The Orbiting Carbon Observatory-2 (OCO-2) Mission

Watching The Earth Breathe…Mapping CO_2 From Space

Progress in Remote Sensing of Carbon Dioxide from Space
The ACOS Project

M. R. Gunson, A. Eldering, D. Crisp, C.E. Miller, and the OCO-2/ACOS Team
Jet Propulsion Laboratory, California Institute of Technology

Global Monitoring Annual Conference, 18 May 2011
NOAA ESRL

The Orbiting Carbon Observatory - 2 (OCO-2)

Watching The Earth Breathe…Mapping CO2 From Space

Salient Features:
Category 2 mission per NPR 7120.5D
Risk class C per NPR 8705.4
High-resolution, three-channel grating spectrometer (JPL)
Partnership with OSC (Spacecraft)
High heritage spacecraft, flies in formation with the A-Train
Launch: February 2013
Operational life: 2 years
Science Team Leader: Dr. David Crisp
Project Scientist: Dr. Michael Gunson, Deputy: Dr. Annmarie Eldering
Project Manager: Dr. Ralph Basilio, Deputy: Said Kaki
Earth Science Flight Projects Office Manager: Dr. Steven Bard
ESSP Acting Program Manager: Greg Stover, LaRC, Mission Manager: James Wells, LaRC
Program Scientist: Dr. Kenneth Jucks, NASA HQ
Program Executive: Eric Ianson, NASA HQ

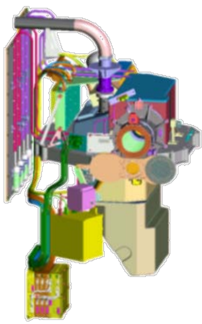
Mission Science Objective: Collect the first space-based global measurements of atmospheric CO_2 with the precision, resolution, and coverage needed to characterize its sources and sinks on regional scales and quantify their variability over the seasonal cycle .

Key Science Products: Retrieve estimates of the column-averaged CO_2 dry air mole fraction (X_{CO2}) on regional scales (≥ 1000 km) from space-based measurements of the absorption of reflected sunlight by atmospheric CO_2 and O_2, collected in cloud-free scenes over ≥80% of range of latitudes on the sunlit hemisphere at monthly intervals for 2 years.

The OCO-2 Mission System is Based on OCO

Jet Propulsion Laboratory
California Institute of Technology

3-Channel Spectrometer (JPL)

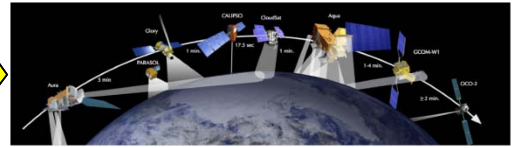


Dedicated Spacecraft Bus (OSC)

Taurus XL Vehicle (OSC)

Mission Operations (OSC)

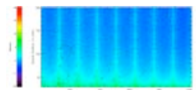
Formation Flying as Part of the A-Train Constellation

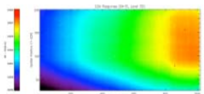


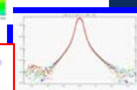
NASA NEN (GSFC) and SN (TDRSS)

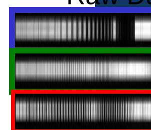
Science Data Operations Center (JPL)

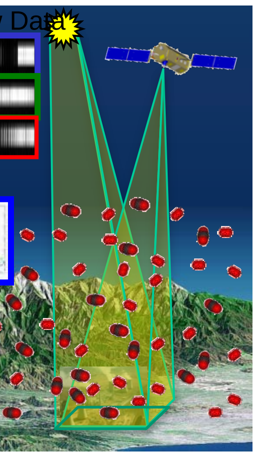
Calibrate Data





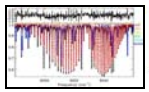




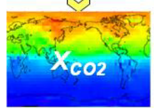


L2 X_{CO2} Retrieval

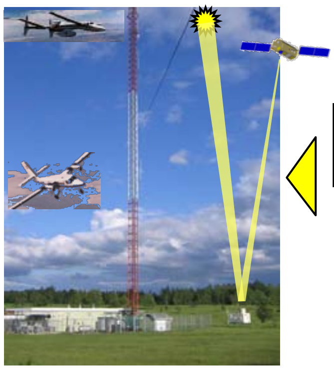
Initial Surf/Atm State → Generate Synthetic Spectrum → Instrument Model → Inverse Model → New State (inc. X_{CO2})



