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*Atmospheric Infrared Sounder*

# 7 Years of AIRS Mid-Tropospheric CO<sub>2</sub>

**E.T. Olsen, M.T. Chahine, L.L. Chen, and T.S. Pagano,  
X. Jiang and Y.L. Yung**

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# Release of CO<sub>2</sub> Data to Community

- ✧ **Level 3 Pre-Release took place in January 2009**
- ✧ **Release L2 & L3 CO<sub>2</sub> Products & Docs at GES DISC**
  - ✧ **December 2009**
  - ✧ **HDF-EOS format**
  - ✧ **Latitude range: 60°S to 90°N**
  - ✧ **New Level 3 Products (2° lat x 2.5° lon)**
    - ✧ **Daily**
    - ✧ **Multi-day (8-day)**
    - ✧ **Calendar Monthly**



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# Released CO<sub>2</sub> Data Products

## ✧ Level 2 Product Content

(individual retrievals, 100km x 100km at nadir)

- ✧ Latitude, Longitude, Date (yr,mon,day), UT (hr,min,sec)
- ✧ Land fraction, Solar Zenith Angle
- ✧ Mid-tropospheric CO<sub>2</sub> (mole fraction)
- ✧ CO<sub>2</sub> 1x1 error matrix (mole fraction)
- ✧ CO<sub>2</sub> Averaging Kernel Profile (100 level, TOA to Surface)

## ✧ Level 3 Product Content

(average over time period, 2° lat x 2.5° lon)

- ✧ Latitude, Longitude [144,91] grid points
- ✧ Mid-tropospheric CO<sub>2</sub> (mole fraction), [144,91] array
- ✧ CO<sub>2</sub> 1x1 error matrix (mole fraction), [144,91] array
- ✧ Count of number of samples averaged, [144,91] array



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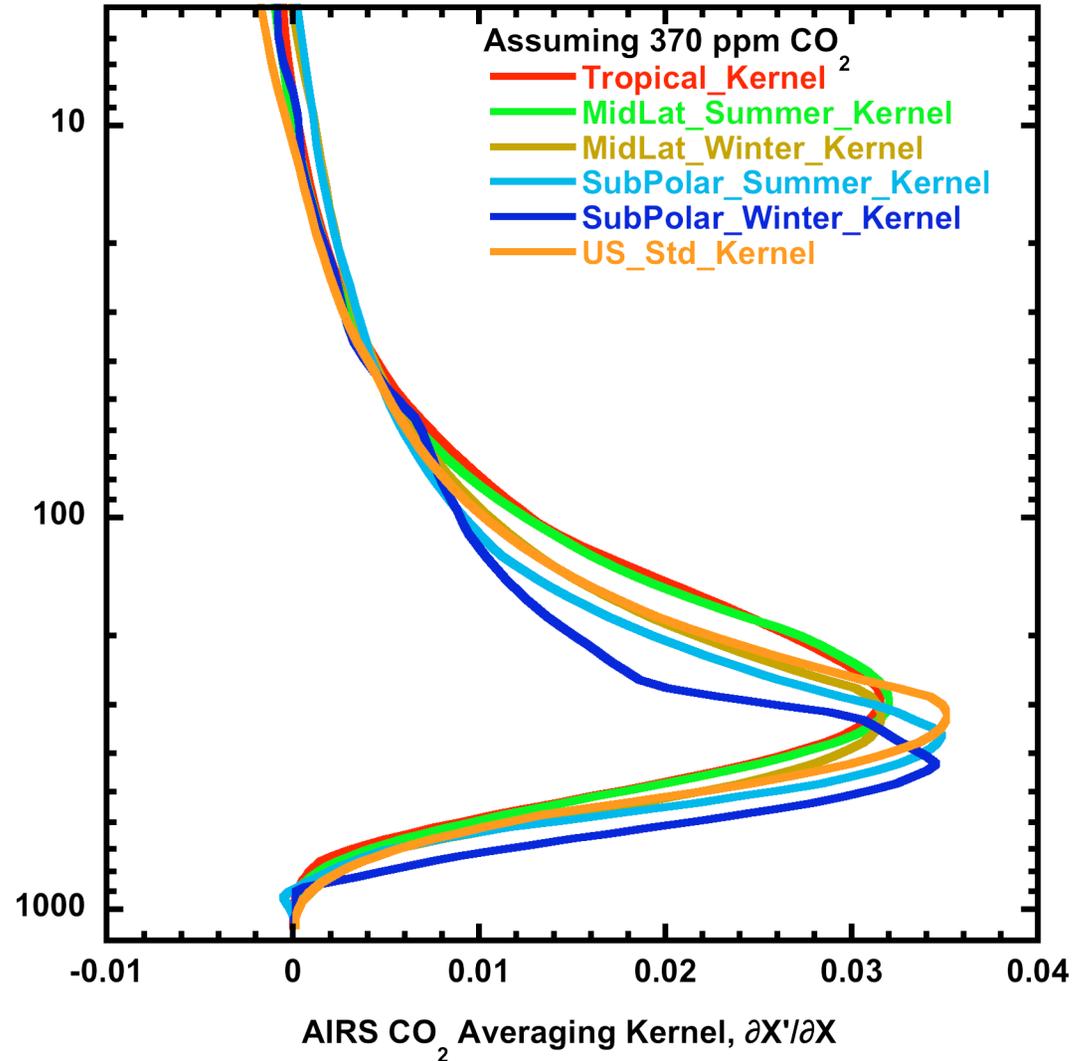
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## Representative AIRS Mid-Trop CO<sub>2</sub> Averaging Kernels

### 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: ~3 ppm increase in retrieved CO<sub>2</sub> near the poles if correction is applied.





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# Quality checks in the VPD retrieval algorithm are very conservative

*A solution is reached when the partial derivatives individually vanish*

## 1. Uniqueness

- We track the variations of residuals with iterations and only accept solutions whose residuals decrease monotonically with iterations; i.e., we seek solutions having a single minimum

## 2. Accuracy:

- We require that a cluster of four adjacent CO<sub>2</sub> retrievals (2x2 array covering a 90x90 km area at nadir) agree to within 2 ppmv in an RMS sense (spatial coherence of retrievals over 1° x 1°).
- We find that the errors in the retrieved CO<sub>2</sub> mixing ratios are uncorrelated, allowing reduction of errors by averaging of retrievals.



