Experience and Expectations with ATMOS and TES

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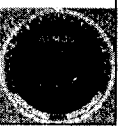
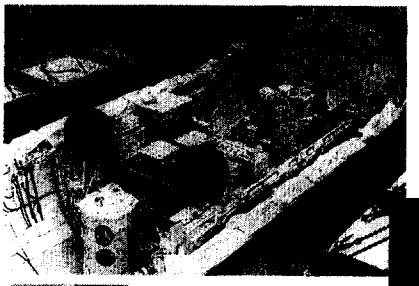
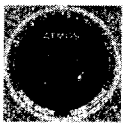
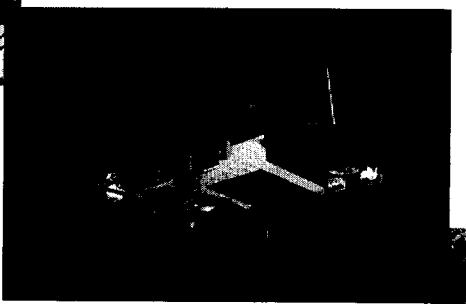


Remote sensing of trace gases in the troposphere







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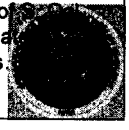
Clouds at high spatial resolution

GOES-9 image o
Coast and the Ca
eddy at 1 km res



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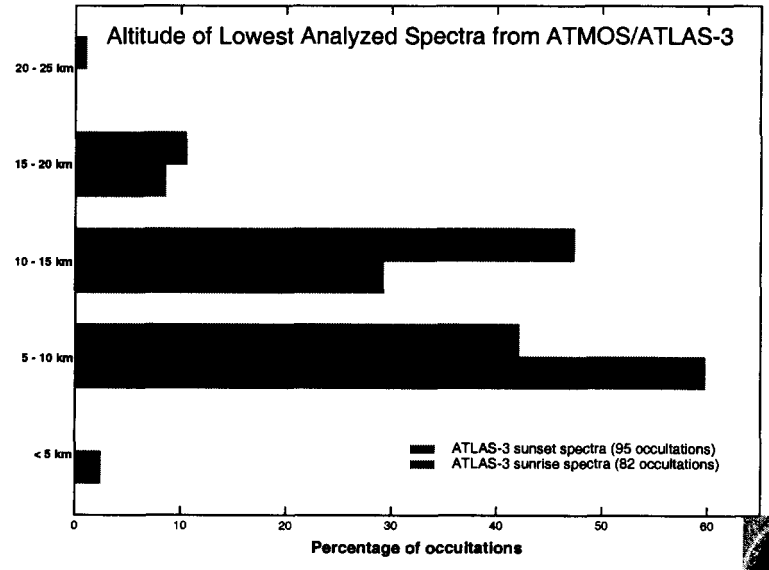

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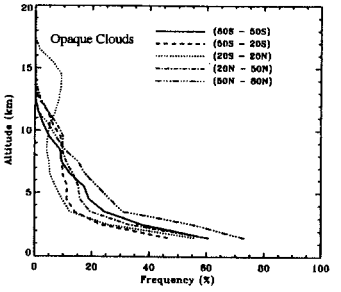
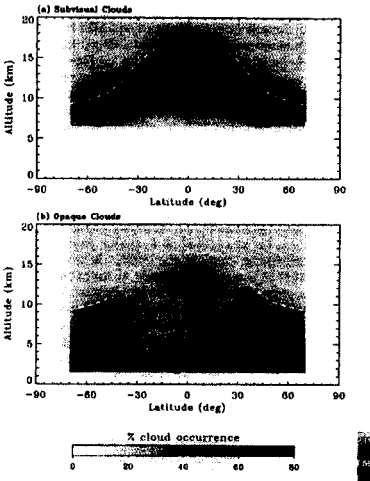
Bar chart of lowest spectra from ATMOS/ATLAS3

Clouds as seen by SAGE

- Measurements at 0.5 and 1.02 μm; 0.5km vertical resolution
- In 88-89, 87% of obs had clouds



Wang et al., 1995



Wang et al.,

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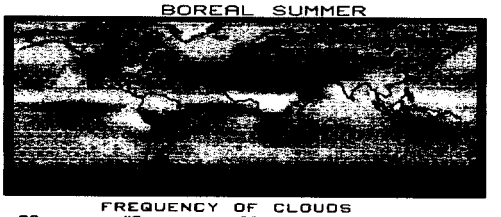
Clouds statistics from nadir



Wylie et al., 1999

- From HIS data clear sky occurrence:
  27% of boreal summer
  24% of boreal winter
- From MODIS data:

Resolution(km)	Percent clear over ocean
17	6.1
21	4.7
24	3.6

- Warren et al.'s compilation of observer reports says, on average, 39% of the Earth's oceans are cloud-free

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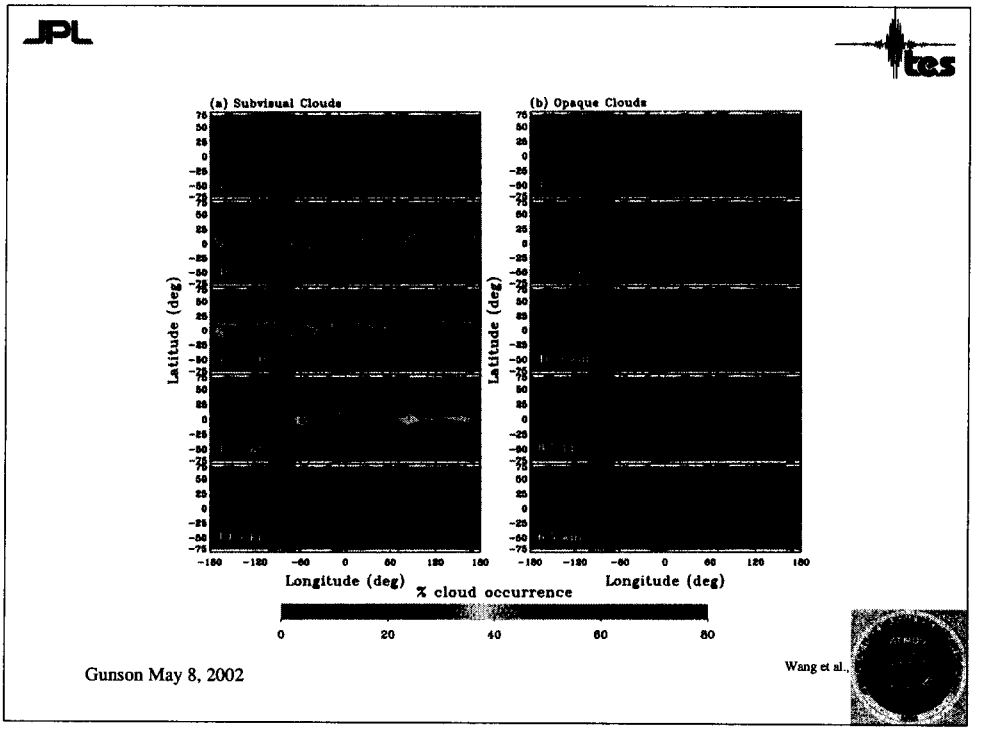

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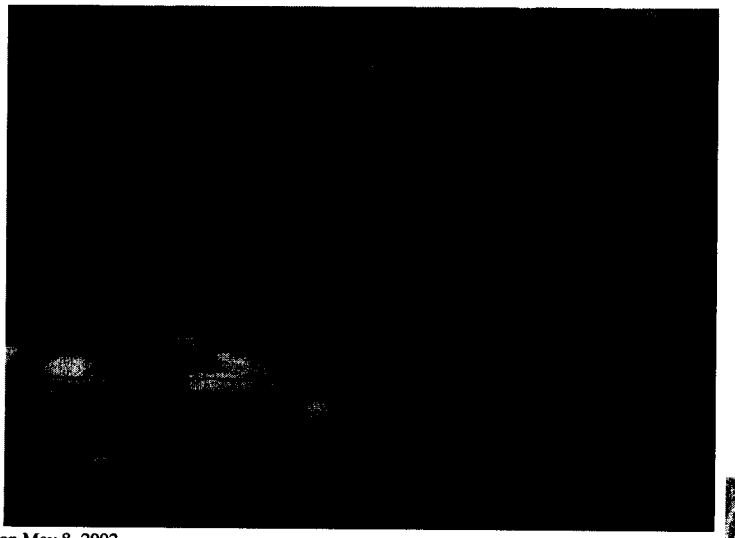
Wang et al.