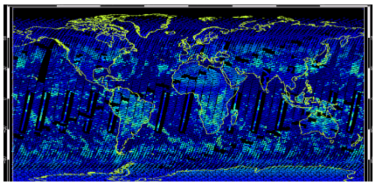
Compare to Observations

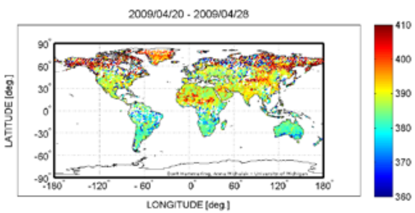


Validation Program



Products Delivered to the GSFC DAAC



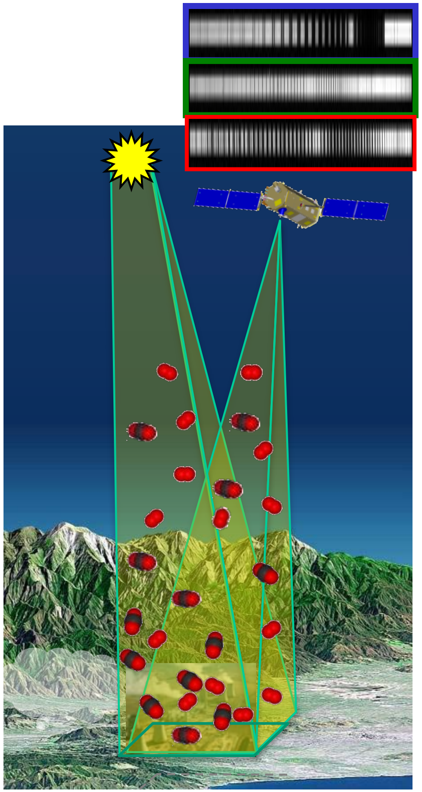


Please visit http://oco.jpl.nasa.gov for more information

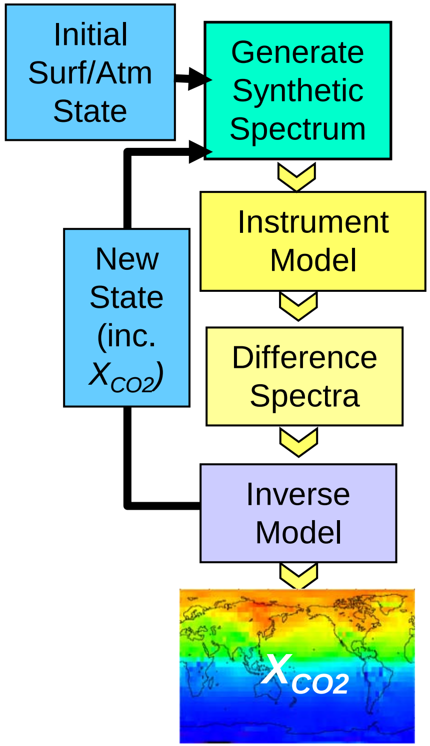
Orbiting Carbon Observatory

Measurement Approach

Collect spectra of CO_2 & O_2 absorption in reflected sunlight over the globe



Retrieve variations in the *column averaged CO_2 dry air mole fraction, X_{CO2}* over sunlit hemisphere

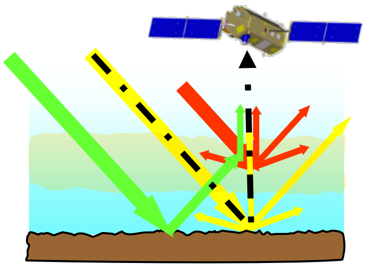


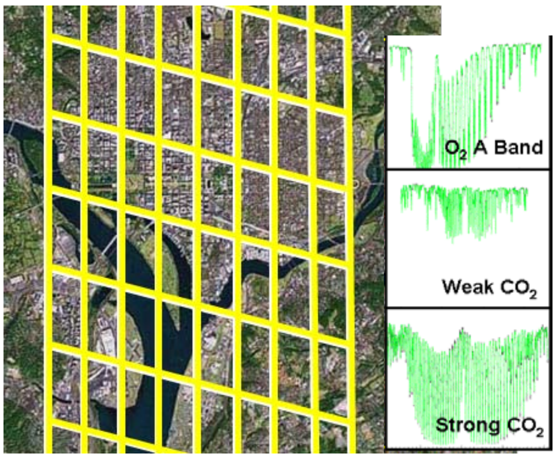
Validate measurements to ensure X_{CO2} precision of 1 - 2 ppm (0.3 - 0.5%)

OCO-2 has Three Observation Modes

Nadir Observations:

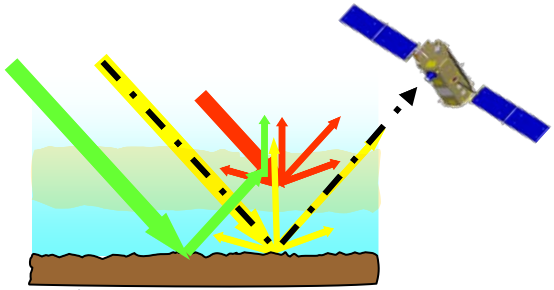
+ Small footprint (< 3 km^2)
– Low Signal/Noise over dark surfaces (ocean, ice)

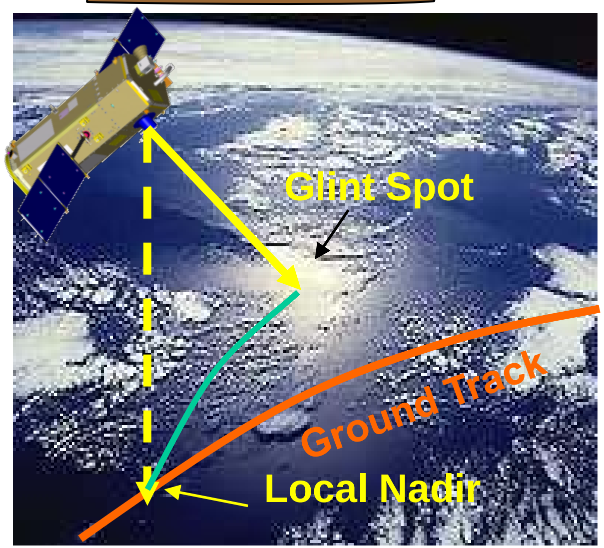




Glint Observations:

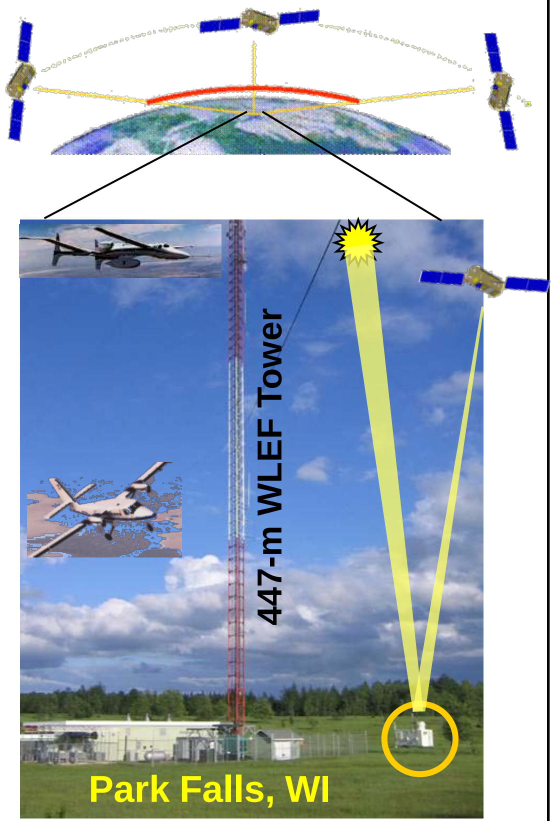
+ Improves Signal/Noise over oceans
– More cloud interference





