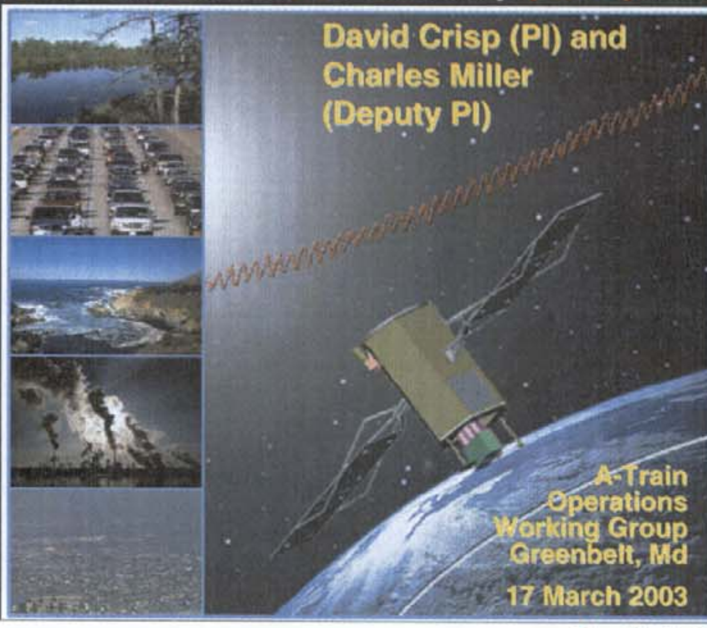
The Orbiting Carbon Observatory (OCO) Mission



The Orbiting Carbon Observatory (OCO)

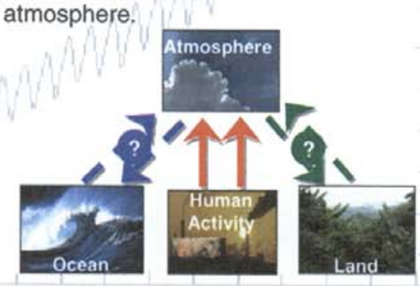
- **OCO will make the first global measurements of CO_2 from space with the precision and spatial resolution needed to quantify carbon sources and sinks**
  - Acquires simultaneous spectroscopic observations of CO_2 and O_2 to estimate the column integrated CO_2 dry air mole fraction, X_{CO2}
  - Precisions of 1 ppm on regional scales
  - Flies ahead of the A-Train constellation
    - 1:15 PM polar orbit, 16 day repeat cycle
- **Nominal launch date: 2007**
- **Team Members**
  - **Mission management:** JPL
  - **Instrument provider:** Hamilton Sundstrand Sensor Systems
  - **Spacecraft provider:** Orbital Sciences
  - **Science Team:** JPL, Caltech, Berkeley, Colorado State, UMBC, Haverford College, Harvard, Wood Hole, NOAA CMDL, NOAA NESDIS, U. Bremen, LSCE, NIWA, CSIRO

Artist's concept of OCO operating in nadir viewing mode. The ground track is highlighted on the surface.

Why Measure CO_2?

Carbon dioxide (CO_2) is the principal

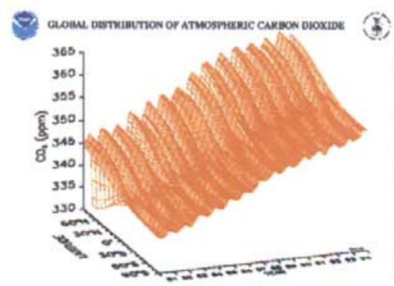
- Atmospheric component of the global carbon cycle
- Anthropogenic driver of climate change
- Only half of CO_2 produced by human activities over the past 30 years has remained in the atmosphere.
  - Where are the sinks?
  - Will this process continue?

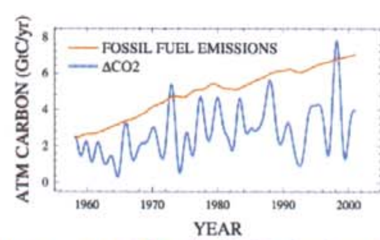


An Uncertain Future

Where are the Missing Carbon Sinks?