Satellite image for an ATMOS obs.



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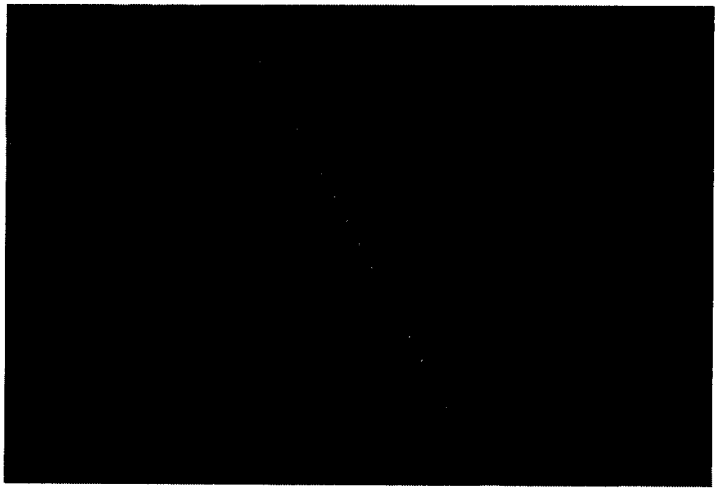
Lines of sight for ATMOS obs.



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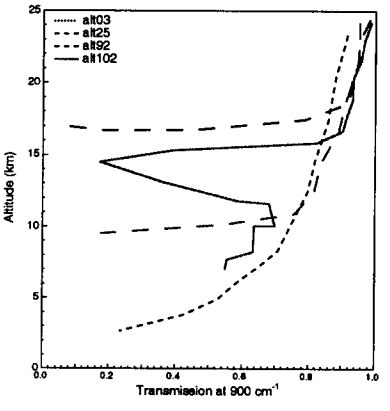
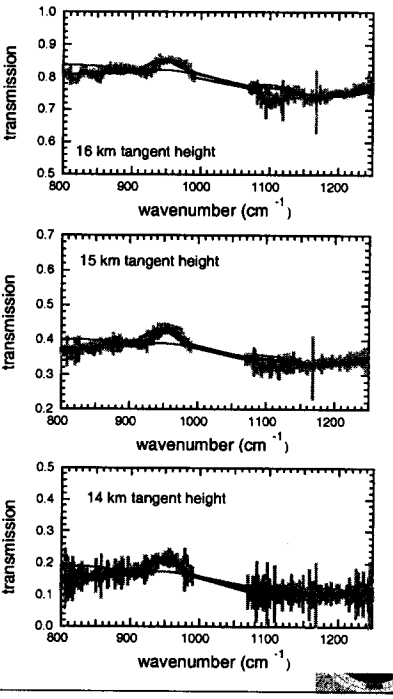
Evidence of clouds in ATMOS spectra





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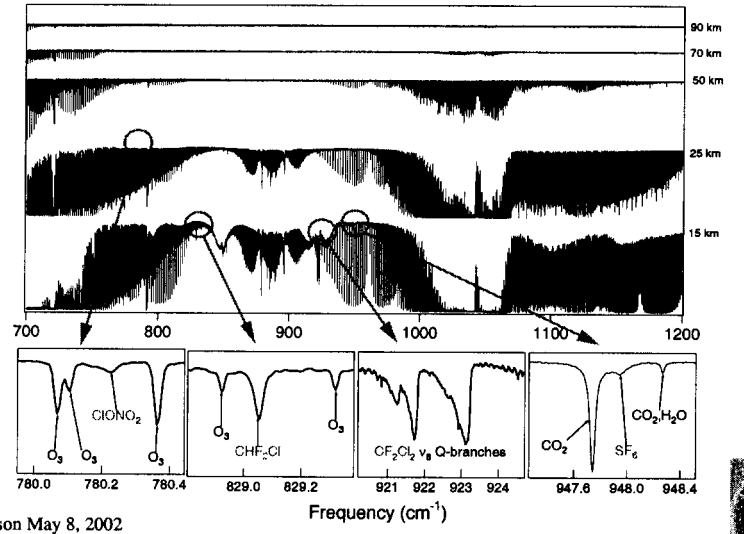
Typical ATMOS Spectra

The upper figure shows the decreasing absorption with altitude, while the bottom figures illustrate spectral features used for trace gas profile retrievals. For clarity, vertical scales differ among the displayed spectra.



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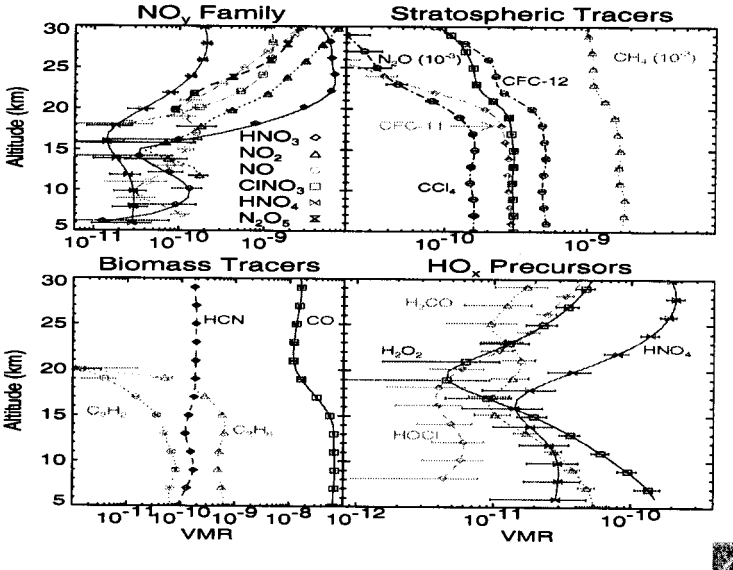
Typical ATMOS Spectra



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NOy, HOx, Stratospheric and Biomass tracers

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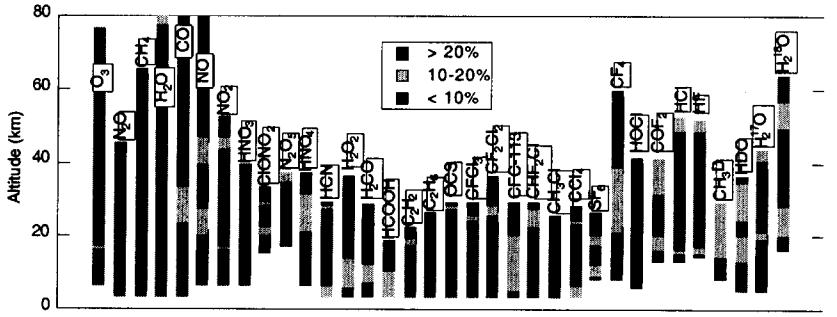
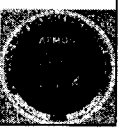
ATMOS has great sensitivity to many gases





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Gas Spectral Ranges

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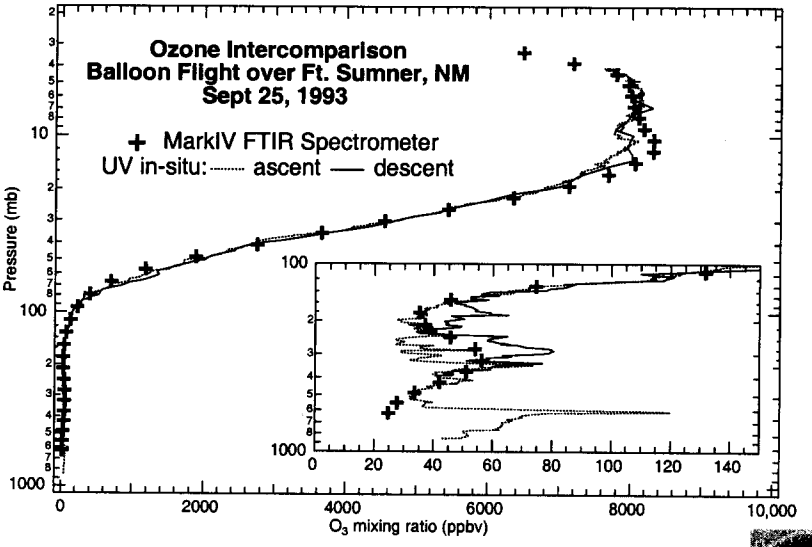

