New Results and Insight Into Tropospheric Composition - (TES) Tropospheric Emission Spectrometer

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Tropospheric ozone and other gases

- The challenge and why
- The how to do 'it'
- Did 'it' work
- What we are trying to do with 'it'
- What else is happening
- What next

ENVIRONMENTAL IMPACTS OF ATMOSPHERIC OZONE

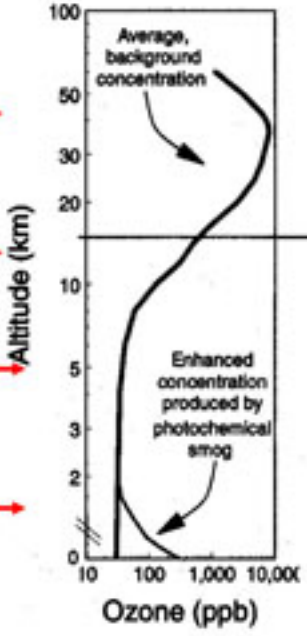
Ozone is..

UV shield

Greenhouse gas

Primary source of OH radicals

Smog



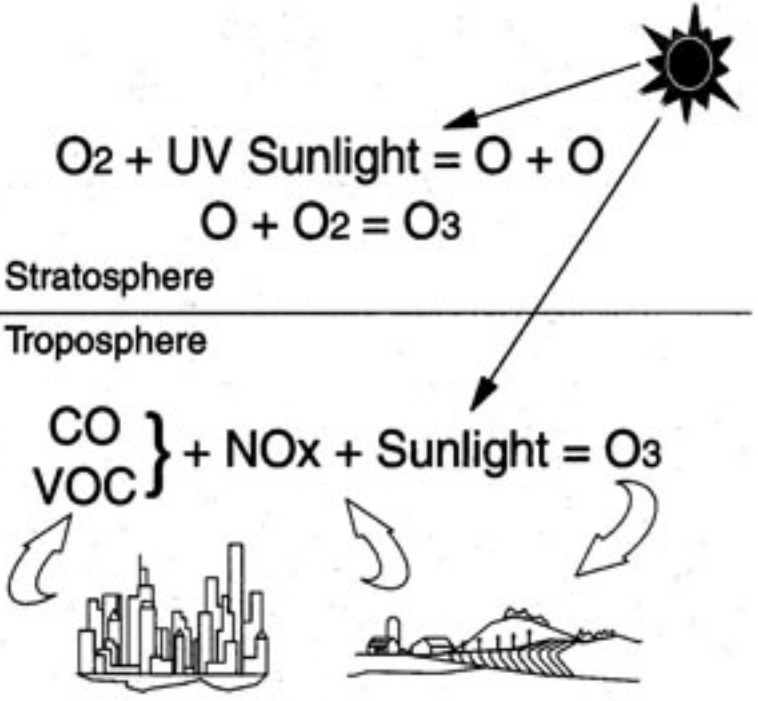
O_2 + UV Sunlight = O + O

O + O_2 = O_3

Stratosphere

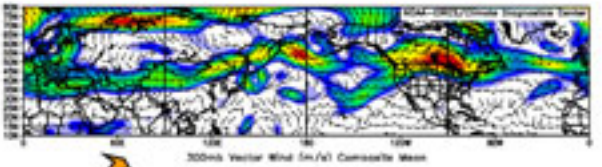
Troposphere

CO, VOC } + NOx + Sunlight = O_3



Jacob (Harvard)

Tropospheric ozone and its precursors are a key measure of air quality and the characterization of the chemical and dynamic processes governing their magnitude and distribution is one of the central extant scientific challenges

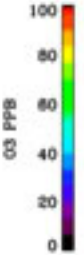


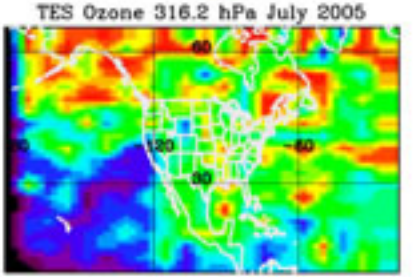
Advection

Anthropogenic sources

Natural sources

Solar radiation



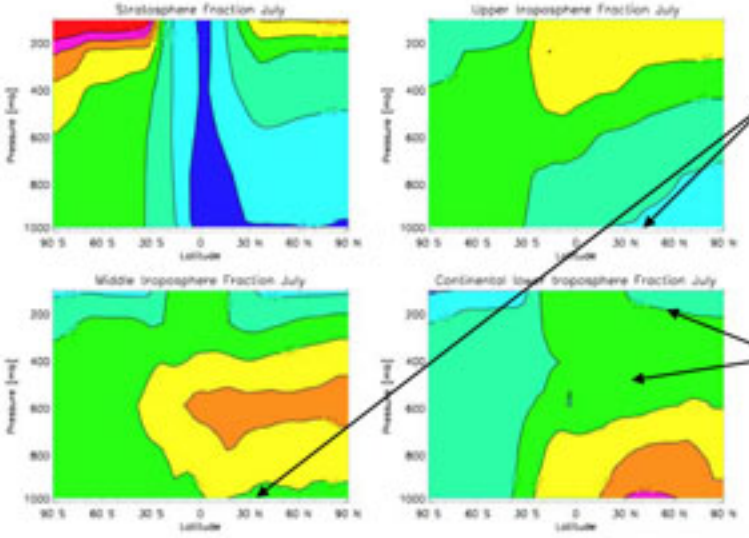


Subsidence

Convection

Spectrometer

Characterization of the vertical distribution of ozone is critical to understanding its role in air quality and climate

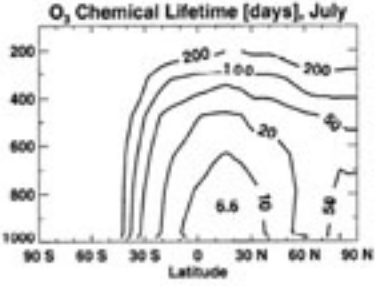


10% and 20% of lower tropospheric ozone originates from the upper and middle troposphere in the northern mid-latitudes

20-30% of the lower tropospheric ozone reaches the upper and middle troposphere in the northern mid-latitudes

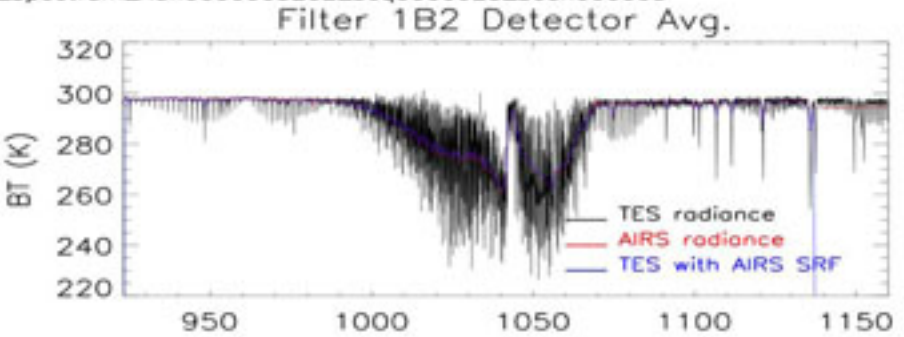
Y. Wang et al, JGR 1998

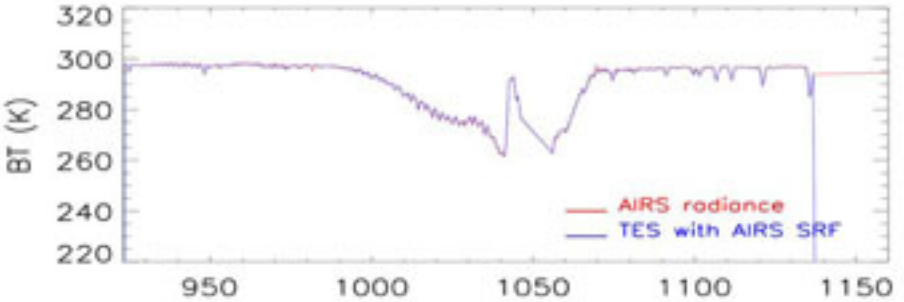
Fractional contribution of source regions to zonal mean ozone distribution for a GEOS-Chem simulation for a climatological period



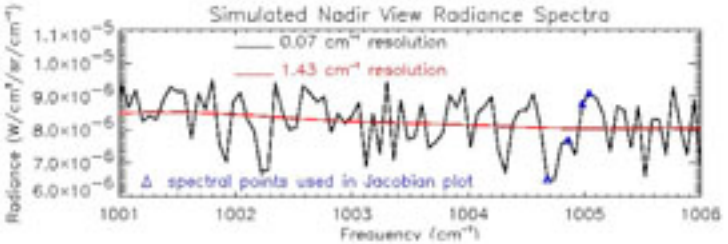
The lifetime of ozone is strongly dependent on its altitude

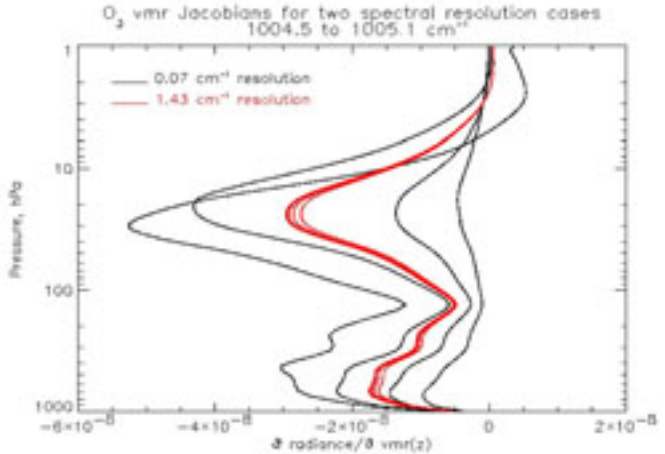
Tgt_Spectrum_Run0000003202_Seq0000023_Scan000003

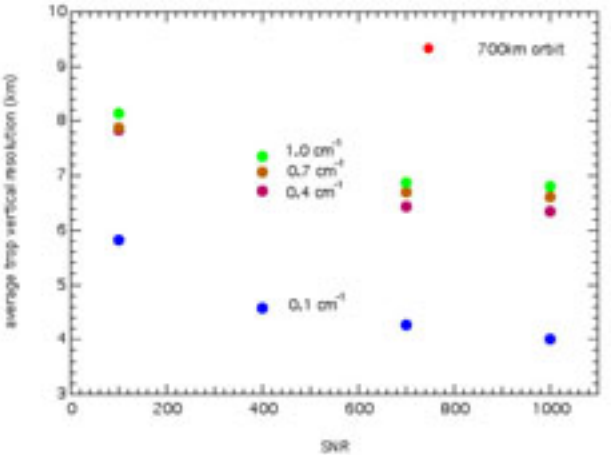




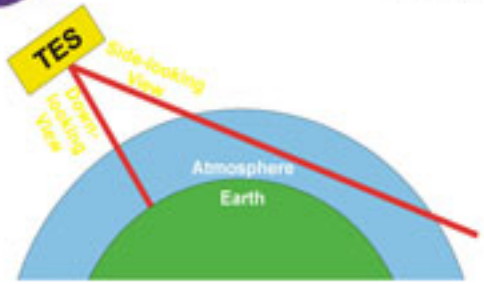
It's the spectral resolution!

