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Atmospheric Infrared Sounder

Retrieval of mid-tropospheric of CO_2 directly from AIRS measurements

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Pasadena, California

Algorithms and Technologies for Multispectral, Hyperspectral and Ultraspectral Imagery XIV
SPIE Defense & Security
Orlando, Florida

Overview

- **Introduction to AIRS on Aqua**
- **Method of Vanishing Partial Derivative for Retrieval of CO_2**
- **Validation with Aircraft In-Situ Measurements**
- **Spatial Patterns of CO_2 :**
  Effects of Weather and Stationary Sources
- **Model Comparisons**

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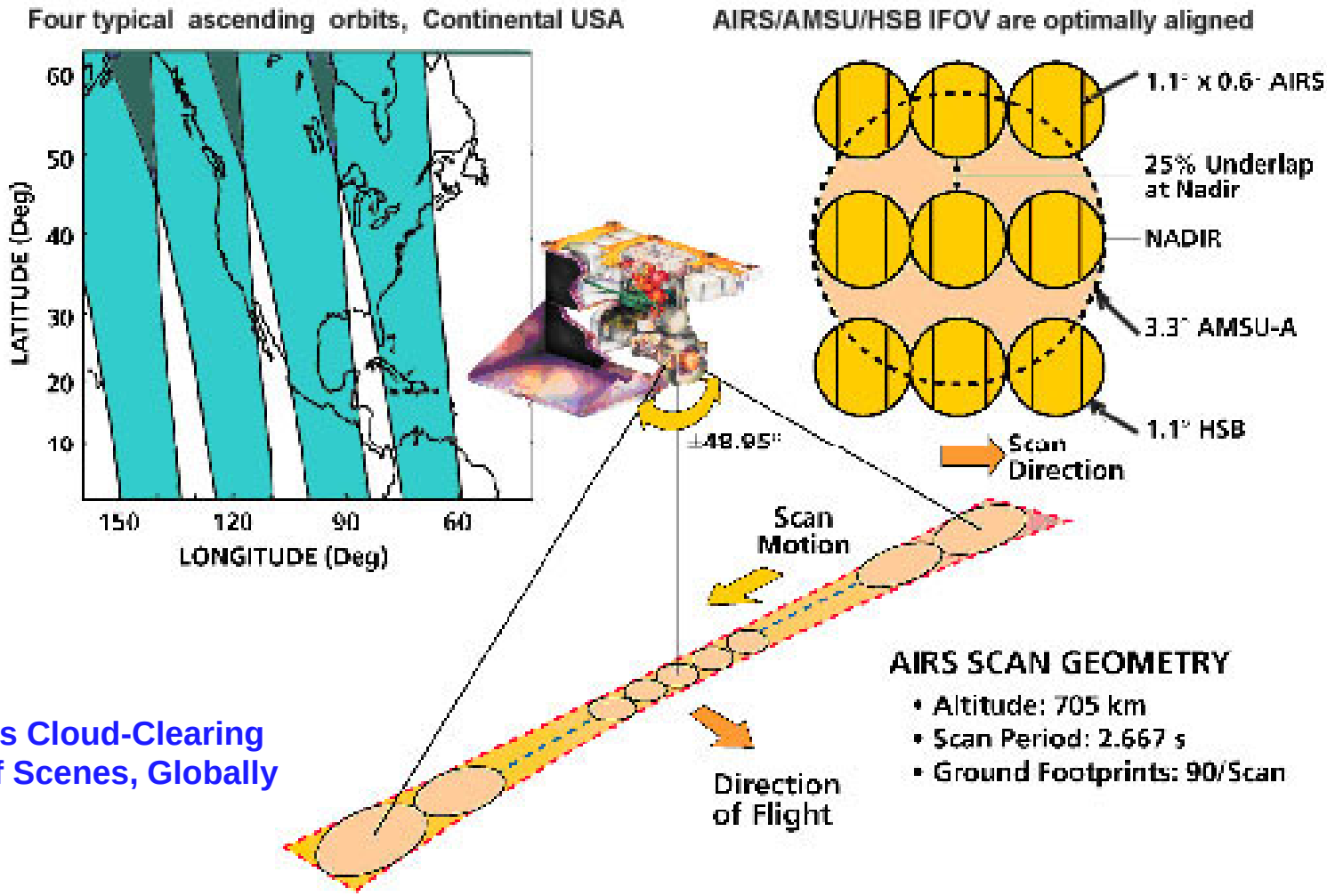
AIRS AMSU-HSB Scan Patterns

Atmospheric Infrared Sounder

Launched by NASA on May 3, 2002



Allows Cloud-Clearing 96% of Scenes, Globally

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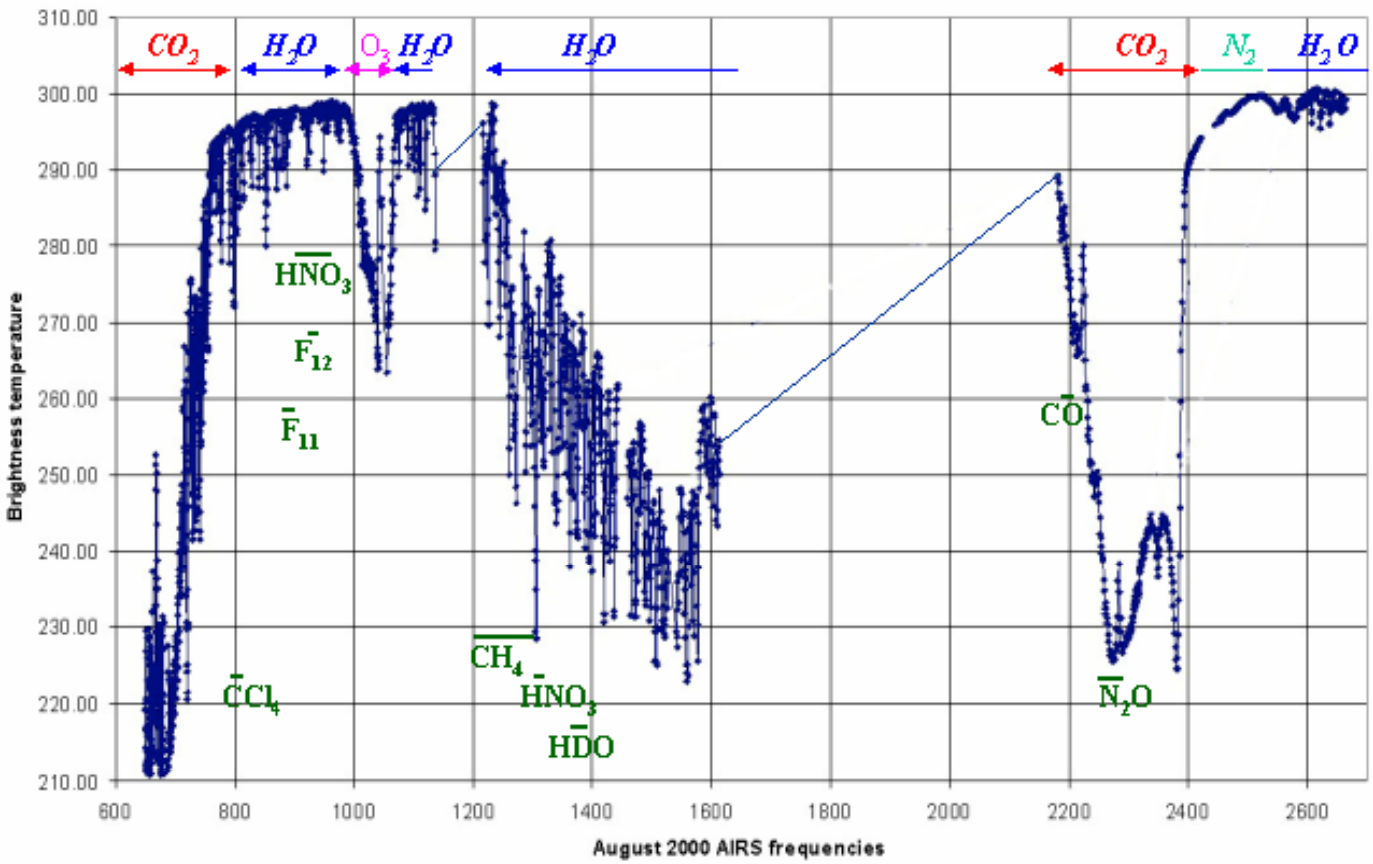
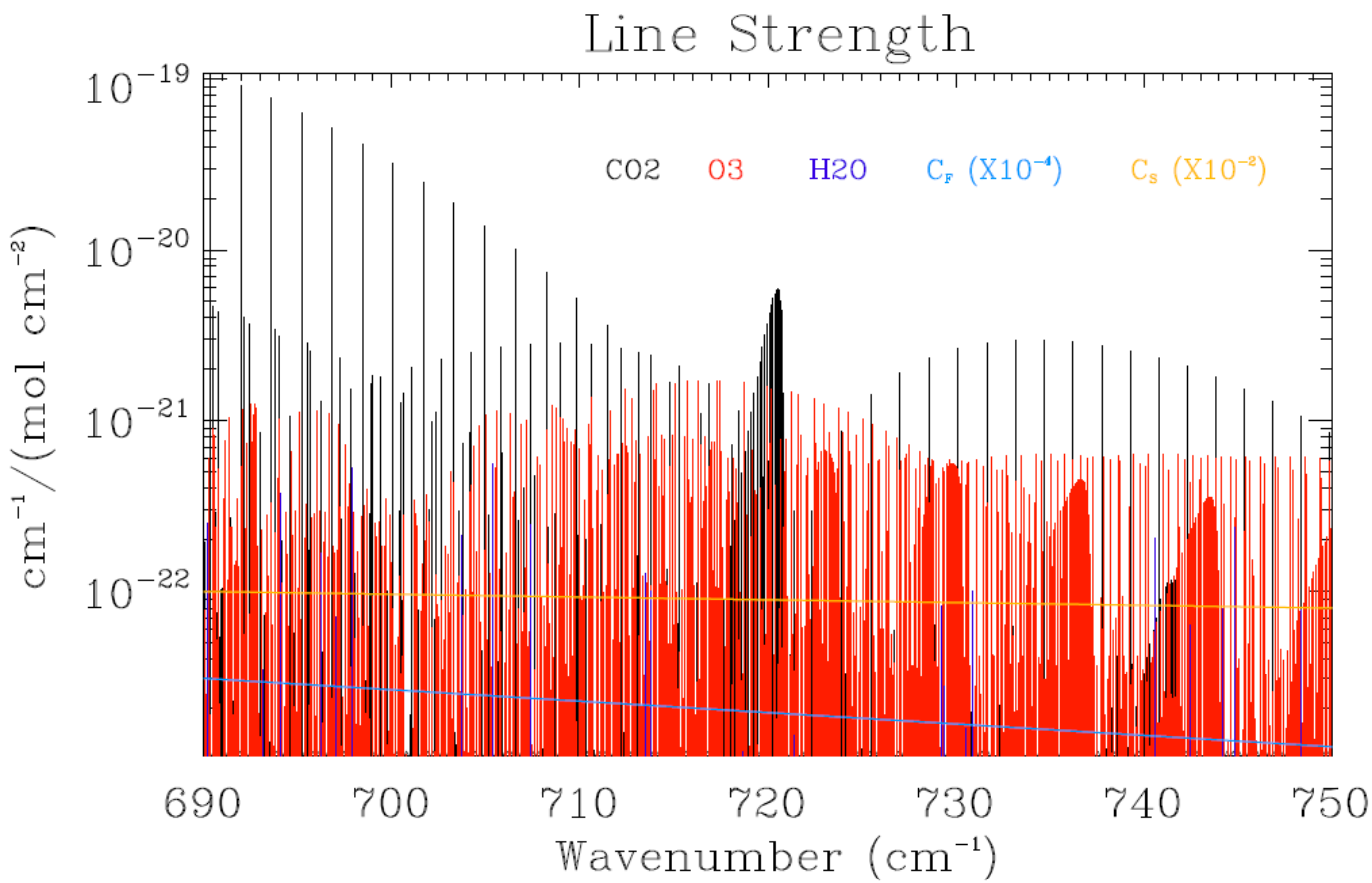
AIRS Infrared Spectrum

