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Atmospheric Infrared Sounder

Remote Sensing of CO_2 in the upper Troposphere by the Atmospheric Infrared Sounder (AIRS) on the Aqua Satellite

Moustafa Chahine[1], Luke Chen[1], Xun Jiang[1], Qinbin Li[1], Ed T. Olsen[1]
Paul Dimotakis[2] and Yuk Yung[2]
and Jim Randerson[3]

Caltech: (1) JPL and (2) Campus and (3) UC Irvine

Global Energy Seminar
Caltech NRG 0.1
26 October 2007

Overview

- Basic Questions
- Retrieval of AIRS CO_2 and Validation with Aircraft Data
- Spatial Patterns of CO_2 :
  Effects of Weather and Stationary Sources
- Stratospheric Sudden Warming: Influence on CO_2 and O_3
- Model Comparisons

Goals

- CO_2 from AIRS offer a unique opportunity to test chemical/transport/dynamical models
- Improve our understanding of stratosphere-troposphere exchange and vertical transport in the models
- *Atmosphere-Surface interactions - In the future*

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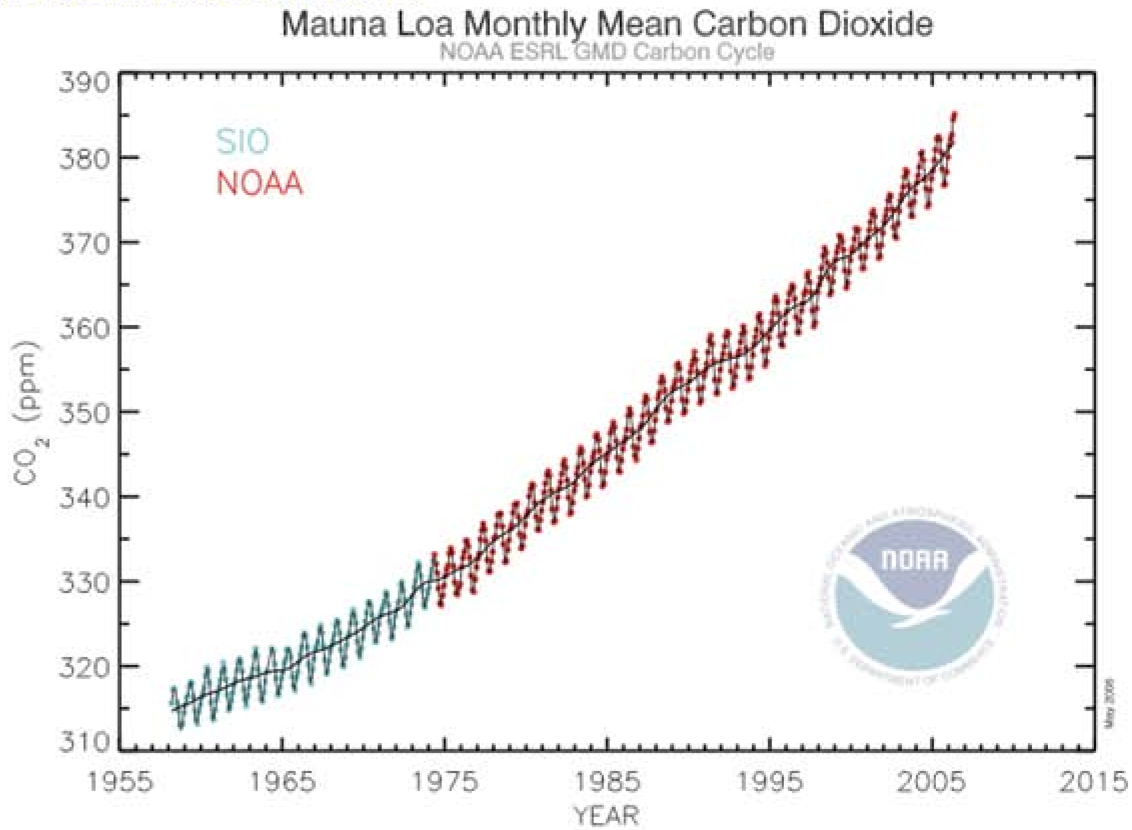
Keeling Atmospheric CO2 Record

Atmospheric Infrared Sounder



Atmospheric carbon dioxide monthly mean mixing ratios. Data prior to May 1974 are from the Scripps Institution of Oceanography (SIO, blue), data since May 1974 are from the National Oceanic and Atmospheric Administration (NOAA, red). A long-term trend curve is fitted to the monthly mean values. Contact: Dr. Pieter Tans, NOAA ESRL GMD Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, and Dr. Ralph Keeling, SIO GRD, La Jolla, California, (858) 534-7582, rkeeling@ucsd.edu.

Increase in atmospheric CO2 from 1958 – 2000:

$$\Delta(CO_2) \approx 380\text{ ppm} - 310\text{ ppm} = 70\text{ppm}$$

Charles David Keeling

Mauna Loa Observatory

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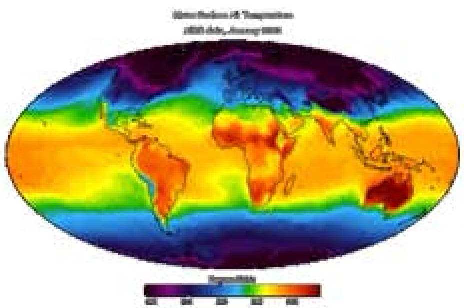
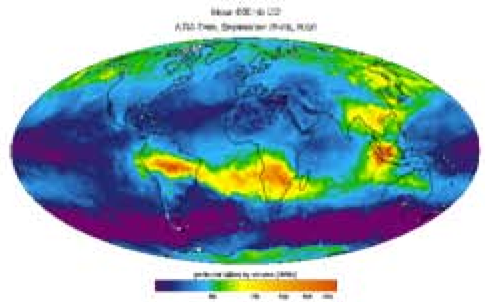
AIRS Climate Data Products

Atmospheric Infrared Sounder

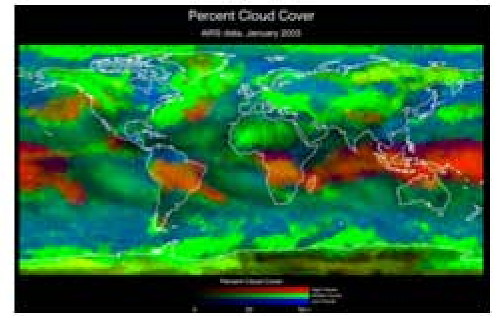
Atmospheric Temperature



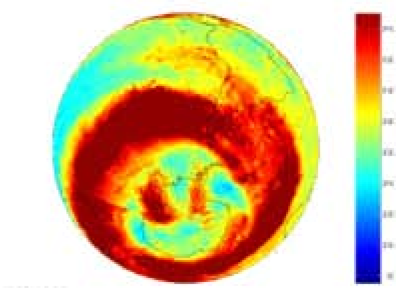
CO



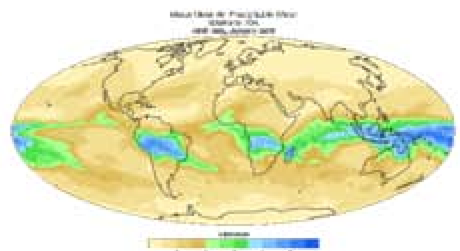
Cloud Properties



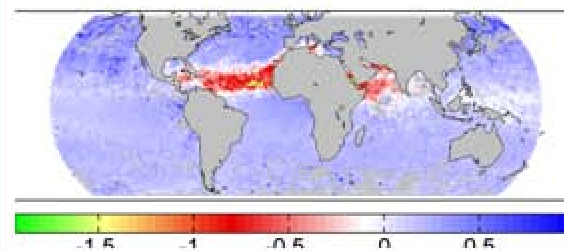
Ozone



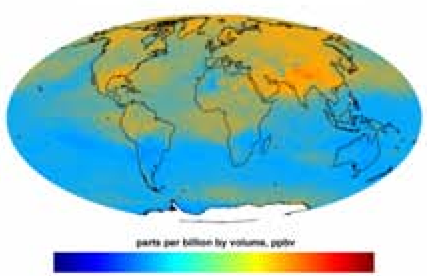
Atmospheric Water Vapor



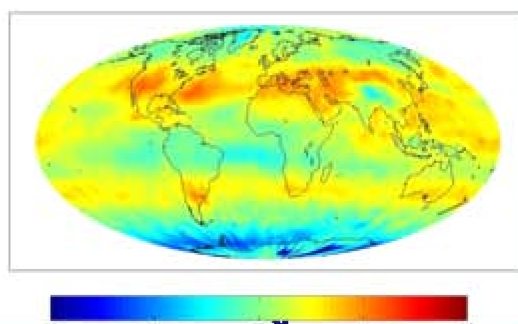
Dust



Methane

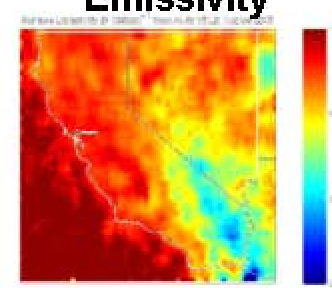


CO2



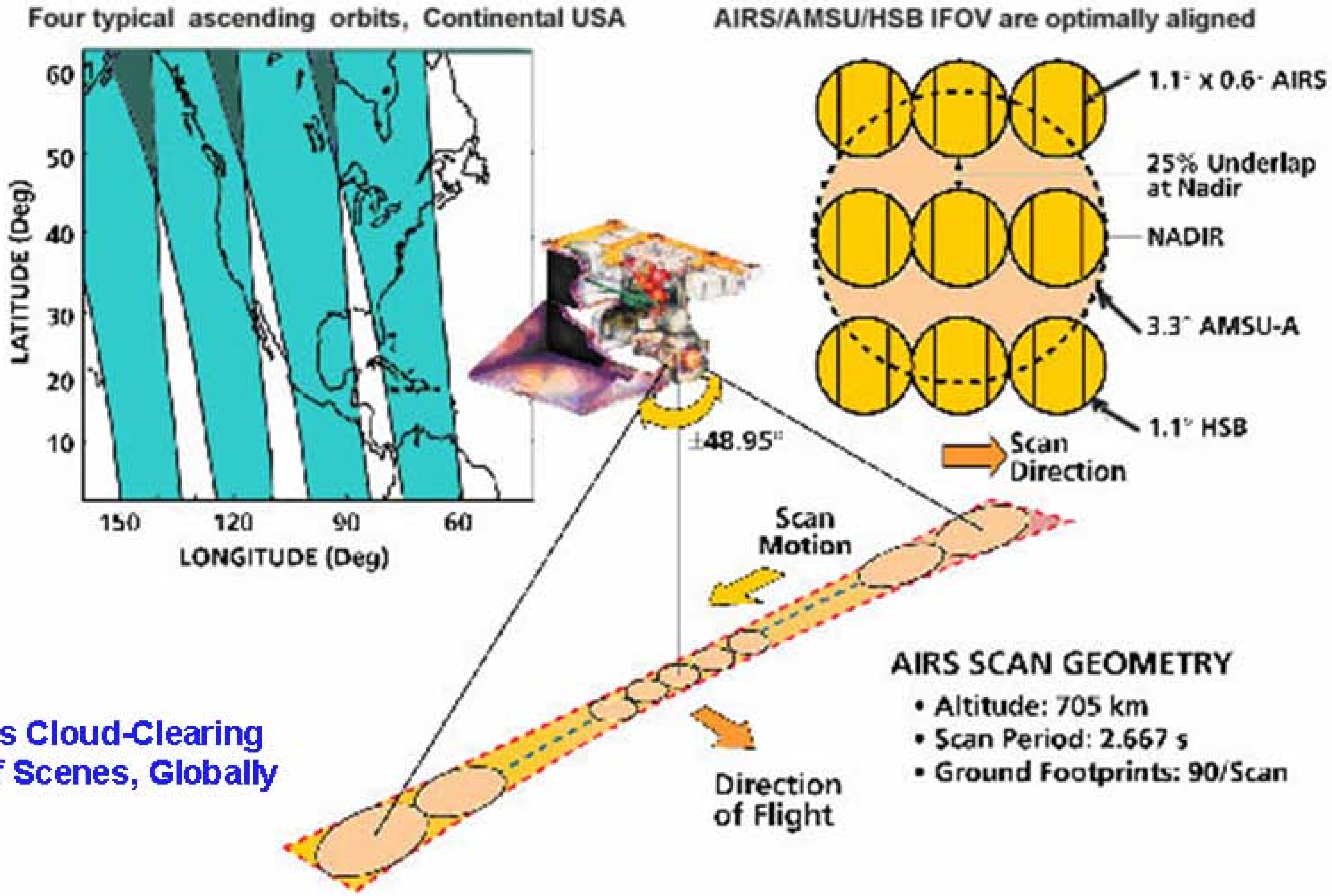
SO2

Emissivity



AIRS AMSU-HSB Scan Patterns

Launched by NASA on May 3, 2002



Allows Cloud-Clearing 96% of Scenes, Globally

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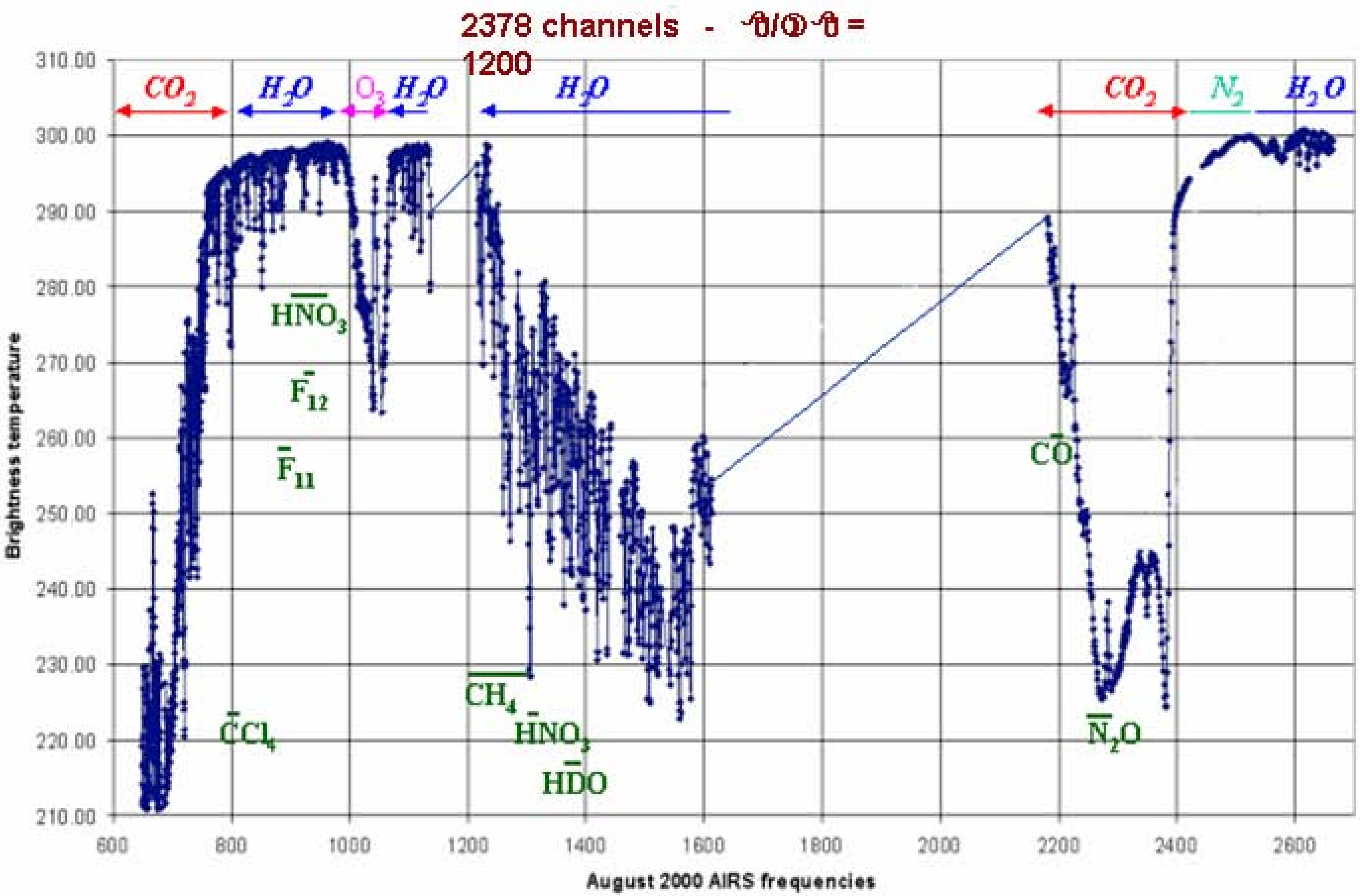
AIRS Infrared Spectrum

