# TES Observations during Texas Air Quality Study II

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Principal Findings Data Analysis Workshop – Texas AQS II

May 31, 2007

Jet Propulsion Laboratory
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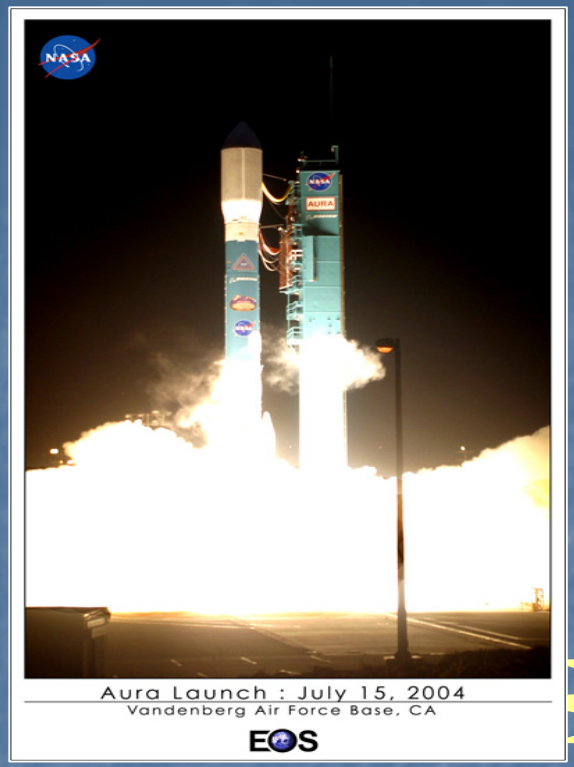
# Tropospheric Emission Spectrometer (TES) on the NASA Aura Satellite



Launched 2004.07.15

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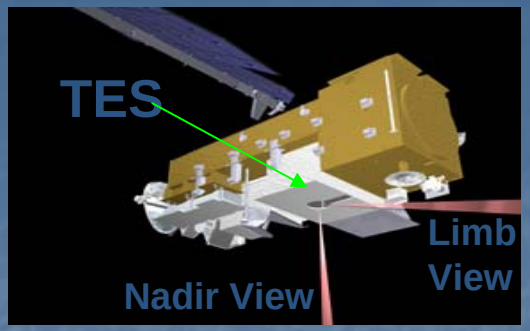
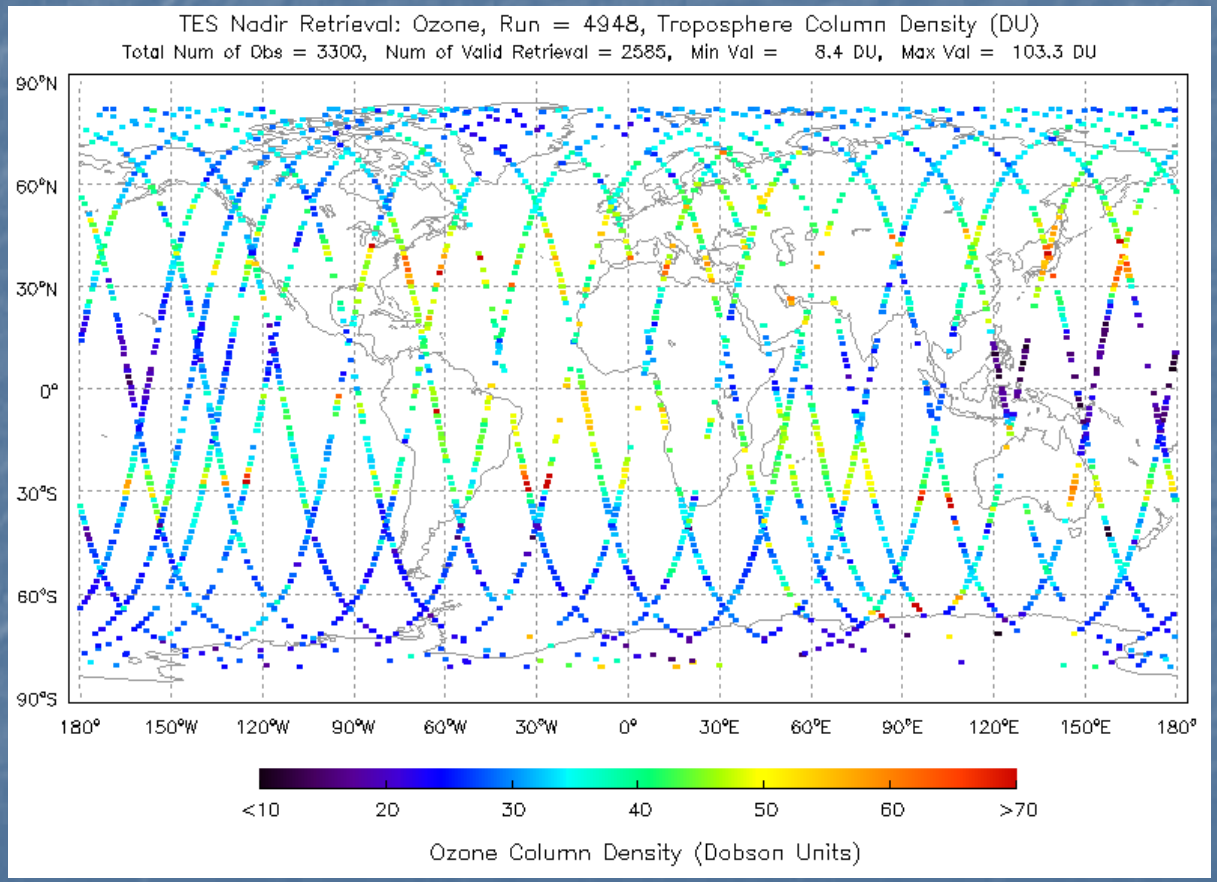



- TES is a Fourier Transform Spectrometer designed to measure tropospheric ozone and its precursors
- Estimates vertical profiles from the surface to .01 mb of temperature, water, ozone, carbon monoxide, nitric acid as well as emissivity, surface temperature and effective cloud parameters
- Measurements made day and night
- Nadir footprint 5 × 8 km
- No routine limb measurements after May 2005

| | |
|---|---|
| Spectrometer Type | Connes'-type 4-port Fourier Transform Spectrometer |
| Max. Optical Path Difference | ± 8.45 cm (normal)<br>± 33.8 cm (hi-res); interchangeable |
| Scan (integration) Time | 4 sec (normal)<br>16 sec (hi-res) |
| Sampling Metrology | Nd:YAG laser |
| Spectral Resolution (unapodized) | 0.06 $cm^{-1}$ (normal)<br>0.015 $cm^{-1}$ (hi-res) |
| Spectral Coverage | 650 to 3050 $cm^{-1}$ (3.2 to 15.4 um) |
| Detector Arrays | 4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K |
| Field of Regard | 45° cone about nadir; trailing limb or cold space; internal calibration sources |
| Pointing Accuracy | 75 urad pitch, 750 urad yaw<br>1100 urad roll |
| Max. Stare Time, | 208 sec (40 nadir scans) |
| Spatial Resolution | 0.5 x 5 km (nadir)<br>2.3 x 23 km (limb) |
| Radiometric Calibration | cavity blackbody (340K) + cold space view |
| Detector Array Co- alignment | Internal thin slit calibration source |
| Nadir NESR (Noise Equivalent Spectral Radiance) | 2B1 filter: 700 $nW/cm^2/sr/cm^{-1}$<br>1B2 filter: 200<br>2A1 filter: 150<br>1A1 filter: 100 |
| Nadir NEDT @290K (Noise Equivalent Delta Temperature) | 2B1: 1.08 K for 16 detector mean<br>1B2: 0.36 K for 16 detector mean<br>2A1: 0.36 K for 16 detector mean<br>1A1: 2.07 K for 15 detector mean |