AIRS Channels for Tropical Atmosphere with T_surf = 301K

2378 channels - $\lambda/\delta\lambda$ = 1200



Pressure Broadening Results in Overlapping Lines of All Species - 15 µm Band



C_s and C_f are the self and foreign component of the continuum absorption in 1/(cm^{-1} molecules cm^{-2})

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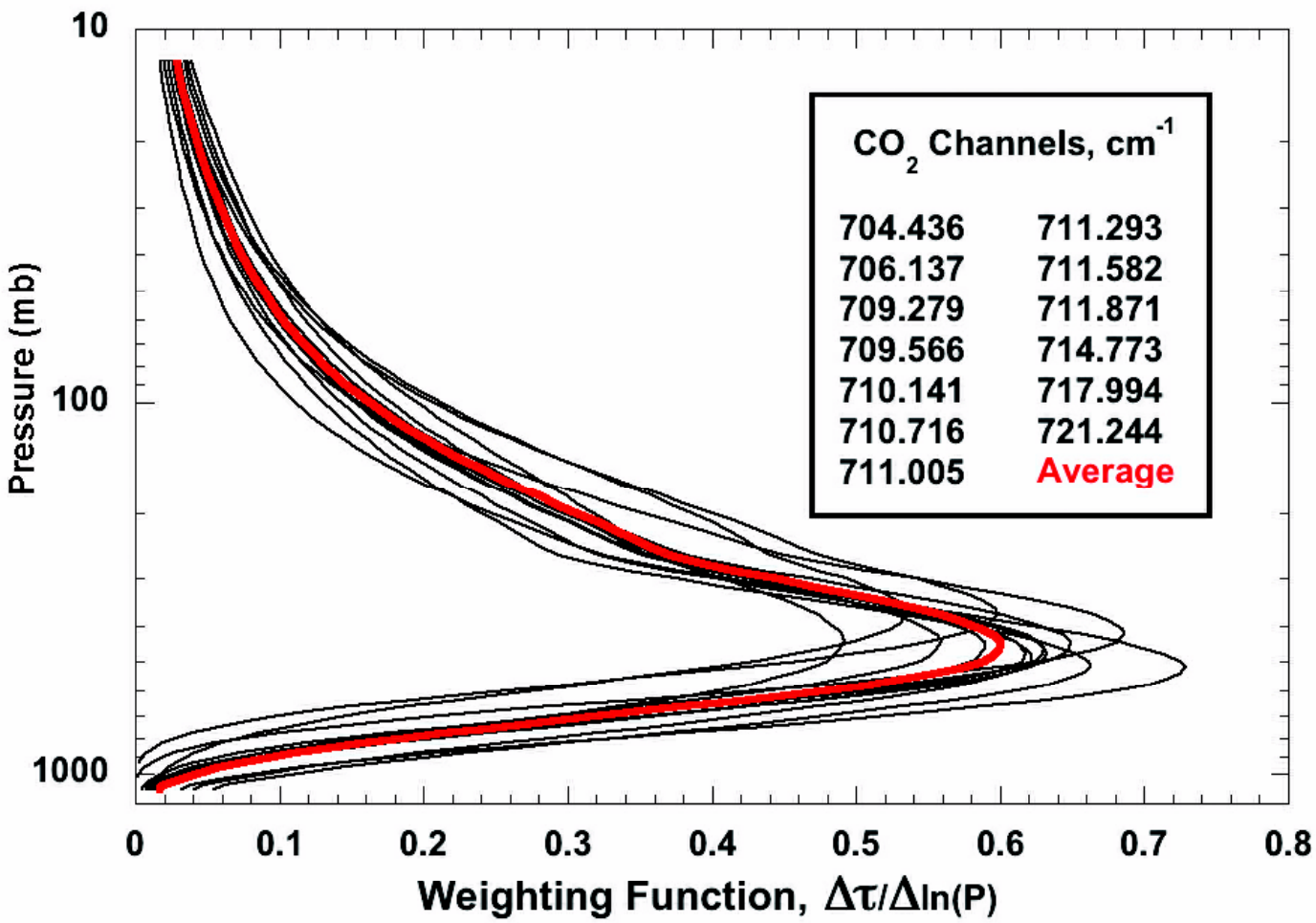
CO_2 Sounding Channels

Mid-Troposphere



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Method of Vanishing Partial Derivatives

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Consider the case where observations are made in a spectral region in the infrared where several minor gases such as CO_2 , O_3 , and H_2O contribute to the observed radiance and a forward calculation of the radiance is made using atmospheric state.

Define the residual function *G*

$$G = \sum_{\nu} [I_{observed}(\nu) - I_{computed}(\nu)]^2 \qquad (1)$$

We desire to find the set of X_i which minimizes the residual function. We express the total differential of *G* as

$$dG = \frac{\partial G}{\partial X_1} dX_1 + \frac{\partial G}{\partial X_2} dX_2 + \frac{\partial G}{\partial X_3} dX_3 + ... + \frac{\partial G}{\partial X_i} dX_i + \varepsilon \qquad (2)$$

From the general property of total differentials, the condition that *G* in equation (1)

should have a maximum or a minimum at a point ($\overline{X}_1$, $\overline{X}_2$, $\overline{X}_3$, ... $\overline{X}_i$) is that

each of the first partial derivatives should individually vanish at that point.

$$\frac{\partial G}{\partial X_1}, \frac{\partial G}{\partial X_2}, \frac{\partial G}{\partial X_3}, ..., \frac{\partial G}{\partial X_i} \qquad (3)$$

Thus *the individual mixing ratio of each of the minor gases considered is determined by the value that makes their first partial derivative in equation (3) vanish* <u>*individually*</u>*.* Therefore, even though the observed spectra cannot differentiate between the individual lines, the partial differentials can! This is the VPD method.

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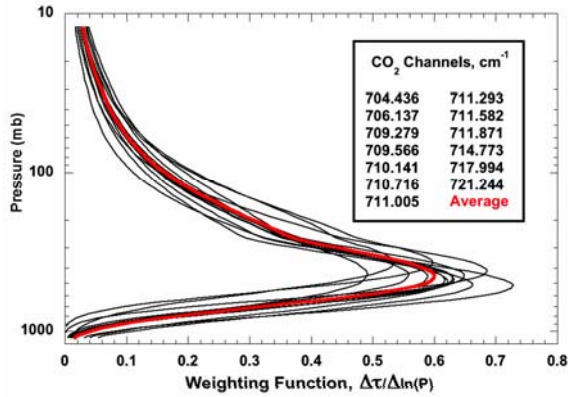
VPD Method, continued

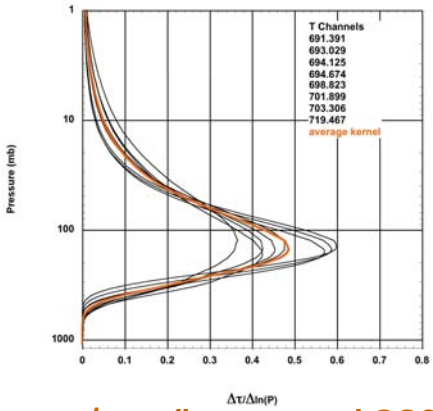
Atmospheric Infrared Sounder

We recognize that Equation (3) is a necessary condition but not sufficient to guarantee a unique solution that minimizes the residual function, G. The variables $\overline{X}_1$, $\overline{X}_2$, $\overline{X}_3$, ... $\overline{X}_i$ are not strictly linearly independent. Hence we adopt an iterative approach, selecting auxiliary sets of channels for T, H_2O and O_3 to separate the interdependence and rejecting solutions that do not minimize the residual function.