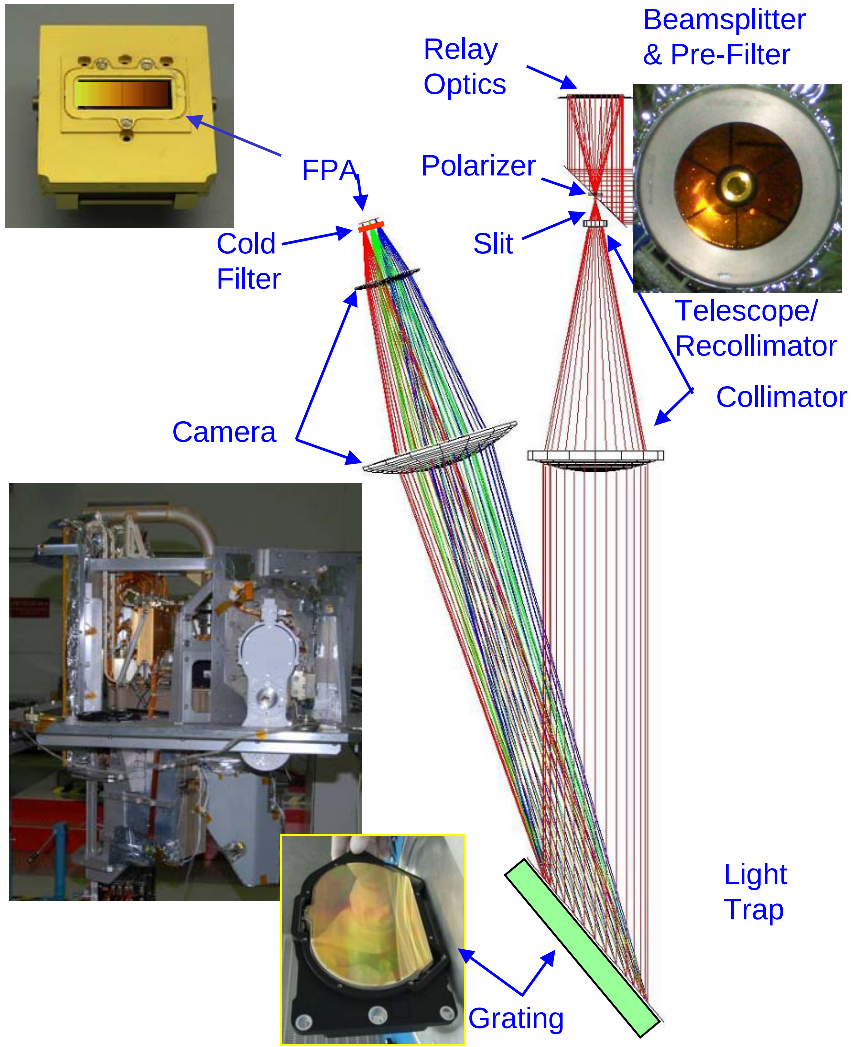
Target Observations:

- Validation over ground based FTS sites, field campaigns, other targets

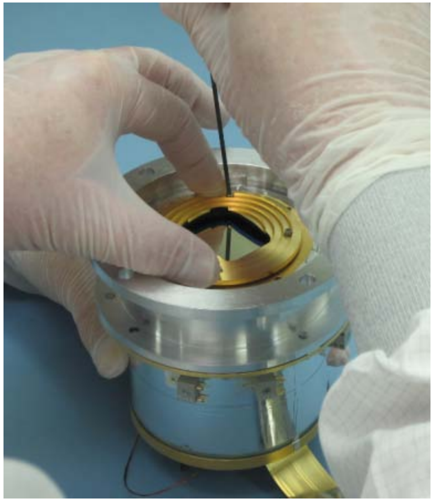


Same Instrument as OCO

- 3 co-bore-sighted, high resolution, imaging grating spectrometers
  - O_2 0.765 μm A-band
  - CO_2 1.61 μm band
  - CO_2 2.06 μm band
- Resolving Power > 20,000
- Optically fast: f/1.8 (high SNR)
- Swath: < 0.8° (10.6 km at nadir)
- 8 Footprints: 1.29 x 2.25 km @ nadir
- Mass: 140 kg
- Power: ~105 W
- **Changes from OCO**
  - New cryocooler selected to replace obsolete OCO system

