# Validation of Six Years of Mid-Tropospheric AIRS $CO_2$

**Edward Olsen[1], Moustafa Chahine[1], Luke Chen[1], Xun Jiang[2], Thomas Pagano[1] and Yuk Yung[3]**

[1] Science Division, Jet Propulsion Laboratory, Caltech

[2] Department of Earth & Atmospheric Sciences, Univ. of Houston

[3] Division of Geological & Planetary Sciences, Caltech

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# Outline

- Validation
  - AIRS Mid-Tropospheric $CO_2$ Averaging Kernels
  - Aircraft profiles of $CO_2$ concentration
    ➔ Direct validation of satellite retrievals
  - CONTRAIL $CO_2$ samples at altitudes 10.5 km to 12.5 km
    ➔ Validate amplitude, phase of seasonal variations and interannual trends as function of latitude
  - TCCON daytime cloud-free column average $CO_2$ measurements
    ➔ Validate phase of seasonal variations and interannual trends; allows estimation of drawdown in PBL
- Conclusions
- A little dessert

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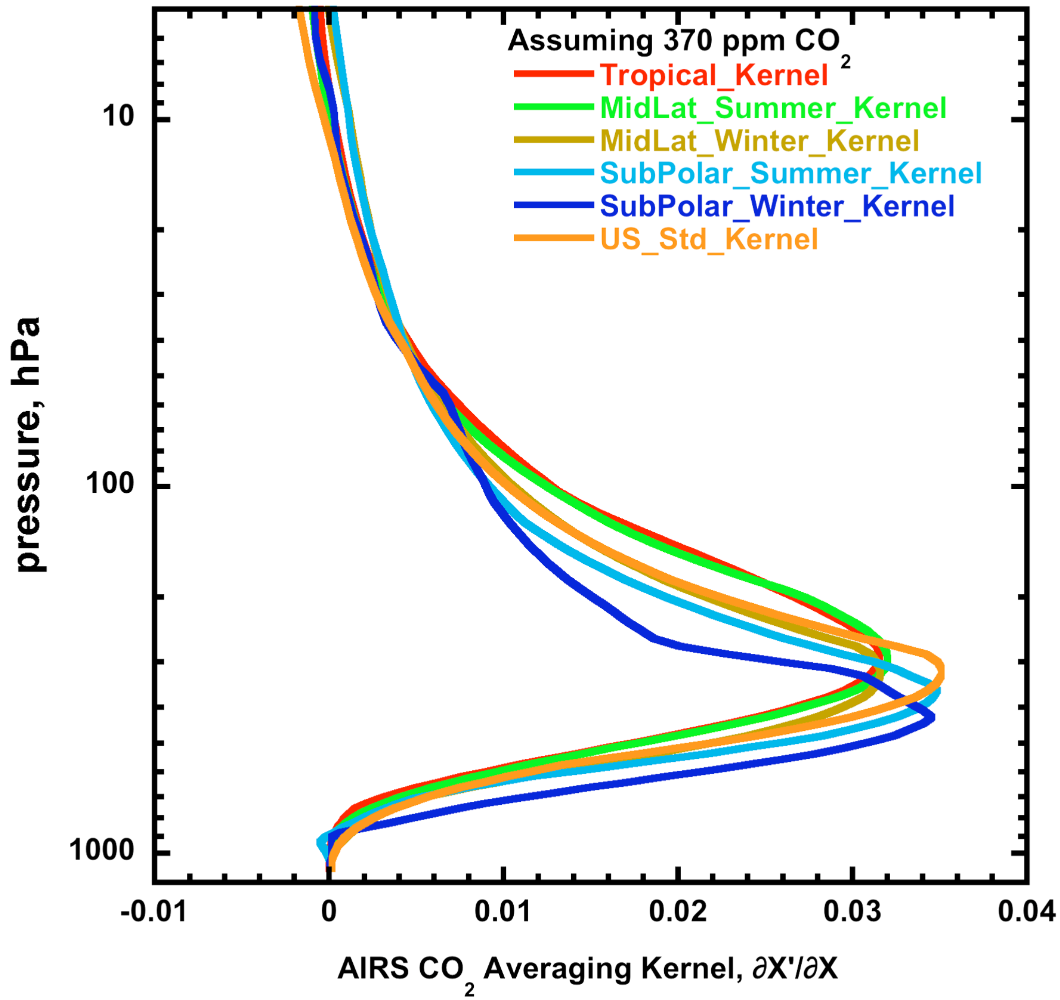
# Representative AIRS Mid-Trop $CO_2$ Averaging Kernels

## AIRS Sensitivity

- Peak sensitivity altitude varies slightly with latitude and season:
  - Tropics: 285 hPa
  - Poles: 425 hPa
- Width at half-maximum is ~ 400 hPa, spanning:
  - Tropics: 120 hPa to 515 hPa
  - Poles: 235 hPa to 640 hPa
- Tails of averaging kernels intrude into stratosphere, where air is older than in troposphere by an amount that varies with latitude (~ 1 yr in tropics; ~5 yrs at poles).
  - Impact: 1-3 ppm near the poles.



# Aircraft Profiles

- ✧ Direct validation of satellite retrievals
  - ❖ Ideal characteristics:
    - ✓ Spiral flight path
    - ✓ Altitude range from near surface to 150 hPa (13.5 km)
    - ✓ Coincide with the satellite overpass

# AIRS $CO_2$ Validation via Aircraft $CO_2$ Profiles

## Aircraft Profiles are Best Available Validation

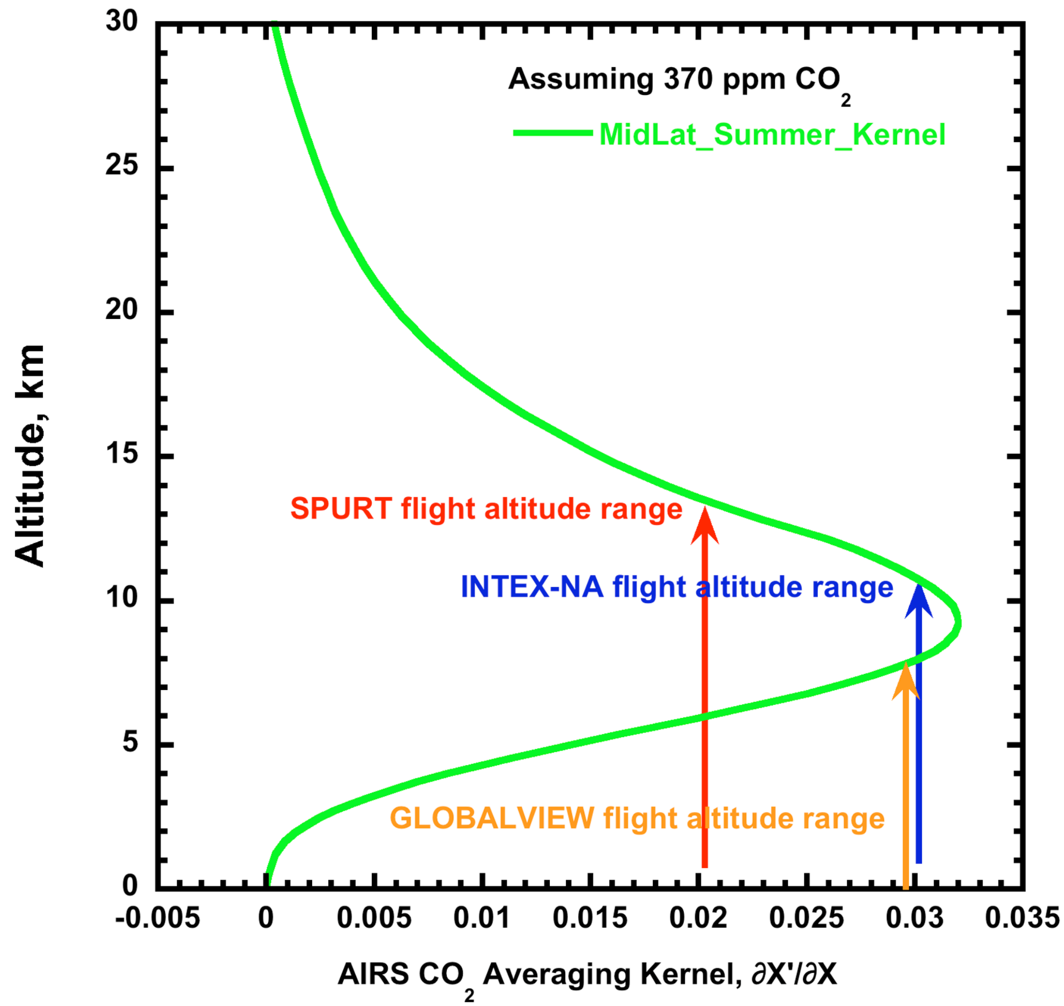
- Convolve the aircraft profiles with the AIRS sensitivity functions to arrive at a single number to compare to the AIRS result.

- SPURT flights in April 2003:
  - Maximum Altitude: 13.7 km
  - Pressure Range: 850 to 140 hPa
- INTEX-NA flights in July 2004:
  - Maximum Altitude: 10.7 km
  - Pressure Range: 850 to 240 hPa

  - Compared to average of same day AIRS retrievals within 500 km radius.

- GLOBALVIEW flights (multi-year, many):
  - Maximum Altitude: 8 km
  - Pressure Range: surface to 360 hPa

- Compare Poker Flats to average UT±4hr AIRS retrievals within 250 km radius.



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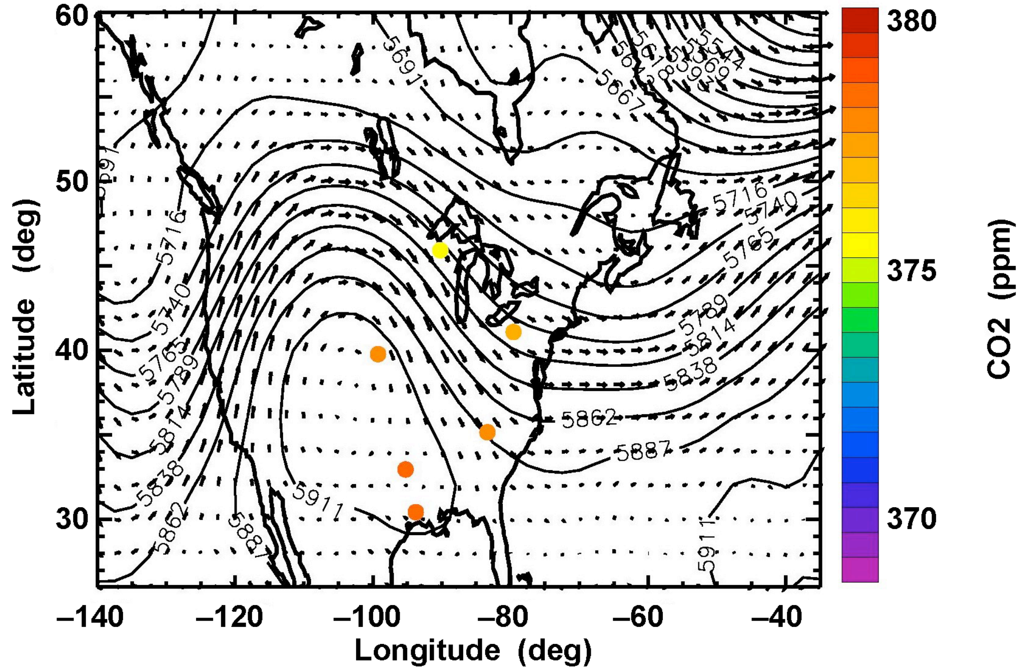
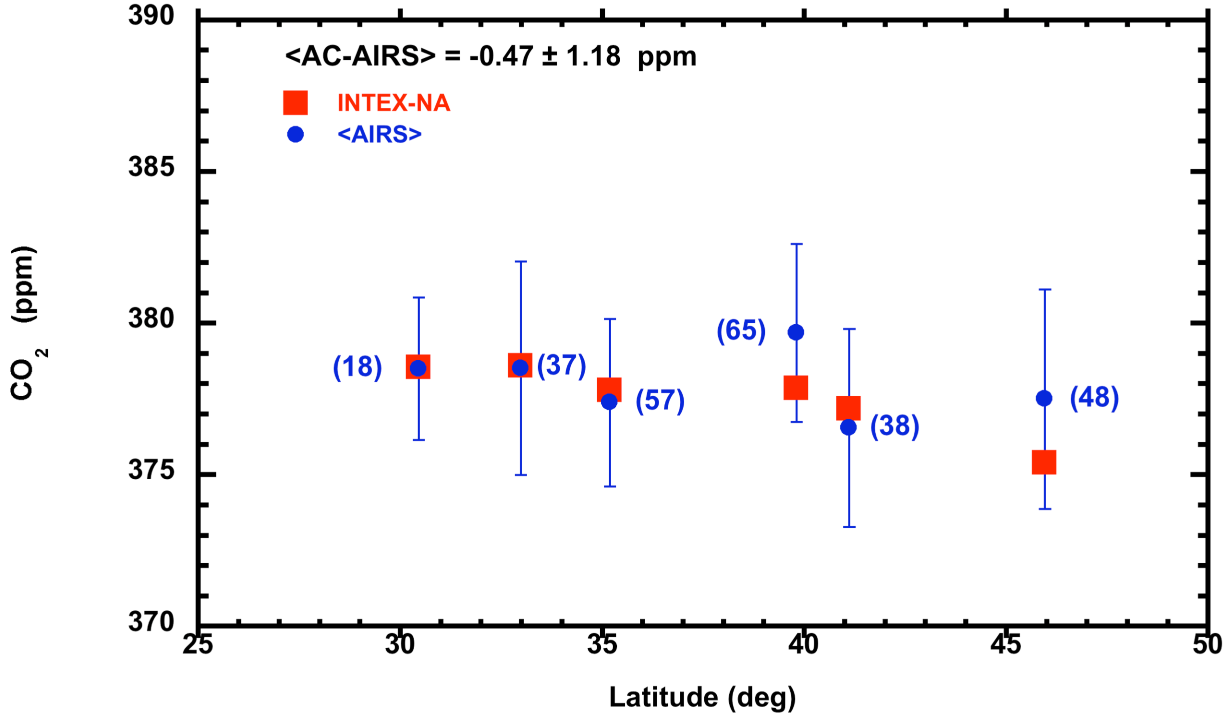
Contours are NCEP 500 mb geopotential height.
Arrows are NCEP 500 mb wind.