AIRS Channels for Tropical Atmosphere with T_surf = 301K



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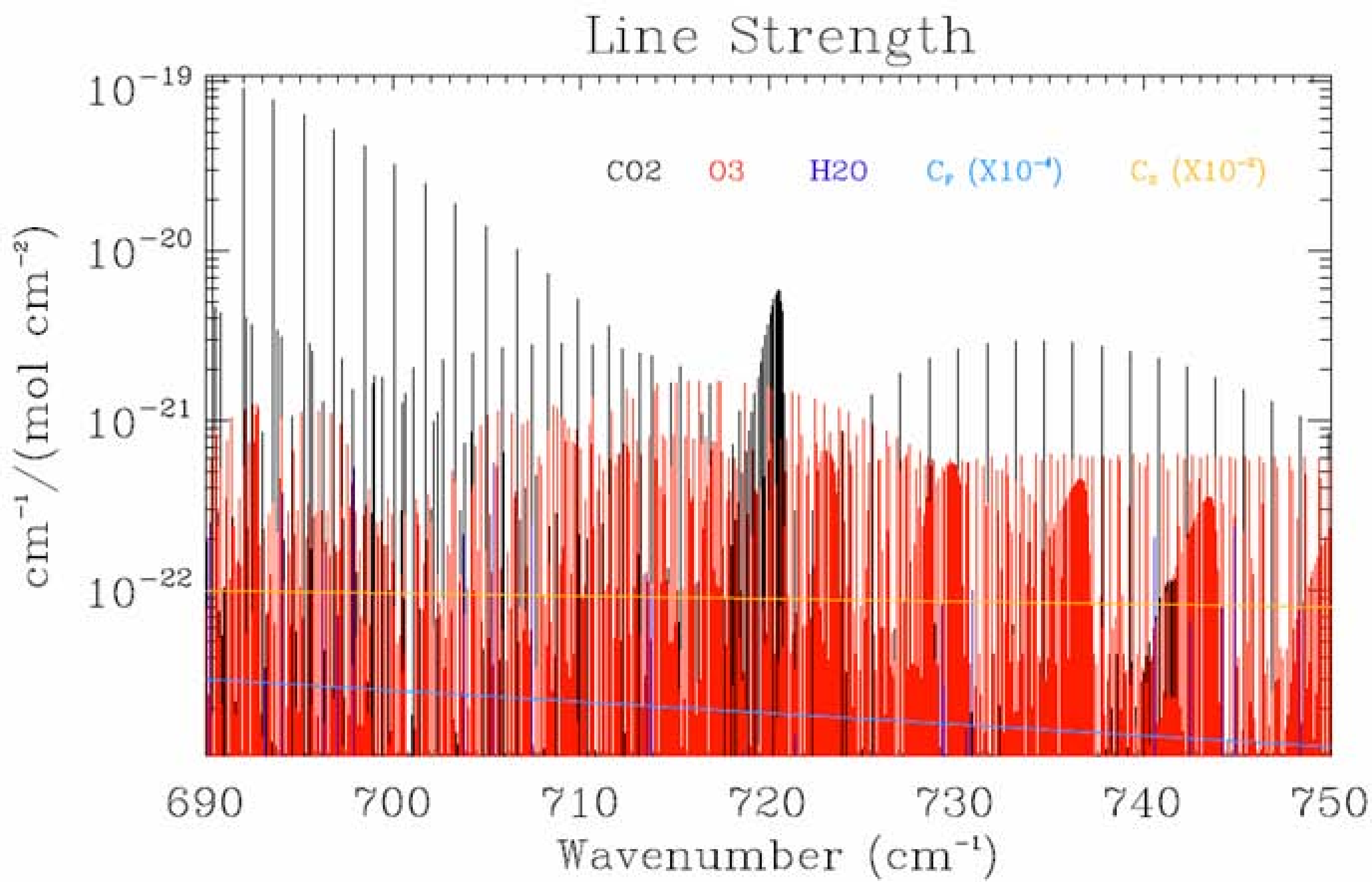
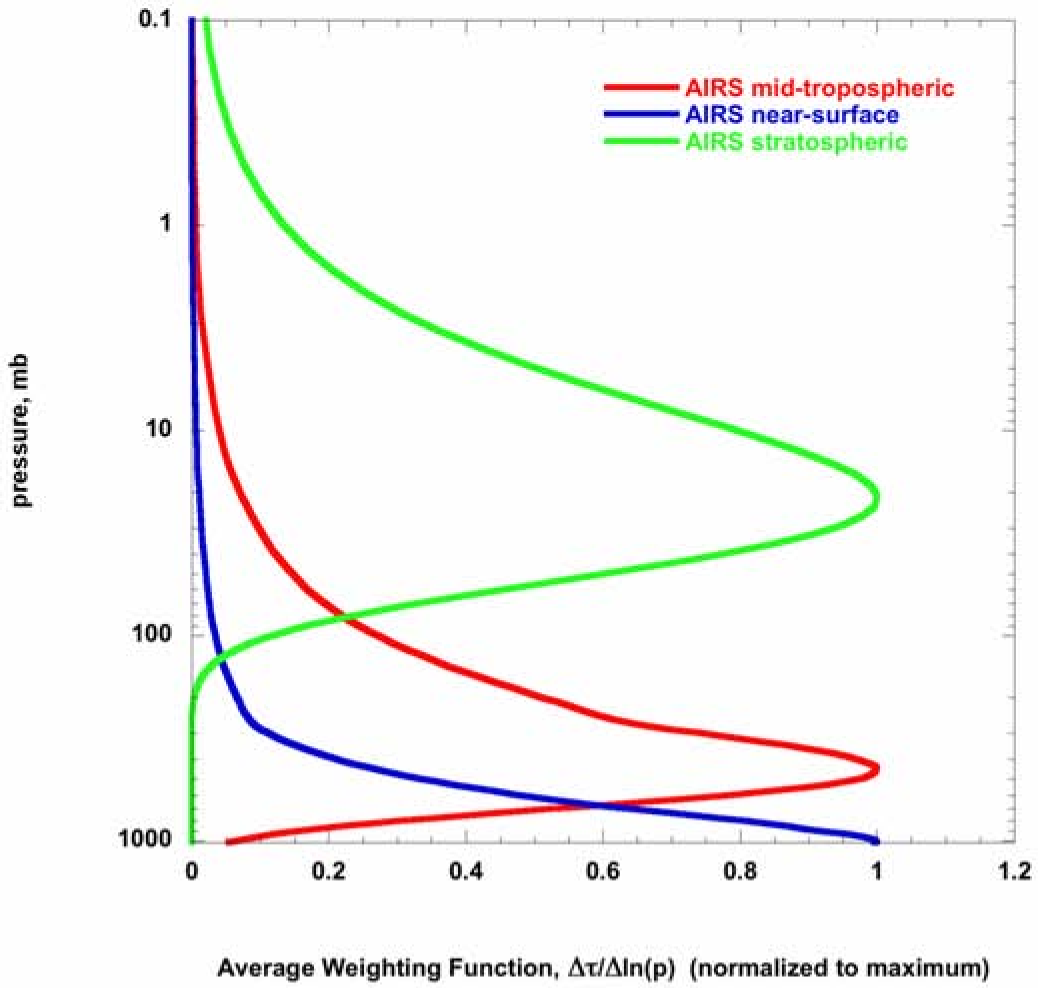
Pressure broadening results in Overlapping lines of all Species - 15 µm band

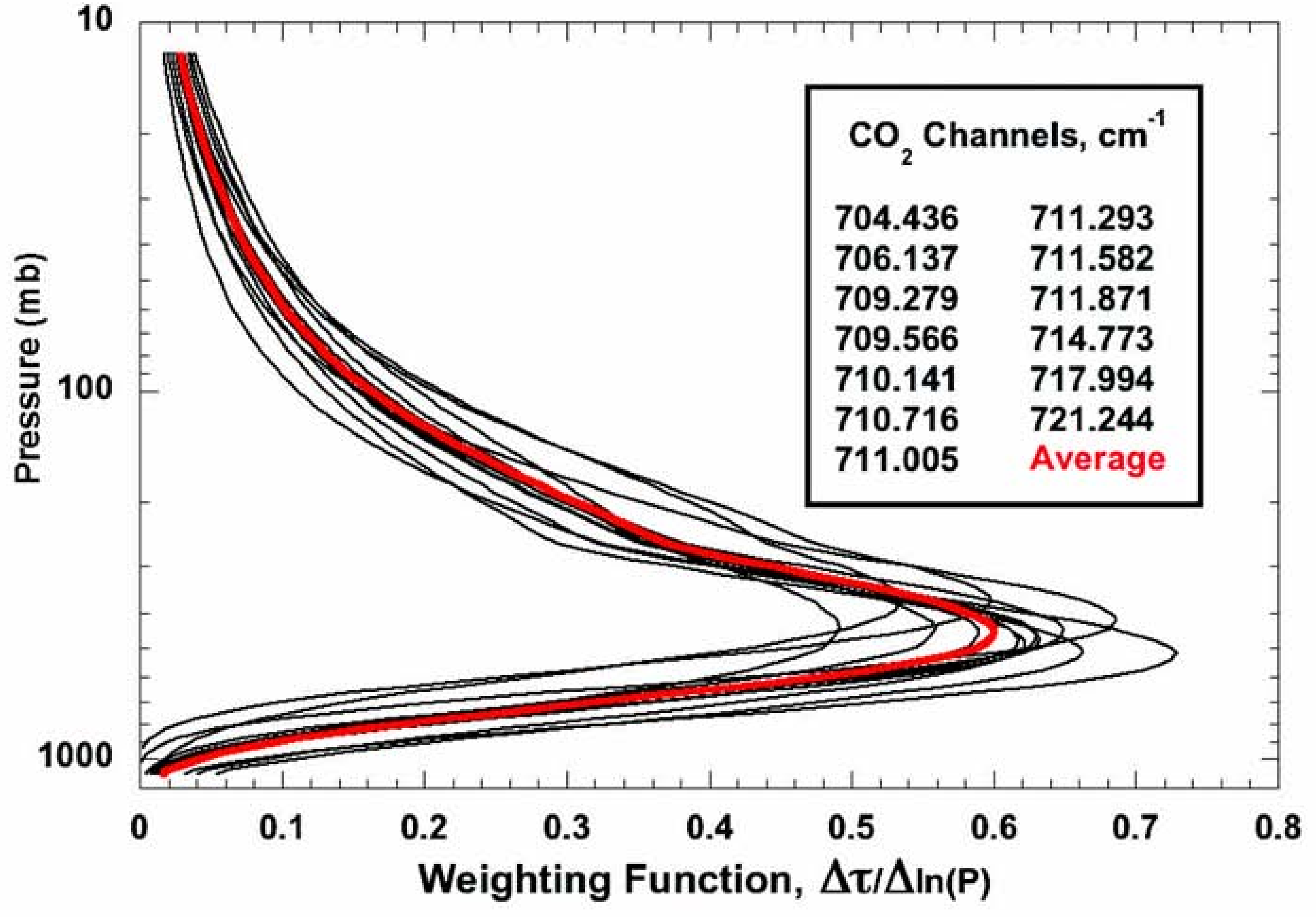


C_s and C_f are the self and foreign component of the continuum absorption in 1/(cm-1 molecules cm-2)

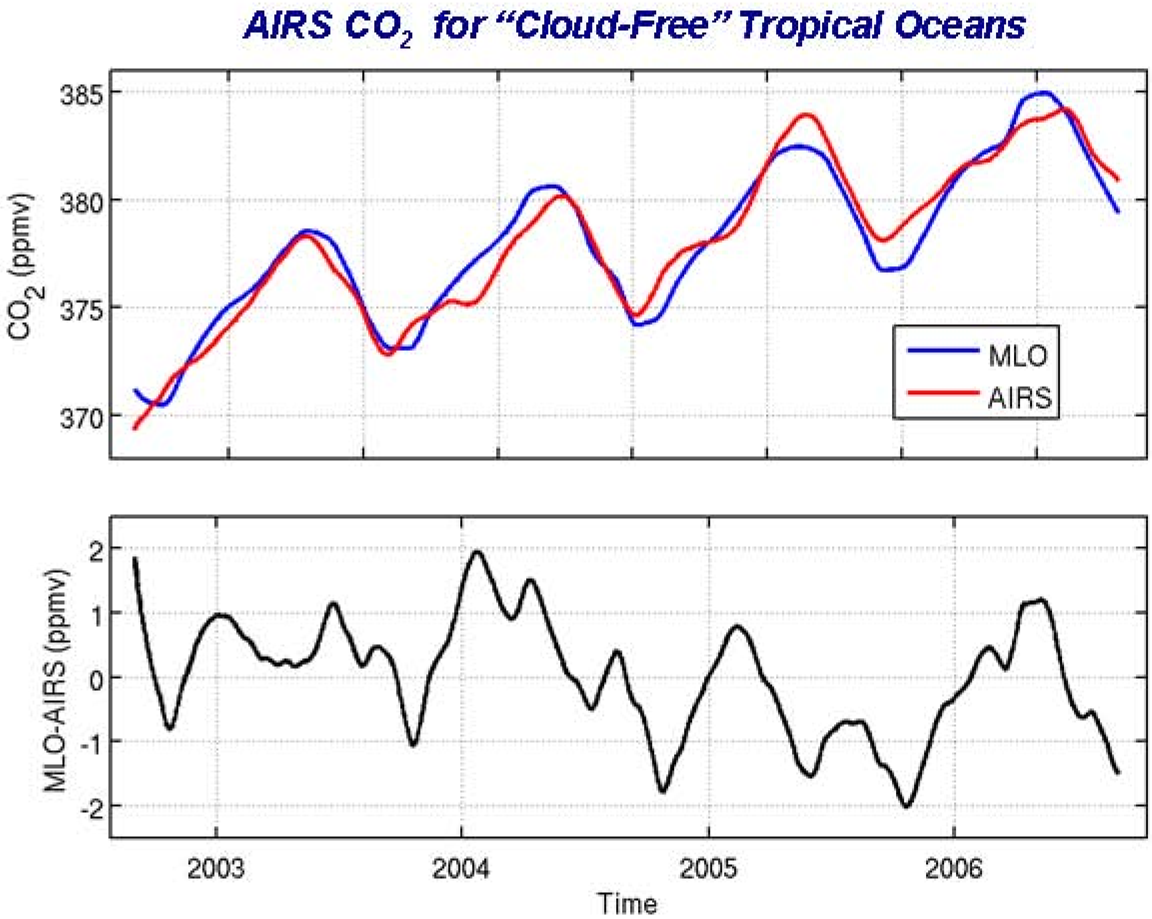
AIRS Sensitivity for retrieving a CO2 profile



CO_2 Sounding Channels
Mid-Troposphere



Comparison of CO2 Annual Variations Mona Loa Observatory (MLO) and AIRS



Larrabee Strow, U Maryland

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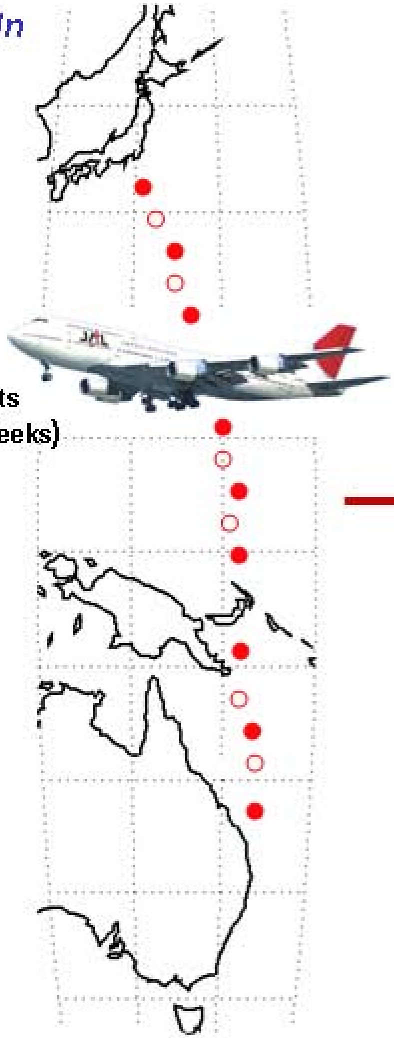
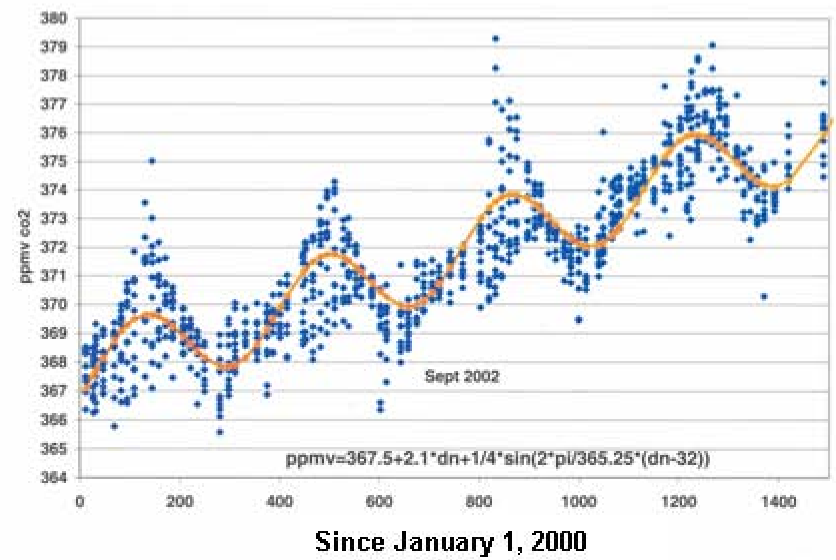
Atmospheric In

Matsueda Airborne Flask

CO_2 Measurements at 10.5 km altitude



JAL Flights
(every two weeks)