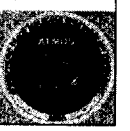

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MkIV/UV ozone intercomparison

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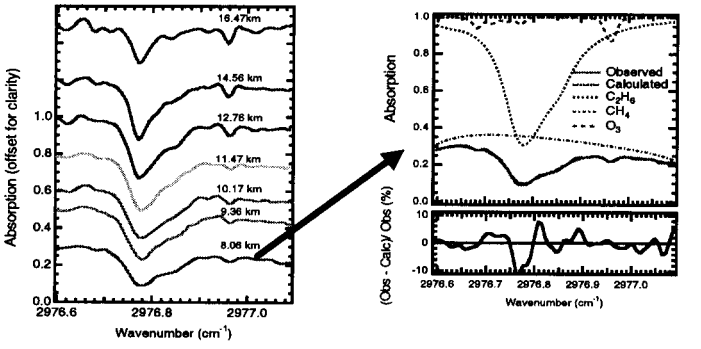
Sample fitting of a C_2H_6 microwindow at a tropospheric altitude from ATMOS ATLAS-3



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Sample fitting of C2H6 microwindow

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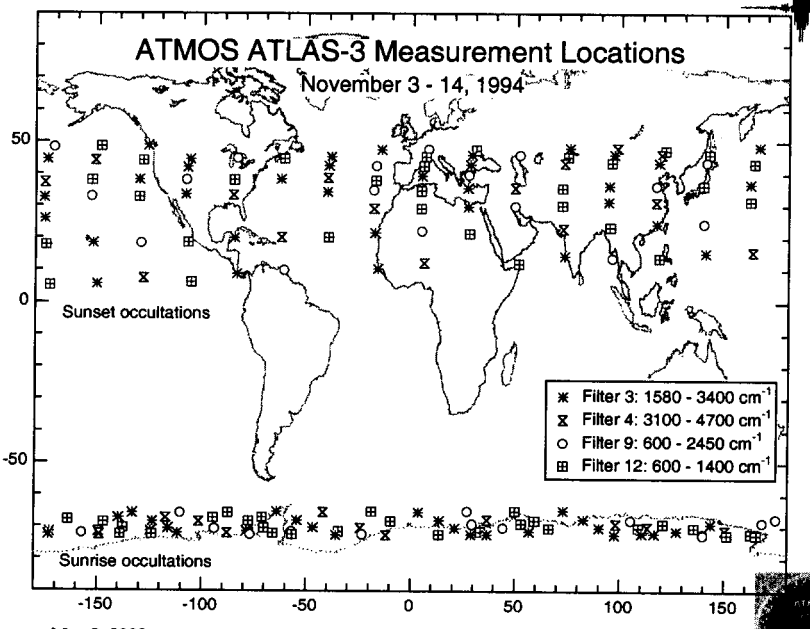
ATMOS ATLAS-3 Measurement Locations

November 3 - 14, 1994



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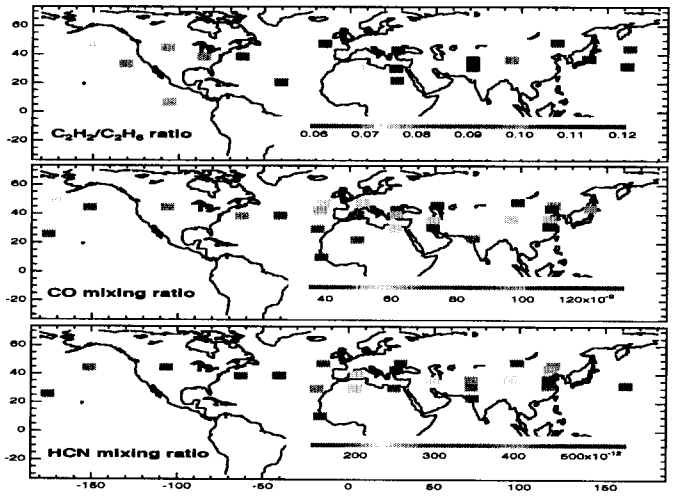
ATMOS ATLAS-3 Observations at 340K Potential Temperature Surface



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C2H2/C2H6, CO, HCN at 340K

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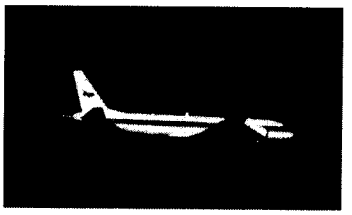
Comparison of ATMOS and SONEX Results

ATMOS ATLAS-3 Flight on STS-66
November 4 - 14, 1994

Covered northern mid-latitudes and southern high latitudes (in and out of polar vortex).

SONEX (SASS Ozone and Nitrogen Oxide Experiment)
October 7 - November 10, 1997
Suite of in-situ instruments measuring aerosols and gases controlling ozone, odd nitrogen and active nitrogen (NO_y) in and out of high air traffic corridors in North Atlantic.



While not temporally co-located, similar locations and time between SONEX and ATMOS/ATLAS-3 provide an excellent oppor preliminary validation of ATMOS tropospheric measurements.

