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

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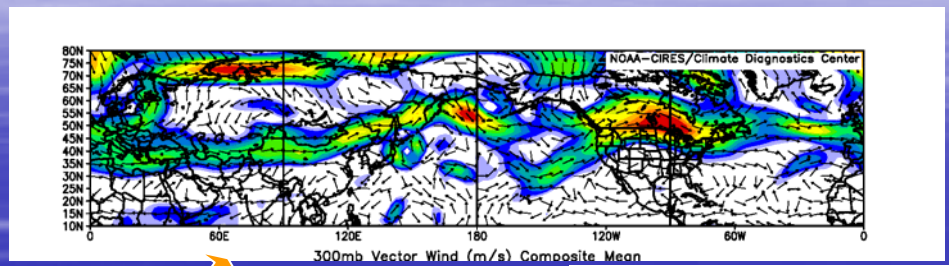
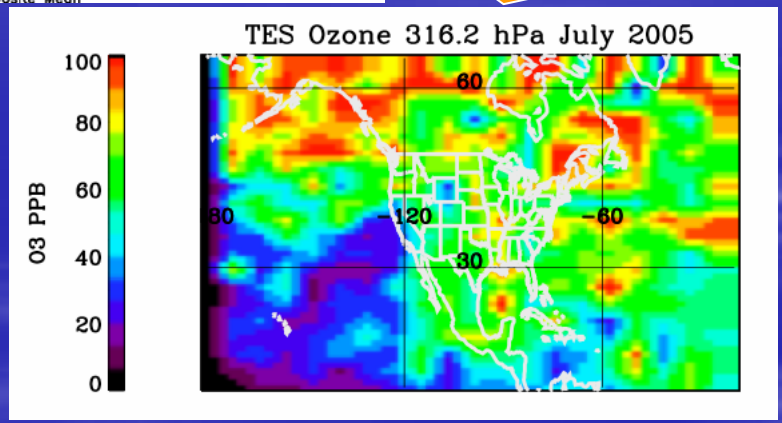


