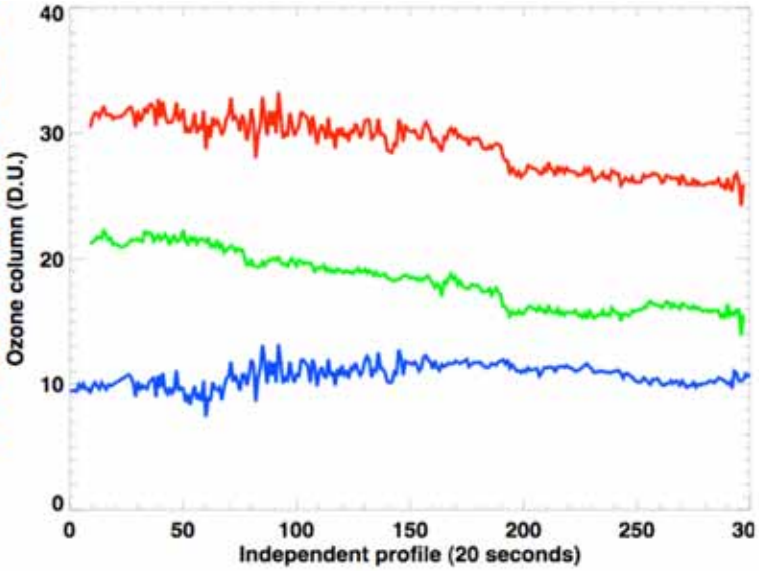


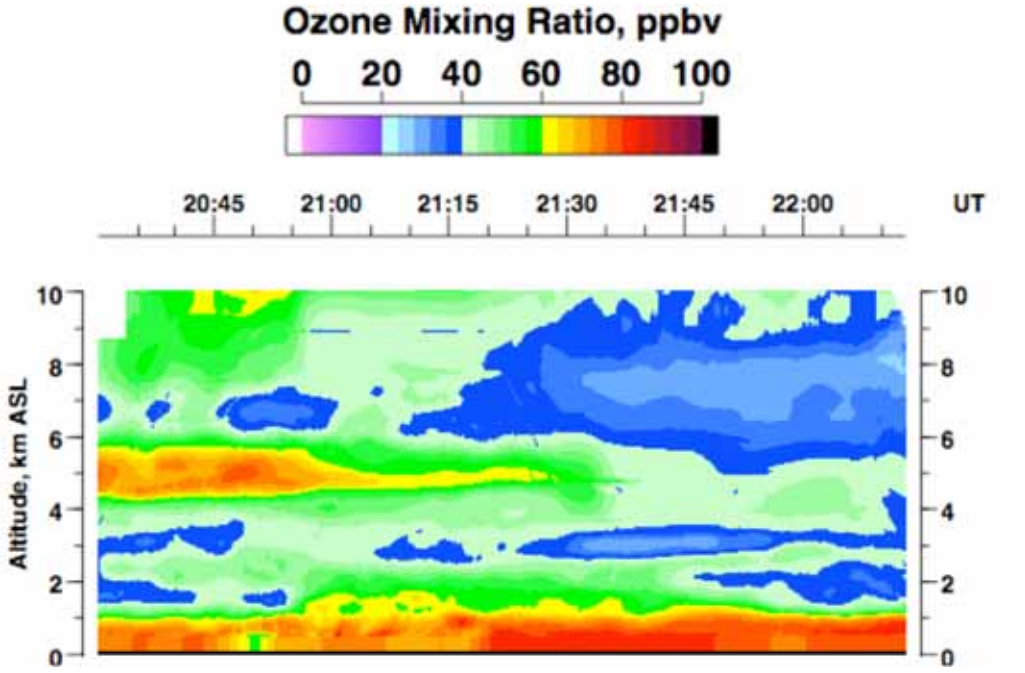
INTEX-B Flight 3 20:30-22:13 UT

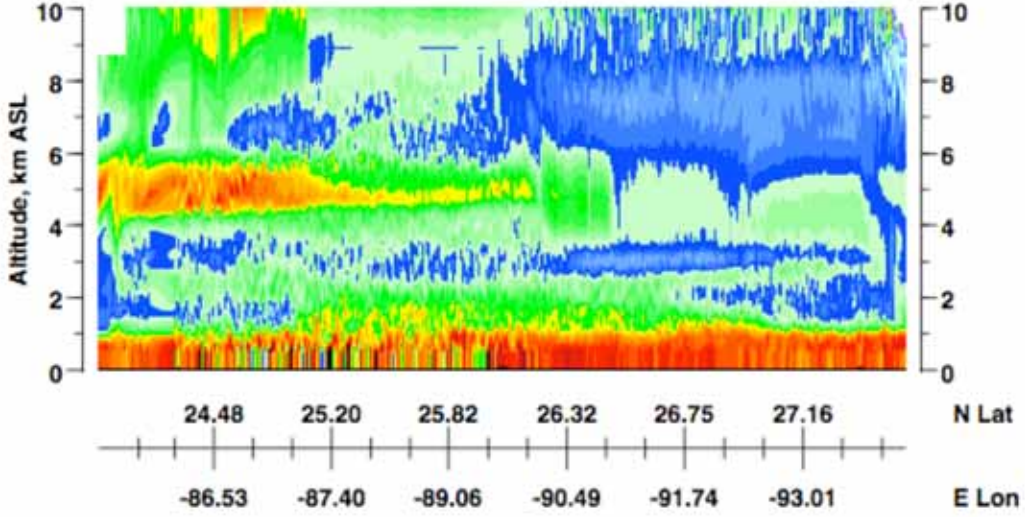
ground to 2 km
2 to 10 km
ground to 10 km

HIGH RESOLUTION LOW RESOLUTION







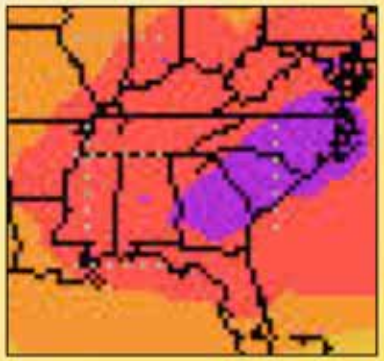


Future Studies at NASA Langley Research Center:

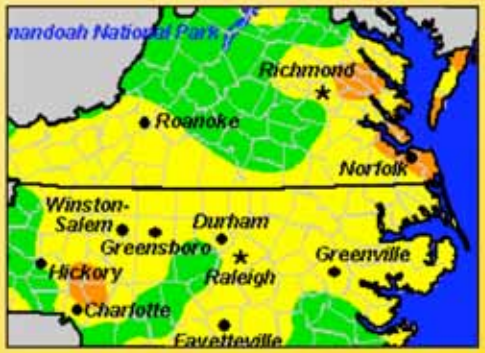
