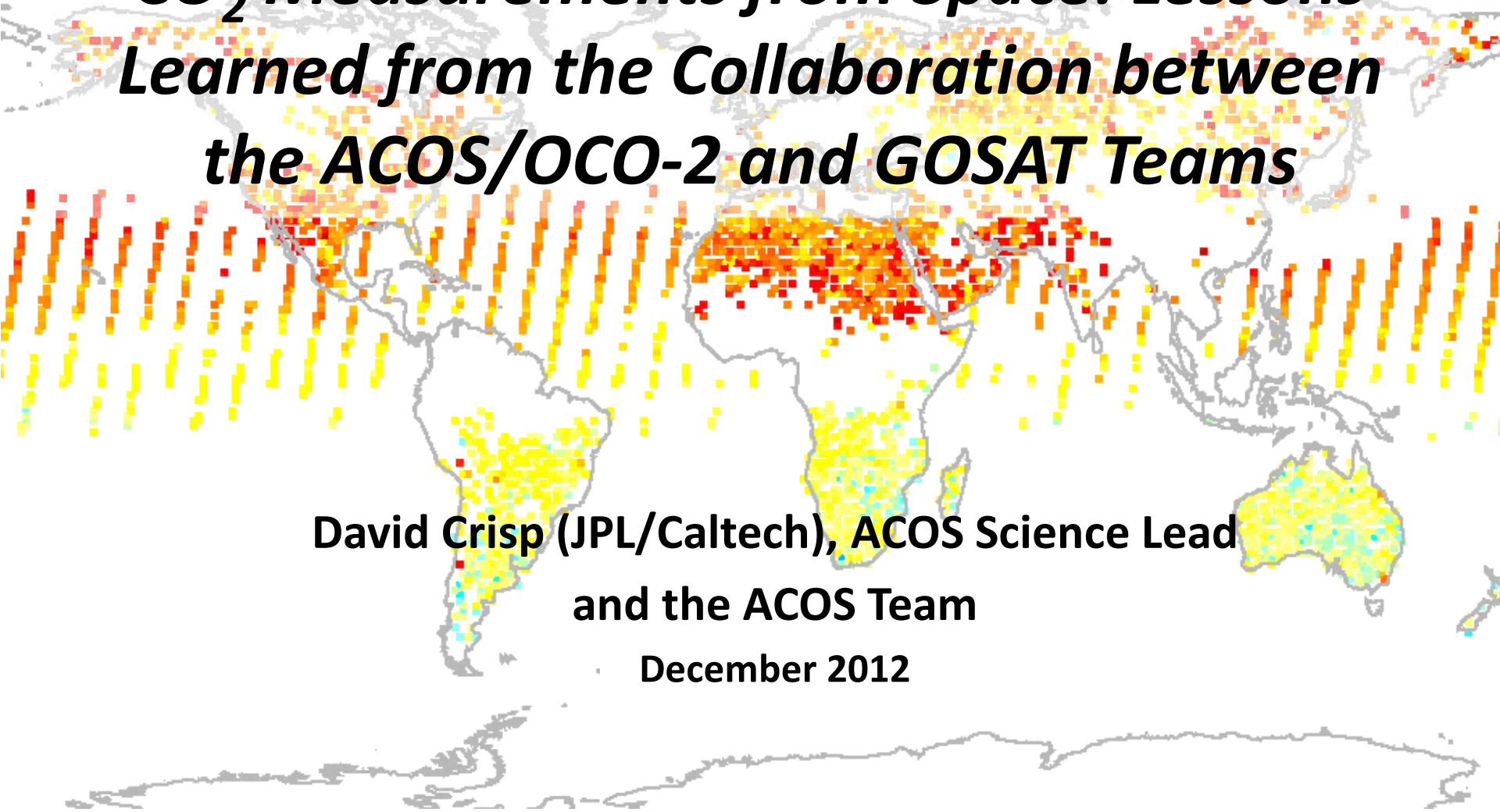
CO_2 Measurements from Space: Lessons Learned from the Collaboration between the ACOS/OCO-2 and GOSAT Teams



