Question #5
What role can satellites take, as a complement to ground based measurement systems, to provide sustained observations to monitor GHG emissions?

Moustafa Chahine, Edward Olsen

NOAA Hyperspectral Spectrometer Workshop

March 29 - 31, 2011
Miami Florida
What role can satellites take, as a complement to ground based measurement systems, to provide sustained observations to monitor GHG emissions (e.g., CO₂, CH₄, O₃, N₂O, CFC’s, NH₃, NF₃) that contribute to global warming

- **AIRS provides the increased spatial/temporal coverage required to identify regional carbon sources and sinks (especially in the Southern Hemisphere)**
  - Global coverage, day and night, cloudy and clear, all seasons
  - Provides integral constraint at coarse spatial scales and long time scales

- **AIRS partial column measurements complement ground based systems**
  - Mid-trop can be used to mitigate transport model errors (vertical and horizontal)
  - Extension to stratosphere will constrain CO₂ at the top end of the upward-looking FTIR averaging kernel and broaden understanding of Strat-Trop exchange
  - Extension to lower troposphere will enhance assimilation studies (esp. for SH)

- **What does AIRS show for future thermal IR atmosphere measurements?**
  - Higher spatial and spectral resolution required for lowest 1 km of atmosphere
  - Global coverage, day and night, cloudy and clear to lowest 1 km of atmosphere

- **The next GEN AIRS?**
  - ARIES concept for thermal sounder – expansion to shortwave for near surface
The Atmospheric Infrared Sounder on NASA’s EOS Aqua Spacecraft

- **AIRS Characteristics**
- **Launched:** May 4, 2002
- **Orbit:** 705 km, 1:30pm, Sun Synch
- **IFOV:** 1.1° x 0.6°  
  (13.5 km x 7.4 km)
- **Scan Range:** ±49.5°
- **Full Aperture OBC Blackbody, ε > 0.998**
- **Full Aperture Space View**
- **Solid State Grating Spectrometer**
  - **IR Spectral Range:** 3.74-4.61 µm, 6.2-8.22 µm, 8.8-15.4 µm
  - **IR Spectral Resolution:** ≈ 1200 (λ/Δλ)
  - **# IR Channels:** 2378 IR
- **VIS Channels:** 4
- **Mass:** 177Kg,  
  **Power:** 256 Watts,  
  **Life:** 5 years (7 years goal)
- **Built:** BAE Systems

**AIRS Spectra**

**AIRS Channels for Tropical Atmosphere with T_{surf} T=301K**  
**Full Spectrum**

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AIRS Products for Weather, Climate and Composition

AIRS Greenhouse Gases

- H₂O: 500 mb Water Vapor (g/kg dry air)
- CH₄: CH₄ VMR at 200 mb (ppm)
- CO₂: Mid-Tropospheric CO₂ (ppm)

Other AIRS Atmospheric Climate Products

- Temperature
- Clouds
- CO
- O₃
AIRS Operational Product
Mid-Tropospheric CO₂
(8-10km)
Global Yield of AIRS Level 2
Mid-Tropospheric CO₂

AIRS Daily CO₂ Yield
1°x1° Spatial Resolution

15,000 CO₂ Soundings

AIRS Monthly CO₂ Yield
1°x1° Spatial Resolution

450,000 CO₂ Soundings

AIRS Level 2 Mid-Tropospheric CO₂ retrieval yield is controlled by requirement for highest quality temperature and water vapor AIRS Level 2 products in 2x2 array of adjacent FOVs

A sounder with higher spatial and spectral resolution will increase yield and extend retrieved CO₂ profile to the near surface.