(Second of Two Tasks)

Relating high temporal satellite total column measurements with surface concentrations

Spectral Measurements



In situ Measurements



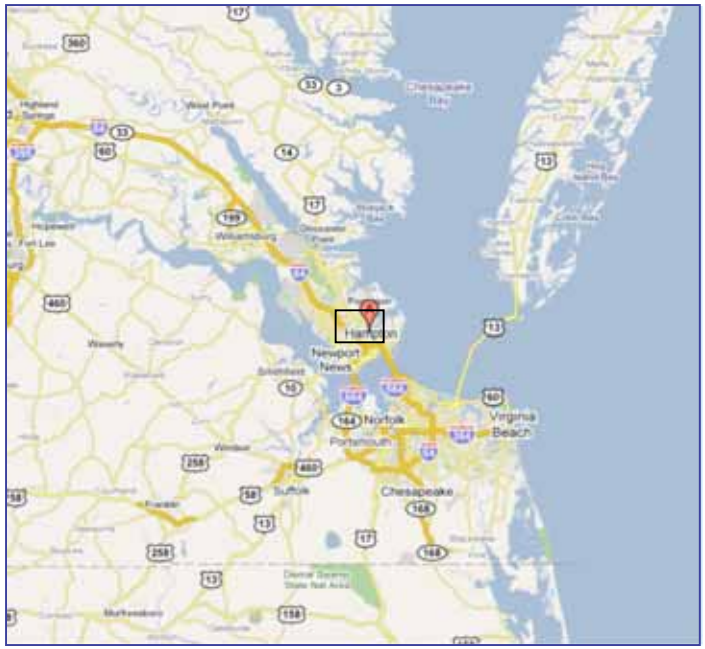
Site at NASA Langley will provide concurrent high temporal resolution measurement of total column measurements and surface *in situ* concentrations