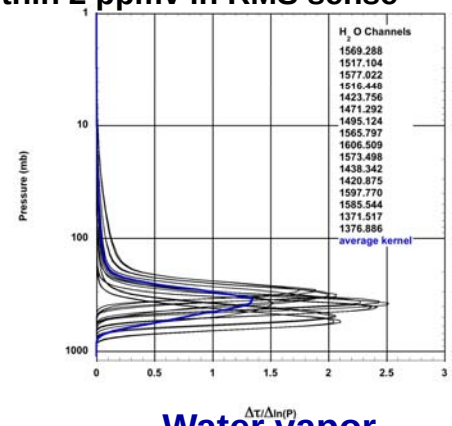


CO_2

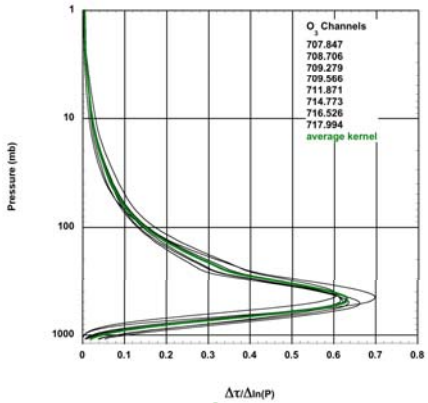
- **Iteration is initialized with AIRS cloud-cleared radiances and retrieved geophysical product profiles of T(p), H_2O(p) and O_3(p)**
- **Each retrieved geophysical product is linearly perturbed and residuals computed for its selected channel set radiances; iteration continues until residual is minimized or change drops below a threshold; solutions shift entire profiles**
- **Iteration for solution of CO_2 is then performed**
- **New CO_2 value is used with original AIRS retrieved geophysical product profiles to initiate another iteration sequence**
- **Solution is reached when CO_2 residual is minimized or change drops below a threshold**
- **Quality check requires 2x2 cluster of adjacent retrievals to agree within 2 ppmv in RMS sense**



Temperature (in saturated CO2 regime)



Water vapor



Ozone

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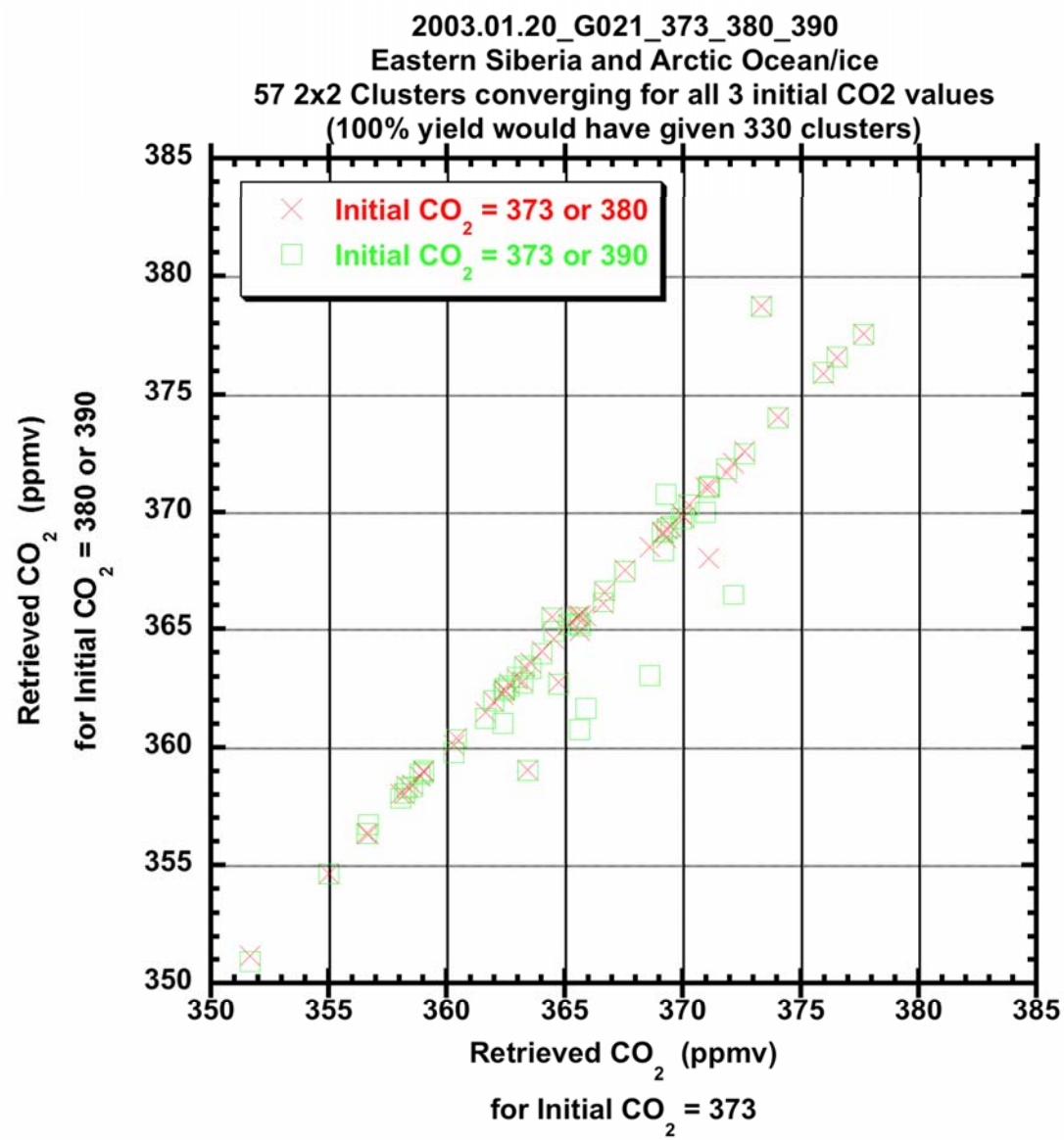
Independence of the Solution

from Initial starting value of the CO_2 Mixing Ratio

Vanishing
Partial
Derivatives
Method



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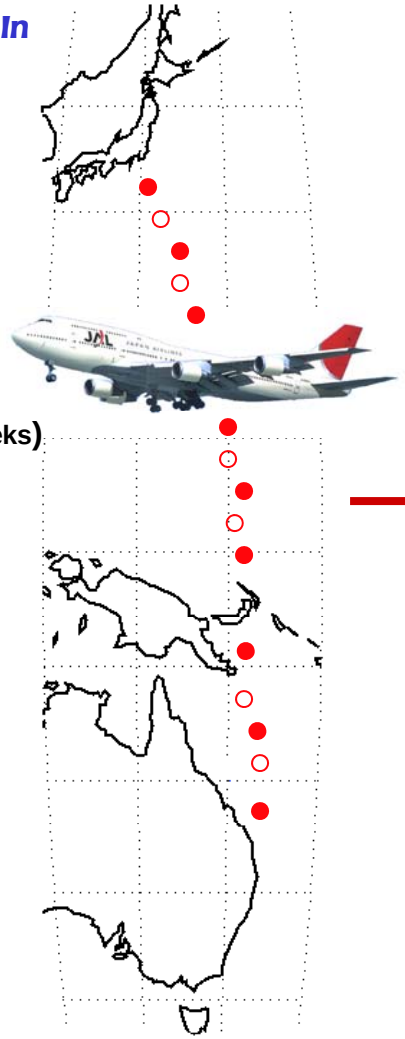
Atmospheric In

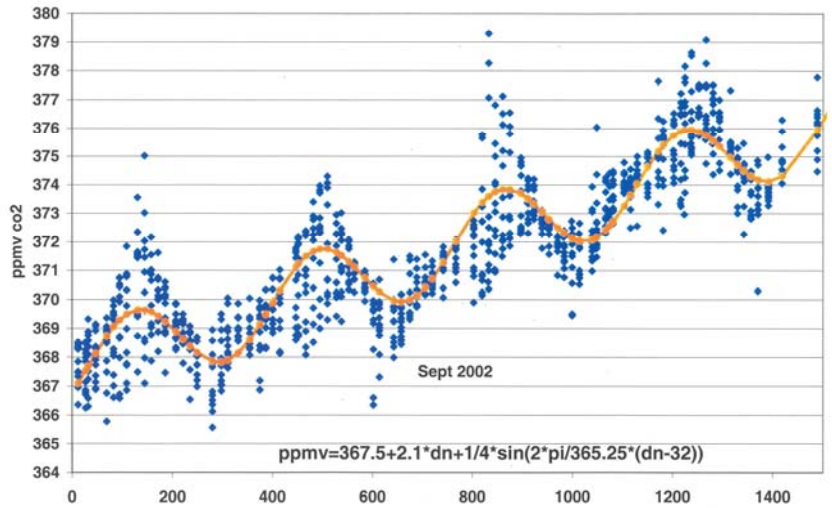
Validation

Matsueda Airborne Flask Measurements

CO_2 Measurements at 10.5 km altitude



JAL Flights
(every two weeks)



Since January 1, 2000

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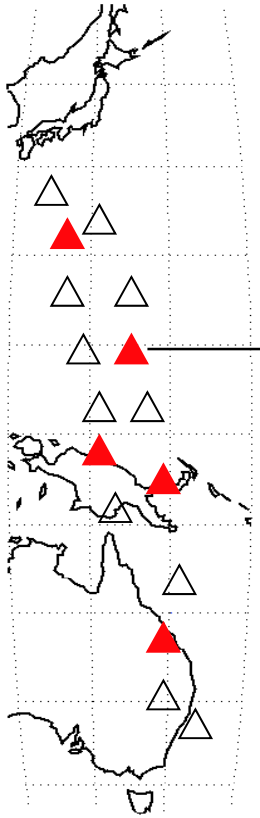
Atmospheric Infrared Sounder

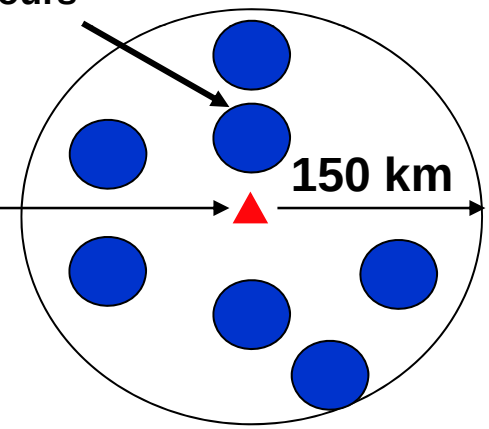
Validation of AIRS Retrieved CO_2 with Matsueda Flask Measurements

Matsueda Airborne Flask
CO_2 Measurements at 10.5 km altitude

Collocated AIRS
CO_2 Retrievals at 5-15 km altitude



Matsueda Measurements



An AIRS Cluster Around Matsueda

45x45 km One AIRS Retrieval

One Matsueda Flask Measurement with collocated AIRS Retrieval

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Evidence that VPD Retrieval Errors are Guassian (Uncorrelated)