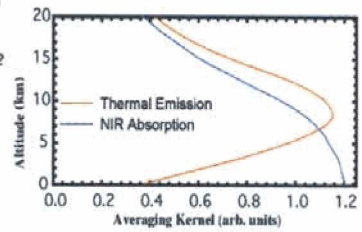
- **What are the relative roles of the oceans and land ecosystems in absorbing CO_2?**
  - Is there a northern hemisphere land sink?
  - What are the relative roles of North America and Eurasia
- **What controls carbon sinks?**
  - Why does the atmospheric buildup vary with uniform emission rates?
  - How will sinks respond to climate change?
- **Reliable climate predictions require an improved understanding of CO_2 sinks**
  - Future atmospheric CO_2 increases
  - Their contributions to global change





Monitoring CO_2 from Space

- **High resolution spectra of reflected sunlight in near IR CO_2 and O_2 bands used to retrieve the column average CO_2 dry air mole fraction, X_{CO2}**
  - Column-integrated CO_2 abundance
    - Maximum contribution from surface
  - Other data needed (provided by OCO)
    - Surface pressure, albedo, atmospheric temperature, water vapor, clouds, aerosols



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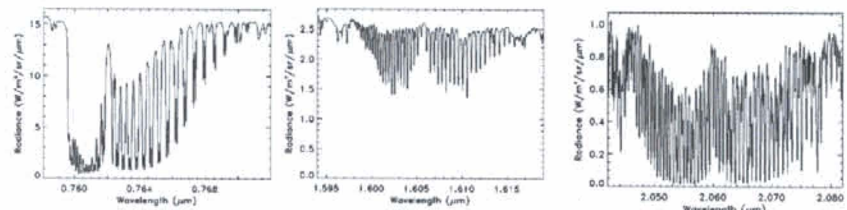
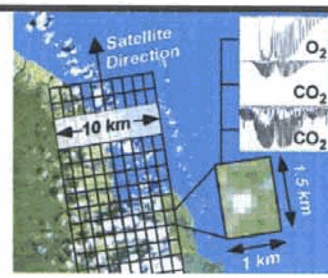
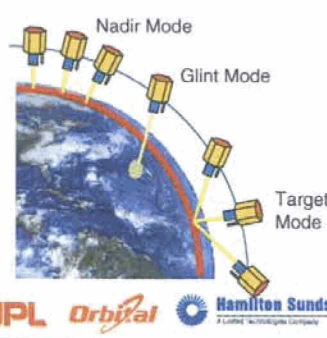


Clouds/Aerosols, Surface Pressure — Column CO_2 — Clouds/Aerosols, H_2O, Temperature

OCO Spatial Sampling Strategy

- **OCO is designed provide an accurate description of X_{CO2} on regional scales**
  - Atmospheric motions mix CO_2 over large areas as it is distributed through the column
  - Source/Sink model resolution limited to 1°x1°
- **OCO flies in the A-train, 15 minutes ahead of the Aqua platform**
  - 1:15 PM equator crossing time yields same ground track as AQUA
  - Global coverage every 16 days
- **OCO samples at high spatial resolution**
  - Nadir mode: 1 km x 1.5 km footprints
    - Isolates cloud-free scenes
    - Provides thousands of samples on regional scales
  - Glint Mode: High SNR over oceans
  - Target modes: Calibration





Validation Program Ensures Accuracy and Minimizes Spatially Coherent Biases

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  - TAO/Taurus Buoy Array
- **Uplooking FTS measurements of X_{CO2}**
  - 3 funded by OCO
  - 4 upgraded NDSC
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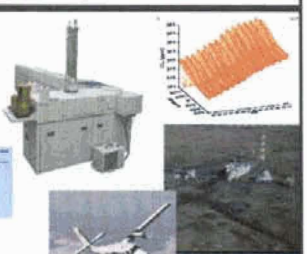
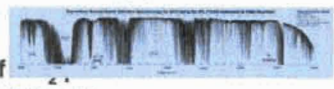
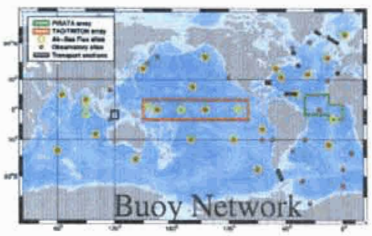
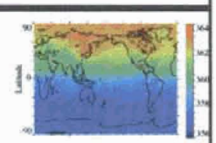
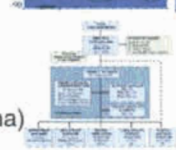
  - Wofsy (US), Ciais (CNRS Aerocarb)
- **Laboratory and on-orbit calibration**