<u>Summer 2009</u>

- Pandora spectral measurements
- NATIVE Trailer

<u>2010</u>

- AERI T & RH sounder
- Permanent Virginia DEQ site

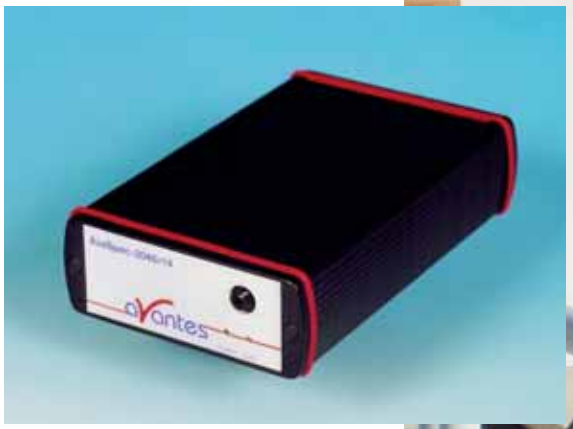


Through Collaboration with Jay Herman at NASA Goddard: Spectrometer Now Functioning at NASA Langley

Pandora is a small UV/Vis spectrometer system, which has been tested and operated since 2006.

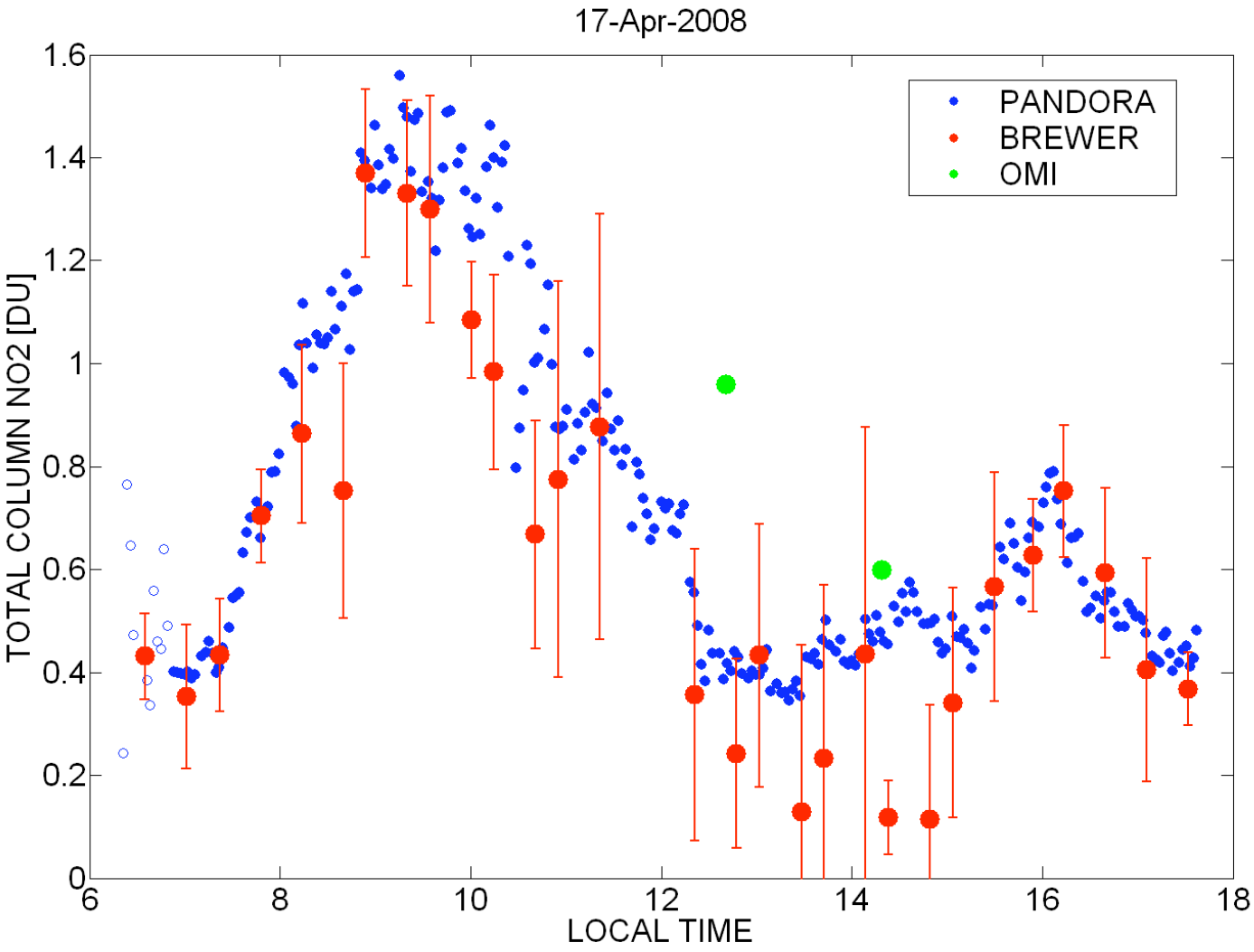
It consists of …

a “miniature” spectrometer

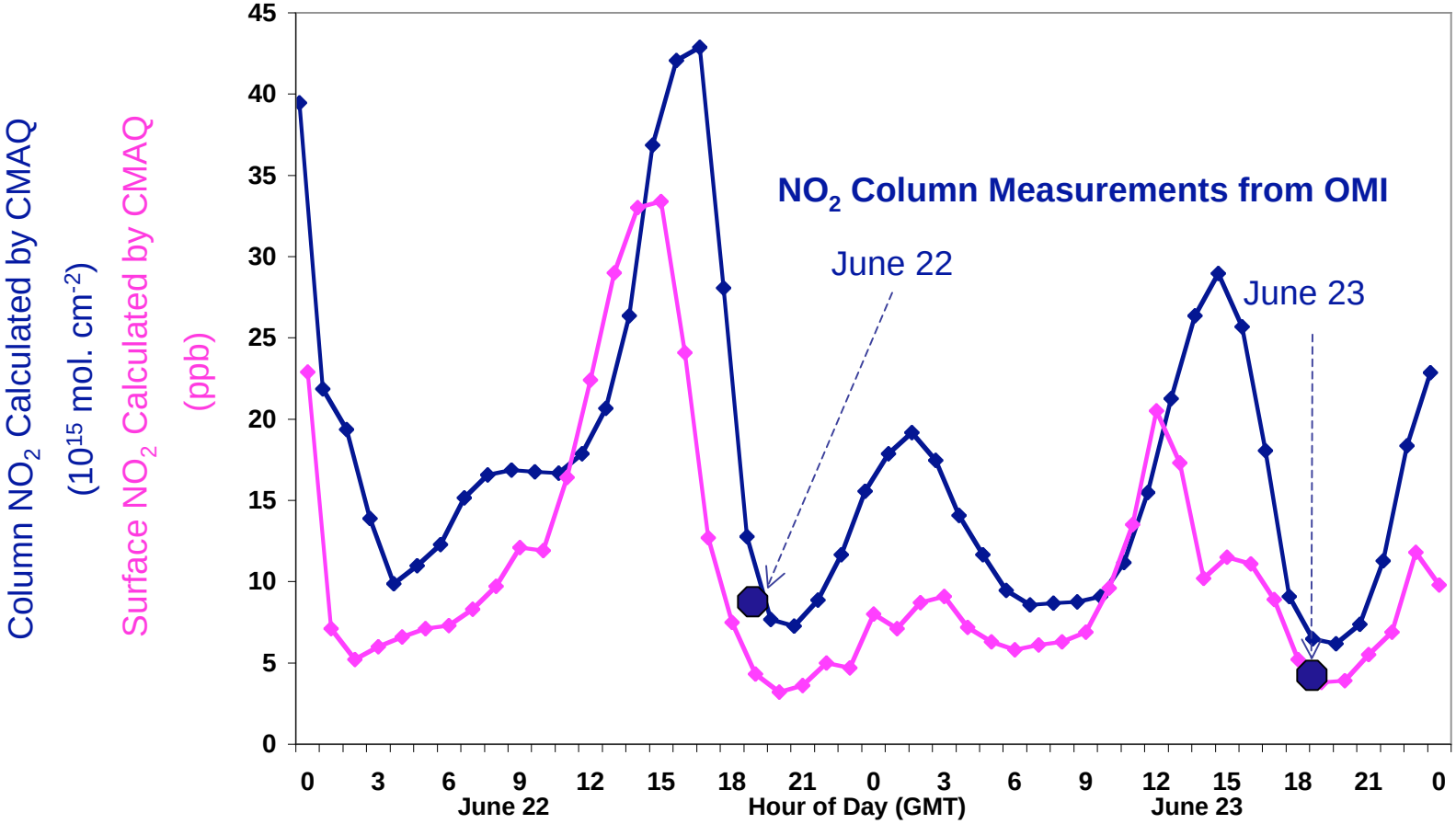