David Crisp (JPL/Caltech), ACOS Science Lead

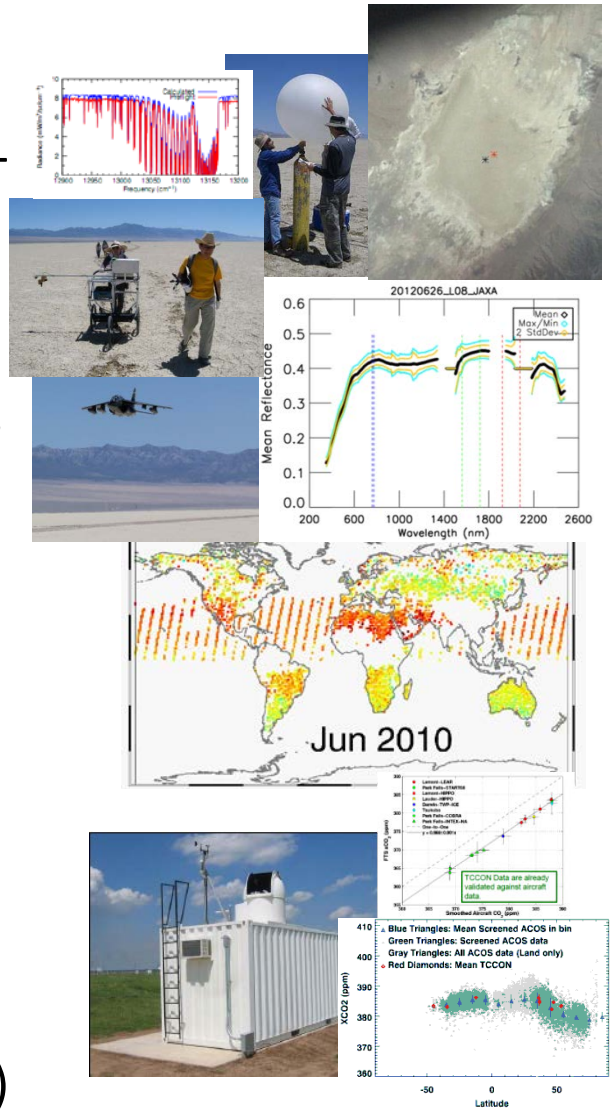
and the ACOS Team

December 2012

The ACOS/GOSAT Collaboration

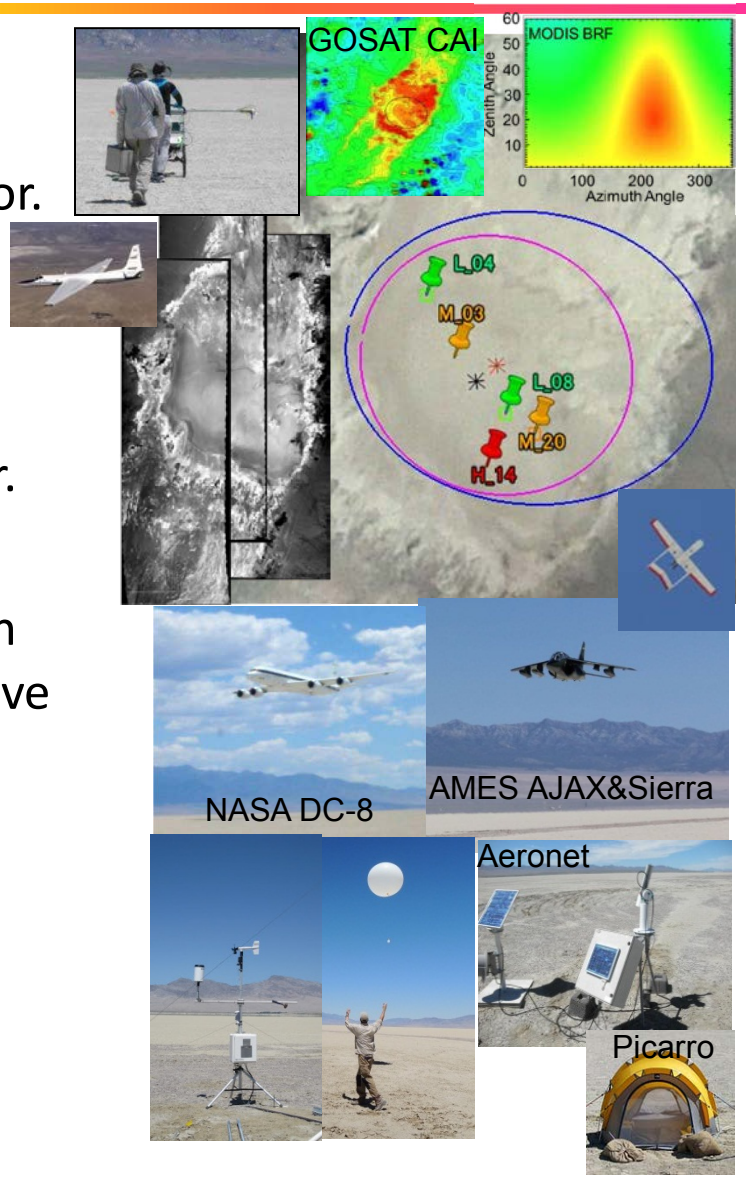
After the loss of OCO, NASA reformulated the OCO Team under the Atmospheric CO_2 Observations for Space (ACOS) task to continue the collaboration with the GOSAT Project Team at JAXA and NIES to:

- Conduct vicarious calibration campaigns in Railroad Valley, Nevada, U.S.A. and analyze results of those campaigns
- Retrieve X_{CO2} from GOSAT spectra
  - Model development, and testing
  - Data production and delivery
- Validate GOSAT retrievals through comparisons of
  - GOSAT retrievals with TCCON measurements
  - 0ther validation standards (surface pressure, aircraft and ground-based CO_2 measurements)

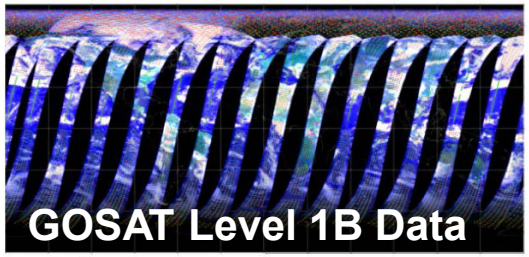


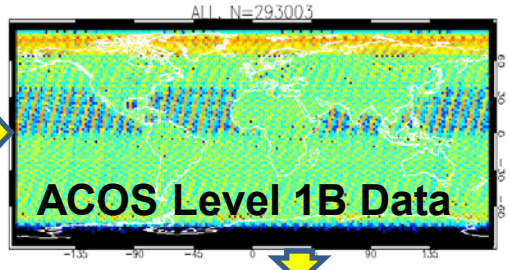
Characterizing Railroad Valley (RRV)

- Spatial variations in surface reflectance were characterized by ground-based measurements collected at several sights across the valley floor.
- Aircraft (ER-2 AVIRIS and MASTER) and spacecraft (ASTER, MODIS, CAI) were used to extrapolate these results to the full valley floor.
- Because GOSAT TANSO-FTS collects data within atmospheric absorption bands, a comprehensive description of the atmosphere is needed to interpret RRV observations.
  - Surface/Balloon Met observations (p,T,q,v)
  - Aerosol: RRV Aeronet station (U. Arizona)
  - Surface CO2 (NASA Ames / Picarro)

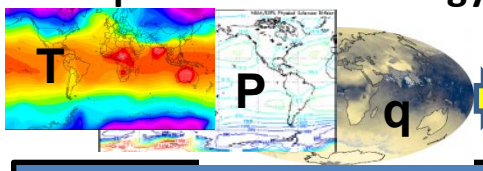


Retrieving X_{CO2} from GOSAT Spectra



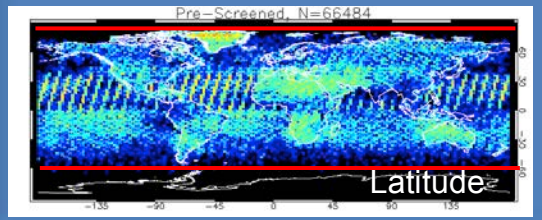


Interpolated Meteorology



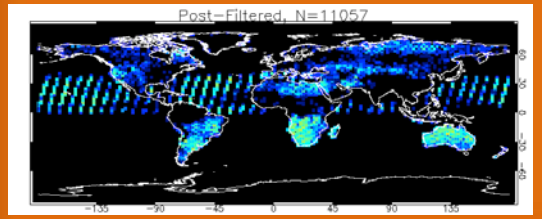
State Vector
CO_2 profile (full)
H_2O profile (scale factor)
Temperature profile (offset)
AOD, Height (4 types)
Surface Pressure
Albedo (Mean, Slope)
Wavelength Shift
Band 1 Zero-Level Offset (GOSAT only)