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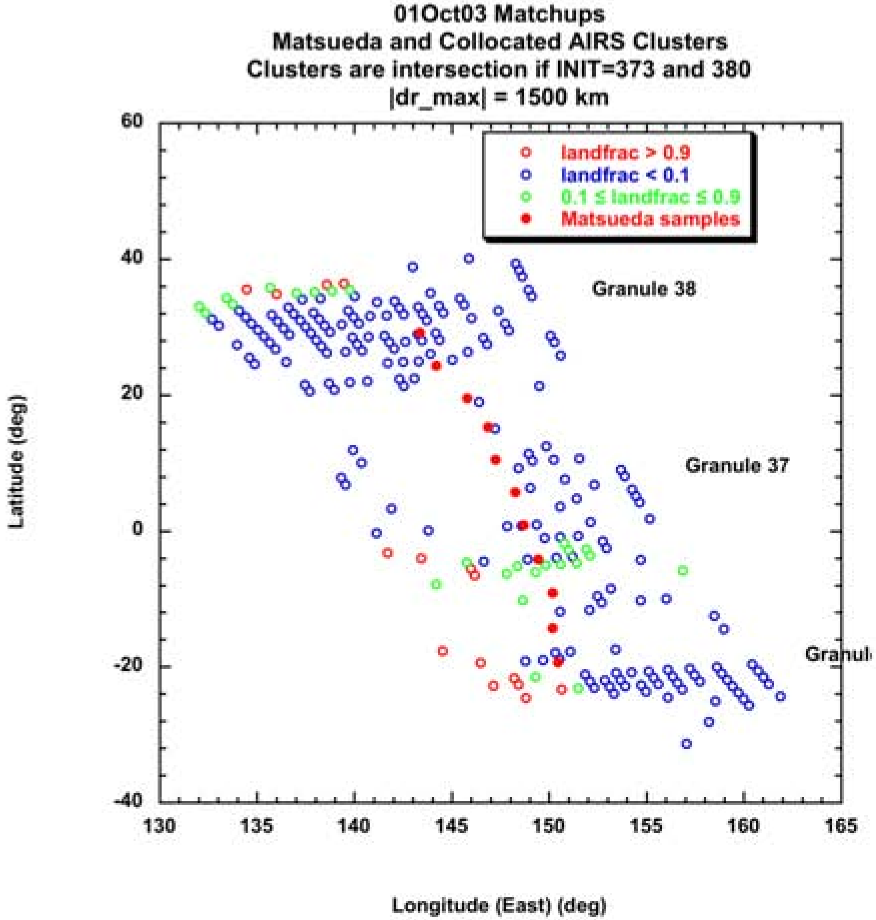
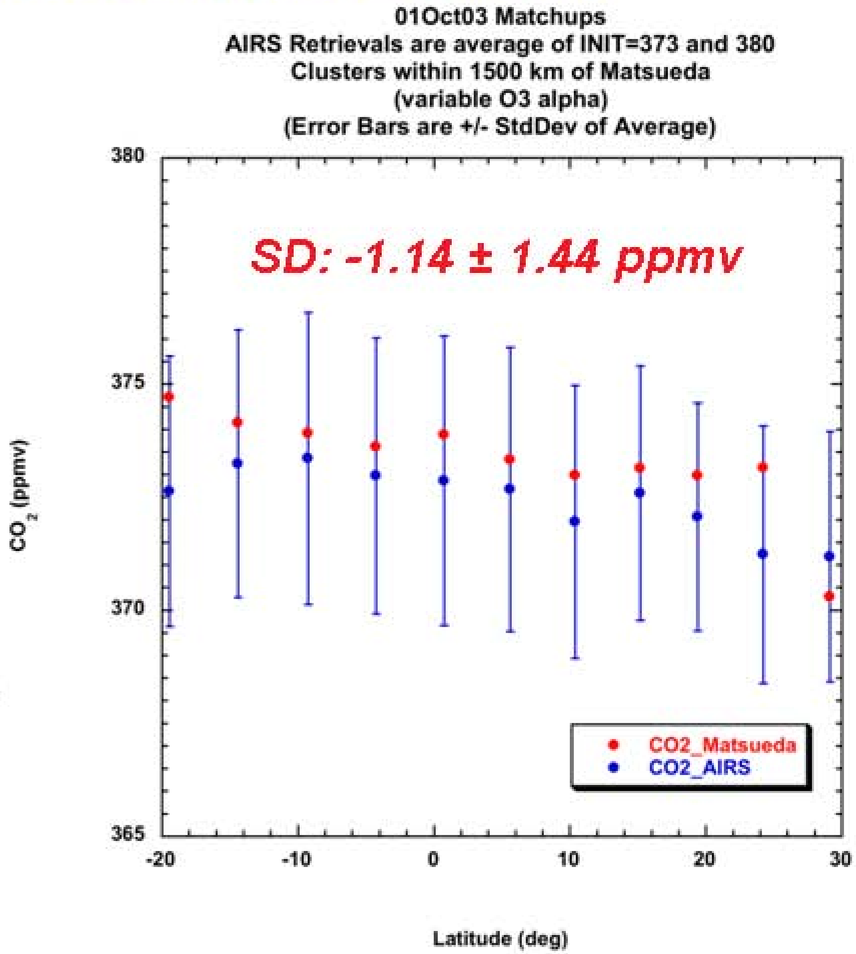
Atmospheric Infrared Sounder

Comparison Between AIRS CO_2 with Matsueda Aircraft Data

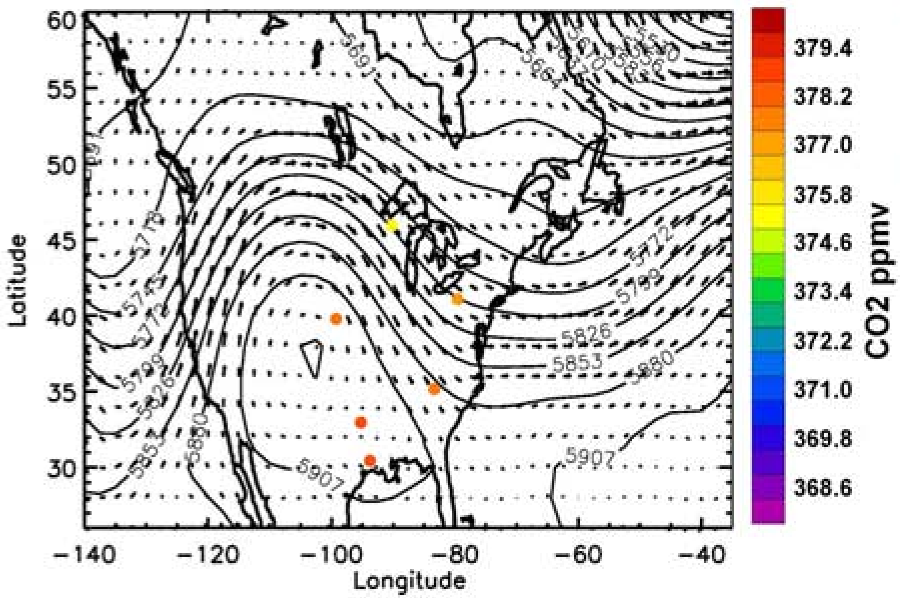


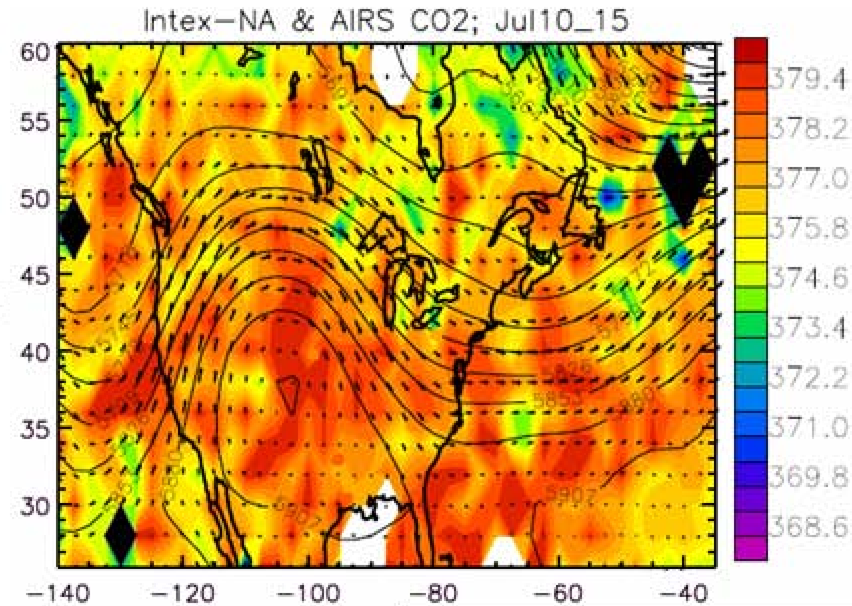


CO_2 retrieved by Vanishing Partial Derivatives (VPD)

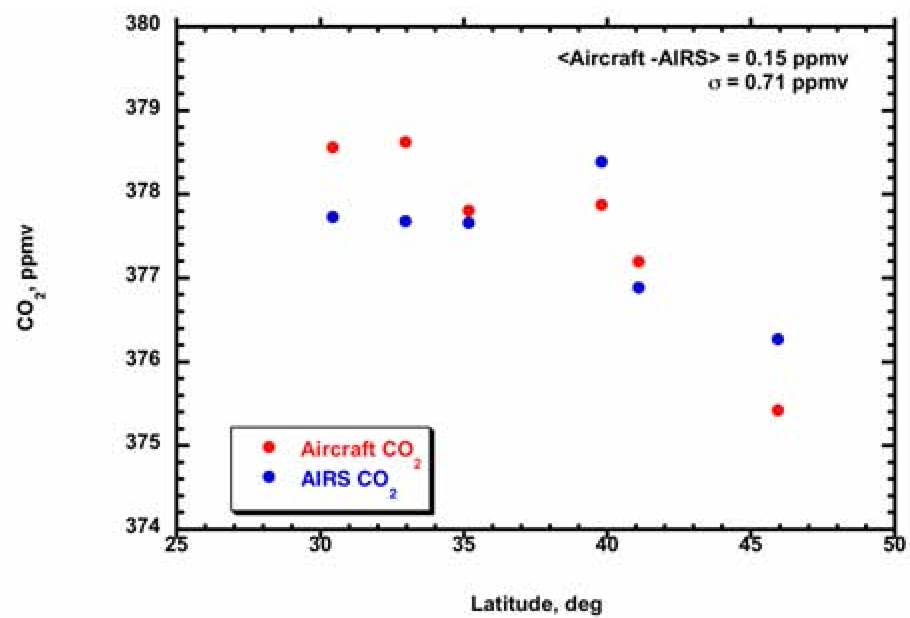
***M. Chahine, C. Barnet, E.T. Olsen, L. Chen and E. Maddy* [2005, GRL]**

INTEX-NA AIRCRAFT MEASUREMENTS OF CO2 PROFILE July 10-15,2004

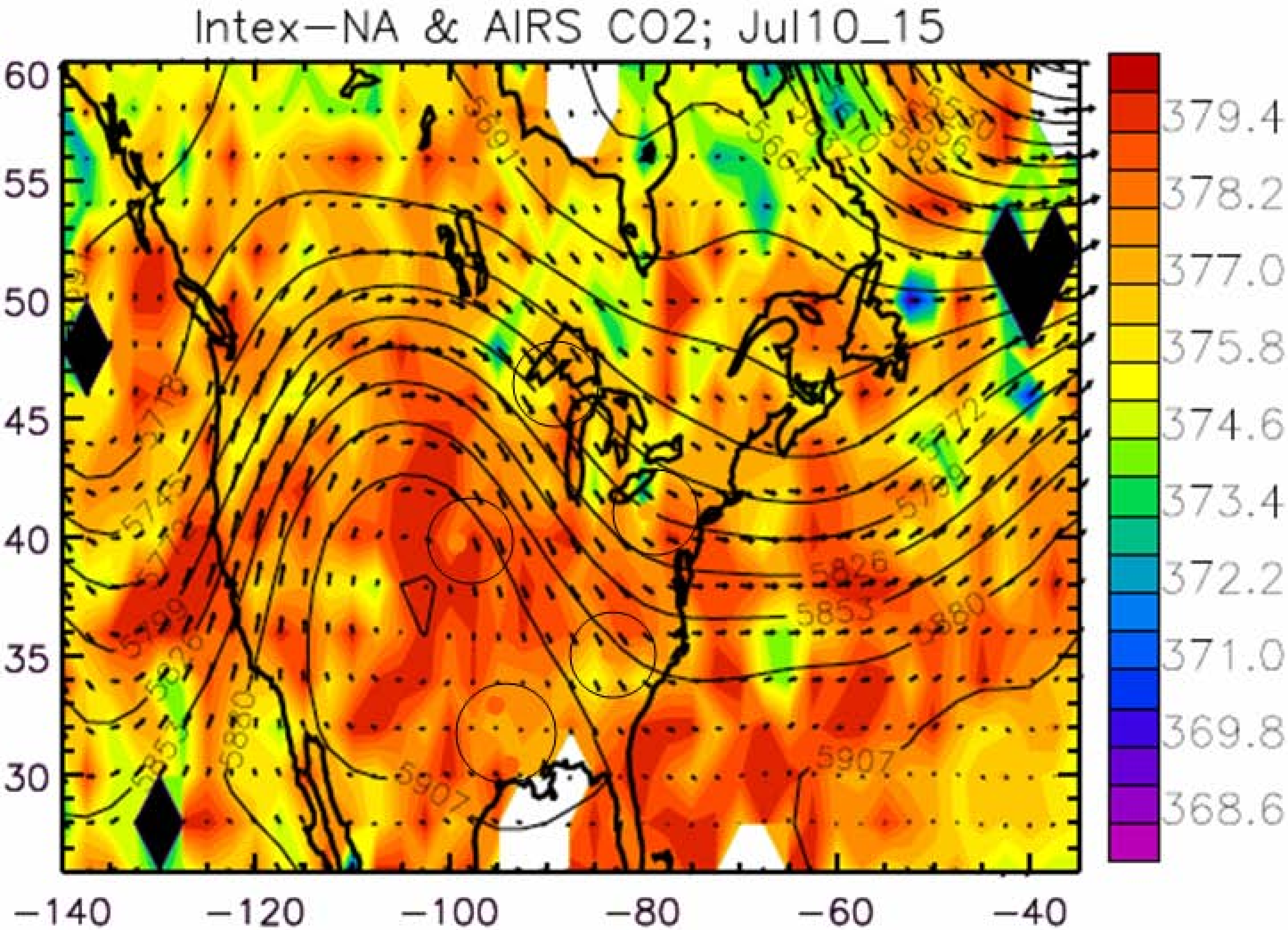




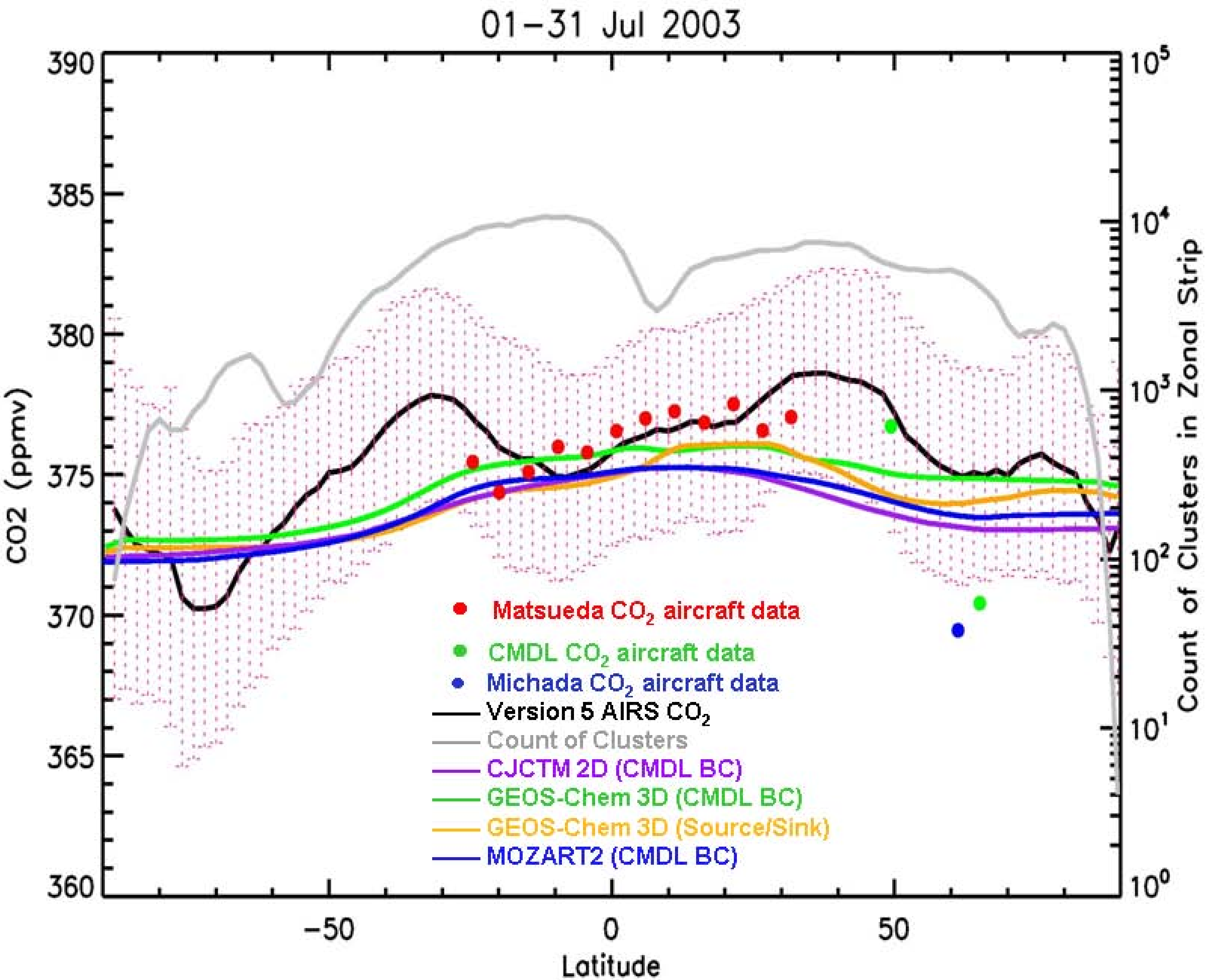
Eye Test:
Find the A/C Measurements



Comparison Accuracy
-0.15 ±0.71 ppmv


Intex–NA & AIRS CO2; Jul10_15
60
55
50
45
40
35
30
–140
–120
–100
–80
–60
–40
379.4
378.2
377.0
375.8
374.6
373.4
372.2
371.0
369.8
368.6
5826
5853
5880
5907