and a head sensor on a tracker

Pandora Provides High Resolution Temporal Measurements



Integrated NO_2 Should Reflect Surface Concentrations

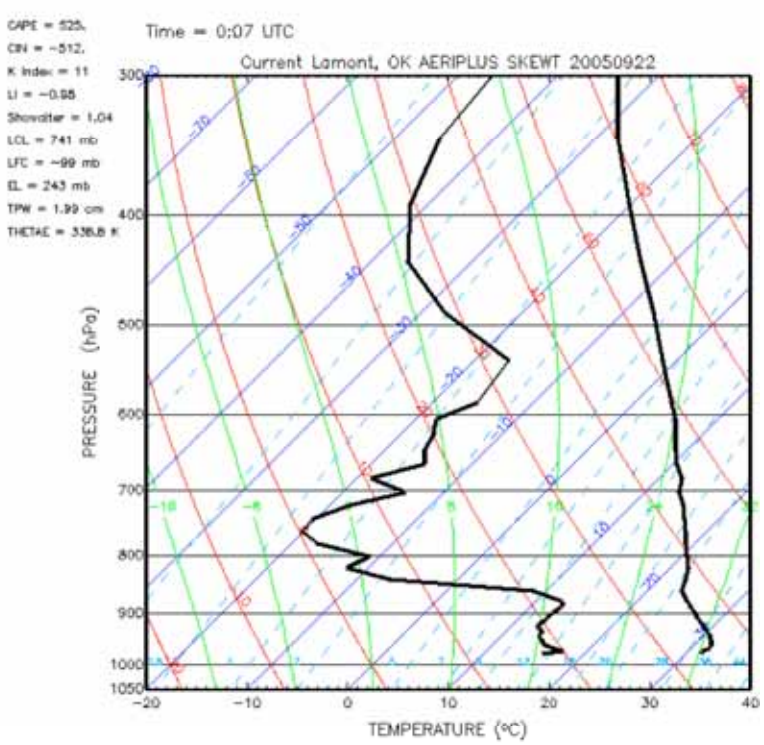


Anne Thompson's NATIVE Trailer will be at NASA Langley during Summer 2009 to Provide *in situ* Measurements

Basic NATIVE Container:
One 40-foot "EKTO" portable container with modifications
Power:
Generator for Lower Power Container #1
Wireless communications (No. America, Europe)
Telescopic Mast