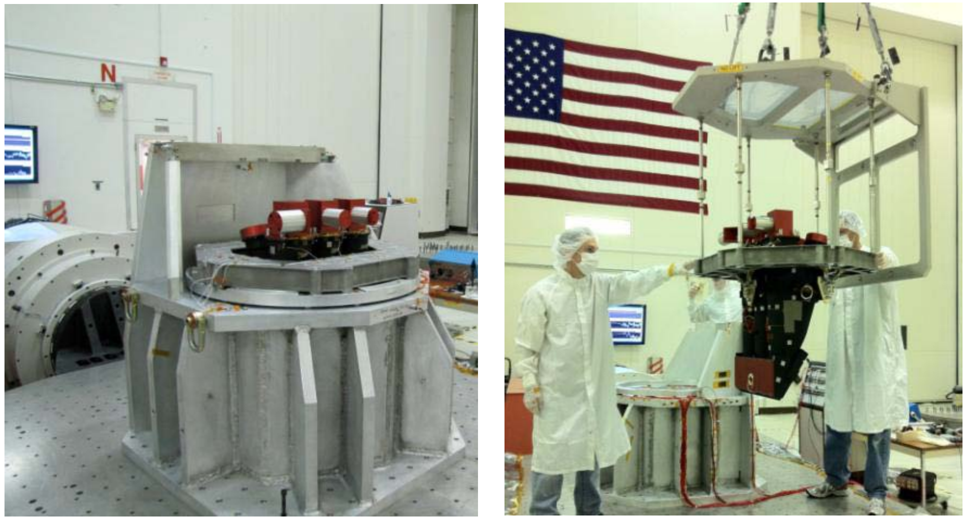


Instrument on Track for Delivery by March 2012

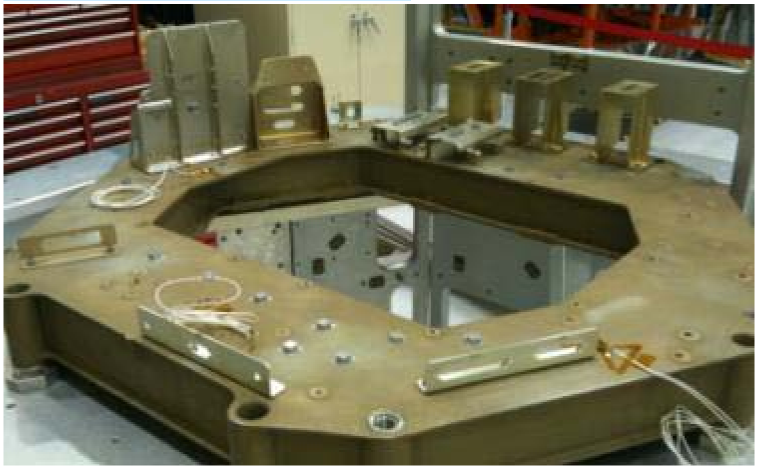


Cryogenic subsystem detector and filter integration completed

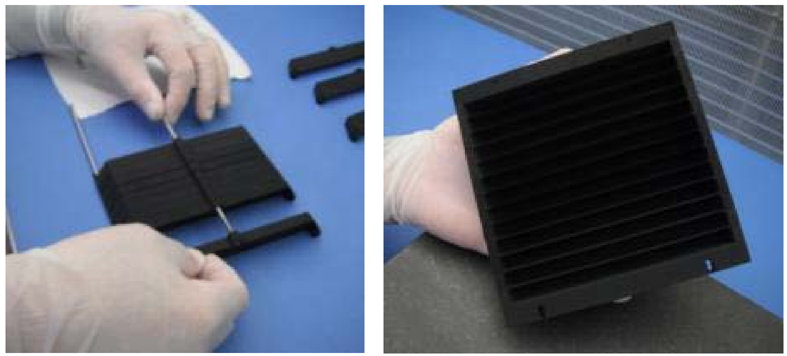
Remote electronics module



Optical bench seating vibration test



Instrument deck platinum resistance thermometers installed



Light trap assembly

Courtesy T. Glavich

The OCO-2 Mission Is Underway

- December 2009: The U.S. Congress added funding to the NASA FY2010 budget to restart the OCO Mission

- February 2010: The President's 2011 NASA budget proposal included funding for a "Carbon Copy" of the OCO mission, now designated "OCO-2," with a launch date "no later than February 2013"

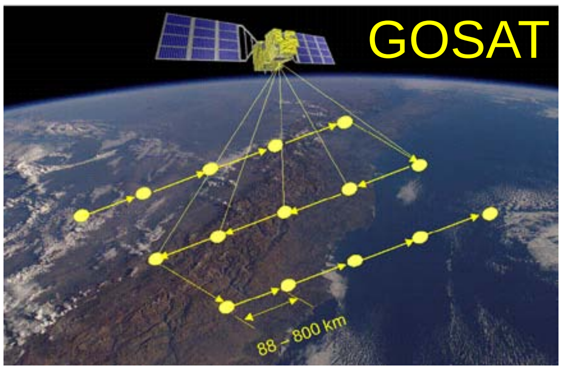
- The OCO-2 mission is being implemented
  - Key NASA reviews completed in late 2010, Mission Implementation Phase began on October 1, 2010
  - Instrument and spacecraft are being built as we speak
  - Launch vehicle selection being revisited following the loss of the Glory Mission

- The instrument is due to begin integration with the spacecraft in March 2012

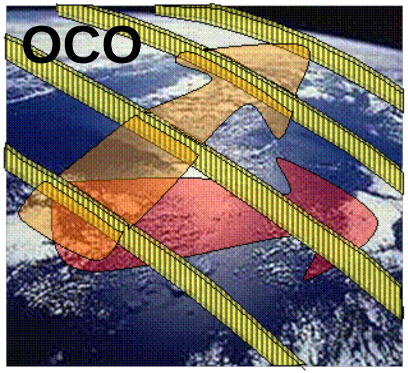
OCO and GOSAT Collaboration

- The OCO and GOSAT teams formed a close partnership during the development phases of these two missions to:
  - Cross calibrate the OCO instrument and TANSO-FTS
  - Cross validate OCO and GOSAT data against a common standard

- If OCO-2 can be completed on schedule, GOSAT will still be conducting its nominal mission during the first year of OCO-2 operations



3-day ground track repeat cycle
- Resolves synoptic-scale weather



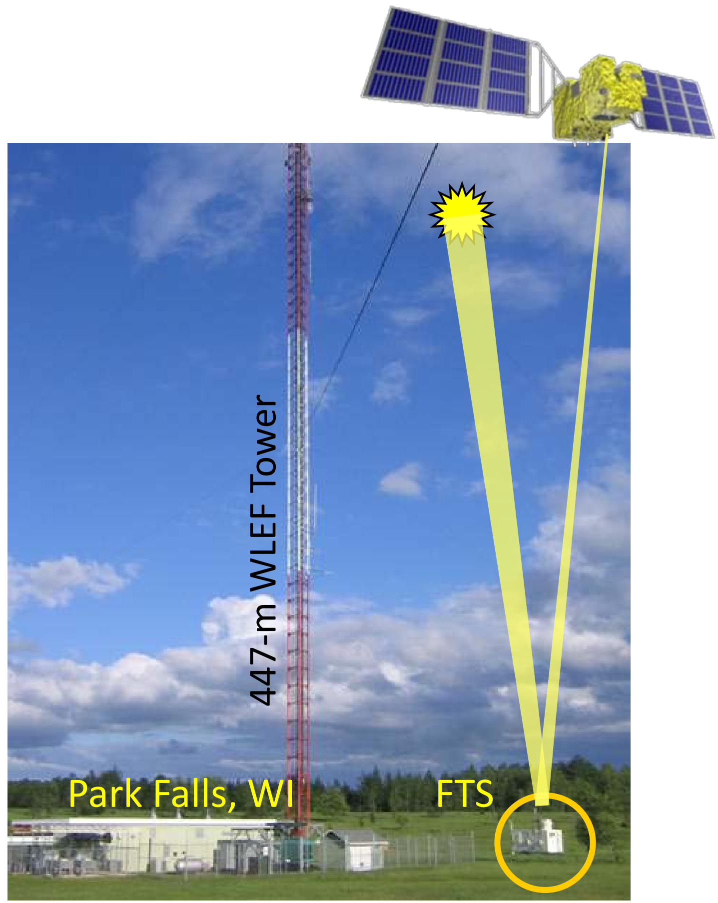
Continuous sampling along track
- High resolution along track