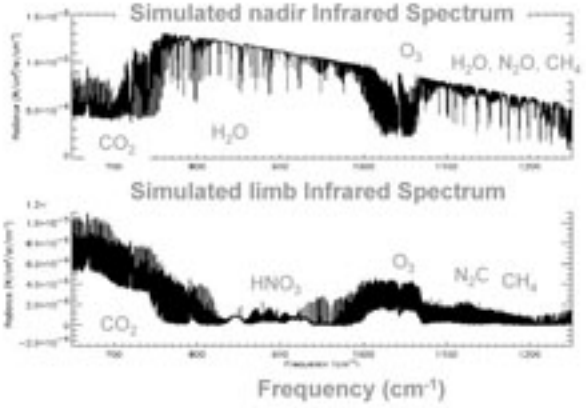






Driving requirements



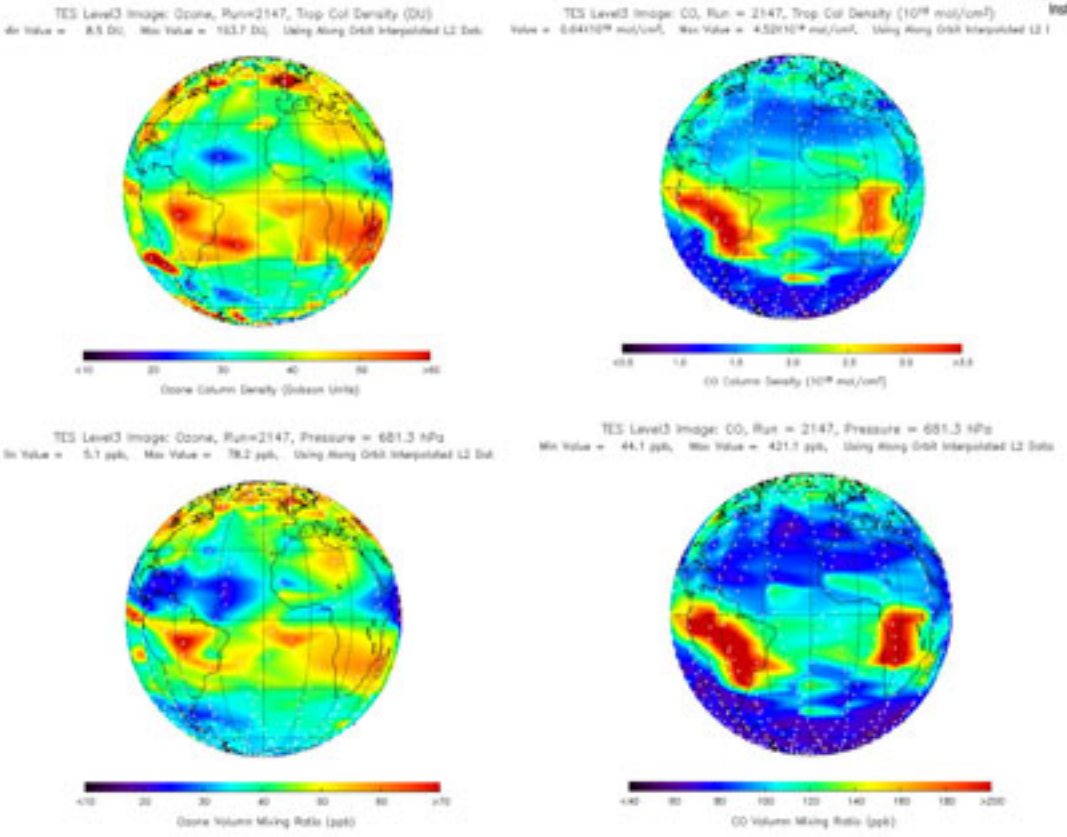


Spectrometer Type	ConnesŠtype 4-port FTS
Max. Optical Path Difference	± 8.45 cm (nadir & calibration) ± 33.8 cm (limb)
Scan (integration) Time	4 sec (nadir & calibration) 16 sec (limb)
Sampling Metrology	Nd:YAG laser
Spectral Resolution (unap)	0.07 cm^{-1} (nadir) 0.018 cm^{-1} (limb)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 mm) in 200 Š 300 cm^{-1} bands
Detector Arrays	4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K
Signal-to-Noise Ratio (spectral)	Up to 200:1 Minimum requirement is 30:1
Radiometric Calibration	Internal, adjustable, cavity blackbody (340K) + cold space view
Spatial Calibration	Illuminated slit scanned across FOV
Radiometric Accuracy	< 1K 650 Š 2500 cm^{-1} < 2K 2500 Š 3050 cm^{-1}

- Fourier transform spectrometer
- Wavelength response: 5 to 15.4 micron
- One scan every 4 or 16 secs
- Four optically-conjugated 1x16 pixel detector arrays
- Spatial resolution of 5 x 8 km at nadir & 2.3 km at limb
- Passively cooled
- 2-axis gimbaled pointing mirror

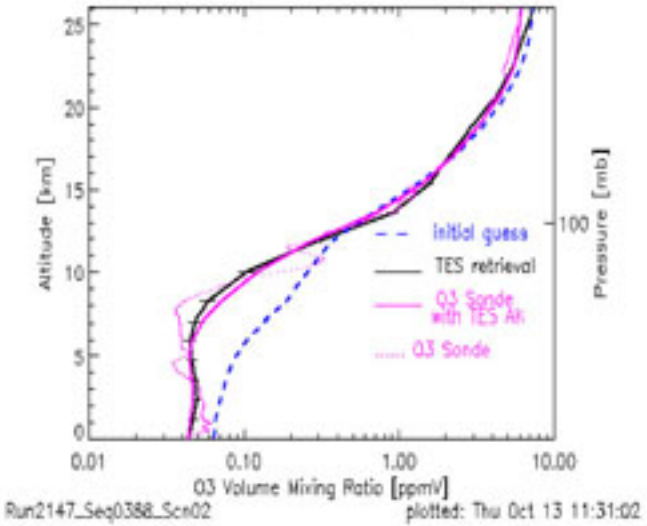
July 15, 2004

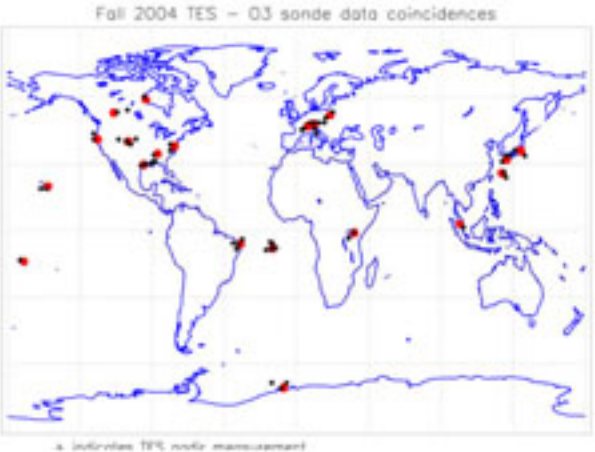
First look……..


TES Level3 Image: Ozone, Run=2147, Trop Col Density (DU)
Ozone Column Density (Dobson Units)
TES Level3 Image: CO, Run = 2147, Trop Col Density
CO Column Density
TES Level3 Image: Ozone, Run=2147, Pressure = 681.3 hPa
Ozone Volume Mixing Ratio (ppb)
TES Level3 Image: CO, Run = 2147, Pressure = 681.3 hPa
CO Volume Mixing Ratio (ppb)

Ozonesondes

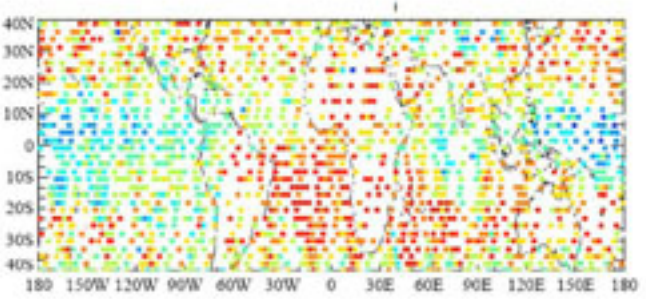
Payerne (47 ° N, 7° E)