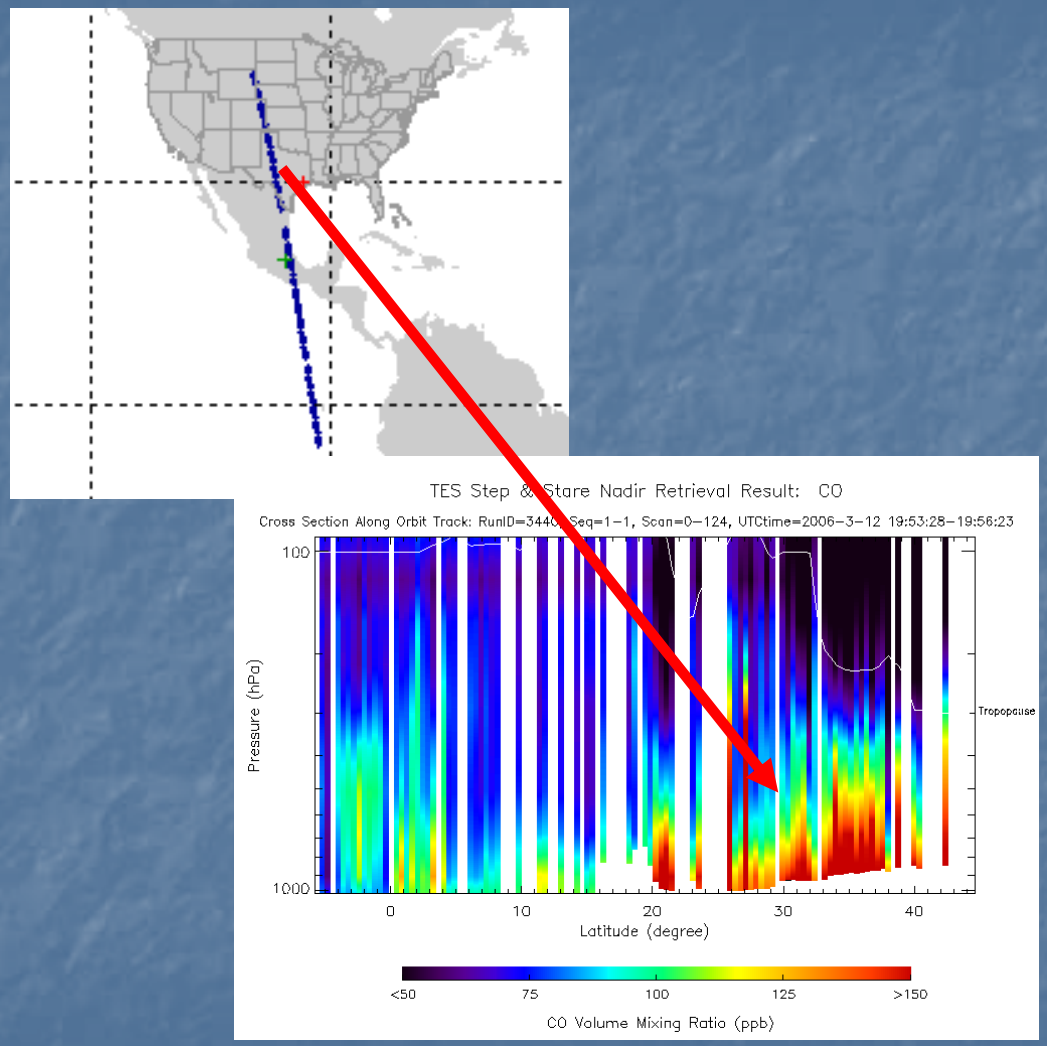
# TES Global Survey Measurements

- The Global Survey is the standard TES operating mode
- Maximum of 3408 nadir scans over ~27 hours (as of Jan 10, 2006)
- Start a GS every other day
- Ground track distance between scans is ~0.4° or ~182 km
- No averaging of scans



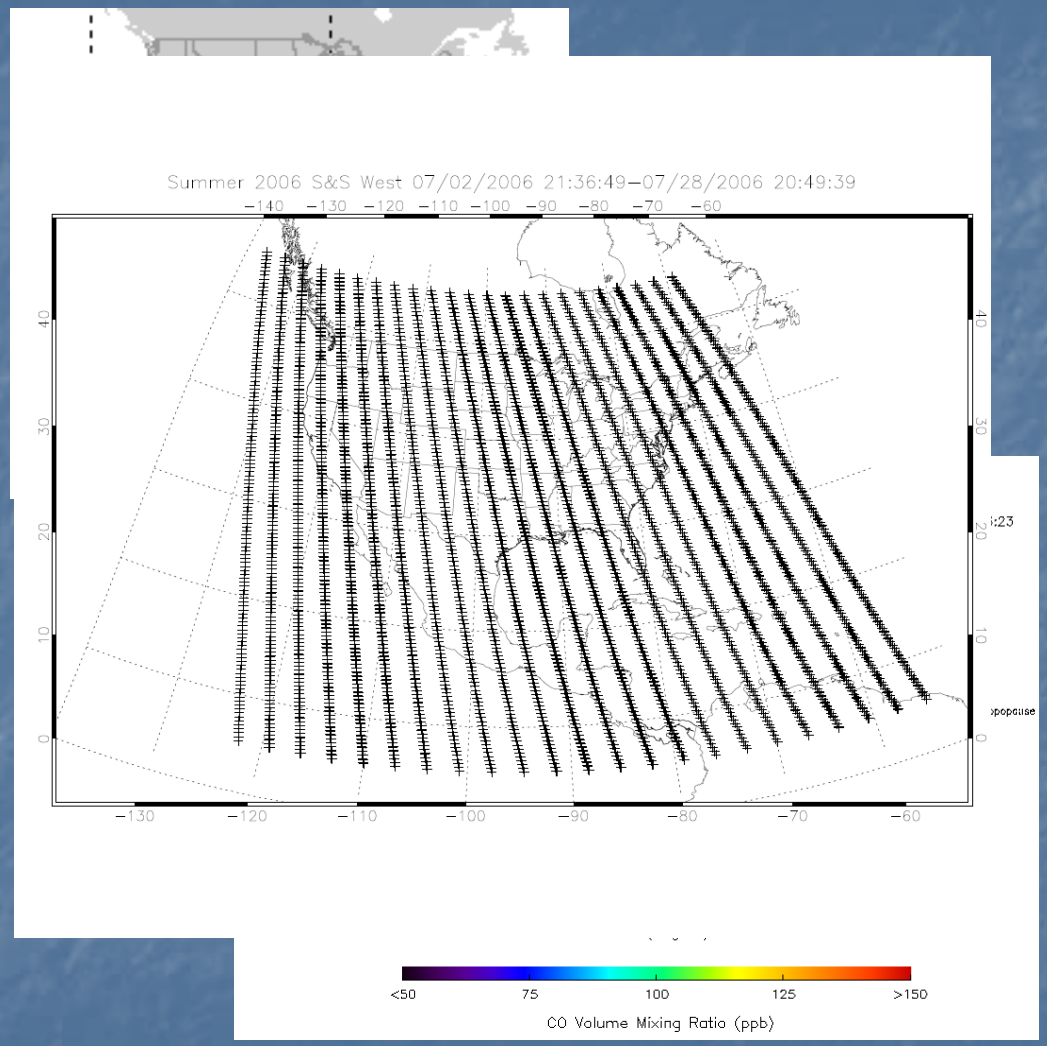
# TES Special Observations

- TES can perform in different observation modes
- Most commonly used mode is called the Step & Stare
- A series of 125 (maximum) nadir scans
- Ground track distance between nadir scans is ~0.4° or ~45 km
- Extensive coverage of the Continental US from July 3 – Oct 10, 2006