Comparison of OCO-2 and GOSAT

	GOSAT	OCO-2
Gases Measured	CO_2, CH_4, O_2, O_3, H_2O	CO_2, O_2
Instruments	SWIR/TIR FTS, CAI	Grating Spectrometer
IFOV / Swath (km)	FTS: 10.5 / 80-790 (160) CAI: 0.5 / 1000	1.29 x 2.25 / 5.2
Sampling rate	0.25, 0.5, 1	4 x 3Hz
Spectral Ranges (µm)	0.758-0.775, 1.56-1.72, 1.92-2.08, 5.56-14.3	0.757-0.772, 1.59-1.62, 2.04-2.08
Observatory Mass	1750 kg	441 kg
Power	3800 Watts	887 Watts
Orbit Altitude	666 km	705 km
Local Time	12:48	13:30
Revisit Time/Orbits	3 Days/72 Orbits	16 Days/233 Orbits
Launch Vehicle	H-IIA	????
Launch Date	January 2009	2013
Nominal Life	5 Years	2 Years

GOSAT: Reducing Risk for OCO-2

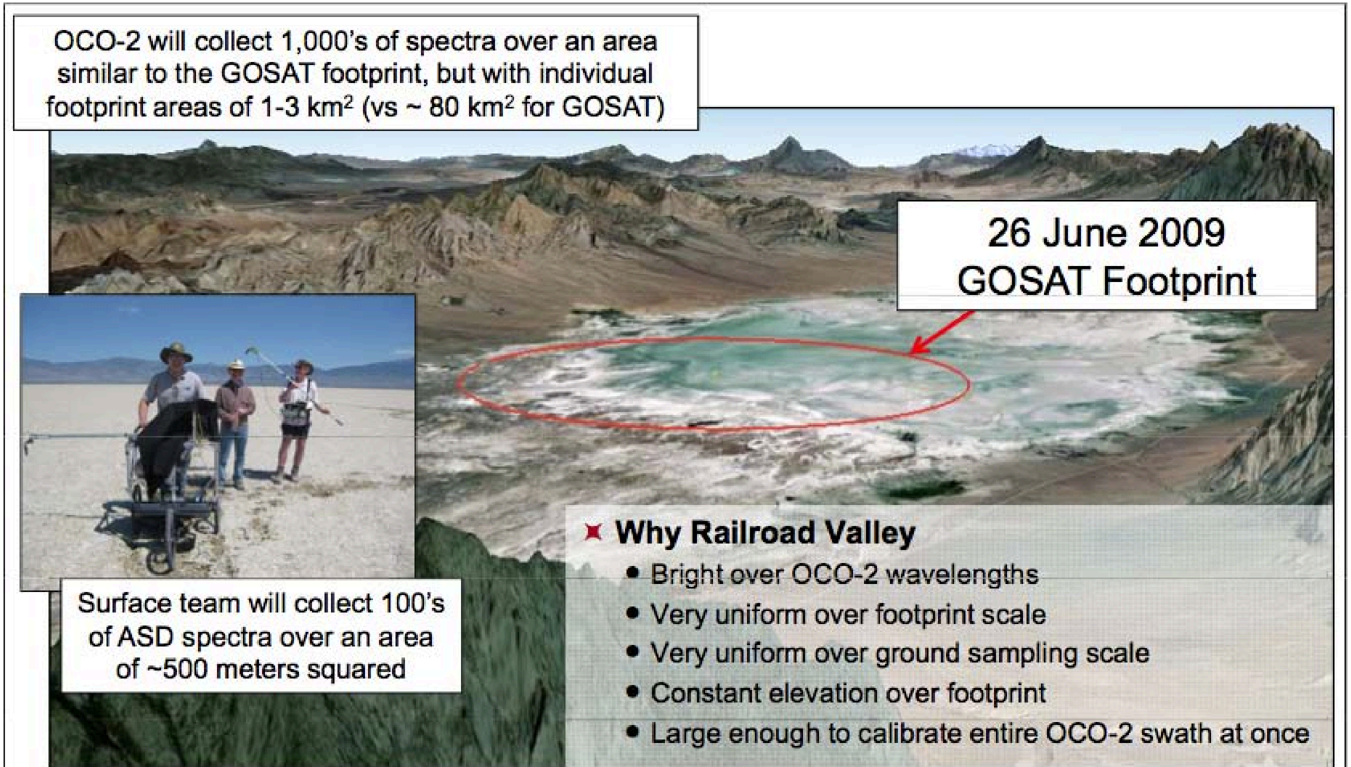
- The Japanese GOSAT satellite is measuring over the same spectral region as OCO-2 with an FTS (TANSO-FTS)
- These measurements are being processed through the OCO retrieval algorithm and allowing us to improve our readiness for OCO-2
- Products available through the GES DISC http://disc.sci.gsfc.nasa.gov/acdisc/documentation/ACOS.shtml
- Our current focus is reducing bias and systematic errors through and applying the lessons learned to OCO-2:
  - **Instrument characterization and calibration**
  - **Algorithm refinements**
  - **Validation**



RRV Vicarious Calibration

- Railroad Valley has been used for vicarious calibration of the GOSAT instrument with field campaigns each year, collecting detailed measurements of surface reflectance
- Upgrading RRV with sensor net to take continuous data