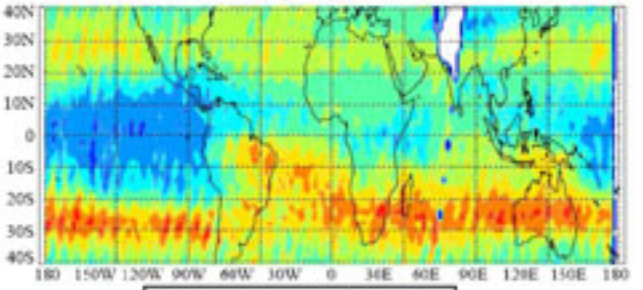


H. Worden and Logan

Tropical Tropospheric Ozone Column : Comparison between TES, GEOS-CHEM and GOME

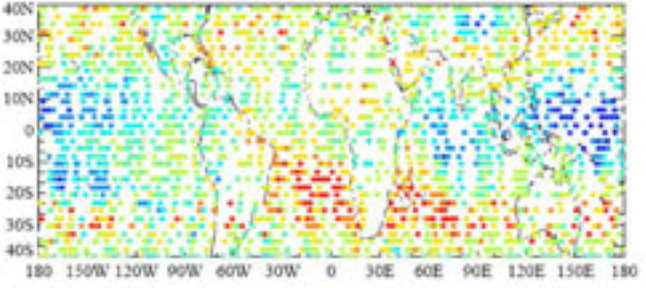


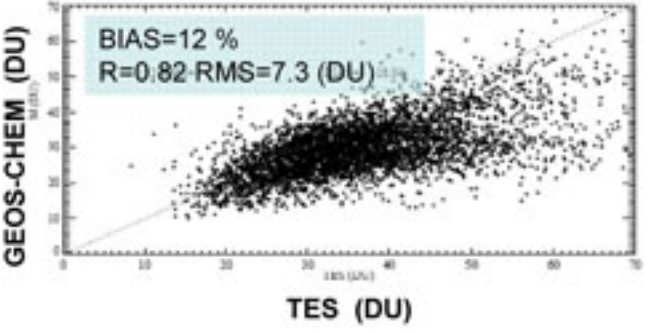
TTOC GOME (DU) Nov. 1997



GOME data from Liu et al. 2005

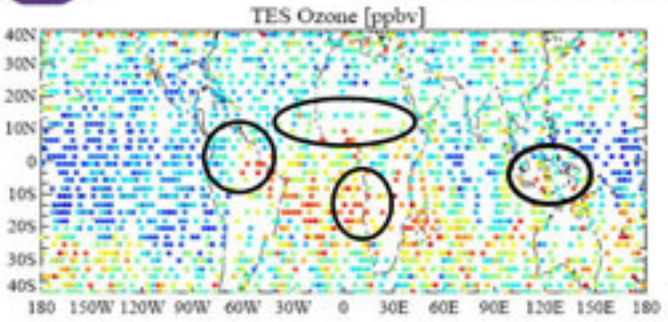
GEOS-CHEM TOC DU

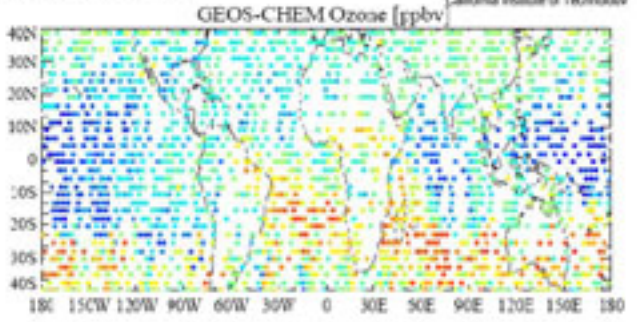


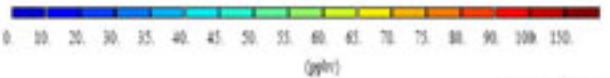


Jourdain and Li

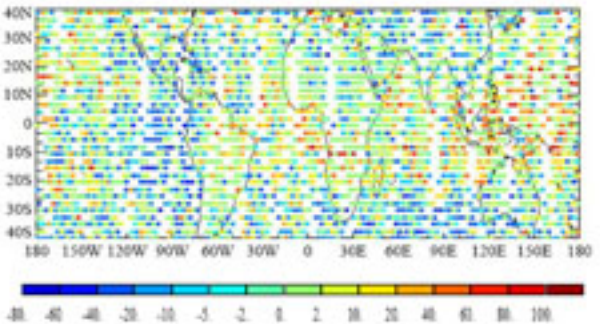
Comparison TES and GEOS-CHEM
1-15 November 2004, 350hPa



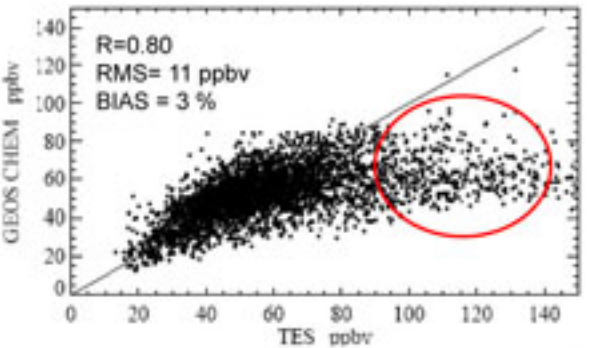




(TES-GEOS_CHEM)/GEOS-CHEM%



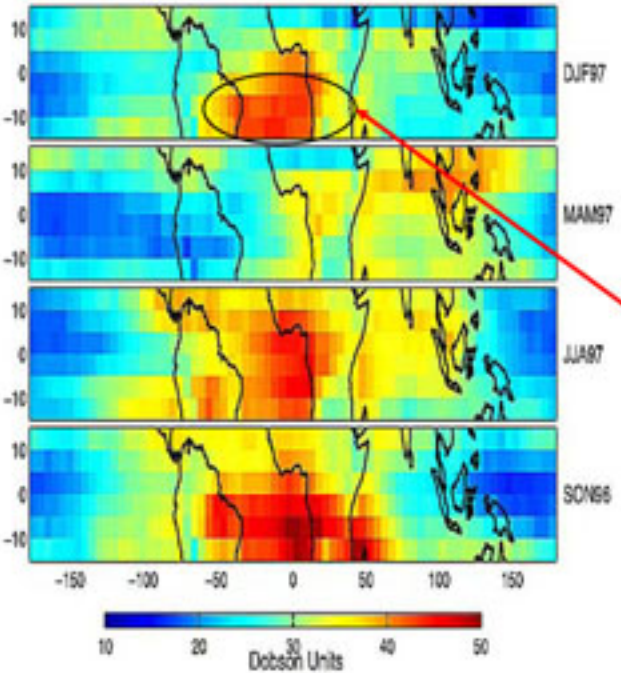
Tropics (30N-30S)



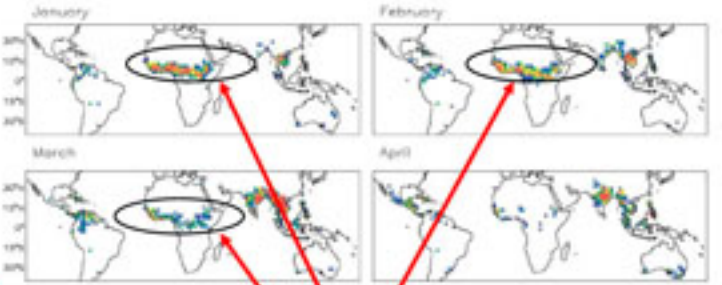
Jourdain and Li

Tropical Atlantic 'Ozone Paradox'

TOMS Tropospheric Ozone Columns
(Martin et al., 2002)

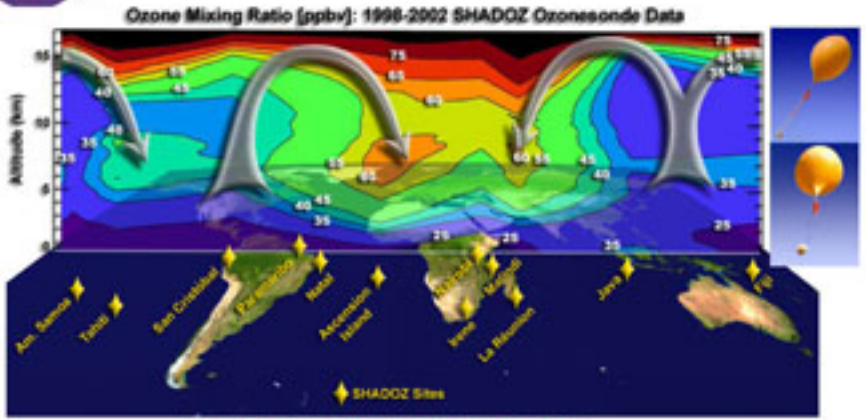


Biomass burning emissions
(Duncan et al., 2003)



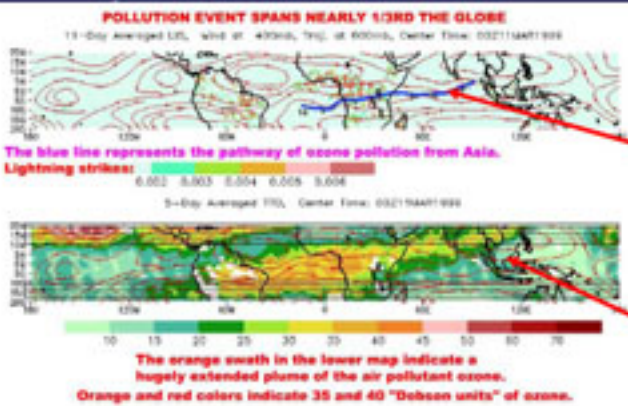
Highest TOCs observed by TOMS over the Southern tropical Atlantic in DJF while the biomass burning occur north of the ITCZ [Thompson et al., GRL, 2000]

Tropical Atlantic 'Ozone Paradox'



February - March

Adding another factor to the South Atlantic 'Ozone Paradox'



Pathway of Asian ozone pollution

Tropical Tropospheric Ozone (TTO)