Version 5 AIRS CO_2



Version 5 AIRS CO_2

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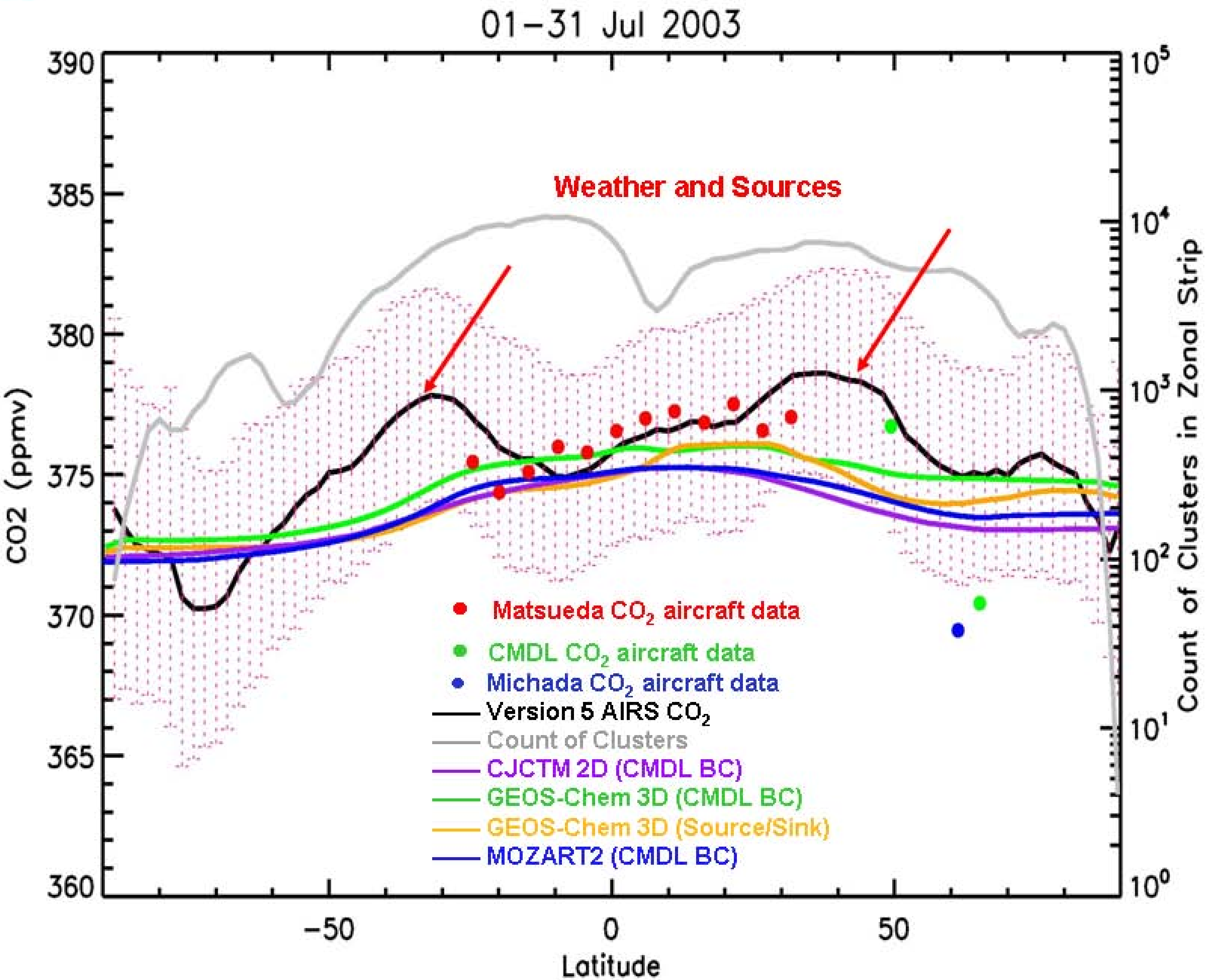
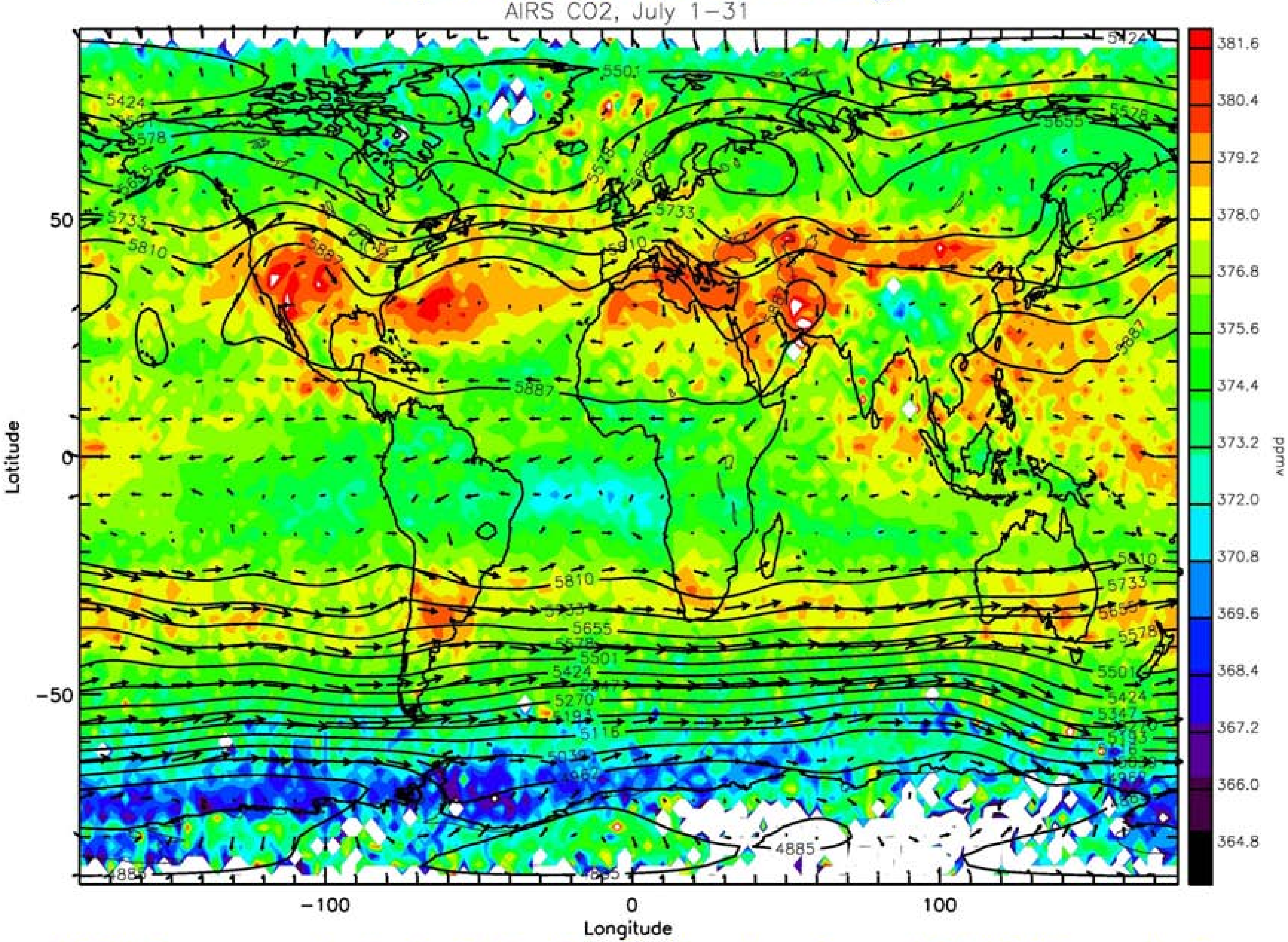
Atmosp