Pre-Processing



X_{CO2} Retrieval Algorithm

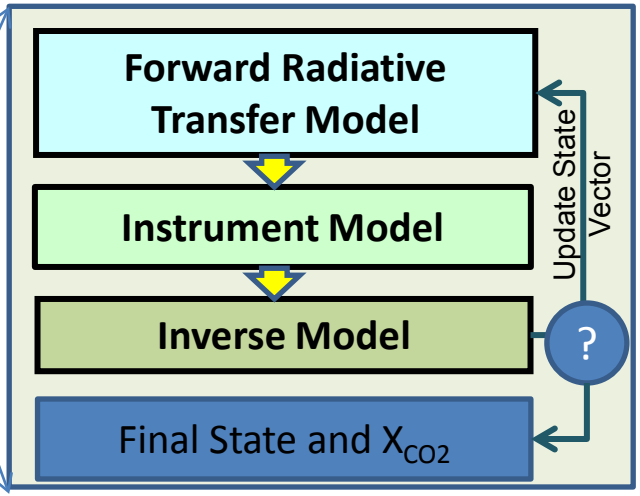
Post-Processing



χ^2
Δp
τ_{aer}
σ_{XCO2}

The ACOS X_{CO2} retrieval algorithm evolved from the OCO retrieval algorithm

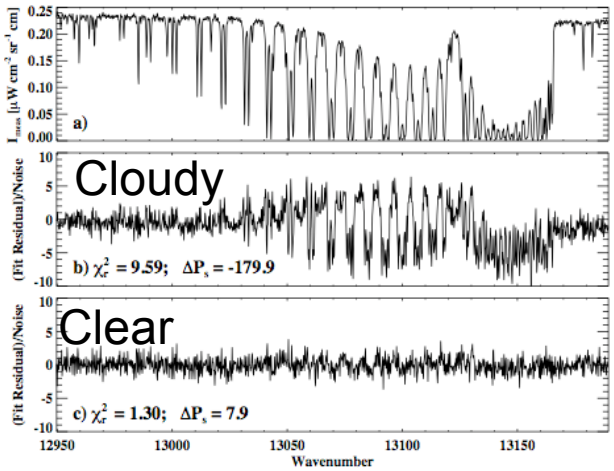
- "Full Physics"
- Optimal Estimation
- Simultaneous 3-band (ABO2, WCO2, SCO2)

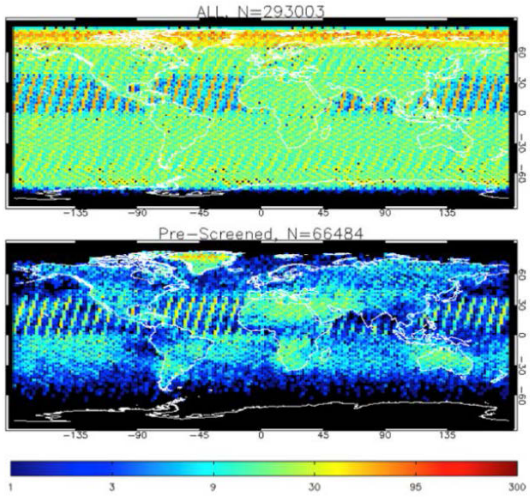


Pre-Processing Filters

- The ACOS GOSAT Pre-Processing Filters screen out :
  - Soundings acquired at solar zenith angles > 85°
  - Soundings contaminated by optically-thick clouds

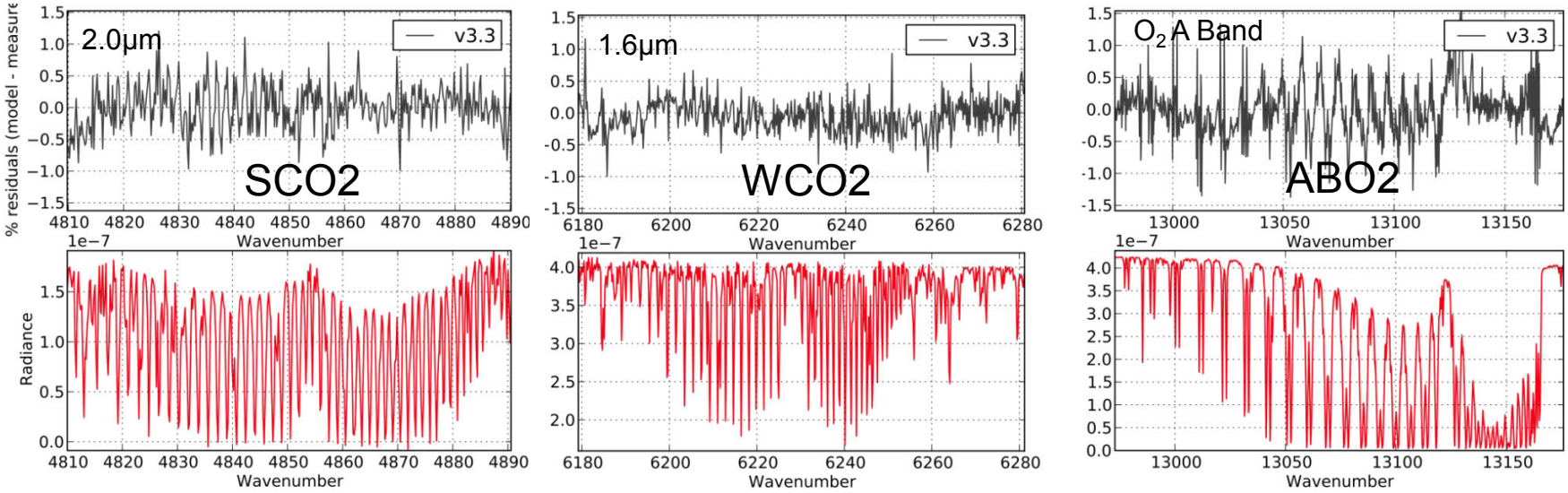
- A Spectroscopic cloud screening algorithm based on the O_2 A-band is being used for GOSAT retrievals (Taylor et al. 2012)
  - Fits a clear sky atmosphere to every sounding in the O_2 A band
  - High values of χ^2 and large differences between the retrieved surface pressure and the ECMWF prior indicate clouds





Shortcomings in Gas Absorption Cross Sections

- Persistent spectrally-dependent residuals in ensembles of GOSAT and TCCON retrievals provide additional evidence of shortcomings gas absorption cross sections
  - Residuals correlated with spectral features limit the retrieval algorithm's ability to exploit the full information content of the spectra, and converge to a unique, best estimate of X_{CO2}



Persistent spectral residuals are seen in all 3 bands used to retrieve X_{CO2} from GOSAT spectra. Those in the SCO2 and ABO2 are most strongly correlated with the band structure. These issues do not impair TCCON X_{CO2} retrievals, because TCCON uses the WCO2 and O2 $^1\Delta_g$ band instead of the A-band in these retrievals.

