Improving Weather and Climate Prediction

- Atmospheric Infrared Sounder (AIRS)
- Advanced Microwave Sounding Unit (AMSU)
- Humidity Sounder from Brazil (HSB)
- Aqua Spacecraft

The 7th International Workshop on Greenhouse Gas Measurements from Space

AIRS multilevel retrieval of Atmospheric CO2

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The Atmospheric Infrared Sounder on NASA’s EOS Aqua Spacecraft

- **AIRS Characteristics**
- **Launch Date:** May 4, 2002, Aqua S/C
- **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)

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*T. Pagano, International Workshop on GHG Measurements from Space, May 16, 2011*
ECMWF Finds High Infrared Sounder Impact

- Microwave satellite measurements (AMSU-A) are responsible for 18% of the forecast error reduction
- Infrared measurements (AIRS and IASI) for 12% each
- 10% of error reduction is due to radio occultation

3 Layers of CO₂ Derived from AIRS by Dr. Chahine, and Colleagues, 2011
Images for July 2003

Stratosphere

Mid-Troposphere

Lower Trop

T. Pagano, International Workshop on GHG Measurements from Space, May 16, 2011
M. Chahine et. al. (JPL)
Global Yield of AIRS Level 2
Mid-Tropospheric CO$_2$

AIRS Daily CO$_2$ Yield
1°x1° Spatial Resolution

AIRS Monthly CO$_2$ Yield
1°x1° Spatial Resolution

AIRS Retrieved Mid-Tropospheric CO2 (ppm,2-sigma) JUL 15 2010

Day/Night, Pole-to-Pole, Land/Ocean/Ice, Cloudy/Clear

AIRS CO2 Data Products Released (2002 to present)
http://airs.jpl.nasa.gov/AIRS_CO2_Data

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How we retrieve CO2…

1. Pick Channels Most Sensitive to CO2 and Least Sensitive to Other Variables

2. Employ Radiative Transfer Algorithm

\[ R(\nu) = S_x(\nu, \varepsilon_\nu, \ldots) + \int_{p_s}^{0} B[\nu, T(p)] \left( \frac{\partial \tau(\nu, p, \langle \ldots \rangle)}{\partial p} \right) dp \]

3. Define Cost Function: Obs - Calc

\[ G^{(n)} = \sum_{\nu} \left[ F^{(n)}(\nu) \right]^2 = \sum_{\nu} \left[ \Theta_M(\nu) - \Theta_C^{(n)}(\nu) \right]^2 \]

4. Employ Gauss Minimization Method

   \[ X_1 \text{'s are } T, H_2O, O_3 \text{ and CO}_2 \]

   \[ dG = \frac{\partial G}{\partial X_1} dX_1 + \frac{\partial G}{\partial X_2} dX_2 + \ldots + \frac{\partial G}{\partial X_i} dX_i + \varepsilon. \]

5. Partial Derivatives Vanish when Minimized

   \[ \frac{\partial G}{\partial X_1}, \frac{\partial G}{\partial X_2}, \frac{\partial G}{\partial X_3}, \ldots, \frac{\partial G}{\partial X_i} = 0 \]

CONTRAIL Measurements provide long timeline and good latitude coverage near peak of AIRS averaging Kernel.

- CONTRAIL flights over ocean between Sidney and Tokyo:
  - Cruising Altitude: 10.5 – 12.5 km
  - Pressure Range: 240 to 180 hPa
  - Latitude Range: 30°S to 30°N
  - Longitude Range: 135°W to 153°W

**CO2 Trend**
- AIRS: 1.96 ± 0.08 ppm
- CONTRAIL: 1.96 ± 0.14 ppm

**CO2 Trend**
- AIRS: 2.07 ± 0.03 ppm
- CONTRAIL: 1.98 ± 0.05 ppm

CONTRAIL Data courtesy of T. Machida, via World Data Centre for Greenhouse Gases [http://gaw.kishou.go.jp](http://gaw.kishou.go.jp)


*T. Pagano, International Workshop on GHG Measurements from Space, May 16, 2011*
First Major Discovery: CO$_2$ is not well mixed in Mid-Troposphere. CO$_2$ Belt.