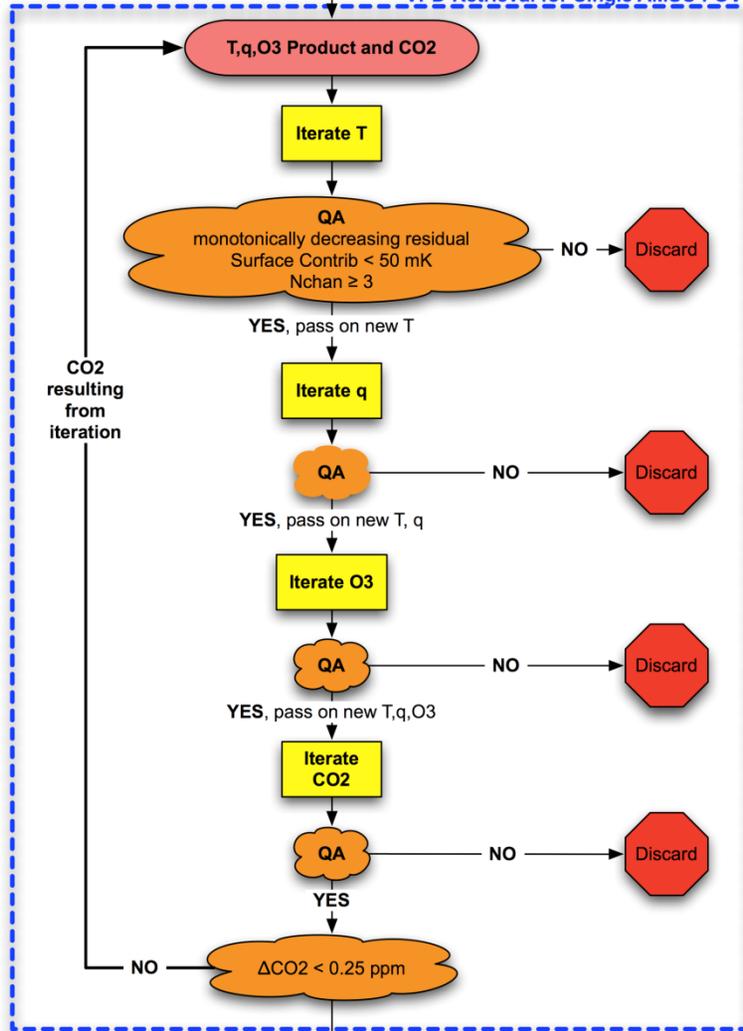
# VPD Algorithm Block Diagram

Atmo:

linearly increasing CO2 with time

Level 2 Retrieval

VPD Retrieval for Single AMSU FOV



YES, pass on CO2 solution

CO2 for Single AMSU FOV

Assemble VPD CO2 results for 2x2 array of adjacent AMSU FOVs

Does 2x2 array contain at least 3 successful retrievals?  
 Is the Standard Deviation of the 3 or 4 successful retrievals no greater than 2 ppm?

NO → Discard

Report CO2 Retrieval

15,000/Day



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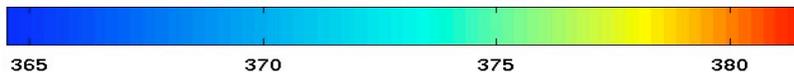
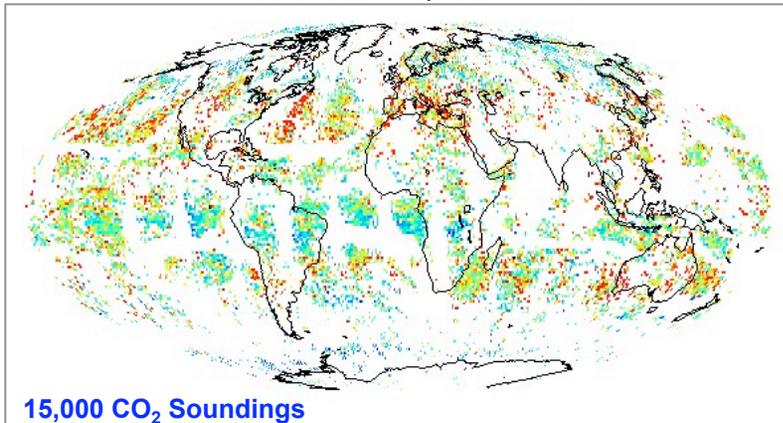
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## Global Yield of AIRS Level 2 Mid-Tropospheric CO<sub>2</sub>

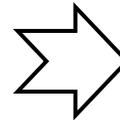
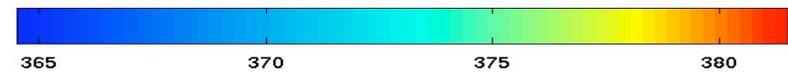
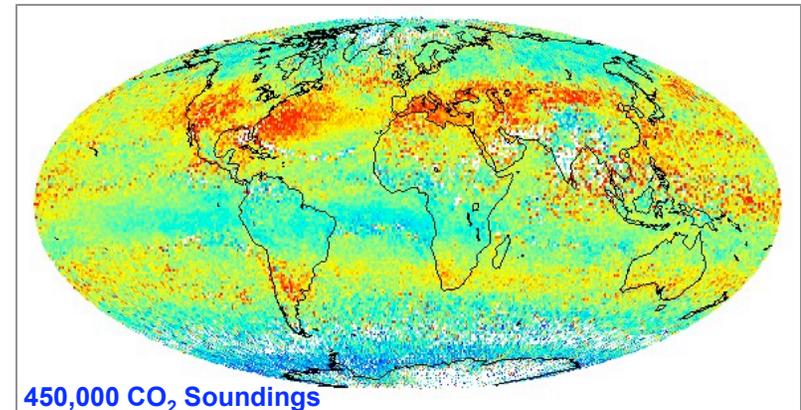
### AIRS Daily CO<sub>2</sub> Yield 1°x1° Spatial Resolution

AIRS V5 CO<sub>2</sub>: Day 2003 7 15 x 1



### AIRS Monthly CO<sub>2</sub> Yield 1°x1° Spatial Resolution

AIRS V5 CO<sub>2</sub>: Day 2003 7 15 x 30



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

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



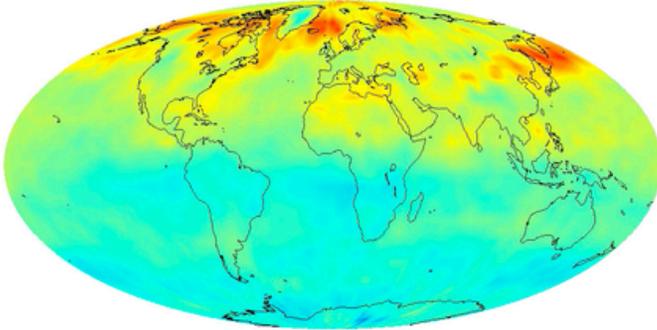
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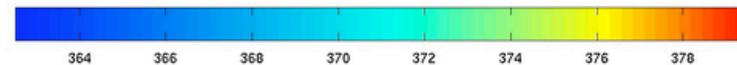
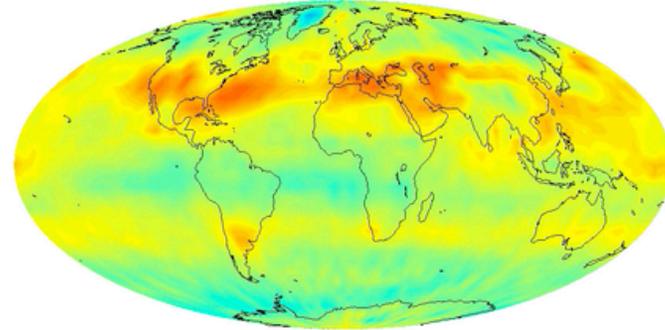
# Monthly Average AIRS Mid-Trop CO<sub>2</sub> May and July – 2003 through 2009

AIRS Mid-Tropospheric CO<sub>2</sub>  
May 2003



CO<sub>2</sub> (ppm)

AIRS Mid-Tropospheric CO<sub>2</sub>  
July 2003



CO<sub>2</sub> (ppm)

