Observing Signatures of Air Pollution from Space: Prospects and Challenges for Nadir Thermal Infrared Spectrometers

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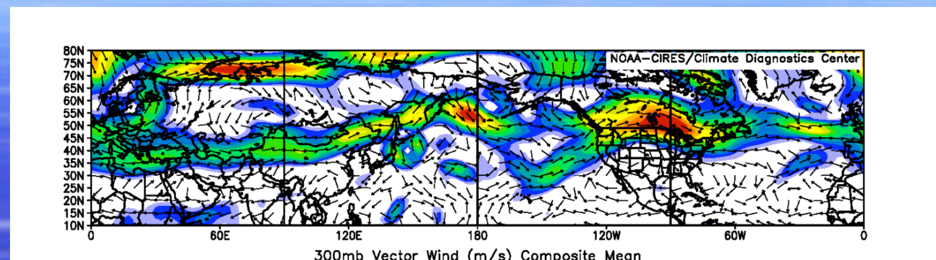
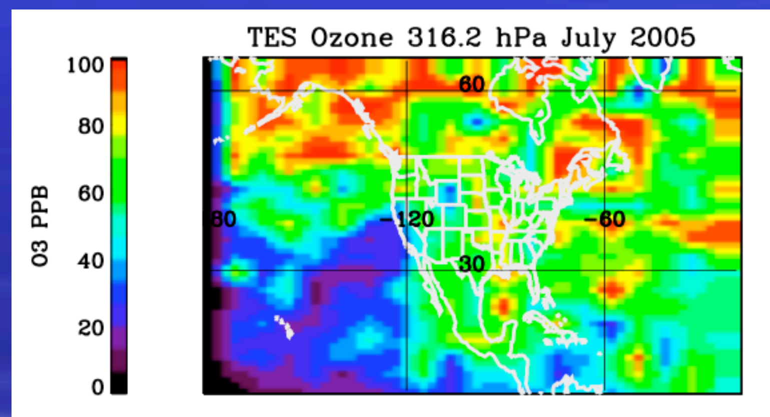
Tropospheric ozone and its precursors are a key measure of air quality and the characterization of the chemical and dynamic processes governing their magnitude and distribution is one of the central extant scientific challenges

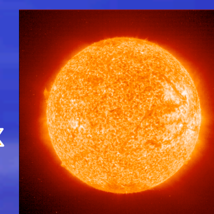


Advection

Anthropogenic sources

Natural sources





Solar radiation

Subsidence

Convection

Ozone damage to yellow poplar plant

http://www.fiaozone.net/species/yellowpop/yellowinj3.htm

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

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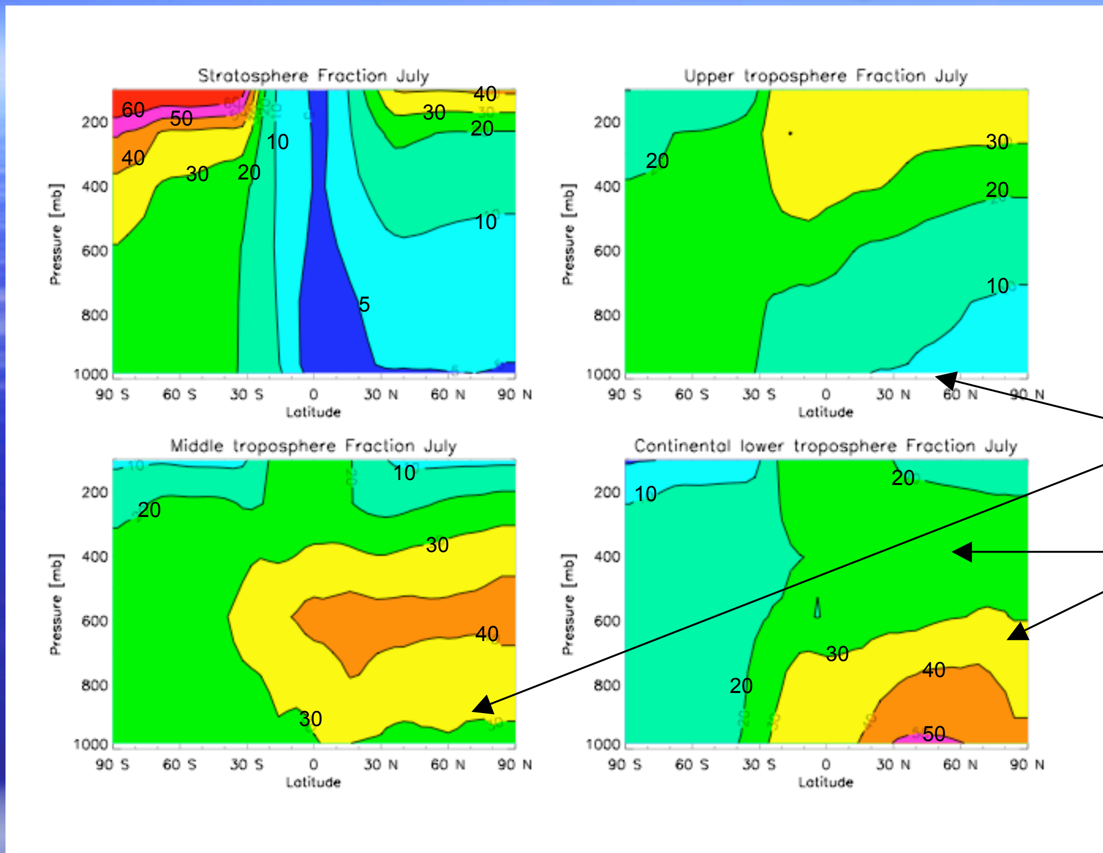