HIPPO Campaign -2009
Steve Wofsy (Harvard)

Hövmoller Diagram of AIRS Observed Mid-Tropospheric CO$_2$

Belt of CO$_2$ in SH (Nov, 2009)

Belt of CO$_2$ in SH

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UofH/JPL Study Finds Influences of El Niño in Mid-Trop CO2 Levels observed by AIRS

- Analysis suggests that the influences of El Niño events and polar vortex on the CO2 concentration are apparent in the AIRS data.

- During El Niño, mid-tropospheric CO2 is enhanced in central Pacific Ocean and diminished in the western Pacific Ocean.

- In the polar region, mid-tropospheric CO2 is diminished if the polar vortex is strong. Polar mid-tropospheric CO2 is enhanced if the polar vortex is weak.

### Factors Affecting the CO₂ Retrievals

<table>
<thead>
<tr>
<th>ν range:</th>
<th>Mid-Troposphere -10km</th>
<th>Stratosphere – 30km</th>
<th>Lower Trop – 2.2km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 CO₂ channels:</td>
<td>17 CO₂ channels:</td>
<td>10 CO₂ channels:</td>
</tr>
<tr>
<td></td>
<td>700 cm⁻¹ – 722 cm⁻¹</td>
<td>650 cm⁻¹ – 680 cm⁻¹</td>
<td>730 cm⁻¹ – 745 cm⁻¹</td>
</tr>
<tr>
<td>T(p)</td>
<td>Strong</td>
<td>Very strong</td>
<td>Strong</td>
</tr>
<tr>
<td>O₃</td>
<td>Strong</td>
<td>Weak</td>
<td>Medium</td>
</tr>
<tr>
<td>H₂O</td>
<td>Medium</td>
<td>No impact</td>
<td>Medium</td>
</tr>
<tr>
<td>Surface emission, E_s (T_s, ε_s)</td>
<td>Very weak</td>
<td>No impact</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*(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
- Lower troposphere: Algorithm Nearly Complete, Preliminary Retrievals Underway

*T. Pagano, International Workshop on GHG Measurements from Space, May 16, 2011*
Jan 2003 Stratospheric CO₂ Retrieval Compared to Models
(AIRS Stratospheric Contribution Function Applied to Models)

**AIRS Retrieved CO₂**
January 2003 Strat CO₂ (T,CO₂) Clim plus PolyLat Init CO₂ smoothed, all crngd clust, iter=2 thru 4

**3-D IMATCH CO₂**

Model profile weighted by AIRS sensitivity function

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**Preliminary**

Both AIRS and models show presence of tropical pipe
- AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)
- AIRS shows additional troposphere intrusion at high latitude

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AIRS Stratospheric CO2
(tropospheric CO2 intrusion/vertical wind)

AIRS CO2 for January, 2003

Vertical velocity (dP/dt) at 120°W in January 2003 (NCEP2 Reanalysis)
Negative (positive) value represents upward (downward) motion. Units are Pa/s.

Omega = dP/dt at 30 hPa (NCEP2 Reanalysis)
Negative Omega --- Upward motion;
Positive Omega --- Downward motion

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AIRS Lower-Tropospheric (2.2km) CO₂
(preliminary results – channel set not yet optimized and surface emission module not yet implemented)

January 2003
AIRS Lower Tropospheric CO₂ Retrievals

July 2003
AIRS Lower Tropospheric CO₂ Retrievals

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PRELIMINARY
Space Observations of CO2 are a Key Part of an Integrated Global Observational Strategy
Summary and Conclusions

- Atmospheric Infrared Sounder
  - Aqua Spacecraft, Launched May 4, 2002
  - Temperature, Water Vapor, Cloud and GHG’s
  - Weather, Climate and Composition
- AIRS Mid- Trop CO₂ Validated to be Accurate to Better than 2ppm
- Science Findings
  - Seasonally-Variable Belt of Enhanced CO₂ in the SH
  - Signature of El Nino Seen in CO₂ Product
  - Stratospheric/Tropospheric Exchange of CO₂ as well as O3
  - CO₂ can be used by Modelers as a Tracer for Vertical Transport
- 8 Years of Mid-Trop CO₂ now available
- AIRS Stratospheric and Lower-Tropospheric Products Under Development
- IR Sounders are a key component in the global GHG observing system
- See http://airs.jpl.nasa.gov
Dr. Mous Chahine
(1935-2011)

A Brilliant Scientist
A Great Visionary
A Caring Mentor
A Good Friend

Please leave your comments at …

T. Pagano, International Workshop on GHG Measurements from Space, May 16, 2011