Advection

Anthropogenic sources

Natural sources

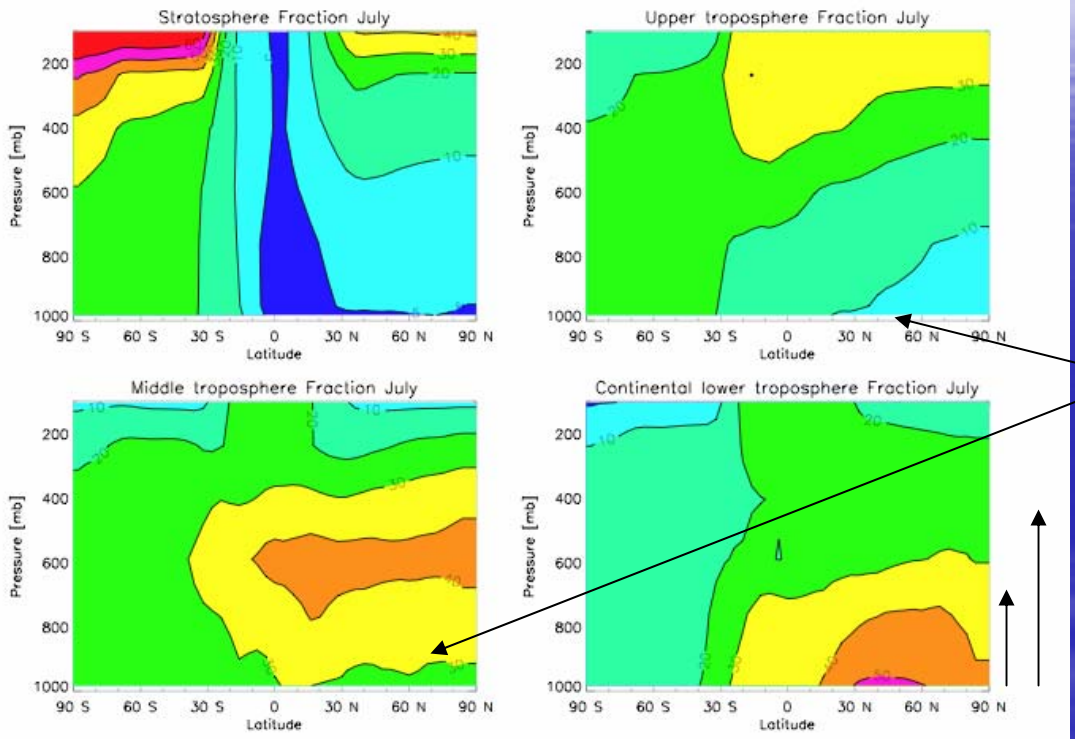
Solar radiation



Convection

Subsidence

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



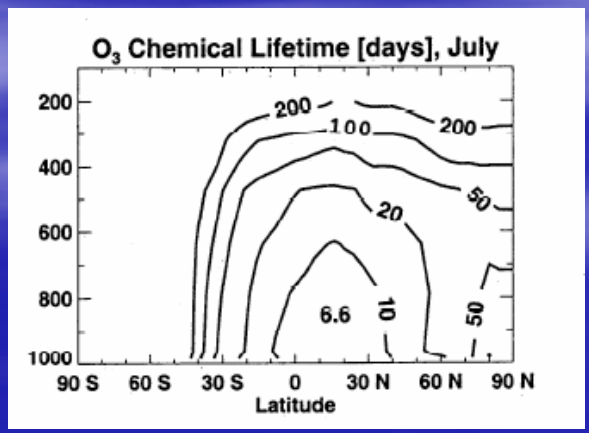
Fractional contribution of source regions to zonal mean ozone distribution for a GEOS-Chem simulation for a climatological period

Wang *et al, JGR 1998*

The 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

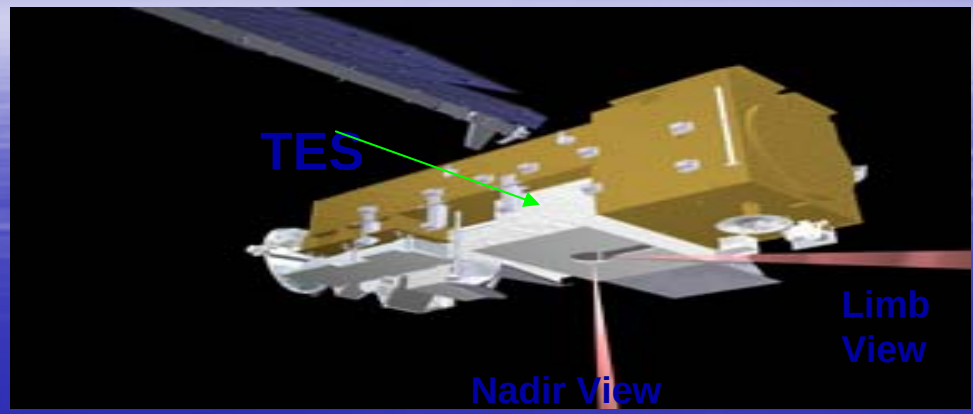
20-30% of the lower tropospheric ozone reaches the upper and middle troposphere in the northern mid-latitudes

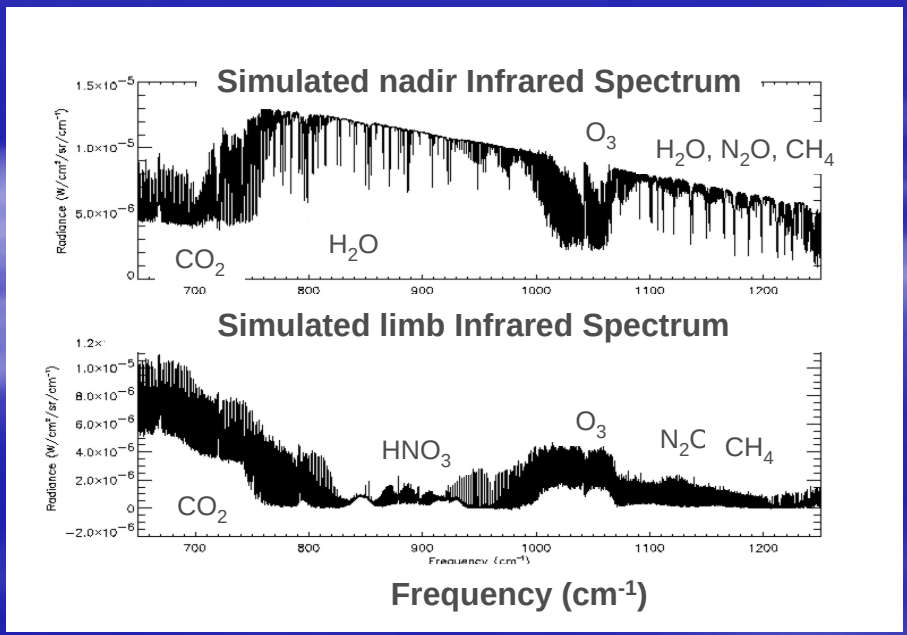


The lifetime of ozone is strongly dependent on altitude and consequently effects the transport of ozone