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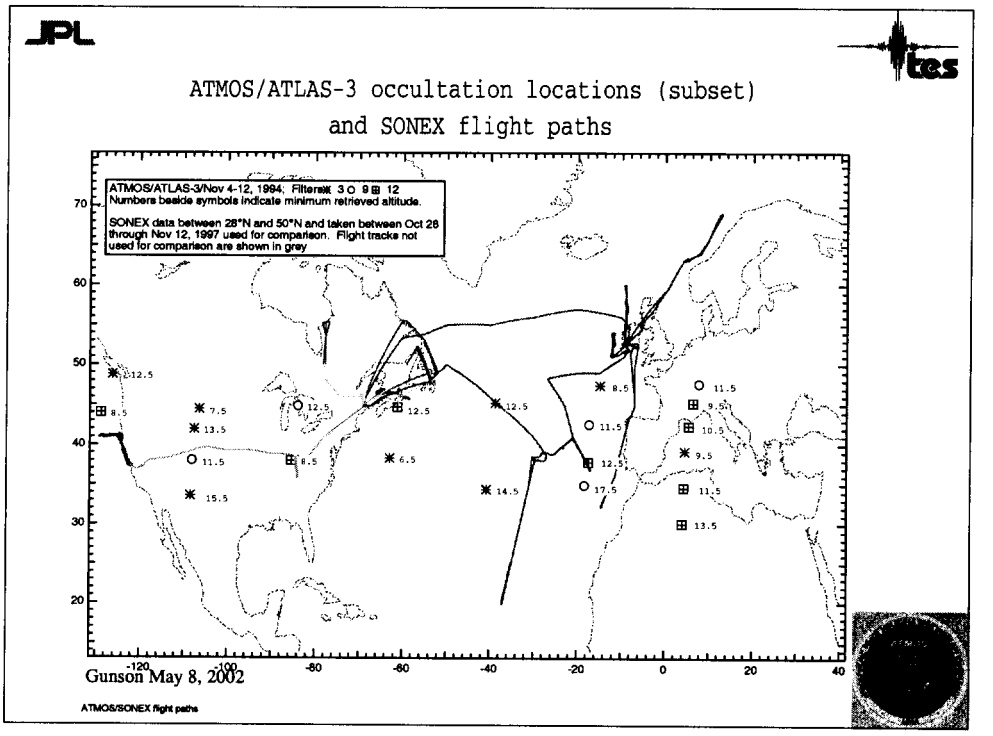
ATMOS/SONEX title page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tes
ATMOS/ATLAS-3 occultation locations (subset)
and SONEX flight paths
ATMOS/ATLAS-3/Nov 4-12, 1994; Filters: 3 O 9 ⊞ 12
Numbers beside symbols indicate minimum retrieved altitude.
SONEX data between 28°N and 50°N and taken between Oct 26 through Nov 12, 1997 used for comparison. Flight tracks not used for comparison are shown in grey
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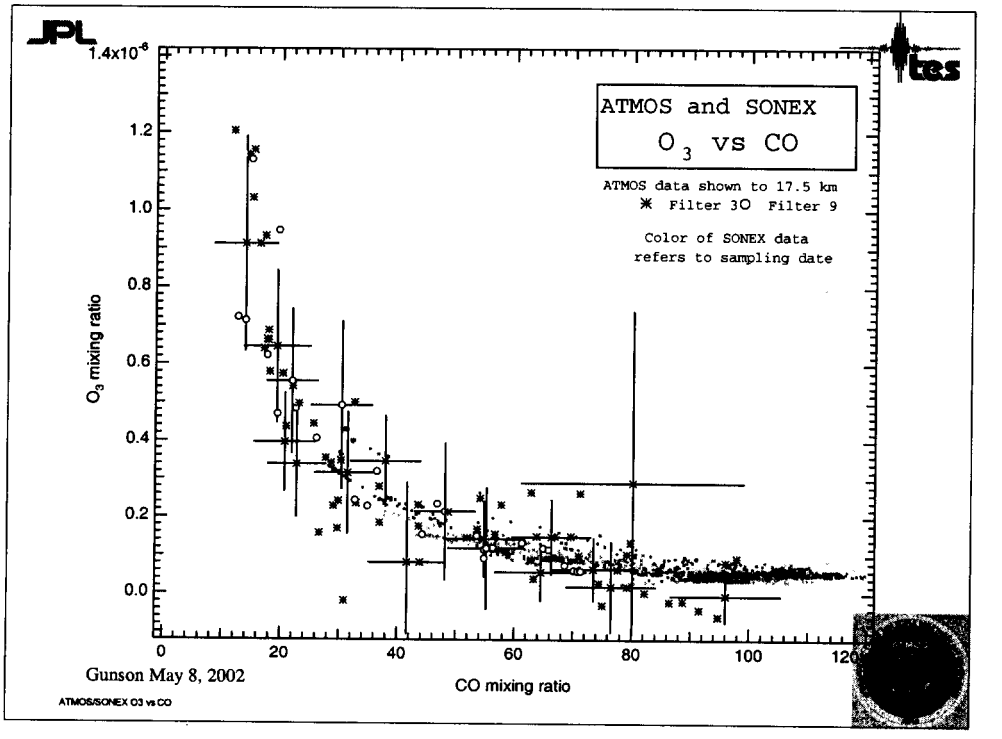
ATMOS/SONEX flight paths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ATMOS and SONEX
O3 vs CO
ATMOS data shown to 17.5 km
Filter 3O Filter 9
Color of SONEX data
refers to sampling date
O3 mixing ratio
CO mixing ratio
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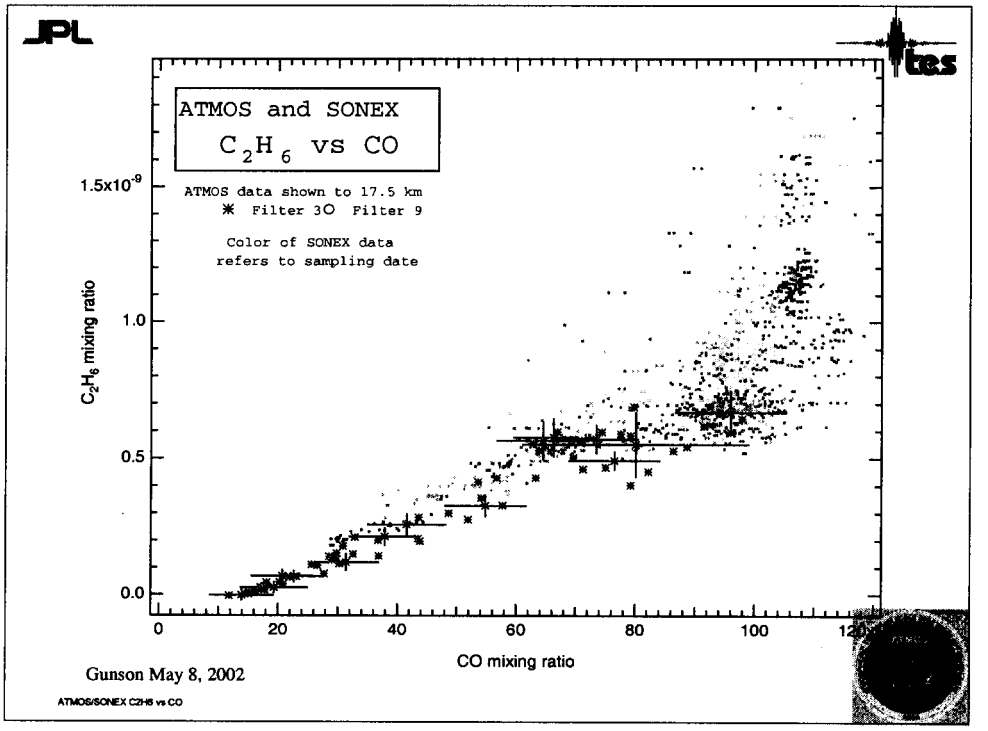
ATMOS/SONEX O3 vs CO


JPL
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ATMOS and SONEX
C_2H_6 vs CO
ATMOS data shown to 17.5 km
* Filter 3O Filter 9
Color of SONEX data
refers to sampling date
1.5x10^{-9}
1.0
0.5
0.0
C_2H_6 mixing ratio
0
20
40
60
80
100
CO mixing ratio
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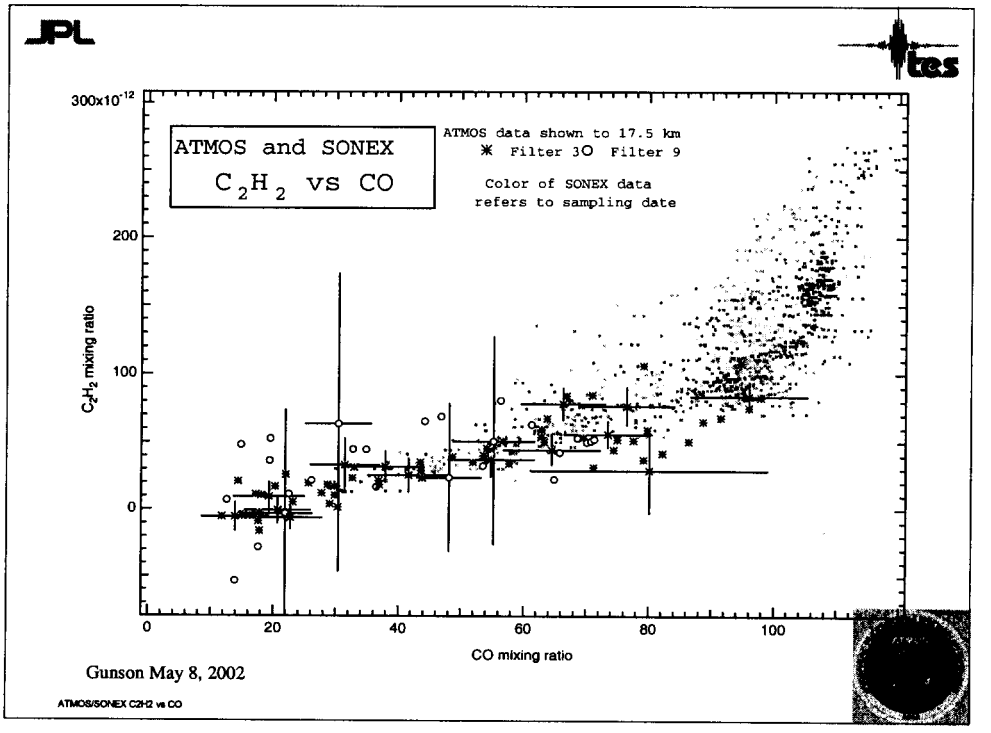
ATMOS/SONEX C2H6 vs CO