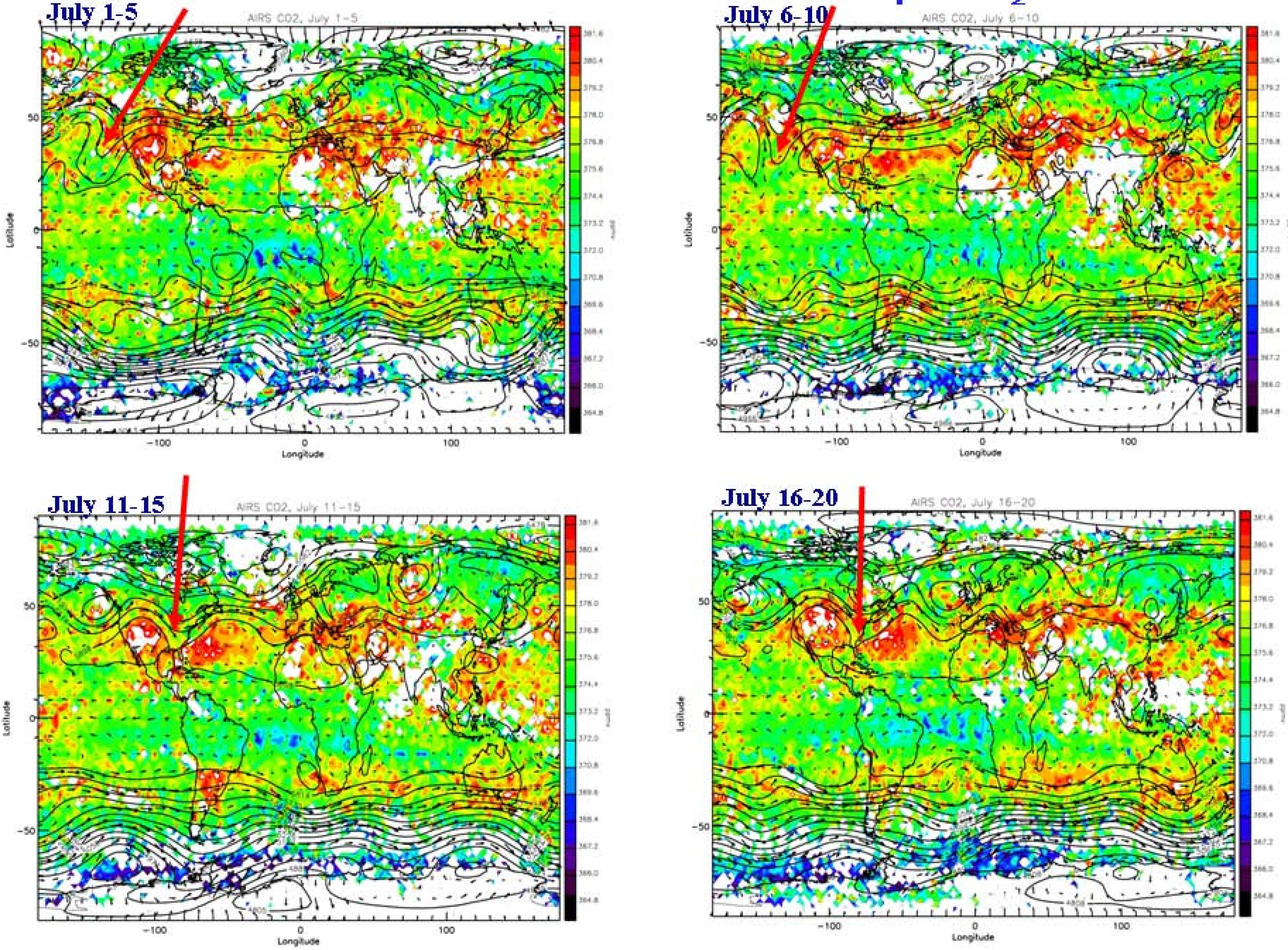


Spatial Pattern of CO_2

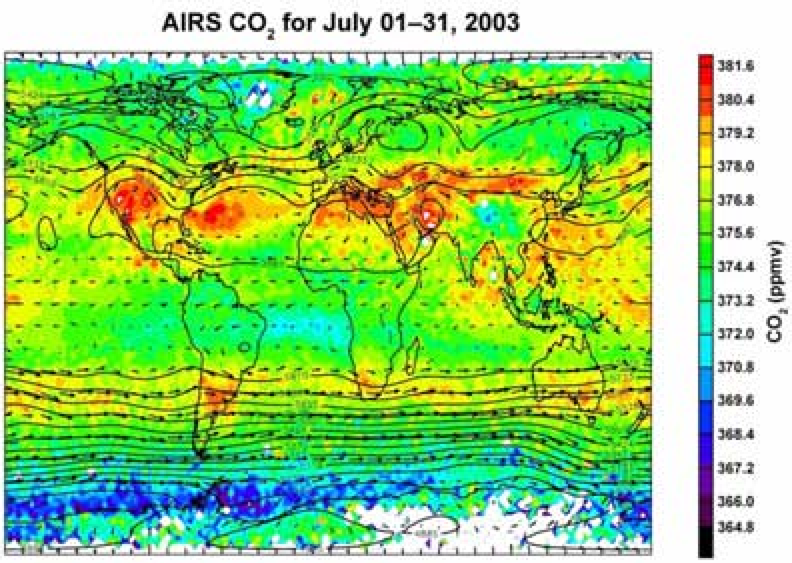


500 hPa geopotential heights & wind vectors from NCEP2 Reanalysis

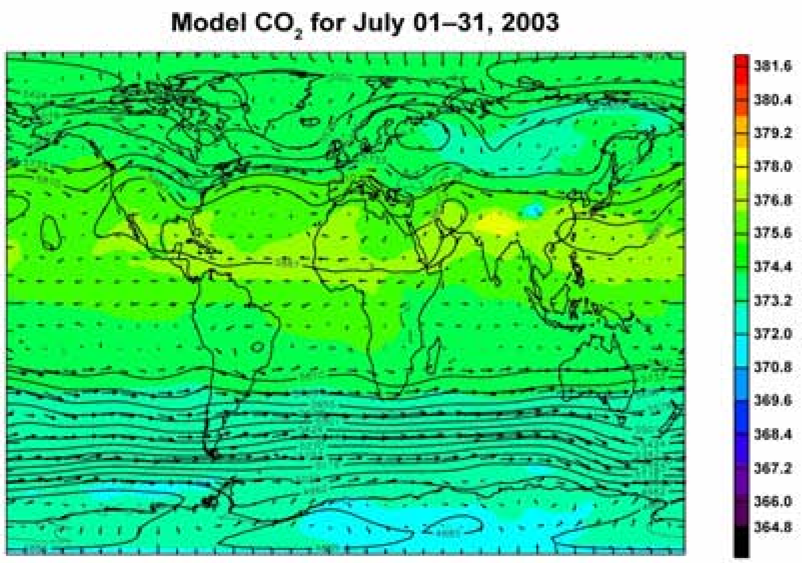
Effects of Weather on Mid Trop CO_2



Models do not Capture the Effects of Weather and Surface Sources

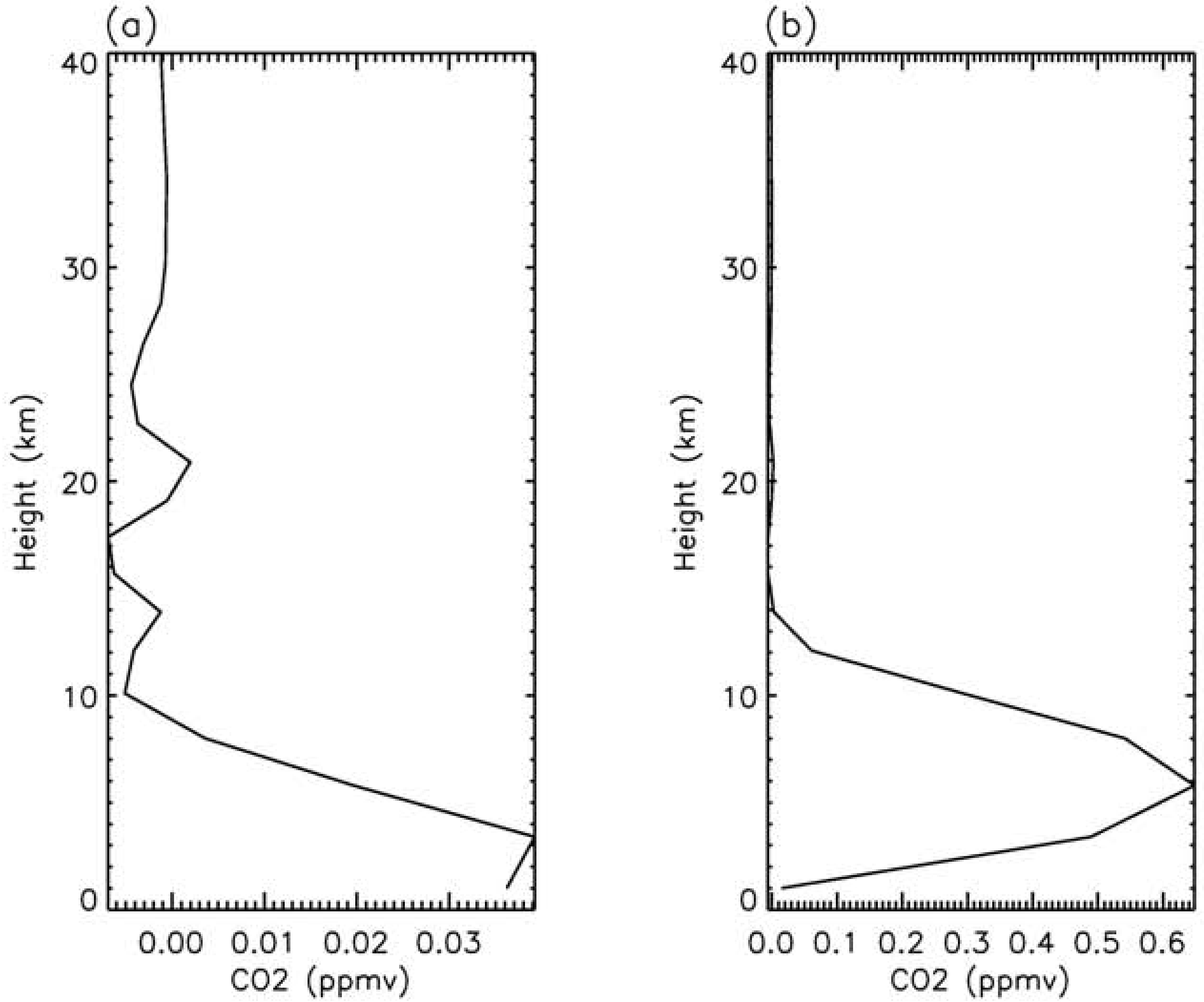


AIRS CO2 Retrieval



GEOS-Chem Model

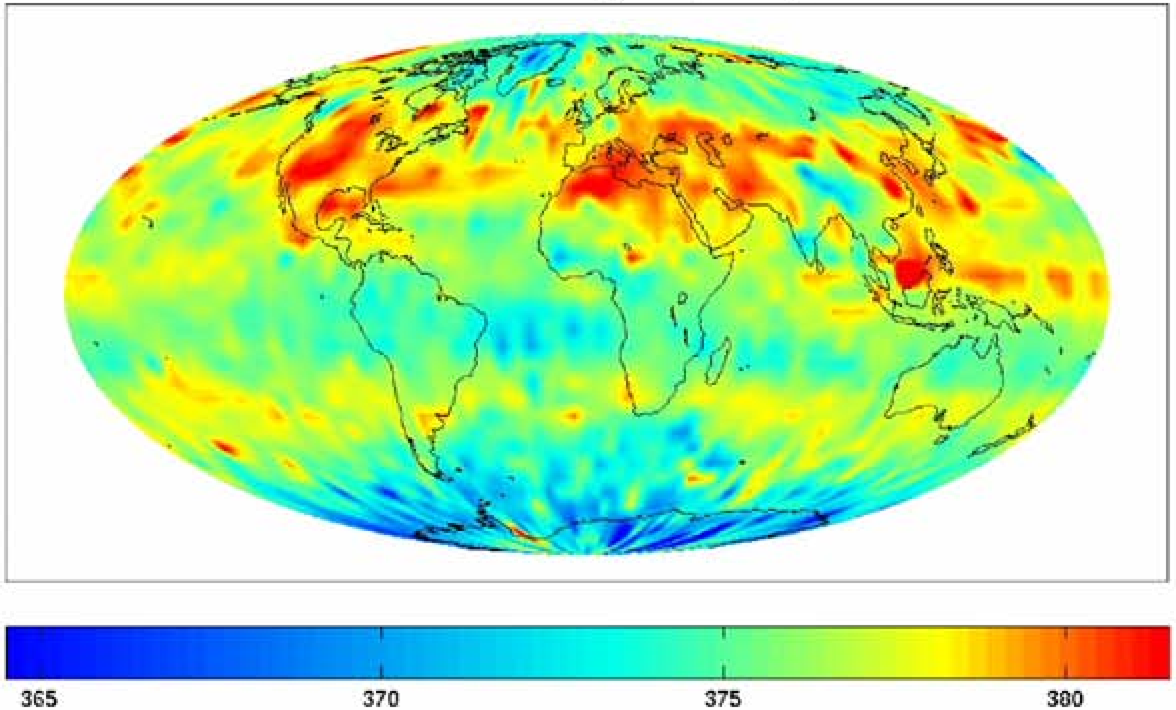
Sensitivity Studies Show that Convection is the Key



Effect of Turbulence Mixing in PBL

Effect of Deep Convection Updraft Mass Flux

AIRS 500 mb CO2. July 2003, V5 Day 3 x 5



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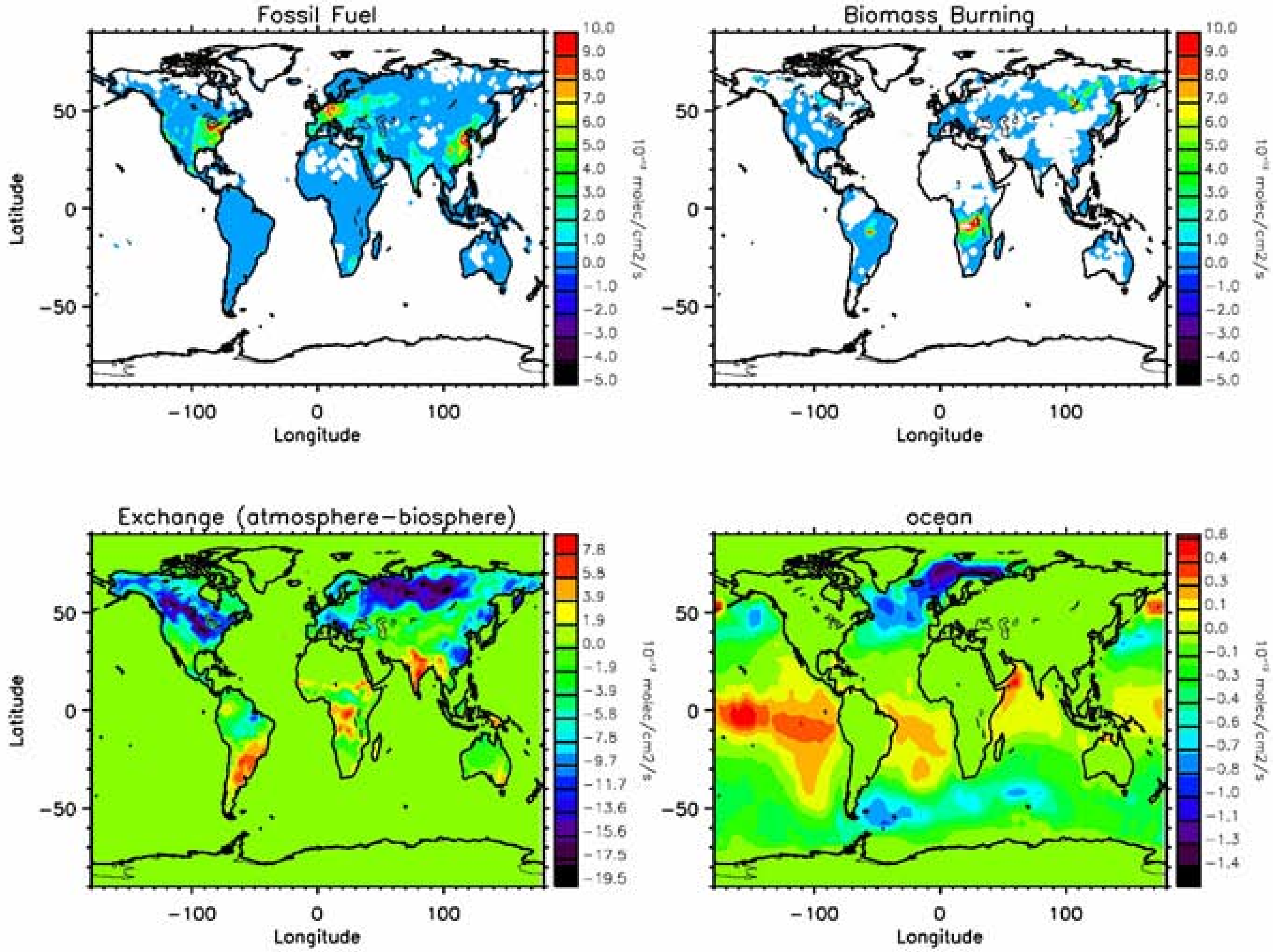
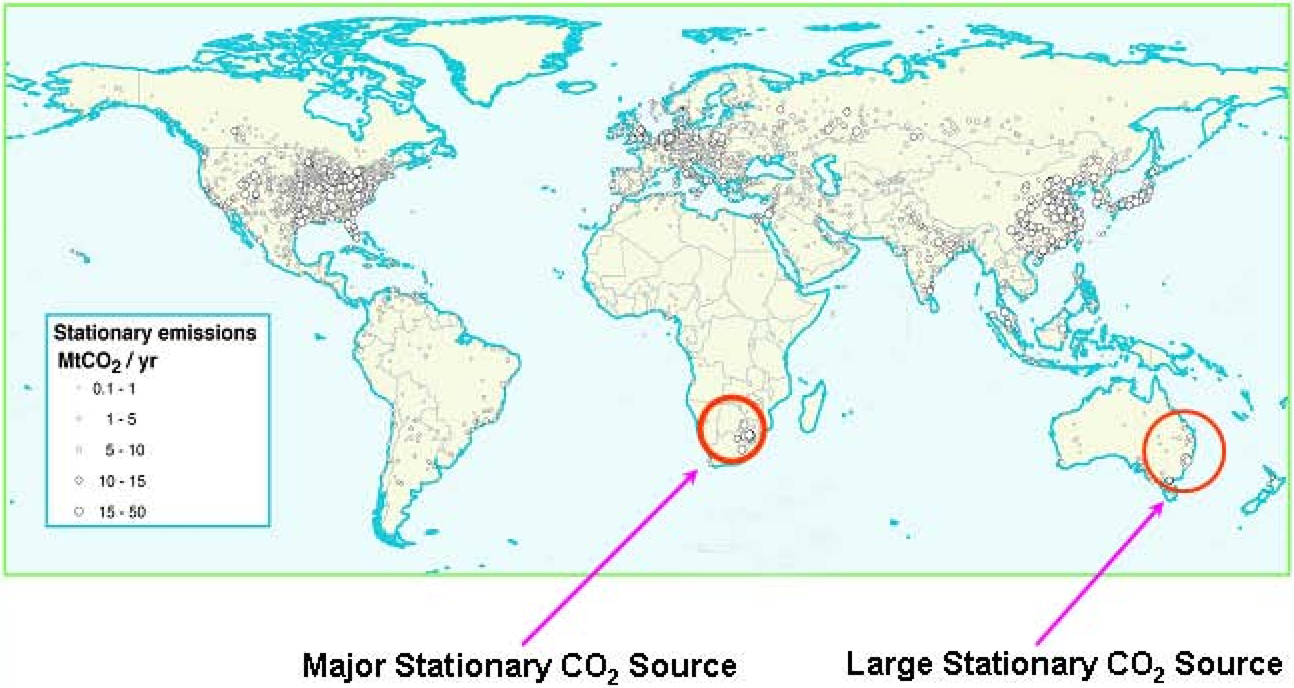
CO2 Sources



Global distribution of large stationary sources of CO2



IPCC

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

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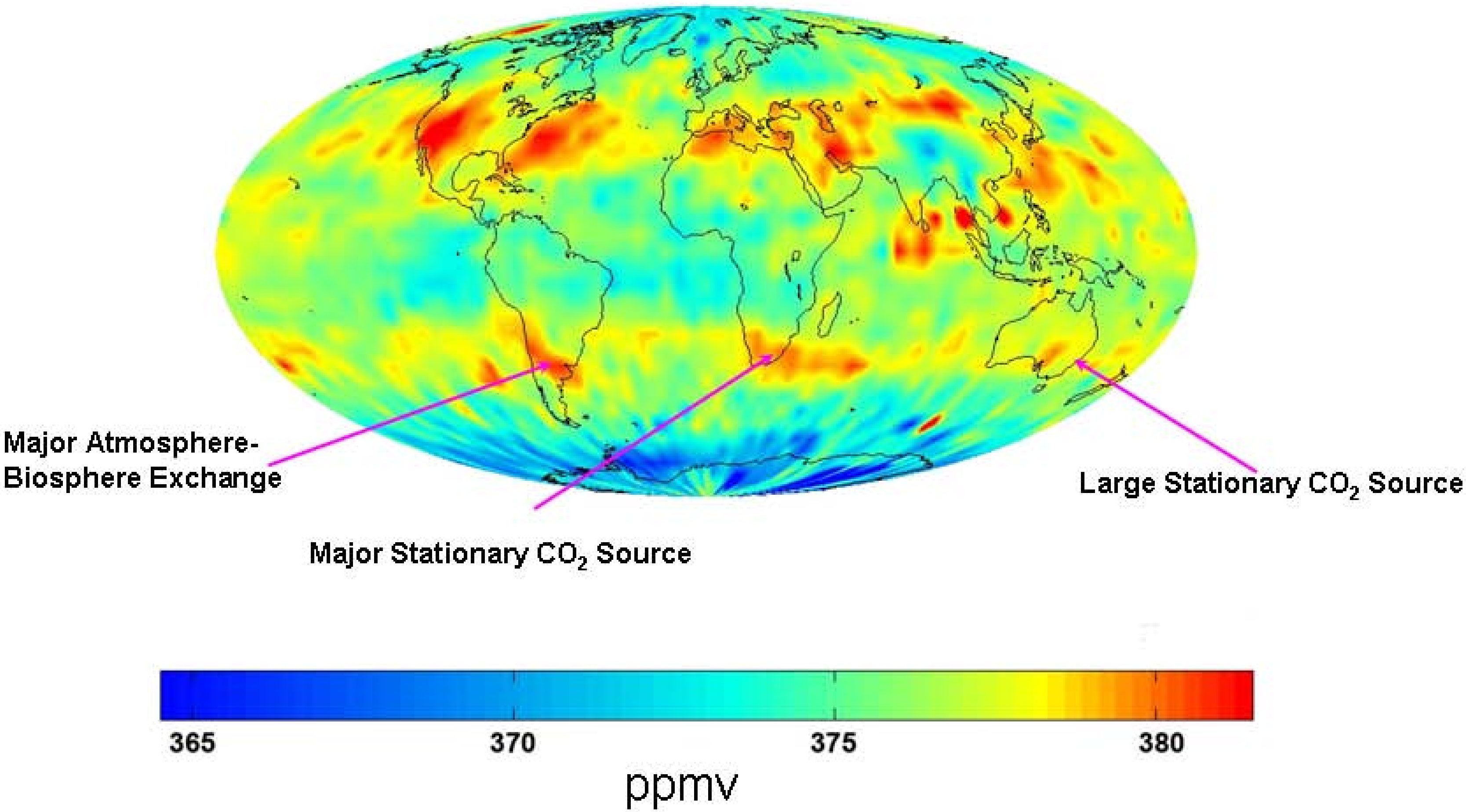
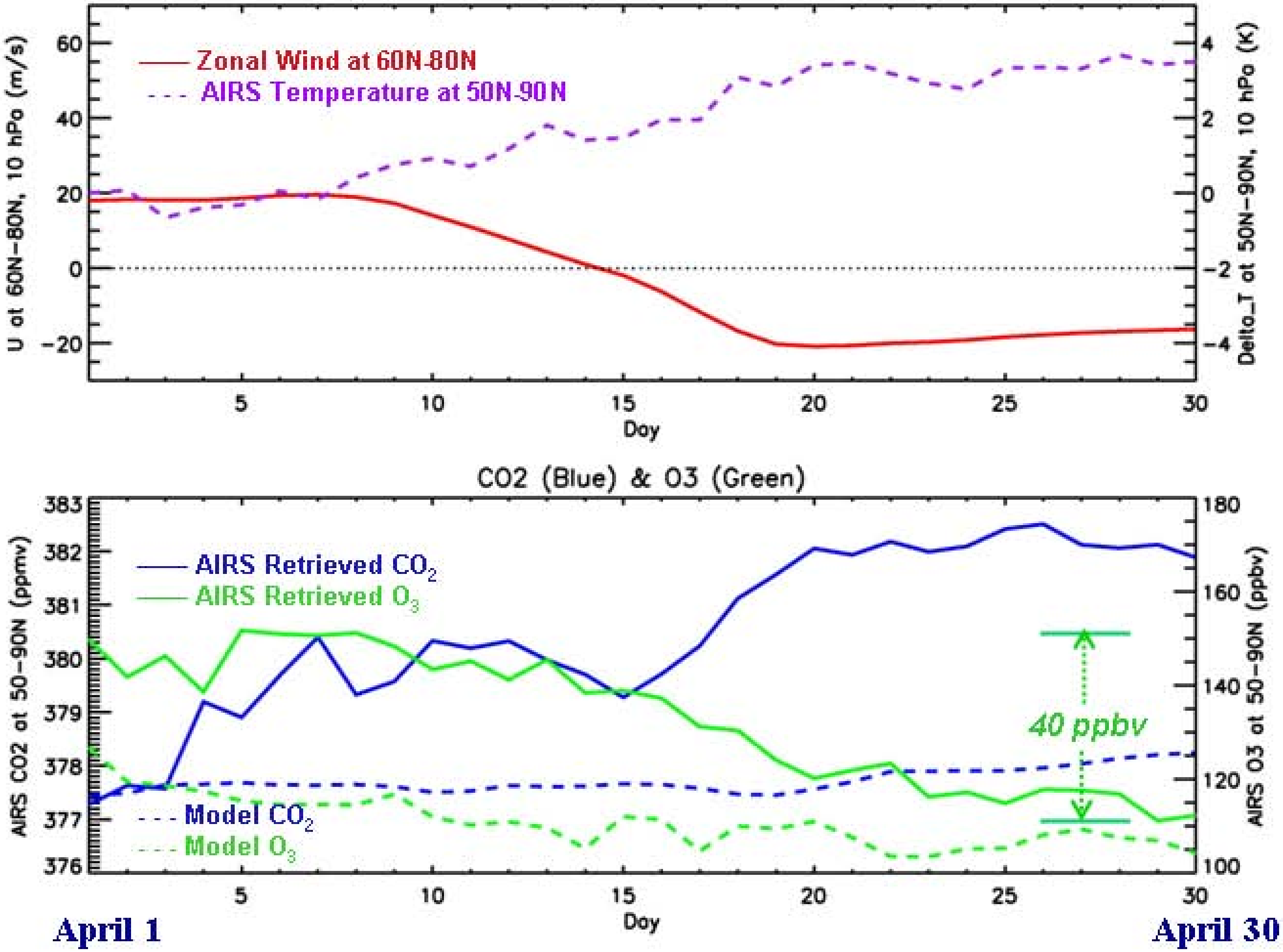
Impact of Weather on Mid-Tropospheric CO_2