Thermal IR sounding allows retrievals day/night, pole-to-pole, land/ocean/ice, cloudy/clear

M. Chahine et. al. (JPL)
Representative AIRS Mid-Trop CO₂ Averaging Kernels

(Individual AKs accompany each AIRS CO₂ sounding in the data products)

M. Chahine et. al. (JPL)
AIRS Data Show
CO₂ is not well mixed in Mid-Troposphere

July 2003 AIRS mid trop CO₂ (5° smoothing) with 500 hPa gph contours

CO₂ is NOT Well Mixed in the mid-troposphere
- Driven by synoptic-scale phenomena (polar/subtropical jet streams)
- Complexity of the Southern Hemisphere not present in models
- AIRS mid-trop data will facilitate modeling of vertical & horizontal transport

M. Chahine et al. (JPL)
AIRS - CarbonTracker upper-tropospheric CO$_2$ difference [ppm] vs. cloud top pressure eight N/S swaths, 2008

Standard product, RMS

Support product, RMS
Comparison of Collocated AIRS CO$_2$ Retrievals with January 2009 HIPPO Data for profiles ranging from near surface to p < 200 hPa

- AIRS collocated within 500 km radius and ± 1 day
- HIPPO QCLS sensor CO$_2$ convolved with AIRS Wt Func
- HIPPO OMS sensor CO$_2$ convolved with AIRS Wt Func
- HIPPO AO sensor CO$_2$ convolved with AIRS Wt Func

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<th>Global</th>
<th>SH</th>
<th>NH</th>
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<tr>
<td>mean</td>
<td>-0.5 ppm</td>
<td>+0.2 ppm</td>
<td>-1.2 ppm</td>
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<tr>
<td>$\sigma$</td>
<td>1.4 ppm</td>
<td>1.5 ppm</td>
<td>0.9 ppm</td>
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HIPPO CO$_2$ vertical profile data courtesy of Steven C. Wofsy
Collocated AIRS Mid-Trop CO\textsubscript{2} and Park Falls FTIR Total Column CO\textsubscript{2}

AIRS and Park Falls Averaging Kernels

\[ \Delta \text{CO}_2 = \langle \text{AIRS} \rangle - \text{Park Falls} \]

AIRS channels deliberately chosen to suppress contribution from surface and near-surface layers

Park Falls Data Courtesy of Paul Wennberg & Gretchen Aleks

M. Chahine et. al. (JPL)
Seasonal Variation of Difference of Daily Average of Collocated AIRS Mid-Trop CO₂ and Park Falls FTIR

Impact of CO₂ Drawdown in PBL
Lat: 45.9N; Lon: 90.3W
Data Span: 6/2/04 thru 12/29/08

\(<\Delta\) = 5.2 ± 1.7
\(<\Delta\) = 0.3 ± 2.3
\(<\Delta\) = 4.3 ± 1.7
\(<\Delta\) = 4.0 ± 2.4

AIRS daytime data collated within radius of 500km of highest quality Park Falls data taken within ± 2 hours of AIRS overpass
Variability seen in 2009 HIPPO Campaign Compares well with AIRS Mid-Trop CO₂

AIRS has observed a seasonally-variable SH CO₂ Belt Since 2003


Assimilation of AIRS mid-trop CO₂ into GEOS5

Conclusions:
Comparison with CMDL surface data indicates that AIRS assimilation is improving the accuracy of surface values of CO₂ in GEOS5.

Differences between GEOS5 and AIRS CO₂ can parameterized by hemisphere, with a systematic negative bias in the model during winter.
Assimilation of AIRS mid-trop CO₂ improves spatial pattern

Assimilation of AIRS mid-trop CO₂ adjusts vertical gradient
May 2003: CO₂(850)-CO₂(400)
(AIRS-run) – (Met-run)

May 2003: CO₂(850)>CO₂(400): fossil fuel+ land carbon source
NH: CO₂(850)<CO₂(400): transported from the NH
NOTE: scale of Met-run is 7x that of difference run

Assimilation of AIRS mid-trop CO₂ improves state estimate by 1 ppm

Spatial variability of AIRS-run is 0.53 ppm which is much larger than that of the Met-run (0.17 ppm)
Influences of El Niño on Mid-Trop CO₂ From AIRS and MOZART-2

Xun Jiang University of Houston

**TOP:**  AIRS detrended and deseasonalized CO₂ anomaly averaged for 11 El Niño months

**MIDDLE:**  AIRS detrended and deseasonalized CO₂ anomaly averaged for 17 La Niña months

**BOTTOM:**  AIRS CO₂ anomaly difference (El Niño – La Niña) (Consistent with change in Walker Circulation)


**TOP:**  MOZART-2 CO₂ anomaly during El Niño

**MIDDLE:**  MOZART-2 CO₂ anomaly during La Niña

**BOTTOM:**  MOZART-2 CO₂ Difference (El Niño – La Niña) (Signal is smaller than observed by AIRS)

NOTE: MOZART-2 results are preliminary. The boundary condition is a climatology and does not include interannual variability. (Courtesy of Maochang Liang for the MOZART-2 model run)
MJO-related AIRS Mid-Tropospheric CO\textsubscript{2} Anomaly
Intraseasonal CO\textsubscript{2} variability across the global tropics


MJO has previously been studied via its impact on atmospheric winds, pressure, temperature, moisture and rainfall.