JPL
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ATMOS and SONEX
C_2H_2 vs CO
ATMOS data shown to 17.5 km
* Filter 3O Filter 9
Color of SONEX data
refers to sampling date
300x10^{-12}
200
100
0
C_2H_2 mixing ratio
0
20
40
60
80
100
CO mixing ratio
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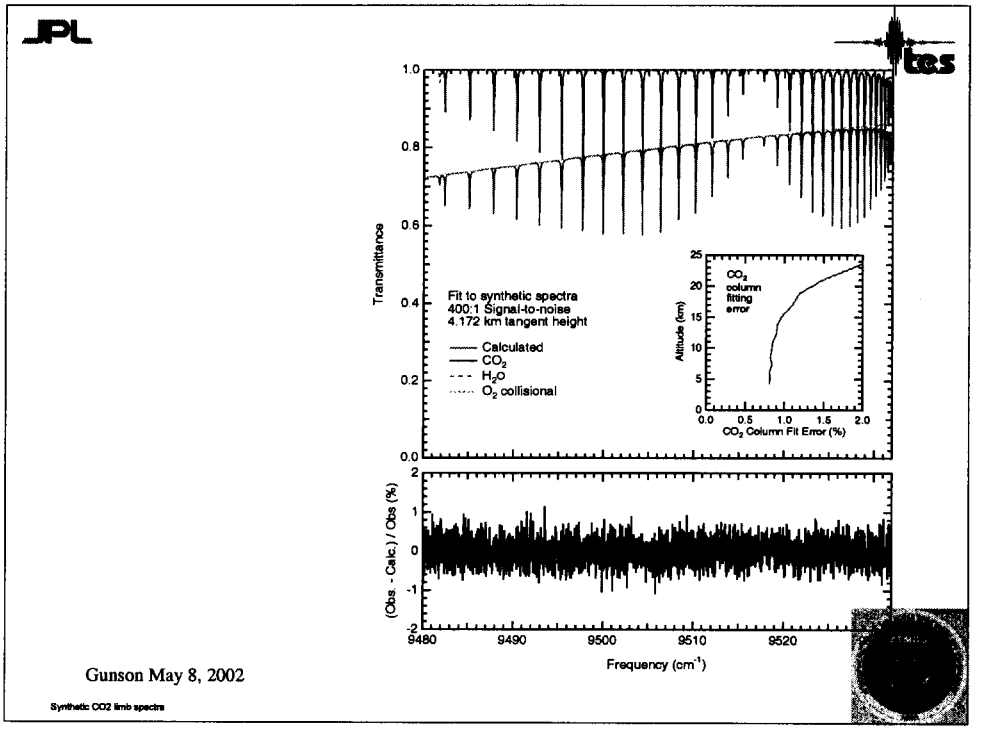
ATMOS/SONEX C2H2 vs CO


JPL
tes
Transmittance
Fit to synthetic spectra
400:1 Signal-to-noise
4.172 km tangent height
Calculated
CO_2
H_2O
O_2 collisional
CO_2 column fitting error
Altitude (km)
CO_2 Column Fit Error (%)
(Obs. - Calc.) / Obs (%)
Frequency (cm^{-1})
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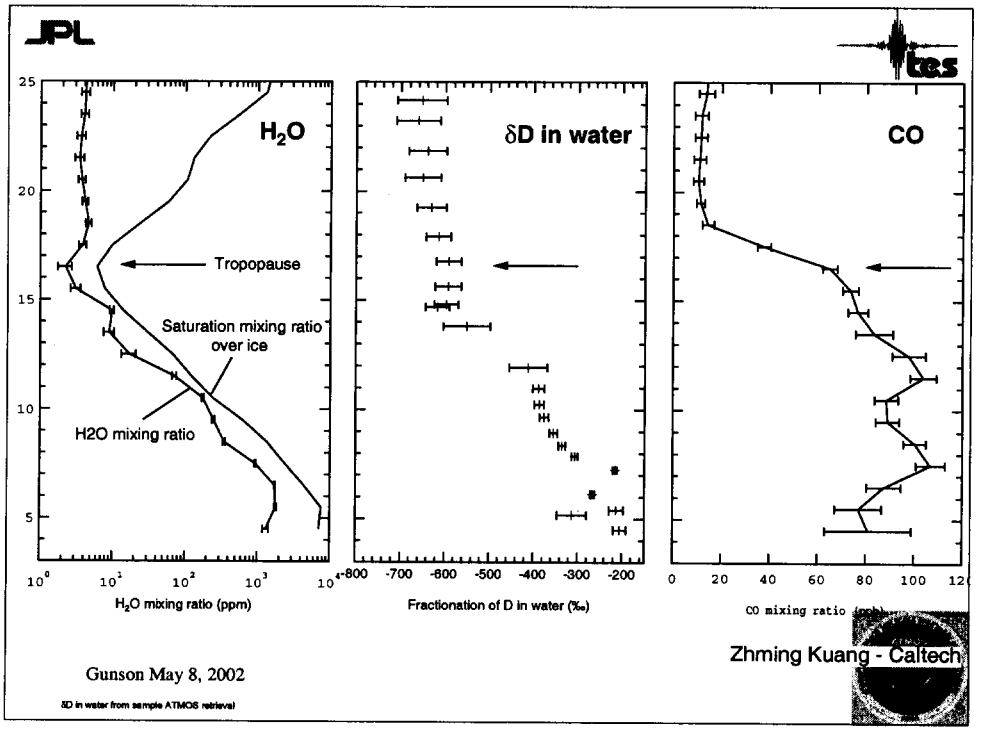
Synthetic CO2 limb spectra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H_2O
Tropopause
Saturation mixing ratio over ice
H2O mixing ratio
H_2O mixing ratio (ppm)
δD in water
Fractionation of D in water (‰)
CO
CO mixing ratio
Zhming Kuang - Caltech
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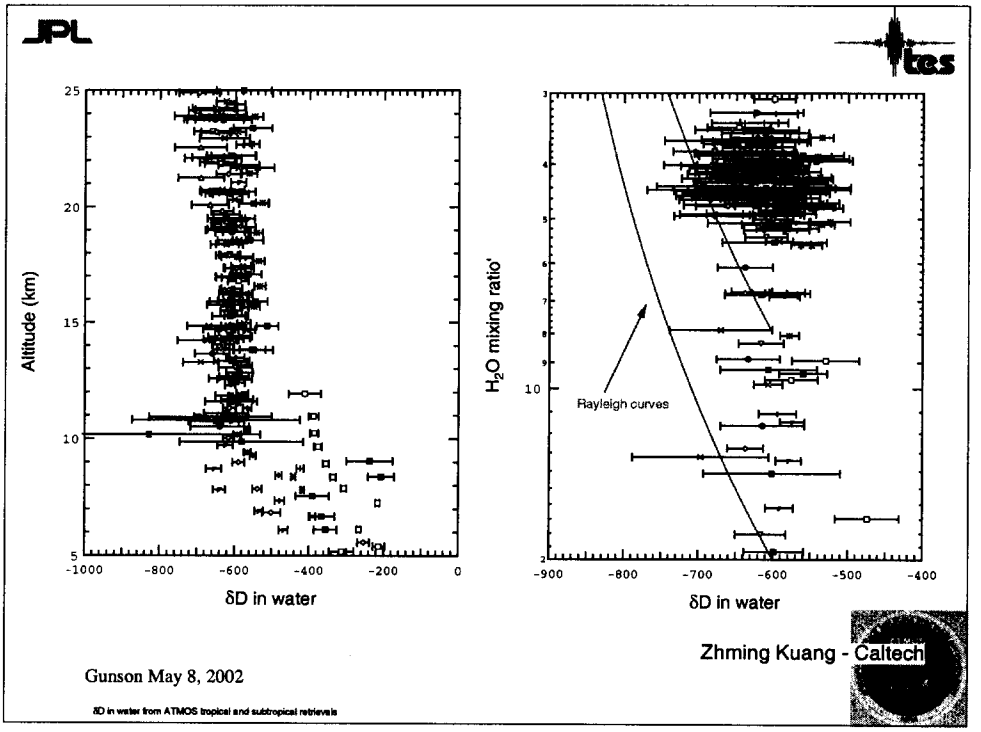
δD in water from sample ATMOS retrieval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Altitude (km)
δD in water
H_2O mixing ratio'
Rayleigh curves
δD in water
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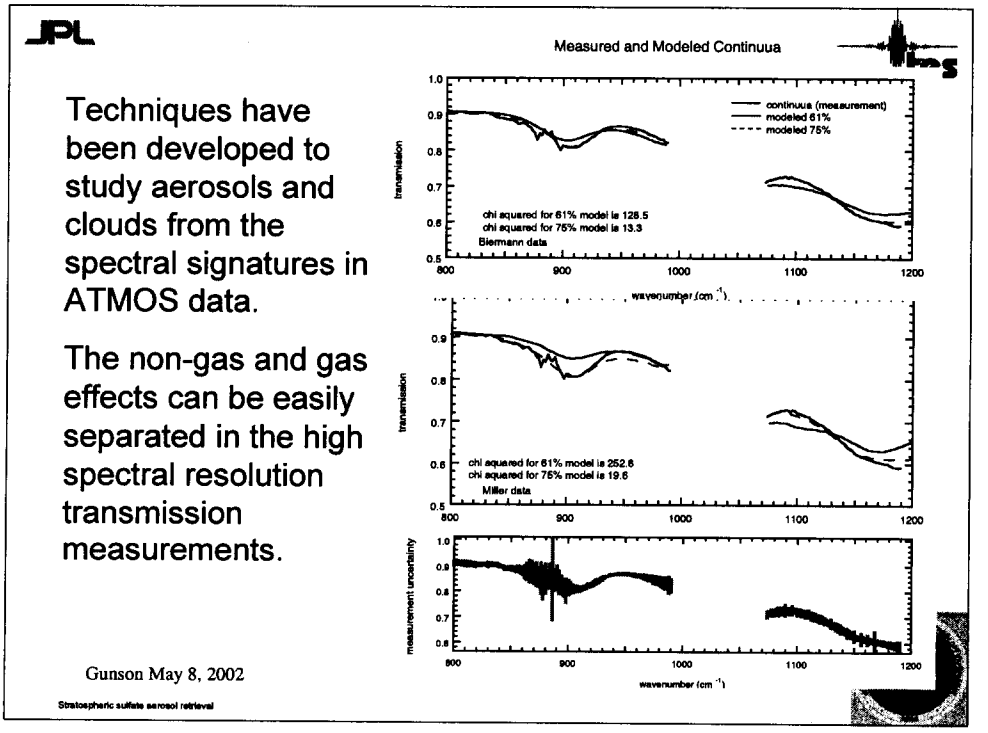
δD in water from ATMOS tropical and subtropical retrievals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Techniques have been developed to study aerosols and clouds from the spectral signatures in ATMOS data.
The non-gas and gas effects can be easily separated in the high spectral resolution transmission measurements.
Measured and Modeled Continuua
tes
continuua (measurement)
modeled 61%
modeled 75%
chi squared for 61% model is 128.5
chi squared for 75% model is 13.3
Biermann data
chi squared for 61% model is 252.6
chi squared for 75% model is 19.6
Miller data
transmission
measurement uncertainty
wavenumber (cm⁻¹)
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Stratospheric sulfate aerosol retrieval

