Methane Sensing Flight of Scanning HIS over Hutchinson, KS, 31 March 2001

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Flight of Opportunity with the Scanning High-resolution Interferometer Sounder (S-HIS) and MODIS Airborne Simulator (MAS)

S-HIS for High Spectral Resolution Infrared Sounding

MAS for High Spatial Resolution IR & Vis Images
Overflight of Hutchinson, Kansas, during TX-2001: Brief Summary including Major Finding

**Objective:** Detection of natural gas in the vicinity of Hutchinson, Kansas

**Background:** A series of explosions within the city limits of Hutchinson, Kansas, occurred in January 2001 shortly after natural gas (methane) leaked from an underground storage facility approximately 7 miles northwest of the city. A flight of opportunity was undertaken by the NASA ER-2 to overfly Hutchinson, KS, during the scheduled deployment for the experiment TX-2001.

**Observations:**

- ER-2 successfully overflew Hutchinson, Kansas, on 31 March 2001 at 18:25 UTC.
- Data were collected over the objective by a University of Wisconsin - Madison infrared spectrometer, which has the potential to detect anomalous levels of methane (the Scanning High-resolution Interferometer Sounder, S-HIS).
- Coincident imaging data were collected from the MODIS Airborne Simulator (MAS) along with the VIS video camera and the ER-2’s RC-10 camera.

**Preliminary Analysis:**

- The MAS imagery shows some obscuration of the area by low broken clouds.

- Assessment of the S-HIS data reveals no anomalously high methane amounts in the clear areas. The analysis technique applied, resulting methane maps, and guidelines on detection limits are described in this report.
Mission Daily Summary as Reported in the Field

ER-2 Flight: 01055

Date: Mar 31, 2001


Mission Objectives:
Map water vapor in the Central Facility region of the ARM SGP site for comparisons to MODIS (Terra at 1729 UTC). Overfly Hutchinson, KS, to detect natural gas leaks with SHIS.

Flight Summary:
Take-off was at 1445 UTC. ER-2 landed at 2015 UTC.

ER-2 flew from Kelly AFB northward to four flight lines oriented parallel to Terra orbital track with the westernmost line centered over the ARM SGP Central Facility (36.606 N, 97.485 W). Starting at the western line, flew the four lines and then returned to the westernmost line to begin the sequence again. Skies during the first sequence contained low clouds in southern 1/2 on western leg (Central Facility was partly cloudy) and were mostly cloudy (low clouds) on the other 3 legs. On the 2nd sequence, the westernmost leg was 70% clear (low cloud at far southern end, isolated thin dissipating water cloud), the next leg about 70% clear, and the 3rd leg about 50% clear (spotty thin cloud); the 4th leg was not flown due to cloud cover. The ER-2 met Terra (1729 UTC) at about the position of the Central Facility on the 2nd sequence. After completing the 2nd sequence (about 1815 UTC), the ER-2 flew north to a SE-NW oriented line to overfly (1825 UTC) natural gas vent wells in the Hutchinson, KS, region. Skies were partly cloudy along this short 3 minute line. The ER-2 then turned for base, overflying the Central Facility in clear skies (about 1847 UTC) on the way home.

Highlights:
Clear sky scenes of Central Facility with MODIS overhead. Partly cloudy views of natural gas venting area in KS.

Instrument Status:
Scanner High-Resolution Interferometer Sounder (SHIS): Scan mode. Good Data.
VIS video camera: Operated. Good video collected.
RC-10 Camera: Operated along line over Central Facility during Terra overpass (1722 - 1737 UTC).

Additional Pilot Notes: Much variability in cloud cover. Diminishing cloud cover with time.
ER-2 Flight Track on 31 March 2001, Mapped over the 1732 UTC GOES-8 11µm Image

**Hutchinson, KS**
line flown East to West about an hour later than GOES image
Scanning HIS: ER2 Centerline Pod
(HIS= High-resolution Interferometer Sounder)

Roots:
• U. of Wisconsin HIS Program, 1978-present
• 1st U2/ER2 HIS, 1985-present
• NAST-I, close cousin, for NPOESS testbed (Wingpod)
• First ER-2 Mission: Wintex, 1999

Characteristics:
Spectral Coverage: 3-17 microns
Spectral Resolution: 0.5 cm\(^{-1}\)
Resolving Power: 1000-6000
Footprint Diameter: 2 km
Cross-Track Pattern: Programmable
Swath Width: 30 km
(normal options) or Nadir only
Sample S-HIS Radiances-24 August 2000
SAFARI Terra Overpass-Clear Water

Longwave

Midwave

Shortwave

CO₂

O₃

CH₄/N₂O

H₂O

H₂O

N₂O

CO

CO₂
Comparison of S-HIS Observed Spectrum with Calculation
--Centered near the 7.7 µm methane band
(ARM Atmospheric Profile, climatological CH₄ in LBLRTM)
General Scanning HIS Applications

- Radiances for Radiative Transfer Model Improvements
- Temperature and Water-vapor Retrievals for Meteorological Observations
- Cloud Radiative Properties Characterization
- Surface Emissivity Research, Supporting Land Surface Temperature Retrievals from Space
- **Trace Gas Retrievals**
- Validation for EOS, NOAA & other Satellite Observations (e.g. MODIS, AIRS)
- Studies Supporting Future Instrument Design Optimization (e.g. IPO CrIS)
Theory of Simplified Trace Gas Mapping Technique

The technique to be applied to the Hutchinson, Kansas, observations from the S-HIS instrument is one developed for the NASA SAFARI experiment to map CO distribution from fires. The method makes use of high spectral resolution emission lines observed by the S-HIS spectrometer to derive an optical depth using weak absorption lines. It is less sophisticated than a full profile retrieval approach, but is very useful for a survey result of localized events.