Implementation Approach

- **International Science Team**
  - Atmospheric remote sensing and spectroscopy
    - JPL, Bremen, CSU, CSIRO, NIWA
  - Carbon Cycle Science
    - NOAA CMDL, GSFC, CSIRO, LSCE, UC Berkeley, Harvard, Woods Hole, UMBC, Caltech
- **JPL Management oversight**
  - Project Management and Mission Assurance (Bharat Chudasama)
  - System Engineering and Mission Planning (George Sprague)
- **Industry Team Members Provide Spacecraft and Instrument**
  - –Ensures rapid infusion of capabilities into US industry
    - Essential to enable future operational missions (NOAA/IPO)
  - –Instrument Provider: UTC Hamilton Sundstrand Sensor Systems
    - –Delivered the last 4 TOMS instruments
    - –Experience with CloudSat O_2 A-Band spectrometer design
  - –Spacecraft Provider: Orbital Sciences Corporation
    - Based on LEOStar-2 Bus


The OCO Instrument

- **Three bore-sighted, high resolution, grating spectrometers**
  - CO_2 1.61 µm band
  - CO_2 2.06 µm band
  - O_2 0.765 µm A-band
- **Similar optics and electronics**
  - 200 mm f/2 refractive optics
  - Spectral Resolution ~20,000
  - RSC Hawaii HgCdTe FPAs for CO_2 channels
  - RSC HyViSI FPA for O_2 channel
- **Existing Designs For Critical Components**
  - Hubble WFC-3 detectors
  - Build-to-Print Aura HIRDLS cooler
- **Provided by Hamilton Sundstrand Sensor Systems (Pomona CA)**
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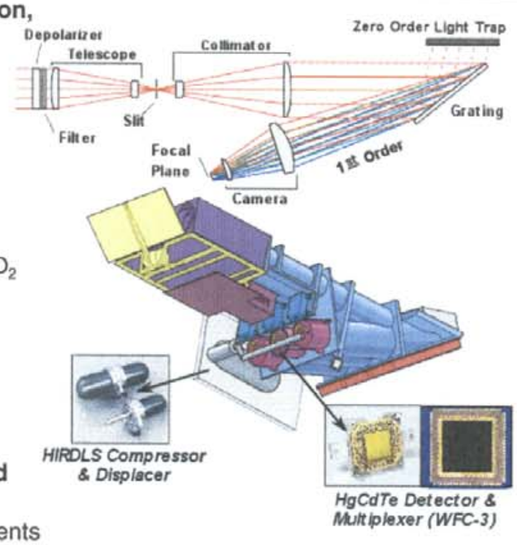
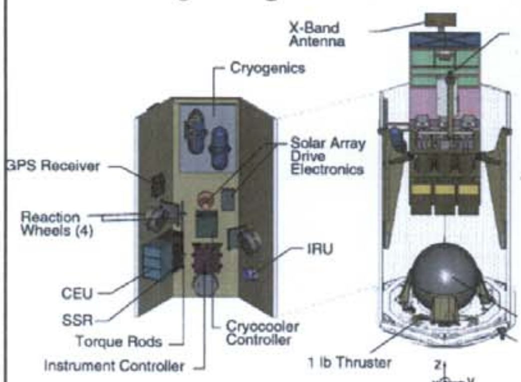


The OCO Spacecraft

- **4th build of Orbital LEOStar-2 Bus**
  - Orbview 4, GALEX, SORCE
  - Now in NASA's RSDO Catalog
- **Satisfies all OCO Requirements with large margins**



Mission Operations and Data Downlink

- OCO mission operations uses Orbital's Multiple-Satellite Operations Facility in Dulles, VA
  - Collocation with Spacecraft development and manufacturing facility
    - lowers development risk
    - Ensures timely technical support during mission operations
- **Universal Space Network (USN) provides high-rate downlink**
  - Primary station in Alaska and backup in Sweden
  - Ample scheduling opportunities for two contacts per day
  - Realtime monitoring of spacecraft and instrument health
  - Science data quick-look capability to verify data integrity