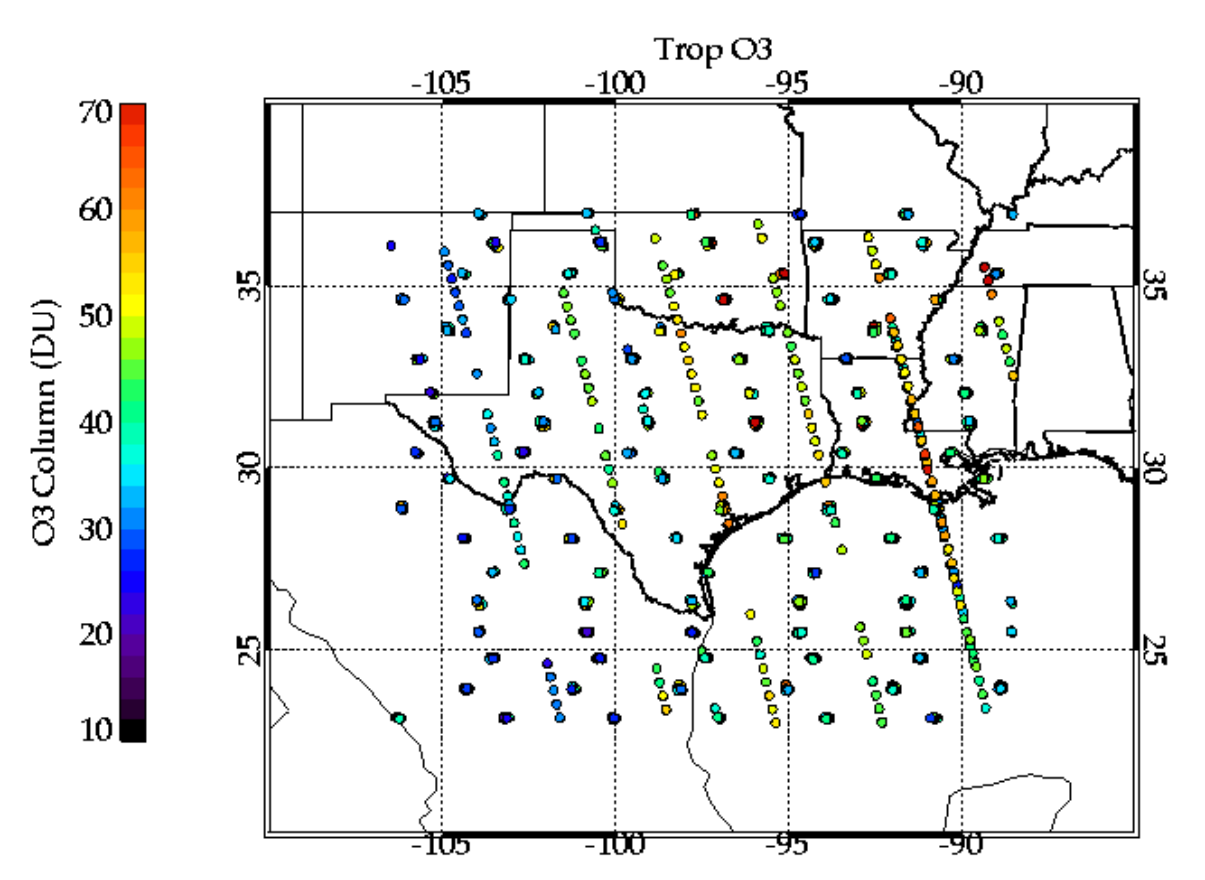
# TES Special Observations

- TES can perform in different observation modes
- Most commonly used mode is called the Step & Stare
- A series of 125 (maximum) nadir scans
- Ground track distance between nadir scans is ~0.4° or ~45 km
- Done on non-GS days
- Extensive coverage of the Continental US from July 3 – Oct 10, 2006



# Coverage over Texas – 2005

- Global Surveys
- 4 Step & Stares: July 31 – Aug 7

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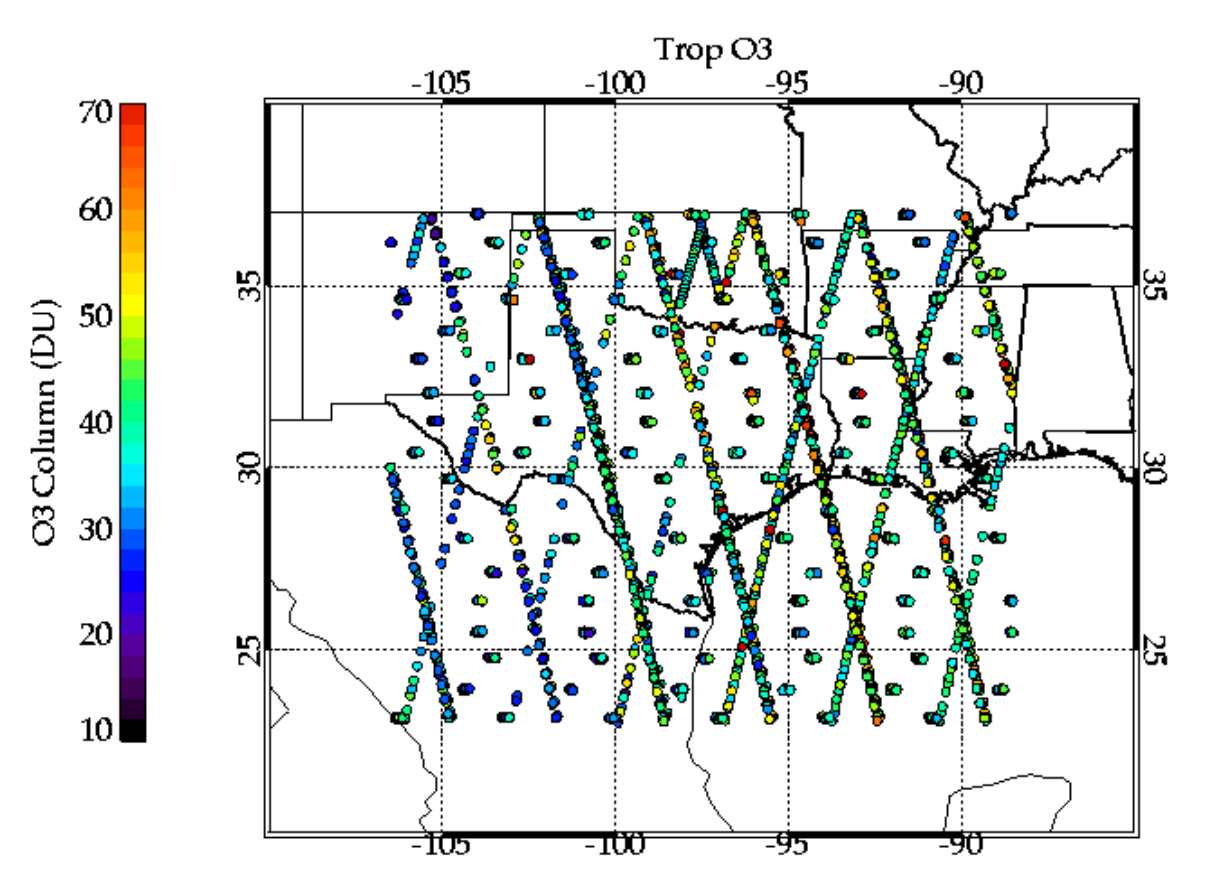
# Coverage over Texas – 2006