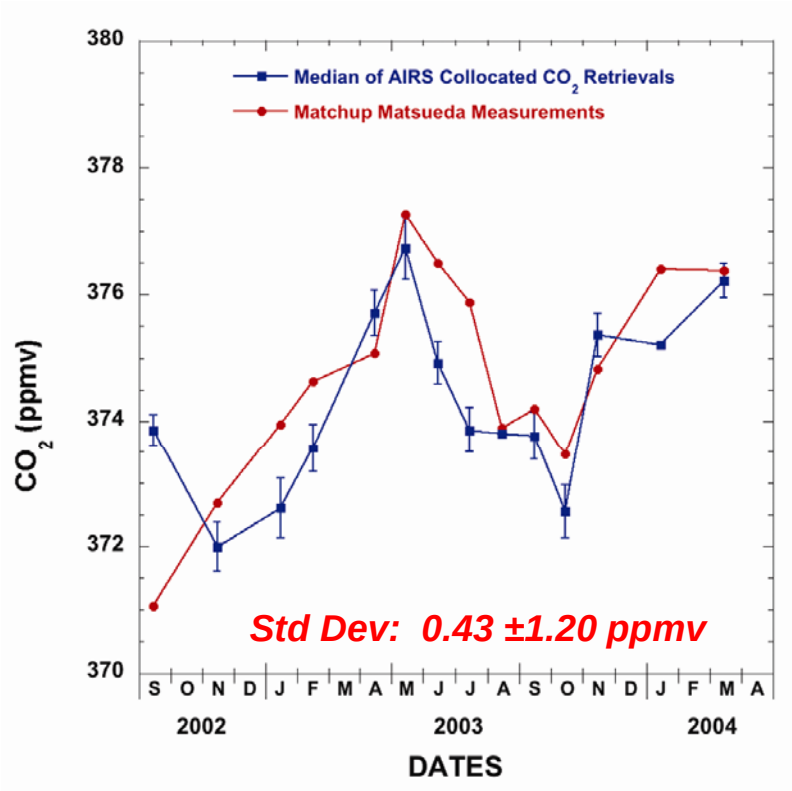
Total number of match ups= 78

SD= ±2.98 *ppmv*

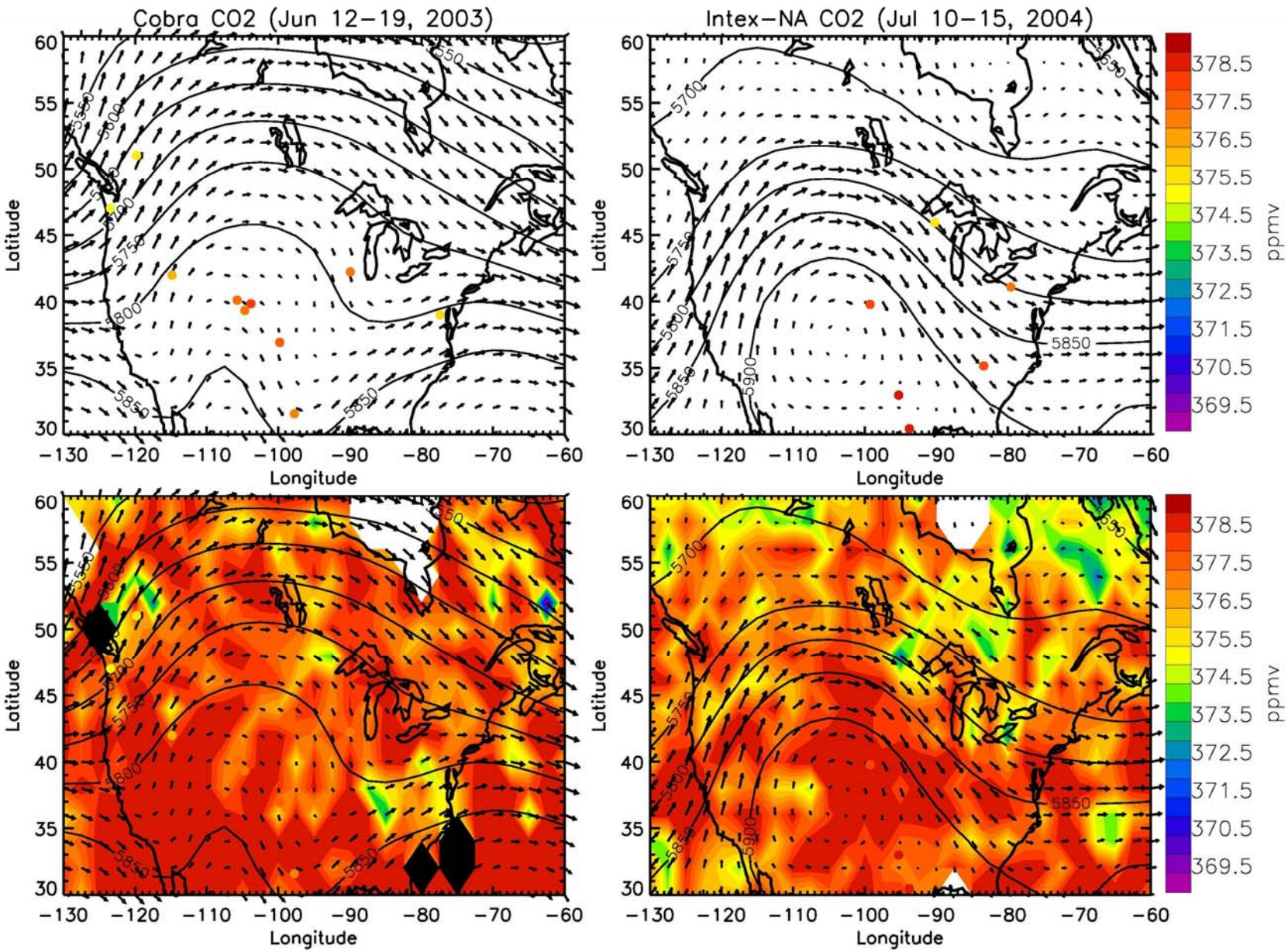
The monthly averages (5.6 clusters/month) yields SD=±1.20 *ppmv*