Tropospheric Emission Spectrometer

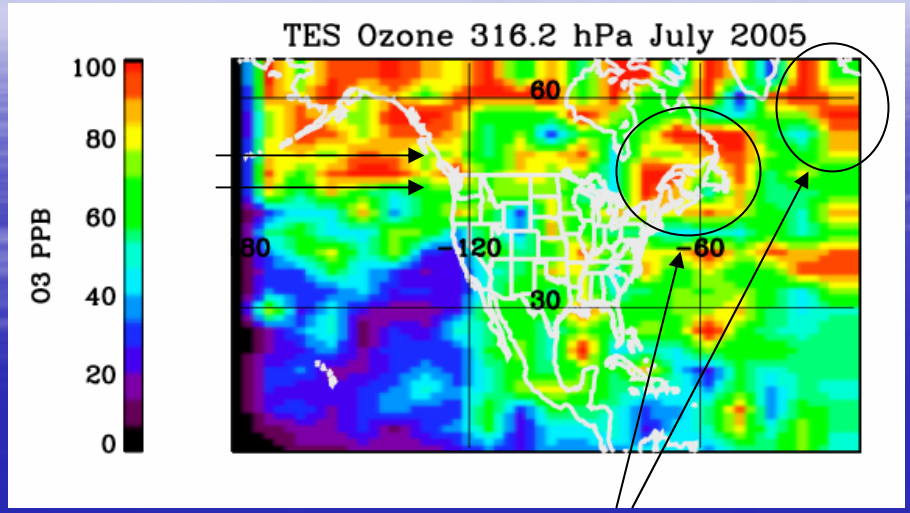
TES is a Fourier Transform Spectrometer designed specifically to measure the vertical distribution of tropospheric ozone and its precursors

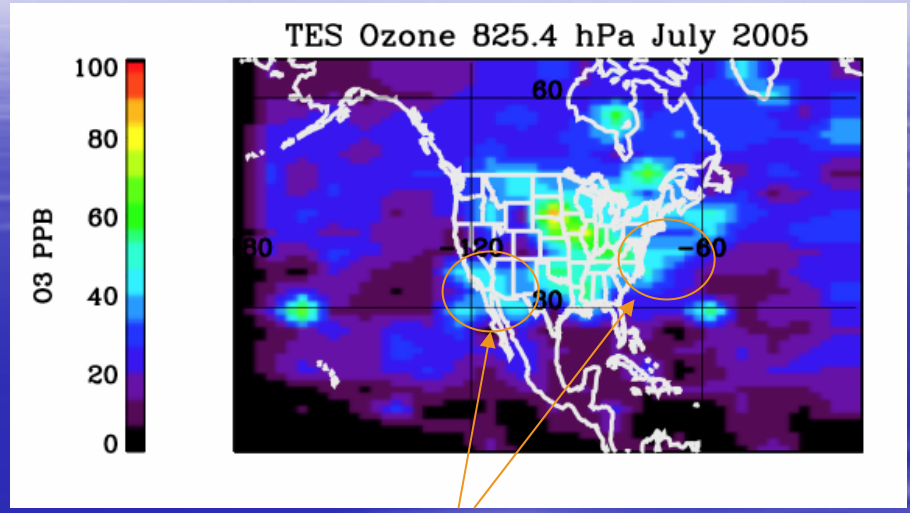




Max. Optical Path Difference	± 8.45 cm (nadir & calibration) ± 33.8 cm (limb); interchangeable
Scan (integration) Time	4 sec (nadir & calibration) 16 sec (limb)
Spectral Resolution (unapodized)	0.06 cm^{-1} (nadir) 0.015 cm^{-1} (limb)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 μm)
Detector Arrays	4 (1 x 16) arrays, optically-conjugated, all MCT PV @65K
Spatial Resolution	0.5 x 5 km (nadir) 2.3 x 23 km (limb)
Nadir NESR (Noise Equivalent Spectral Radiance)	2B1 filter: 700 $nW/cm^2/sr/cm^{-1}$ 1B2 filter: 200 2A1 filter: 150 1A1 filter: 100
Nadir NEDT @290K (Noise Equivalent Delta Temperature)	2B1: 1.08 K for 16 detector average 1B2: 0.36 K for 16 detector average 2A1: 0.36 K for 16 detector average 1A1: 2.07 K for 15 detector average