- Global Surveys
- Step & Stares:
  - Feb – March
  - July – October

- Sep 1-9: Instrument anomaly – No Data
- Sep 26-29: Instrument de-ice – No Data



# TES L2 Data Products Update – Version 2 (V002)

- TES Version 2 data has processed for all TES runs since launch
- Significant improvements over previous version
  - L1B calibration improvement
  - L2 algorithm improvements
  - More extensive quality control information
- Version 2 includes HDO as a standard product
- Version 2 includes the first limb retrievals
  - Stratosphere only for this version
- Data available at the Langley Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov/) or the Aura Validation Data Center (http://avdc.gsfc.nasa.gov)
- Information on using TES data in the *TES L2 Data User's Guide* available at the Langley ASDC or the TES website

# TES L2 Data Products Update – Version 3 (V003)

- TES Version 3 data has just begun processing
- Improvements over previous version
  - L2 atmospheric temperature profile improvements
  - L2 nadir ozone improved in the upper troposphere
  - Species dependent quality control information
- Version 3 includes improved limb retrievals in the troposphere
- Updated *TES L2 Data User's Guide* for Version 3 data available
- Estimated that processing of all TES data with V003 will be complete by the end of 2007

# TES L2 Product Validation Status
## (as of Feb 2007)

| Species | Validation Status |
|---|---|
| Nadir Ozone | Validated Stage 2 |
| Nadir Carbon Monoxide | Validated Stage 2 |
| Nadir Water (Lower/Middle Troposphere | Validated Stage 2 |
| Nadir Water (Upper Troposphere | Validated Stage 2 |
| Nadir Temperature | Validated Stage 2 |
| Sea Surface Temperature | Validated Stage 2 |
| Land Surface Temperature/Emissivity | Beta (Provisional in 2007) |
| Nadir Methane | Beta (Provisional in 2007) |
| Nadir HDO | Validated Stage 1 |
| Limb Nitric Acid | Beta (Provisional in 2007) |
| Limb Ozone | Beta (Provisional in 2007) |
| Limb Temperature | Beta (Provisional in 2007) |

# Case Study: August 23, 2006

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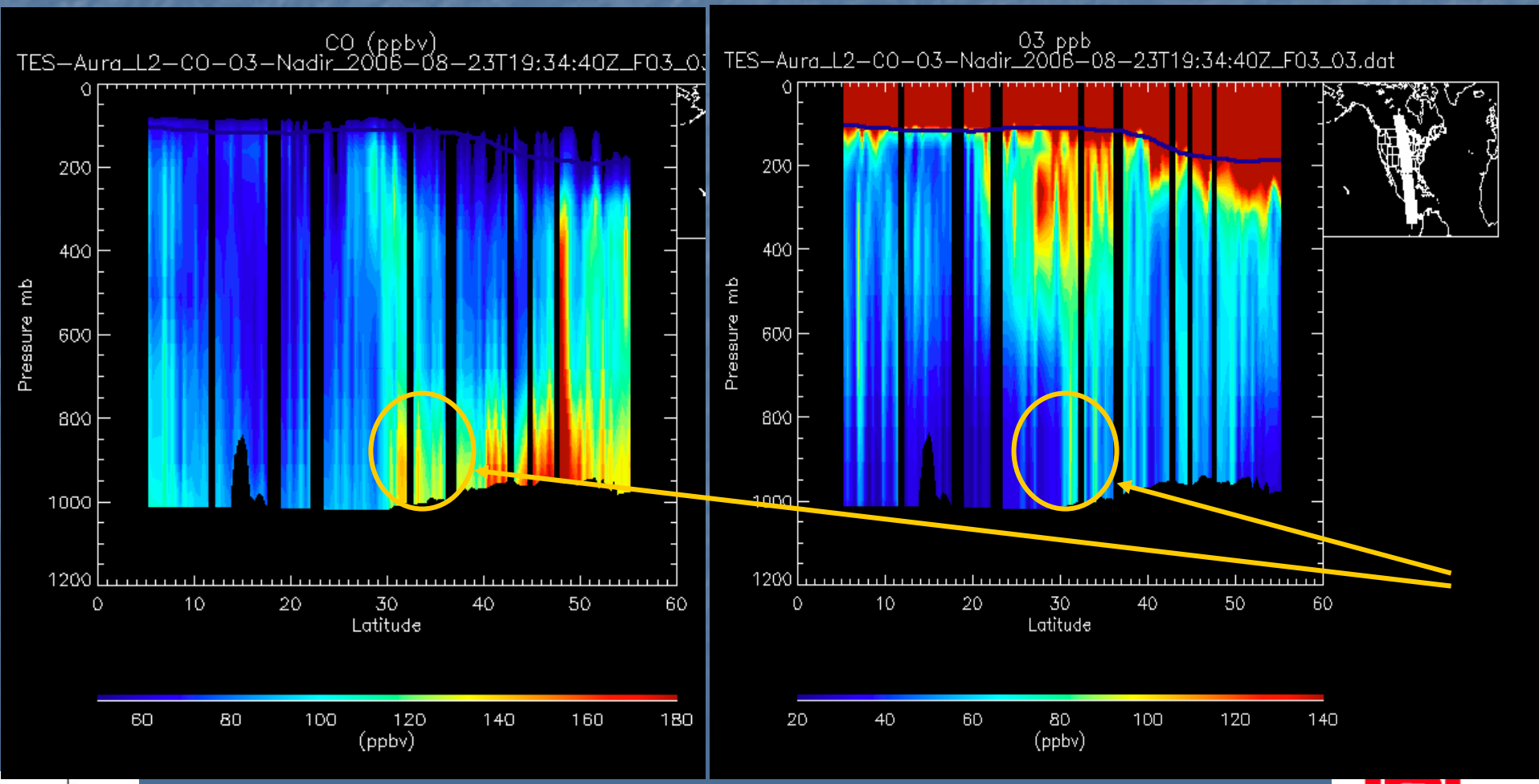
# Synthesis of satellite observations, *in-situ* measurements, and chemistry and transport models

- Observations of ozone and carbon monoxide profiles in the free troposphere from TES can provide critical information for studying boundary layer exchange.
- Ground *in-situ* observations such as AIRNow are the standard for boundary layer measurements of ozone and its precursors
- Chemistry and transport models such as the real-time air quality modeling system (RAQMS) are the critical link between these two observations
- The integration of these assets can provide valuable input into the science objectives for TexAQS.