A ratio of on-line to off-line emission for selected lines of the gas of interest provides a measure of the gas amount. The simple form of the equations can easily be derived from a single-layer atmosphere approximation.

The equation used for the Optical Depth in this analysis is:

\[ OD = - \ln (\tau) = - \ln \left( \frac{N_{\text{on}} - B(T_A)}{N_{\text{off}} - B(T_A)} \right) \]

where \( \tau \) is the atmospheric transmission for selected wavenumbers, \( N \) is the S-HIS observed upwelling spectral radiance, and \( B(.) \) is the Planck emission function at a temperature \( T_A \) which approximates the mean atmospheric temperature.
Methane Sensitive Wavenumbers

Radiance
(mW/m² sr cm⁻¹)

“Off-line” References

Wavenumber (cm⁻¹)

Selected weak lines isolated from water-vapor lines

2 Mapping Channels

MidLatitude Summer Calculations, nadir viewing from 20 km, SHIS resolution

with methane
without methane
Following Analyses Demonstrate:

- Sensitivity to several % elevations in total column methane (based on angle-dependent cross-track results)
- Good immunity of methane maps to contamination by water-vapor variations (interfering species for methane spectral absorption features)
- Partial obscuration of the target area by clouds
- No substantial elevation of large-scale methane optical depth over climatological values in clear areas
- However, our detection limit does not preclude a relatively large mixing ratio in a thin layer [e.g. a 50% increase (0.8 ppmv) in the lowest 0.5 km changes total optical depth by only 3% and is close to the detection limit]
Methane Map including Hutchinson, KS (grid location 30, S7) --No elevated regions identifiable

Relative Optical Depth Scale (CH$_4$ OD x 0.76; H$_2$O OD x 1)
S-HIS Methane Map compared to MAS 8.6 µm Image
--Clouds cause lower apparent optical depth

Hutchinson

Yaggy
gas storage
field
Methane Map including Hutchinson, KS, 3-31-01
--Grid with 2-km footprints; 1230.0, 1241.1 cm$^{-1}$ methane lines
Methane Map for a Clear Scene (see MAS 8.6 µm Image)
Clear segment, flying south to ARM site, 3-31-01 1844 UTC

20 km N of DOE ARM Central Facility
Methane Map Sensitivity

Cross-track “limb darkened” by ~15% (upper) & flattened (lower)

--Demonstrates sensitivity to 3-5 % changes in total optical depth

Clear segment flying south to ARM site 3-31-01 1844 UTC

20 km N of DOE ARM Central Facility
**Methane Map**, E of DOE ARM Central Facility 3-31-01

--Demonstrates effects of aircraft turn & clouds

Clouds reduce apparent optical depth

Cross-track bias induced by ER2 left turn

--Uncompensated viewing angle change
**Methane Map**, E of DOE ARM Central Facility 3-31-01 --Comparison to MODIS 8.6 µm image showing clouds
**Methane Maps**: Range of Optical Depths (OD), 3-31-01
(Near Hutchinson, relative OD* = 0.334)

* Color Scale x 1.32

Clear Portion
E of ARM
1754 UTC
--Relative
OD=0.333

Clear segment
N of ARM
1844 UTC
--Relative
OD=0.337
Methane & Water Vapor Relative Optical Depths
--Averages of 30x70 km areas & clear sub-areas

<table>
<thead>
<tr>
<th>Location</th>
<th>Methane</th>
<th>Water Vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near Hutchinson</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Just North of ARM site</td>
<td>100.9</td>
<td>114</td>
</tr>
<tr>
<td>East of ARM site</td>
<td>99.7</td>
<td>130</td>
</tr>
<tr>
<td>Further NE of ARM site</td>
<td>102.8</td>
<td>126</td>
</tr>
</tbody>
</table>

Methane optical depth is reasonably uniform & independent of water vapor variations
Methane (upper) & Water Vapor (lower) Maps
Clear segment, flying south to ARM site, 3-31-01 1844 UTC

909 cm$^{-1}$ water vapor line (same color scale as CH4)
Methane (upper) & Water Vapor (lower) Maps

Clear segment, flying south to ARM site, 3-31-01 1844 UTC

909 cm\(^{-1}\) water vapor line
Methane (upper) & Water Vapor (lower) Maps
Mainly clear segment, east of ARM site, 3-31-01 1754 UTC

909 cm\(^{-1}\)
water vapor line
Methane (upper) & Water Vapor (lower) Maps
Mainly clear segment, east of ARM site, 3-31-01 1754 UTC

909 cm\(^{-1}\) water vapor line
Methane (upper) & Water Vapor (lower) Maps

Hutchinson Segment, 3-31-01 1825 UTC

909 cm$^{-1}$
water vapor line
Methane (upper) & Water Vapor (lower) Maps
Hutchinson Segment, 3-31-01 1825 UTC

909 cm$^{-1}$
water vapor line
Conclusions

- New mapping techniques demonstrated sensitivity to several % elevations in total column methane.
- Results show good immunity to contamination of methane maps by water vapor variations (interfering species for methane spectral absorption features).
- Spatial coverage limited by cloud cover and single pass.
- No substantial elevation of large-scale methane optical depth over climatological values observed in clear areas.
- The detection limit does not preclude a relatively large mixing ratio in a thin layer (e.g. a 50% increase in the lowest 0.5 km (0.8 ppmv) changes total optical depth by only 3% and is close to the detection limit).