The vertical distribution of ozone is governed by chemical and dynamical processes that lead to significant vertical exchange between the upper, middle, and lower troposphere

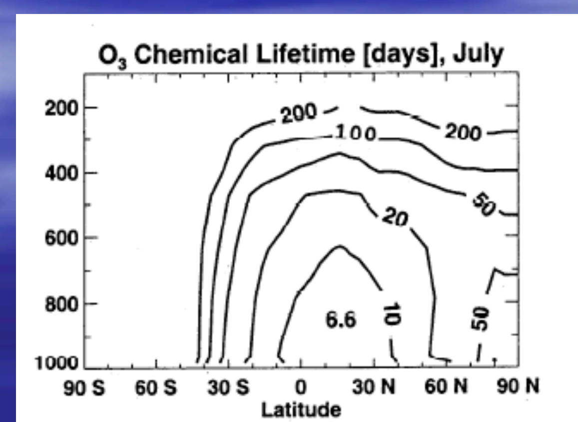
10% and 20% of lower tropospheric ozone originates from the upper and middle troposphere in the northern mid-latitudes

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

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

Wang *et al, JGR 1998*

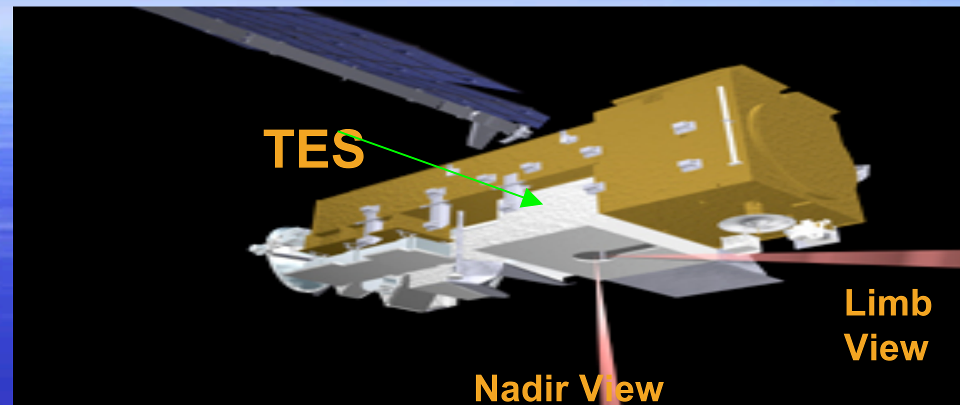
The lifetime of ozone is strongly dependent on altitude and consequently effects how far ozone can be transported