Patterns of tropospheric ozone

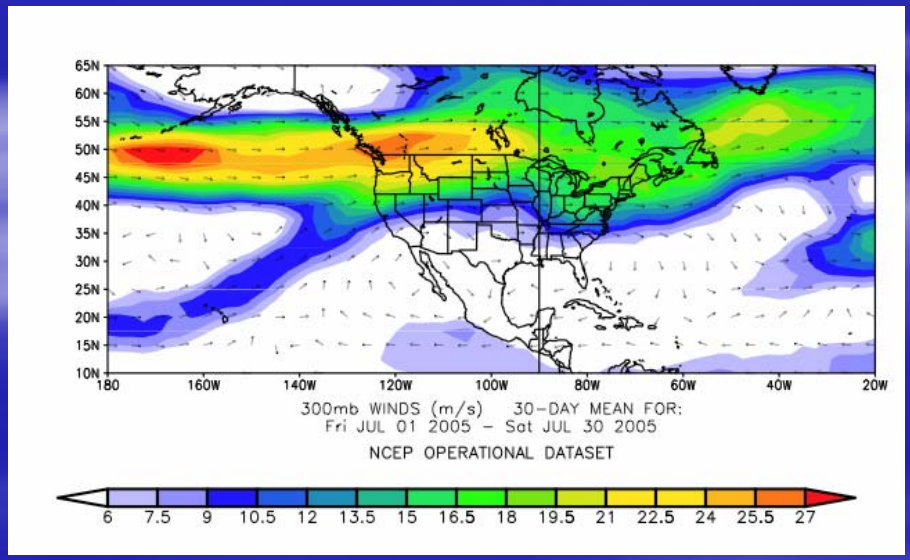


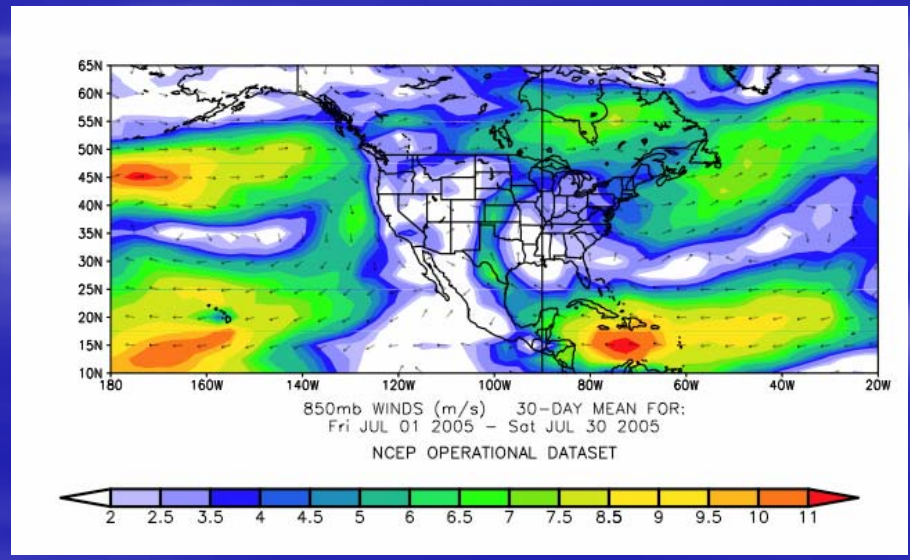


Transport of ozone from Asia?

Upper tropospheric ozone produced From the eastern seaboard?

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





Observations of ozone alone can not provide a complete dynamical/chemical picture