# Elevated CO and O3 over Houston region observed from TES Step & Stare on August 23, 2006

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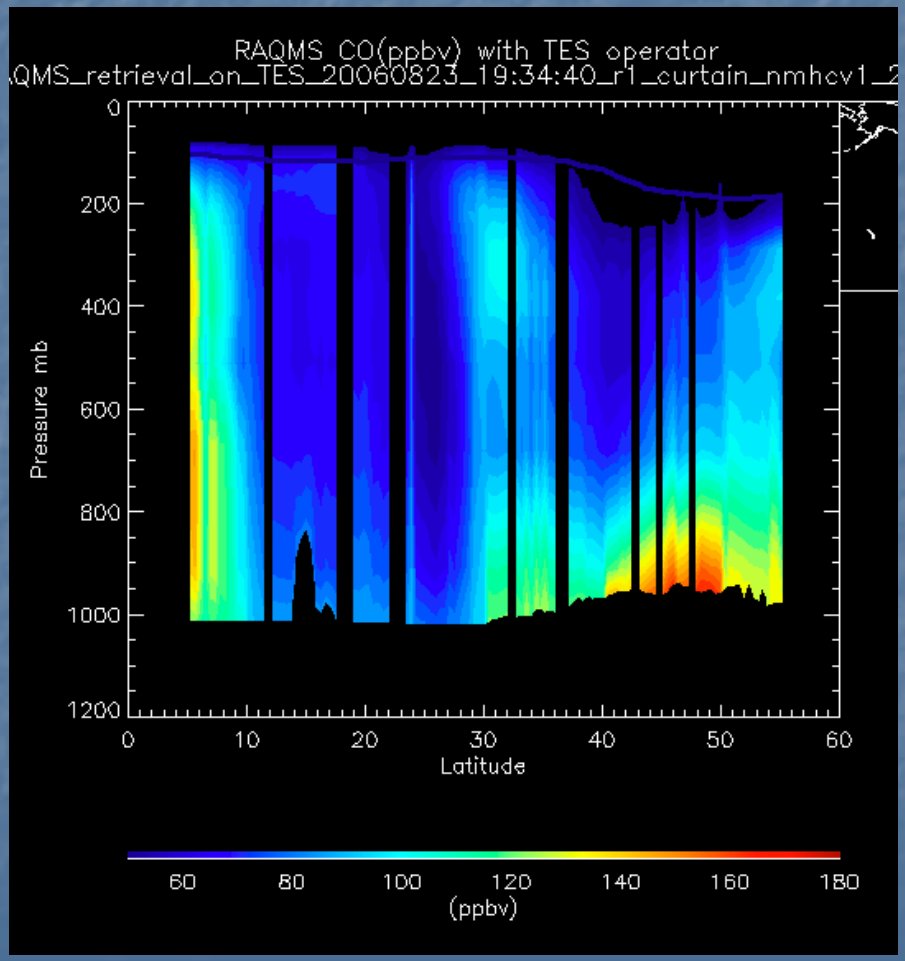
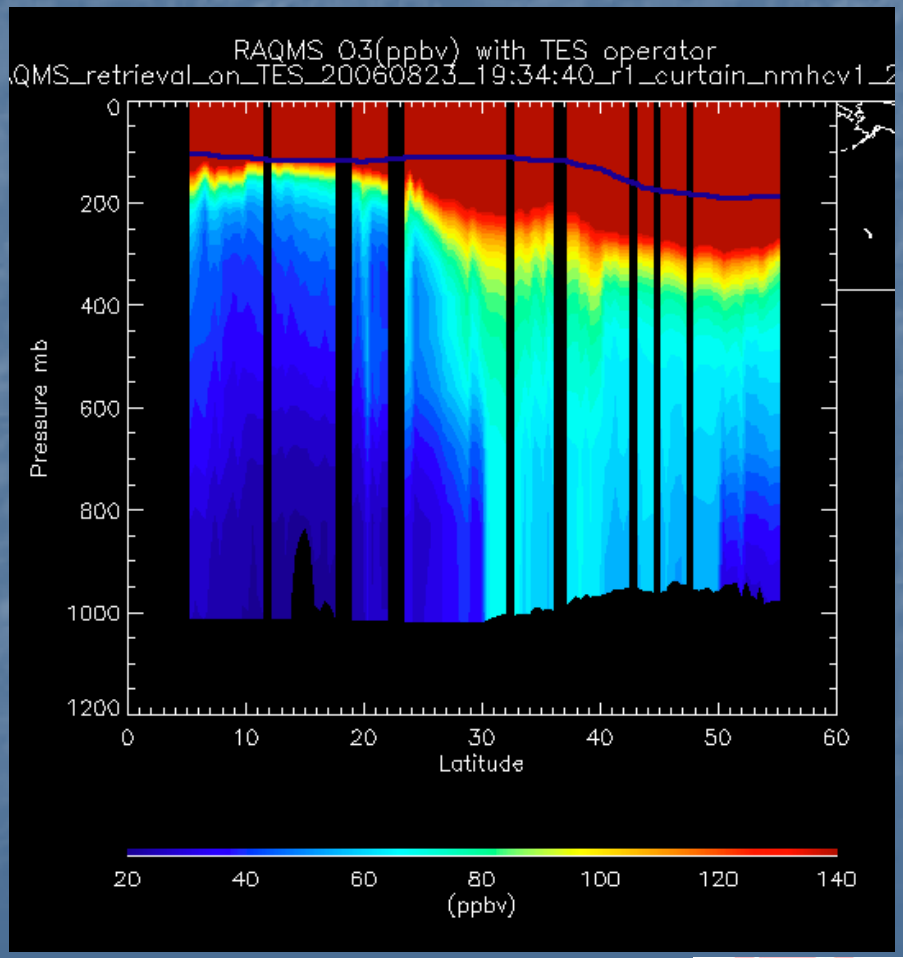
# RAQMS with the TES *Observation Operator*