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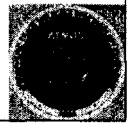
Clouds in ATMOS

- Rinsland et al (1998) studied the 1994 data from ATMOS, examining vertical dependence of extinction and relative signals in the 8-12 μm band.
- Kahn et al (2002) investigated broken and opaque clouds using geostationary satellite data, brightness temperatures, spectral fits with ice model and vertical dependence of extinction. Cloud presence was verified, but cloud microphysical properties clouds not be discriminated.



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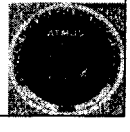
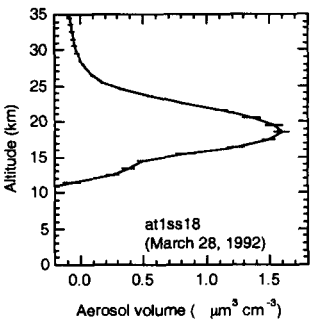
Thin clouds and aerosol

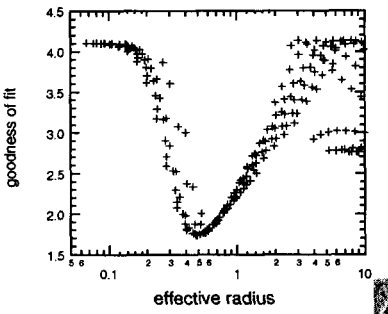
- SAGE reports detection of subvisual cirrus which does not end SAGE measurement
- Few ATMOS measurements show extinction that increases and then decreases
- Stratospheric aerosols are easy to separate because of small gas signal at those tangent altitudes
- Thin clouds difficult for ATMOS - geometry and FOV
- Aerosols in troposphere complicated by water vapor



Stratospheric sulfuric acid

- Can fit spectral shape of SSA in ATMOS data
- Vertical profiles of aerosol volume retrieved
- Composition of sulfuric acid can be determined for post-volcanic loadings
- Effective size is constrained from MkIV due to additional short wavelengths





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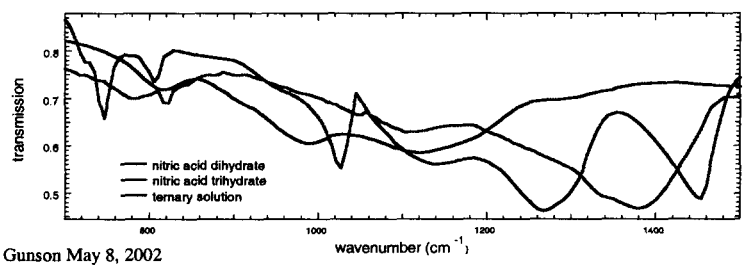
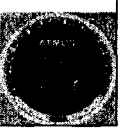
Looking ahead

- PSC measurements with high spectral resolution ir instruments may add insight to composition, but heterogeneity and viewing geometry may present challenges
- Limb thermal emission instruments (TES, MIPAS) should be able to characterize SSA
- Limb viewing of clouds likely to be opaque for thermal emission instruments
- Sensitivity of nadir thermal emission measurements to vertical location of clouds and aerosols is still being studied