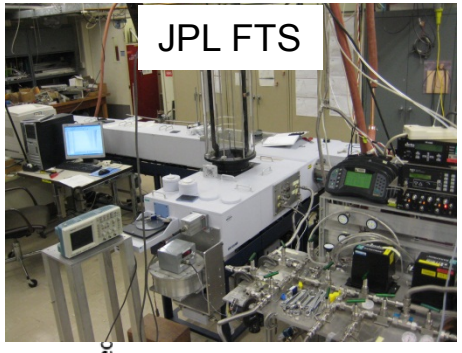
Improving the Gas Absorption Cross Sections

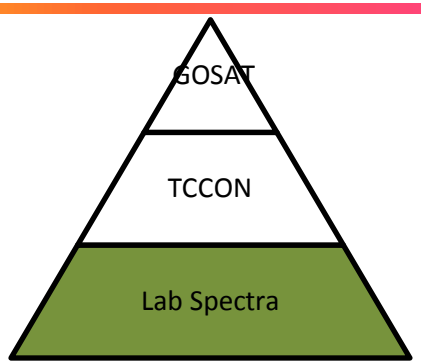
The ACOS ABSCO team embarked on a three-element approach to improve our understanding the CO_2 and O_2 absorption bands needed to retrieve X_{CO2}, including:

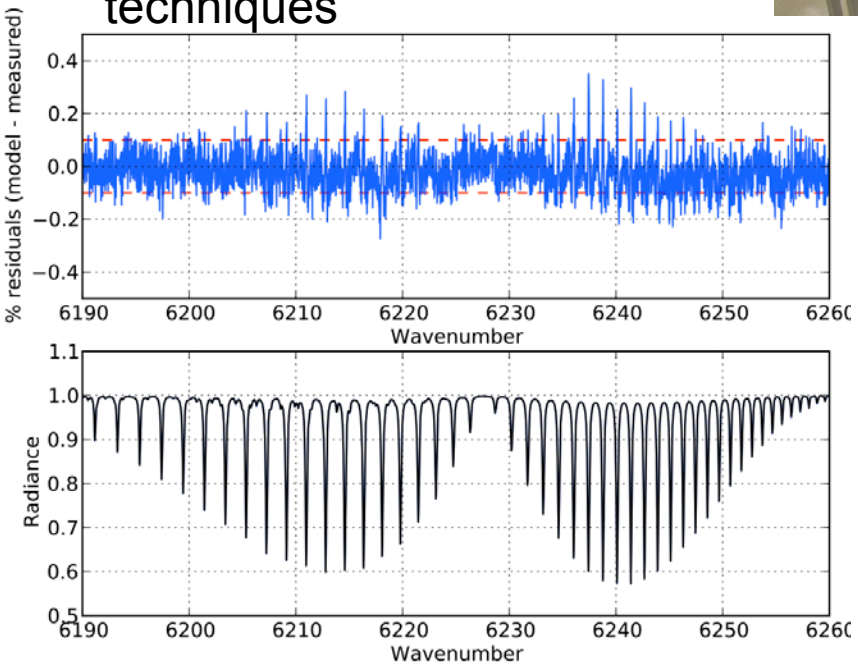
- New laboratory measurements (Long path FTS, Cavity Ring-down, Photoacoustic)
- Ground-based direct solar observations from TCCON
- GOSAT measurements

Line Parameters from Lab Spectra

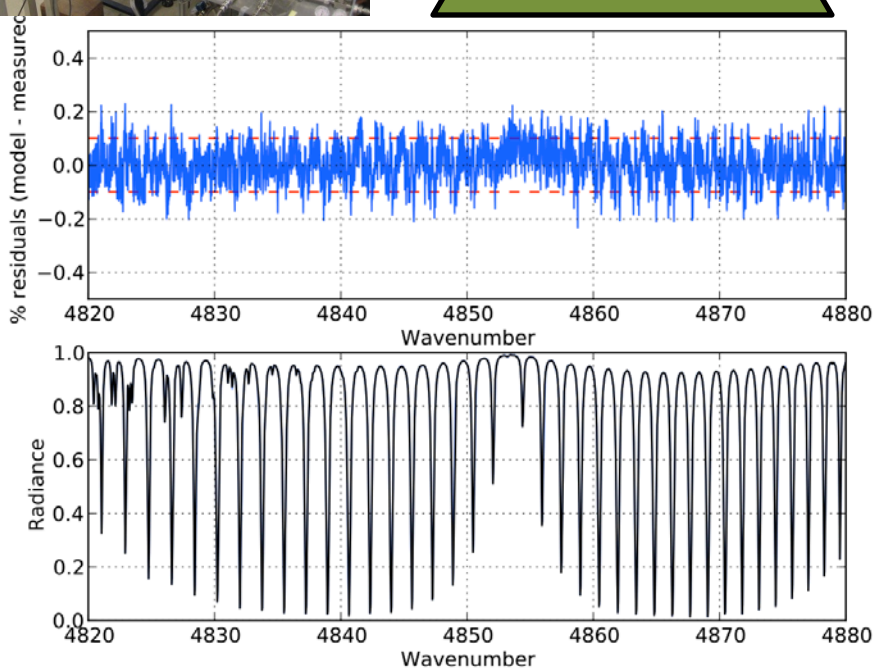
- Improved characterization of laboratory cell conditions
- New methods (FS-CRDS, photoacoustic)
- Advanced, multi-spectral fitting techniques







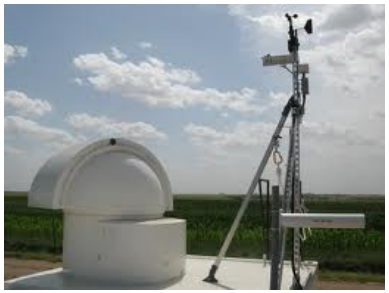
1.6 μm band, path length 32.54m
optical path difference 75cm
Total cell pressure is 742 Torr
Sample is 9.03% air-broadened $^{16}O^{12}C^{16}O$

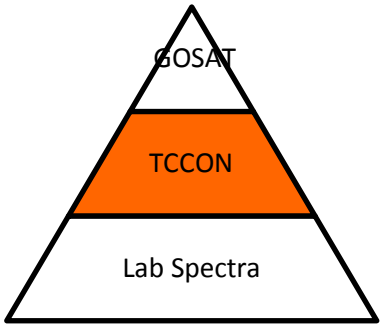


2 μm band, path length 29.3m
Optical path difference 112.5 cm
Total pressure 599.8 Torr
Sample: 4.95% air-broadened $^{16}O^{12}C^{16}O$