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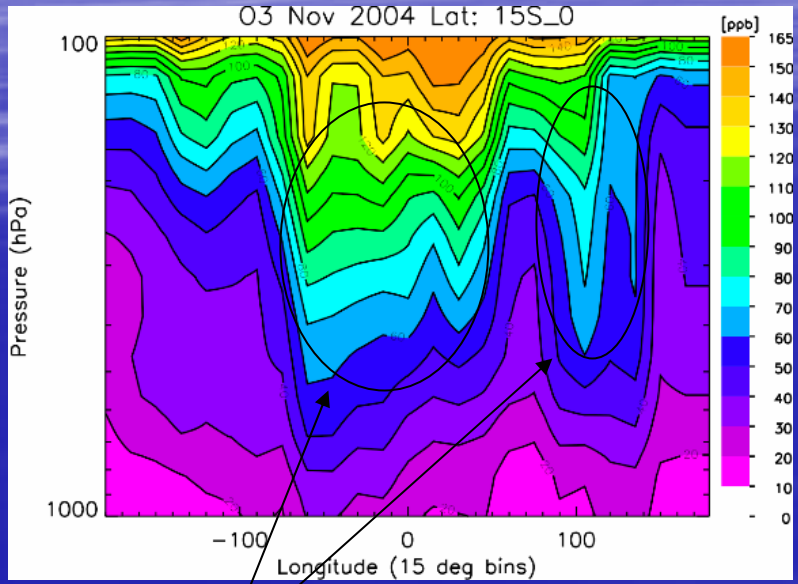
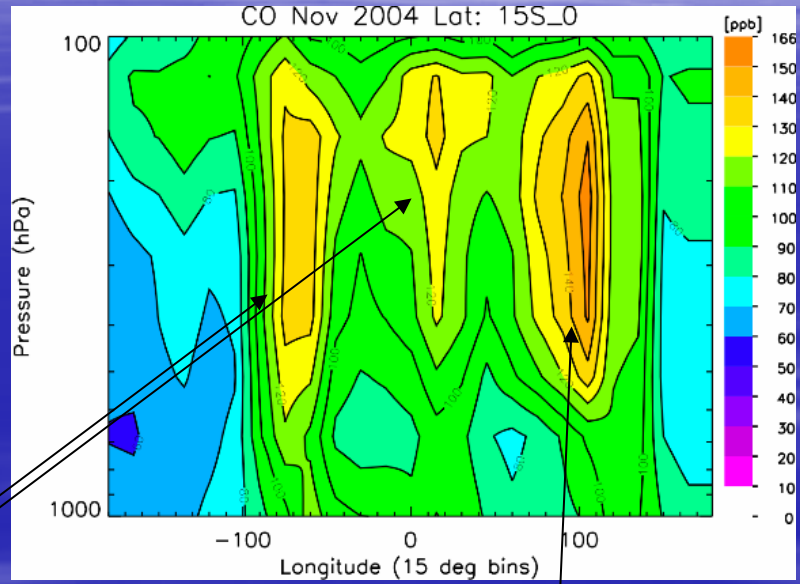
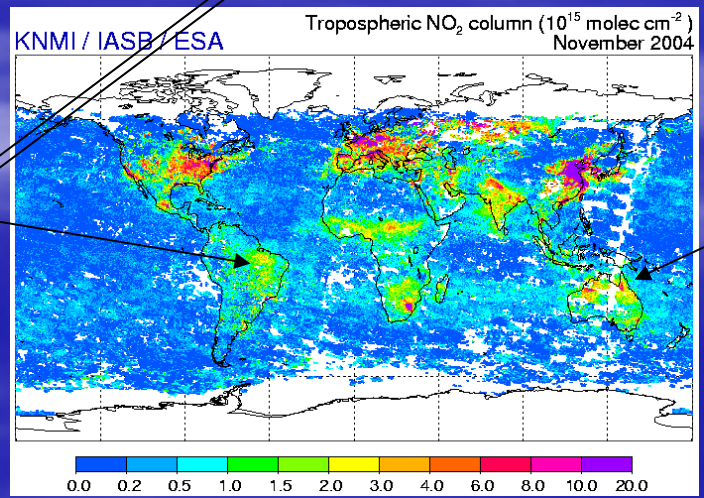
Observations of ozone, carbon monoxide, and NO_2 over the southern tropics for November 2004