OCO Data Products

- **Level 0: Error-corrected, time-ordered, Raw Telemetry**
  - Science and Calibration data: spectral radiances in the 0.76 μm O_2, and 1.61, and 2.06 μm CO_2 channels expressed as in DN
    - 3x45 spectra/second recorded across a 10-km wide cross-track swath Engineering data: Instrument temperatures, voltages, etc.
- **Level 1a: Corrected Spectral Radiances**
  - Spectra corrected for bias, gain, linearity variations
  - Time tagged and labeled with local spacecraft nadir
- **Level 1b: Calibrated Spectral Radiances**
  - Flagged for optically-thick clouds and aerosols, with SNR estimates
  - Individual soundings Geolocated from satellite position and pointing
- **Level 2: Retrieved Atmospheric and surface Properties**
  - X_{CO2}, Column CO_2, O_2, H_2O, aerosols/cloud, surface albedos and pressure
- **Level 3: Gridded Products**
  - Mean X_{CO2}, Column CO_2, O_2, H_2O, and surface pressure at 1° Latitude intervals along the orbit track
- **Level 4: Retrieved Sources and Sinks at Regional Scales**

OCO Data Product Summary

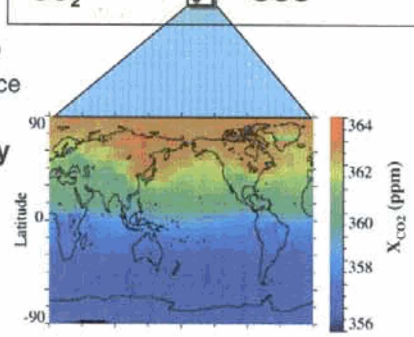
Level	Data Product	Data Rate	Latency
0	Raw corrected data	90 - 112 Gb/day	30 days
1	Calibrated radiances	236 Gb/day	30 days
2	XCO2, O2, H2O, cloud, aerosol, T, p(surface), albedo	1.0 Gb/day	30 days
3	XCO2 maps	N/A	30 days
4a	CO2 sources and sinks	N/A	As available
4b	Assimilation of XCO2 fields	N/A	As available
N/A	Spectral Line Parameters	N/A	As available
N/A	FTIR XCO2 data	N/A	As available

OCO in the A-Train

Summary

- **OCO will provide critical data for**
  - Understanding the carbon cycle
    - Essential for developing carbon management strategies
  - Predicting weather and climate
    - Understanding sources/sinks essential for predicting CO_2 buildup
    - O_2 A-Band will provide global surface pressure measurements
- **OCO validates technologies critically needed for future operational CO_2 monitoring missions**
  - Satisfies an unaccommodated measurement need identified by NPOESS

Climate Forcing/Response		
•$T/H_2O/O_3$	☑	AIRS/TES/MLS
•Clouds	☑	CloudSat
•Aerosols	☑	CALIPSO
•CO_2	☑	OCO



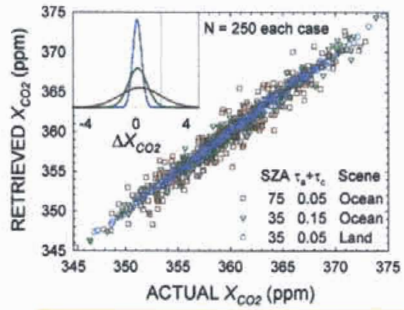
Orbiting Carbon Observatory (OCO) 15 JPL Orbital Hamilton Sundstrand