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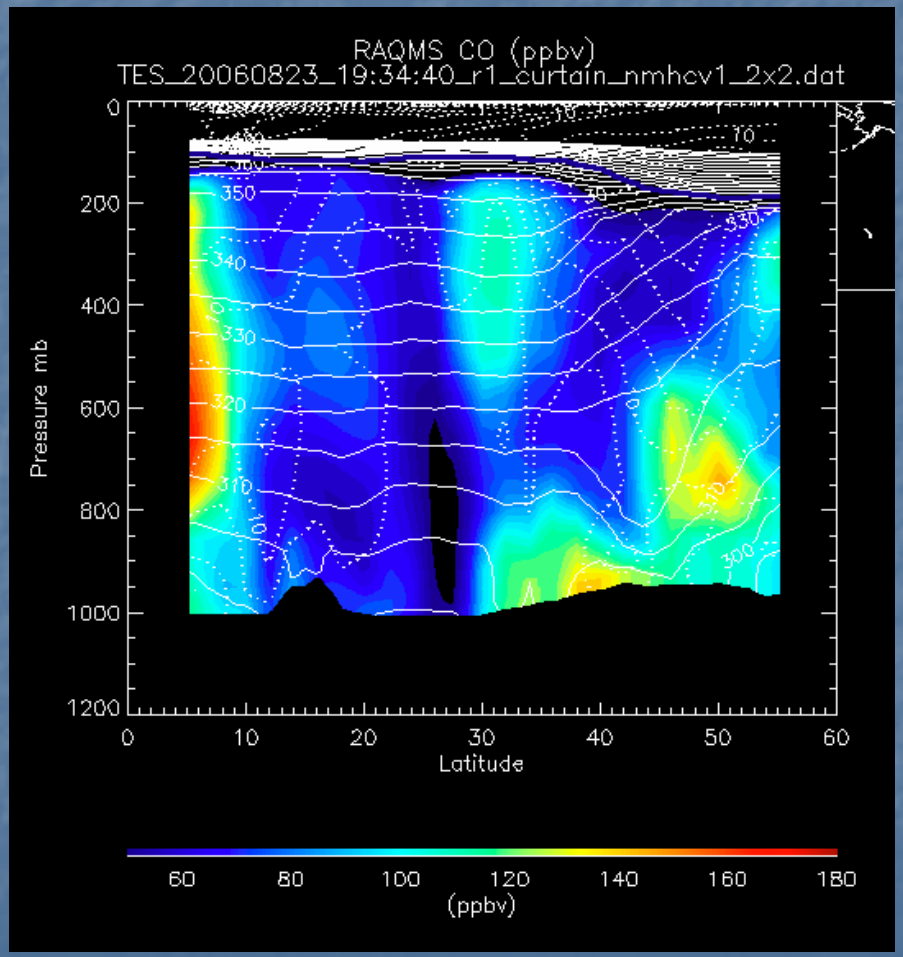
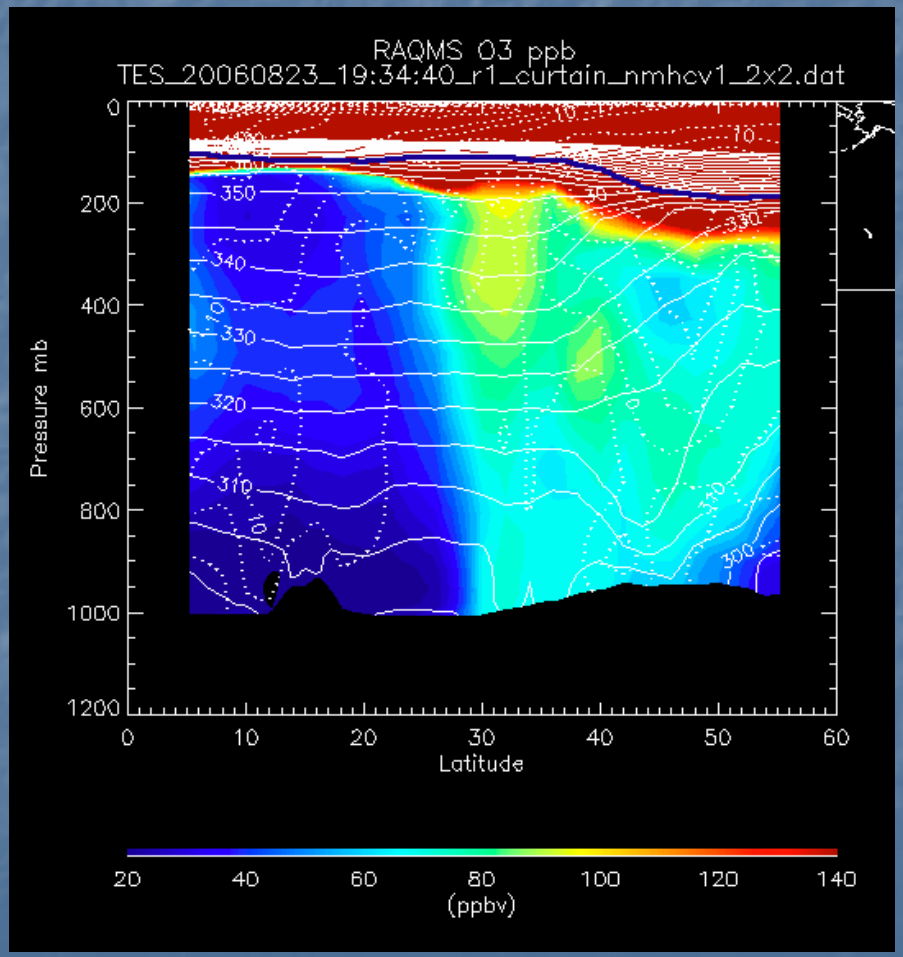
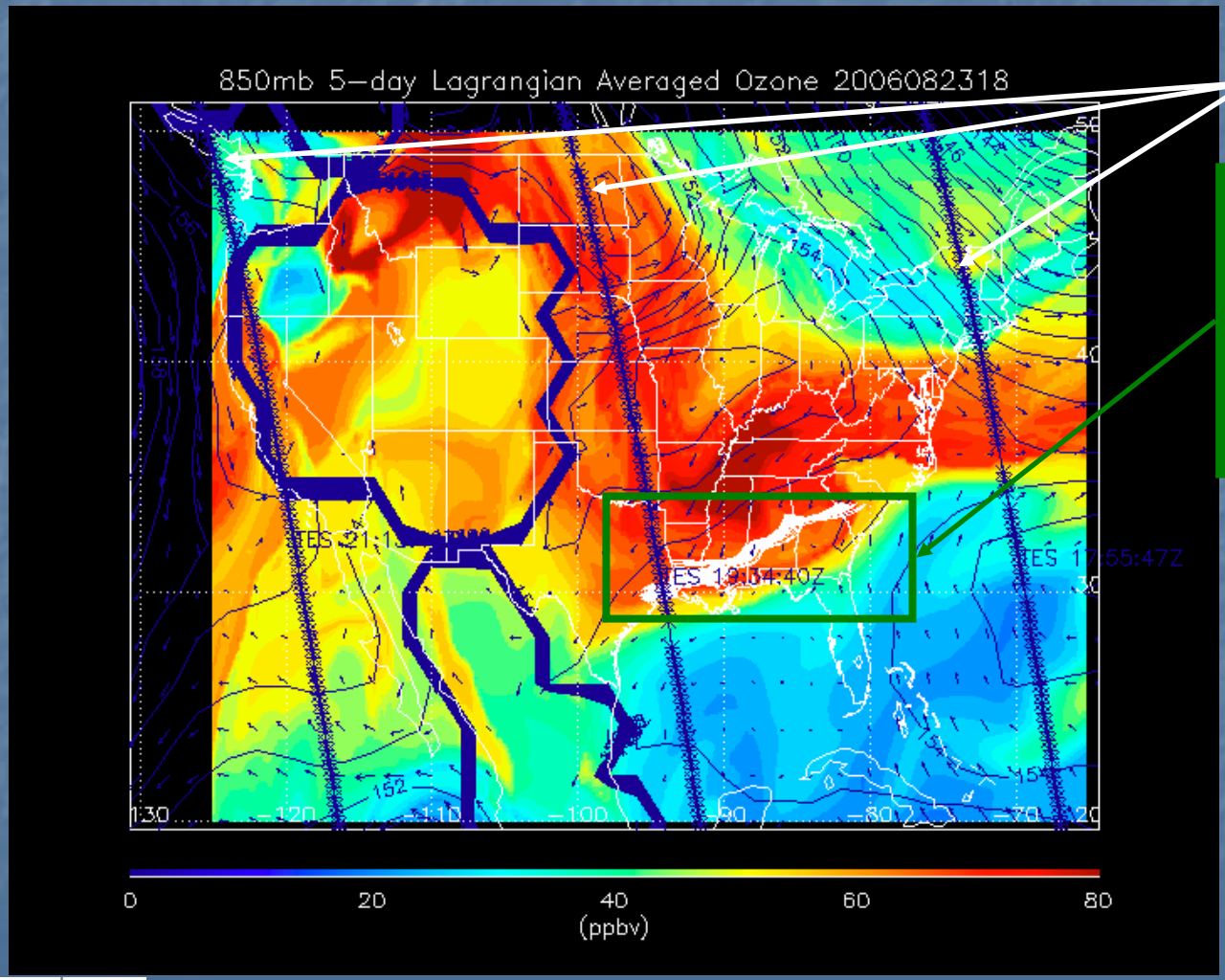
# RAQMS CO and O3 Model Fields



# What is the origin of the ozone and CO enhancement?




White lines represent 5-day back-trajectories emanating from Houston AIRNow Metropolitan statistical area (MSA) sites

Each point represents ozone averaged over a 5-day back-trajectory

Moderate values (60-70ppb) over Houston, but high values over Tennessee, Kentucky, Alabama, and Arkansas (~80 ppb)