These are approximately related by the Guassian relationship

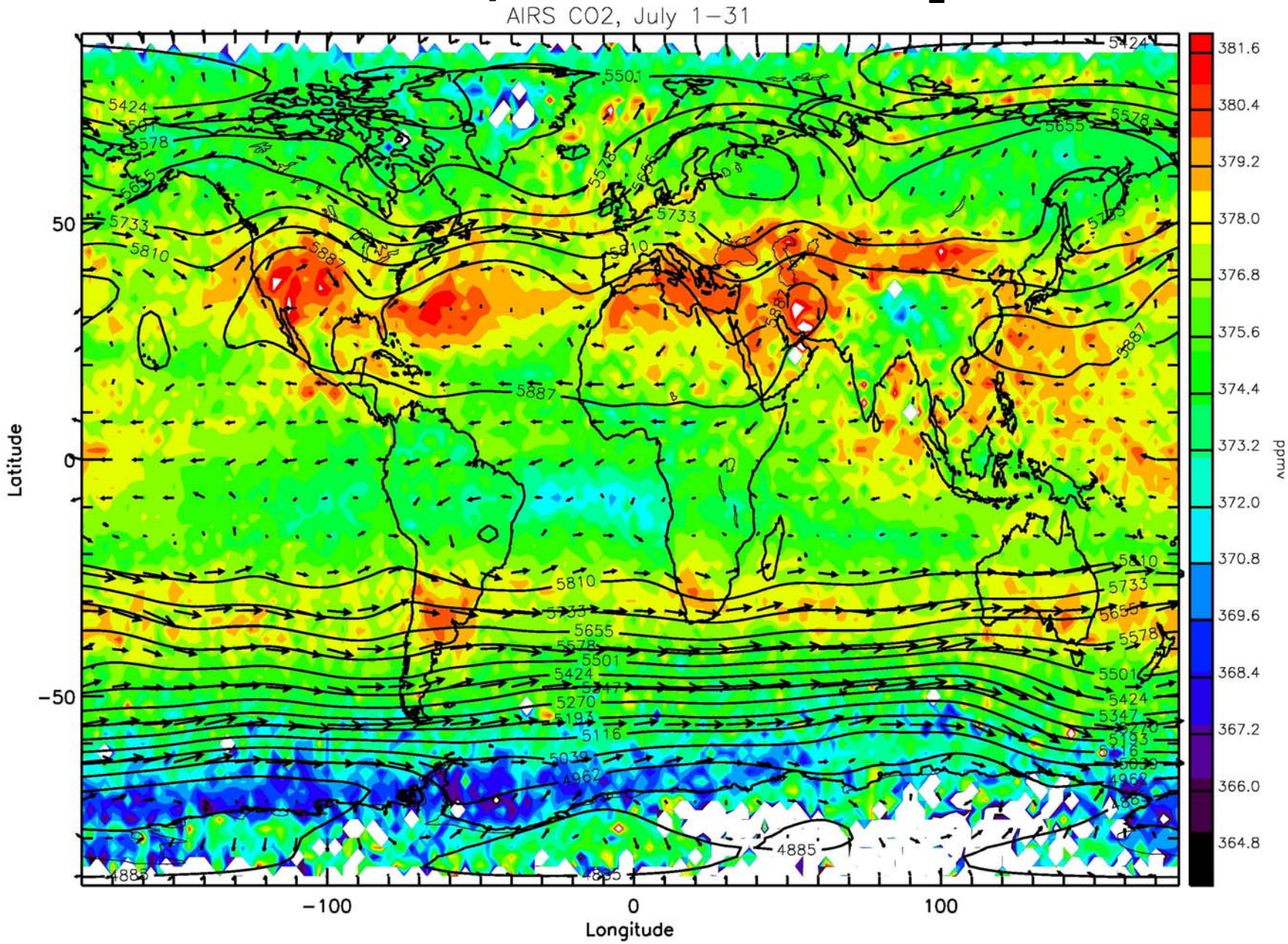
$$\frac{2.98}{\sqrt{5.6}} = 1.26$$



VALIDATION OF VPD CO_2 VIA AIRCRAFT CO_2 PROFILE MEASUREMENTS OVER CONUS in 2003 and 2004

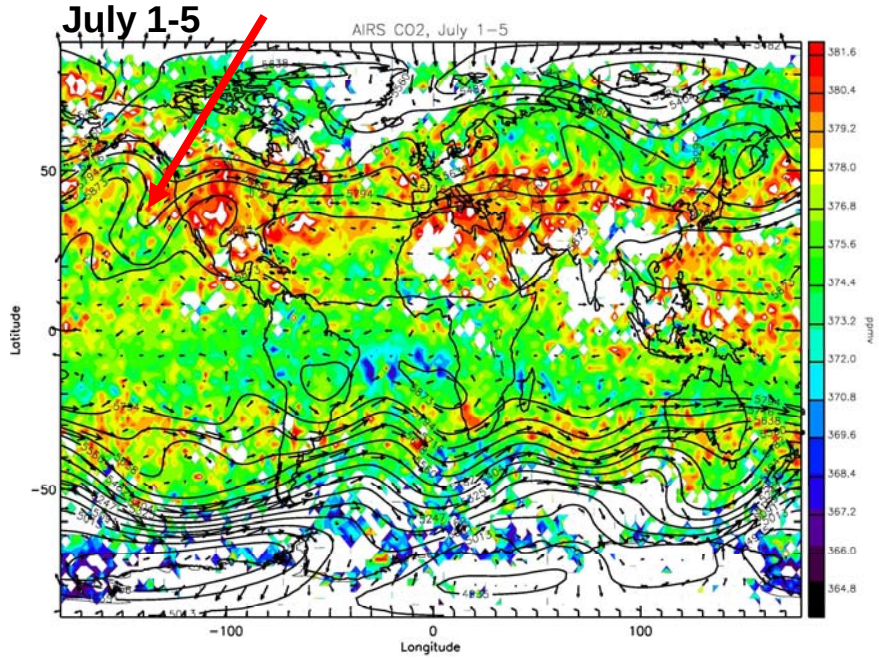


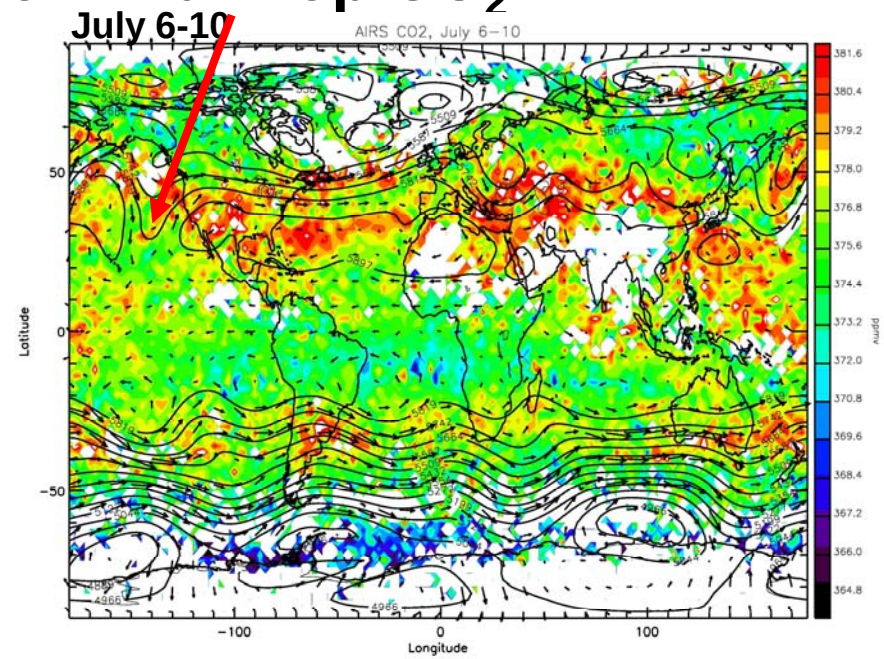
VPD Spatial Pattern of CO_2

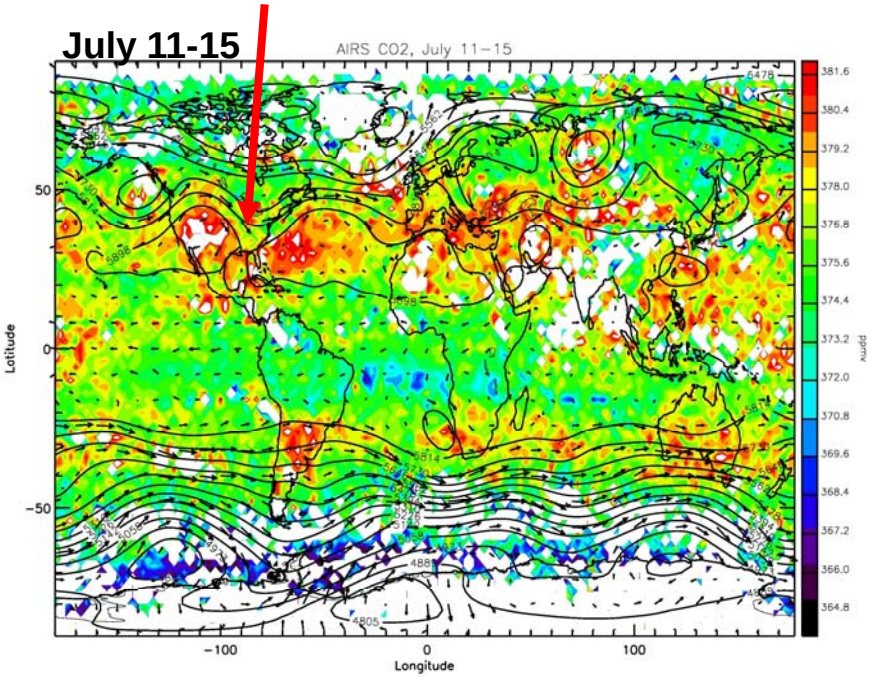


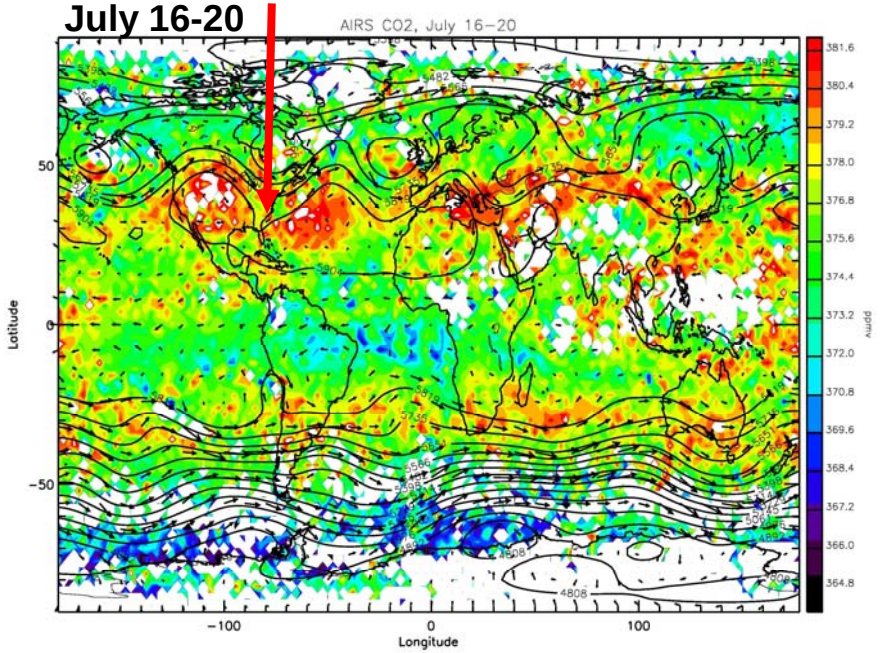
500 hPa geopotential heights & wind vectors from NCEP2 Reanalysis

Effects of Weather on Mid Trop CO_2









Global distribution of large stationary sources of CO2

Major Stationary CO_2 Source

Large Stationary CO_2 Source

IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO UNEP

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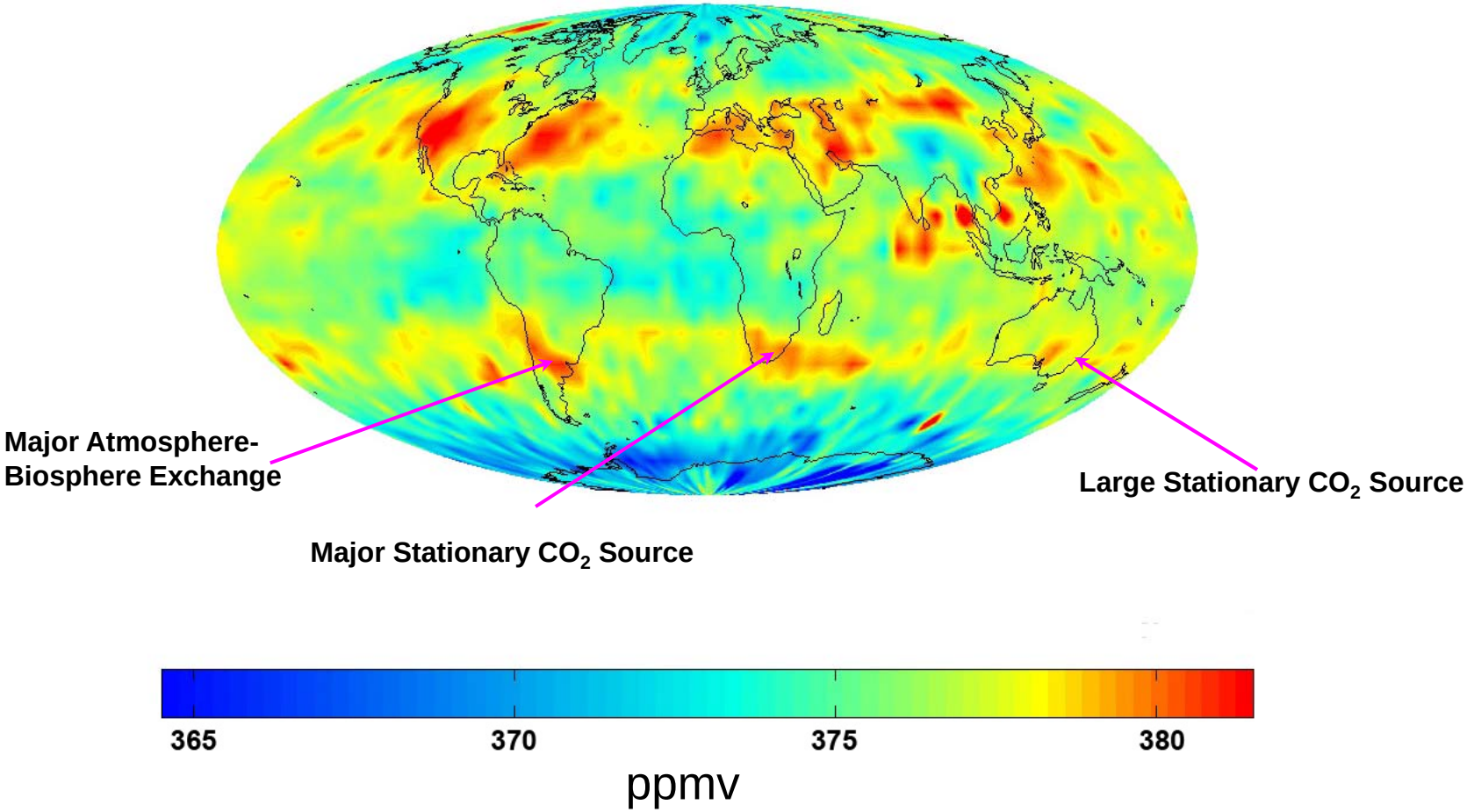
Impact of Weather and Large Stationary Sources on Mid-Tropospheric CO_2

