Radiative Transfer Models for IASI
Variable CO$_2$

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Radiative Transfer for IASI: Comparisons to ECMWF

- IASI Biases vs ECMWF (no sondes available yet)
- Poster: Compare AIRS vs IASI ECMWF biases for about 1 1/2 month time period of clear ocean scenes. Agreement better than 0.1K for mid-tropospheric channels.
- Here emphasize absolute comparisons to ECMWF, and
- Examine regions (upper trop) where some IASI and AIRS channels don’t agree
- Variable CO$_2$ makes detailed comparisons to ECMWF difficult, so instead, use ECMWF to solve for CO$_2$ for lower-trop channels (in the 550 mbar range, most previous work in the 200-300 mbar range).
ACDS and ICDS: AIRS/IASI Cal/Climate Data Subsets

- ACDS being produced at GSFC/DAAC and is available to anyone. (This work uses similar subset produced at UMBC.)
- We have produced ~1 1/2 months of ICDS.
- Plan to produce 1-2 years of ICDS in future.
- Use for calibration, radiative transfer studies, \( \text{CO}_2 \) retrievals

Subset data into:

1. Clear (ocean/land)
2. Small random selection of FOVs (nadir only)
3. Fixed sites (ARM sites, Antarctica (Dome C), desert, etc.)
4. High convective clouds (Aumann, JPL) to record counts of coldest scenes

- Files sizes are ~200 Mbytes/day (AIRS)
- Ocean clear OK, land clear needs work
- Use IASI imager in clear algorithm, hope to use AVHRR vis for daytime clear in future.
- Subset algorithm only looks at uniformity, additional filters used for “clear” (to avoid stratus, for example).
IASI Cal/Climate Data Set: “Uniform” Fields
AIRS Result: ECMWF Biases (± 40 deg) Tied to Sondes (as advertised)
IASI Non-LTE Bias
AIRS Non-LTE Algorithm Works at 9:30 am

![Graph showing bias in K against wavenumber (cm⁻¹)]
IASI Bias and Std. Summary
Clear FOVS, Ocean, Night

![Graph showing B(T) in K and O - C or Std (K) vs Wavenumber (cm⁻¹)]
Now Add AIRS Biases
ECMWF SST stays the same, 9:30 am about 0.1K colder than 1:30 pm
IASI Shortwave Window Bias Also Smaller

![Graph showing B(T) in K and O-C in K against Wavenumber (cm⁻¹)]
High-Peaking CO\textsubscript{2} Channels
IASI Biases Sometimes Much More Negative??

![Graph showing CO\textsubscript{2} channels comparison between IASI and AIRS](image)

- IASI Biases
- AIRS Biases
- CO\textsubscript{2} Channels
- ASL
- L. Strow
- ICDS
- ECMWF Biases
- IASI
- L. Strow
Quite Good IASI/AIRS Agreement to 2250 cm$^{-1}$
IASI Tropospheric CO$_2$ Biases:
Assuming 2 ppm/year CO$_2$ growth since 2002. Biases $\sim$0.25K high
AIRS Biases with RS-90 ARM Mods

$\text{CO}_2$ growth should add $4.5 \times 2\text{ ppm/year} \times 0.03\text{ K/ppm} = 0.27\text{ K}$
AIRS Biases with RS-90 ARM Mods

Higher $H_2O$ errors *may* just be ECMWF
AIRS Biases with RS-90 ARM Mods
V5 RTA Mods not done between 2275 and 2380 cm$^{-1}$, no ground truth
IASI Conclusions

- AIRS versus IASI (double-diff) \(\sim 0.1\)K or less! (from poster)
- Biases very similar to AIRS
- AIRS-like RTA modifications derived from ARM RS-90 sondes should also improve IASI biases relative to ECMWF in CO\(_2\) regions. Water regions uncertain, re-examine.
- Some issues in longwave, next to Q-branches and band edge. IASI biases lower than AIRS. No firm conclusions.
- CO\(_2\) growth estimates needed to estimate biases. Or, use biases to estimate CO\(_2\).
CO₂ with AIRS (and IASI)