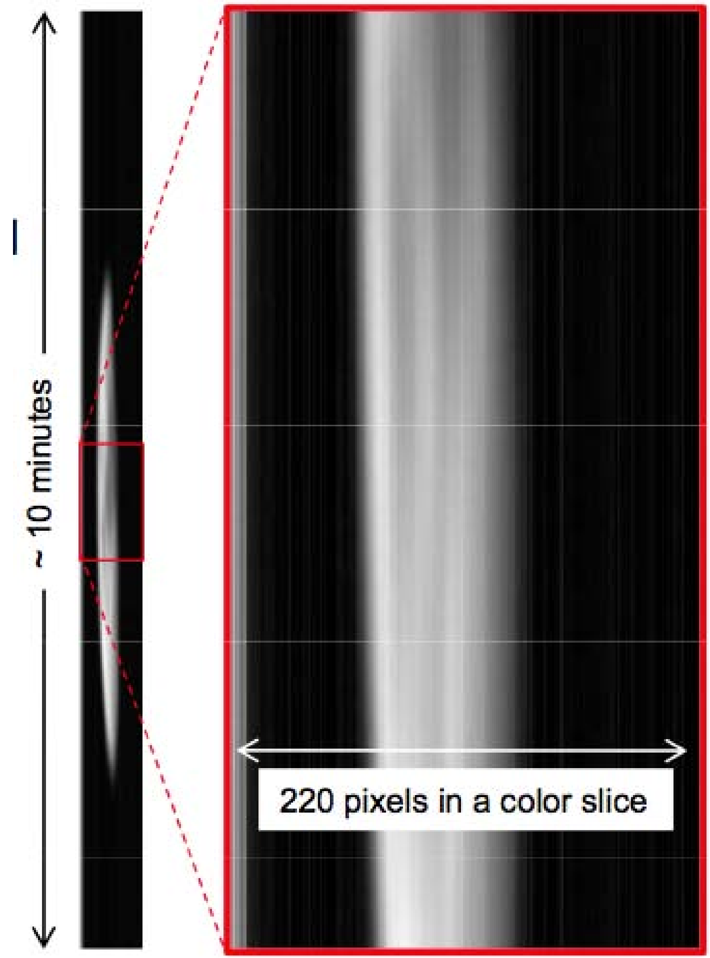
- OCO-2 will use continuous measurement with enhanced field campaigns twice a year
- Frequency of measurement increased based on GOSAT experience



Courtesy R. Pollock

Solar, Dark, and Lunar Calibration

- OCO-2 will look at the sun through a solar diffuser – every orbit
- Dark calibration with aperture door closed and lamps off – every orbit
- Solar doppler calibration (look at the sun through the entire daylight side of an orbit – once every six months)
- Lunar calibration required for absolute and relative pointing
- This serves to remove the uncertainty in the offset between the instrument boresight and the star tracker. Also used in radiance calibration
- Lunar calibration to be performed once every lunar month
- Frequency increased based on GOSAT experience



Courtesy R. Pollock

Algorithm Improvements

- The full physics retrieval algorithm now runs quickly (from 24 hours down to ~15 minutes per sounding)
- Recent algorithm changes include
  - Updates to radiative transfer code and jacobians
  - Small corrections to geometric inputs
  - Inclusion of ocean glint retrievals
- Algorithm updates focus on
  - Improved formulation of state vector (with an emphasis on the representation of aerosols and clouds)
  - Review of *a priori* and constraints
  - Implementation of sigma pressure levels (handle topography more consistently)
  - Verifying *a posteriori* error estimates
  - Further algorithm speed improvements
- Upgrading unit testing and rapid assessment capability
  - Creating capability to verify physics and implementation at low level (ray-tracing, optical depth calculation, scattering coefficients, etc)
  - Can perform unit test as code is modified, and then quickly evaluate impact on key science variables

Identifying Cloudy Scenes

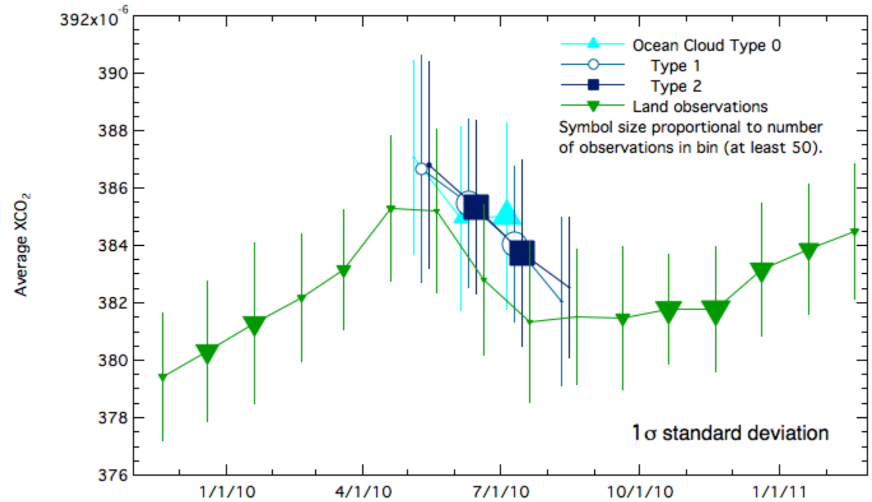
- The ABO2 method is a single iteration clear-sky surface pressure retrieval.
- The ABO2 results from ACOS/GOSAT were compared to MODIS cloud data taken within +/- 7.5 mins.
- The method is very effective for high clouds, and fairly effective for low clouds.
- This method will be used to identify cloudy scenes and eliminate them from OCO-2 processing.

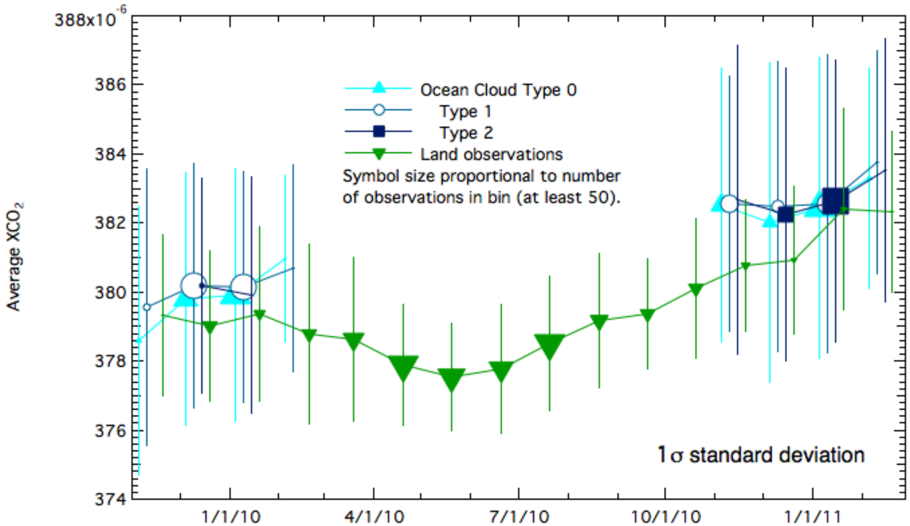
Low Cloud ($p > 0.75*p_s$)		High Cloud ($p < 0.4*p_s$)	
TOD Range	**Clear Classification**	**TOD Range**	**Clear Classification**
0.0 to 1.0	100%	0.0 to 0.1	97%
1.0 to 2.0	94%	0.1 to 0.2	72%
2.0 to 3.0	77%	0.2 to 0.3	21%
> 3.0	68%	> 0.3	3%