# Comparison of AIRS $CO_2$ Collocated with INTEX-NA Aircraft Data




Numbers in parentheses are number of same-day AIRS retrievals collocated within a radius of 500 km which are averaged for comparison to convolved aircraft profile.

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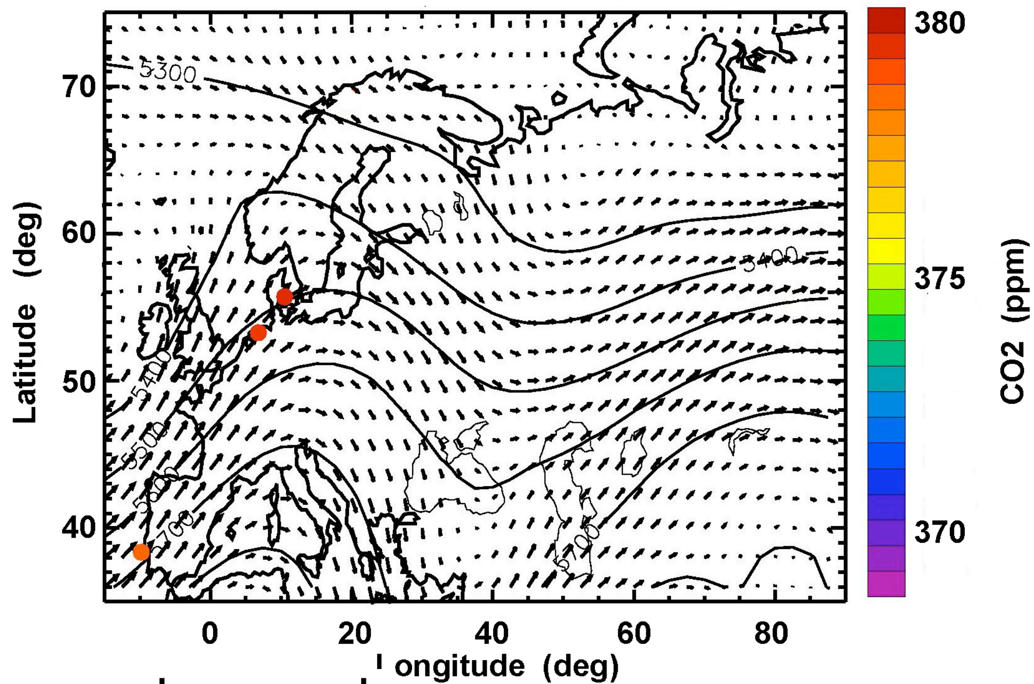
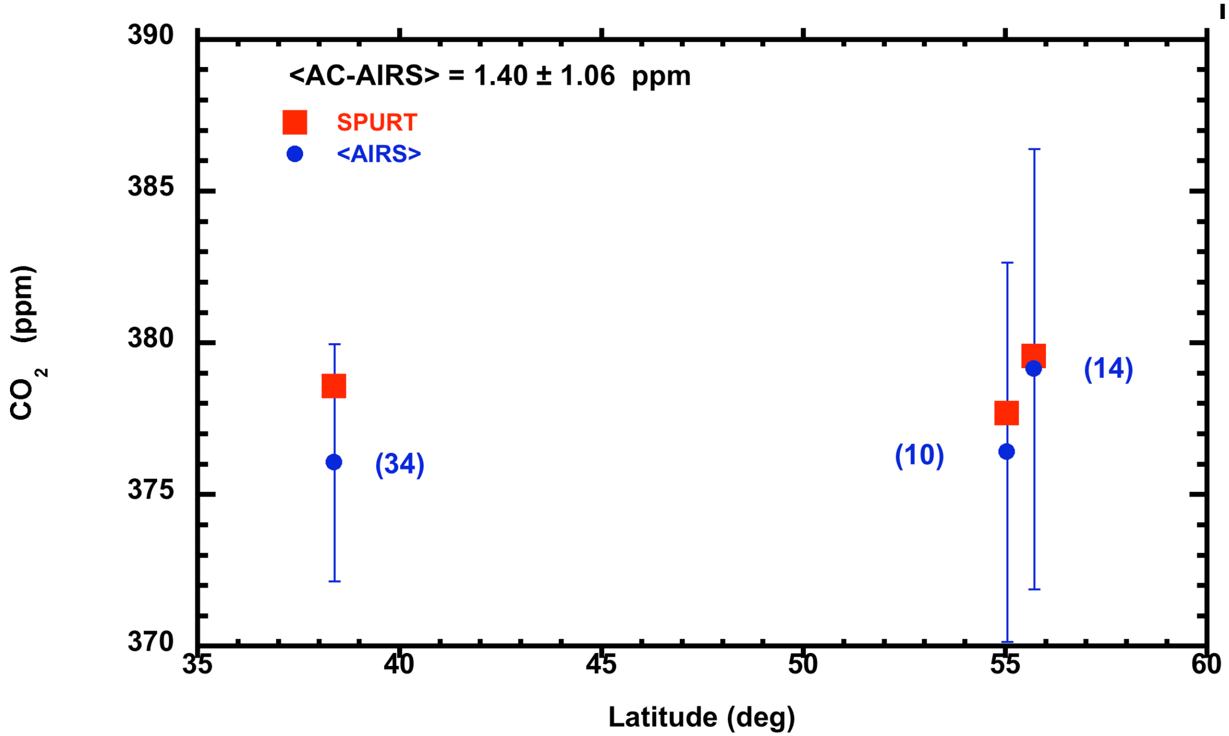
Contours are NCEP 500 mb geopotential height.
Arrows are NCEP 500 mb wind.

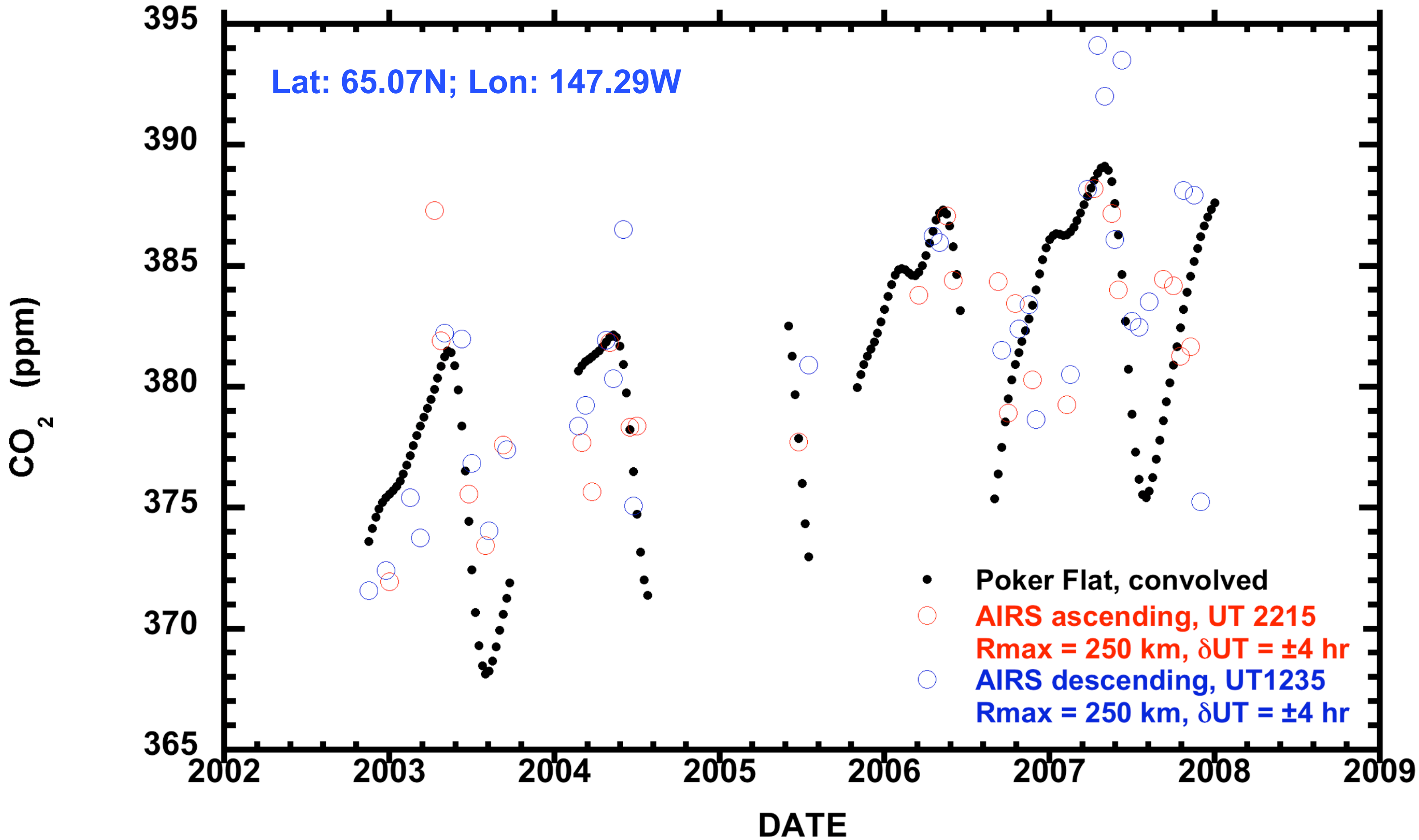
# Comparison of AIRS $CO_2$ Collocated with SPURT Aircraft Data




Numbers in parentheses are number of same-day AIRS retrievals collocated within a radius of 500 km which are averaged for comparison to convolved aircraft profile.