Meteorological tower: P-T-U, wind speed & direction
Standard Instruments:
TEI (Thermoelectron Instrument) Model 49C **Ozone**
TEI Model 48C Trace level **CO** Analyzer
TEI Model 43C Trace level **SO_2** Analyzer
TEI Model 42C Trace level **NO-NO_x** Analyzer
Ozonesondes, ENSCI Ground Station & Supplies
Calibration gases, Computer server
Yankee Ultraviolet Multi-filter Rotating Shadowband Radiometer (UVMFR-7)
ESC Data Acquisition System

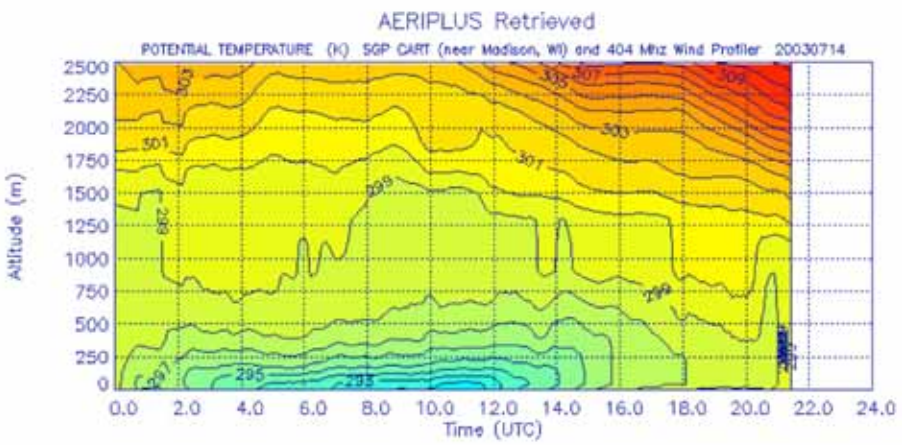
AERI:
Atmospheric Emitted Radiance Interferometer