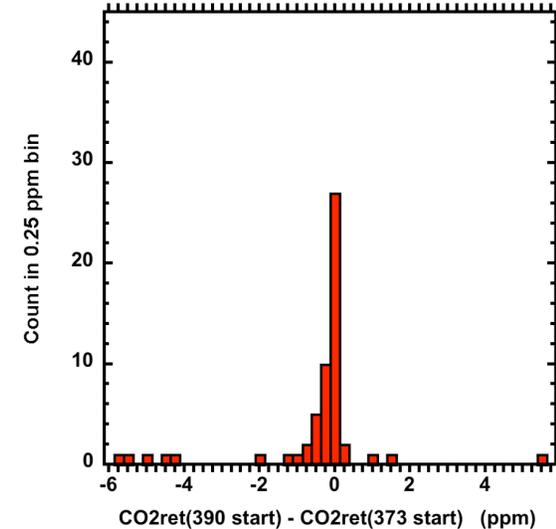
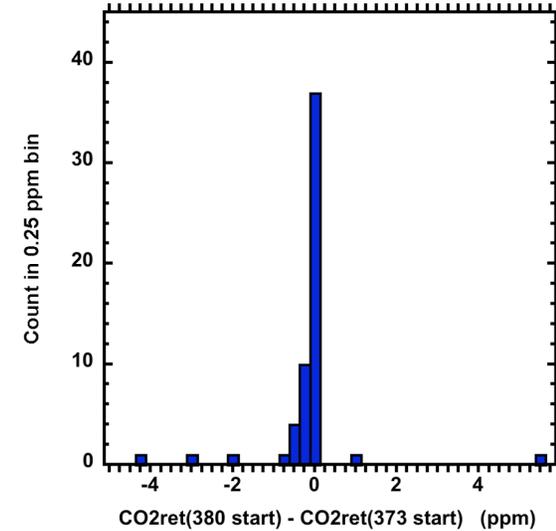
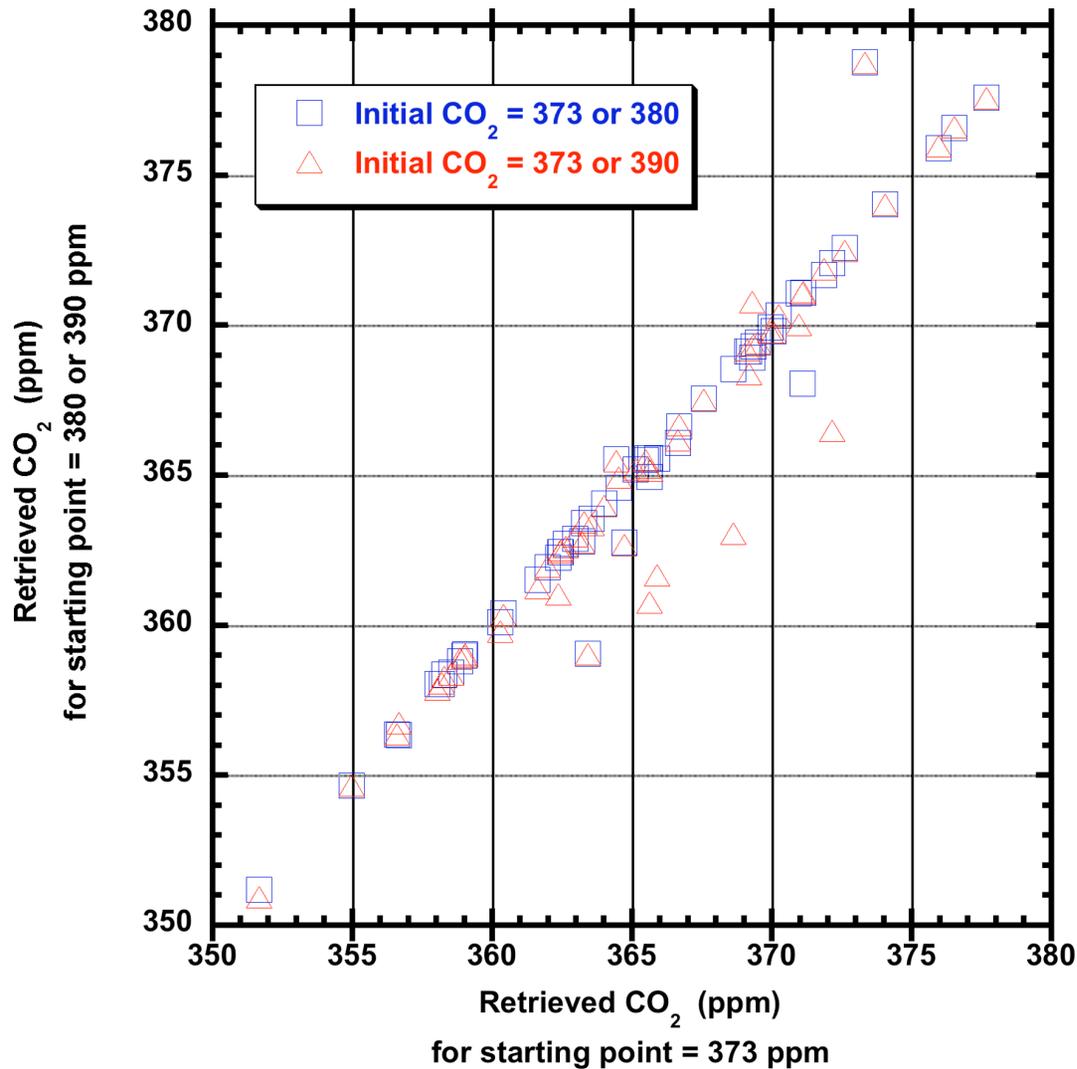


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# VPD CO<sub>2</sub> Solution is Stable to Variation of Iteration Starting Point





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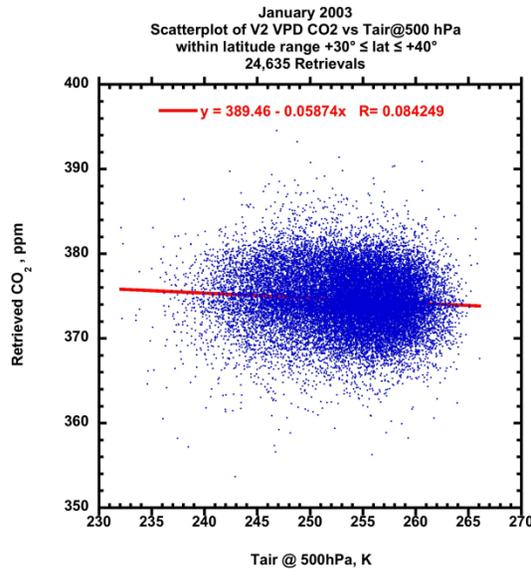
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## Negligible Correlations Between Retrieved Parameters Introduced by VPD Retrieval Algorithm

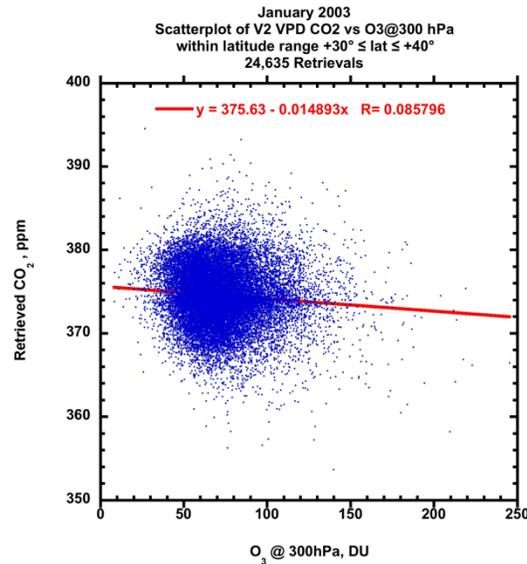
Example for latitude band 30N to 40N during January, 2003