Evaluation with TCCON data

TCCON retrieval for Park Falls 22 Dec. 2004
~12 air masses

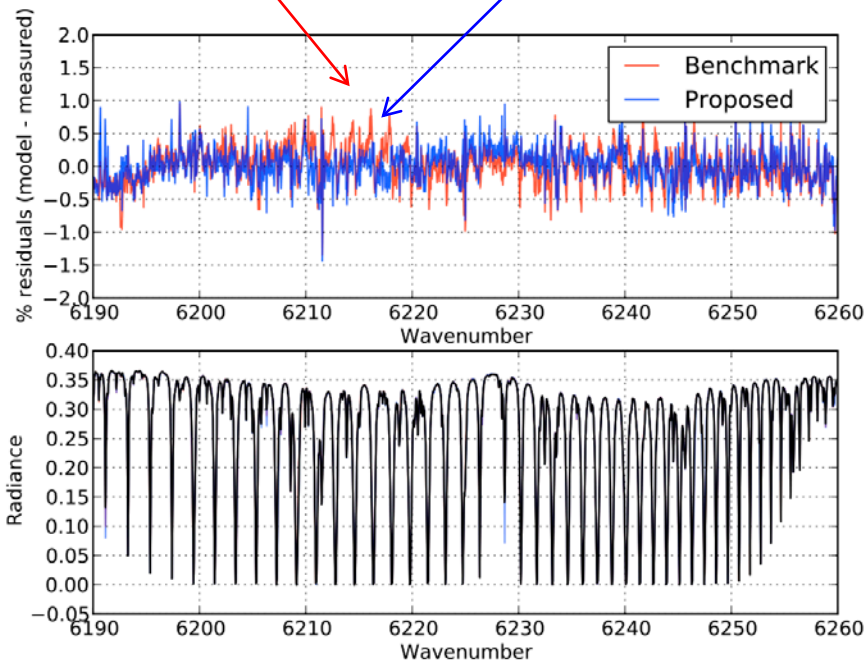


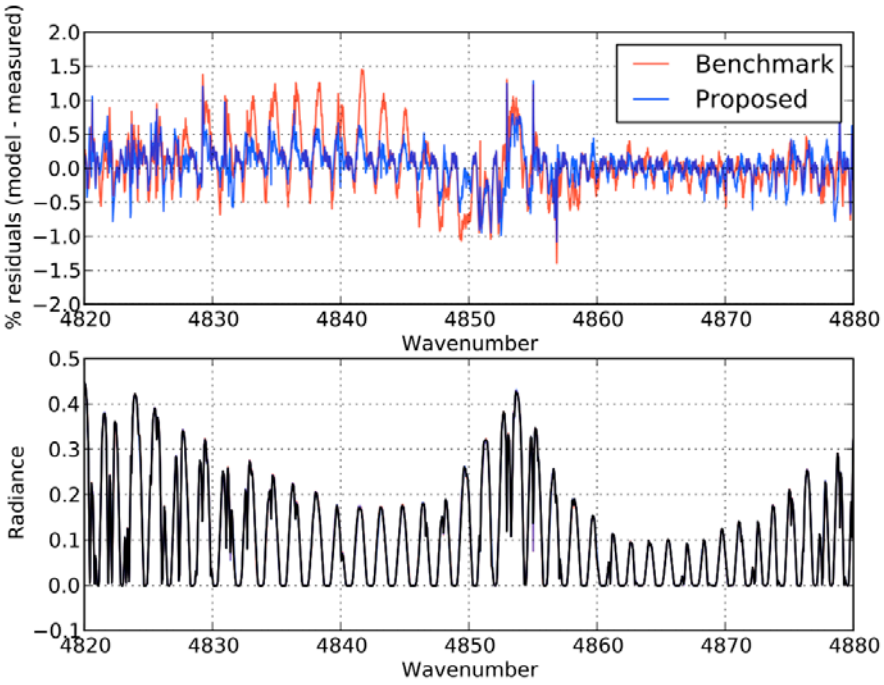


State of the art
First-order line mixing, Voigt shapes

"Ongoing" model
Nearest-neighbor line mixing
Speed dependent profile

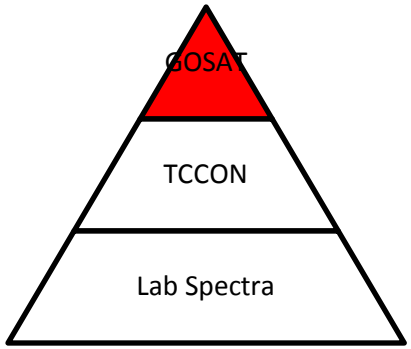
Thompson et al., *JQRST* [2012]
Results shown here do not include H_2O broadening of CO_2.

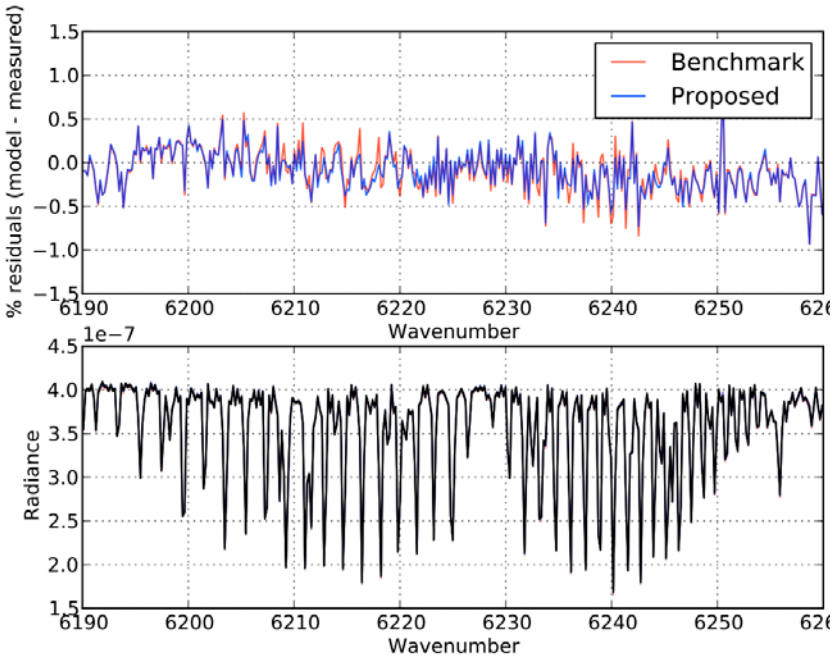


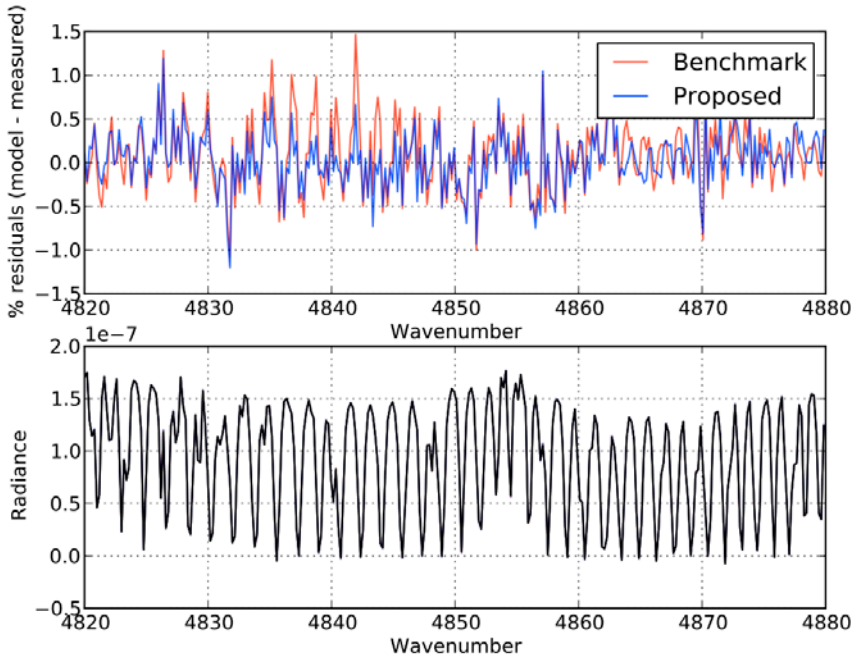


Evaluation with GOSAT data

- Mean of soundings over TCCON stations
- Three-band retrieval using surface pressure to estimate Column-averaged dry mole fraction $\mathbf{X_{co2}}$