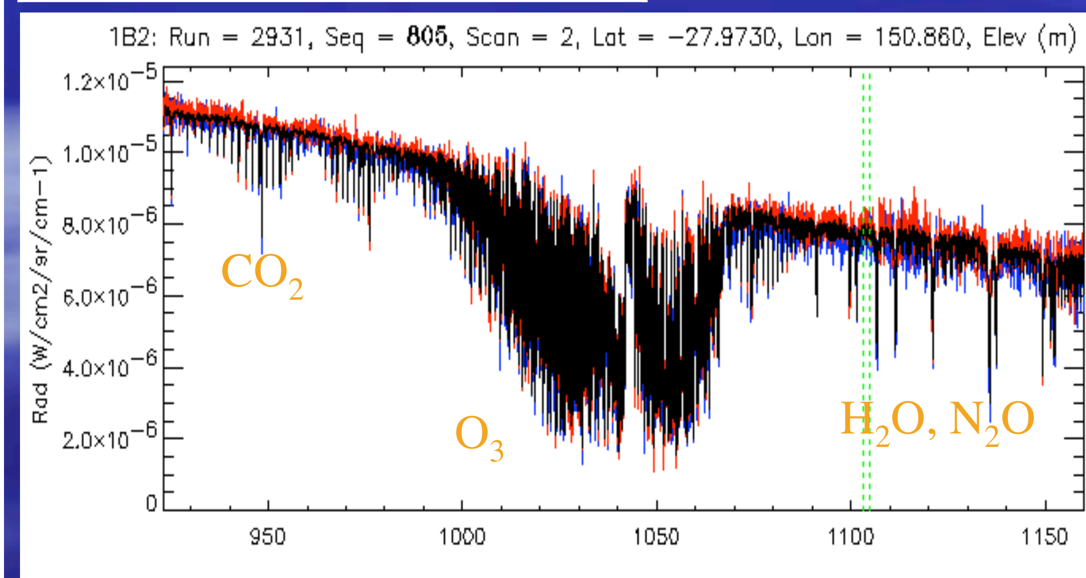


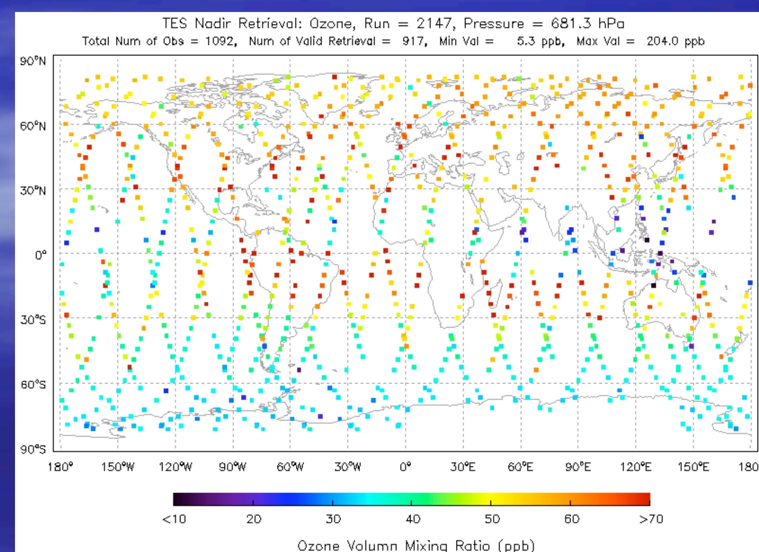
Tropospheric Emission Spectrometer

TES is a Fourier Transform Spectrometer designed specifically to measure the vertical distribution of tropospheric ozone and its precursors

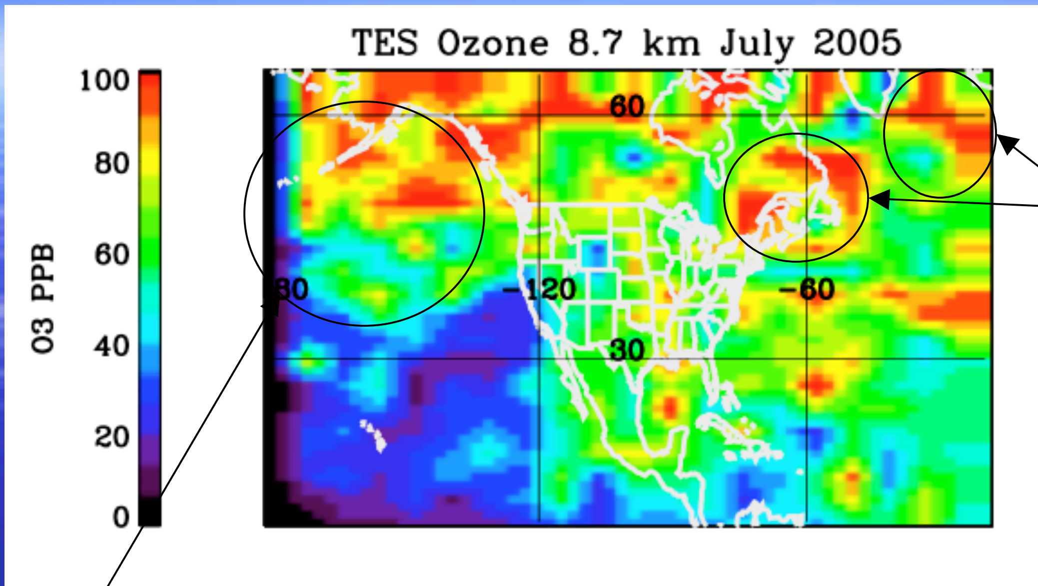
Spectral Resolution (unapodized)	0.06 cm^{-1} (nadir)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 μm)
Coverage	72 observations/orbit 16 orbits/day
Spatial Resolution	0.5 x 5 km (nadir)
Nadir NEDT @290K (Noise Equivalent Delta Temperature)	2B1: 1.08 K 1B2: 0.36 K 2A1: 0.36 K 1A1: 2.07 K





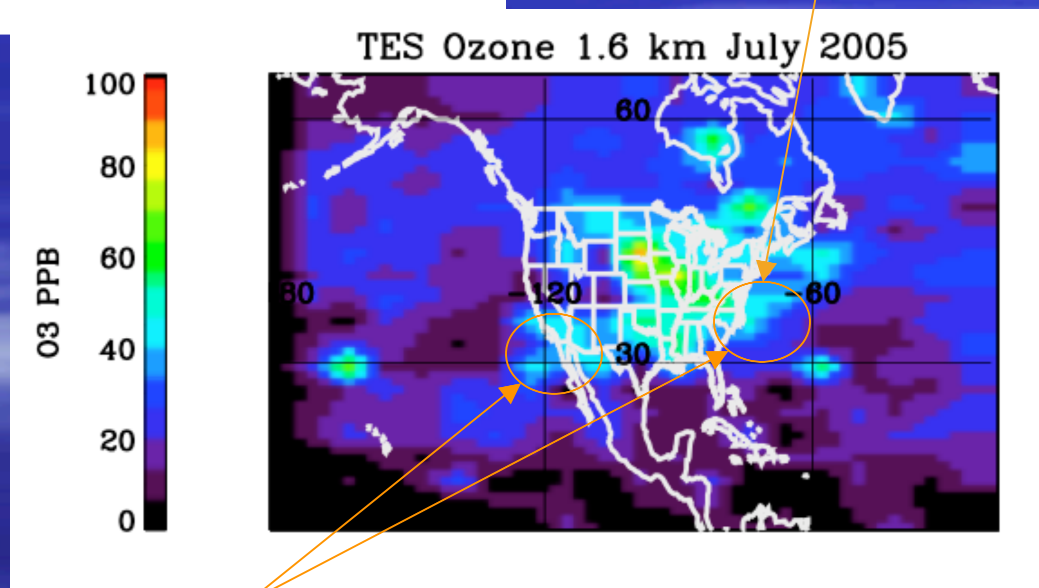


TES observations capture the vertical distribution of tropospheric ozone



Upper tropospheric ozone outflow from North America likely due to frontal lifting and convection of pollution from the lower troposphere