Elevated ozone primarily over the tropical Atlantic and Indonesia/Australia

Precursor sources can be displaced relative to ozone

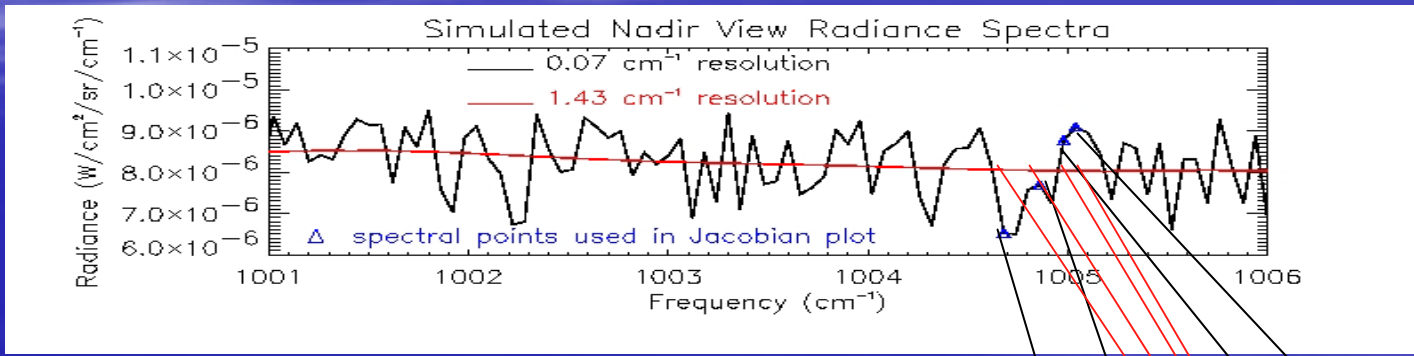


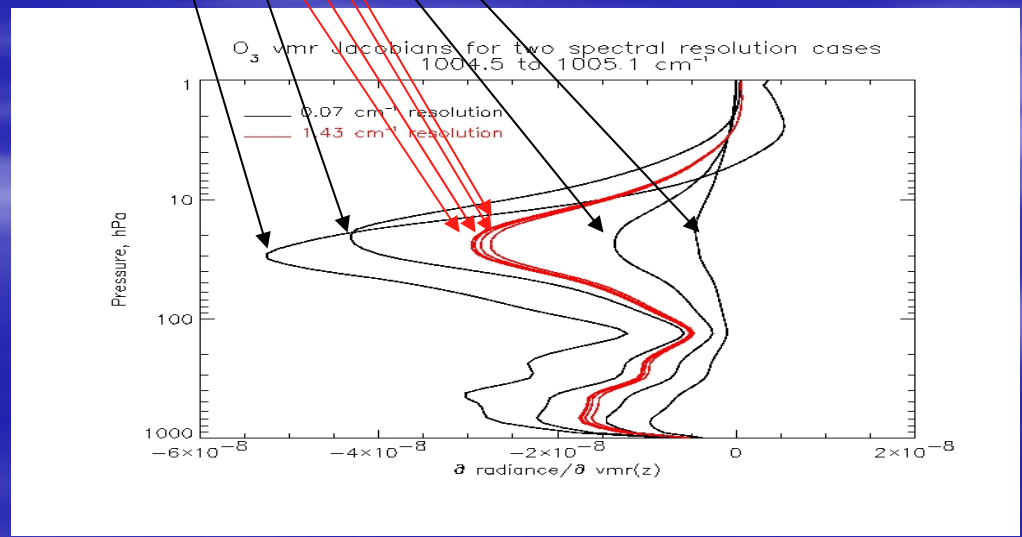
Or they can be more co-located

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

Spectral resolution --> vertical resolution

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



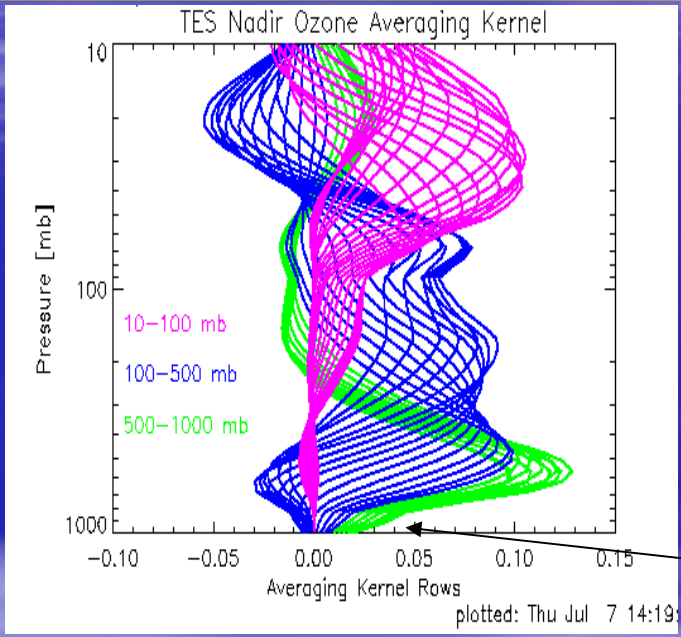


At a spectral resolution of 0.07 cm^{-1}, the spectral radiances respond differently to changes in the vertical distribution of ozone.