# Comparison of AIRS Collocated Retrievals with Poker Flats GLOBALVIEW Aircraft Data



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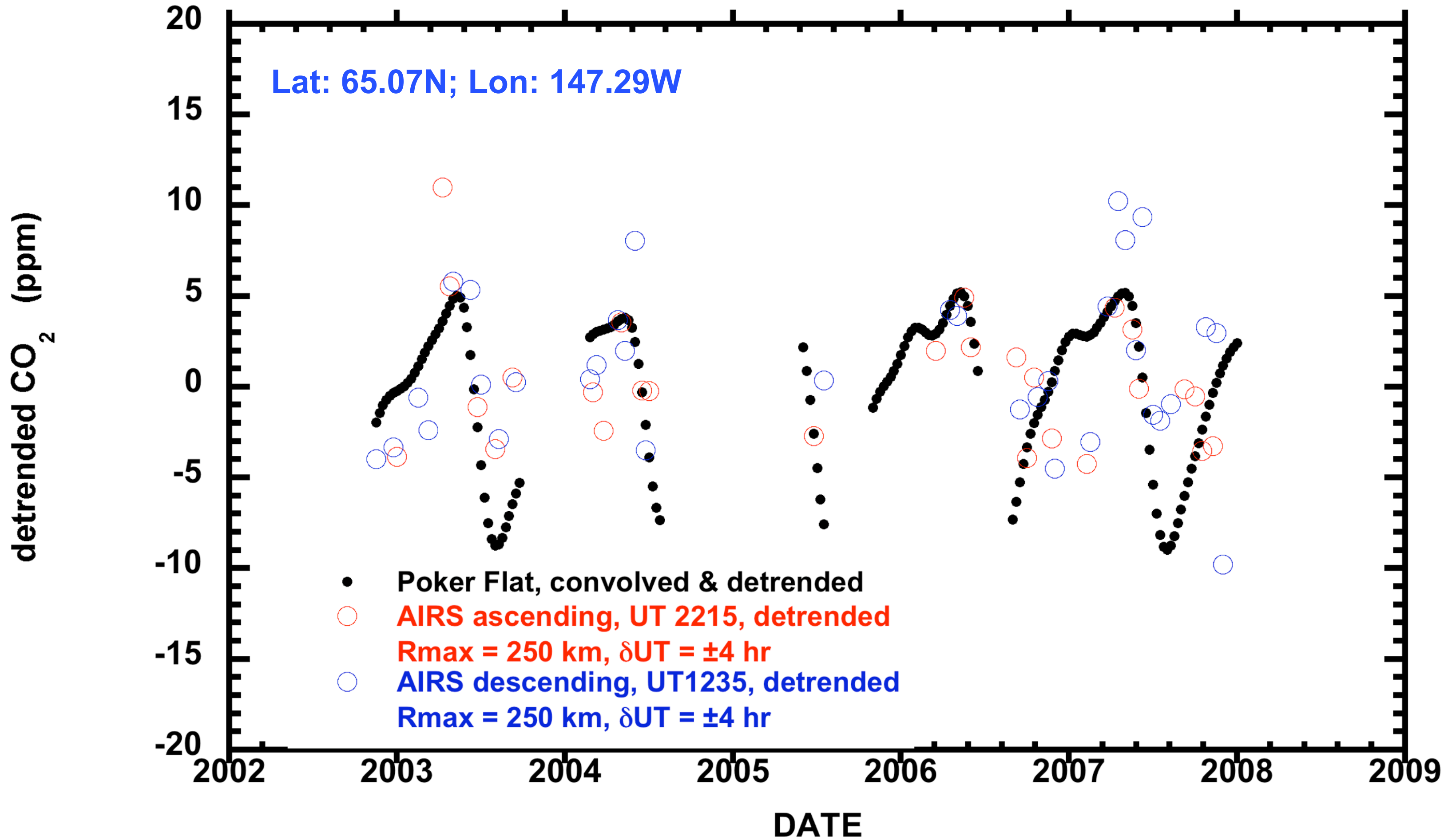
# Comparison of AIRS Collocated Retrievals with Poker Flats GLOBALVIEW Aircraft Data



# CONTRAIL $CO_2$ Samples at Altitudes Between 10.5 km and 12.5 km

- Provide a long-term history for 30°S ≤ latitude ≤ 30°N over the Western Pacific Ocean at an altitude near that of the AIRS sensitivity maximum for the duration of the mission

  - Validate:

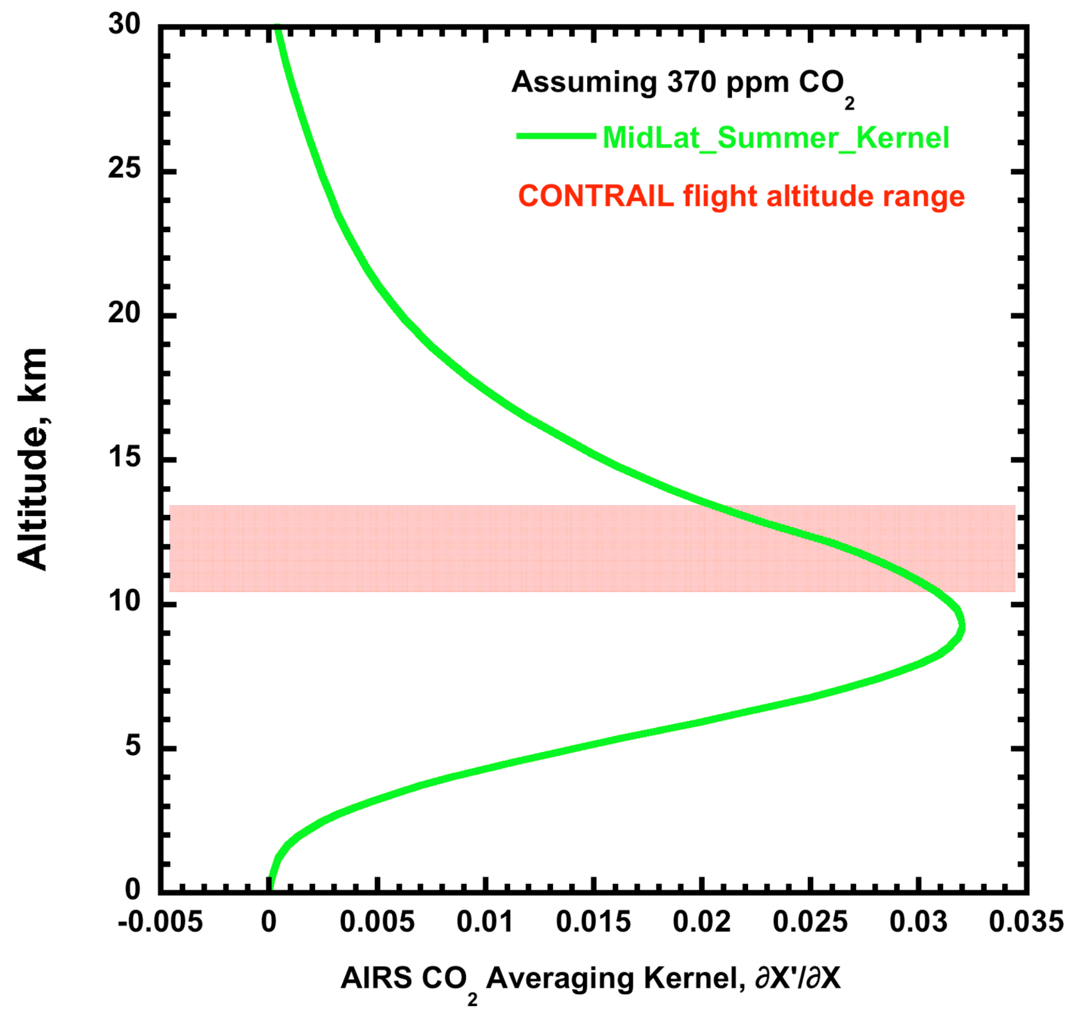
    - ✓ Amplitude and phase of seasonal variations
    - ✓ Latitude-dependent interannual trend

# AIRS $CO_2$ Comparison to CONTRAIL $CO_2$ Measurements

## CONTRAIL Measurements provide long timeline and wide latitude coverage

- 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
  - Flight Periodicity: ~ twice/month
  - Sample Spacing: ~ 500 km

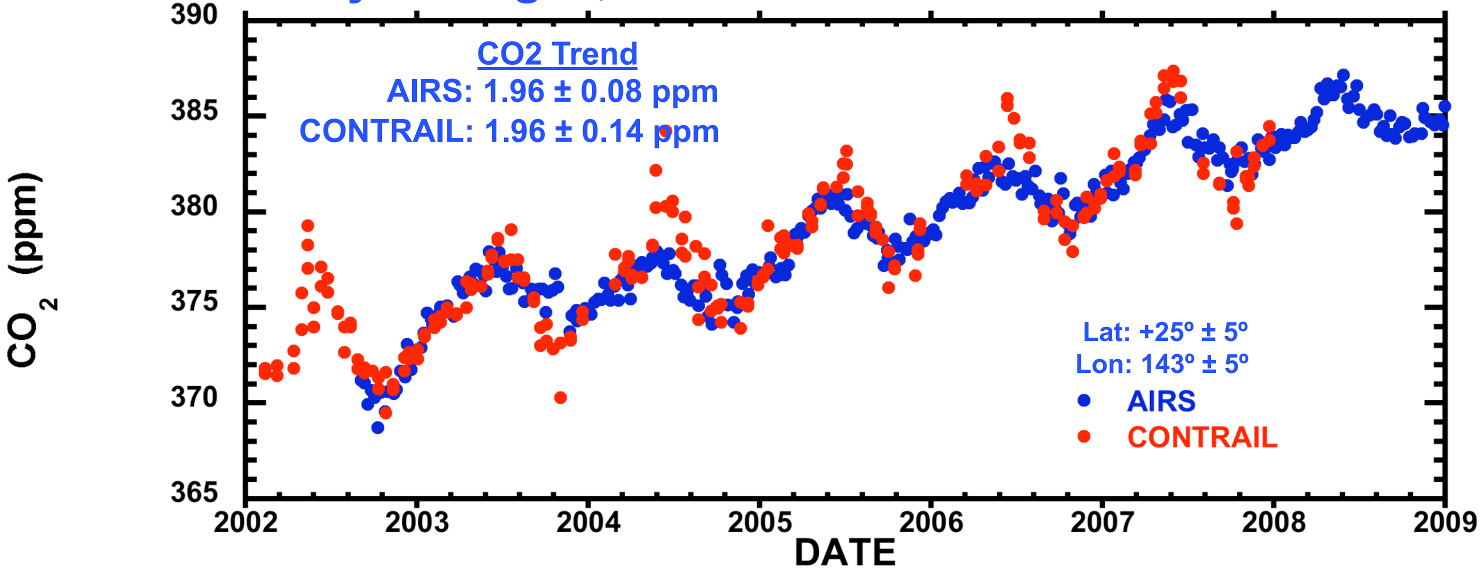
- Direct comparison of CONTRAIL flask samples with average of collocated AIRS retrievals.
- Collocated AIRS retrievals are within 250 km radius and 4 hrs of flight.