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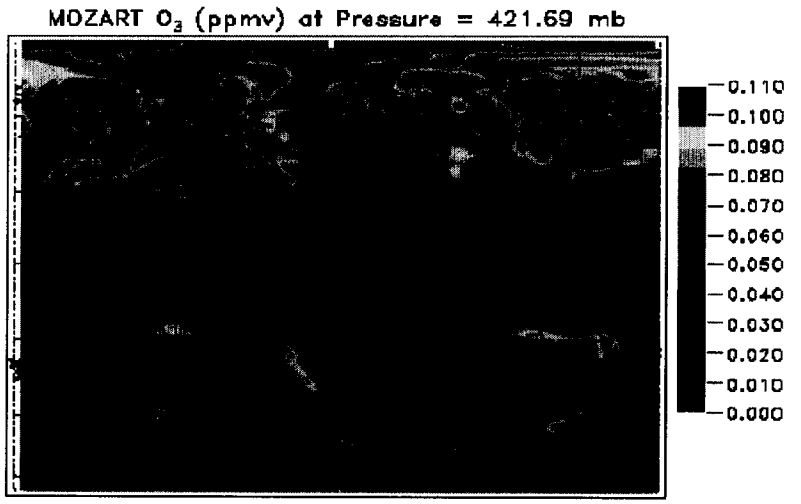
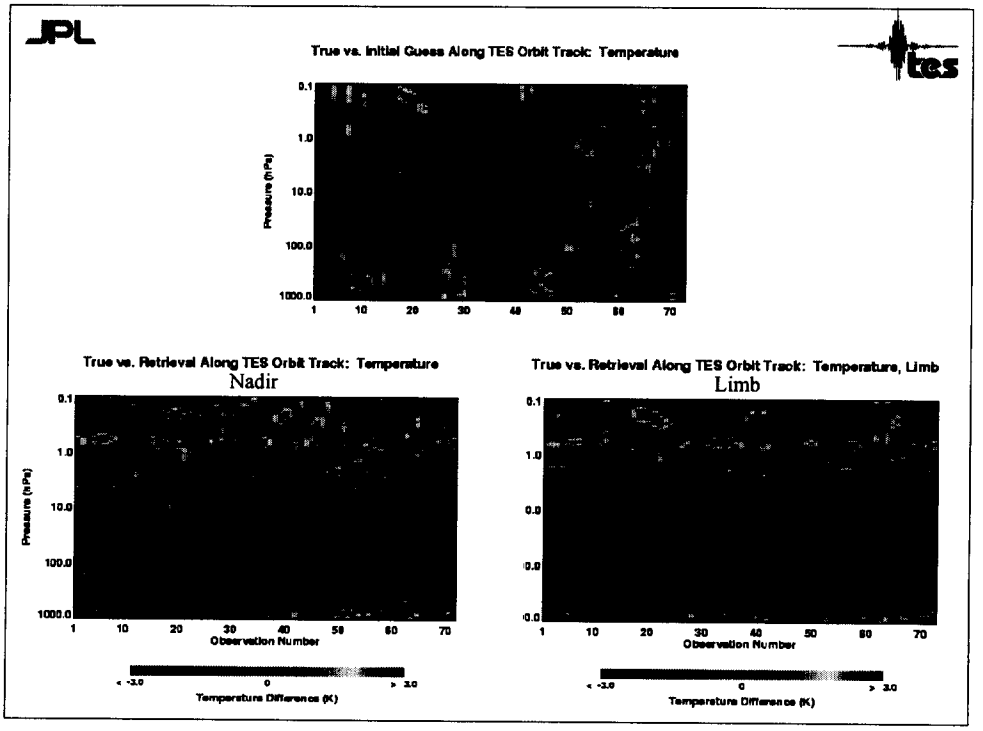
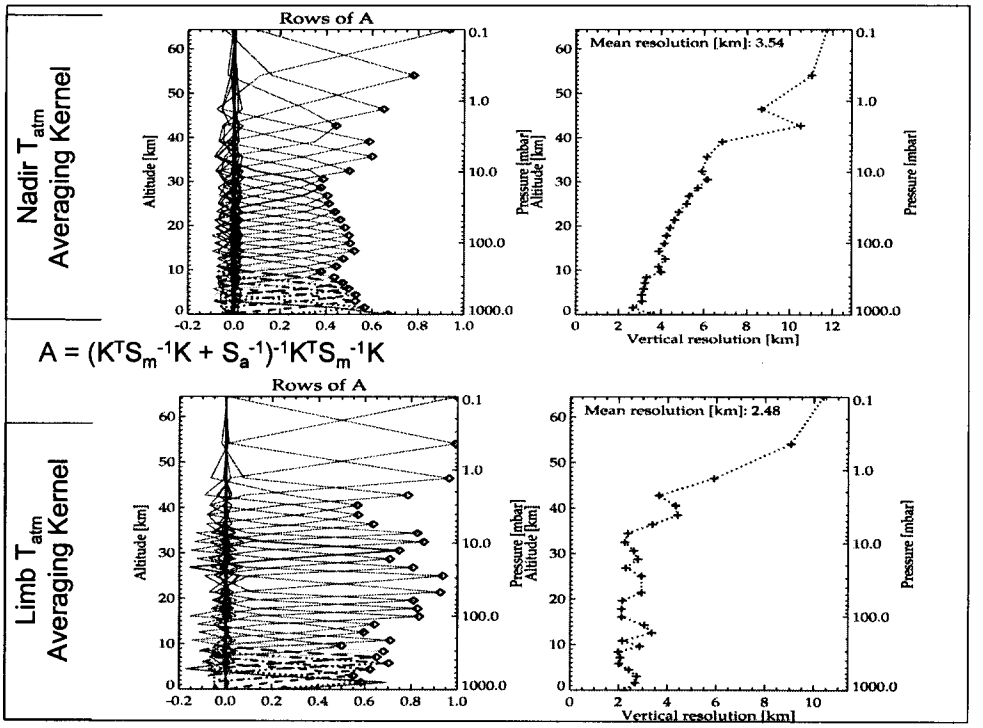
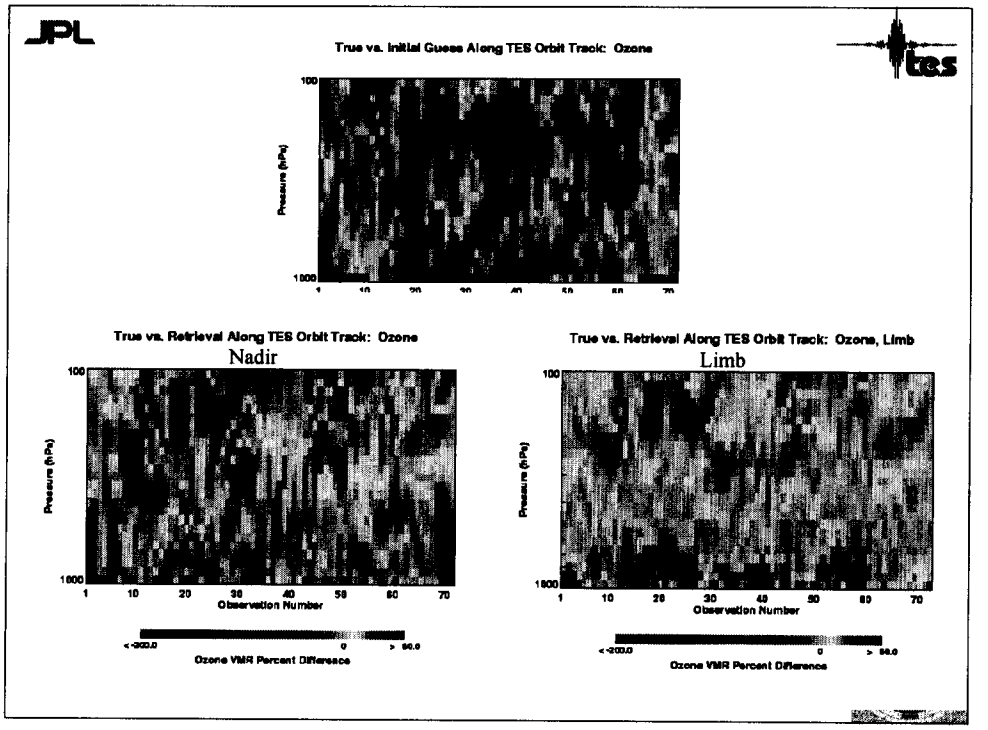
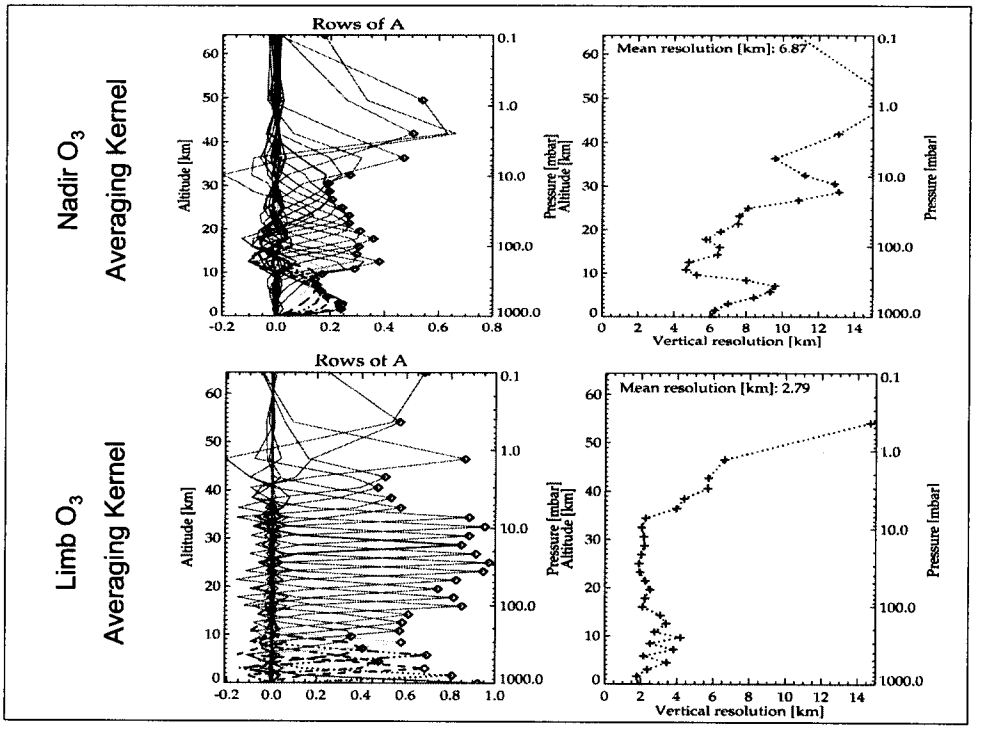