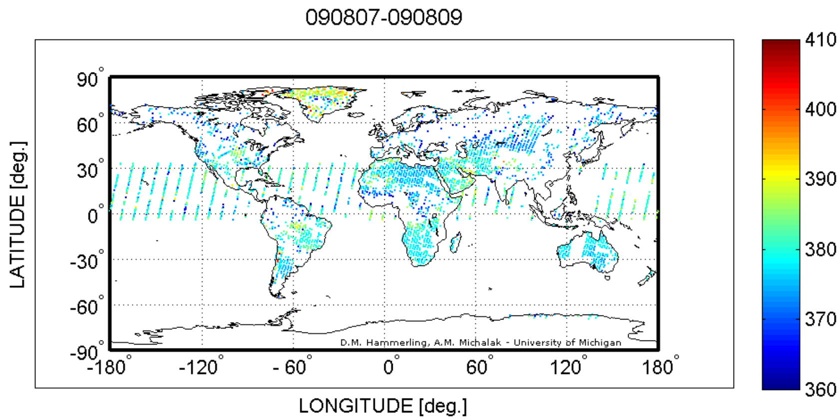
Ocean Glint Mode Observations

Jet Propulsion Laboratory
California Institute of Technology

- ACOS B2.8 data product now includes retrievals over ocean from GOSAT glint observations
- Initial validation by comparison to retrievals over land
- Overall, it appears to have similar characteristics

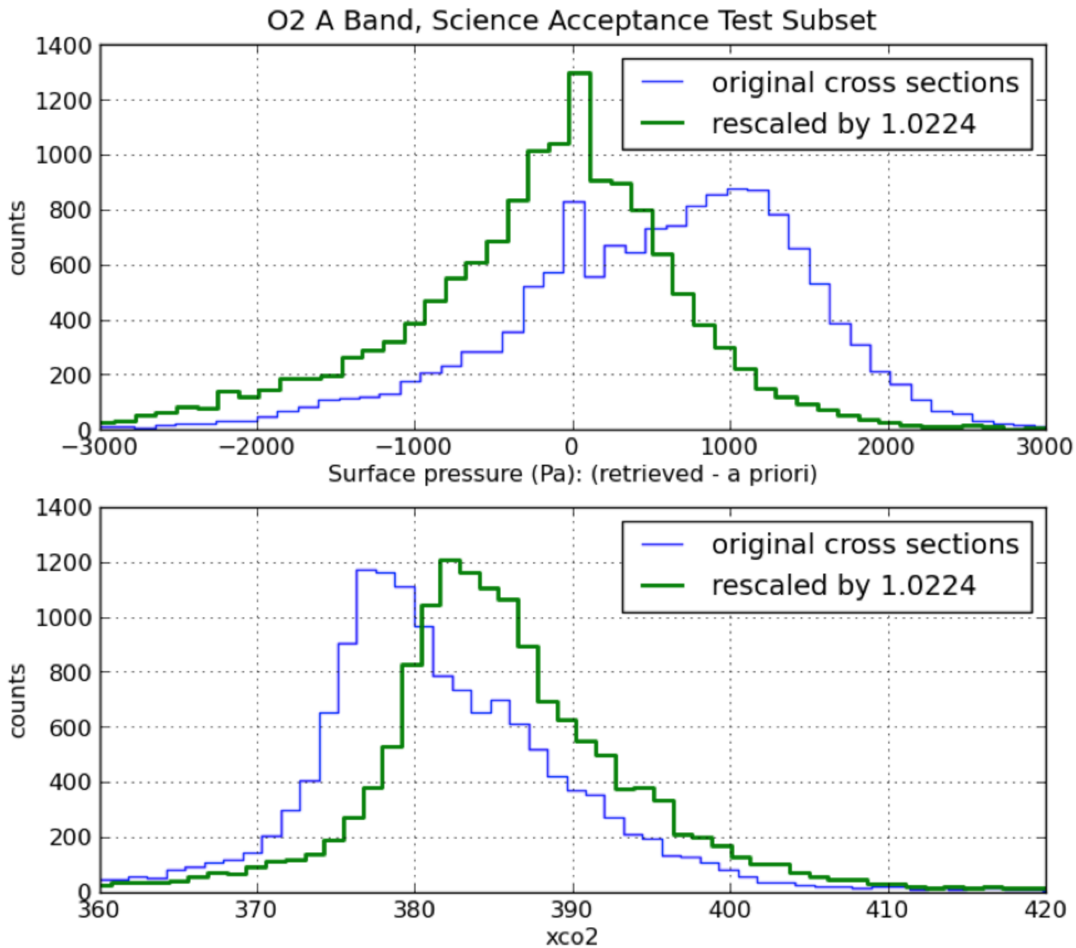






Spectroscopy – O_2 A-band

- From ground-based measurements, there is evidence that the A-band spectroscopy is causing the surface pressure bias
- Scaling A-band to achieve zero bias of surface pressure with ECMWF changes the X_{CO2} by 7 ppm