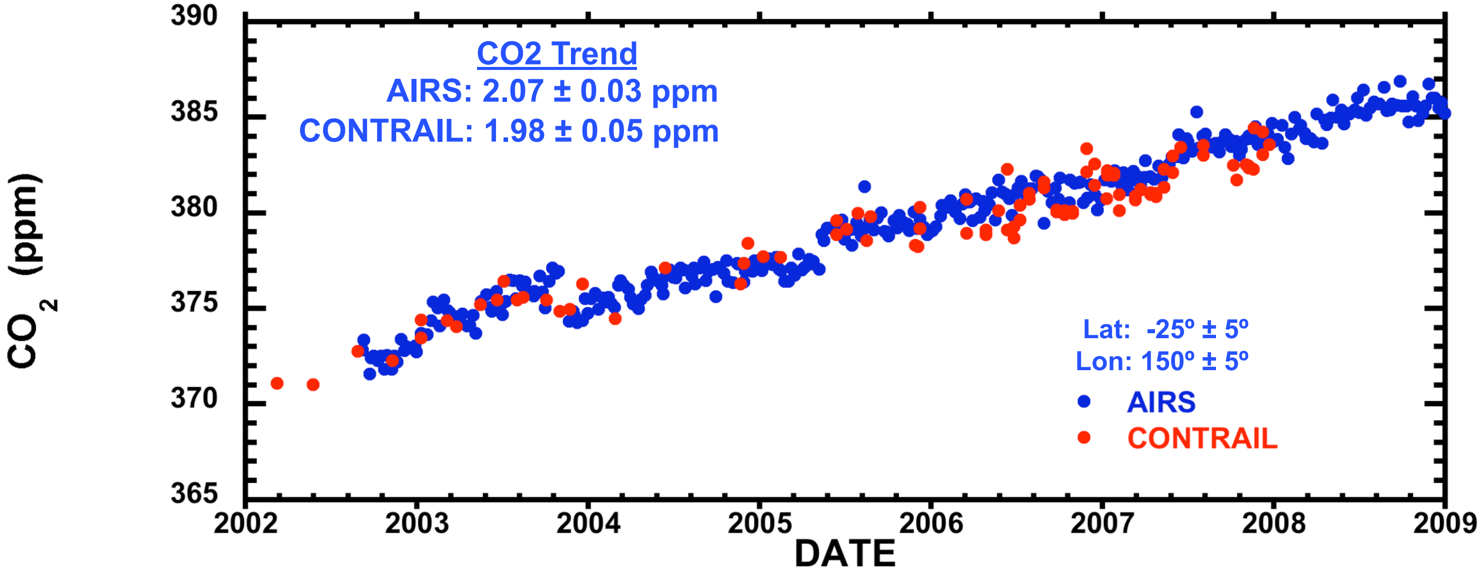


# Time Series for AIRS $CO_2$ and CONTRAIL Aircraft Data

## (in 10°x10° boxes at extremes of latitude for cruising altitude)

## AIRS Data are 7-day averages; CONTRAIL data are individual measurements

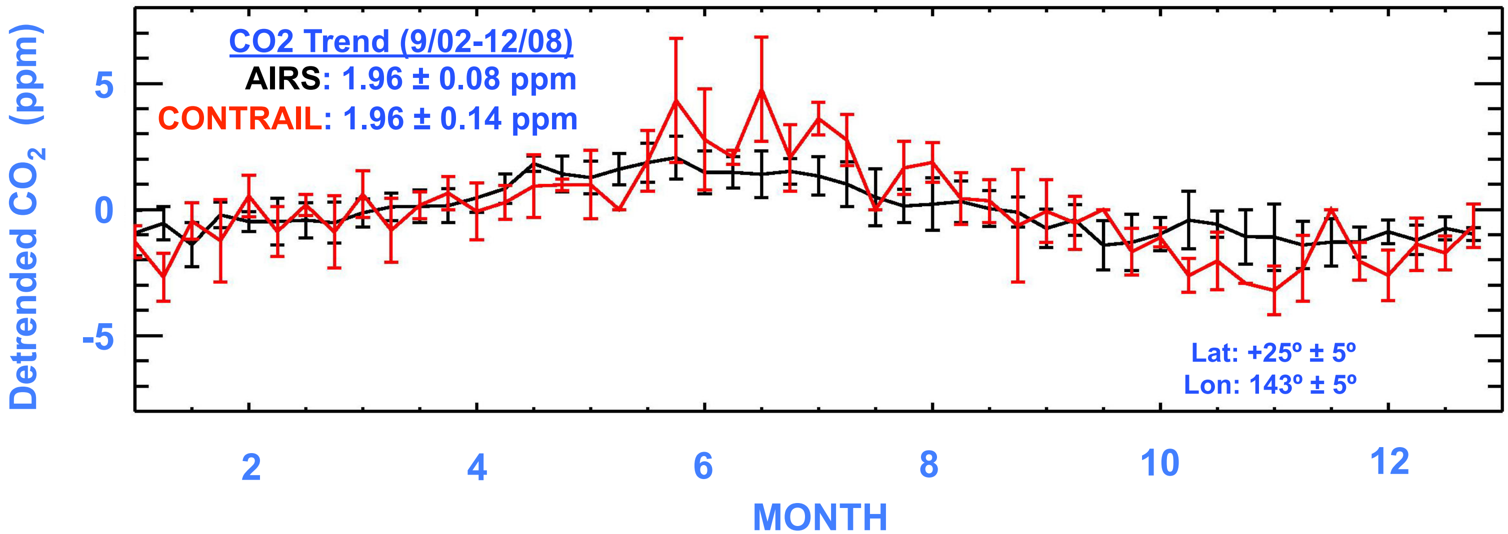


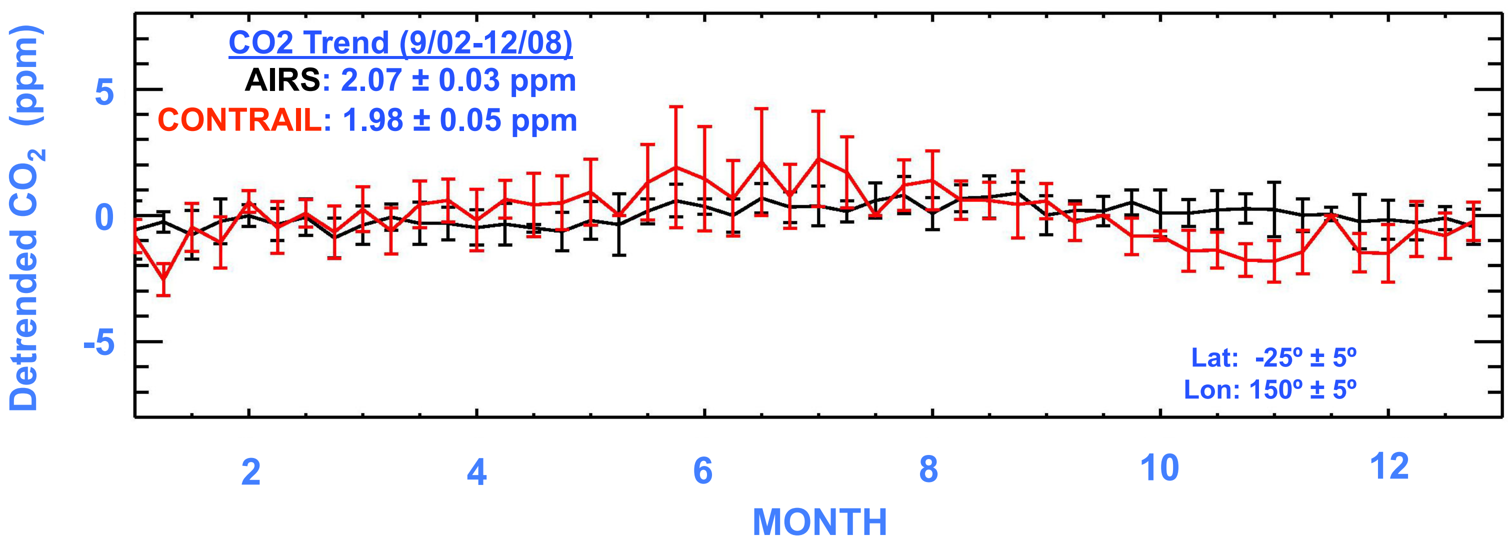



# Seasonal Cycle of AIRS $CO_2$ and CONTRAIL $CO_2$

## (in 10°x10° boxes at extremes of latitude for cruising altitude)

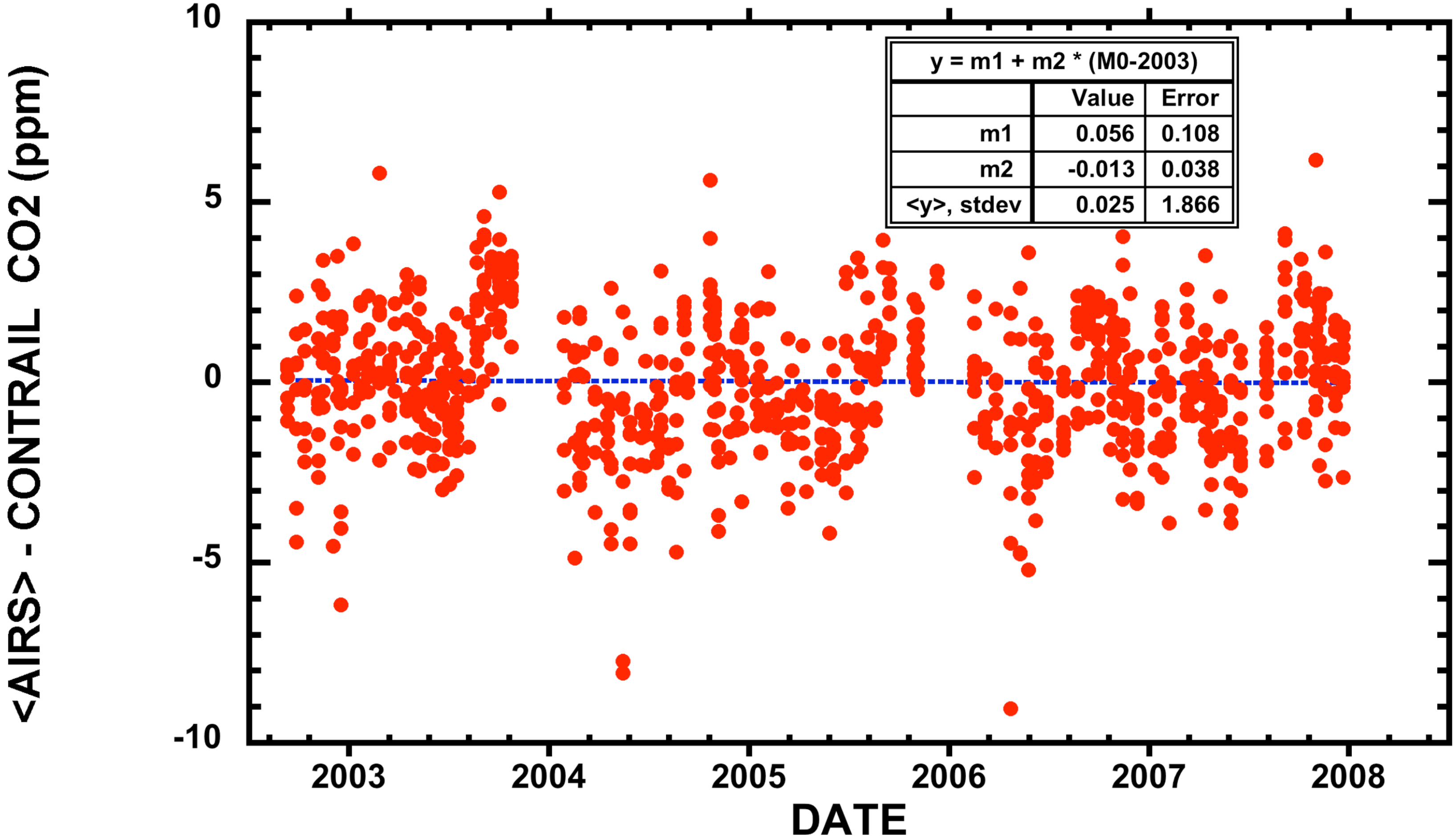
## AIRS Data are 7-Day Averages Centered on CONTRAIL Daily Averages



# Time Series for Difference of Collocated AIRS $CO_2$ and CONTRAIL Aircraft Data

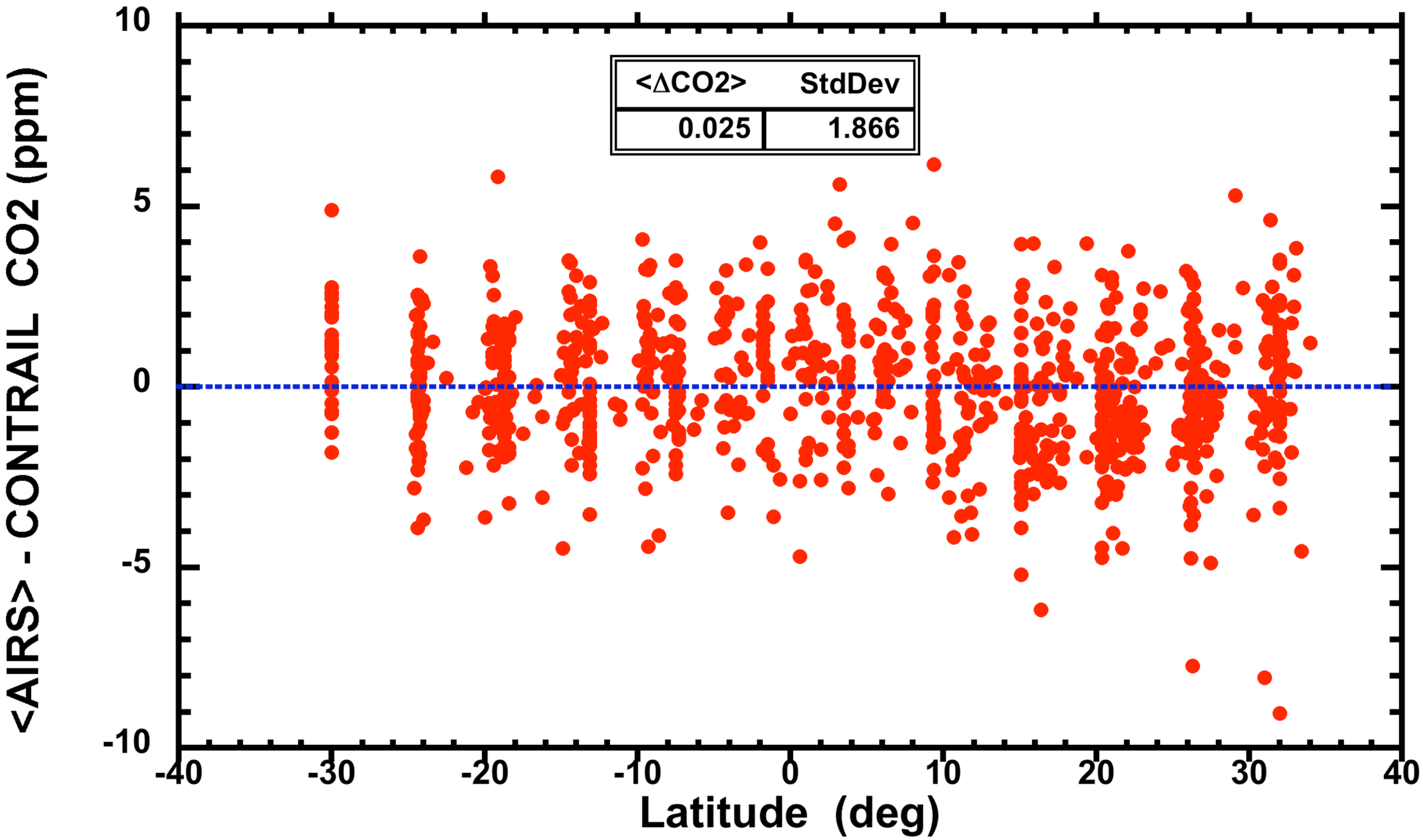
## (at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)




