Global Lower-Tropospheric Measurements of CO$_2$ with AIRS


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and the
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Try to sense as low in the atmosphere as possible. Complements Chahine’s 250 mbar retrievals.

Must handle surface carefully.
Clear only. May try cloud-cleared radiances in the future.
Ocean zonal CO$_2$ derived using this algorithm extensively validated in our 2007 JGR paper.
This work: Validate land CO$_2$ measurements. Nominal reporting grid is 1-2 months, 5 degree grid boxes.
Data

- **FOV Selection**
  - Used AIRS ACDS clear FOVs
  - Removed about 7% of FOVs due to cirrus
  - ECMWF (with adjustments) used for atmospheric state.

- **Atmospheric State**
  - Atmospheric state from ECMWF adjusted for $T_{sfc}$ and total column water. Some FOVs removed due to poor water vapor.
  - Sea surface emissivity - Masuda. Land surface emissivity: UW MODIS-based model.
  - Further adjustments to the $\epsilon T_s$ product done simultaneously with CO$_2$ retrieval.
ECMWF strongly ties temperature to sondes, dynamic bias adjustment procedure applied to satellite data.

Difference of Std of bias between AIRS and ECMWF and AIRS NEDT is $\sim 0.03$ to $0.05K$, equivalent to $\sim 1-2$ ppm of CO$_2$. 
CO₂ Retrieval

- **790 cm⁻¹** (surface channel, no CO₂ sensitivity)
- **791 cm⁻¹** (temperature insensitive CO₂ channel)

\[
B_{obs}^{790} - B_{calc}^{790} = J_{T_s}^{790} \delta T_s
\]
\[
B_{obs}^{791} - B_{calc}^{791} = J_{T_s}^{791} \delta T_s + J_{CO_2}^{791} \delta CO_2
\]

- Assume emissivity constant between 790 and 791 cm⁻¹.
- Jacobians \( J \) computed for each FOV
- CO₂ also retrieved similarly using SW channels (2395 cm⁻¹ region). These are much more temperature sensitive and provide a diagnostic on errors in ECMWF T(z).
Bias Adjustment Needed for LW and SW CO\textsubscript{2} Retrieval

- Spectroscopy plus radiometric errors could easily reach 5-10 ppm
- Used NOAA’s GlobalView data set

- 400-500 mbar sensitivity limited validation to 11 aircraft sites (all US). Hope to find more validation data sets in Russia, Amazonia.
- Limited CO₂ profile information even with aircraft sites.
- Simple approach; use the highest altitude flight only (usually 5-8 km).
- GlobalView smooths the raw data. Form time series → and linearly interpolate to AIRS measurement times. Coincidence criteria: 4 degrees lat/lon and 4 days.
Sample Histograms of Obs-Calc CO₂, Day
Std due to AIRS Noise should be 7-9 ppm CO₂
Sample Histograms of Obs-Calc CO₂, Night
- Errors appear to be relatively gaussian
- Mean bias derived from \( \sim200-500 \) AIRS FOVs per site
- Daytime (Nighttime) Bias: 7.70 (6.28) ppm
- Individual site Std: \( \sim6 \) ppm.
- Uncertainty = (mean over 11 sites)/\( \sqrt{11} \) \( \approx 0.4 \text{ ppm} \). Roughly the same as single site statistical uncertainty. Too low; US only sites too homogeneous.
Hard to examine AIRS versus aircraft CO$_2$ time series since single FOV noise high.

So, fit AIRS data with the a simple function:

$$f(t) = A + Rt + C_1 \sin(\omega_y t + \phi_1) + C_2 \sin(2\omega_y t + \phi_2),$$

Two examples: HAA (7500 m) and BNE (7000 m)
Southern Hemisphere Independent Data Set
Rarotonga, Cook Islands (RTA) - Cape Grim, Tasmania, Australia (AIA)

RTA: 4500 m, ocean, good agreement AIA: 6500 m, daytime bias implies we are a few ppm low
AIRS Trends
Northern Hemisphere (30-50 deg) zonal avg
Weighed mean of the pressure field - using the calculated Jacobians as the weighing function.

Overall, Daytime sees lower over continental areas.

Fill in blanks with surrounding averaged data (Sahara/Poles).

For now we use night only climatological Jacobians for CT comparisons.
Yearly mean (Fall to Fall) - 2002 to 2006
CO2 mean over all 5 years
5-Year Seasonal Mean

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Basics
Calibration
Results
Comparison
Conclusion
AIRS Growth Rate

Very rough estimate, just raw differences

- Mean is around 2.5ppm/year
- Will fit each grid point to rate equation in future
- Higher rates for high-latitude land? Southern Africa anomaly is Kalahari Desert - will investigate.
Carbontracker - NOAA’s assimilated CO2 transport model. Uses GlobalView data as ingest.

Data is in 4D form - We average in time and interpolate to AIRS pressure levels before applying our measurement weighting function.
Error in Using Zonal Jacobian Climatology

Left: Zonal climatology, Right: Actual Jacobians

Climatology for Jacobians introduces 1-2 ppm errors. Will fix.
5-Year seasonal mean - Spring - Summer
5-Year seasonal mean - Fall - Winter

CarbonTracker CO2 - SEP/NOV All Years

AIRS CO2 - Night - SEP/NOV - ALL YEARS

CarbonTracker CO2 - DEC/FEB All Years

AIRS CO2 - Night - DEC/FEB - ALL YEARS
Seasonal Cycle of Year 2006 - Spring - Summer

CarbonTracker CO2 - MAR/MAY 2006

AIRS CO2 - Night - MAR/MAY 2006

CarbonTracker CO2 - JUN/AUG 2006

AIRS CO2 - Night - JUN/AUG 2006
Seasonal Cycle of Year 2006 - Fall - Winter

CarbonTracker CO2 - SEP/NOV 2006

AIRS CO2 - Night - SEP/NOV 2006

CarbonTracker CO2 - DEC/FEB 2006

AIRS CO2 - Night - DEC/FEB 2006
Scimachy - near IR - daytime only.
5-Year seasonal mean - Spring/Summer
5-Year seasonal mean - Fall/Winter
Very encouraging results

Not discussed: AIRS SW versus LW differences suggest that ECMWF errors are equivalent to \( \sim 1 \) ppm.

AIRS and the assimilated model CarbonTracker agree to some degree. AIRS indicates CarbonTracker transport is too “strong”.

Of concern, our low SH ocean \( \text{CO}_2 \). That is also where our day/night differences are largest.

Some agreement with preliminary SCIAMACHY data. SCIAMACHY unreasonably low at times?? (Will discuss with Bremen.)

Need to generate, and save, gridded Jacobians for proper comparison to CarbonTracker (or other models).

Like to improve clear yield in NH winter, or move to cloud-cleared radiances??
250 mbar (Chahine) vs 450 mbar (UMBC) CO$_2$