Chatfield et al., GRL 2003

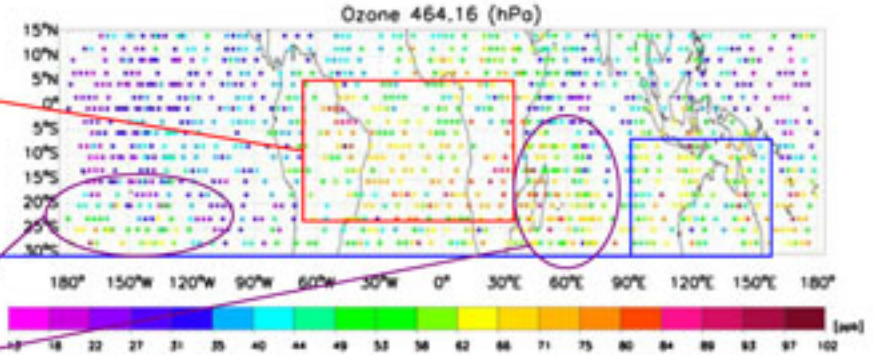
TES O3 and CO maps for November 4-16

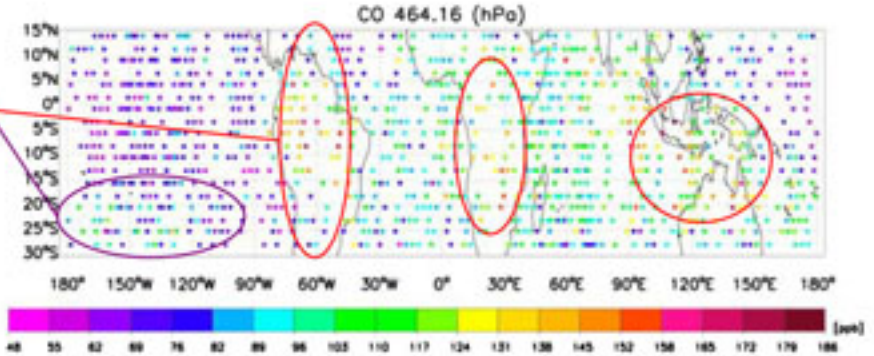
Elevated ozone over Atlantic

Elevated ozone over Indonesia/Australia

Transport from Africa and/or Australia?

Elevated CO over continents

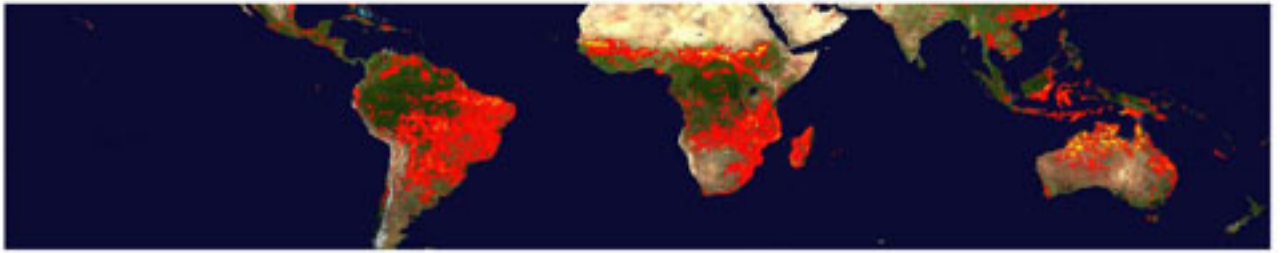




Bowman

Signatures of biomass burning

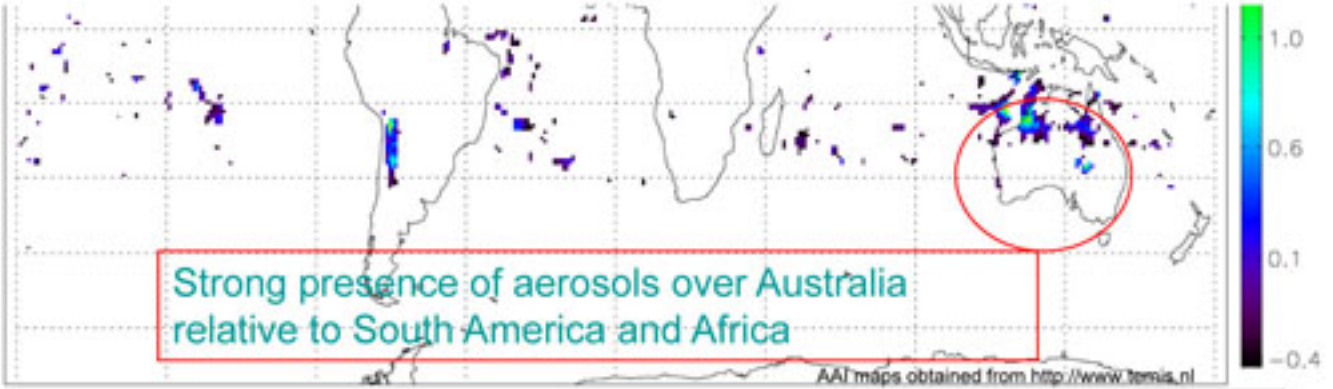
MODIS fire counts November 5-15



Red indicates at least one fire count
Yellow indicates a large number of fire counts

MODIS map obtained from
http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2005211-2005220

Sciamachy absorbing aerosol index (AAI) November 2004



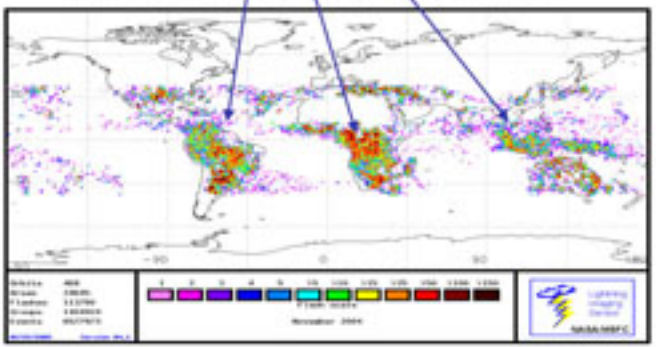
Bowman

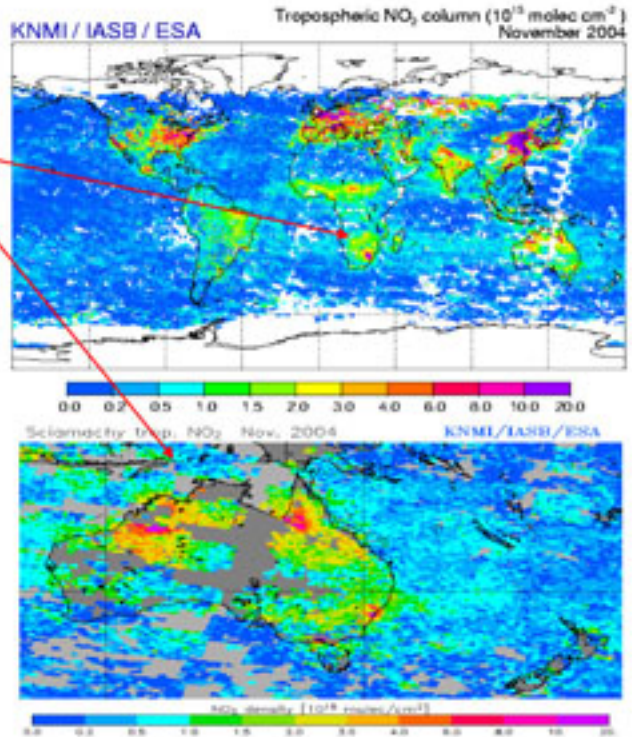
NO_x signatures and distributions

Sciamachy data indicates particularly high NO_2 columns in Australia and South Africa

Lightning flash counts are high over South America, Africa, and Indonesia/Australia

http://thunder.msfc.nasa.gov/data/query/distributions.html



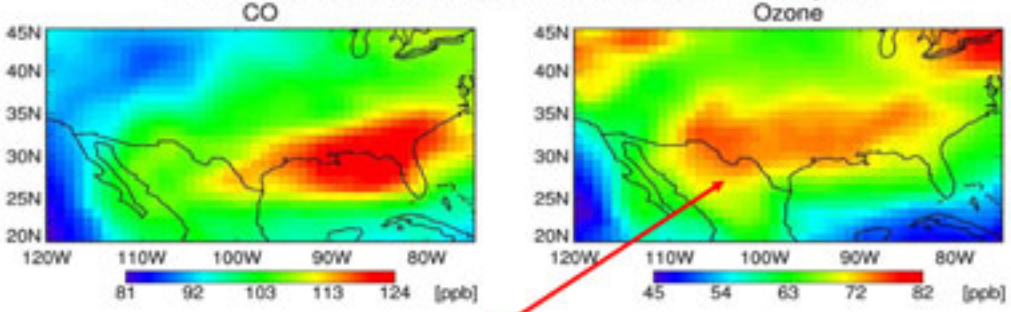


Sciamachy data available at http://www.temis.nl/airpollution/no2.html

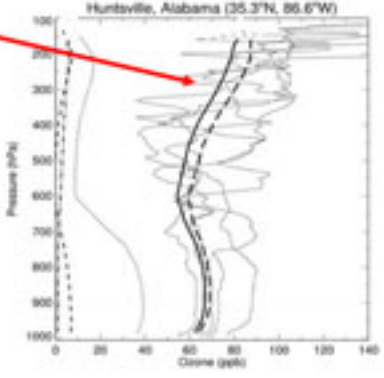
Bowman

Summertime Ozone Maximum over the Southern U.S.

GEOS-CHEM CO and ozone concentrations, 300 hPa, July 2000



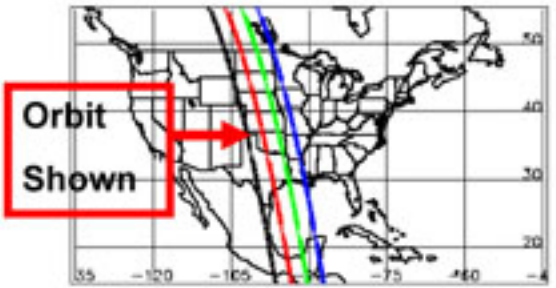
A large maximum in ozone (>80 ppb) in the upper troposphere across the southern U.S. The upper tropospheric anticyclone centered over the southern U.S. can circulate convective outflow over the U.S. for several days before eventual export to the Atlantic. Rapid ozone production (up to 10 ppb/day) takes place in the circulating outflow.