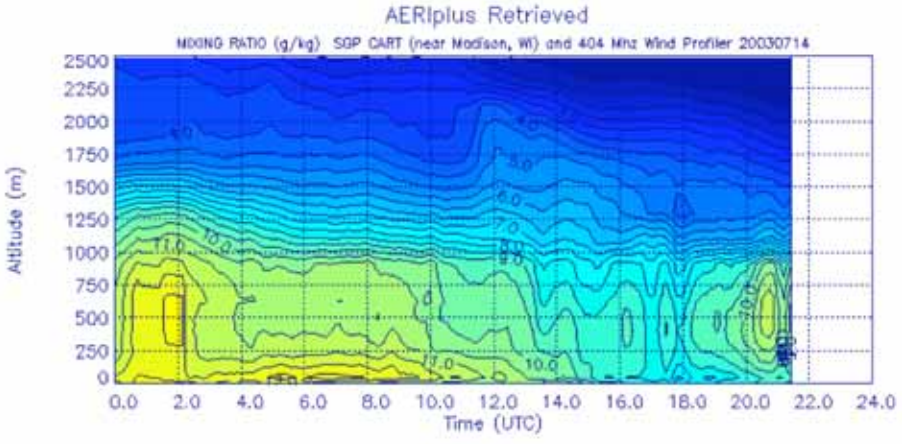
- Unit purchased with FY09 “stimulus funding”
- Will be permanently installed in early 2010
- Will provide continuous information about vertical distribution of temperature and humidity in planetary boundary layer



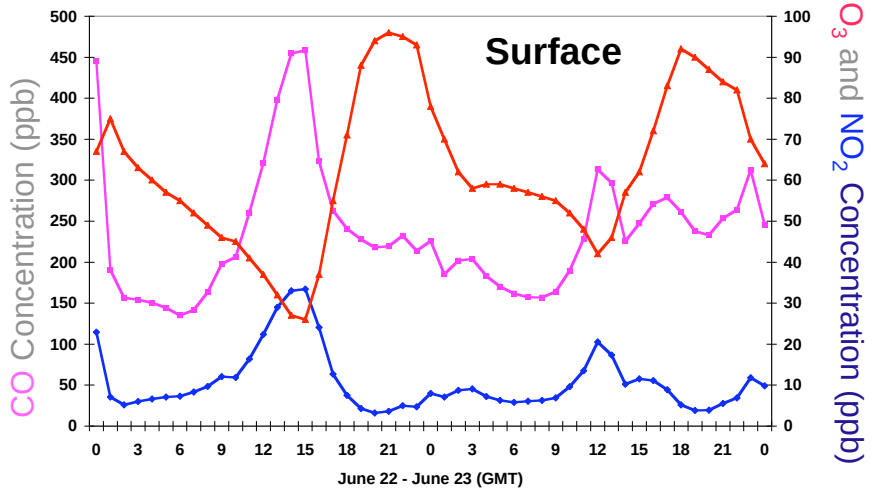
Langley Site will Provide High Temporal Resolution of Surface Concentrations and Column Integrals of Tropospheric Trace Gases as Well as Detailed Information about the Structure of the Planetary Boundary Layer

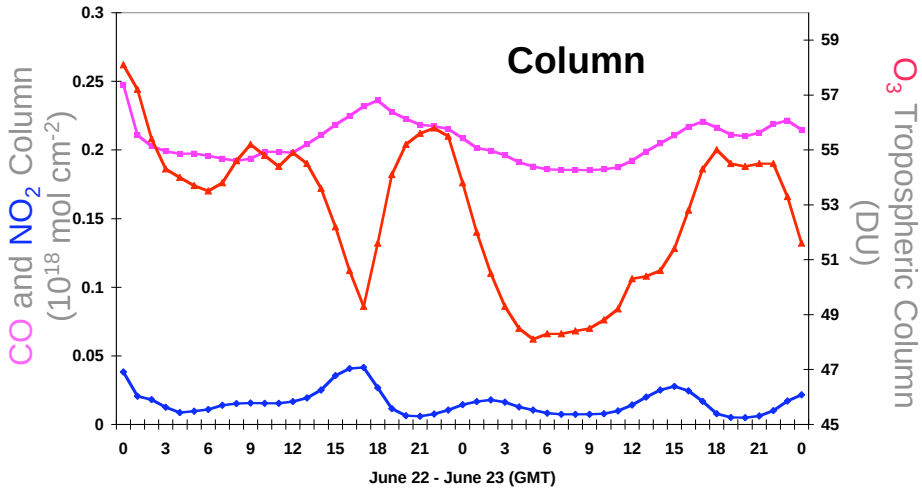
AERI Time-resolved Evolution of Planetary Boundary Layer