**CO<sub>2</sub> and T**



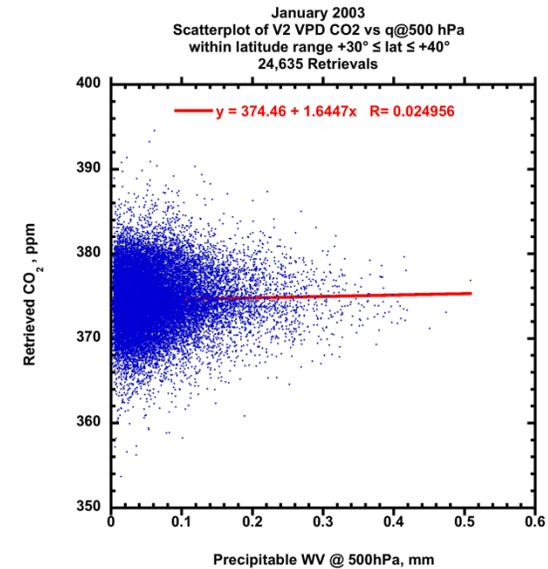
**R=0.0842**

**CO<sub>2</sub> and O<sub>3</sub>**



**R=0.0857**

**CO<sub>2</sub> and H<sub>2</sub>O**



**R=0.0249**

Correlations are seen when there is a physical mechanism,  
e.g., stratospheric intrusion



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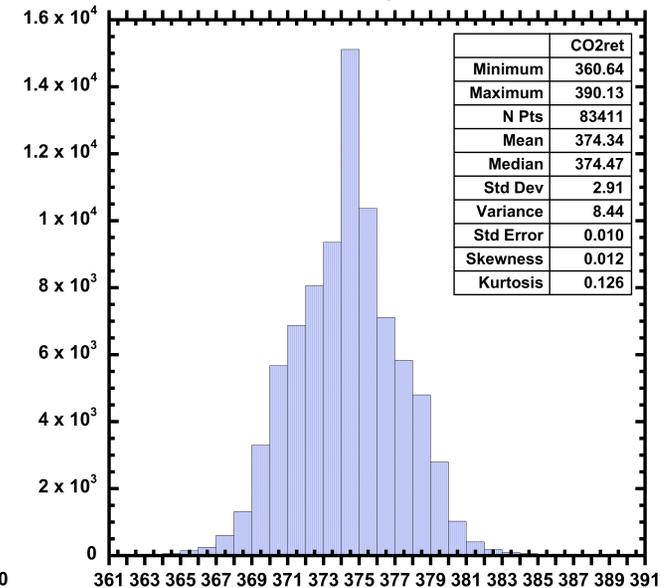
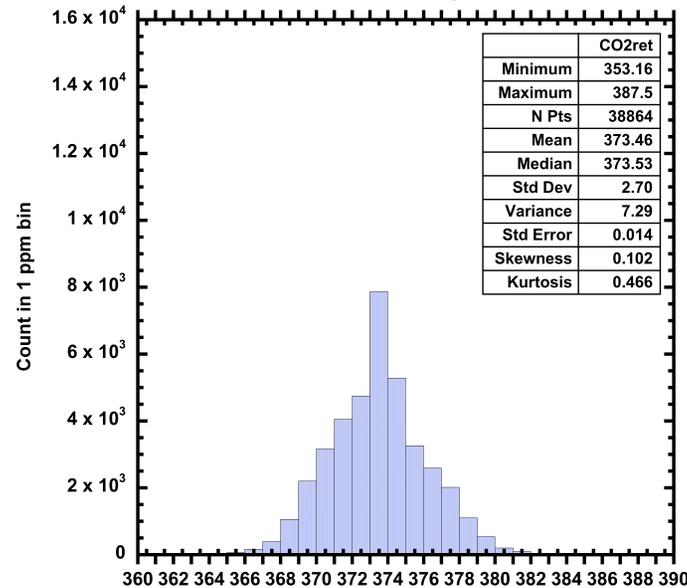
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# VPD CO<sub>2</sub> for |lat| ≤ 10°

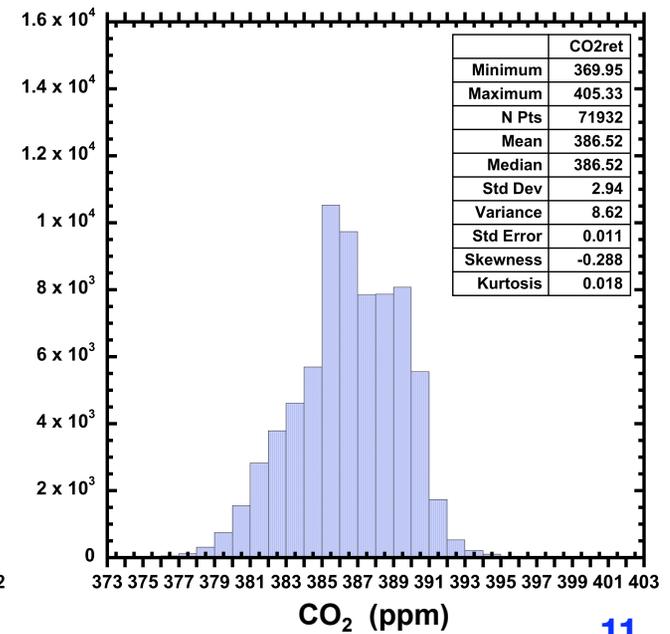
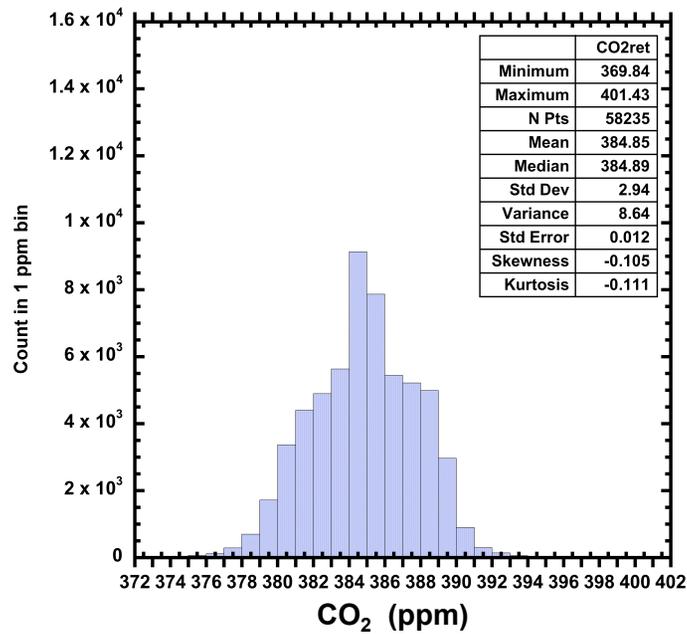
January