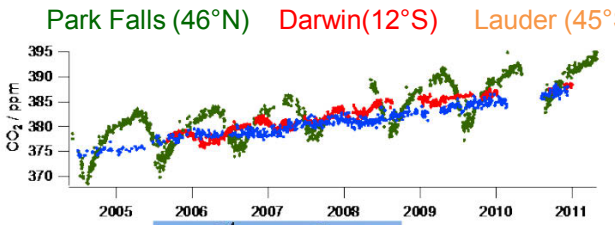






Identifying and Correcting Regional Scale Biases in ACOS/GOSAT X_{CO2}

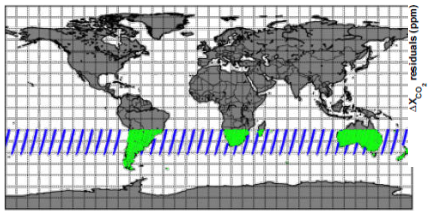
- The ACOS task developed three approaches for identifying and correcting regional scale biases

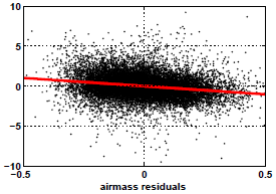


1. **TCCON Validation**: Uses direct comparisons between nearly coincident ACOS GOSAT and TCCON X_{CO2} retrievals

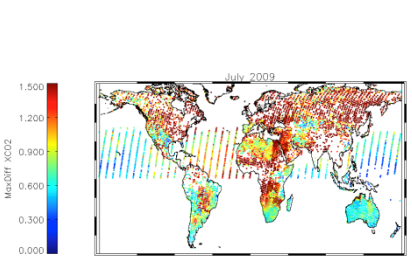
TCCON
total carbon column observing network

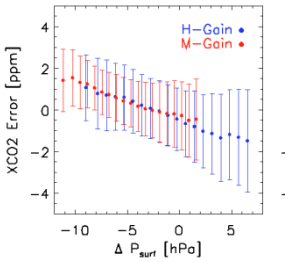
2. **Southern Hemisphere Approximation:** Identifies spurious correlations between X_{CO2} retrievals and other environment parameters at mid latitudes in the southern hemisphere, where X_{CO2} variations are known to be small.





3. **Multi-Model Means**: Compare ACOS GOSAT XCO2 retrievals to the average XCO2 fields generated by flux inversion models



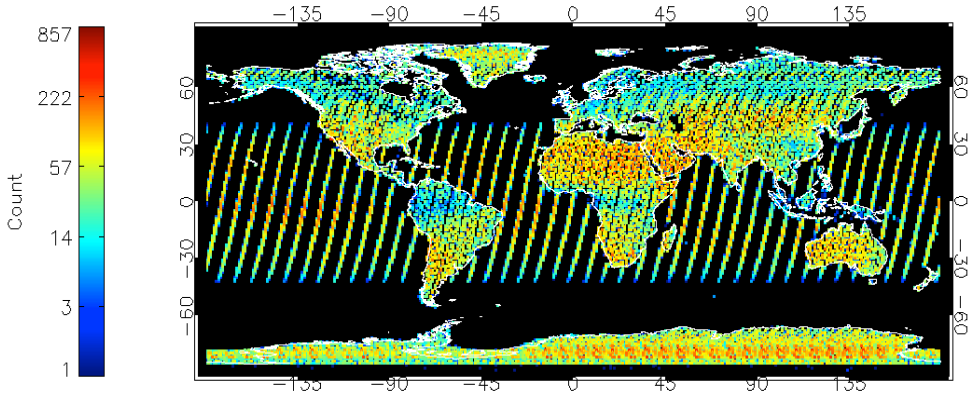


Post-Processing Filters

Post Processing filters use diagnostic information from the retrievals to identify unreliable soundings, so that they can be screened from further use.

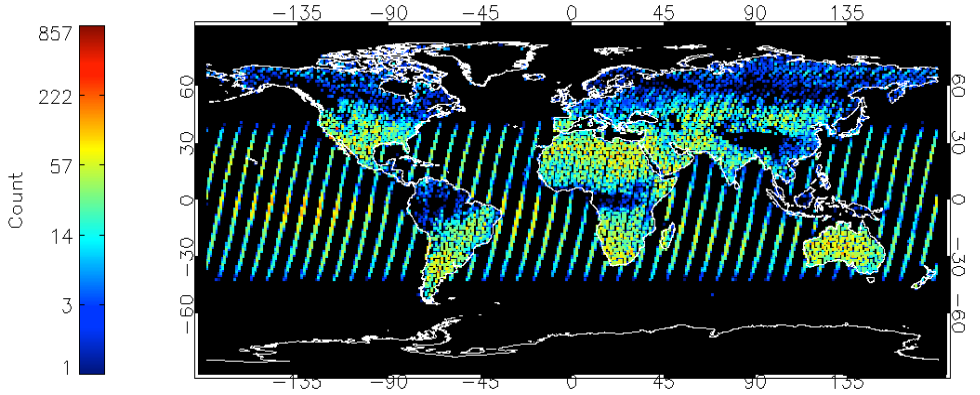
	Converged XCO_2 Retrievals	Passed Filters	Percent Passed
Glint	185k	79k	43%
Land H	447k	91k	20% (35%*)
Land M	98k	50k	66%