Backup

Orbiting Carbon Observatory (OCO) 16 JPL Orbital Hamilton Sundstrand

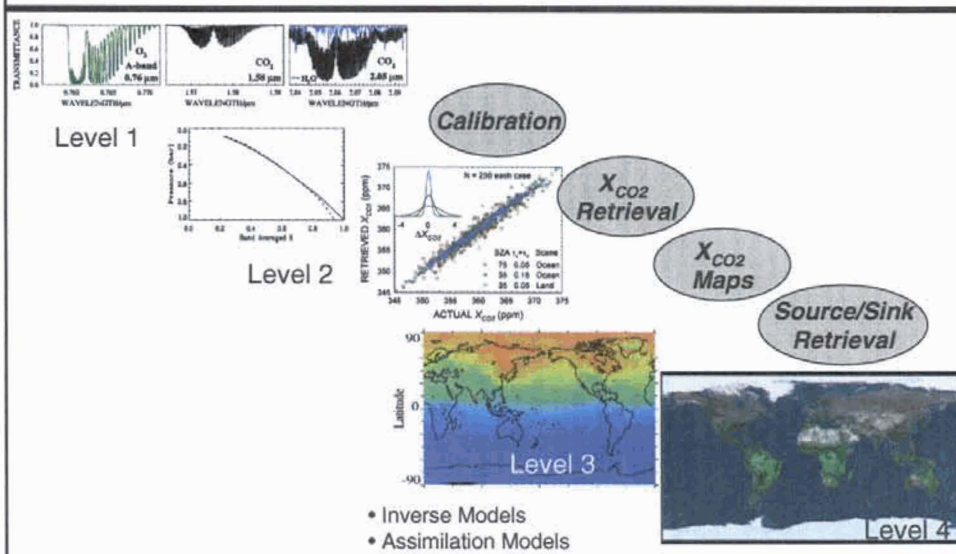
Simulated Performance

- Accuracies of 1ppm needed to identify CO_2 sources and sinks.
- Realistic, end-to-end, Observational System Simulation Experiments
  - Reflected radiances for a range of atmospheric/surface conditions
  - Simultaneous retrieval algorithm
  - Flight-like sampling approach, instrument model
- Results:
  - Simultaneous retrieval of 0.76, 1.61 and 2.06 µm spectra effectively separates CO_2 column changes from changes in the other state variables, yielding X_{CO2} estimates near 1 ppm for a wide range of conditions
  - CO_2 1.61 µm band is well suited for retrieving CO_2 column abundances
  - CO_2 2.06 µm band CO_2, cloud, aerosol, water vapor, temperature
  - O_2 A-band constrains clouds, aerosols, and surface pressure



End-to-end retrievals of X_{CO2} from individual simulated nadir soundings at SZAs of 35° and 75°. The simulations include sub-visual cirrus clouds ($0.02 \le \tau_c \le 0.05$), light to moderate aerosol loadings ($0.05 \le \tau_a \le 0.15$), over ocean and land surfaces.
INSET: Distribution of X_{CO2} errors (ppm) for each case

Rigorous Physics Based Retrieval Algorithms



Project Status and Schedule

Contract Start	October 2, 2002
Project Kick-Off Meeting	October 10, 2002
Risk Mitigation Phase begins	October 10, 2002
System Requirement Review (SRR)	June 30, 2003
Risk Mitigation Phase Final Review	July 29, 2003
Preliminary Design Review (PDR)	June, 2004
Critical Design Review (CDR)	July, 2005
Launch	July, 2007
Mission Check out (PLSR)	One Month After Launch
Mission Operations	24 Months

OCO Science Team

David Crisp, PI
Charles Miller, Deputy PI

Education
Gil Yanow

Retrieval Algorithms
D. O'Brien
G. Stephens
G. Toon
Y. Yung

Cal/Val
F. Bréon
L. Brown
J. Burrows
P. Ciais
B. Connor
C. Miller
R. Salawitch
S. Sander
P. Tans
P. Wennberg
S. Wofsy

Source/Sink Modeling
R. Atlas
S. Doney
I. Fung
D. Jacob
S. Pawson
J. Randerson
P. Rayner

Ground Data System Interface
B. Sen

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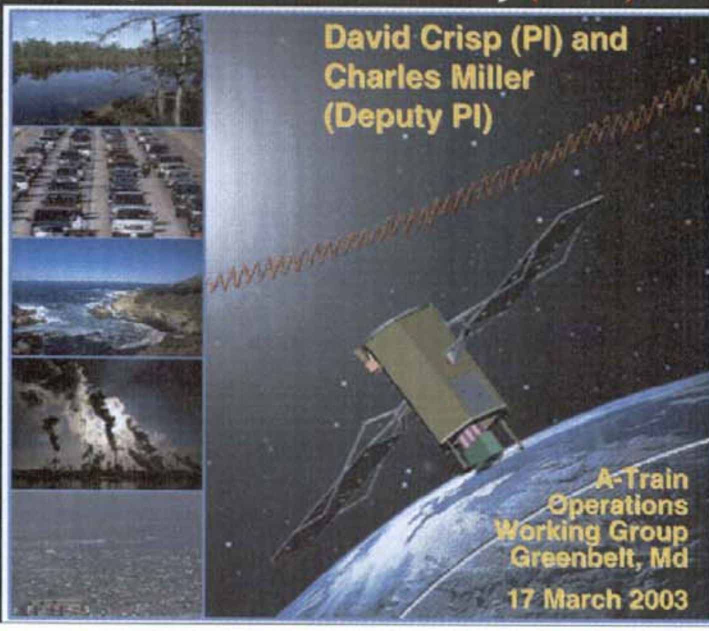