July 24-28, 2003



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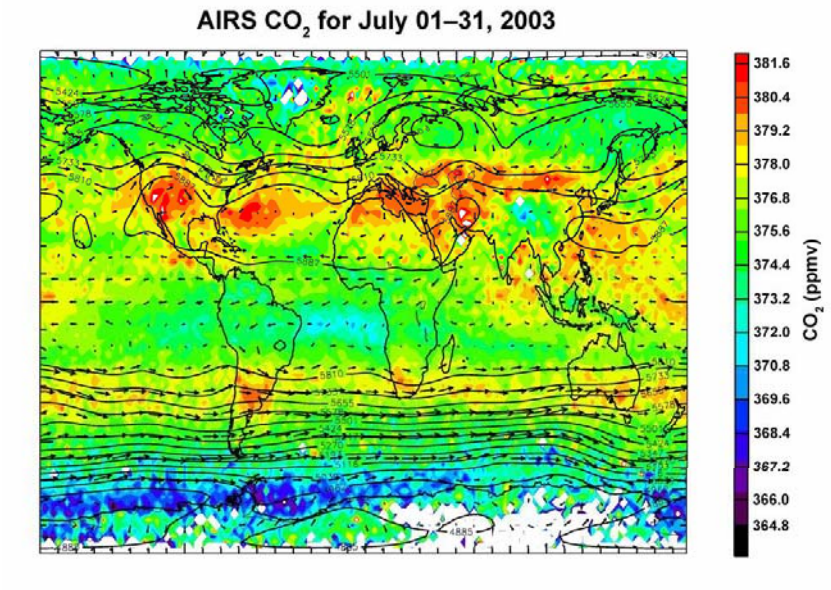
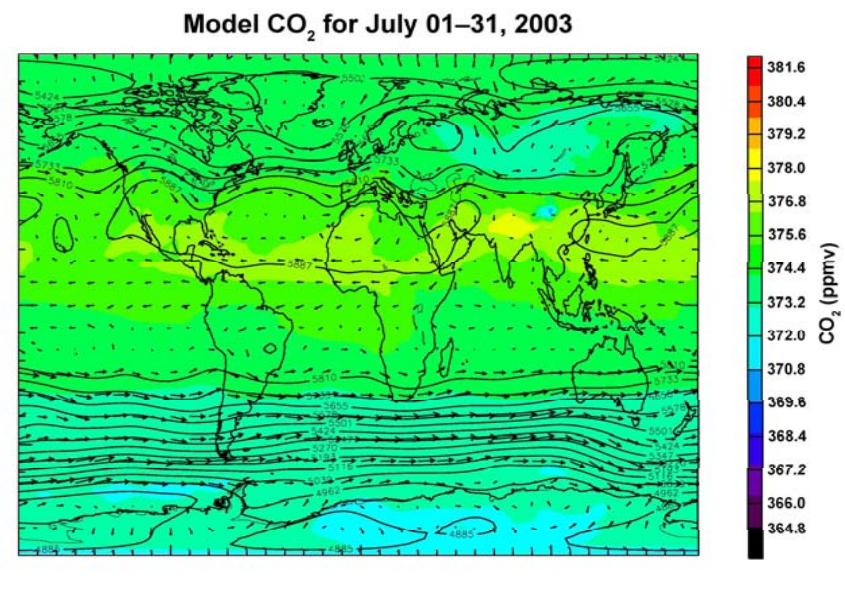
Models do not Capture the Effects of Weather and Surface Sources





AIRS VPD Retrieval

GEOS-Chem Model

QuickTime™ and a
decompressor
are needed to see this picture.

Conclusions

- **Introduction to AIRS on Aqua**
- **Method of Vanishing Partial Derivative for Retrieval of CO_2**
- **The AIRS VPD retrieved upper tropospheric CO_2 agrees reasonably well with in situ aircraft observations.**
  - Additional validation data are needed at high latitudes
- **The rich time-varying spatial structure of CO_2 in the mid-troposphere is not capture by models**
- **Satellite retrieval of CO2 profiles provide a new tool to study the dynamics of the atmosphere**

BACKUP

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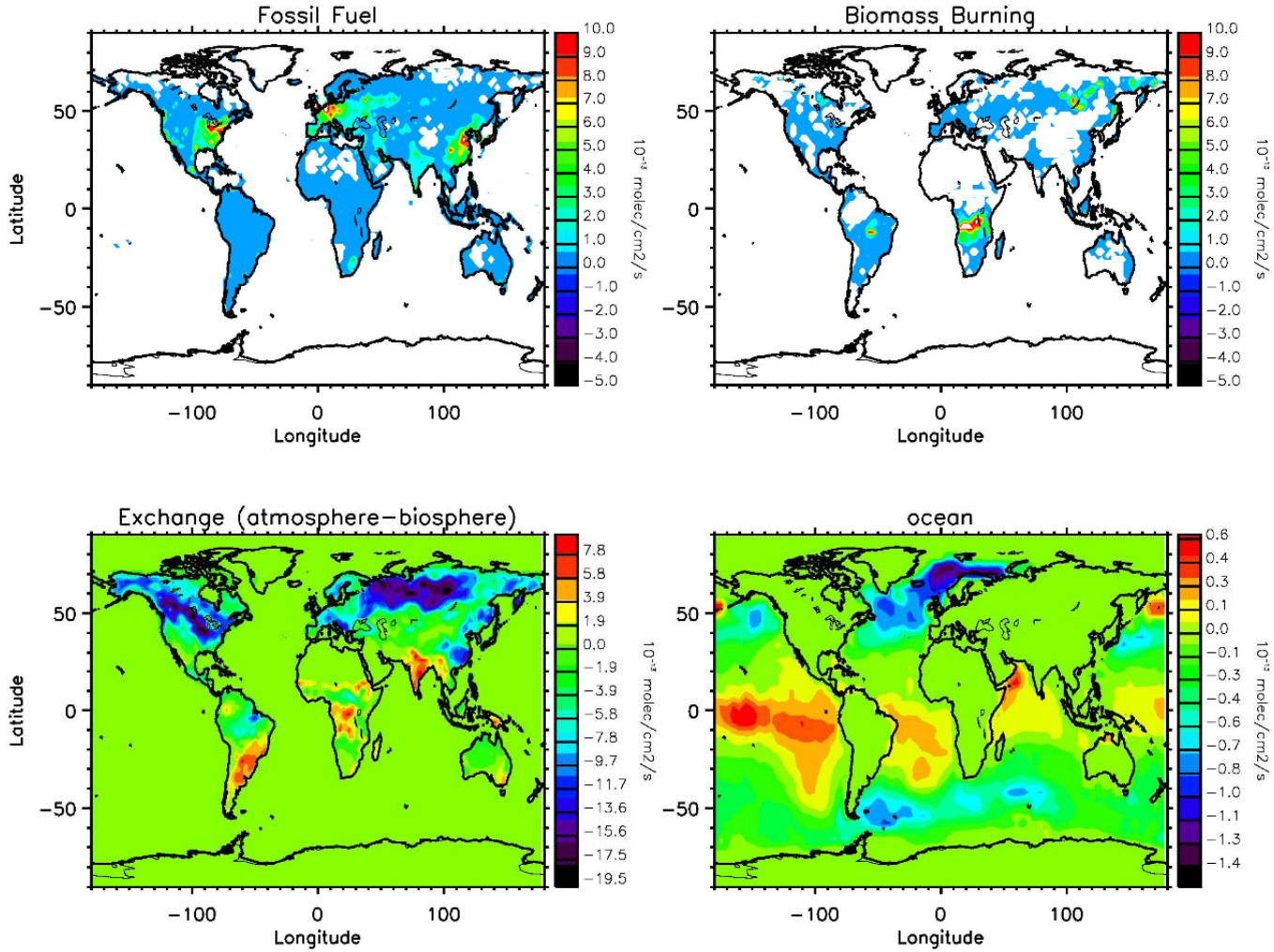
CO2 Sources



Conclusions

- The AIRS retrieved upper tropospheric CO_2 agrees reasonably well with in situ aircraft observations in the tropics.
  - Additional validation data are needed at high latitudes.

- The convective vertical transports flux is crucial for models simulation of upper tropospheric CO_2.

- The rich structure of CO2 calls for additional satellite observations
  - The Orbiting Carbon Observatory (OCO) to be launched 12/08

Un modèle sans observations n'est qu'un exercice mathématique gratuit.
Des observations sans modèle n'apportent que confusion.
Jacques-Louis Lions (CNES)

Models without data are but mathematical exercises.
Data without models only add to the confusion.