Its impact upon mid-tropospheric CO\textsubscript{2} has now been detected.

This provides a new window of study of this planetary-scale zonal overturning circulation anomaly.

The CO\textsubscript{2} anomaly is driven by the eastward-propagating vertical circulation of the MJO and implies that CO\textsubscript{2} values are higher at the surface than in the upper troposphere.

This intraseasonal CO\textsubscript{2} variability provides a robustness test for chemical transport models.
Mid-Trop CO₂ Bias due to H₂O Absorption is Small

- Peak-to-Peak MJO Amplitude of H₂O at 600 hPa ≈ 1.4 g/kg
  [Tian et al. (2006), Vertical moist thermodynamic structure and spatial-temporal evolution of the MJO in AIRS observations, J. Atmos. Sci., 63, 2462]

- Then Potential Bias in CO₂ ≈ 1.4 × 0.13 < 0.2 ppm

Observations between 10° S – 10° N

![Graph showing AIRS ΔCO₂ vs. AIRS ΔH₂O](image)

Slope = 0.13 ± 0.01

# Factors Affecting the CO₂ Retrievals

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<th>Mid-Troposphere -10km</th>
<th>Stratosphere – 30km</th>
<th>Lower Trop – 2.2km</th>
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<td>$T(p)$</td>
<td>Strong</td>
<td>Very strong</td>
<td>Strong</td>
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<tr>
<td>$O_3$</td>
<td>Strong</td>
<td>Weak</td>
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<td>$H_2O$</td>
<td>Medium</td>
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<td>Medium</td>
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<tr>
<td>Surface emission, $E_s$ ($T_s$, $\epsilon_s$)</td>
<td>Very weak</td>
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<td>Medium</td>
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<tr>
<td>$\Delta G/\Delta CO_2^*$</td>
<td>~0.4</td>
<td>~0.2</td>
<td>~0.5</td>
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*(ΔG/ΔCO₂) describes the sensitivity of observed spectra to changes in CO₂. It is a function of the lapse rate of atmospheric temperature profiles which is 7 K/km in the mid-troposphere, 1.5K/km in the stratosphere and 10K/km near surface.

- Mid-troposphere: Operational and Released to the Public (Sept 2002 – Present)
- Stratosphere: Algorithm Completed, QA and Validation Underway (8/2010)

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3 Layers of CO$_2$ Derived from AIRS

Summary

- Stratosphere
- Mid-Troposphere
- Lower Troposphere

Sensitivity of AIRS Channels to CO2

January 20003

M. Chahine et. al. (JPL)
# 3 Layers of CO₂ Derived from AIRS

## Current Status

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<thead>
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*Continuous Updates

M. Chahine et. al. (JPL)
ARIES can map GHG emissions from large cities and counties

ARIES Characteristics:
• Extension of AIRS Methodology
• Global Maps Daily (±55° Swath)
• Spatial Resolution: 2 km
• Spectral Range: 3.0 – 15.4 µm
• Spectral Resolution: 0.5 cm⁻¹

Over 5000 Channels

Products:
Vertical Profiles of:
T, H₂O CO₂, CH₄, CO, N₂O, SO₂, HNO₃, O₃

<table>
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<th>Products</th>
<th>IFOV (km)</th>
<th>(\lambda_1 (\mu m))</th>
<th>(\lambda_2 (\mu m))</th>
<th>(R,\Delta\nu) (cm⁻¹)</th>
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<td>3.39 2950</td>
<td>4.76 2100</td>
<td>2.0</td>
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<td>15.38 650</td>
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T. Pagano et. al. (JPL)
Moustafa T. Chahine
1935 - 2011