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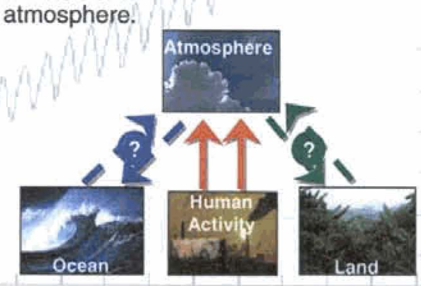

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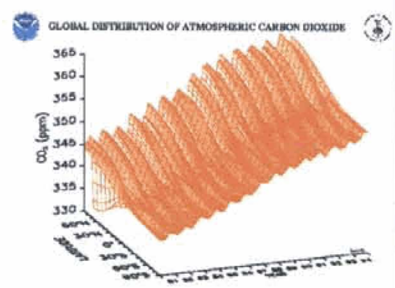

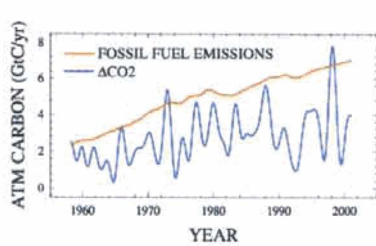

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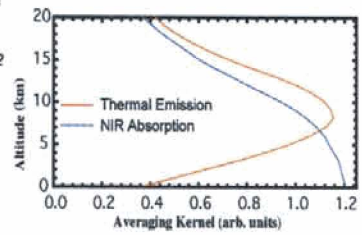

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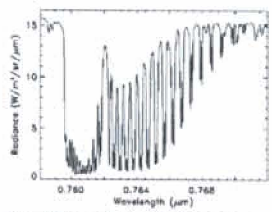
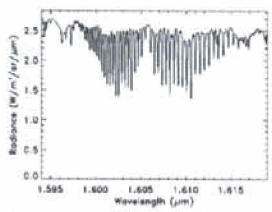
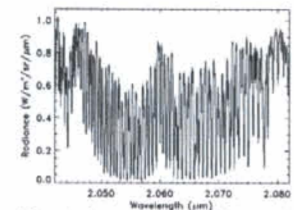


Clouds/Aerosols, Surface Pressure



Column CO_2



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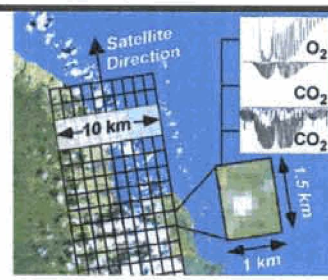

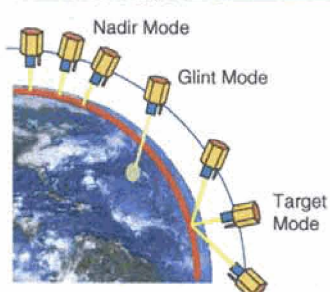

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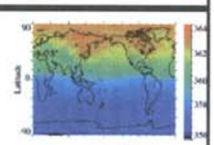

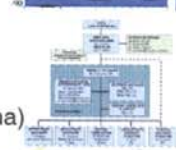

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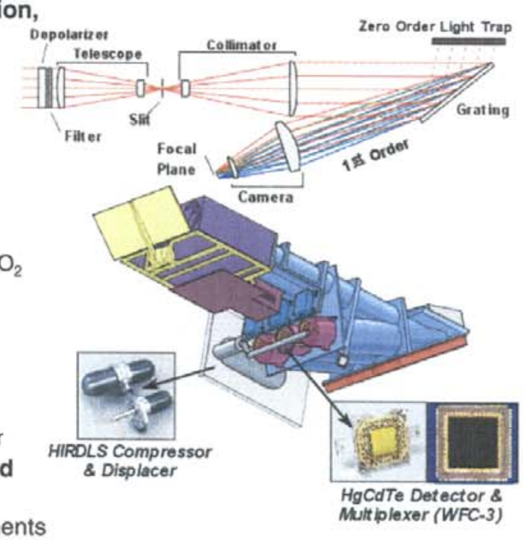