CMAQ Calculated Integrated and Surface Calculations





For 2010 and Beyond:

Working Partnership with the Virginia Department of Environmental Quality and the U.S. EPA

- Permanent state monitoring site to be located at NASA Langley
- Agreement with U.S. EPA for testing state-of-the-art instruments

For 2010 and Beyond:

Working Partnership with the Virginia Department of Environmental Quality and the U.S. EPA

- Permanent state monitoring site to be located at NASA Langley
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- **Potential validation facility for GEO-CAPE**

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Summary and Next Steps

Scale, Scale, Scale……

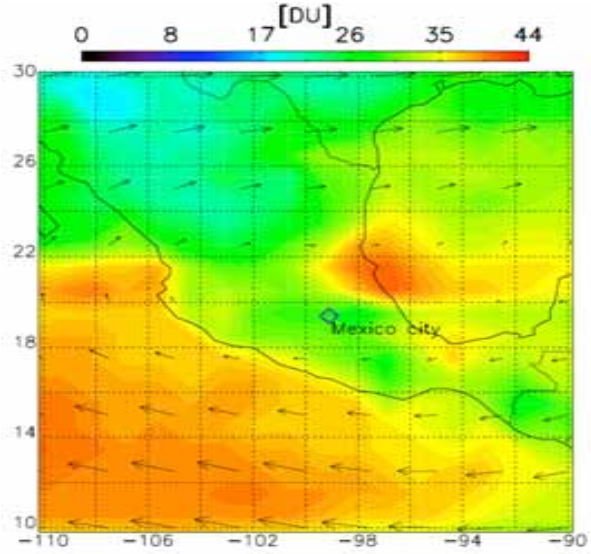
The maturity of atmospheric composition satellite measurements poses the challenge of relating measurements to smaller scales

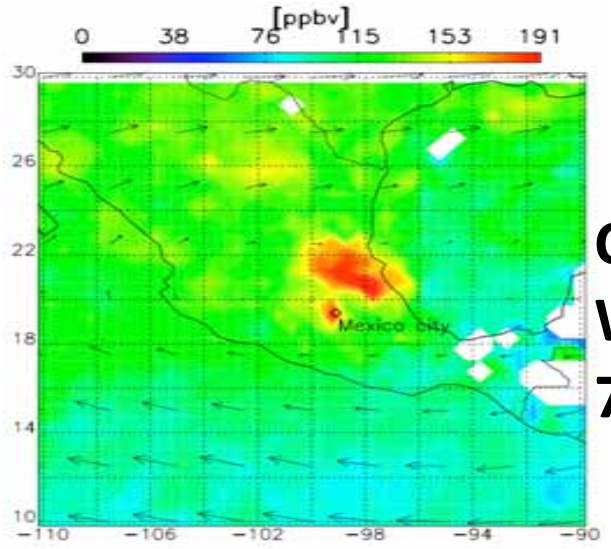
- Conventional validation for ozone has focused on relating TOR measurements to in situ column measurements, generally from sondes
- Validation of hemispheric and regional patterns have been validated directly and from inference using soybean crop damage
- Examples found where correlations exist on daily and urban case studies
- Further study needed to understand relationship between surface and satellite-derived tropospheric quantities
- New site at NASA Langley being developed to provide data that will help to understand relationship of high resolution temporal variability for both column and in situ measurements