**Over 5.25 years, bias ~ 0.2 ppm, stdev < 2 ppm and trend difference < 0.015 ppm/yr**

# Difference Between Collocated AIRS $CO_2$ and CONTRAIL Aircraft Data as a Function of Latitude

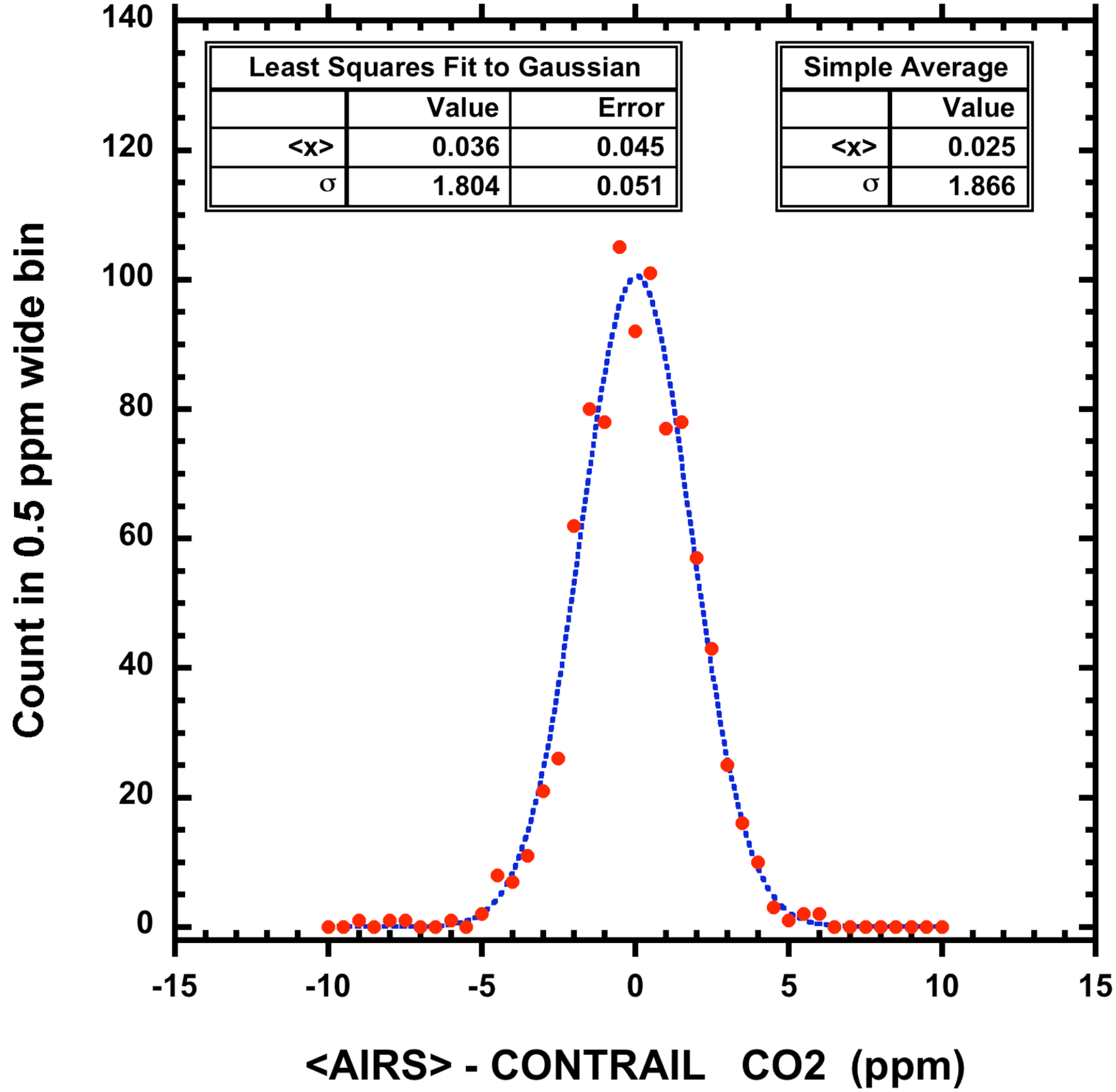
## (at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)




Over 5.25 years, bias ~ 0.03 ppm, stdev < 2 ppm and no apparent latitude dependence

# PDF of Difference Between Collocated AIRS $CO_2$ and CONTRAIL Aircraft Data

### (at least 3 AIRS retrievals collocated within 250 km radius & 4 hrs)




**Over 5.25 years**

**PDF is Gaussian**

**bias ~ 0.04 ppm**

**std dev < 2 ppm**

# TCCON Daytime Cloud-Free Column Average $CO_2$ Measurements

- Provide a history of column average $CO_2$ at widely scattered locations around the globe

- Validate:
  - ✓ Amplitude and phase of seasonal variations
  - ✓ Interannual trend at select locations around globe
  - ✓ Allow estimation of seasonal vegetative drawdown of $CO_2$ in PBL

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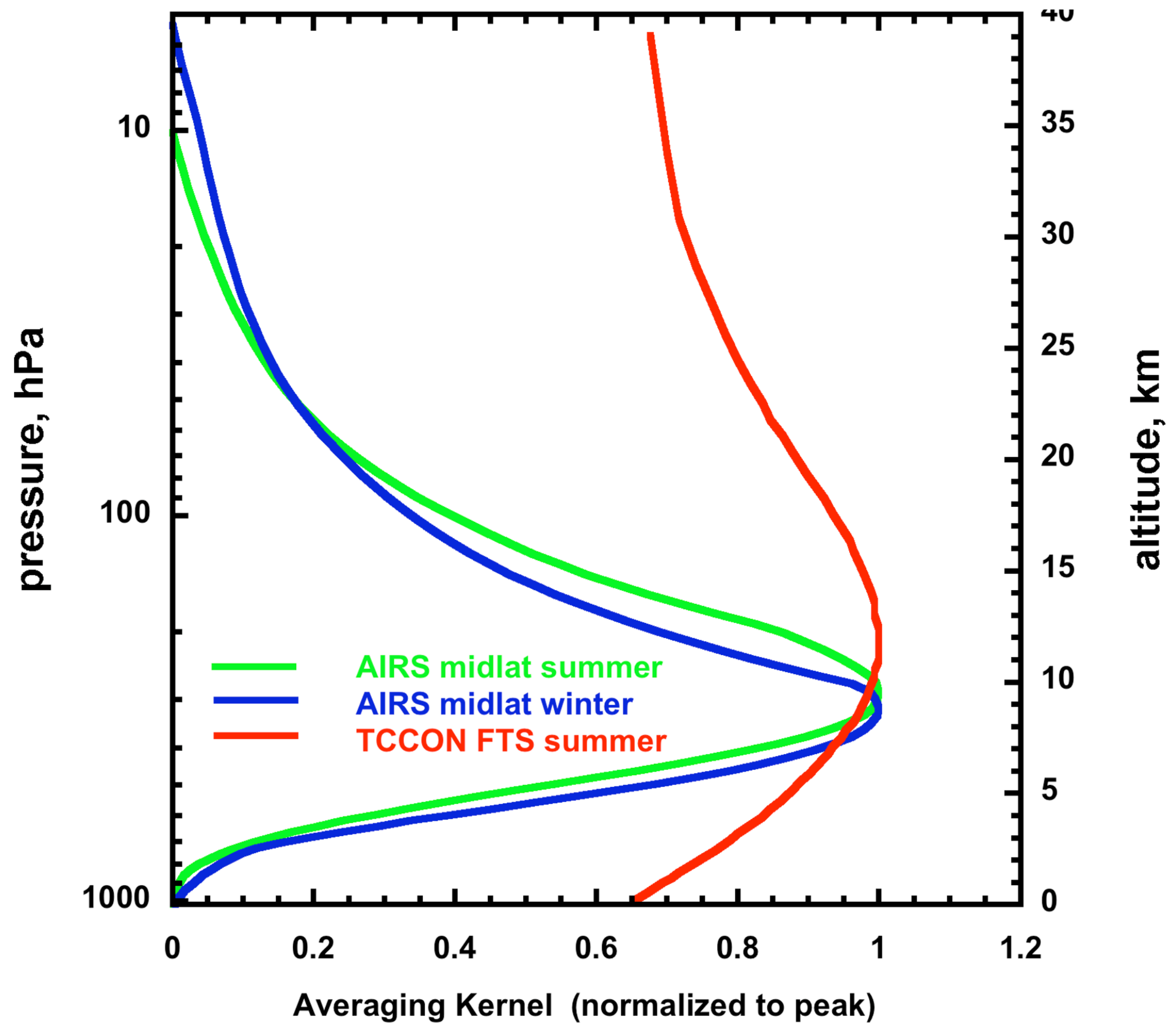
# Comparison of Averaging Kernels for AIRS Mid-Trop $CO_2$ and TCCON FTS