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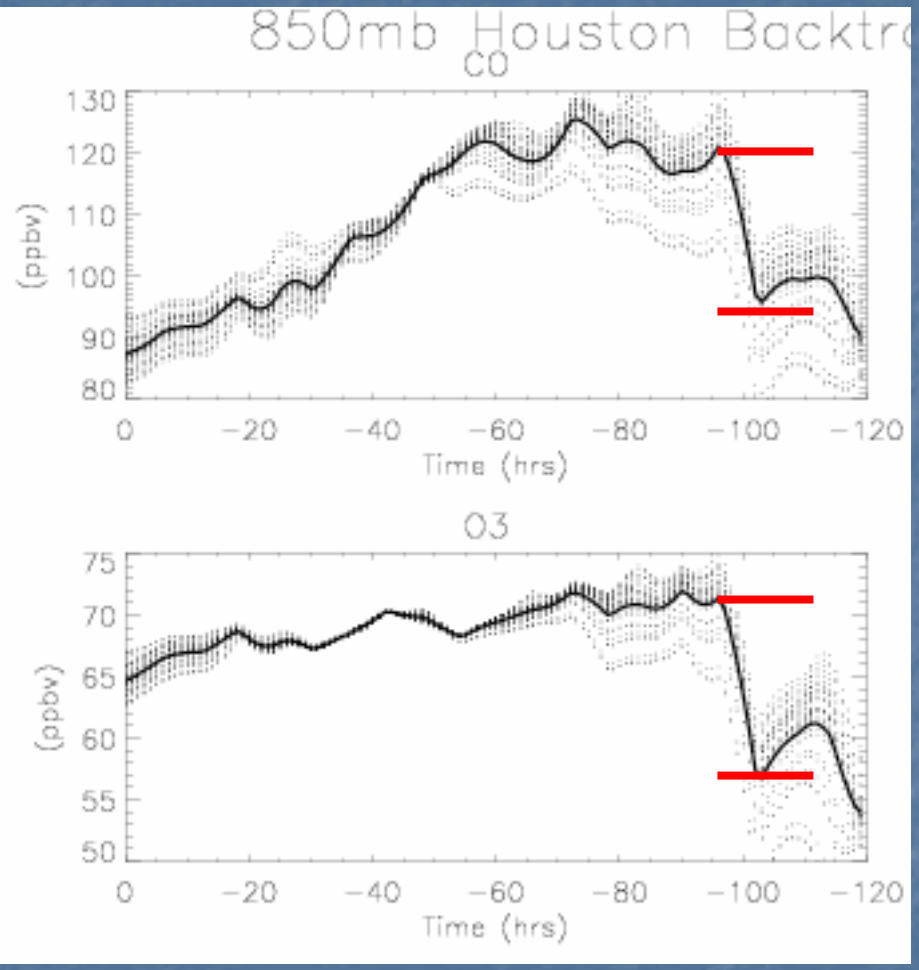
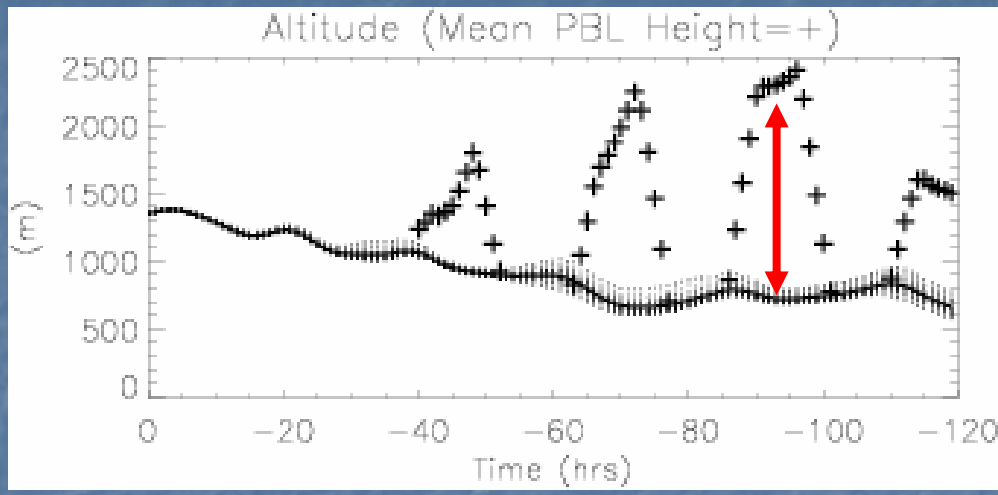
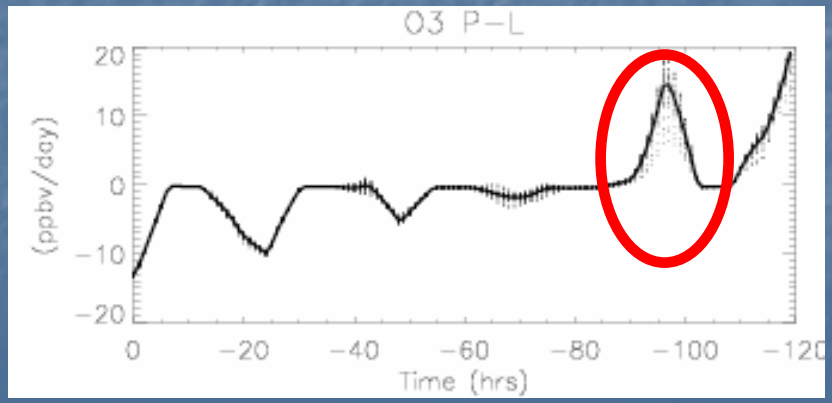
# Process history of O3 and CO




Ozone production in the boundary layer about 4 days prior to arrival in Houston

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# Conclusions from Aug 23 Case

- TES retrievals of CO and ozone vertical profiles in conjunction with the RAQMS global model provide a means of investigating the impact of distant sources on the background concentrations over Texas.
- Enhancement observed from TES east of the Houston area in both CO and ozone, slightly higher than RAQMS fields.
- Model analysis suggests anthropogenic production of ozone from surface emissions at -90 hrs.
- Ozone at 850 mb on Aug 23rd, 2006 is above the boundary layer and therefore will have minimal impact on Houston air quality.
- Validation of TES estimates with respect to IONS ozone sonde measurements will be performed.

# TCEQ High Priority SIP-Relevant Science Questions

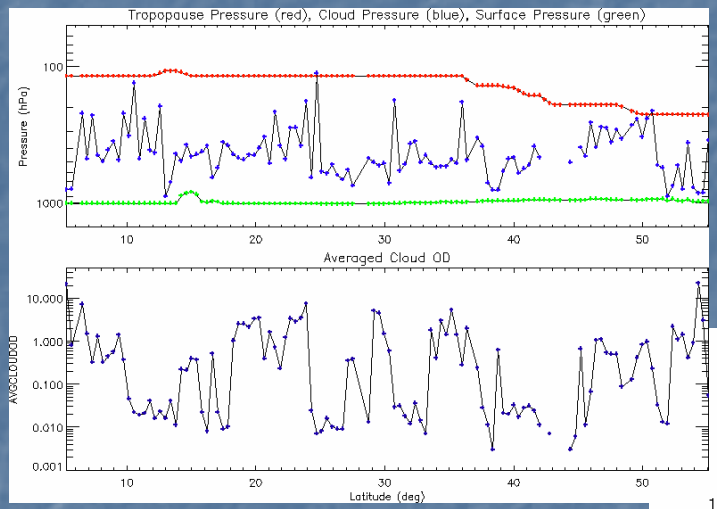
- G: How do emissions from local and distant sources interact to determine the air quality in Texas? What meteorological and chemical conditions exist when elevated background ozone and aerosol from distant regions affect Texas? How high are background concentrations of ozone and aerosol, and how do they vary spatially and temporally?
- H: Which areas within Texas adversely affect the air quality of non-attainment areas within Texas? Which areas outside of Texas adversely affect the air quality of non-attainment areas within Texas?