July

2003



2009





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# Validation and Comparisons with In Situ Measurements

- ✧ **Aircraft profiles of CO<sub>2</sub> concentration**
  - ➔ **Direct validation of satellite retrievals**
    - ✧ **Ideal Characteristics**
      - ✧ **Spiral flight path**
      - ✧ **Altitude range from near surface to 150 hPa (13.5 km)**
      - ✧ **Coincident with the satellite overpass**
  
- ✧ **CONTRAIL CO<sub>2</sub> 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<sub>2</sub> measurements**
  - ➔ **Validate phase of seasonal variations and interannual trends; allows estimation of drawdown in PBL**
  
- ✧ **Surface stations**
  - ➔ **Estimate differences between free troposphere and planetary boundary layer; compare interannual trends**



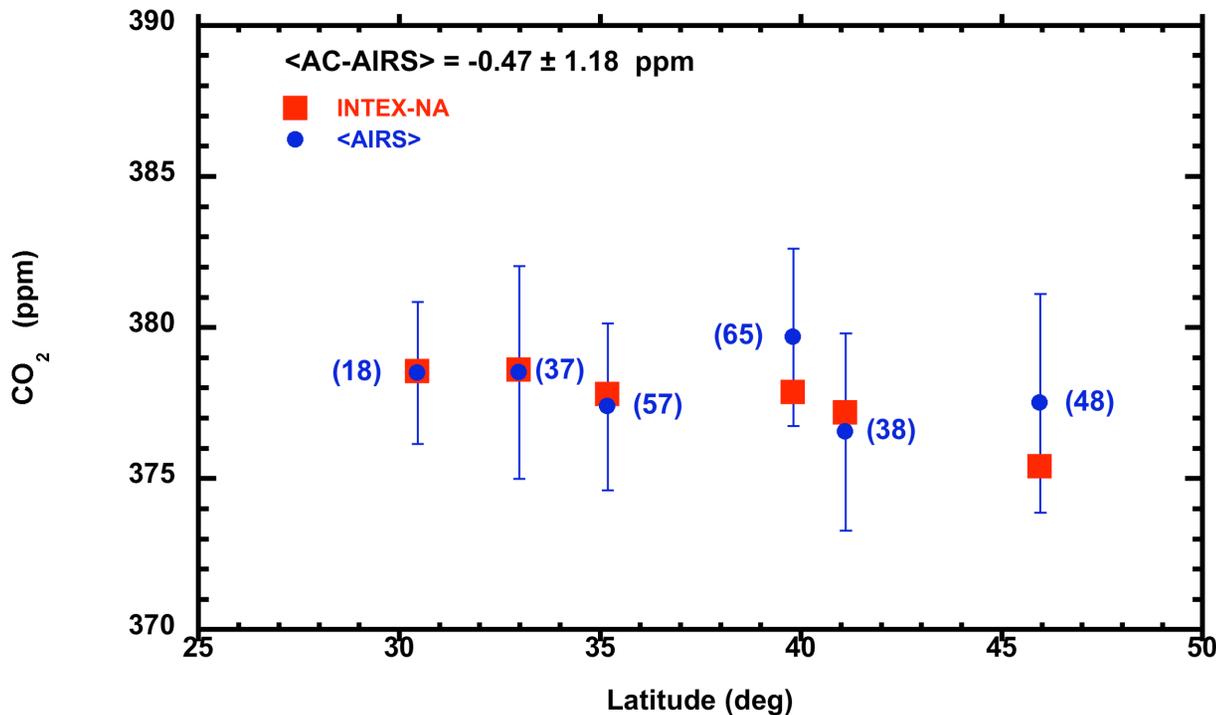
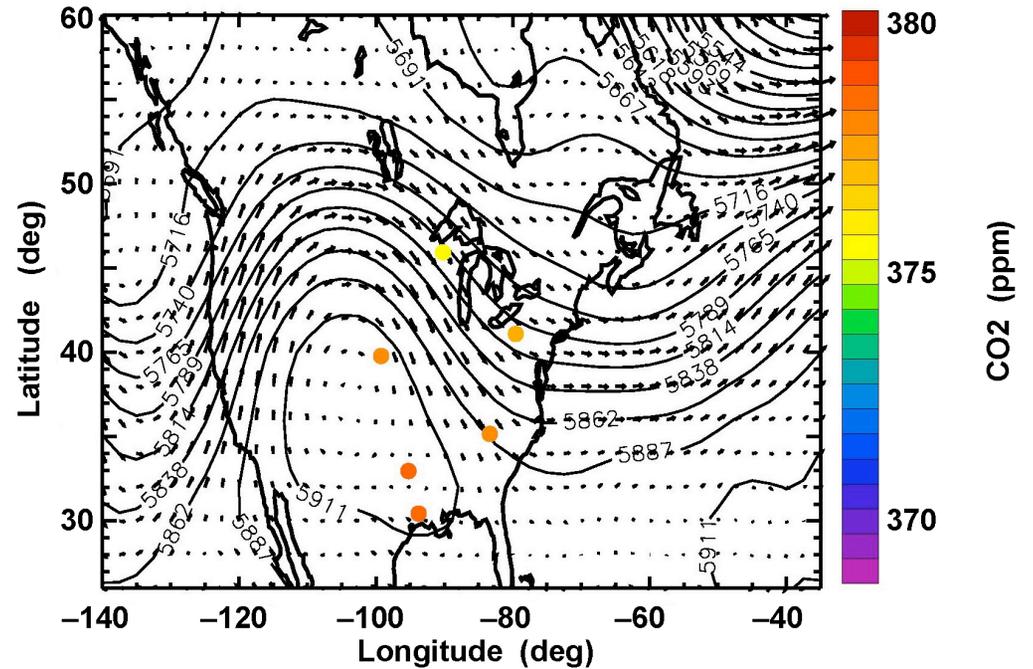
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Contours are NCEP 500 mb  
geopotential height.  
Arrows are NCEP 500 mb  
wind.