## AIRS Sensitivity

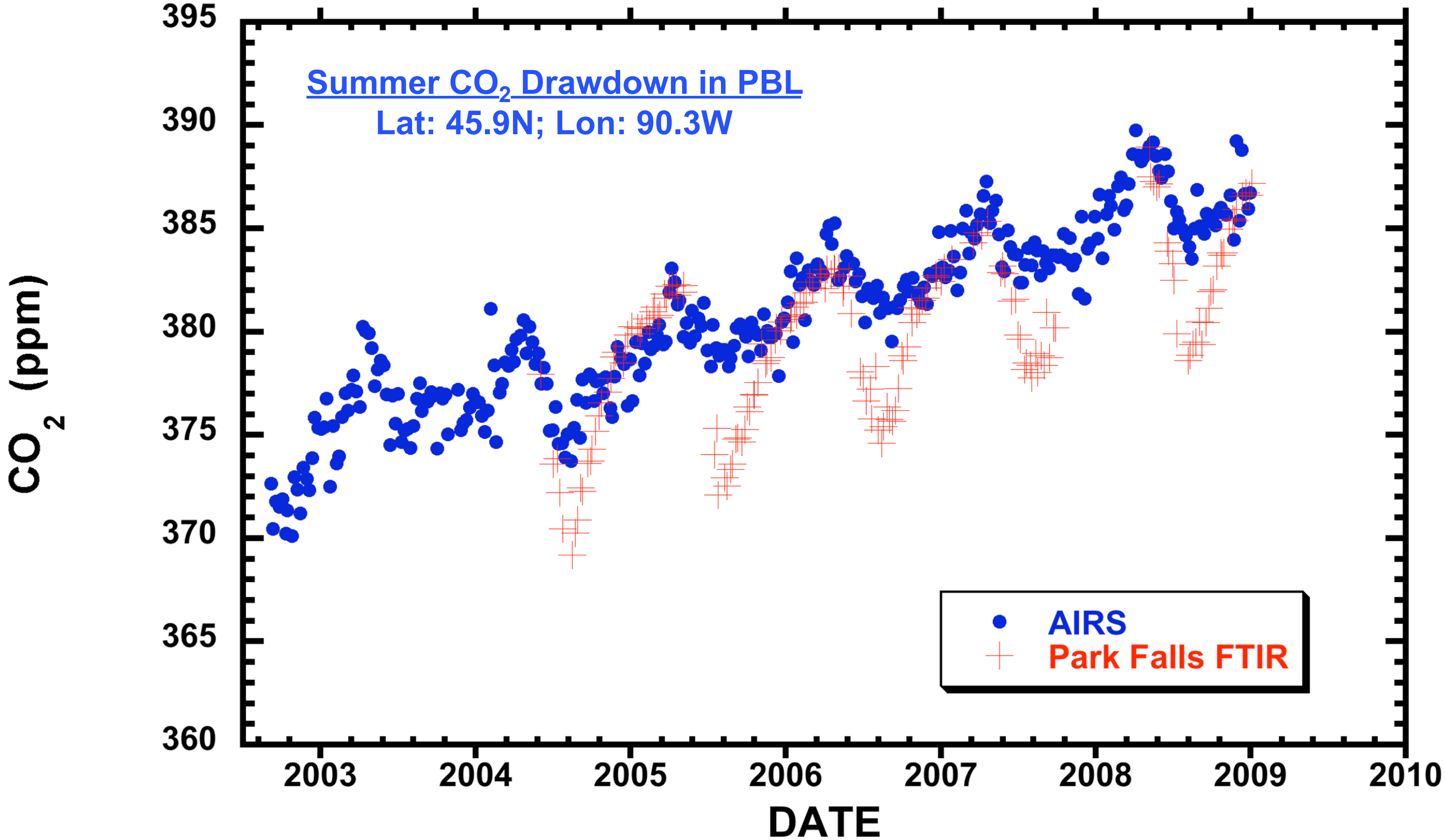
- Mid-latitude peak sensitivity altitude changes minimally with season:
  - •Summer: 300 hPa
  - •Winter: 330 hPa
- Width at half-maximum broadens slightly in winter, spanning:
  - •Summer: 125 hPa to 515 hPa (390)
  - •Winter: 150 hPa to 565 hPa (415)

## FTS Sensitivity

- Kernel is broad peak covering the full atmospheric column; excellent for determining the column average $CO_2$
- In particular, high sensitivity in the PBL, the location of maximum $CO_2$ variability.
- Data are daytime, clear sky

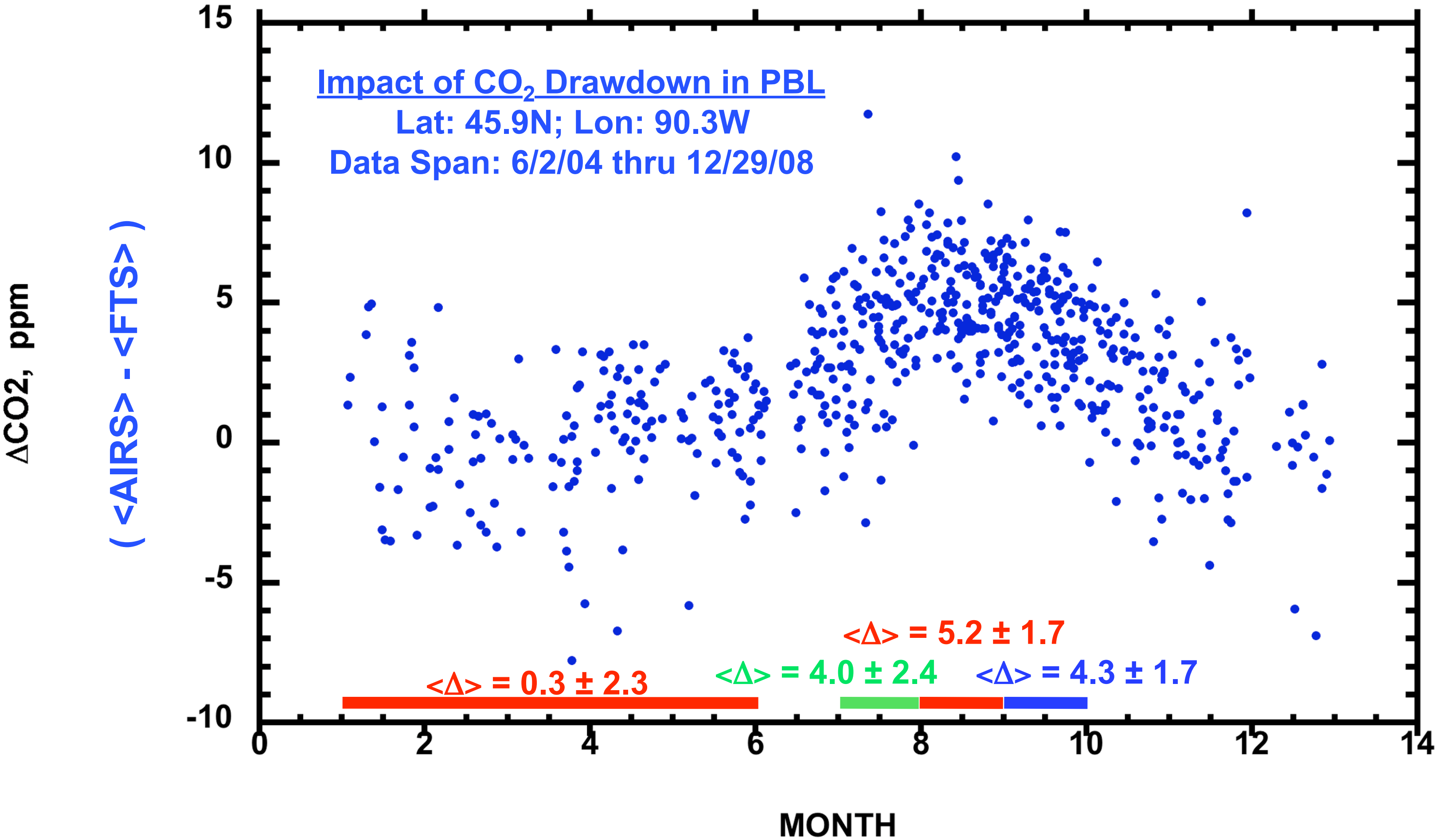


# Comparison of 7-Day Averages of Collocated AIRS Mid-Trop $CO_2$ and Park Falls FTS




AIRS daytime data collated within radius of 500km of Park Falls
Average of Selected Park Falls Pre-Release Data from Paul Wennberg & Gretchen Aleks

# Comparison of Daily Averages of Collocated AIRS Mid-Trop $CO_2$ and Park Falls FTS




AIRS daytime data collated within radius of 500km of highest quality Park Falls data taken within ± 2 hours of AIRS overpass

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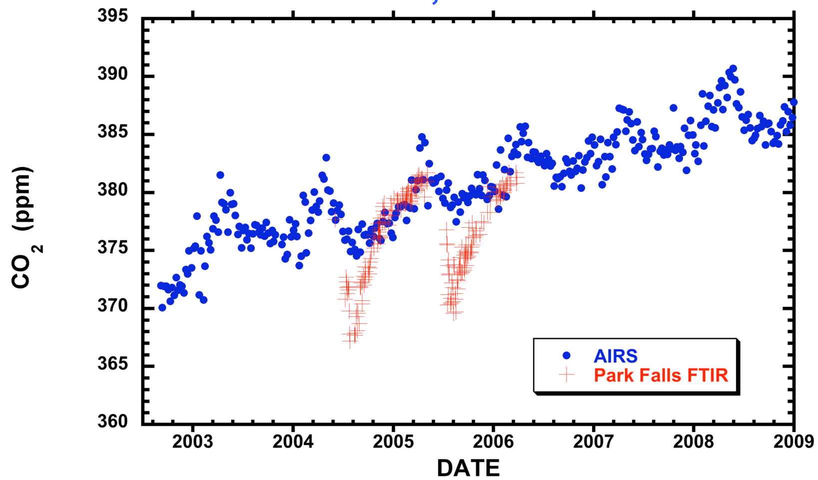
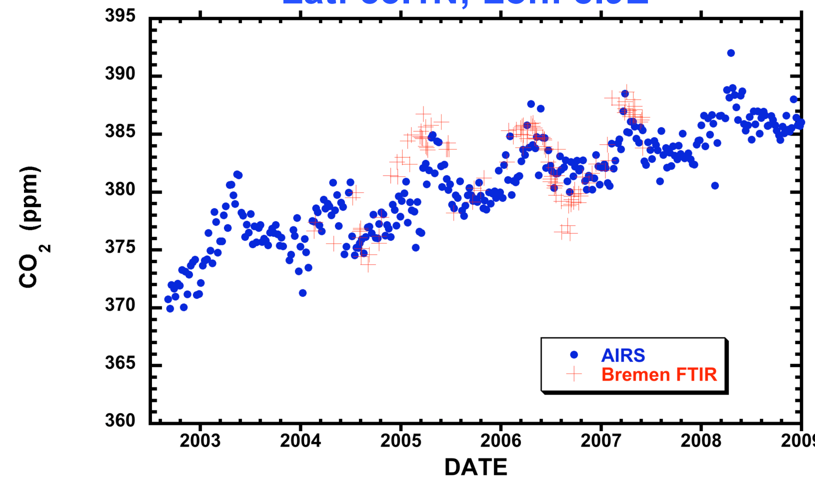
# Comparison of 7-Day Averages of AIRS Mid-Trop $CO_2$ and Daily TCCON FTS