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

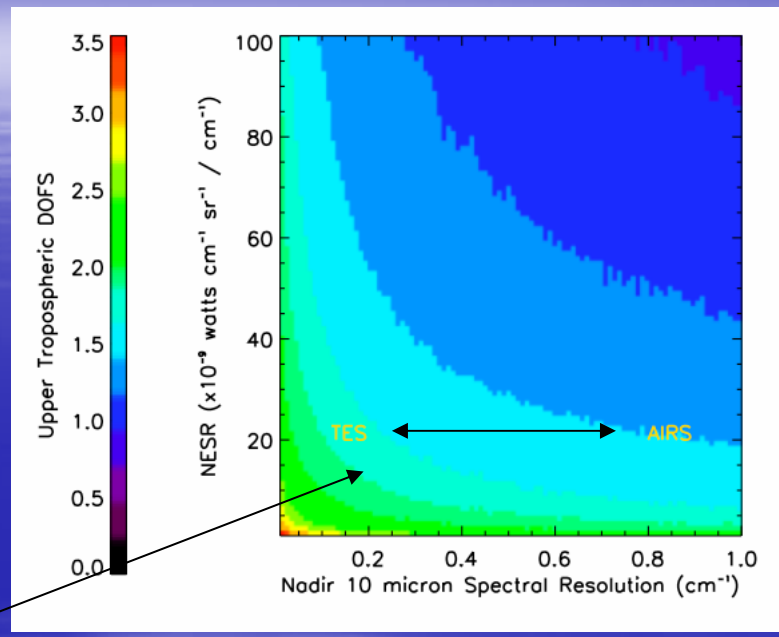
The *what* and *where* of vertical resolution

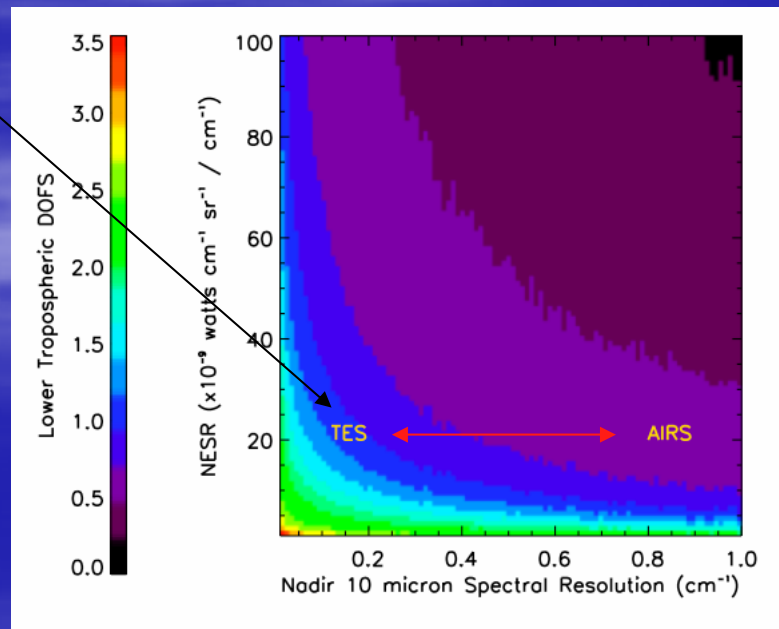
For the thermal infrared, spectral resolution and noise provide bounds for both *what* and *where* vertical resolution is obtainable



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

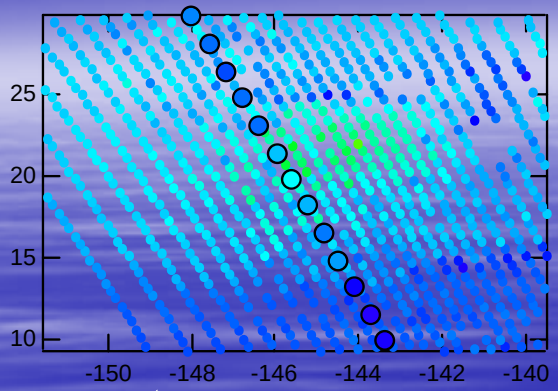




The averaging kernel characterizes the sensitivity of an ozone profile estimate to variations in the fine structure of the true atmospheric state.