## Comparison of AIRS CO<sub>2</sub> 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.



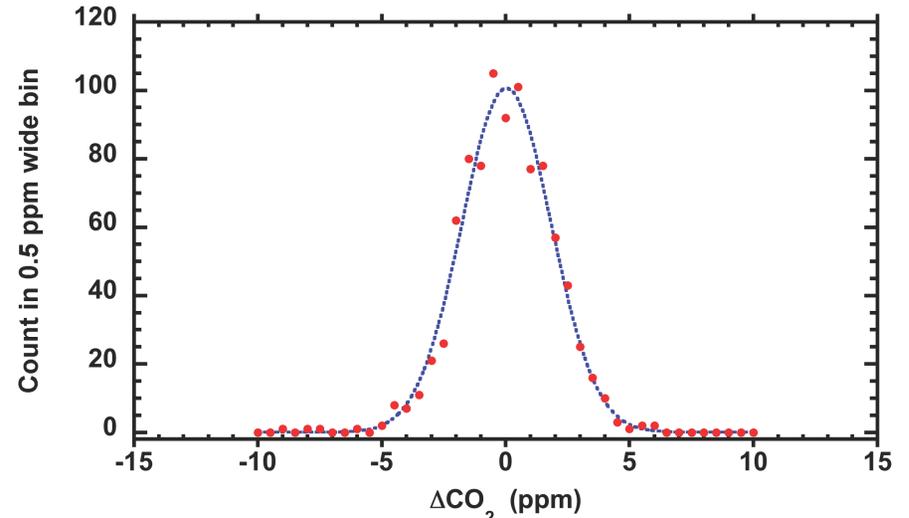
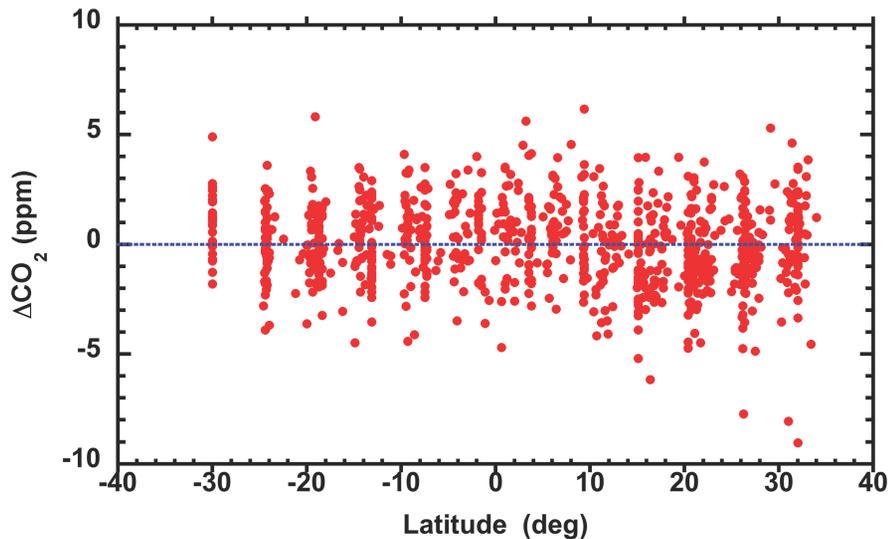
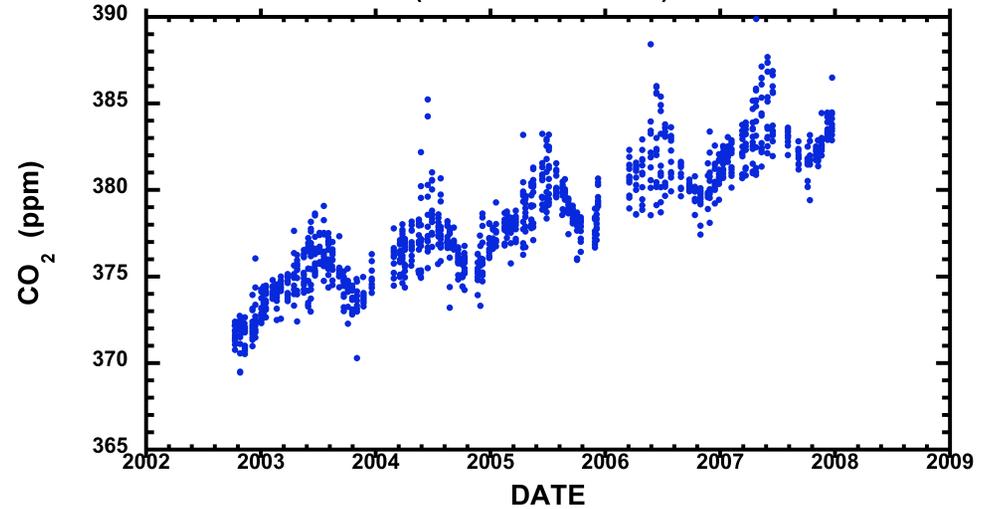
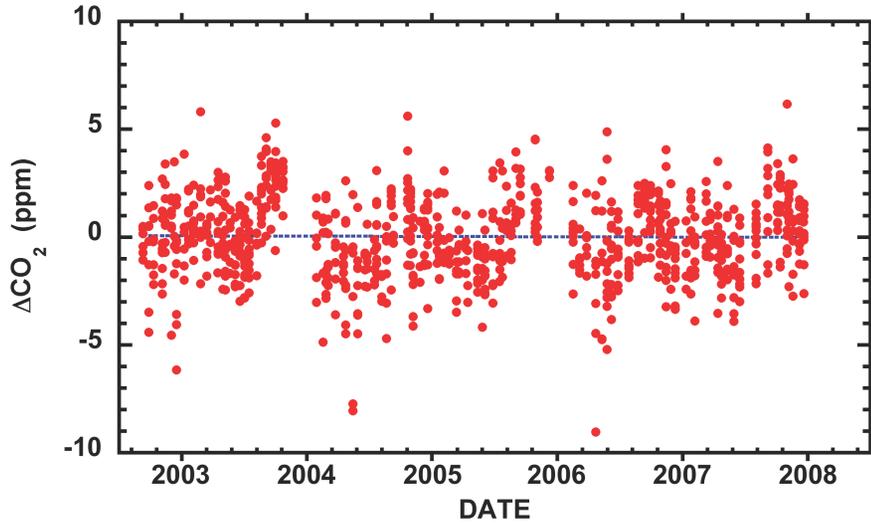
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$\Delta\text{CO}_2 = \langle \text{AIRS CO}_2 \rangle - \text{CONTRAIL CO}_2$   
AIRS Data collocated within 500 km radius and  $\pm 4$  hours  
are averaged to compare to the 911 CONTRAIL measurements  
taken while aircraft cruised at altitude  $\geq 10.5$  km

CONTRAIL CO<sub>2</sub> Airborne Flask Measurements  
(altitude  $\geq 10.5$  km)



$\langle \Delta\text{CO}_2 \rangle = 0.04 \pm 0.04$  ppm  
 $\sigma = 1.80 \pm 0.05$  ppm