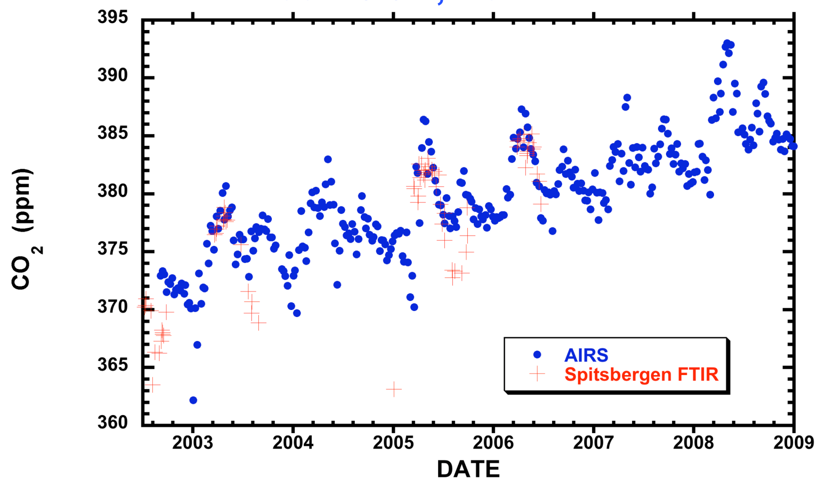
## Lat: 45.9N; Lon: 90.3W



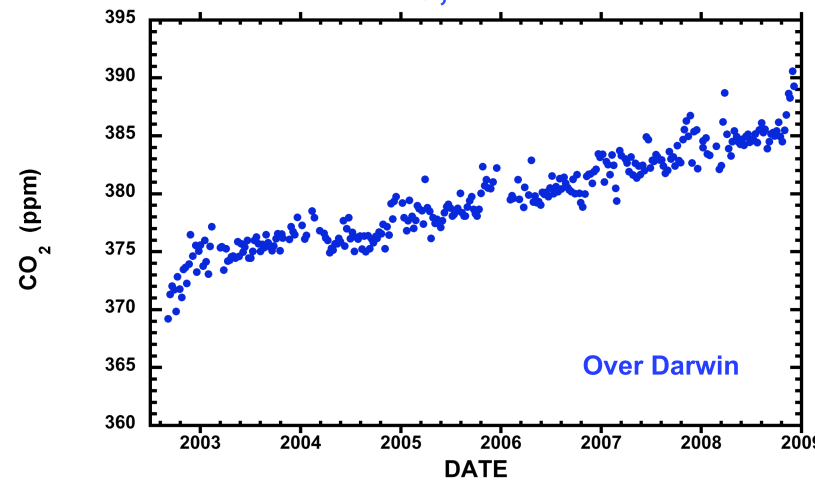

## Lat: 53.1N; Lon: 8.9E




## Lat: 78.9N; Lon: 12.4E




## Lat: 12S; Lon: 131E




**AIRS Data Collocated within radius of 250 km of FTS Sites**

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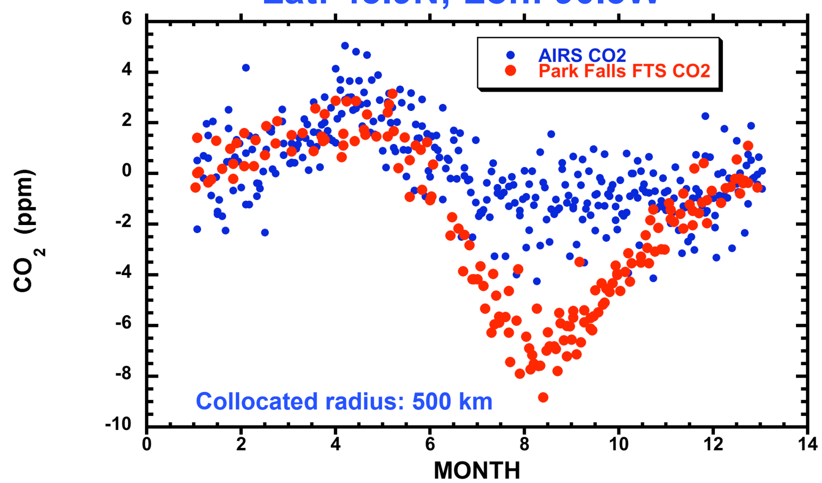
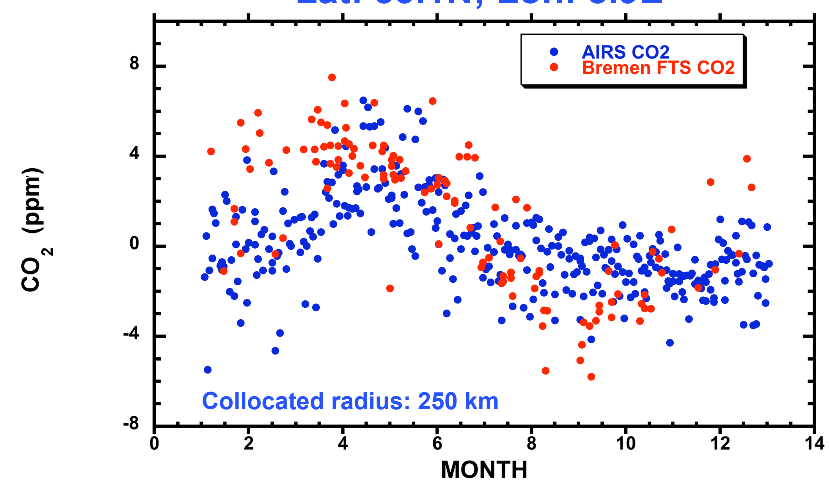
# Detrended Seasonal 7-Day Averages of AIRS Mid-Trop $CO_2$ and TCCON FTS $CO_2$

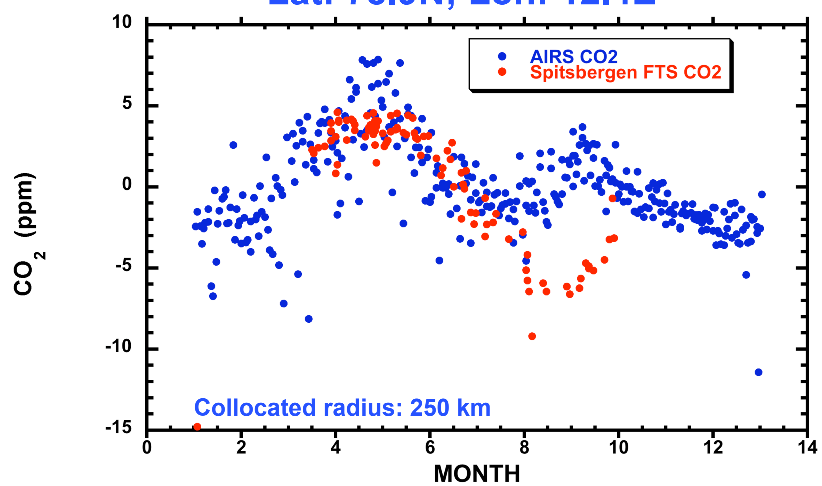
## Lat: 45.9N; Lon: 90.3W



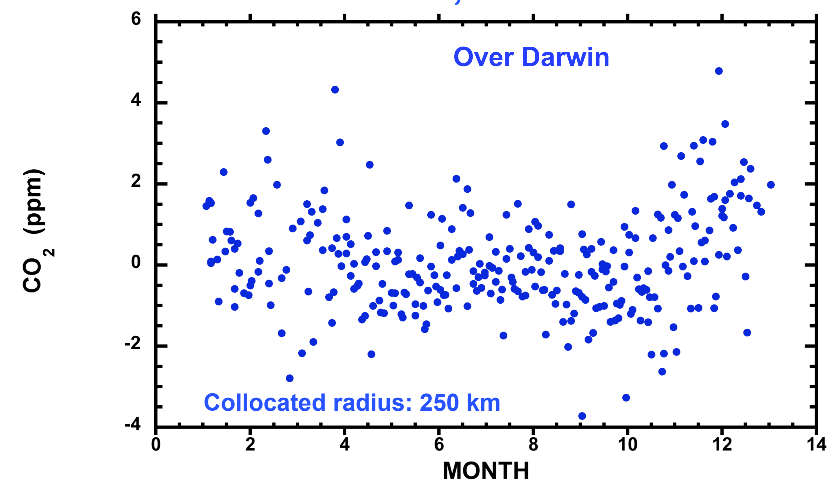

## Lat: 53.1N; Lon: 8.9E




## Lat: 78.9N; Lon: 12.4E




## Lat: 12S; Lon: 131E




Collocated radius: 250 km

# Validation of AIRS CO2 Growth Trends

| Time Series | | *in situ* Rate/std ppm/yr | AIRS Rate/std ppm/yr | AIRS – *in situ* Rate ppm/yr |
|---|---|---|---|---|
| AIRS | 60S-60N (1/03 – 12/08) | | 2.02 ± 0.08 | |
| CONTRAIL | 30S-30N (1/02 – 12/07) | 2.01 ± 0.04 | 1.98 ± 0.05 | -0.03 |
| CONTRAIL | 25S ± 5° (1/02 – 12/07) | 1.98 ± 0.05 | 2.07 ± 0.03 | +0.09 |
| CONTRAIL | 25N ± 5° (1/02 – 12/07) | 1.96 ± 0.14 | 1.96 ± 0.08 | +0.00 |
| Shemya | 53N (1/02 – 12/07) | 1.97 ± 0.40 | 2.03 ± 0.11 | +0.06 |
| Sand | 28N (1/02 – 12/07) | 1.91 ± 0.21 | 1.96 ± 0.09 | +0.05 |
| Ascension | 8S (1/02 – 12/07) | 2.05 ± 0.04 | 1.98 ± 0.03 | -0.07 |
| Mauna Loa | 20S (1/02 – 12/08) | 1.94 ± 0.12 | 1.95 ± 0.01 | +0.01 |
| Crozet | 46S (6/02 – 12/07) | 1.95 ± 0.03 | 2.17 ± 0.05 | +0.22 |
| Macquarie | 54S (1/02 – 12/07) | 1.98 ± 0.03 | 2.11 ± 0.07 | +0.13 |

**Summary of growth rates per year and the differences between AIRS and several in situ measurements**

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# Assimilate AIRS Level 2 $CO_2$ with Ensamble Kalman Filter into CAM 3.5

**Beta Testing**

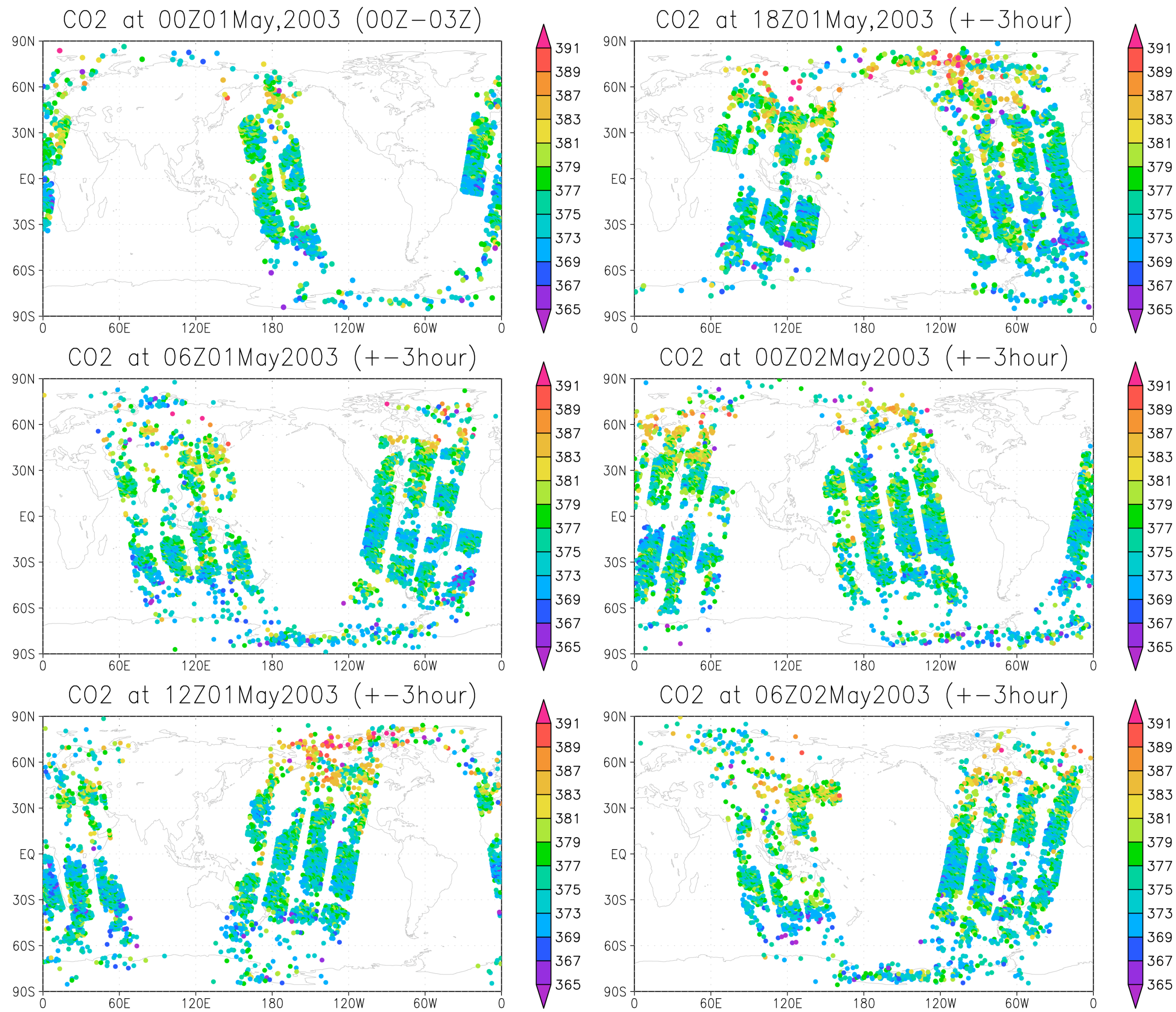
**Motivation:**

**Accurate carbon flux estimation from inversion needs far more $CO_2$ observations than current surface obs can provide.**

**Goals:**

**Generate global $CO_2$ map every 6-hours; start with AIRS then GoSat**

**Propagate AIRS $CO_2$ in both horizontal and vertical direction through data assimilation and transport model**




Eugenia Kalnay (UMCP), Junjie Liu and Inez Fung (UC Berkeley)