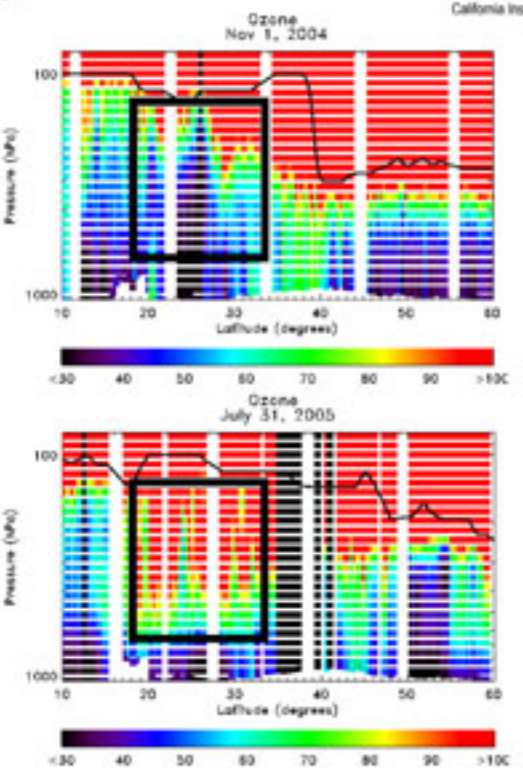


Li et al. [JGR, 2005]

Evolution of ozone through SE North America

Enhanced ozone in the troposphere over Eastern Mexico, South Texas and the Gulf of Mexico (~20-30° N) in Summer of 2005. The differences are seen in both the upper and lower troposphere.





Off-shore ozone plume in California coastal regions

Wind fields implicate central valley pollution as a primary contributor to coastal plume

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

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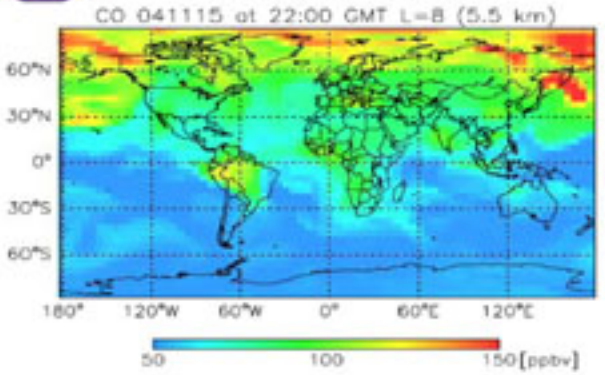
Ozone precursor NO2 observed by Sciamachy to be high throughout urban areas and central valley

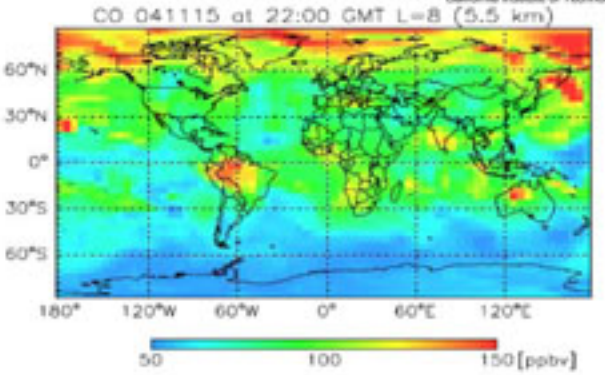
J. Worden et al.

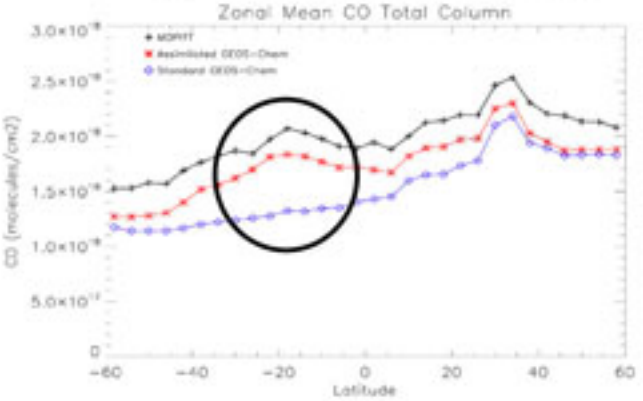
Assimilation of TES CO into the GEOS-CHEM CTM

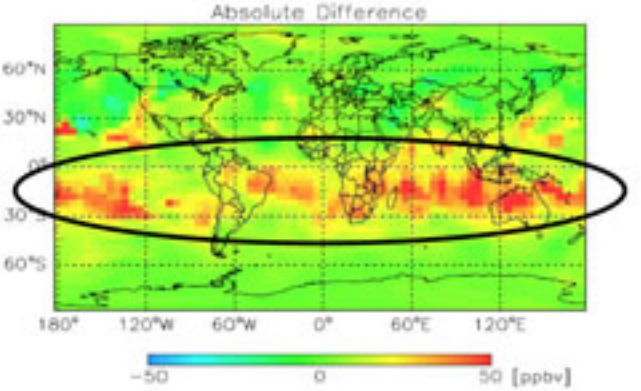
Without Assimilation



With Assimilation

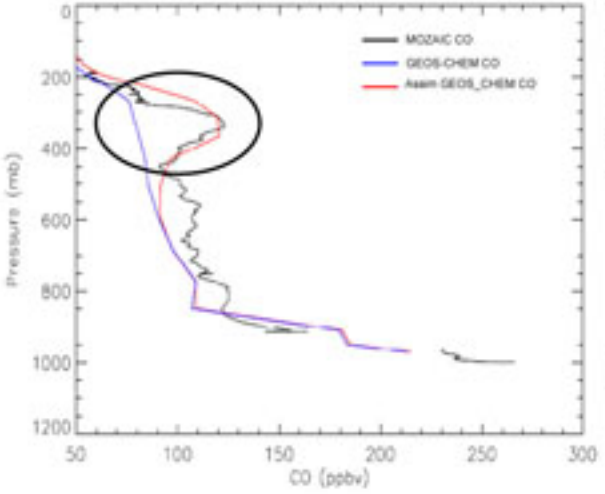


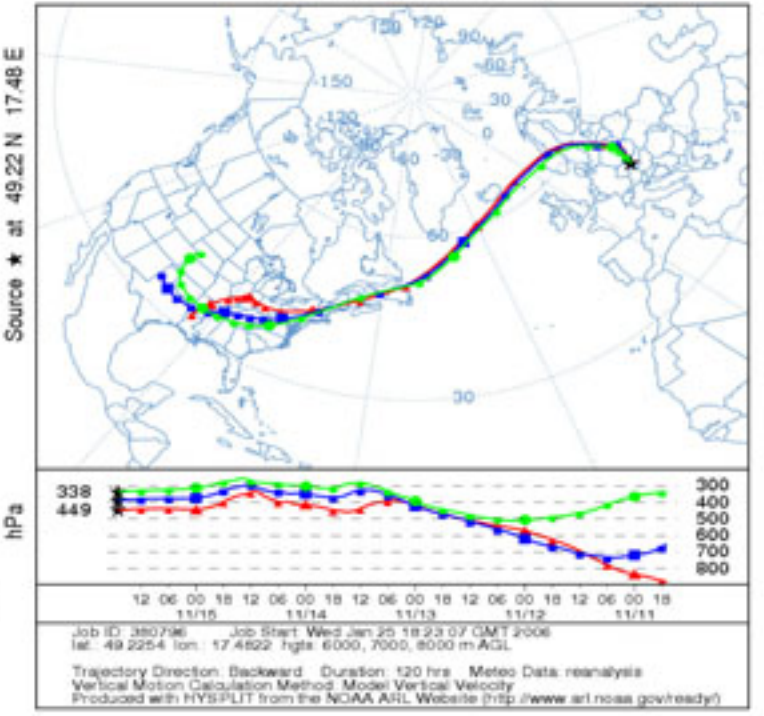




Richards and Li

Assimilation of TES CO into the GEOS-CHEM CTM

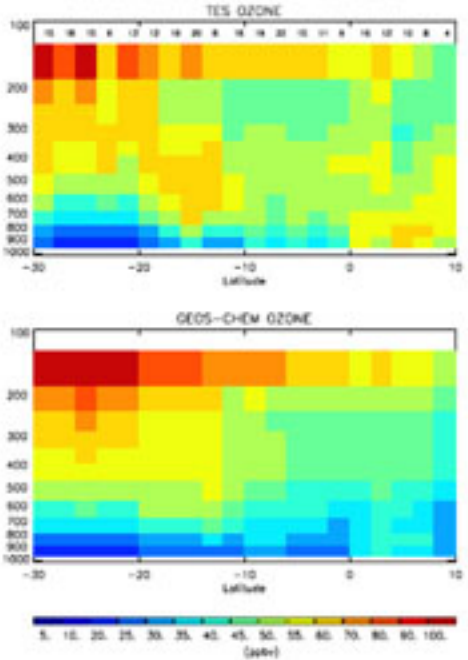




Richards and Li

Tropical Ozone Paradox Resolved

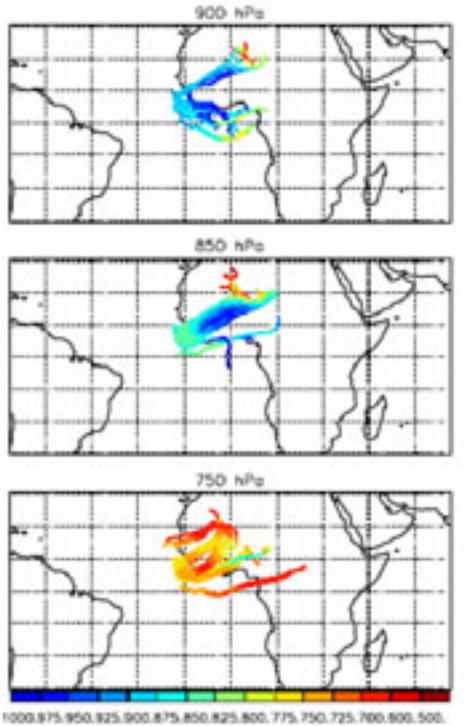
TES tropical Atlantic observations of ozone



GEOS-CHEM predictions of ozone

- There is a long standing difference between balloon/ *in-situ* observations of ozone and ozone columns from instruments such as TOMS
- TES provides the first observation from space resolving lower and upper tropospheric ozone over the Tropical Atlantic Ocean during the Northern Africa biomass burning season.
- TES observations shows the elevated ozone north of the equator which corresponds to the Hartmattan winds that bring dust off the Sahara as well as biomass emissions.

