Experience and Expectations with ATMOS and TES

Michael R. Gunson
Jet Propulsion Laboratory
California Institute of Technology
Tel: 818 354 2124
Michael.Gunson@jpl.nasa.gov

Gunson May 8, 2002

Remote sensing of trace gases in the troposphere

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Clouds at high spatial resolution

Altitude of Lowest Analyzed Spectra from ATMOS/ATLAS-3

- ATLAS-3 sunset spectra (95 occultations)
- ATLAS-3 sunrise spectra (82 occultations)

Percentage of occultations

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Clouds as seen by SAGE
Satellite image for an ATMOS obs.
Lines of sight for ATMOS obs.

Evidence of clouds in ATMOS spectra
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.
ATMOS has great sensitivity to many gases

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Ozone Intercomparison
Balloon Flight over Ft. Sumner, NM
Sept 25, 1993

+ Mark IV FTIR Spectrometer
UV in-situ: ascent — descent

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Sample fitting of a C$_2$H$_6$ microwindow at a tropospheric altitude from ATMOS ATLAS-3

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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$_x$) 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 opportunity for preliminary validation of ATMOS tropospheric measurements.

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ATMOS/ATLAS-3 occultation locations (subset) and SONEX flight paths

ATMOS data shown to 17.5 km
Filter 3O Filter 9
Color of SONEX data refers to sampling date
Filter 30 Filter 9

Color of SONEX data refers to sampling date.

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H2O

Saturation mixing ratio over ice

H2O mixing ratio

10^5 10^6 10^7 10^8

H2O mixing ratio (ppm)

δD in water

Fractionation of D in water (%)

CO

CO mixing ratio

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3D in water from samples from JPL water
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.
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 could not be discriminated.

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

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**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

![Graph showing vertical profiles of aerosol volume and goodness of fit](image1)

**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

![Graph showing transmission spectra](image2)
Mozart model for O\textsubscript{3} at 422 mb with TES targets for a single orbit overplotted (X)
\[ A = (K^{-1} S_m + S_a^{-1})^{-1} K^{-1} S_m^{-1} K \]
Statistics for Nadir Cases

Temperature Retrievals

<table>
<thead>
<tr>
<th>Region</th>
<th>Tropos. Vertical Resolution (km)</th>
<th>Degrees of Freedom Signal</th>
<th>Tropos. RMS Error (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic &amp; Antarctic</td>
<td>3.4</td>
<td>13.8</td>
<td>0.72</td>
</tr>
<tr>
<td>Southern Mid-Lat.</td>
<td>3.3</td>
<td>14.8</td>
<td>0.81</td>
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<tr>
<td>Tropics</td>
<td>3.0</td>
<td>16.3</td>
<td>0.76</td>
</tr>
<tr>
<td>Northern Mid-Lat.</td>
<td>3.3</td>
<td>16.3</td>
<td>0.82</td>
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</table>

H$_2$O Retrievals

<table>
<thead>
<tr>
<th>Region</th>
<th>Tropos. Vertical Resolution (km)</th>
<th>Degrees of Freedom Signal</th>
<th>Total Column Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic &amp; Antarctic</td>
<td>6.1</td>
<td>4.6</td>
<td>10.4</td>
</tr>
<tr>
<td>Southern Mid-Lat.</td>
<td>3.8</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Tropics</td>
<td>3.8</td>
<td>4.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Northern Mid-Lat.</td>
<td>3.8</td>
<td>5.9</td>
<td>6.1</td>
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</tbody>
</table>

O$_3$ Retrievals

<table>
<thead>
<tr>
<th>Region</th>
<th>Tropos. Vertical Resolution (km)</th>
<th>Degrees of Freedom Signal</th>
<th>Total Column Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic &amp; Antarctic</td>
<td>6.0</td>
<td>6.4</td>
<td>1.3</td>
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<tr>
<td>Southern Mid-Lat.</td>
<td>6.7</td>
<td>7.1</td>
<td>0.78</td>
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<tr>
<td>Tropics</td>
<td>7.2</td>
<td>7.8</td>
<td>0.83</td>
</tr>
<tr>
<td>Northern Mid-Lat.</td>
<td>6.7</td>
<td>7.4</td>
<td>0.46</td>
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CH$_4$ Retrievals

<table>
<thead>
<tr>
<th>Region</th>
<th>Tropos. Vertical Resolution (km)</th>
<th>Degrees of Freedom Signal</th>
<th>Total Column Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic &amp; Antarctic</td>
<td>6.6</td>
<td>4.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Southern Mid-Lat.</td>
<td>6.7</td>
<td>4.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Tropics</td>
<td>6.3</td>
<td>6.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Northern Mid-Lat.</td>
<td>6.3</td>
<td>6.3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Average Values for 73 Limb Cases

<table>
<thead>
<tr>
<th>Retrieved Species</th>
<th>Errors (True-Retrieved)</th>
<th>Degrees of Freedom For Signal</th>
<th>Vertical Resolution (km) (0-33 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T$_{atm}$</td>
<td>0.56 K (0-33 km)</td>
<td>20.2</td>
<td>2.50</td>
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<tr>
<td>O$_3$</td>
<td>1.0 % (column)</td>
<td>20.2</td>
<td>2.72</td>
</tr>
<tr>
<td>HNO$_3$</td>
<td>8.6 % (column)</td>
<td>12.1</td>
<td>3.28</td>
</tr>
</tbody>
</table>

Characterization of limb capabilities continues
TES will have sensitivity to:

CO
C\textsubscript{2}H\textsubscript{2}
C\textsubscript{2}H\textsubscript{4}
C\textsubscript{2}H\textsubscript{6}
PAN
Halogens
and more.....

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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 CO₂ 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 of 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

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