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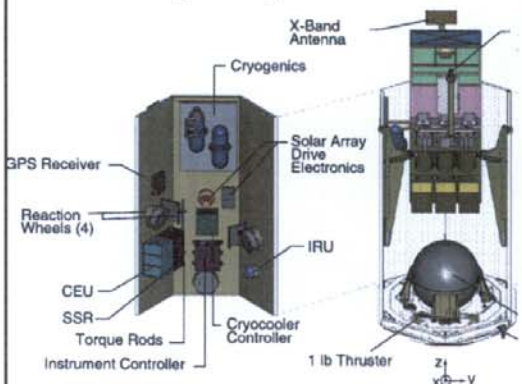

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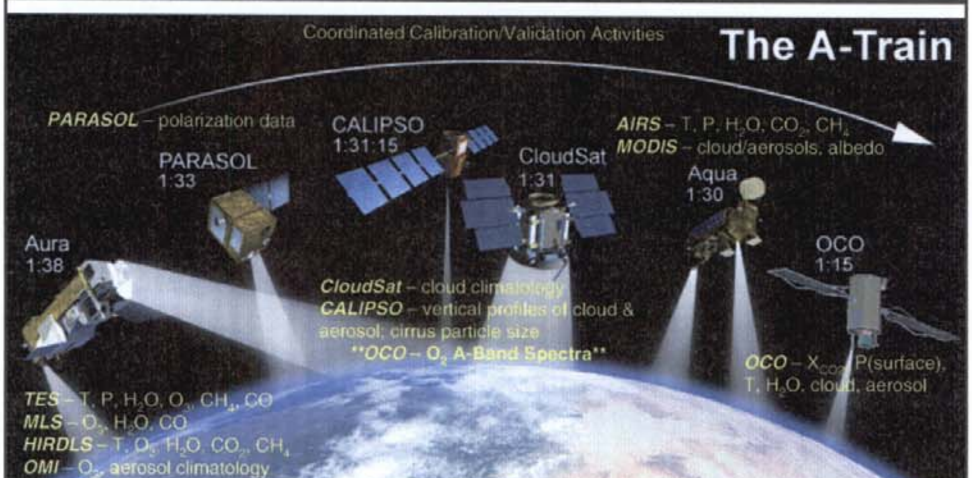
  - Individual soundings Geolocated from satellite position and pointing
- **Level 2: Retrieved Atmospheric and surface Properties**
  - X_{CO2}, Column CO_2, O_2, H_2O, aerosols/cloud, surface albedos and pressure
- **Level 3: Gridded Products**
  - Mean X_{CO2}, Column CO_2, O_2, H_2O, and surface pressure at 1° Latitude intervals along the orbit track
- **Level 4: Retrieved Sources and Sinks at Regional Scales**

OCO Data Product Summary

Level	Data Product	Data Rate	Latency
0	Raw corrected data	90 - 112 Gb/day	30 days
1	Calibrated radiances	236 Gb/day	30 days
2	XCO2, O2, H2O, cloud, aerosol, T, p(surface), albedo	1.0 Gb/day	30 days
3	XCO2 maps	N/A	30 days
4a	CO2 sources and sinks	N/A	As available
4b	Assimilation of XCO2 fields	N/A	As available
N/A	Spectral Line Parameters	N/A	As available
N/A	FTIR XCO2 data	N/A	As available

OCO in the A-Train

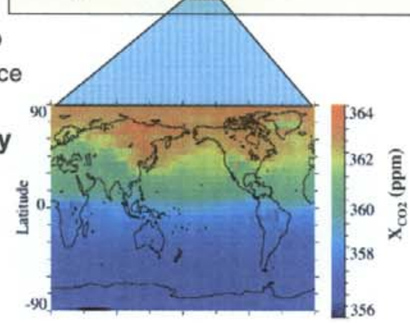


Summary

- **OCO will provide critical data for**
  - Understanding the carbon cycle
    - Essential for developing carbon management strategies
  - Predicting weather and climate
    - Understanding sources/sinks essential for predicting CO_2 buildup
    - O_2 A-Band will provide global surface pressure measurements
- **OCO validates technologies critically needed for future operational CO_2 monitoring missions**
  - Satisfies an unaccommodated measurement need identified by NPOESS