- 4-years of AIRS CO₂
- *Simple* approach, easy to reprocess. Originally just after rates.
- Motivation
  - RTA validation
  - AIRS climate monitoring
  - CO₂ transport; help understand sinks? Use lower-peaking channels.
- CO₂ Jacobian centered around 550 mbar
- Start slow: Ocean/Night only clear FOVs; Good for validation, bad for sources/sinks and/or transport;
- ECMWF used for temperature - tied to sondes.
- SST and TCW from AIRS (UMBC values, on a per FOV basis.)
- Validated via NOAA CMDL MBL, JAL, 2 ocean aircraft sites
- GOAL: provide useful data for modelers, show utility of lower-peaking AIRS channels
Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO₂

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Measurements of midday vertical atmospheric CO₂ distributions reveal annual-mean vertical CO₂ gradients that are inconsistent with atmospheric models that estimate a large transfer of terrestrial carbon from tropical to northern latitudes. The three models that most closely reproduce the observed annual-mean vertical CO₂ gradients estimate weaker northern uptake of ~1.5 petagrams of carbon per year (Pg C year⁻¹) and weaker tropical emissions of +0.1 Pg C year⁻¹ compared with previous consensus estimates of ~2.4 and +1.8 Pg C year⁻¹, respectively. This suggests that northern terrestrial uptake of industrial CO₂ emissions plays a smaller role than previously thought and that, after subtracting land-use emissions, tropical ecosystems may currently be strong sinks for CO₂.

Our ability to diagnose the fate of anthropogenic carbon emissions depends critically on interpreting spatial and temporal gradients of atmospheric CO₂ concentrations (1). Studies using global atmospheric transport models to infer surface fluxes from boundary-layer CO₂ concentration observations have generally estimated the northern mid-latitudes to be a sink of approximately 2 to 3.5 Pg C year⁻¹ of CO₂. Analyses of surface ocean partial pressure of CO₂ (2), atmospheric carbon isotope (6), and atmospheric oxygen (7) measurements have further indicated that most of this northern sink must reside on land. Tropical fluxes are not well constrained by the atmospheric observing network, but global mass-balance requirements have led to estimates of strong (1 to 2 Pg C year⁻¹) tropical carbon sources (4, 5). Attribution of the Northern Hemisphere terrestrial carbon sink (8–13) and reconciliation of estimates of land-use carbon emissions and intact forest carbon uptake in the tropics (14–19) have motivated considerable research, but these fluxes remain quantitatively uncertain. The full range of results in a recent inverse model comparison study (5), and in independent studies (5, 20, 21), spans budgets with northern terrestrial uptake of 0.5 to 4 Pg C year⁻¹, and tropical terrestrial emissions of −1 to +4 Pg C year⁻¹. Here, we analyzed observations of the vertical distribution of CO₂ in the atmosphere that provide new constraints on the latitudinal distribution of carbon fluxes.

Previous inverse studies have used boundary-layer data almost exclusively. Flask samples from profiling aircraft have been collected and measured at a number of locations for up to several decades (22–24), but efforts to compile these observations from multiple institutions and to compare them with predictions of global models have been limited. Figure 1 shows average vertical profiles of atmospheric CO₂ derived from flask samples collected from aircraft during midday at 12 global locations (fig. S1), with records extending over periods from 4 to 27 years (table S1 and fig. S2) (25). These seasonal and annual-mean profiles reflect the combined influences of surface fluxes and atmospheric mixing. During the summer in the Northern Hemisphere, midday atmospheric CO₂ concentrations are generally lower near the surface than in the free troposphere, reflecting the greater impact of terrestrial photosynthesis over industrial emissions at this time. Sampling locations over or immediately downwind of continents show larger gradients than those over or downwind of ocean basins in response to stronger land-based fluxes, and higher-latitude locations show greater CO₂ drawdown at high altitude. Conversely, during the winter, respiration and fossil-fuel sources lead to elevated low-altitude atmospheric CO₂ concentrations at northern locations. The gradients are comparable in magnitude in both seasons, but the positive