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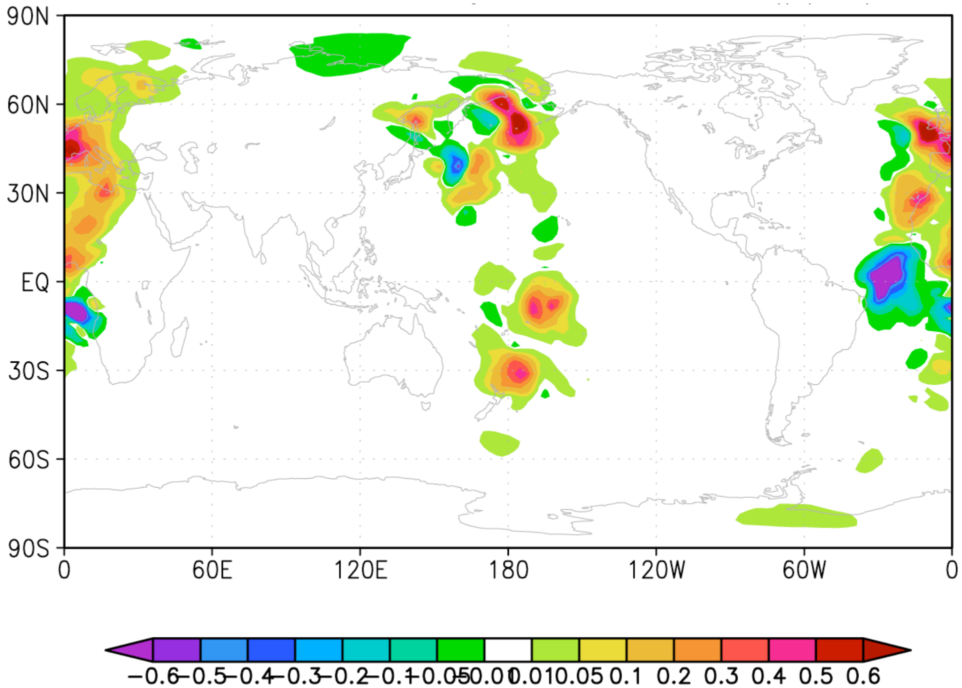
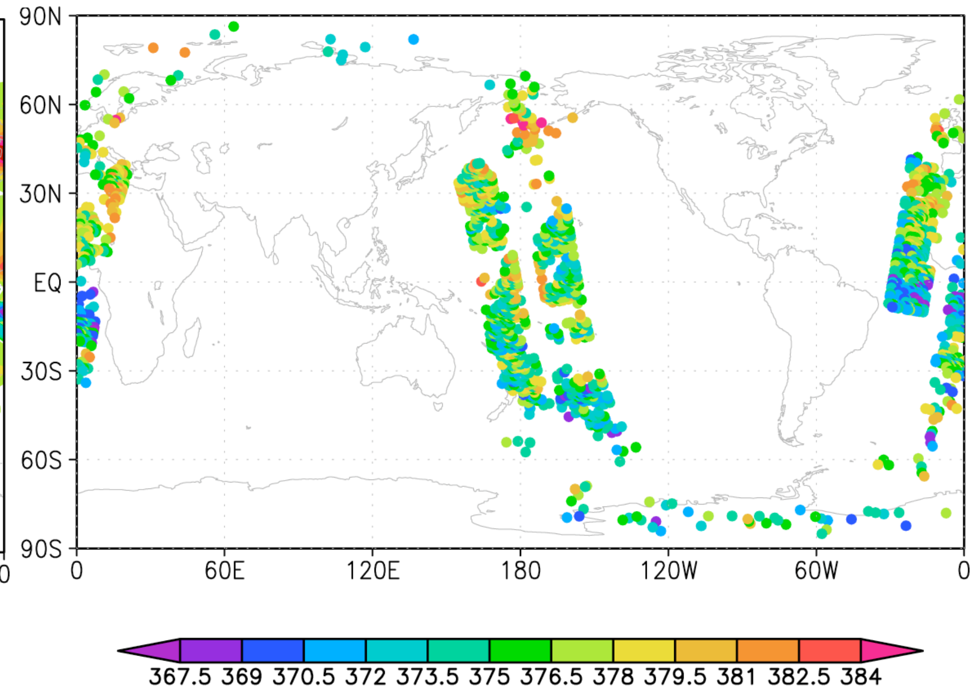
# Single $CO_2$ Analysis Step

## 350 hPa $CO_2$ analysis increment (ppm)




## $CO_2$ at 00Z01May2003 (+3hour) after QC




- **Analysis increment= analysis-background forecast**
- **Spatial pattern of analysis increment follows the observation coverage.**
- **Propagate observation information horizontally.**

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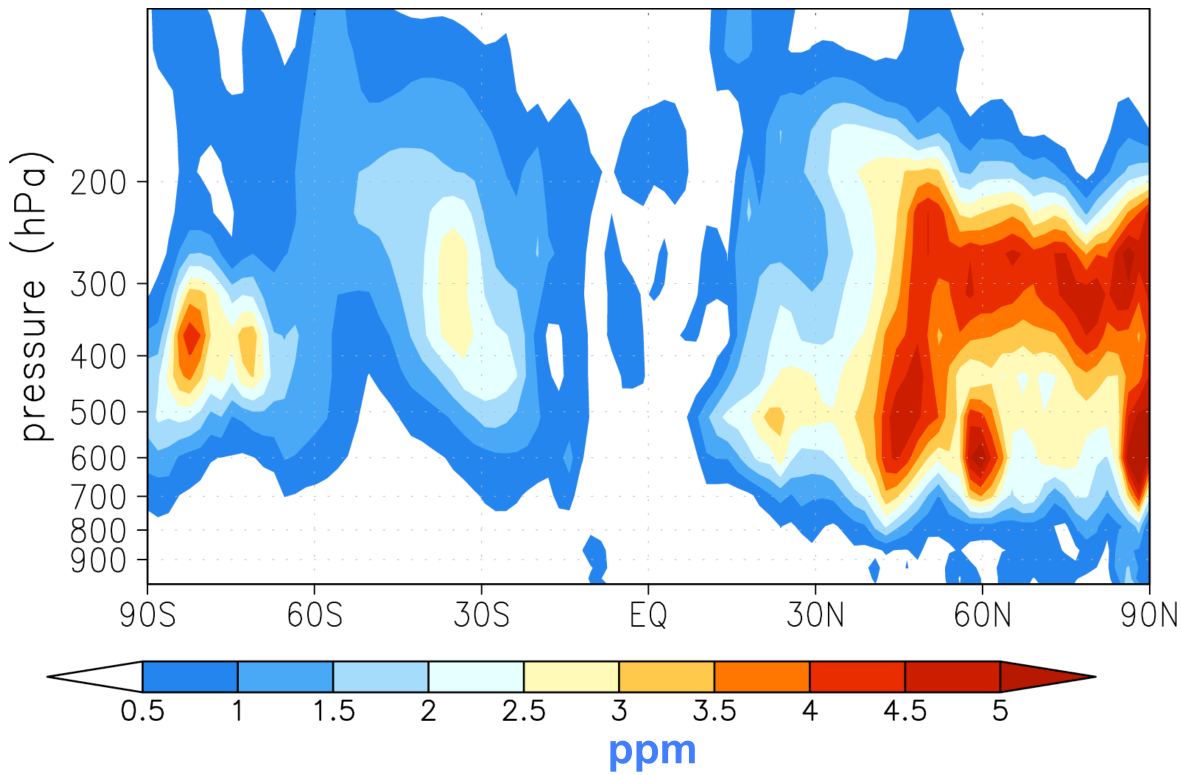
# $CO_2$ Difference between $CO_2$ Assimilation Run and Meteorological Run




1. Adjustment by AIRS $CO_2$ spans from 800hPa to 100hPa
2. The adjustment is larger in the NH

Eugenia Kalnay (UMCP), Junjie Liu and Inez Fung (UC Berkeley)

# Conclusions

✧AIRS middle tropospheric $CO_2$ long term trends and seasonal variations are consistent with *in situ* measurements over different spatial, temporal scales

for latitude range 30°S to 80°N

with standard deviation better than 2 ppm

✧ AIRS $CO_2$ retrievals are valuable as a tracer to study concentration, distribution and transport of $CO_2$ in the free troposphere and validate coupling of the atmospheric physics and dynamics in chemistry transport models

✧ Need more high-quality *in situ* validation measurements

- ✧ There are ~5,000 radiosonde launches/day
- ✧ Desire 10% (500) $CO_2$ profiles/day around the globe
- ✧ Require Southern Hemisphere expanded coverage
- ✧ Expanded TCCON network; high latitudes of NH & SH

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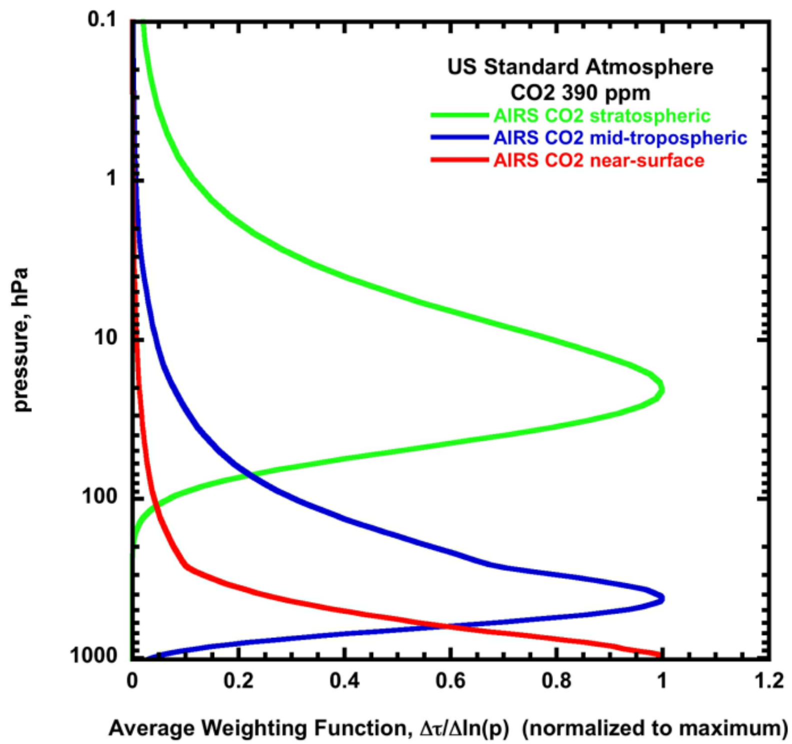
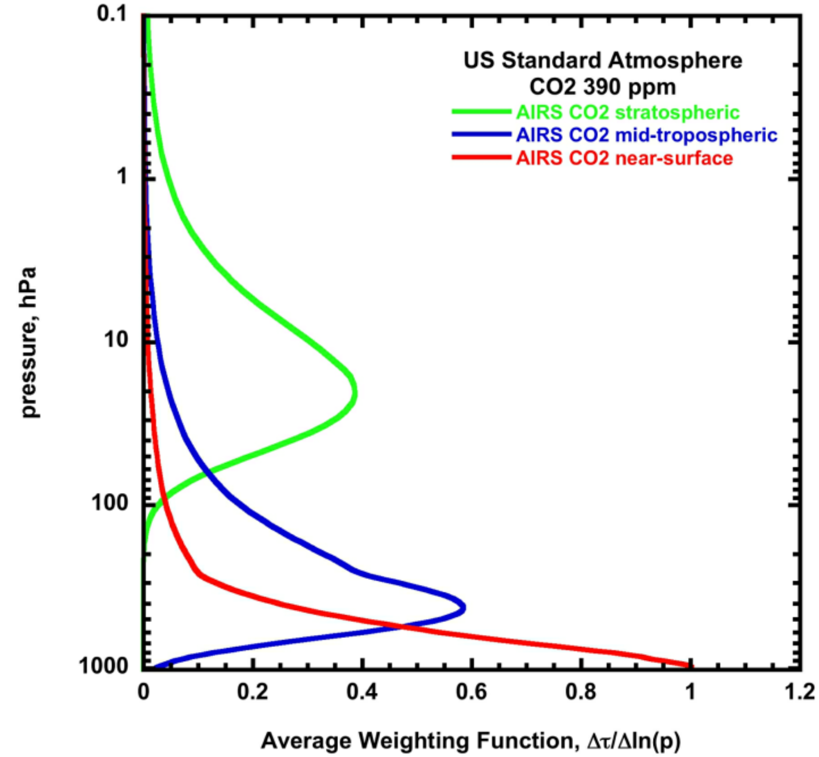
# AIRS sensitivity for retrieving $CO_2$
# AIRS can do it for three atmospheric levels

*Normalized to Maximum*




*Not Normalized*




- Mid-troposphere (Completed)
  2002 to present
  Accuracy of 1 - 2 ppm
- Stratosphere (2009)
- Near-Surface (2010)