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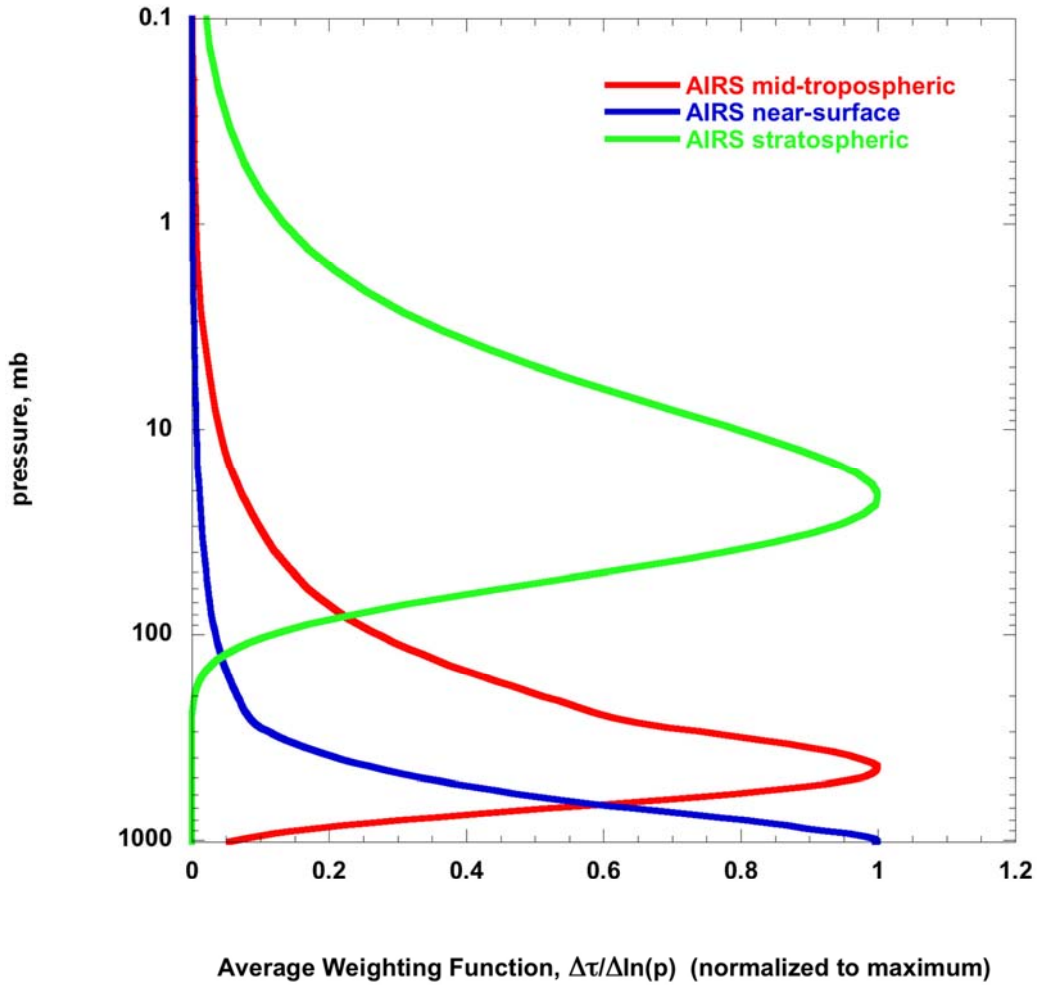
AIRS Sensitivity for retrieving a CO2 profile



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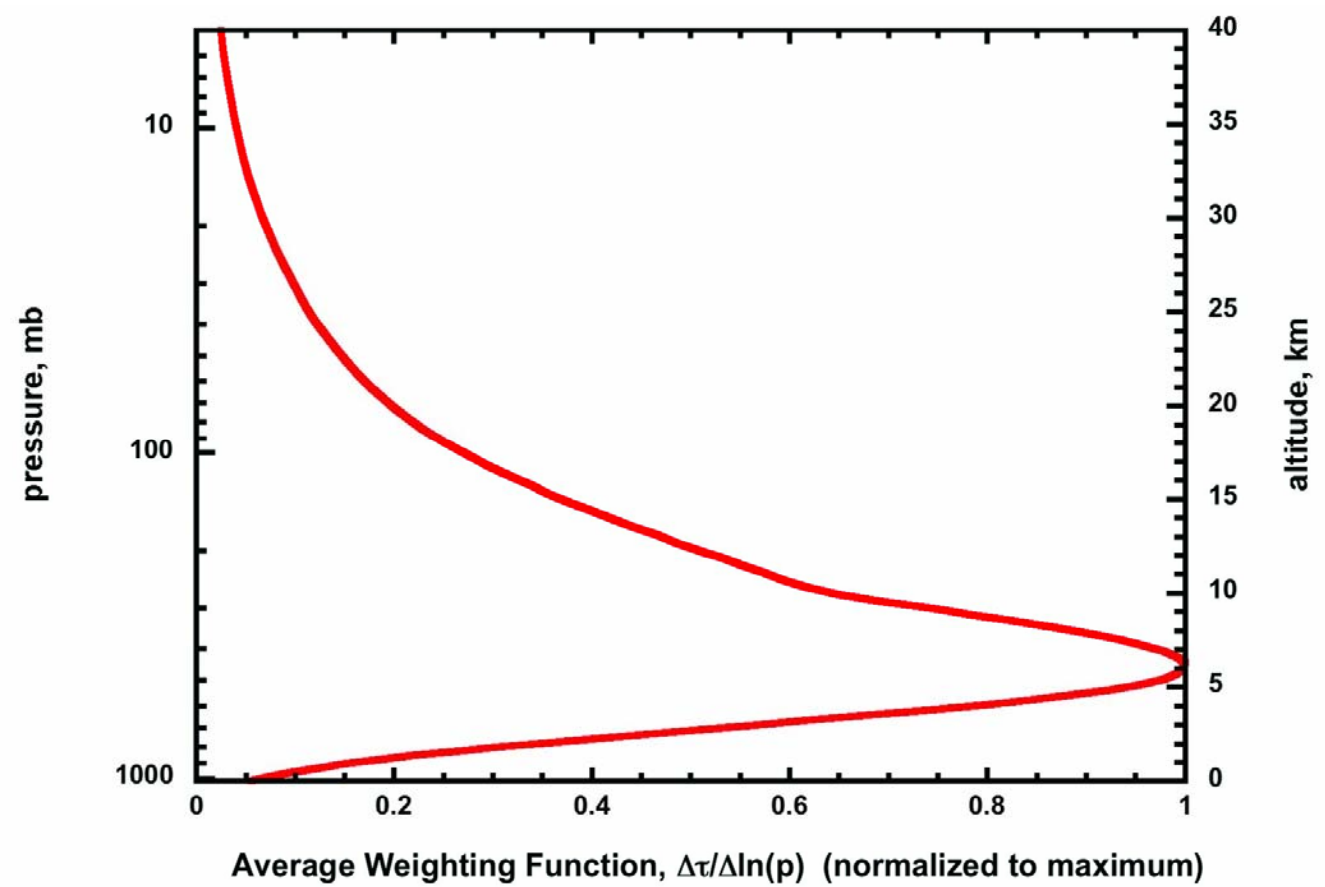
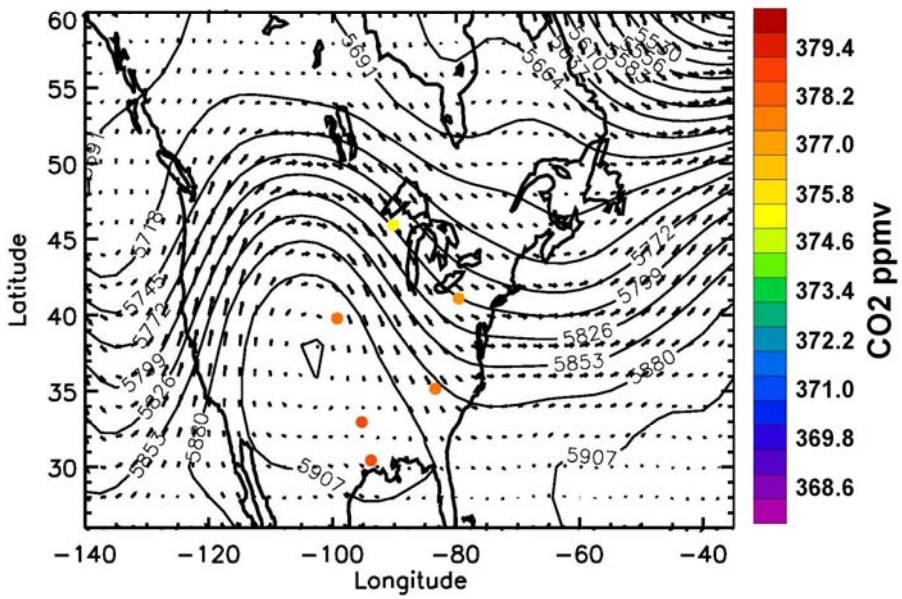
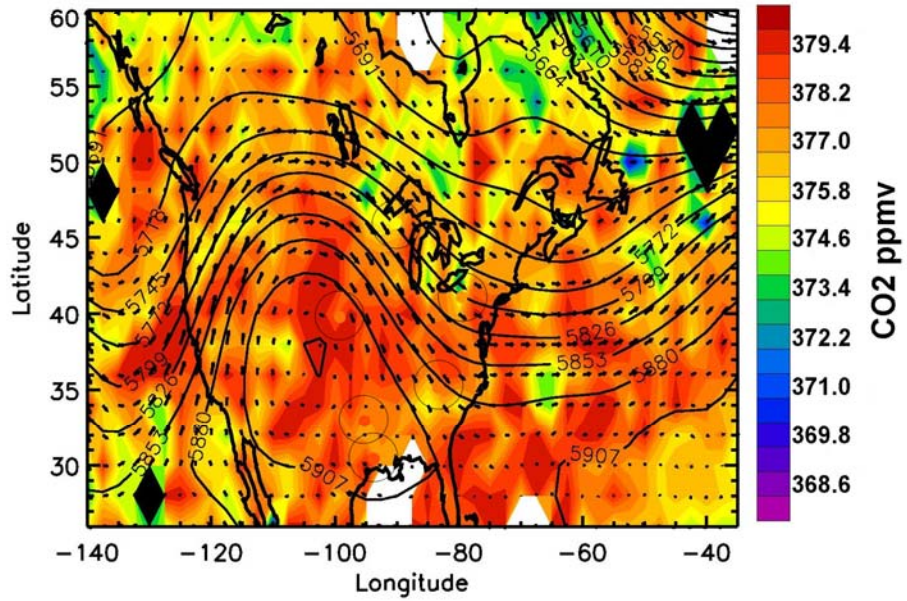
CO_2 Sounding Channels