†Deceased.
Methodology

- Use ECMWF $T(z)$, mean tied to radiosondes. Fit for SST and TCW using 2616 and 2609 cm$^{-1}$ channels (night only).
- Solve

$$BT_i^{obs} - BT_i^{calc \ (ECMWF)} = \frac{dB_i}{dCO_2} \delta CO_2 + \frac{dB_i}{dT} \delta T_s$$

for $\delta CO_2$ using 2+ channels.
- LW: Two channels, 791.7 cm$^{-1}$ used for CO$_2$ and $T_s$; 790.3 cm$^{-1}$ used for $T_s$ only. Temperature insensitive.
- SW: 2392-2420 cm$^{-1}$; Temperature sensitive, 26 channels, diagnose ECMWF errors ($\sim$ 1 ppm jump on Feb. 2006)
- CO$_2$ zonally averaged into 4 degree latitude bins
- **Main difference between this work, and previous work:** Lower peaking CO$_2$ Jacobians.
This Work: $791 \text{ cm}^{-1}$ Channel $dR/d(CO_2^i)$ Peaks Closer to Surface

![Graph showing pressure vs. dBT/dCO_2 with lines labeled Crevoisier et. al., Engelen and McNally, Chahine et. al., and This Work.](image-url)
Finding “Clean” CO$_2$ Channels
Ratio of $dBT/d_{CO_2}$ to $dBT/dT_{profile}$

Why 791.7 cm$^{-1}$ Channel
ASL

Raw Biases, Northern Hemisphere Average

![Graph showing raw biases over time for Northern Hemisphere with two lines representing different CO2 absorption lines: 791.7 cm⁻¹ and 790.3 cm⁻¹.](image)
AIRS Calibrated (1-number, 1-time) Using MLO
MLO at ~650 mbar, close to peak of CO$_2$ W.F.
AIRS RTA only good to ~8 ppm for any channel (2%)
AIRS 4-Year CO$_2$ Climatology

The image shows a plot of CO$_2$ concentration over time and latitude. The x-axis represents time from 2003 to 2006, and the y-axis represents latitude from $-50$ to $50$. The color bar on the right indicates CO$_2$ concentrations ranging from 368 to 384 ppm.
AIRS vs MBL; 25-50 Deg. Latitude

![Graph showing CO$_2$ levels over time with MBL and AIRS comparisons.](image-url)
JAL Comparisons: 30N - 15N Latitudes

- JAL: 30N 250 hPa
- JAL: 20N 250 hPa
- JAL: 25N 250 hPa
- JAL: 15N 250 hPa
JAL Comparisons: 10N - 5S Latitudes

IASI
L. Strow
ICDS
ECMWF Biases
CO₂
Validation of AIRS with MBL, JAL etc.
Comparison of AIRS and IASI CO$_2$ for May 2007
AIRS Seasonal Amplitude vs MBL/JAL/etc.
AIRS vs MBL Min/Max Amplitudes

Detrended CO$_2$ (ppm) vs Latitude

- Max/Min MBL
- Max/Min AIRS
AIRS Seasonal Phase vs MBL
AIRS vs MBL/MLO CO$_2$ Growth Rates

![Graph showing CO$_2$ growth rates against latitude for AIRS and MBL/MLO datasets.](image)

- AIRS 3-Yr
- AIRS 4-Yr
- MBL 3-Yr
- MLO 4-Yr

Latitudes range from -60 to 60 degrees.
AIRS vs MBL Growth Rates: Offsets and Harmonic Terms Removed

- AIRS LW: 20-40 lat
- MBL: 20-40 lat
- AIRS SW: 20-40 lat

ΔCO₂ (ppmv) vs Time (2003-2006)
Rate Variability 20-40 Deg.lat; AIRS=2.44, MBL=1.92 ppm/yr
Blue Bars: AIRS=1.86, MBL=2.07 ppm/yr;
Red Bars: AIRS=2.56, MBL=2.88 ppm/yr
CO₂ Conclusions

- Excellent results using very clear FOVs over ocean
- Initial work shows similar results with cloud-cleared data, allowing more convective situations to be examined for transport
- Basic technique should work over land, first clear, then cloud-cleared data.
- This work sets a baseline on stability of AIRS (and eventually IASI), esp. with regard to trends.