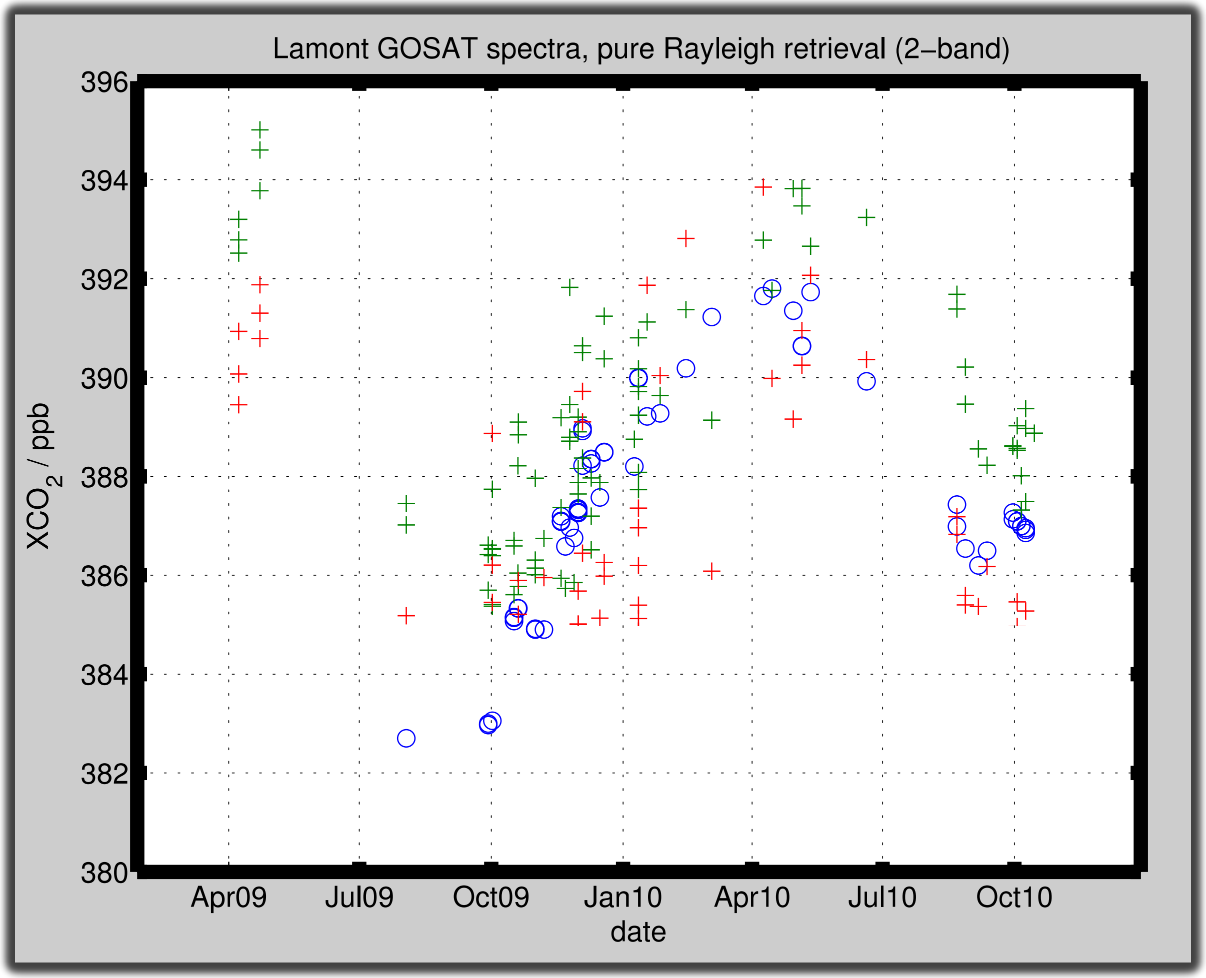


Courtesy D. Thompson

Spectroscopy – CO_2 bands

- There are inconsistencies in the spectroscopy between the CO_2 weak and strong bands
- This is about a 3 ppm bias in our current choice of line strength parameters

Courtesy C. Frankenberg



Validation – TCCON and Estimating Bias

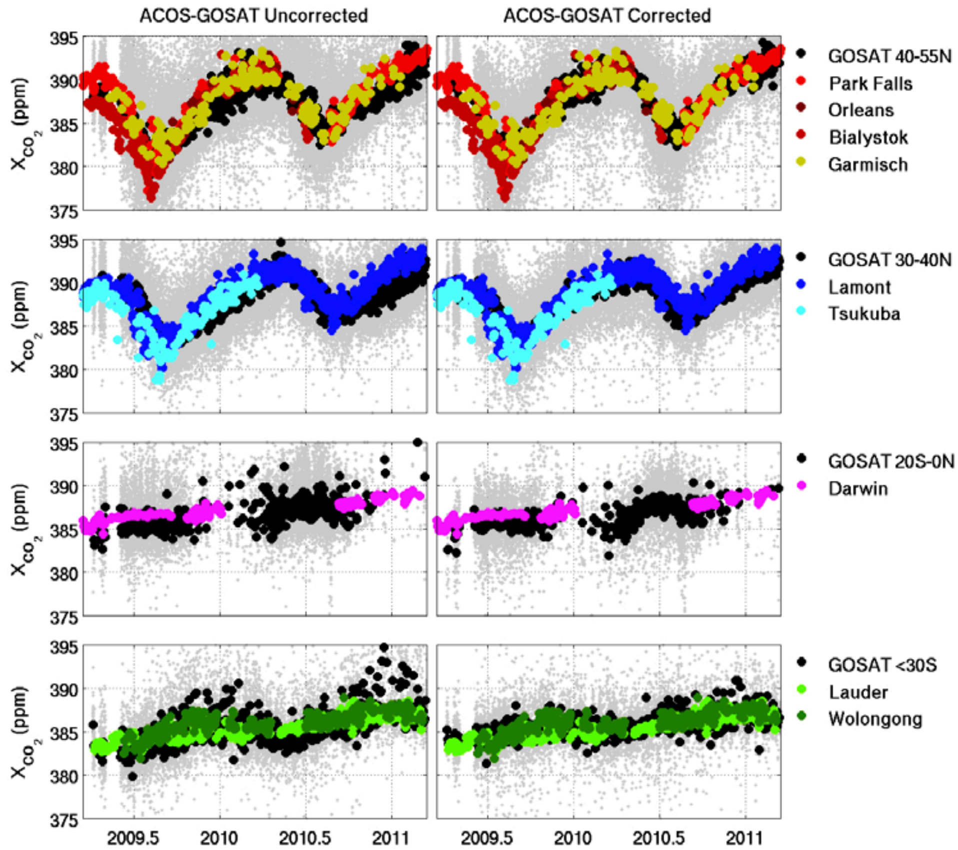
- ACOS uses the TCCON network for the validation as will OCO-2

- Key lessons
  - Criteria coincidence/framework
  - Approaches to use this data in rapid testing mode

- Using coincidences to derive systematic factors in bias
  - Recommendation to users

Courtesy

D. Wunch



Conclusions

- OCO-2 instrument is being constructed and ready for thermal-vacuum testing in the latter half of 2011
- The instrument will be tested and characterized ready for observatory integration by March of 2012
- Working with the GOSAT data has provided the team with critical tests of the OCO retrieval algorithm and validation approach
- The algorithm is faster and more robust but there are still areas for development to reduce biases
- ***OCO-2 will be prepared to rapidly process, evaluate, and validate the OCO-2 data early after on-orbit operations begin***