Influx of upper tropospheric ozone from Asia transported by the jet stream



Offshore ozone plume from Southern California and the Eastern seaboard

Observations of ozone and its precursors can provide a more complete dynamical/chemical picture

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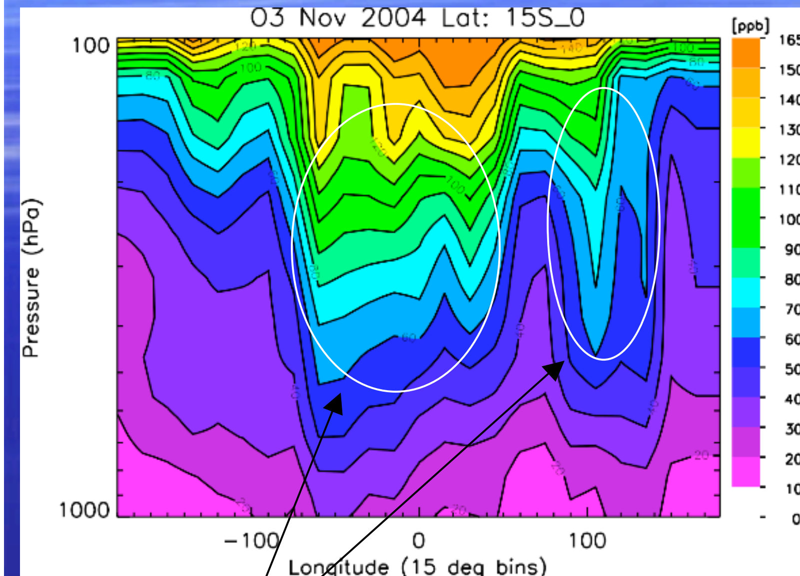
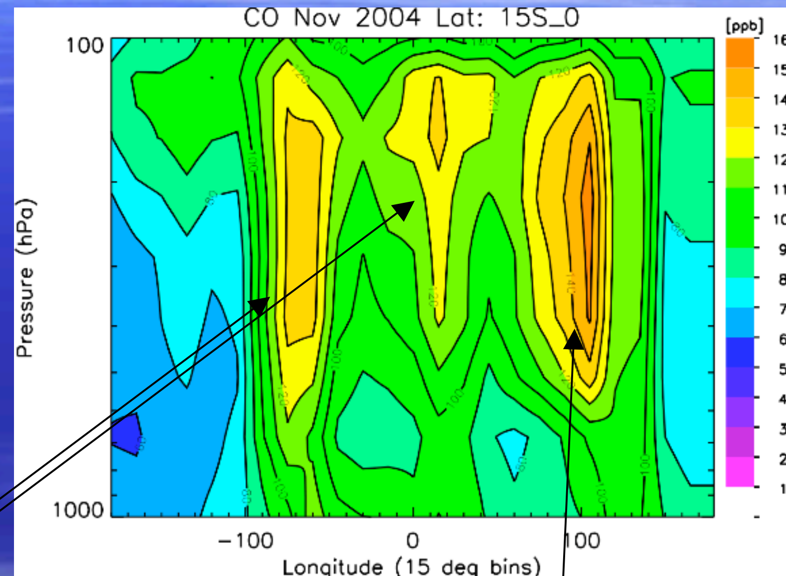
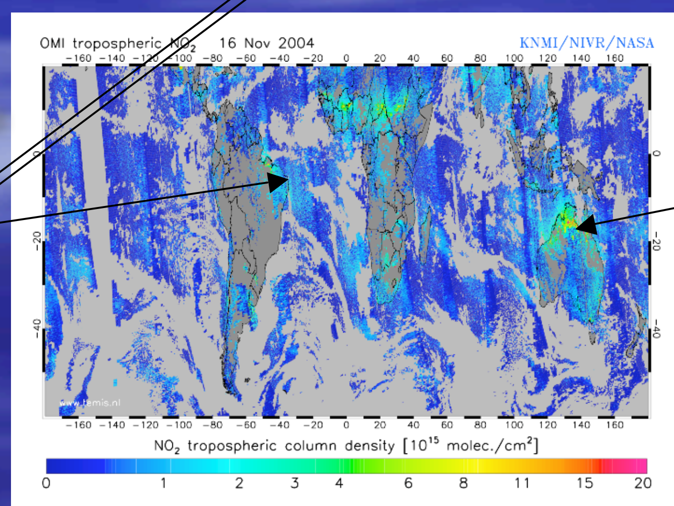
TES observations of ozone, carbon monoxide, and OMI NO_2 over the southern tropics for November 2004