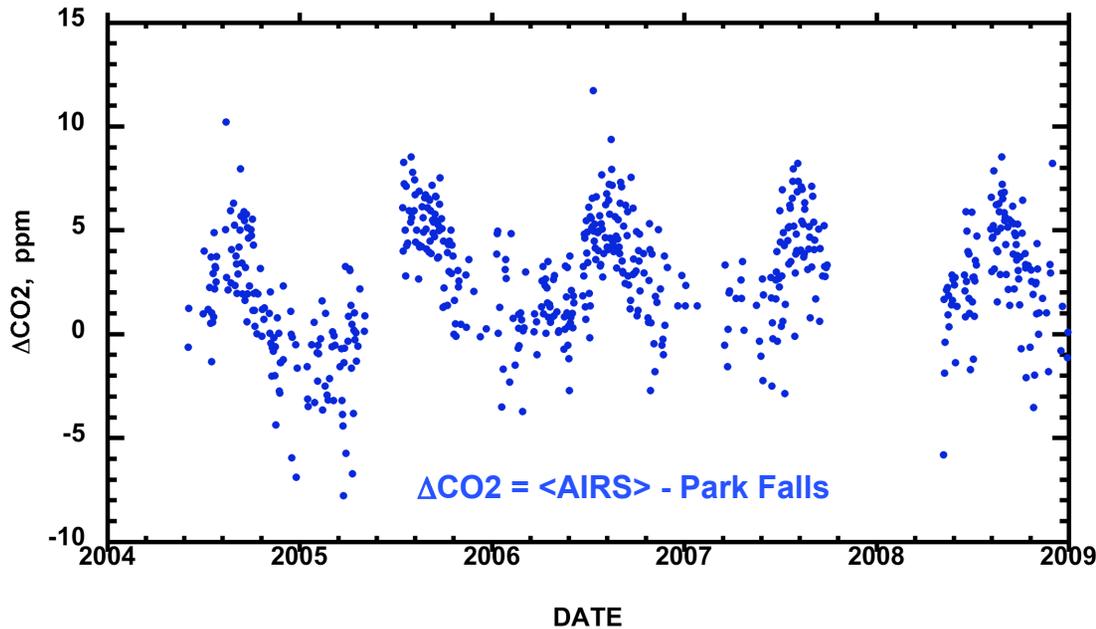
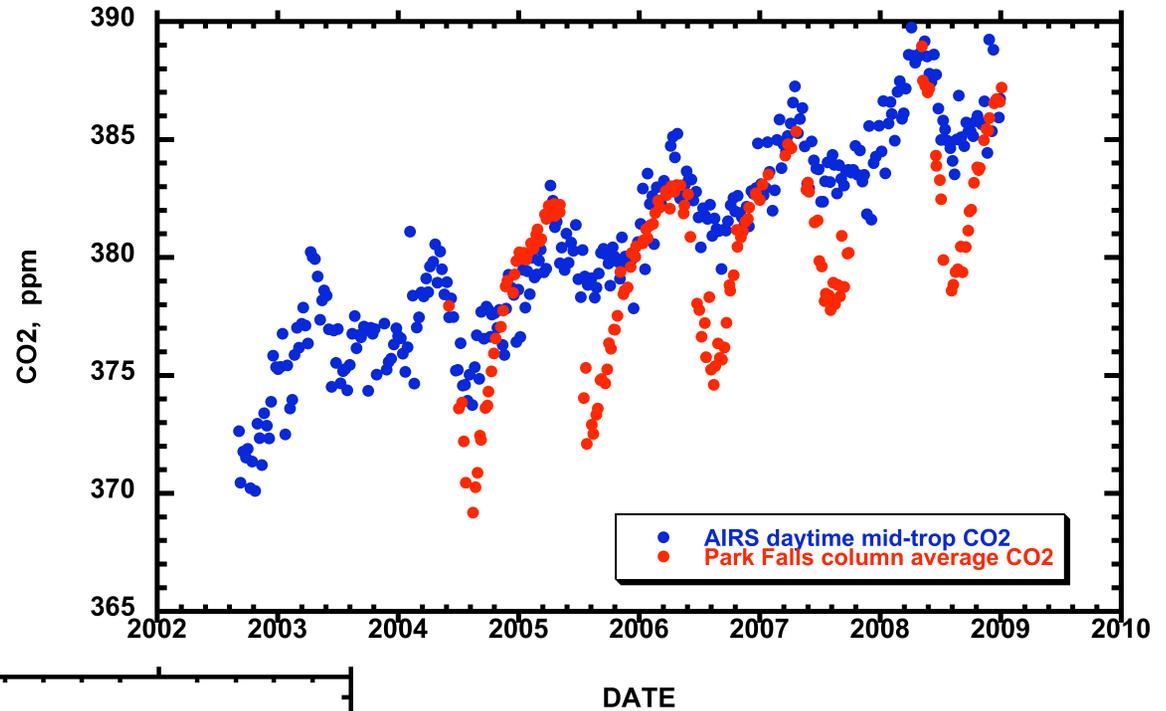
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# Collocated AIRS Mid-Trop CO<sub>2</sub> and Park Falls FTS

AIRS and Park Falls Time Series  
AIRS 7-Day avg and PF Daily  
AIRS data collocated within  
Radius 500 km and Time  $\pm$  2 hr



Summer CO<sub>2</sub> Drawdown in PBL

Lat: 45.9N; Lon: 90.3W

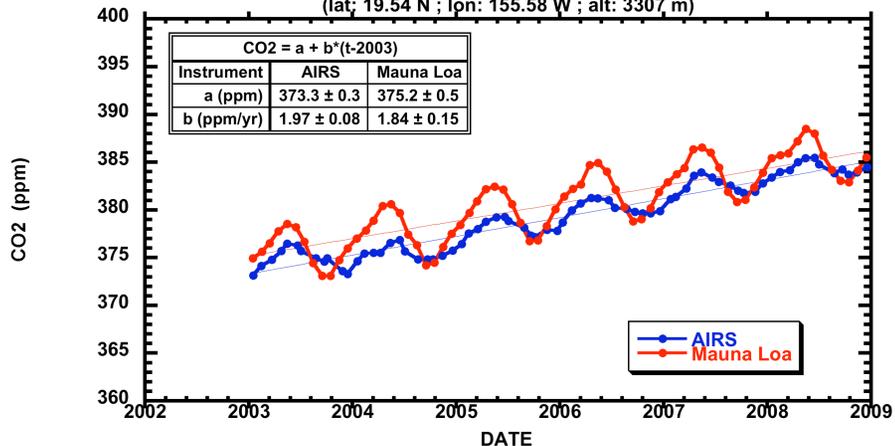
AIRS-Park Falls  
Both daily averages  
AIRS data collocated within  
Radius 500 km and Time  $\pm$  2 hr

Park Falls Data courtesy of  
Paul Wennberg & Gretchen Aleks

# Monthly Average Time Series for AIRS CO<sub>2</sub> Collocated within 500km and Surface Stations

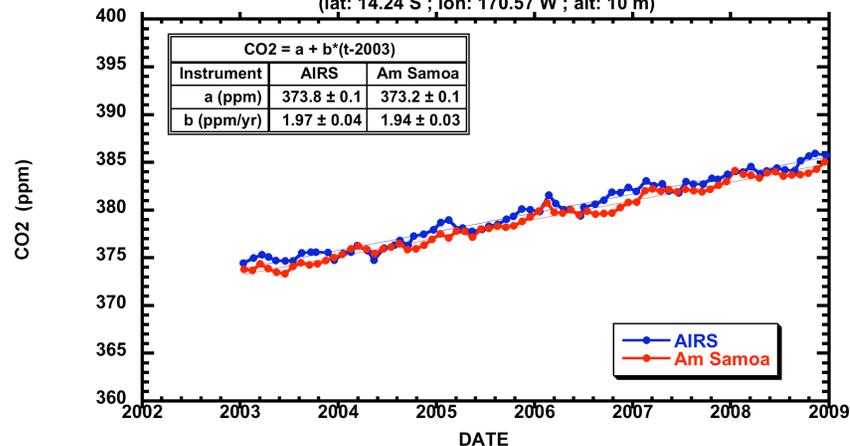
## Northern Hemisphere

Monthly Average CO<sub>2</sub>  
Mauna Loa Station and AIRS mid-Tropospheric Retrievals  
AIRS Retrievals Collocated within 500 km radius  
(lat: 19.54 N ; lon: 155.58 W ; alt: 3307, m)