July 24-28, 2003



Influence of Sudden Stratospheric Warming on CO_2 and O3
AIRS- April 2003



AIRS retrieved upper tropospheric CO_2 increases while AIRS 300 mb O_3 decreases following a sudden stratospheric warming event

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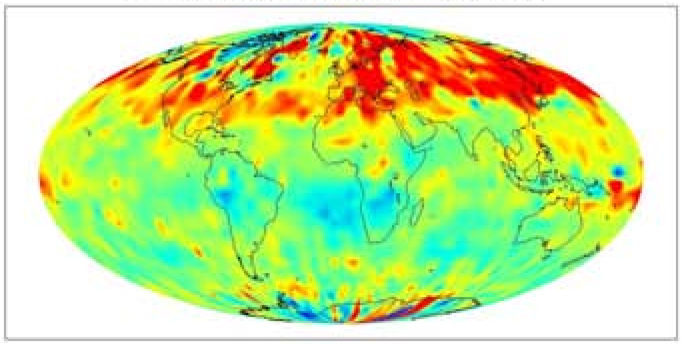
Atmospheric Infrared Sounder

Sudden Stratospheric Warming (SSW)

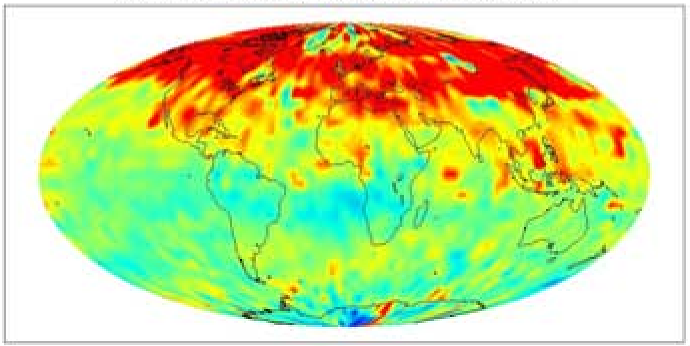
April 2003

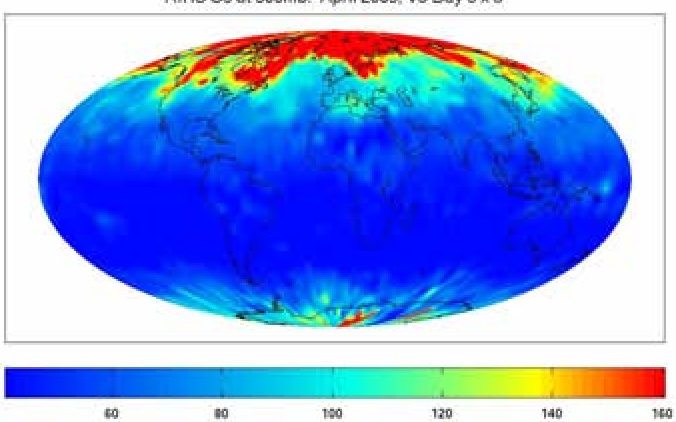
Before SSW

After SSW

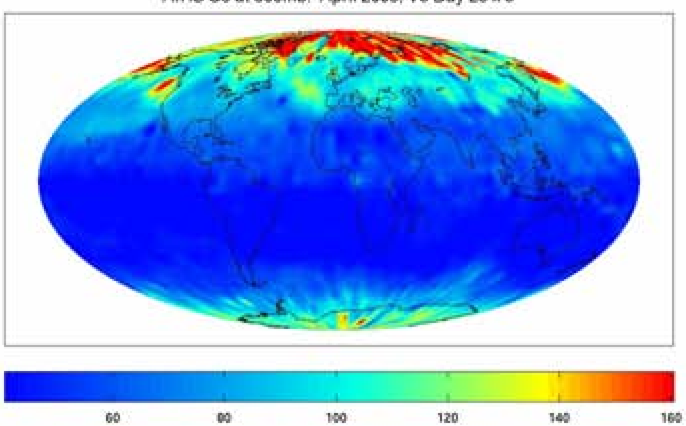


CO2





O3



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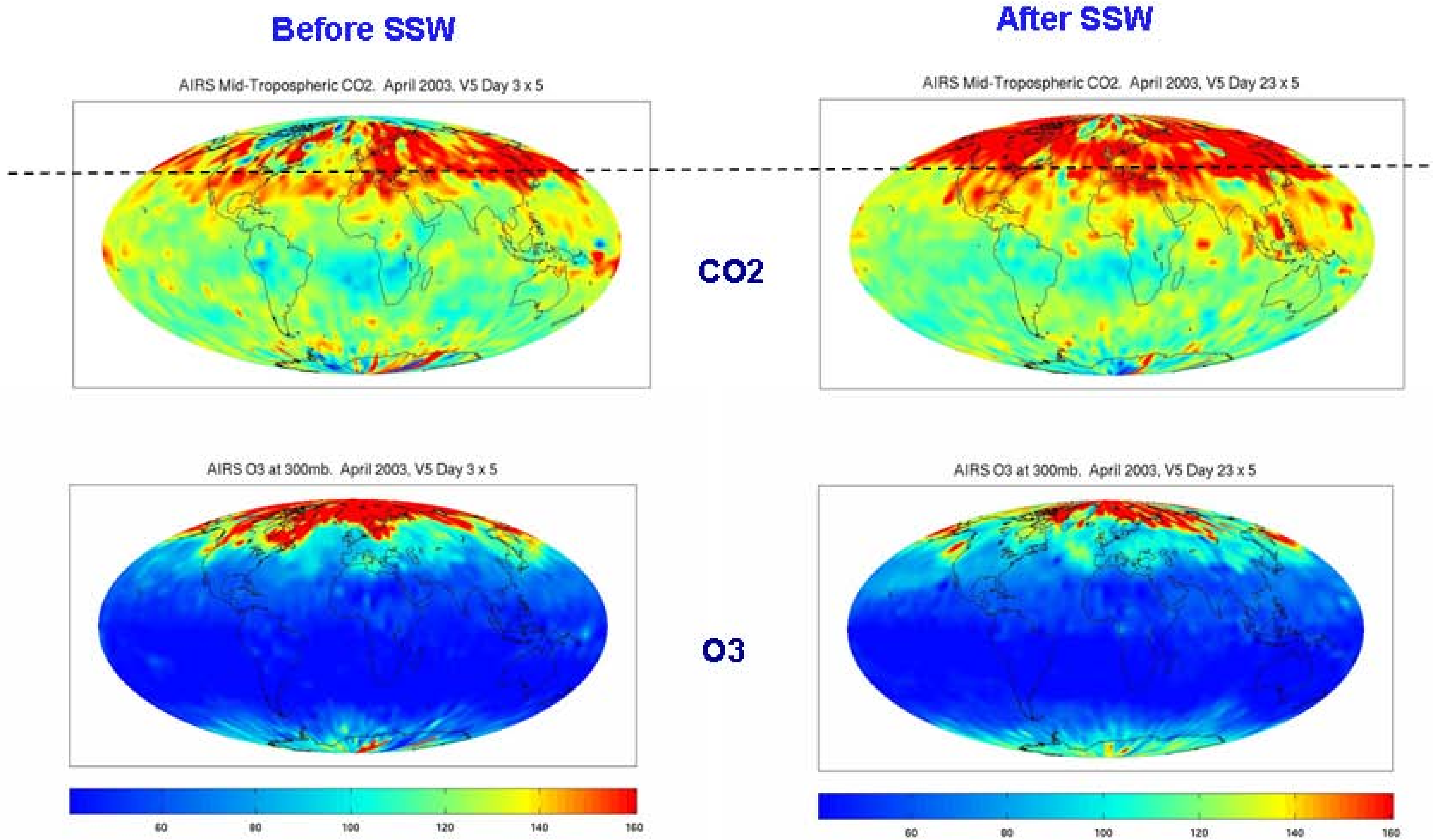
Sudden Stratospheric Warming (SSW)

April 2003



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Atmospheric Infrared Sounder

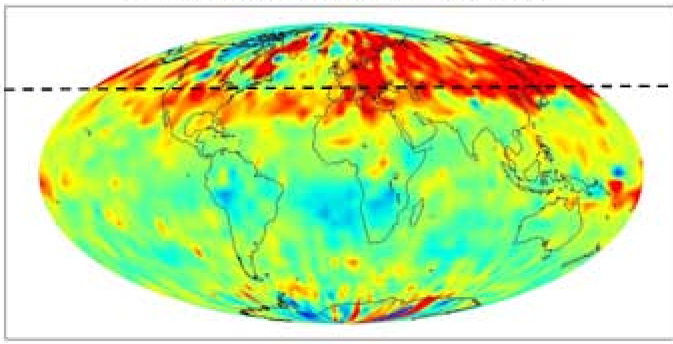
Sudden Stratospheric Warming (SSW)

April 2003

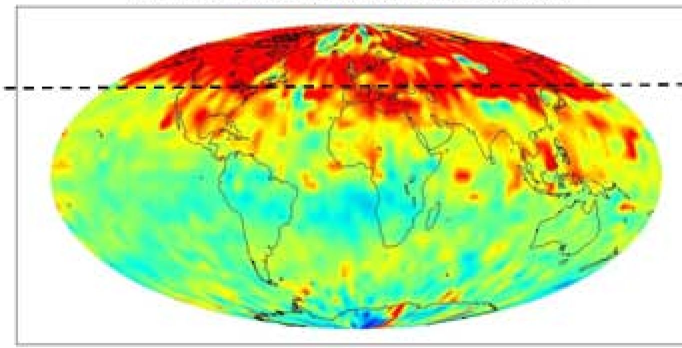
Before SSW

After SSW

AIRS Mid-Tropospheric CO2. April 2003, V5 Day 3 x 5

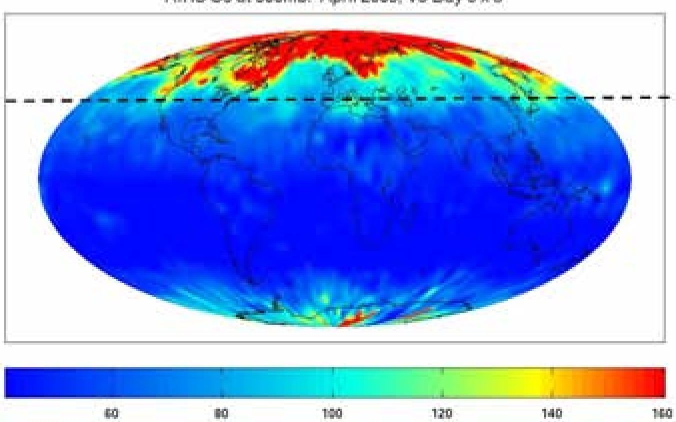


AIRS Mid-Tropospheric CO2. April 2003, V5 Day 23 x 5

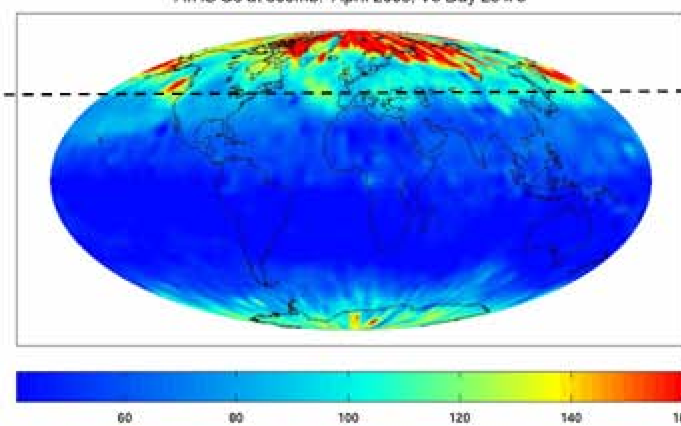


CO2

AIRS O3 at 300mb. April 2003, V5 Day 3 x 5



AIRS O3 at 300mb. April 2003, V5 Day 23 x 5



O3

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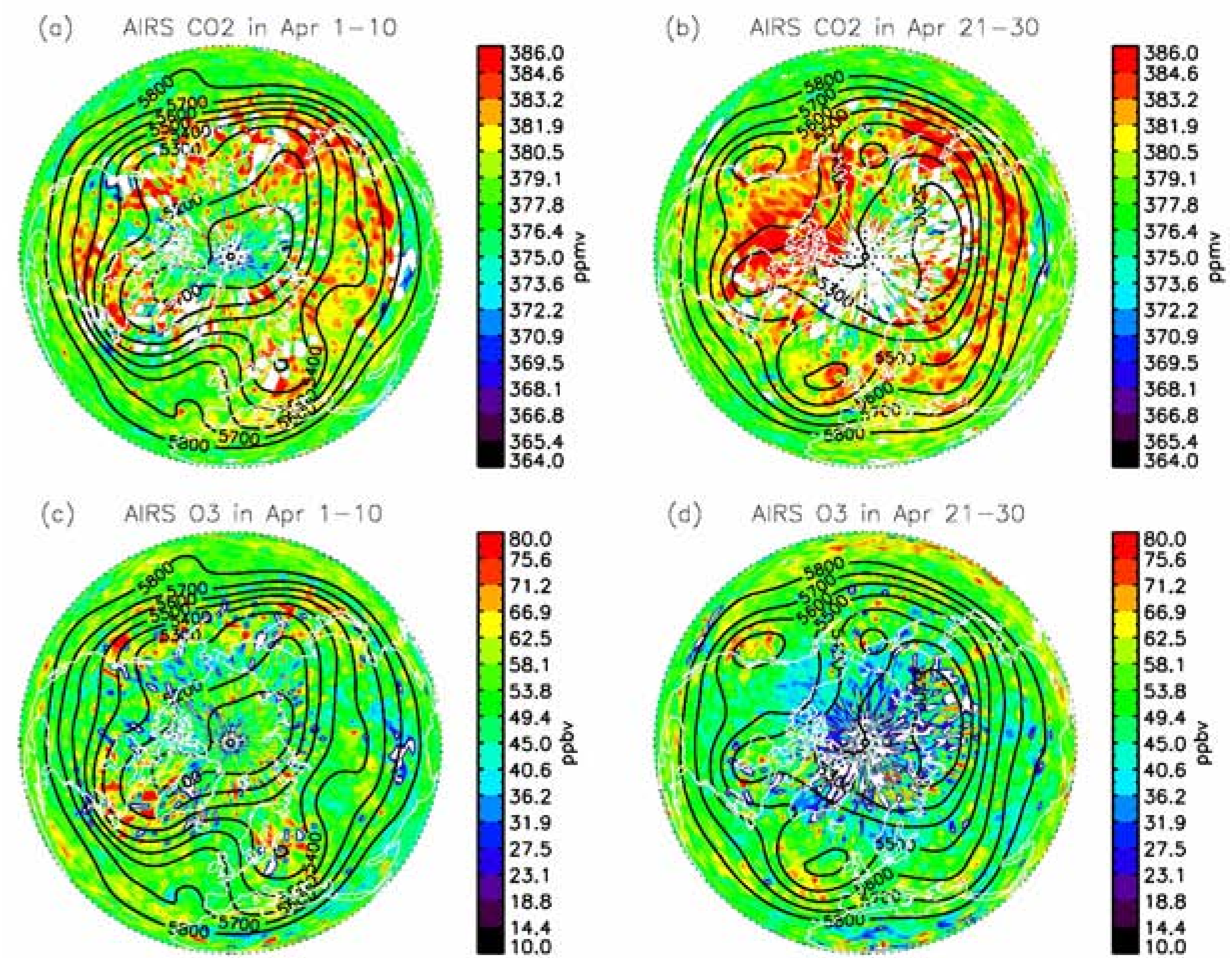
Atmospheric Infrared Sounder