Elevated ozone primarily over the tropical Atlantic and Indonesia/Australia

Precursor sources can be displaced relative to ozone



Or they can be more co-located

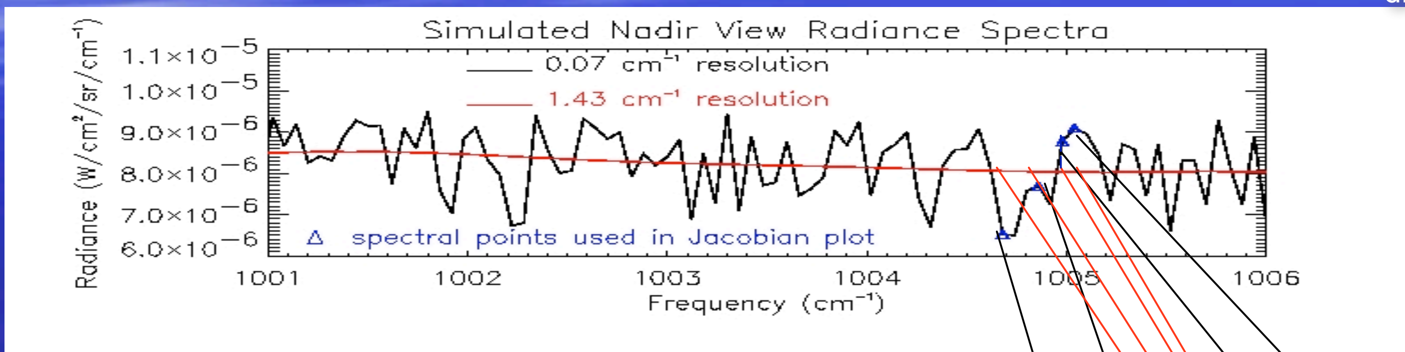
OMI NO_2 columns courtesy of P. Veefkind, H. Eskes (KNMI), and F. Boersma (Harvard)

Spectral resolution --> vertical resolution

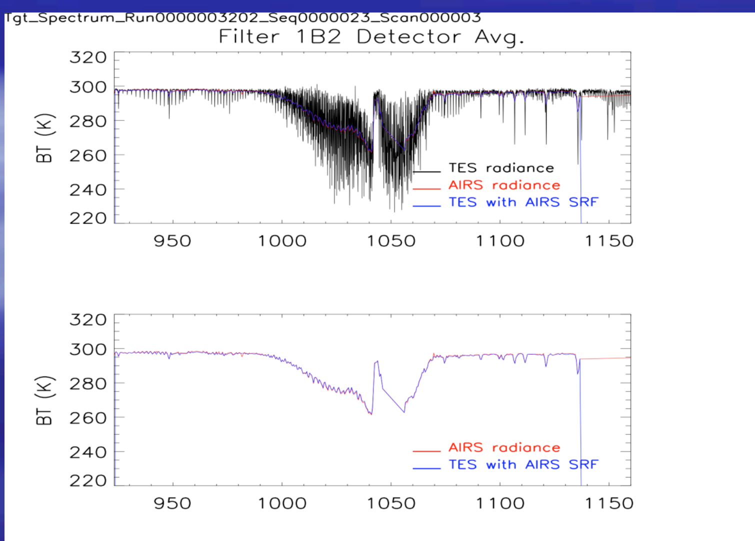
Vertical resolution is obtained by exploiting the pressure dependence of spectral lines in the thermal infrared

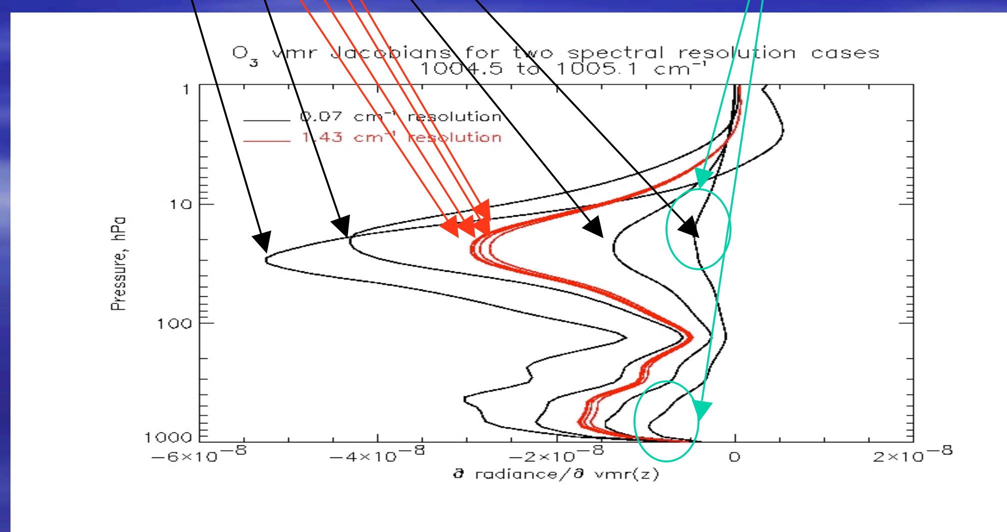
At a spectral resolution of 1.43 cm^{-1}, the spectral radiances respond *in the same way* to changes to the vertical distribution of ozone

At a spectral resolution of 0.07 cm^{-1}, the spectral radiances respond differently to changes in the vertical distribution of ozone.