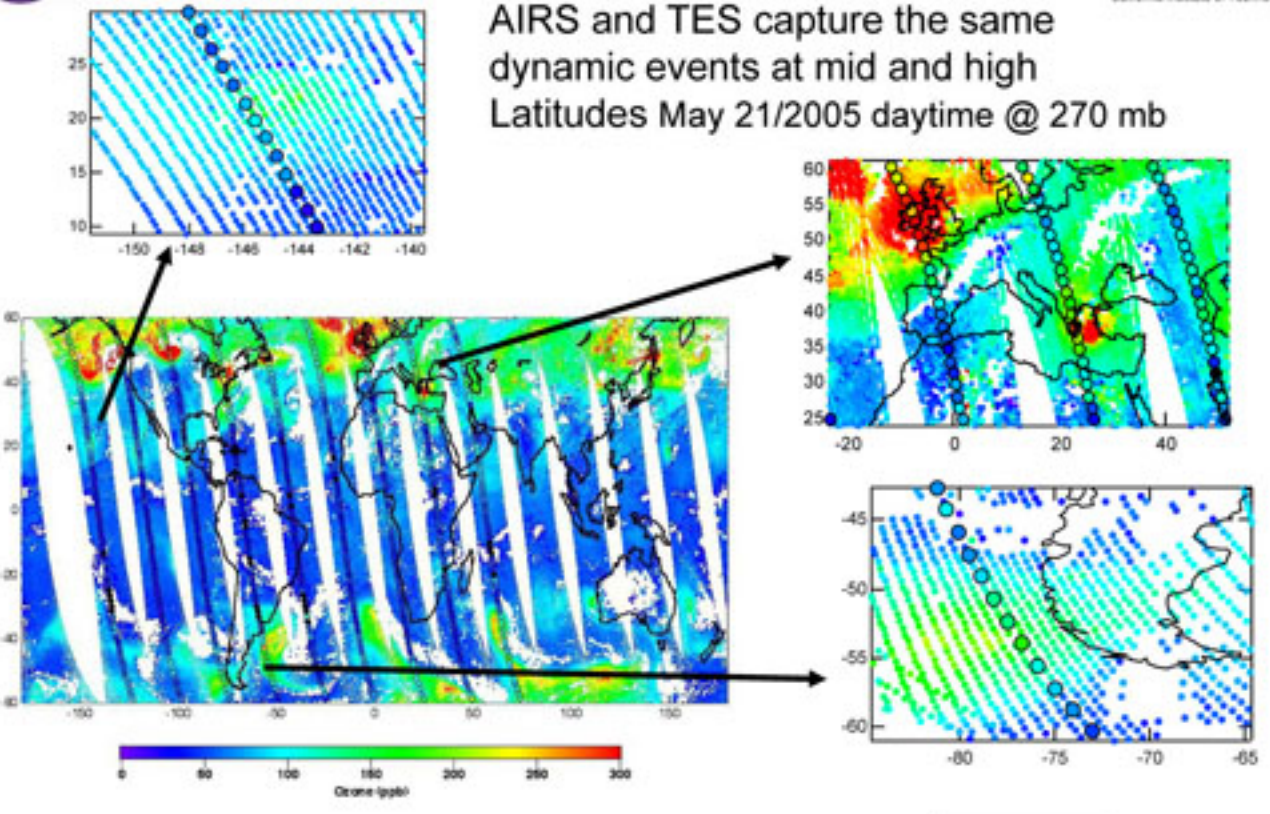
Trajectories show how air is brought off of African coast



L. Jourdain and H. Worden

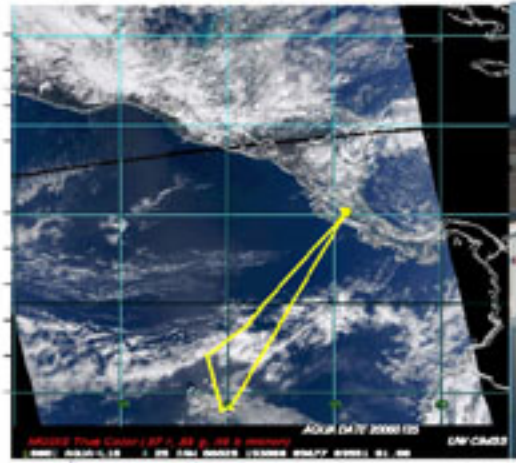
Dynamics and STE

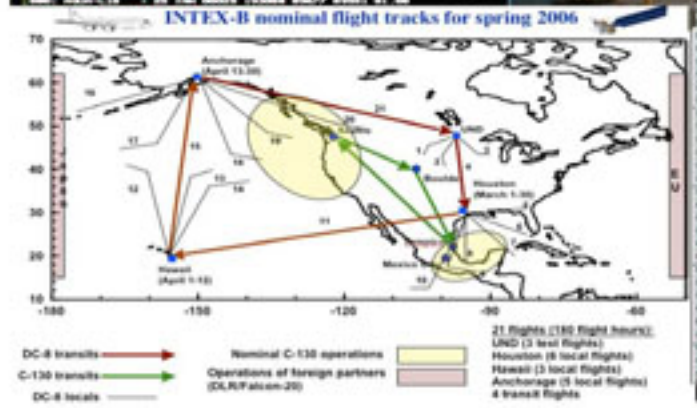
AIRS and TES capture the same dynamic events at mid and high Latitudes May 21/2005 daytime @ 270 mb

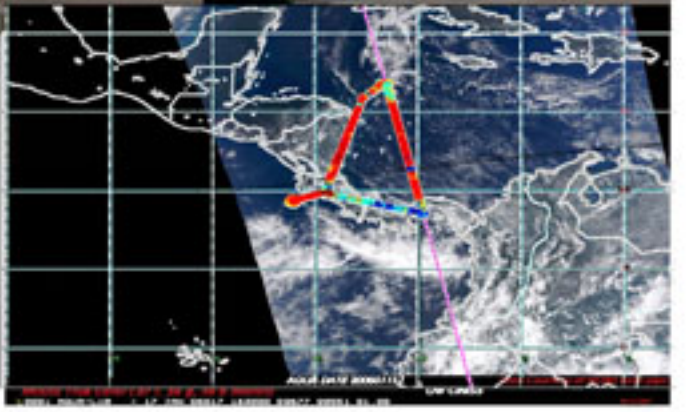


Irion et al.

CR-AVE and INTEX-B



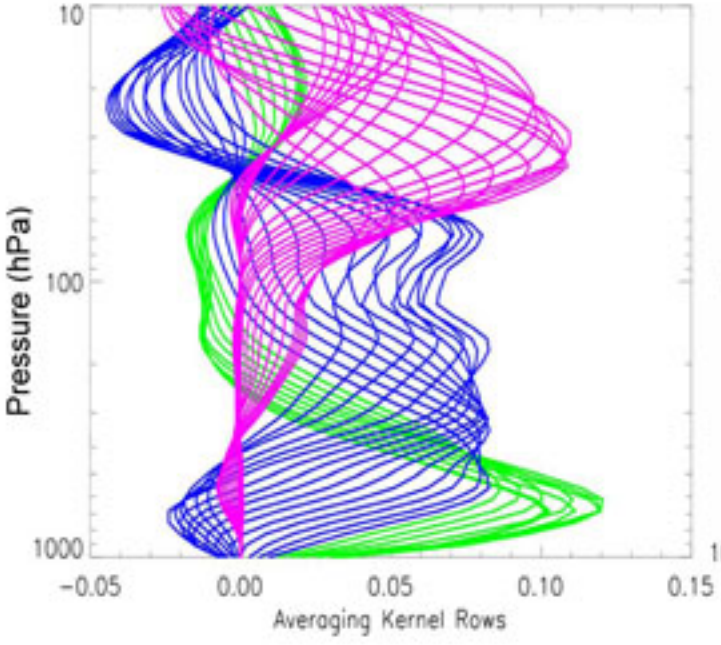




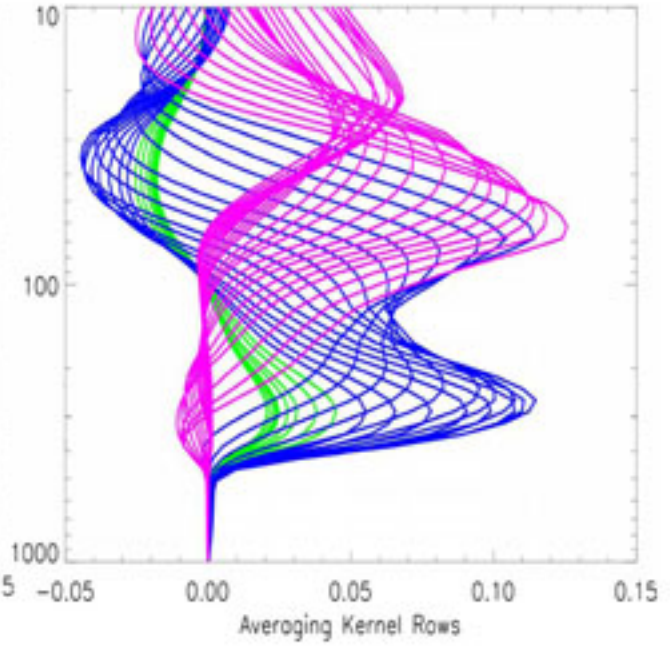
Jet Propulsion Laboratory
California Institute of Technology