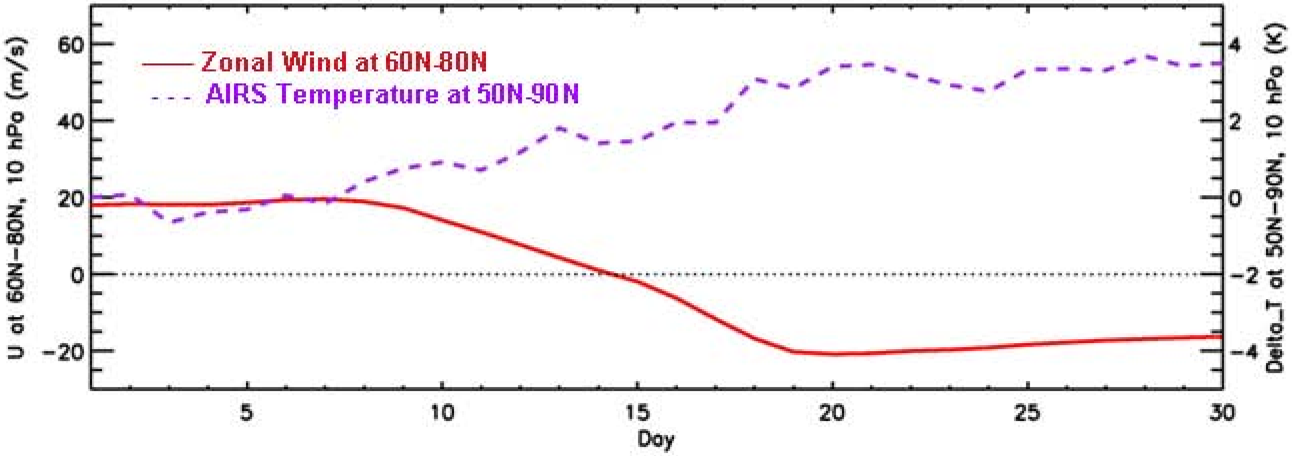
Sudden Stratospheric Warming (SSW)

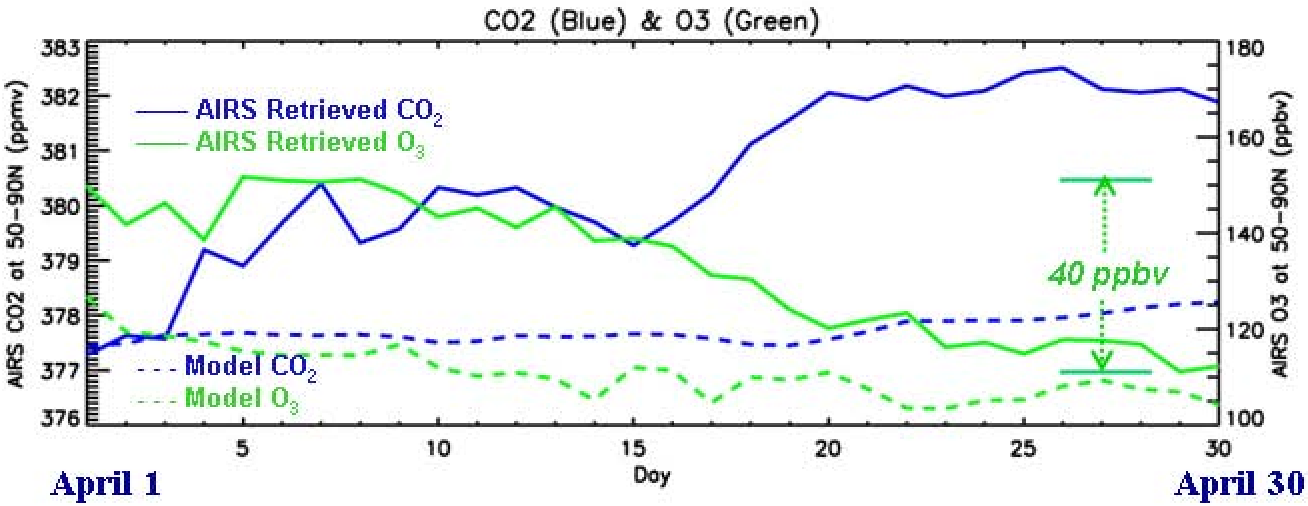
April 2003

Before SSW **After SSW**



Influence of Sudden Stratospheric Warming on CO_2 and O3
AIRS- April 2003





AIRS retrieved upper tropospheric CO_2 increases while AIRS 300 mb O_3 decreases following a sudden stratospheric warming event

Atmospheric Fluorine Compounds is Indicators of Air Movements

GASEOUS fluorine compounds are supposed not to occur aturally in the atmosphere. Volatile fluorine compounds would not be expected to result from chemical equilibria etween fluorine compounds on the surface of the Earth, and is improbable that biological systems contribute significant uantities of organic fluorine compounds.

It is, however, estimated that about 10^6 tons of fluorine ompounds are released each year into the atmosphere, and hese include halomethanes from aerosol dispensers, fire xtinguishers, refrigerant fluids and anaesthetics, and sulphur exafluoride from electrical equipment. By contrast with these able compounds, reactive compounds such as hydrogen luoride, which are also industrial products, are rapidly cavenged from the atmosphere by physical and chemical rocesses.

The presence of stable sulphur and carbon fluorides in the tmosphere is not in any sense a hazard, and their existence as only been detected by the very sensitive technique of gas hase electron absorption. The fluorides are, however, of pecial interest because they enter the atmosphere only from ndustrial and domestic sources, whereas other gaseous ndustrial emissions are also natural products; their distri-ution in the atmosphere can therefore be a useful indicator f air movements and wind directions.

Table 1 Observations at Adrigole, Co. Cork, Ireland (51° 40′ N, 09° 45′ W)

Wind heading	Concentration by volume CCl_3F	Concentration by volume SF_6	Turbidity
45°–135°	1.0×10^{-11} (4)	2.9×10^{-14} (3)	0.03 (7)
25°–315°	1.9×10^{-10} (3)	1.2×10^{-13} (3)	0.19 (2)

The number of observations is shown in parentheses.

We report in this communication preliminary measurements of the atmospheric concentrations of sulphur hexafluoride and trichlorofluoromethane in south-west Ireland during July and August 1970. Analyses were made using a gas chromatograph with an electron capture detector. Experimental conditions were arranged so that ionization in the detector was complete[1] and under these circumstances errors are only likely to be caused by loss of sample during collection and chromatography; for example, by irreversible adsorption. Calibration of the system showed that such losses probably did not exceed 30%. Our results are shown in Table 1; the atmospheric turbidity was measured with a 'Volz' sun photometer using the technique described by Flowers, McCormick and Kurfis[2]. Air arriving at the monitoring site from a north-westerly direction does not pass over any source of either CCl_3F or SF_6 and so the concentrations measured under these conditions can be regarded as representative of the northern hemisphere back-ground. If the industrial outputs of these compounds are assumed constant at about 2×10^5 and 10^2 tons per year respec-tively, the atmospheric lifetimes would seem to be 1 yr and 4.6 years.

Although other halocarbons such as CF_2Cl_2 and perfluoro-cyclobutane are almost certainly present in the atmosphere, they were not observed in our preliminary experiments because of their relatively low rate of reaction with thermal electrons in the electron capture detector. An unknown electron absorbing compound was, however, always found to be present in the air at a concentration of about 3×10^{-11} by volume and, although its retention time in the chromatograph column suggested a boiling point of about 75° C, it has not been possible to identify it.

The high concentrations of CCl_3F and SF_6 associated with easterly winds from continental Europe and the appreciably increased turbidity lend support to the proposal that these compounds can be used as indicators of air masses which have recently been polluted by industrial effluents.

J. E. LOVELOCK

Department of Applied Physical Science,
University of Reading,
Reading RG6 2AL

Conclusions

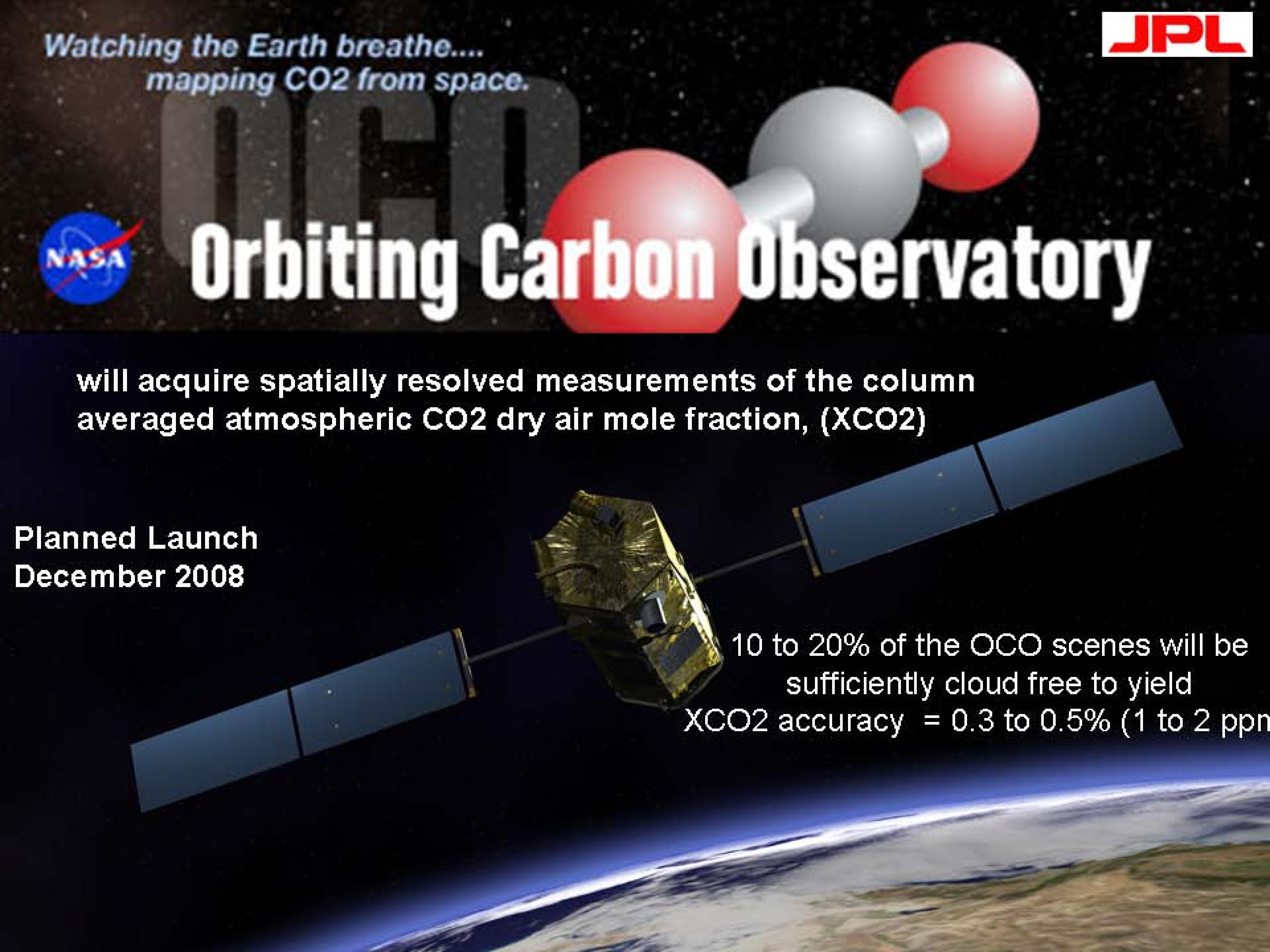
- The AIRS retrieved upper tropospheric CO_2 agrees reasonably well with in situ aircraft observations in the tropics.
  - Additional validation data are needed at high latitudes.

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

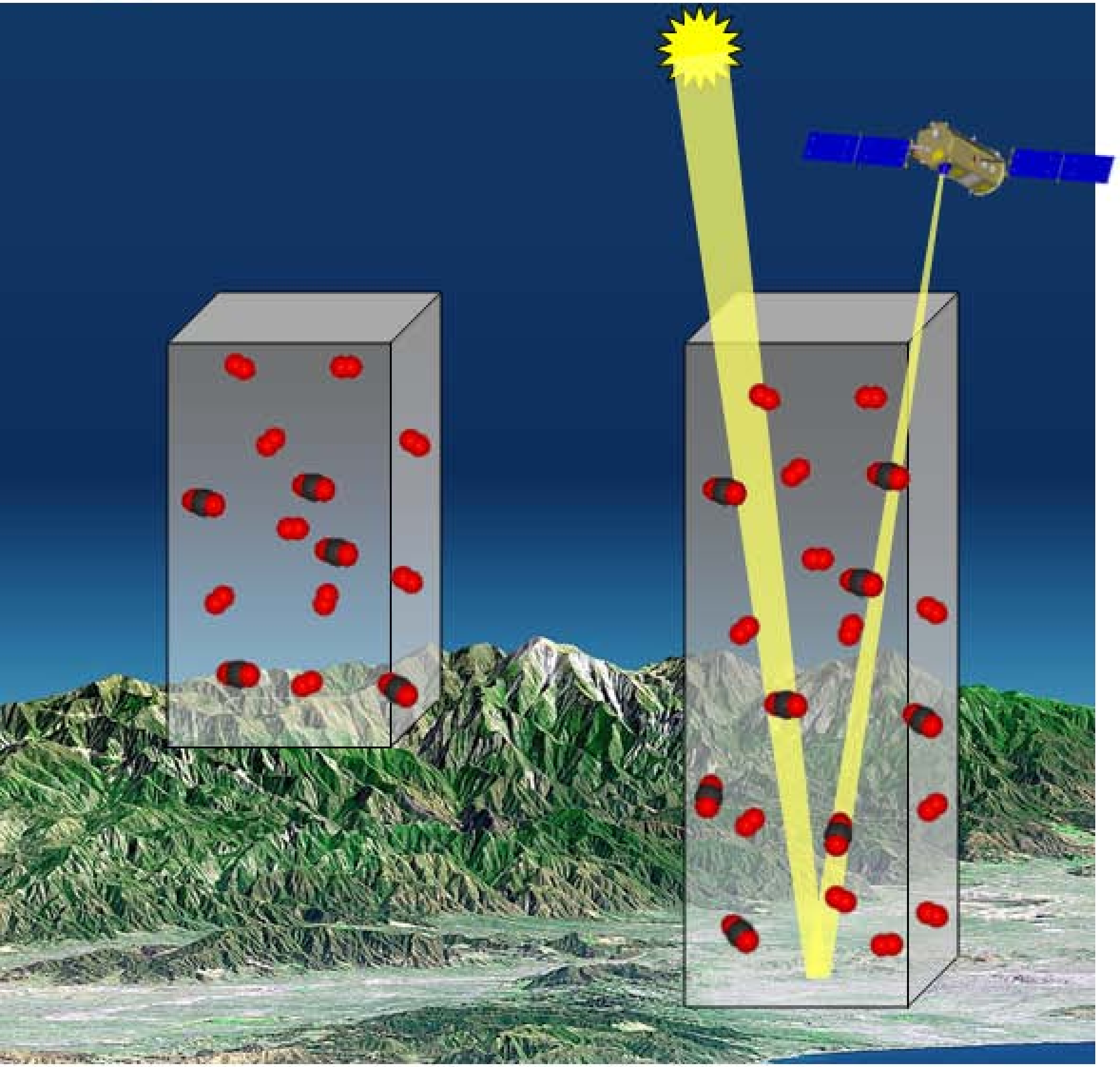
- The rich structure of CO2 calls for additional satellite observations
  - The Orbiting Carbon Observatory (OCO) to be launched 12/08

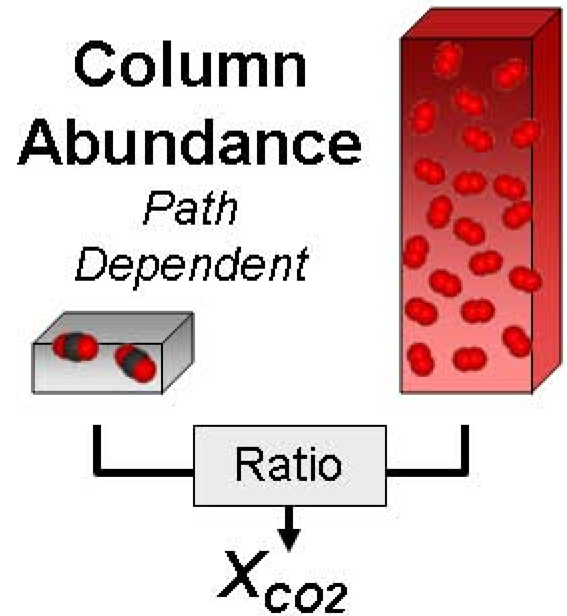
Un modèle sans observations n'est qu'un exercice mathématique gratuit.
Des observations sans modèle n'apportent que confusion.
Jacques-Louis Lions (CNES)

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


Watching the Earth breathe....
mapping CO2 from space.
JPL
NASA
OCO
Orbiting Carbon Observatory
will acquire spatially resolved measurements of the column averaged atmospheric CO2 dry air mole fraction, (XCO2)
Planned Launch
December 2008
10 to 20% of the OCO scenes will be sufficiently cloud free to yield
XCO2 accuracy = 0.3 to 0.5% (1 to 2 ppm

What Will OCO Measure?