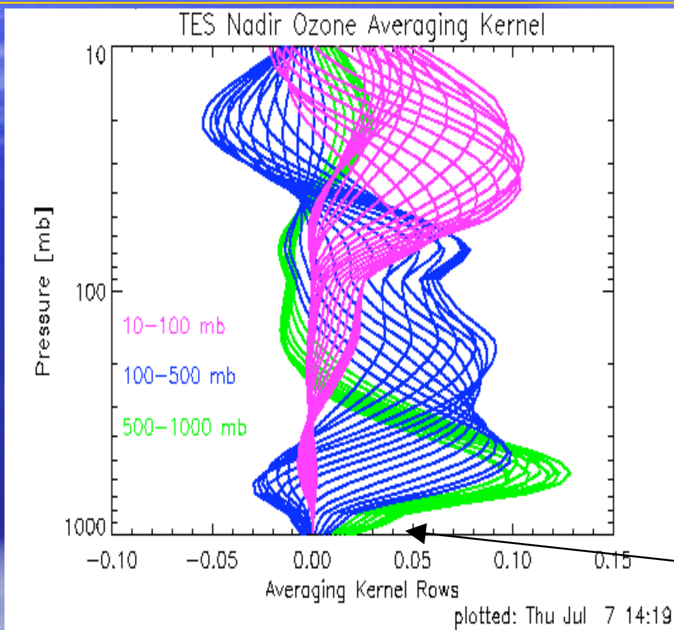
The spectral wings of the ozone lines have greater sensitivity to the lower troposphere than the stratosphere



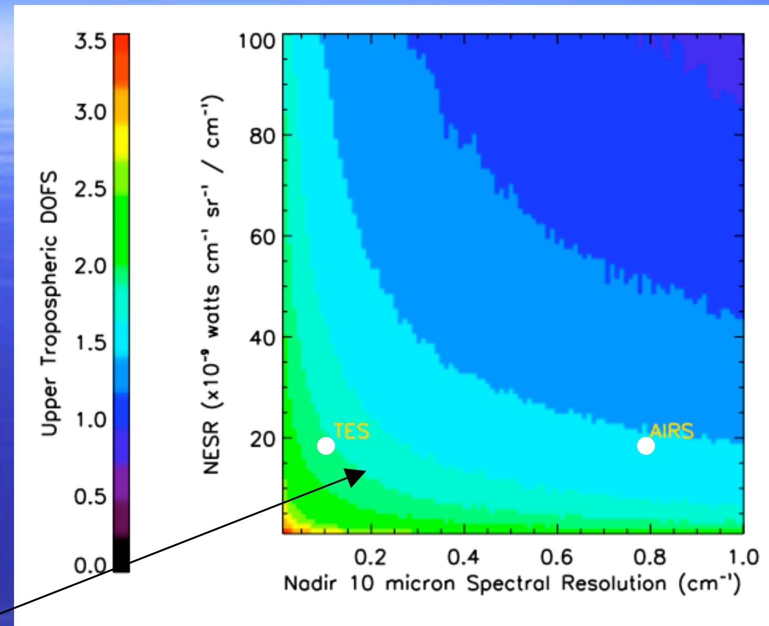


The *what* and *where* of vertical resolution

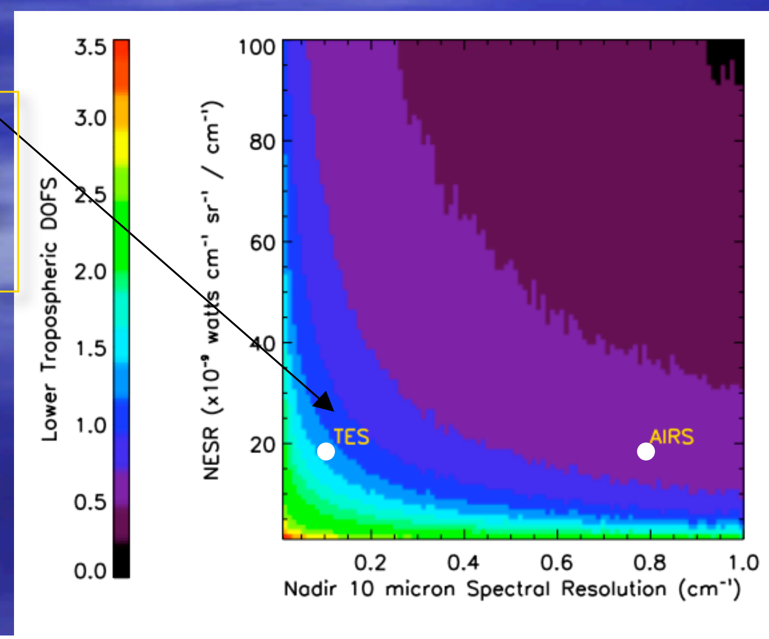
For the thermal infrared, spectral resolution and noise provide bounds for both *what* and *where* vertical resolution is obtainable



The difference in vertical sensitivity between TES and AIRS is much less in the upper troposphere than in lower troposphere