Test Team Photo, April 24, 2003

Backup Slides

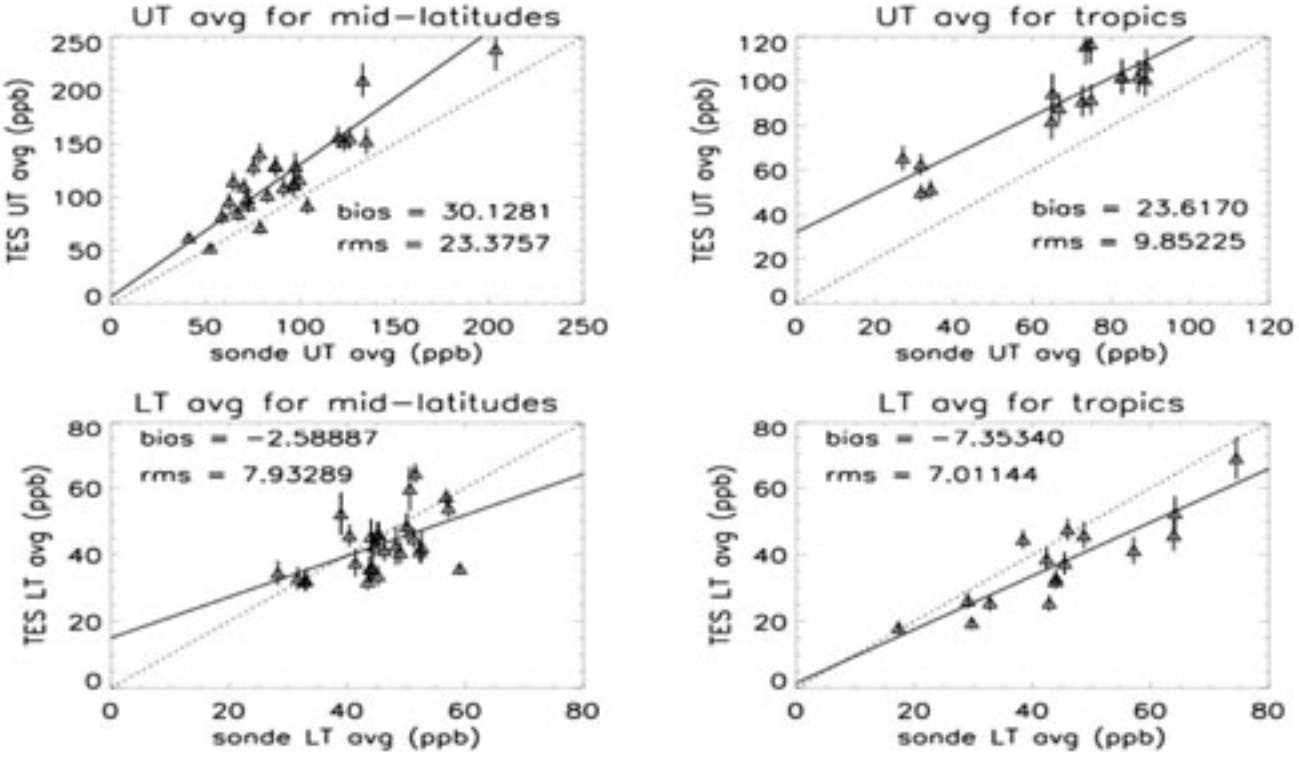


Clear (DOFS = 4.1)



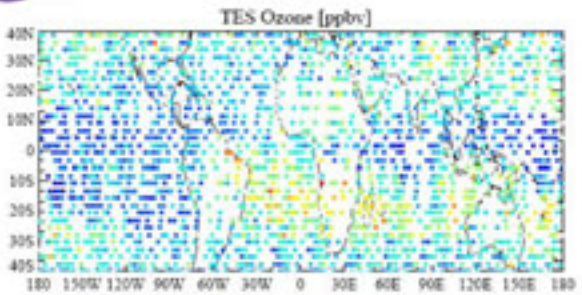
Cloud at 483 hPa (DOFS = 3.0)

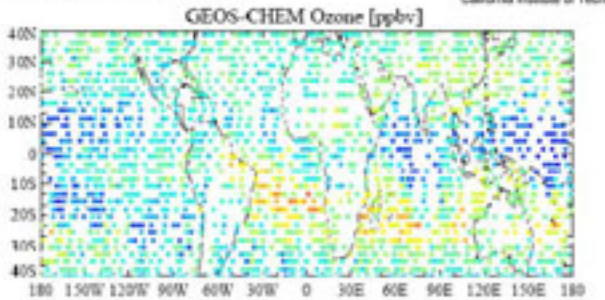
Tropospheric ozone
TES and Ozonesondes



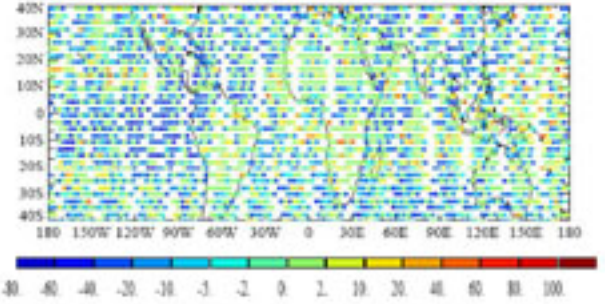
H. Worden and Logan

Comparison TES and GEOS-CHEM
1-15 November 2004, 500hPa

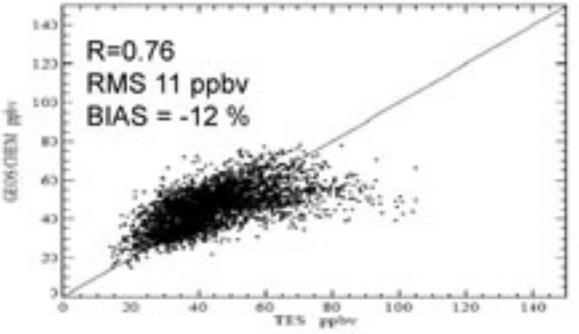




(TES-GEOS_CHEM)/GEOS-CHEM%



Tropics (30N-30S)

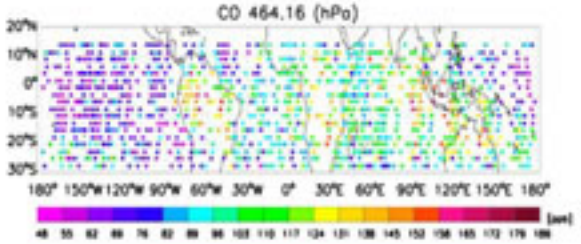


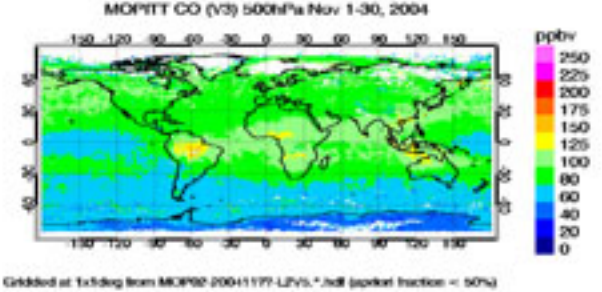
For comparison with GEOS-CHEM :

$$\ln \hat{x}_{model} = \ln x_a + A\,(\ln x_{model} - \ln x_a)$$

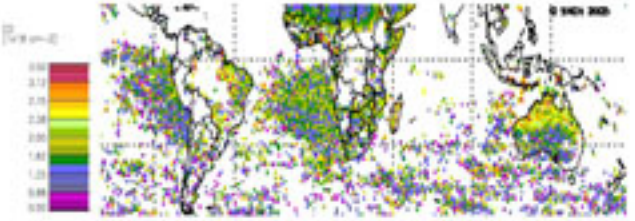
Jourdain and Li

Comparison to MOPITT and Sciamachy tropospheric CO





Sciamachy near-infrared CO tropospheric column estimates



MOPITT maps obtained from
http://www.eos.ucar.edu/mopitt/data/plots/mapsv3_mon.html

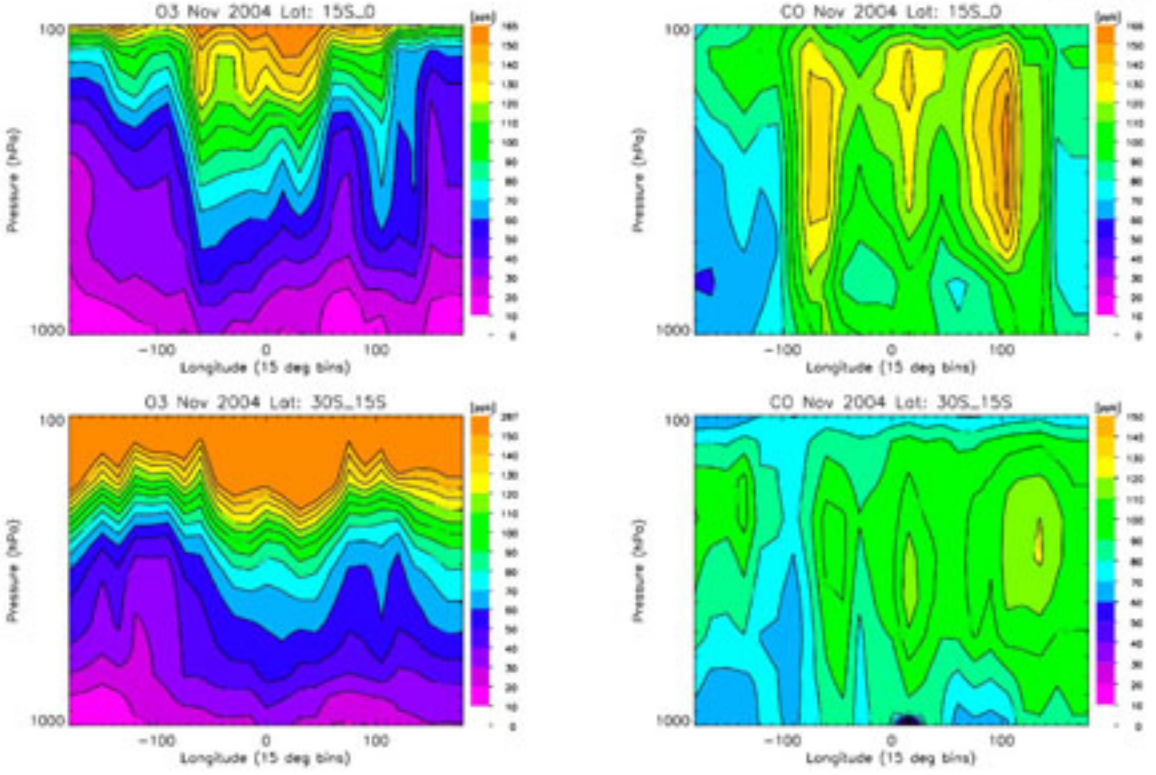
Sciamachy maps provided courtesy of Annemieke Gloudemans at SRON