** Over non ice-covered surfaces*

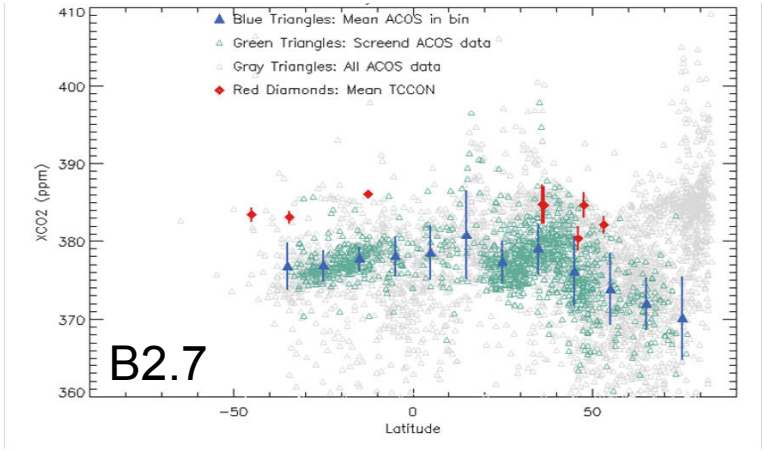


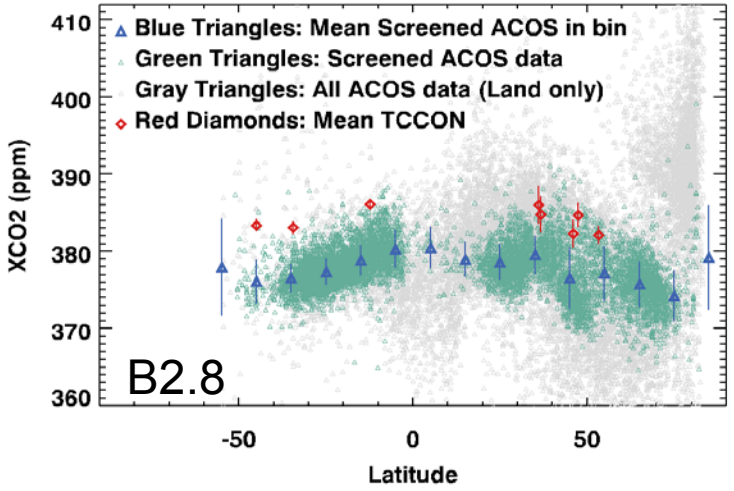
Above: All cloud-free soundings processed by the L2 algorithm.

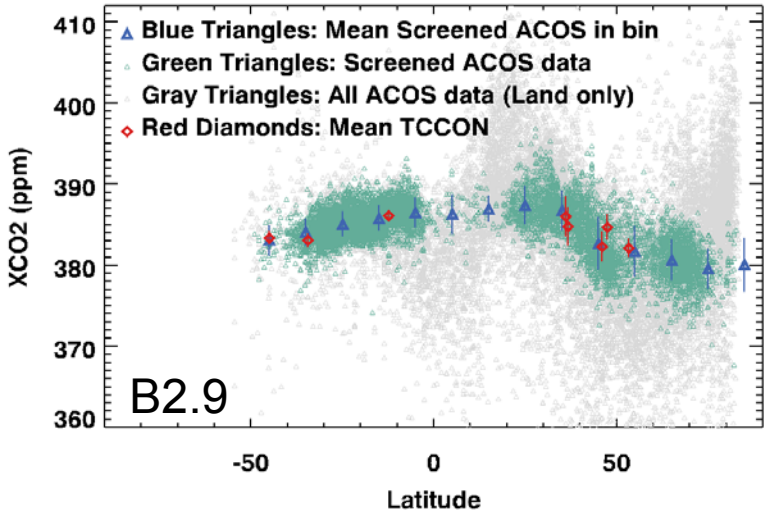
Below: Soundings that passed all Post-Processing filters