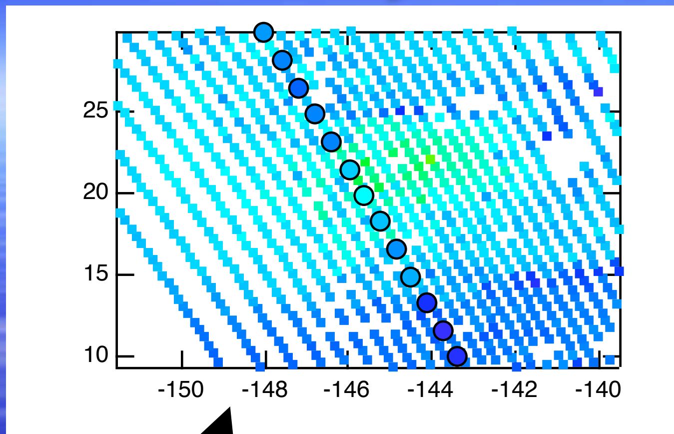
Sensitivity to boundary layer ozone dependant on thermal contrast



The averaging kernel characterizes the sensitivity of an ozone profile estimate to variations in the fine structure of the atmospheric state.

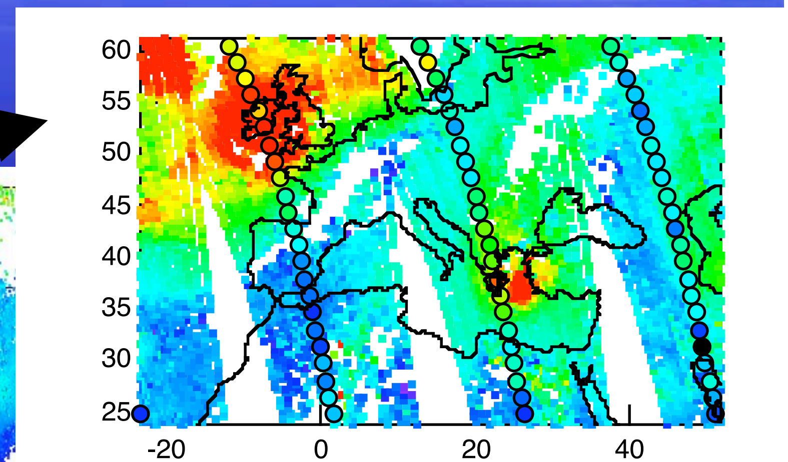
The peaks and widths of the kernel define the location and degree of vertical resolution

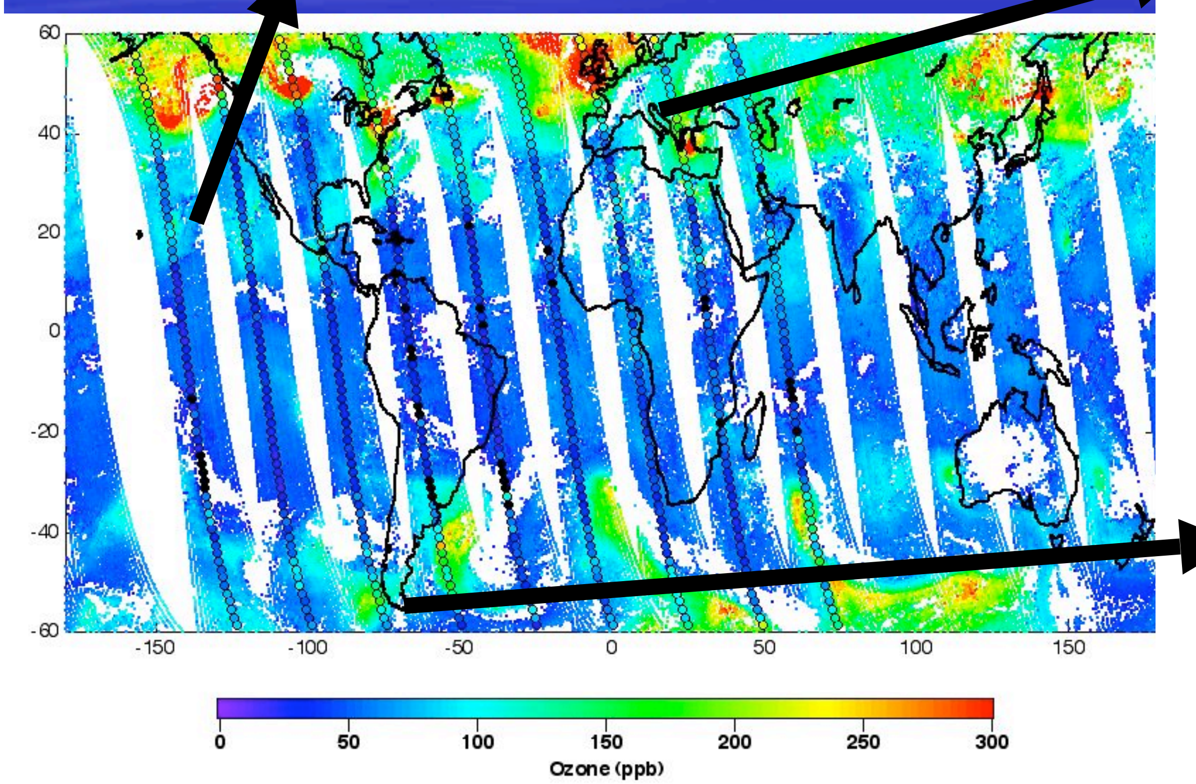
Key observational *desirderatum*: spatial coverage