Climate Forcing/Response

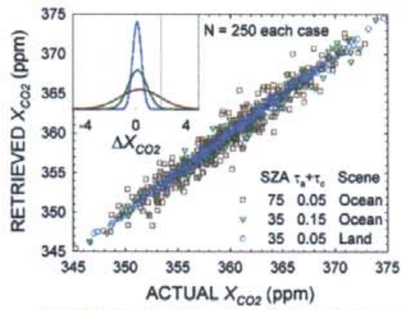
•$T/H_2O/O_3$	☑	AIRS/TES/MLS
•Clouds	☑	CloudSat
•Aerosols	☑	CALIPSO
•CO_2	☑	OCO



Backup

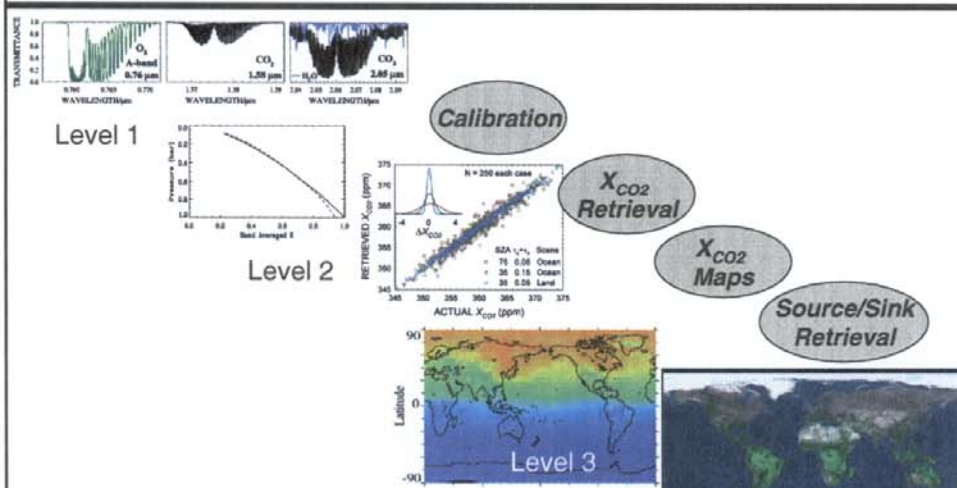
Simulated Performance

- Accuracies of 1ppm needed to identify CO_2 sources and sinks.
- Realistic, end-to-end, Observational System Simulation Experiments
  - Reflected radiances for a range of atmospheric/surface conditions
  - Simultaneous retrieval algorithm
  - Flight-like sampling approach, instrument model
- Results:
  - Simultaneous retrieval of 0.76, 1.61 and 2.06 µm spectra effectively separates CO_2 column changes from changes in the other state variables, yielding X_{CO2} estimates near 1 ppm for a wide range of conditions
  - CO_2 1.61 µm band is well suited for retrieving CO_2 column abundances
  - CO_2 2.06 µm band CO_2, cloud, aerosol, water vapor, temperature
  - O_2 A-band constrains clouds, aerosols, and surface pressure



End-to-end retrievals of X_{CO2} from individual simulated nadir soundings at SZAs of 35° and 75°. The simulations include sub-visual cirrus clouds ($0.02 \leq \tau_c \leq 0.05$), light to moderate aerosol loadings ($0.05 \leq \tau_a \leq 0.15$), over ocean and land surfaces.
INSET: Distribution of X_{CO2} errors (ppm) for each case

Rigorous Physics Based Retrieval Algorithms



- Inverse Models
- Assimilation Models

Project Status and Schedule

Contract Start	October 2, 2002
Project Kick-Off Meeting	October 10, 2002
Risk Mitigation Phase begins	October 10, 2002
System Requirement Review (SRR)	June 30, 2003
Risk Mitigation Phase Final Review	July 29, 2003
Preliminary Design Review (PDR)	June, 2004
Critical Design Review (CDR)	July, 2005
Launch	July, 2007
Mission Check out (PLSR)	One Month After Launch
Mission Operations	24 Months

OCO Science Team

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