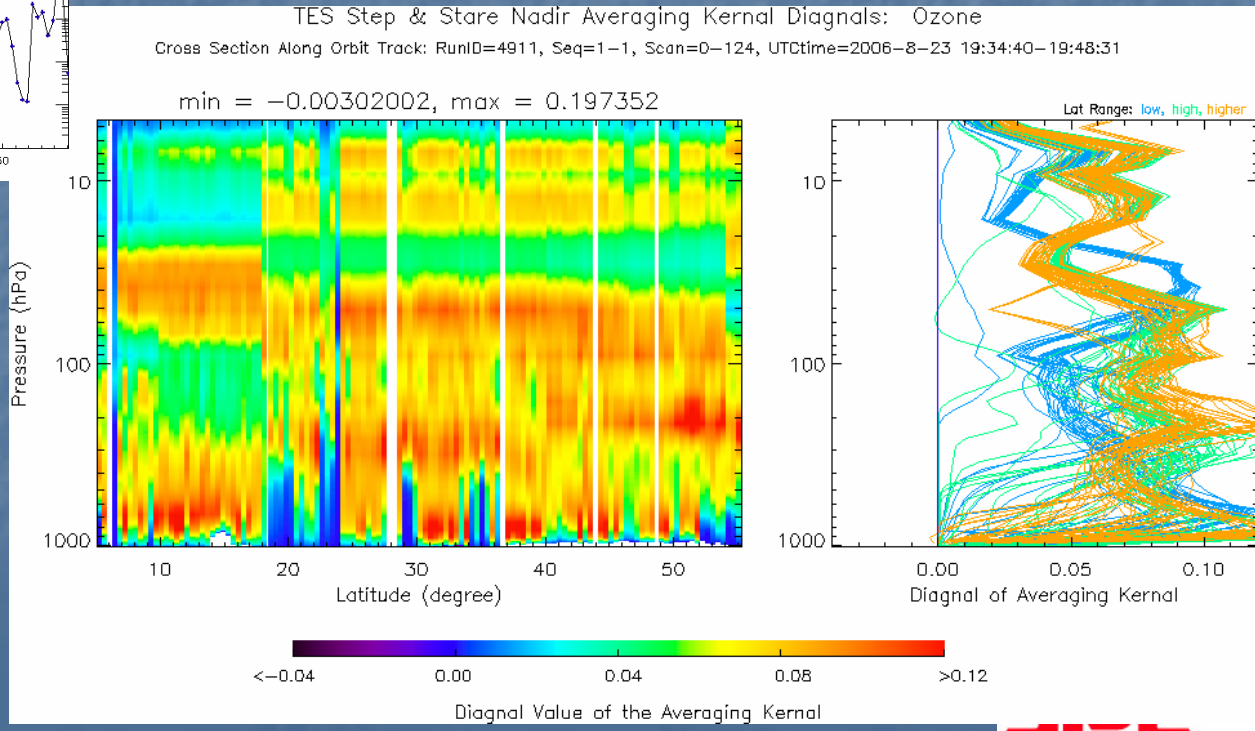
# Conclusions – Future Work

- TES retrievals can provide information on the vertical structure of O3 and CO in the troposphere
- TES data combined with trajectory models can provide information on the transport of ozone and carbon monoxide events
- Look at global survey measurements in East/Central Texas over TES data record to provide estimates of the lower tropospheric background conditions for O3 and CO
  - Surface data, Ozonesonde data, Tower data
- Examine the TES night time measurements (transport and background)

# Extra

# TES Sensitivity Metric: The Averaging Kernel

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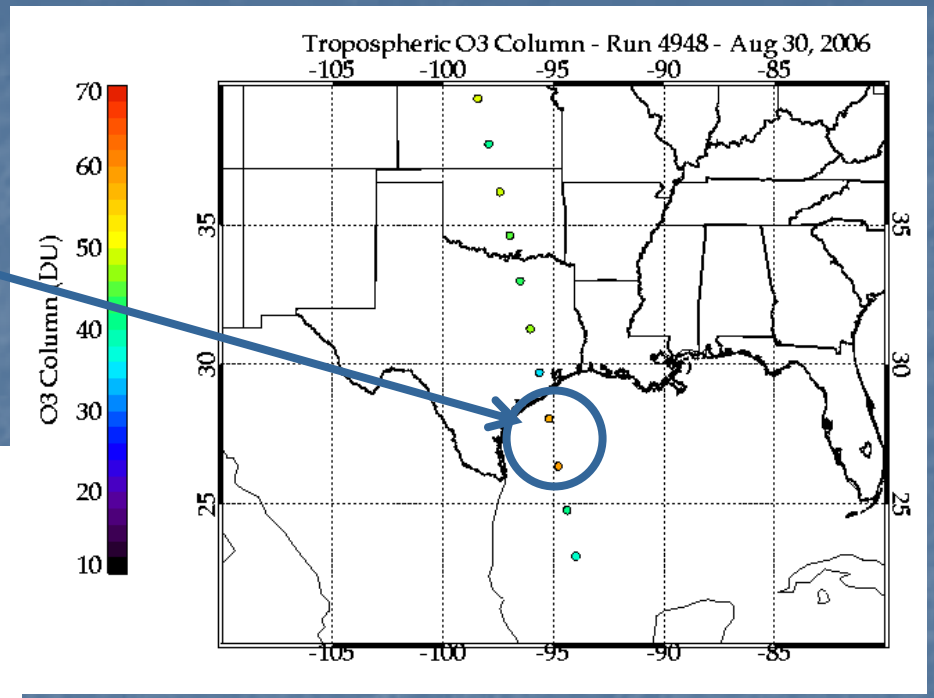
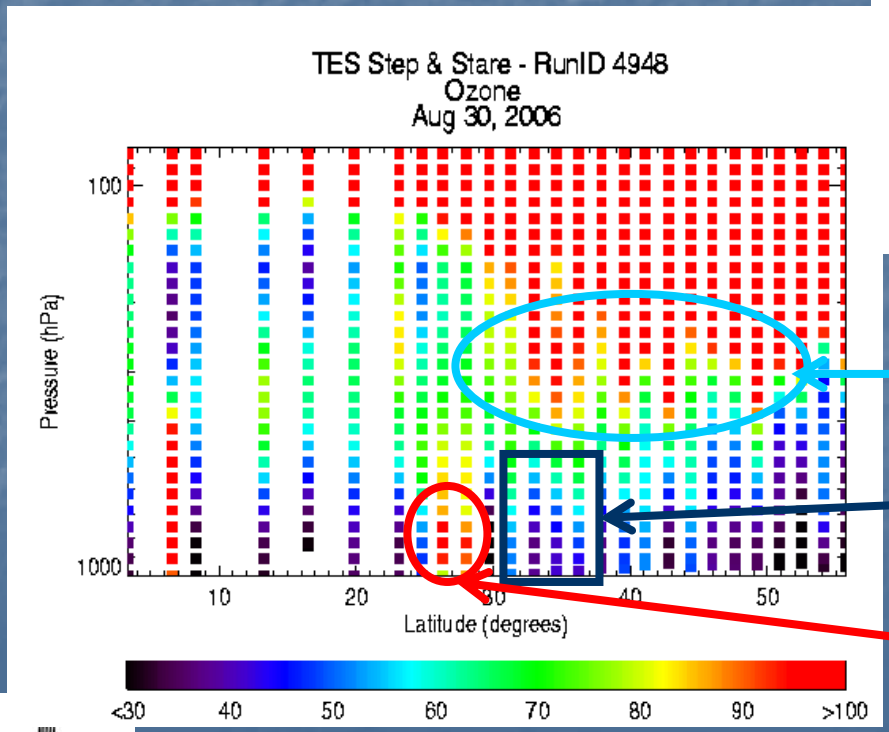
# TES Observations – Aug 30, 2006

- TES Global Survey
- High ozone in the troposphere over the Gulf of Mexico seen in Trop Column
- Lower values over East TX




- Enhancement in ozone in middle troposphere over TX, OK, KA
- Low ozone in lower troposphere over East Texas, Central Oklahoma
- High ozone in lower troposphere over the Gulf (still under investigation)

# TES L2 Product Validation Update

- Primary TES Level 2 nadir data products are validated and usable in scientific analyses
  - Version 2 is being used for validation papers that are in preparation
- Analyses using INTEX-B aircraft and IONS-06 data played a key role in
  - Validation of TES data products
  - Evaluation of data product updates
- Limb products HNO3 and O3 have undergone preliminary validation analysis
- *TES L2 Validation Report* (V002 Data) available at the Langley ASDC

# Validation Status Definitions

| Term | Definition |
|---|---|
| Beta | Early release products for users to gain familiarity with data formats and parameters. |
| Provisional | Limited comparisons with independent sources have been made and obvious artifacts fixed. |
| Validated Stage 1 | Uncertainties are estimated from independent measurements at selected locations and times. |
| Validated Stage 2 | Uncertainties are estimated from more widely distributed independent measurements. |
| Validated Stage 3 | Uncertainties are estimated from independent measurements representing global conditions. |