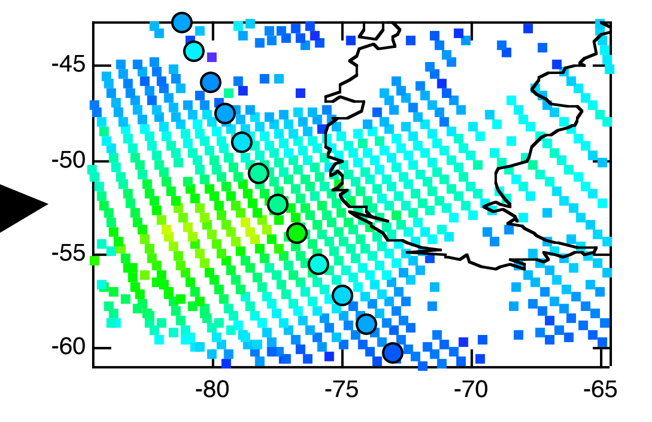


AIRS and TES capture the same dynamic events at mid and high latitudes

May 21/2005 daytime @ 270 mb







Conclusions and Future Directions

- The characterization of the chemical and dynamic processes governing the distribution and evolution of ozone and its precursors requires observations that can measure the vertical structure of ozone
- High spectral resolution allows thermal infrared spectrometers such as TES to achieve sensitivity to the vertical structure of tropospheric ozone, particularly in the lower troposphere
- Lower spectral resolution grating spectrometers such as AIRS obtain excellent global spatial coverage
- Thermal infrared observations from instruments such as TES and AIRS are generally insensitive to boundary layer ozone, except in cases of high thermal contrast, e.g., desert scenes.
- Future mission concepts should incorporate high spectral resolution (TES), high spatial coverage (AIRS), and sensitivity to boundary layer ozone.

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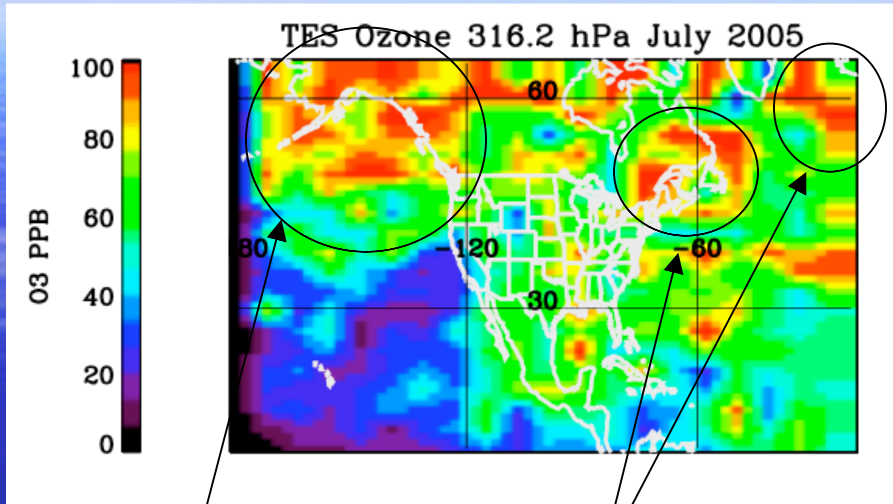
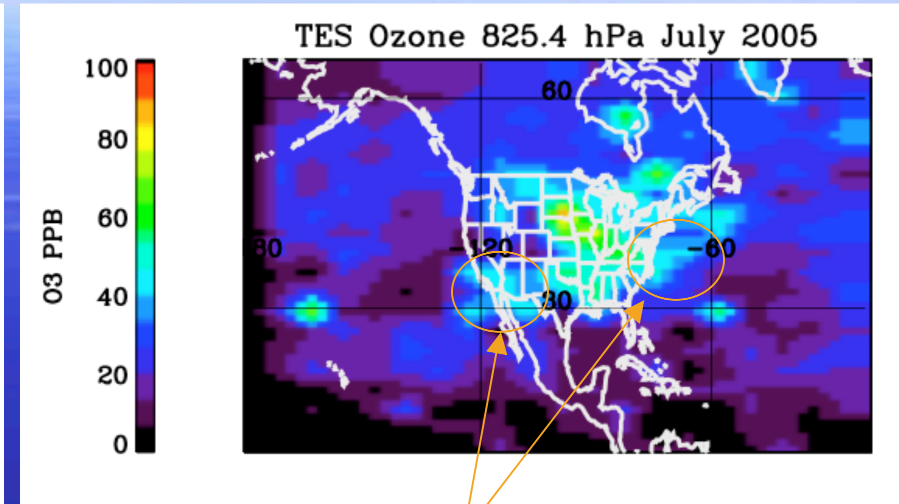
Backup slides

Patterns of tropospheric ozone





Influx of upper tropospheric ozone from Asia transported by the jet stream

Upper tropospheric ozone produced From the eastern seaboard?

Evidence of offshore plume from Southern California and the Eastern seaboard area