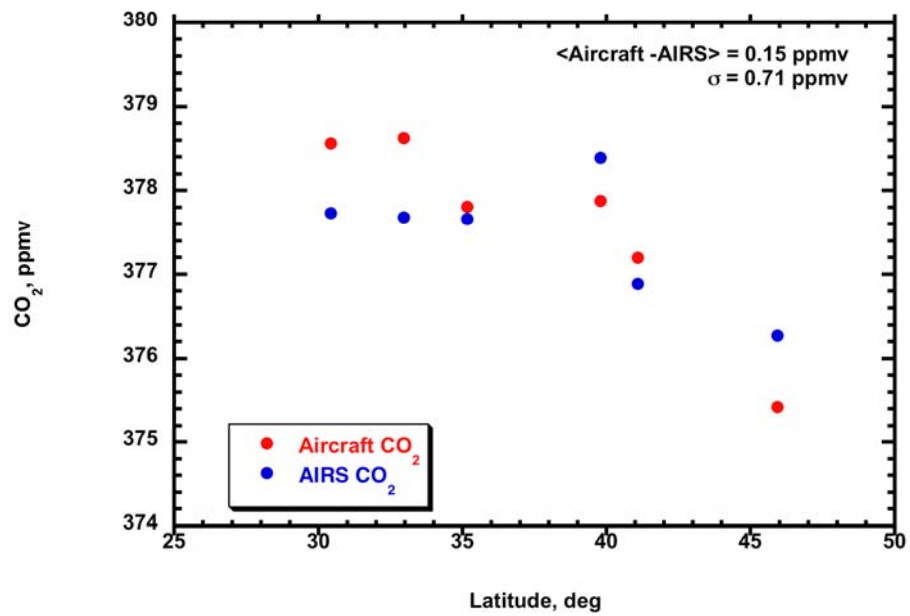
Mid-Troposphere



COMPARE VPD CO_2 TO INTEX-NA AIRCRAFT CO_2 PROFILE MEASUREMENTS DURING July 10-15,2004







Eye Test:
Find the A/C Measurements

Comparison Accuracy
-0.15 ±0.71 ppmv

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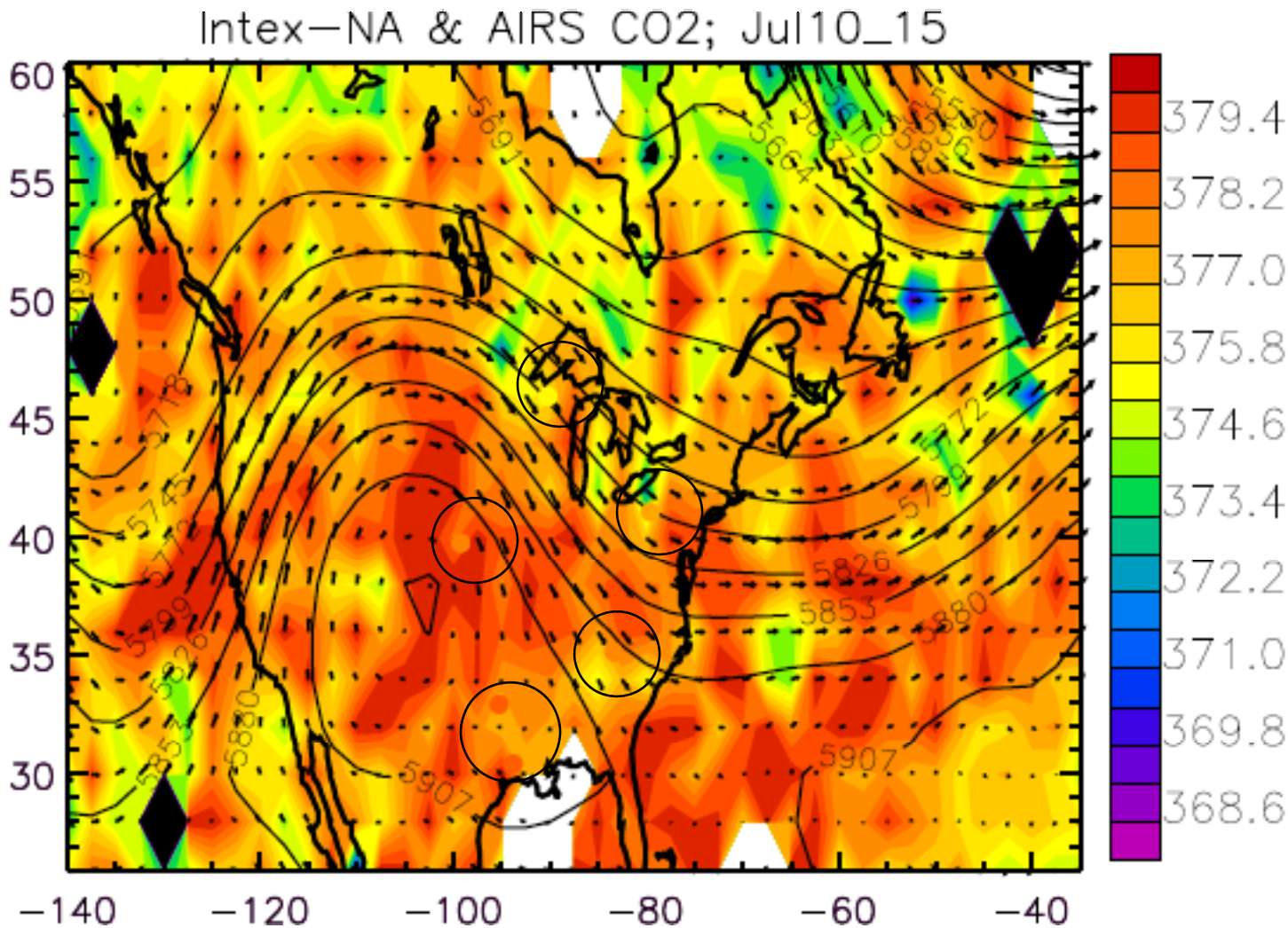
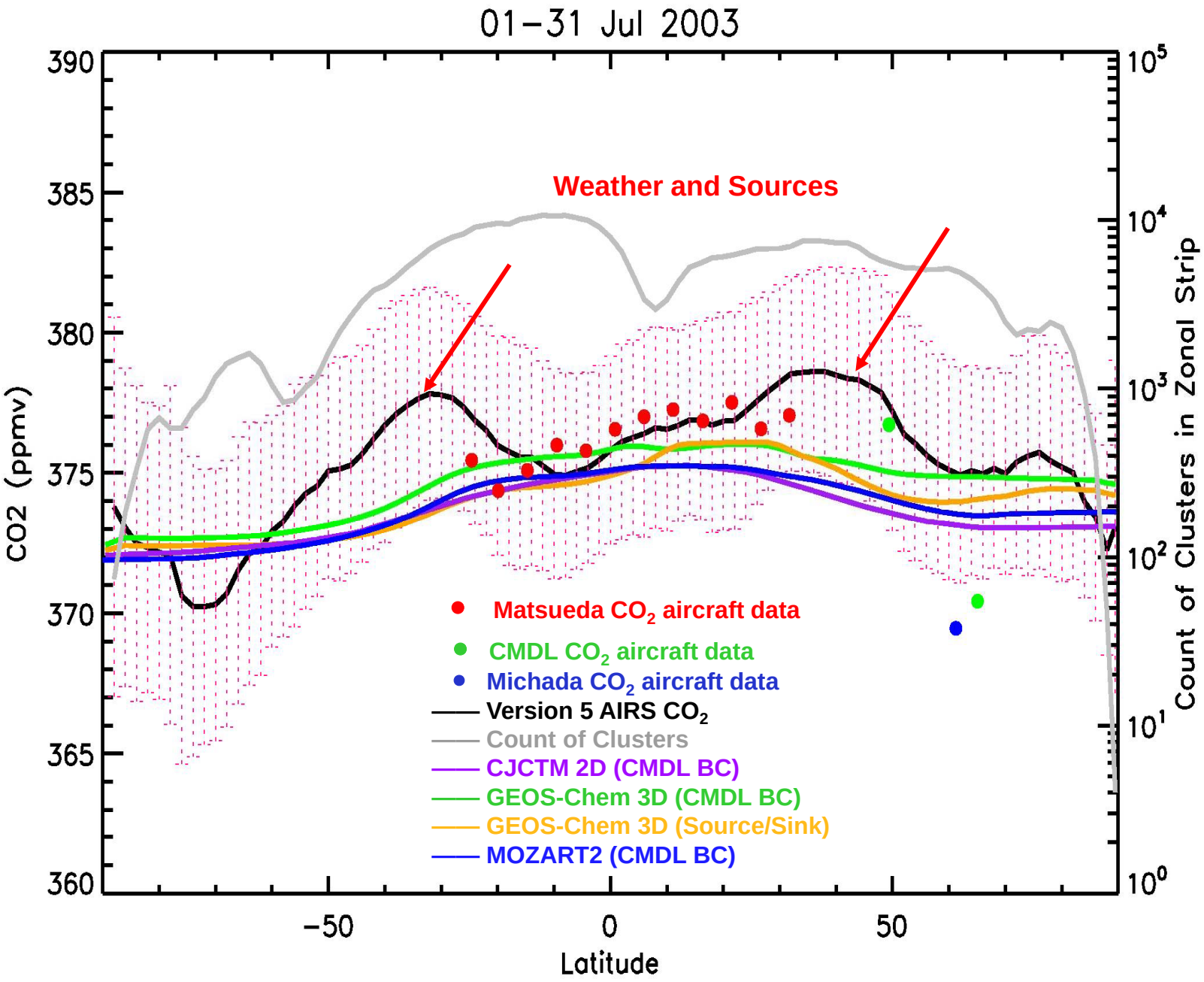
Atmospheric



Version 5 AIRS CO_2