Back-up Slides

Urban Plumes Observed in Multiple Satellite Data Sets

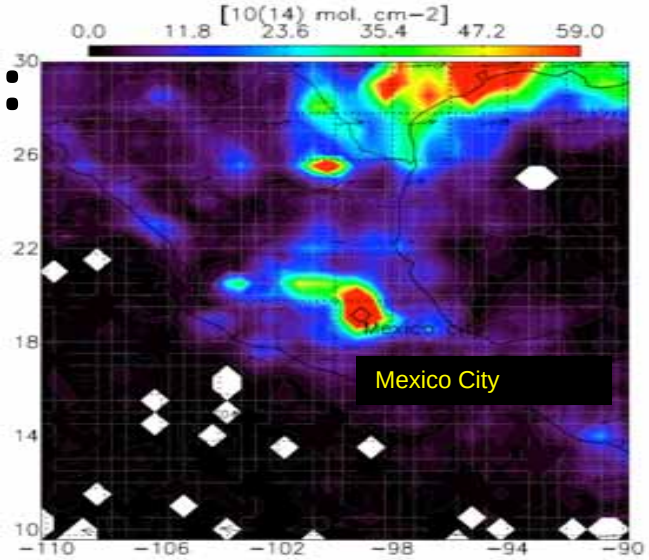
TOR and Winds-- 700 hPa





CO and Winds-- 700 hPa

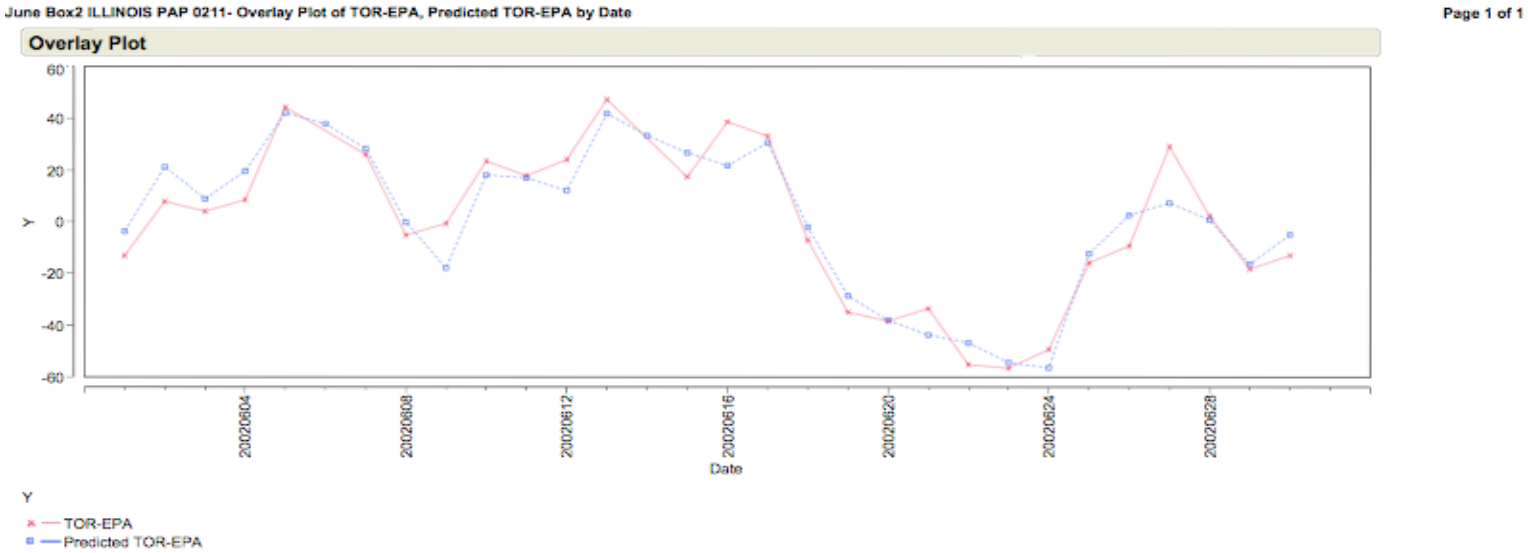
Monthly Climatology: January, 2006



NO_2 (SCIA) and Winds--700hPa

Will the Relationship Between Satellite and Surface Measurements Ever Be Understood?

Statistical Relationship Found Between Satellite and Surface Ozone Values for Subset of Data



Statistical Model Finds Difference in Satellite Data and Surface O_3 Dependent on Following Variables:

WS, T, DP, P, (WS*T),(T*DP) and (T*P)

$$TOR\text{-}O_3 = 2968.72 + 1.03\ WS - 3.63\ T + 1.54\ DP - 93.75\ P + 0.48\ *(T*WS) + 0.23\ *\ (T*DP) - 4.74\ (T*P)$$