Elevated CO is observed between TES, MOPITT, and Sciamachy over South America, Africa, and Australia/Indonesia

A CO "plume" is observed by TES and MOPITT from the east of Australia extending across the south Pacific

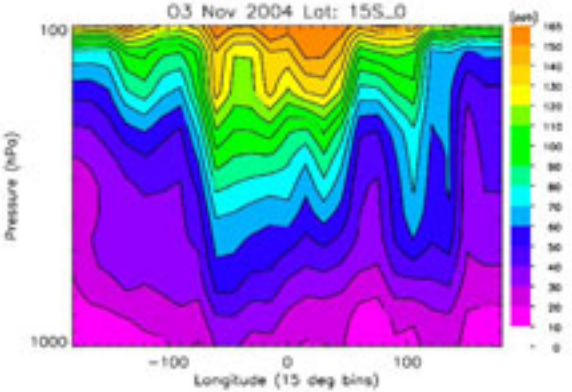
Bowman

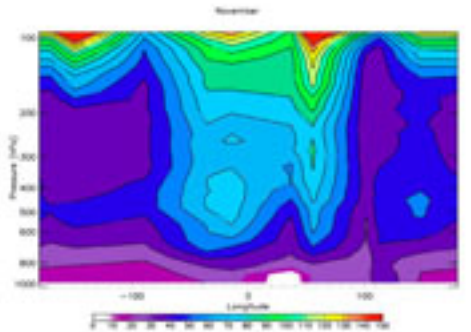
Mean Ozone and CO profiles November 4-16

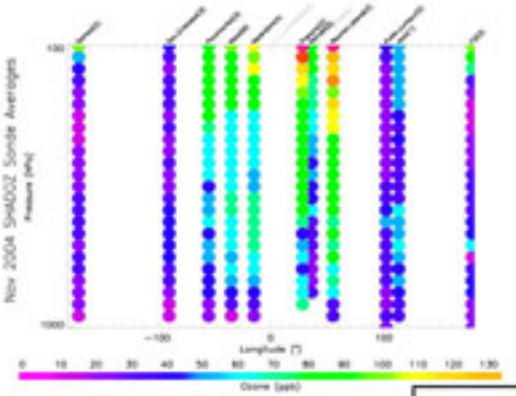


Bowman

Comparison to the SHADOZ Network





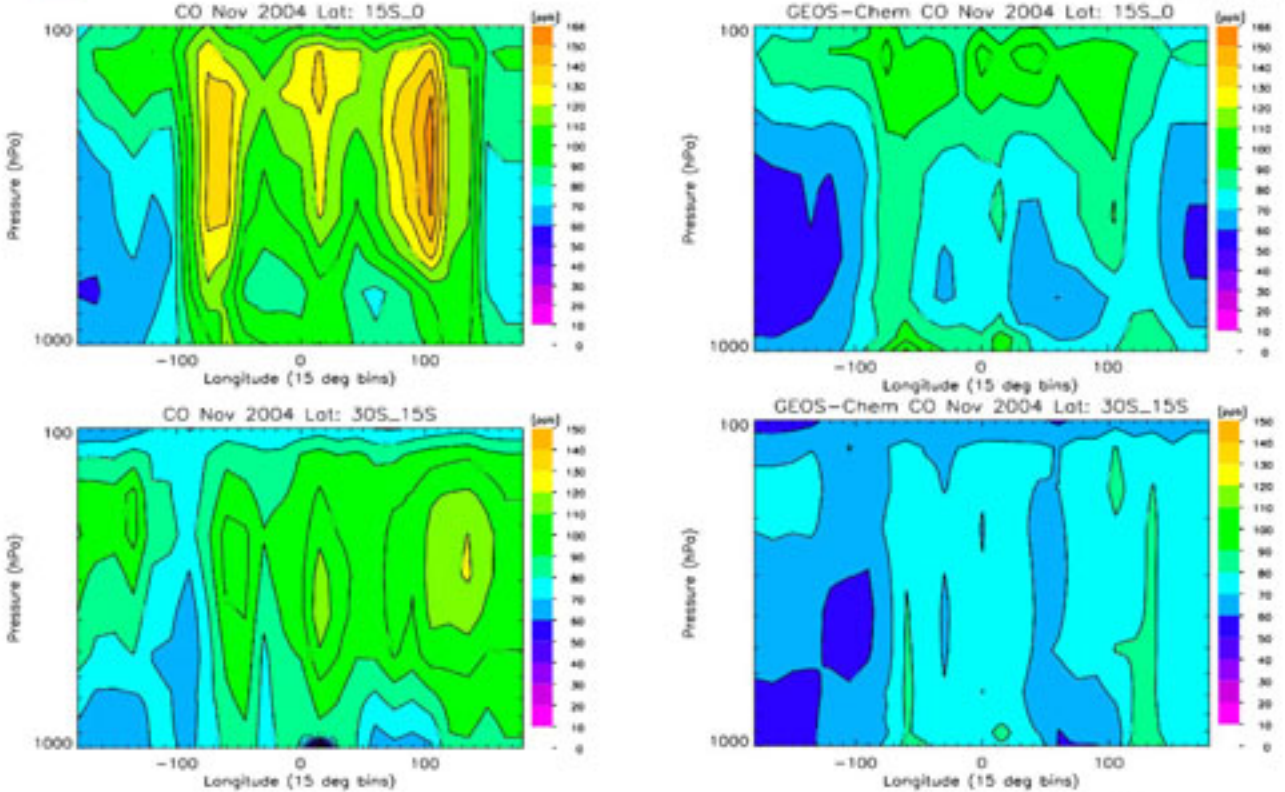


Shadoz mean of ozone was calculated
from 1998-2004 for the month of November based on 11 sites
covering a latitudinal and longitudinal range of 21S to 3N

Averages for November of 2004 are also included

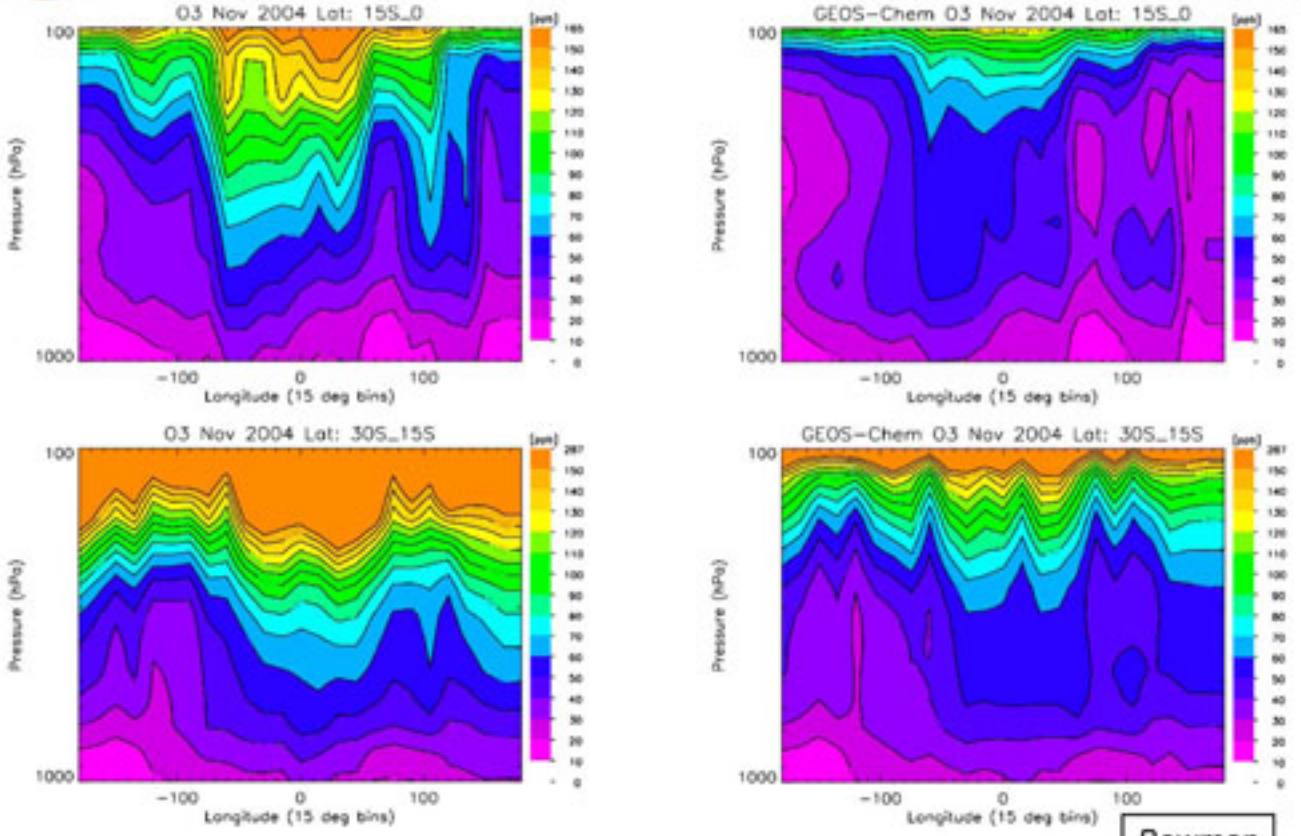
Bowman

Comparisons to GEOS-Chem CO



Bowman

Comparison to GEOS-Chem O_3



Bowman