X_{CO2} is the normalized CO_2 mixing ratio in a column of air.

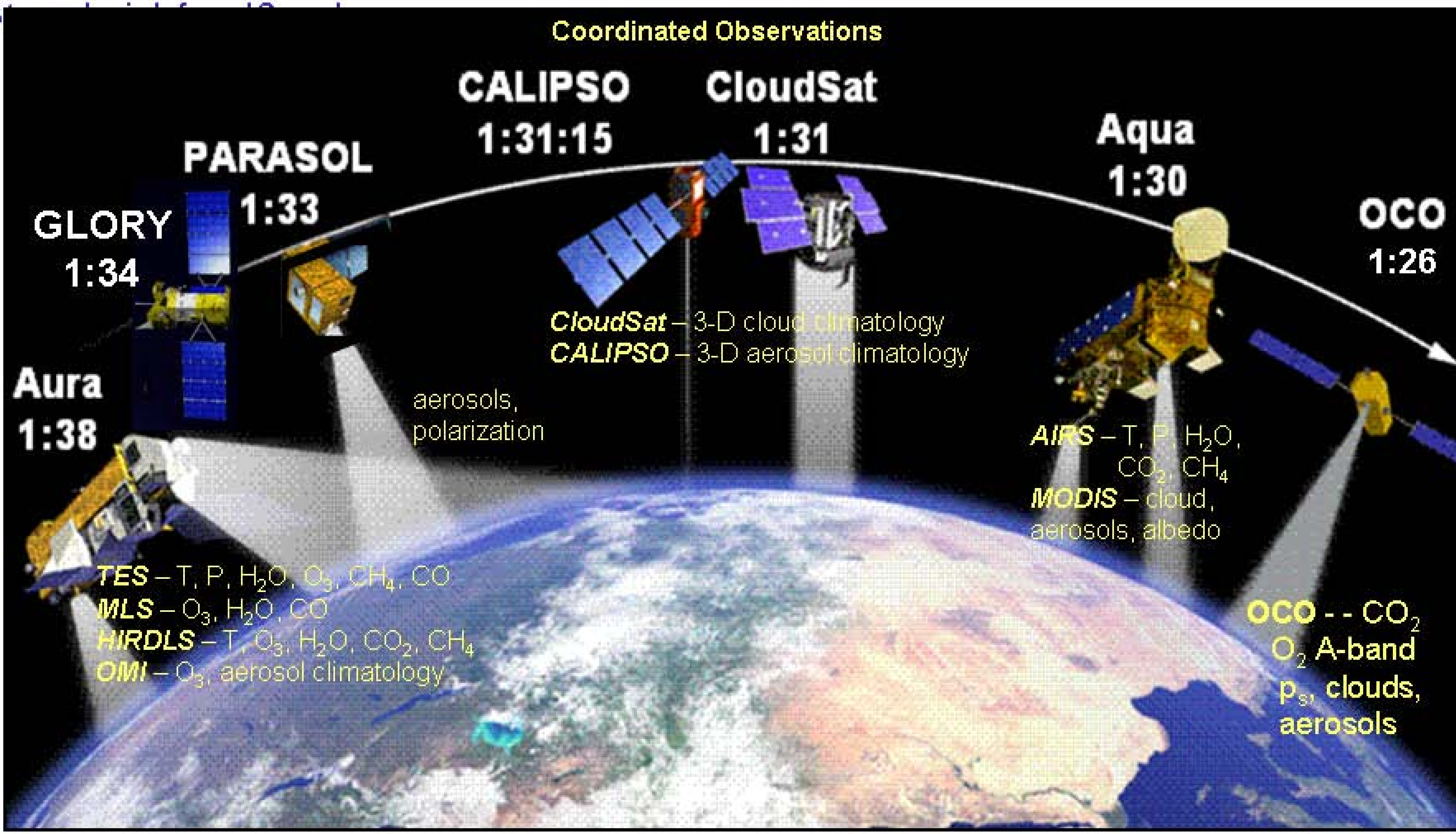
Focuses on CO2 concentration variability rather than topographic variability (number of molecules)

Accuracy: 1 ppm (0.3%)

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

OCO Will Fly in the A-Train December 2008



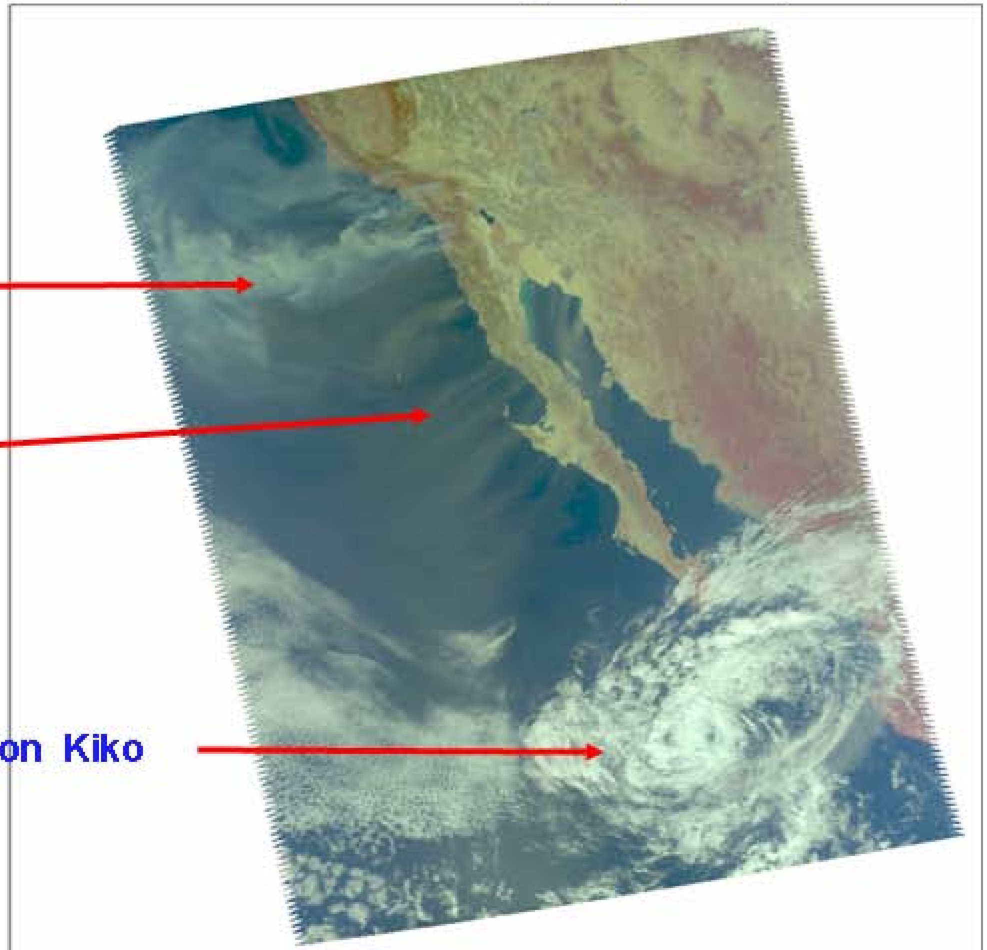
OCO Will fly on the A-Train, 4 minutes ahead of the AIRS on Aqua

Collaboration
AIRS and OCO

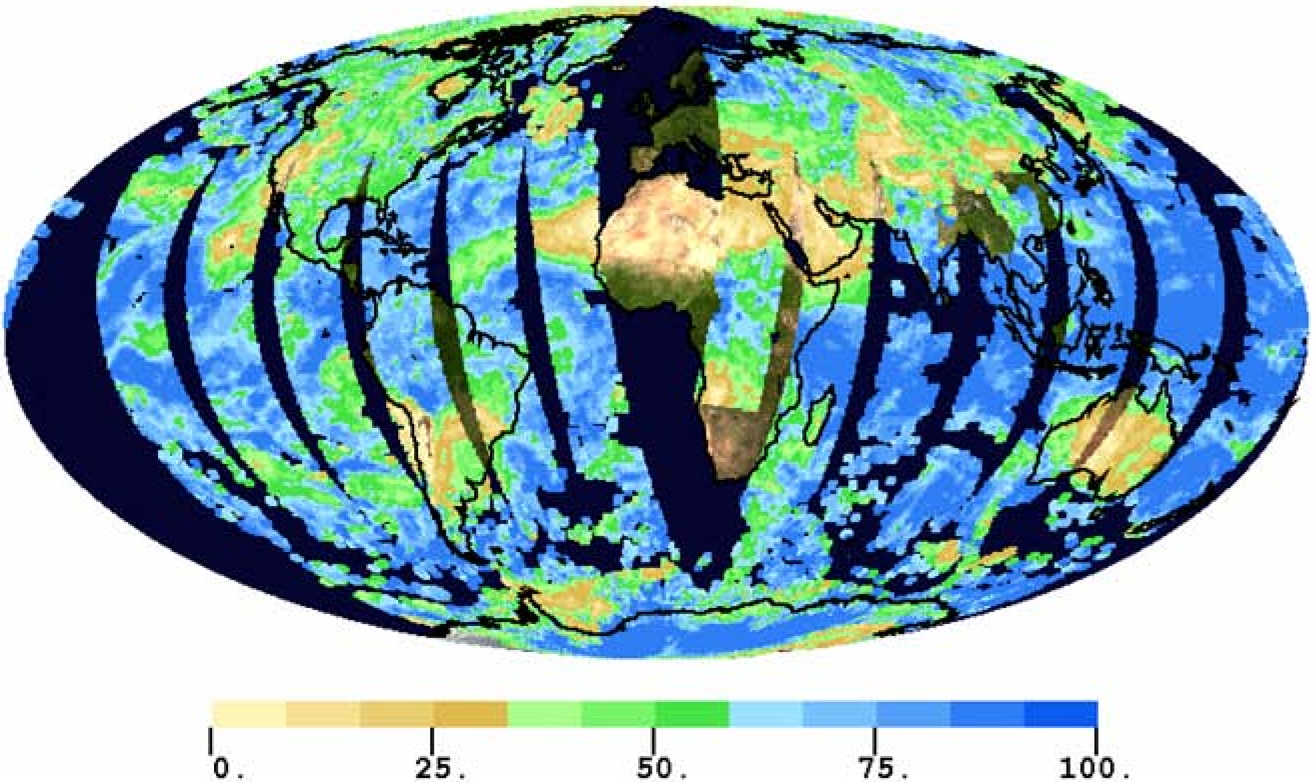
2009 -20xx

Visible AIRS image from AIRS shows the smoke from the raging fires streaming off the California coast into the eastern Pacific.

Oct. 23 at 20:53 UTC (1:53 p.m. PDT)



AIRS DAILY SURFACE RELATIVE HUMIDITY (%) 20070719



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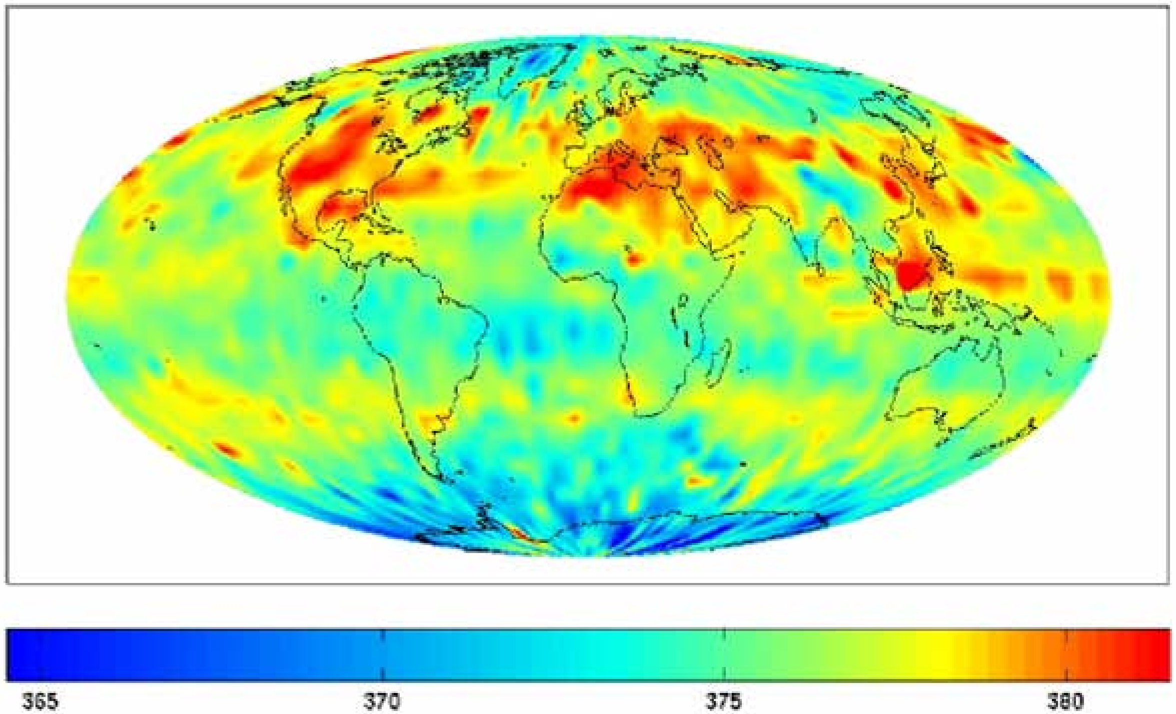
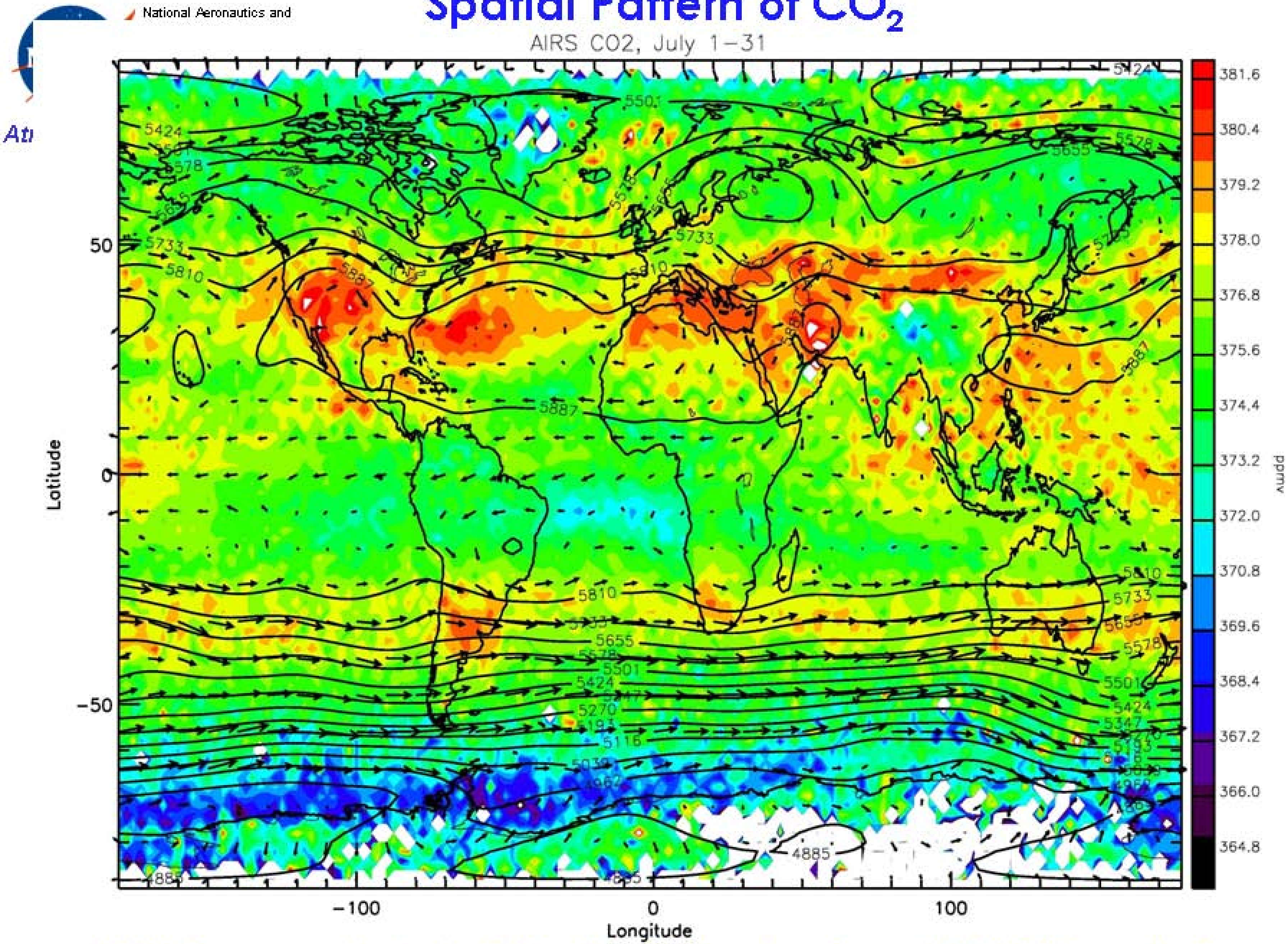
Atmospheric Infrared Sounder

AIRS 500 mb CO2. July 2003, V5 Day 3 x 5



Spatial Pattern of CO_2



500 hPa geopotential heights & wind vectors from NCEP2 Reanalysis