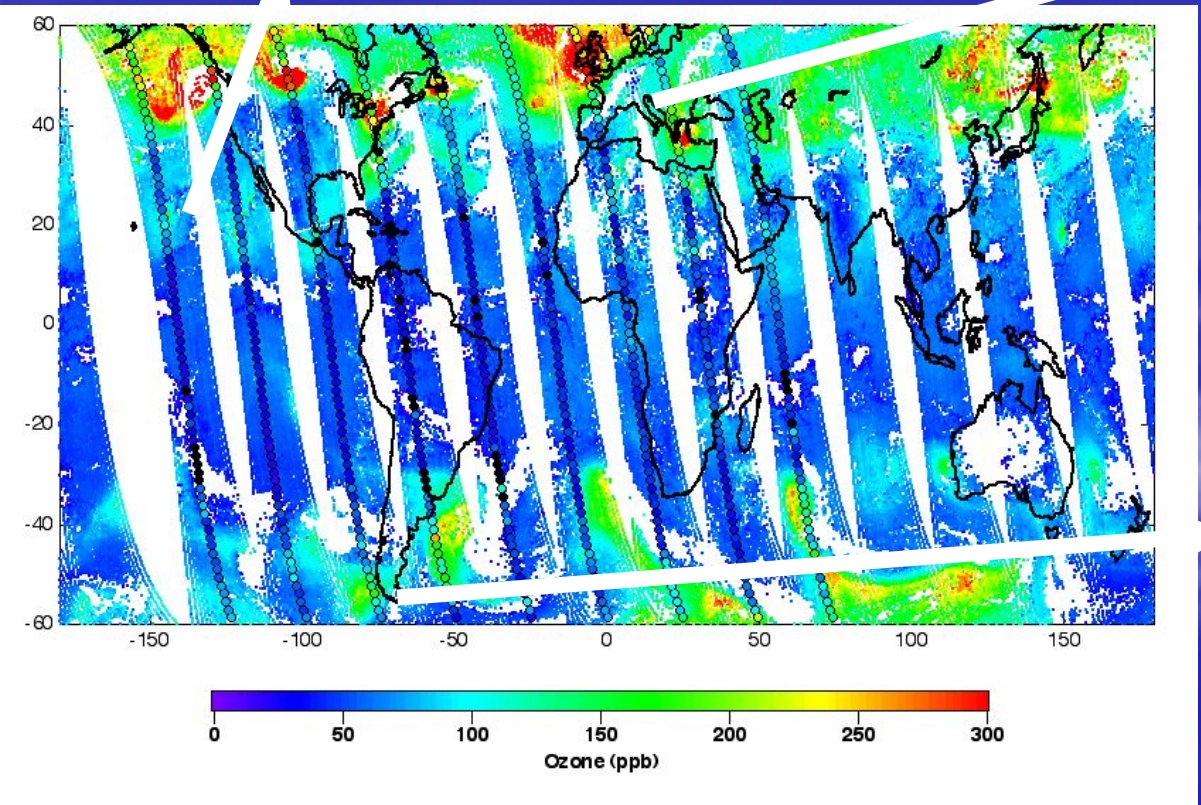
The peaks and widths of the kernel define the location and degree of vertical resolution

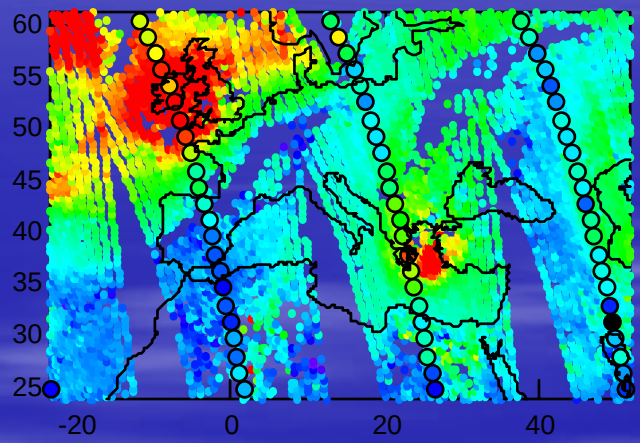
Key observational *desirderatum*: spatial coverage

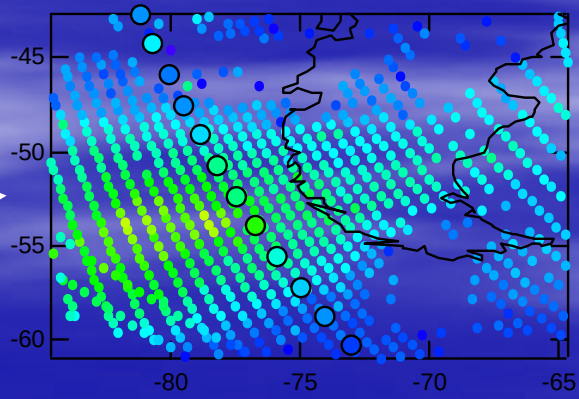


AIRS and TES capture the same dynamic events at mid and high latitudes

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 is necessary for thermal infrared spectrometers such as TES to achieve sensitivity to the vertical structure of ozone
- TES lacks the spatial coverage of lower spectral resolution grating spectrometers such as AIRS
- Thermal infrared observations from instruments such as TES and AIRS are intrinsically 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 processes, which would include wavelengths outside of the thermal infrared.