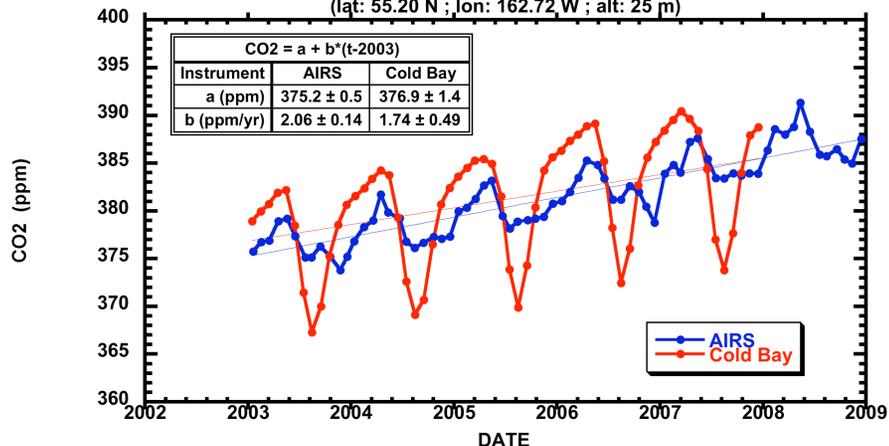


## Southern Hemisphere

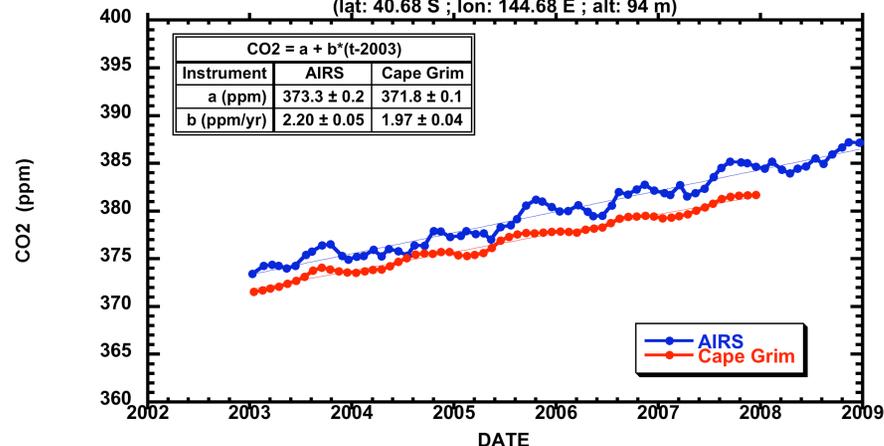
Monthly Average CO<sub>2</sub>  
American Samoa Ground Station and AIRS mid-Tropospheric Retrievals  
AIRS Retrievals Collocated within 500 km radius  
(lat: 14.24 S ; lon: 170.57 W ; alt: 10 m)



Monthly Average CO<sub>2</sub>  
Cold Bay Ground Station and AIRS mid-Tropospheric Retrievals  
AIRS Retrievals Collocated within 500 km radius  
(lat: 55.20 N ; lon: 162.72 W ; alt: 25 m)



Monthly Average CO<sub>2</sub>  
Cape Grim Ground Station and AIRS mid-Tropospheric Retrievals  
AIRS Retrievals Collocated within 500 km radius  
(lat: 40.68 S ; lon: 144.68 E ; alt: 94 m)



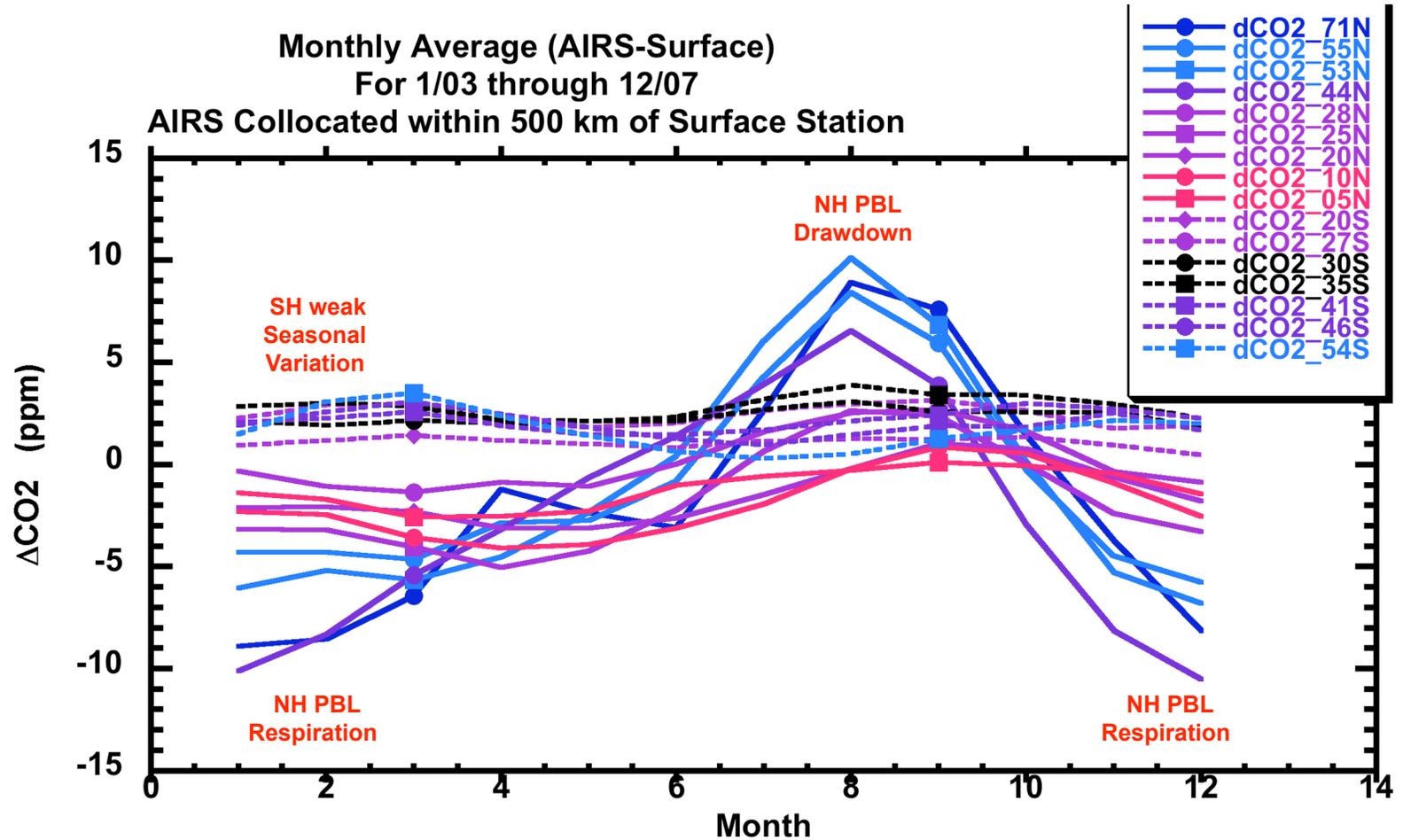


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## Seasonal Variation of Difference between AIRS Mid-Trop CO<sub>2</sub> and Surface Station CO<sub>2</sub>





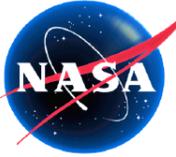
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## Future Work

- ✧ **We have received funding from NASA HQ to retrieve near-surface CO<sub>2</sub> using AIRS spectra**
  - ✧ **We have initiated tradeoff studies to optimize the set of channels used in the retrieval**
  - ✧ **Account for the surface emissivity and surface temperature**
  - ✧ **Retrievals over oceans (September 2010)**
  - ✧ **Retrievals over land (June 2011)**



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***THANK YOU !***