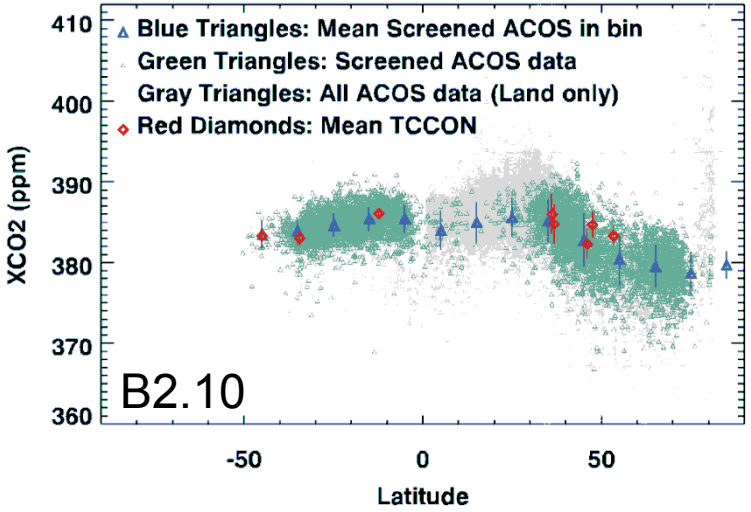


TCCON Comparisons Show Improvements in ACOS GOSAT X_{CO2} Bias and Random Error



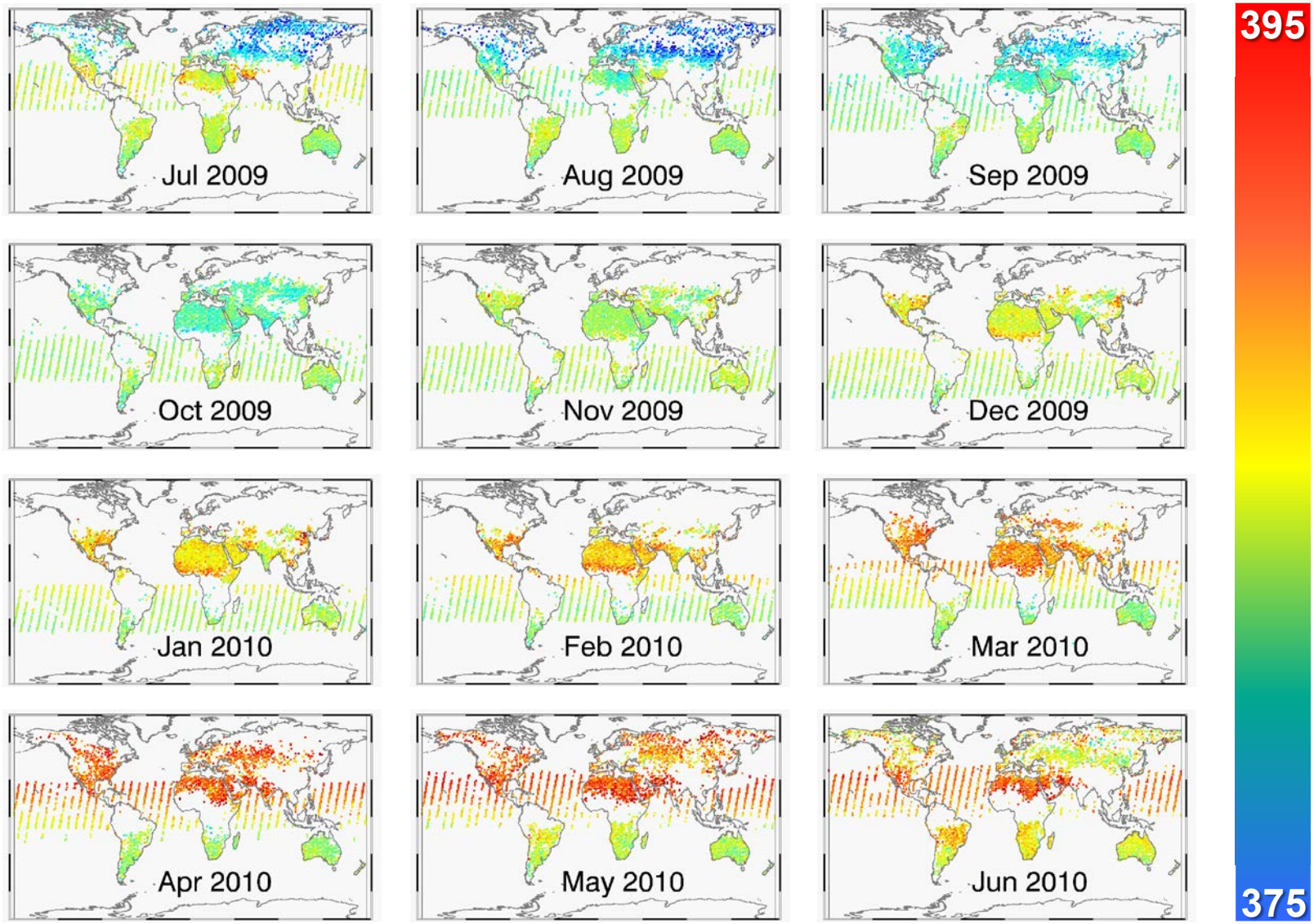






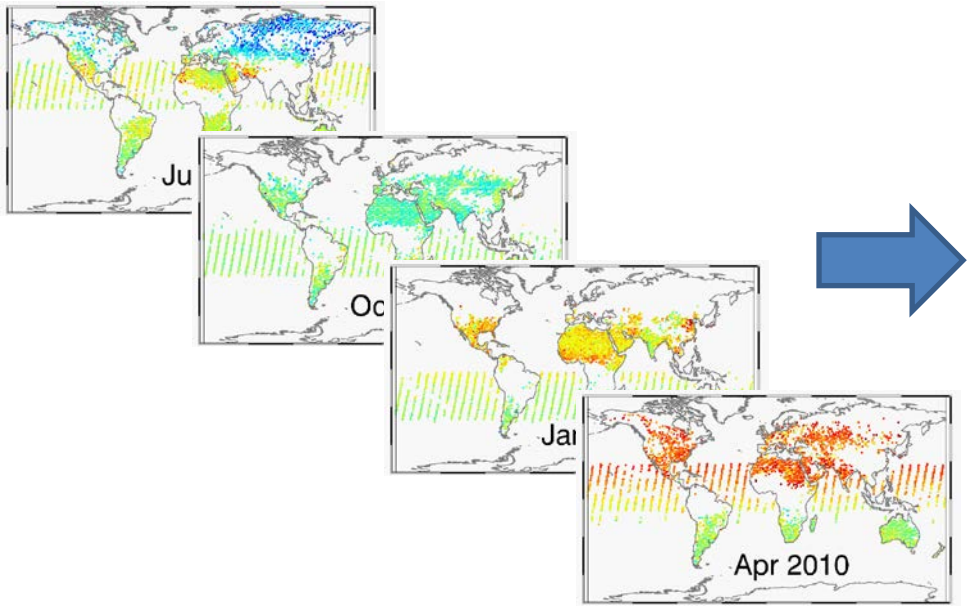
Zonal profiles of ACOS/GOSAT XCO2 estimates (green and grey triangles) are compared to the monthly mean XCO2 estimates from TCCON stations (red diamonds) for July 2009. The precision (scatter), bias, and yield of the ACOS/GOSAT products have improved over time (Crisp et al. 2011).

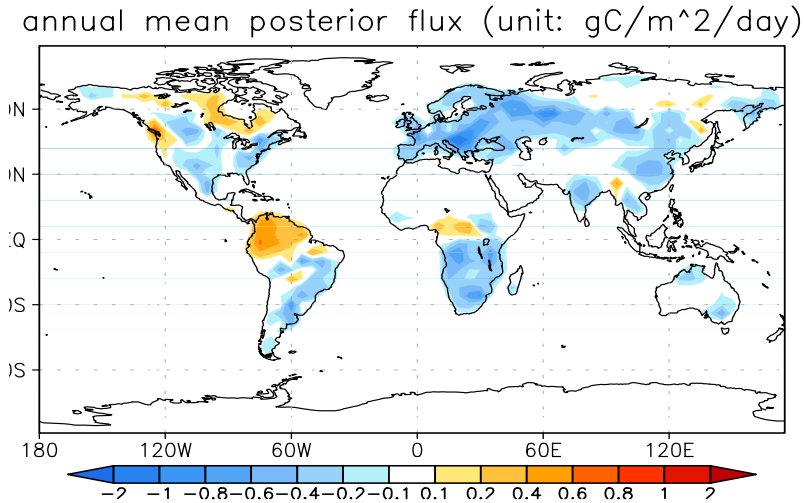
ACOS GOSAT B2.10 X_{CO2} Retrievals



Preliminary Flux Inversion Studies Using ACOS GOSAT X_{CO2} Data

- The availability of ACOS GOSAT B2.9 products has motivated a new set of flux inversion studies from several groups, including:
  - David Baker, Colorado State University/CIRA, USA
  - Frederic Chevallier, LSCE/CEA, France
  - Dylan Jones and Feng Deng, University of Toronto, Canada
  - Junjie Liu, et al., JPL, U. Md., U.C. Berkeley, USA
  - Paul Palmer and Liang Feng, University of Edinburgh, U.





Posterior biosphere flux: -5.4 GtC/year (sink)
[J. Liu, K. Bowman, and the NASA Carbon Monitoring System Flux Pilot Project Team]

Conclusions (to date)

- The ACOS/OCO-2 "Full Physics" retrieval algorithm is:
  - currently in place and is generating an exploratory GOSAT X_{CO2} product
  - still evolving to address known errors and biases
- Validation of GOSAT X_{CO2} retrievals against multiple standards
  - indicate errors < 2 ppm (0.5%) on regional scales over much of the globe
  - are providing valuable insights into the causes of regional-scale bias
- Preliminary flux inversion results clearly demonstrate the utility of total column CO_2 measurements, but
  - persistent data gaps preclude accurate flux inversions over many regions
  - results still dominated by X_{CO2} variations with amplitudes comparable to the bias corrections and known transport model errors
- Lessons learned from this experience are expected to substantially accelerate the delivery of high quality products from the OCO-2