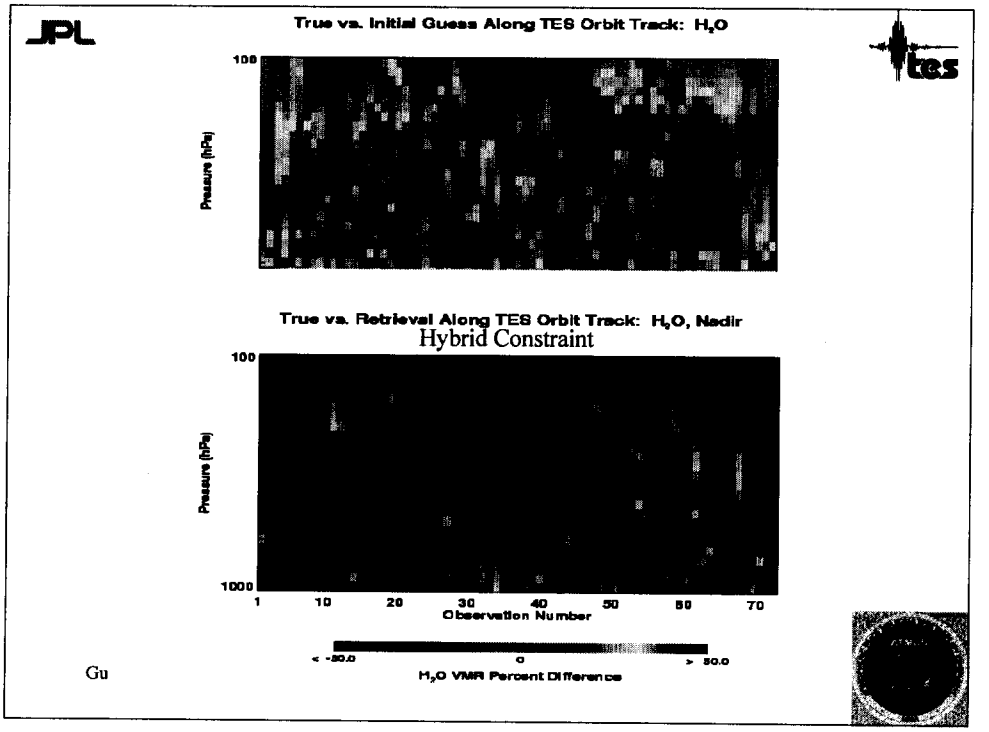
Mozart model for O_3 at 422 mb with TES targets for a single orbit overplotted (**X**)




Nadir T_{atm} Averaging Kernel
Rows of A
Altitude [km]
Pressure [mbar]
Mean resolution [km]: 3.54
Vertical resolution [km]
$A = (K^T S_m^{-1} K + S_a^{-1})^{-1} K^T S_m^{-1} K$
Limb T_{atm} Averaging Kernel
Rows of A
Mean resolution [km]: 2.48
Vertical resolution [km]


JPL
True vs. Initial Guess Along TES Orbit Track: Ozone
Pressure (hPa)
True vs. Retrieval Along TES Orbit Track: Ozone
Nadir
Observation Number
Ozone VMR Percent Difference
True vs. Retrieval Along TES Orbit Track: Ozone, Limb
Limb
Observation Number
Ozone VMR Percent Difference


Nadir O_3
Averaging Kernel
Rows of A
Mean resolution [km]: 6.87
Vertical resolution [km]
Limb O_3
Averaging Kernel
Rows of A
Mean resolution [km]: 2.79
Vertical resolution [km]
Altitude [km]
Pressure [mbar]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True vs. Initial Guess Along TES Orbit Track: H_2O
Pressure (hPa)
True vs. Retrieval Along TES Orbit Track: H_2O, Nadir
Hybrid Constraint
Observation Number
H_2O VMR Percent Difference
Gu

Statistics for Nadir Cases

Temperature Retrievals

Region 17-19 observations each	Tropos. Vertical Resolution (km)	Degrees of Freedom Signal	Tropos. RMS Error (K)
Arctic & Antarctic	3.4	13.8	0.72
Southern Mid- Lat.	3.3	14.8	0.81
Tropics	3.0	16.3	0.76
Northern Mid-Lat.	3.3	15.3	0.82

H_2O Retrievals

Region 17-19 observations each	Tropos. Vertical Resolution (km)	Degrees of Freedom Signal	Total Column Error (%)
Arctic & Antarctic	5.1	4.8	10.4
Southern Mid- Lat.	3.8	3.0	2.6
Tropics	3.8	4.6	3.5
Northern Mid-Lat.	3.8	3.9	6.1

O_3 Retrievals

Region 17-19 observations each	Tropos. Vertical Resolution (km)	Degrees of Freedom Signal	Total Column Error (%)
Arctic & Antarctic	6.0	6.4	1.3
Southern Mid- Lat.	6.7	7.1	0.78
Tropics	7.2	7.8	0.53
Northern Mid-Lat.	6.7	7.4	0.45

CH_4 Retrievals

Region 17-19 observations each	Tropos. Vertical Resolution (km)	Degrees of Freedom Signal	Total Column Error (%)
Arctic & Antarctic	6.5	4.5	1.0
Southern Mid- Lat.	6.7	4.9	0.7
Tropics	6.3	5.9	1.7
Northern Mid-Lat.	6.3	5.3	1.1

Average Values for 73 Limb Cases

Retrieved Species	Errors (True-Retrieved)	Degrees of Freedom For Signal	Vertical Resolution (km) (0-33 km)
T_atm	0.56 K (0-33 km)	20.2	2.50
O_3	1.0 % (column)	20.2	2.72
HNO_3	8.6 % (column)	12.1	3.28

Characterization of limb capabilities continues

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TES will have sensitivity to:

CO

C_2H_2

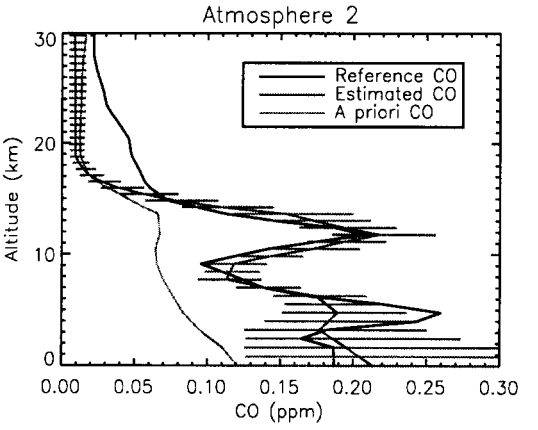
C_2H_4

C_2H_6

PAN

Halogens

and more.....



Gunson May 8, 2002

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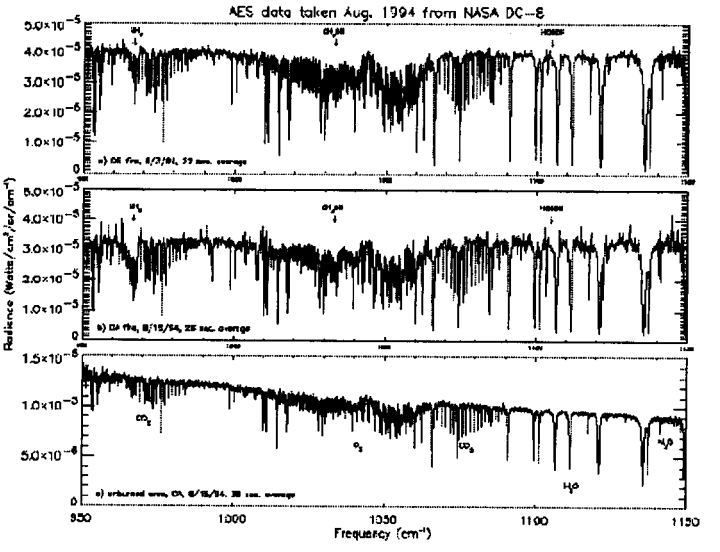

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In summary

- High spectral resolution mid IR solar occultation and thermal emission measurements allow for the observation of many trace gases on a global scale
- Statistics on encountering clouds from SAGE and ATMOS show that they will probe into the free tropospheric on a reasonably frequent basis
- At the limb, the opacity of the atmosphere at these mid-IR wavelengths precludes useful observations of the boundary layer but the near-IR is a better region for CO_2 etc. (if we can understand the radiative transfer effect of thin aerosols and clouds in retrieval algorithms)
- Nadir observations will provide measurements of the distribution some important trace gases in the boundary layer, e.g., O3 and CO - we may be able to measure other surface source gases in plumes or similar circumstances

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- The experience by MODIS, AIRS and other EOS instruments on the distribution of clouds and frequency of observation of clear sky conditions needs to be appreciated. Clear sky observations over ocean represent the simplest geophysical conditions for remote sensing measurements. TES will learn a great deal from this experience.
- We are only just coming to terms with the impact of thin clouds or aerosols on retrievals of trace gas abundances in the boundary layer, or indeed what we might learn about the clouds or aerosols themselves
- The measurement frequency has an obvious impact on what we can or might learn in model analyses BUT
- It is important to have a concerted and highly coordinated approach to answering any scientific questions in tropospheric chemistry by ground, aircraft, satellite based observations with model analyses