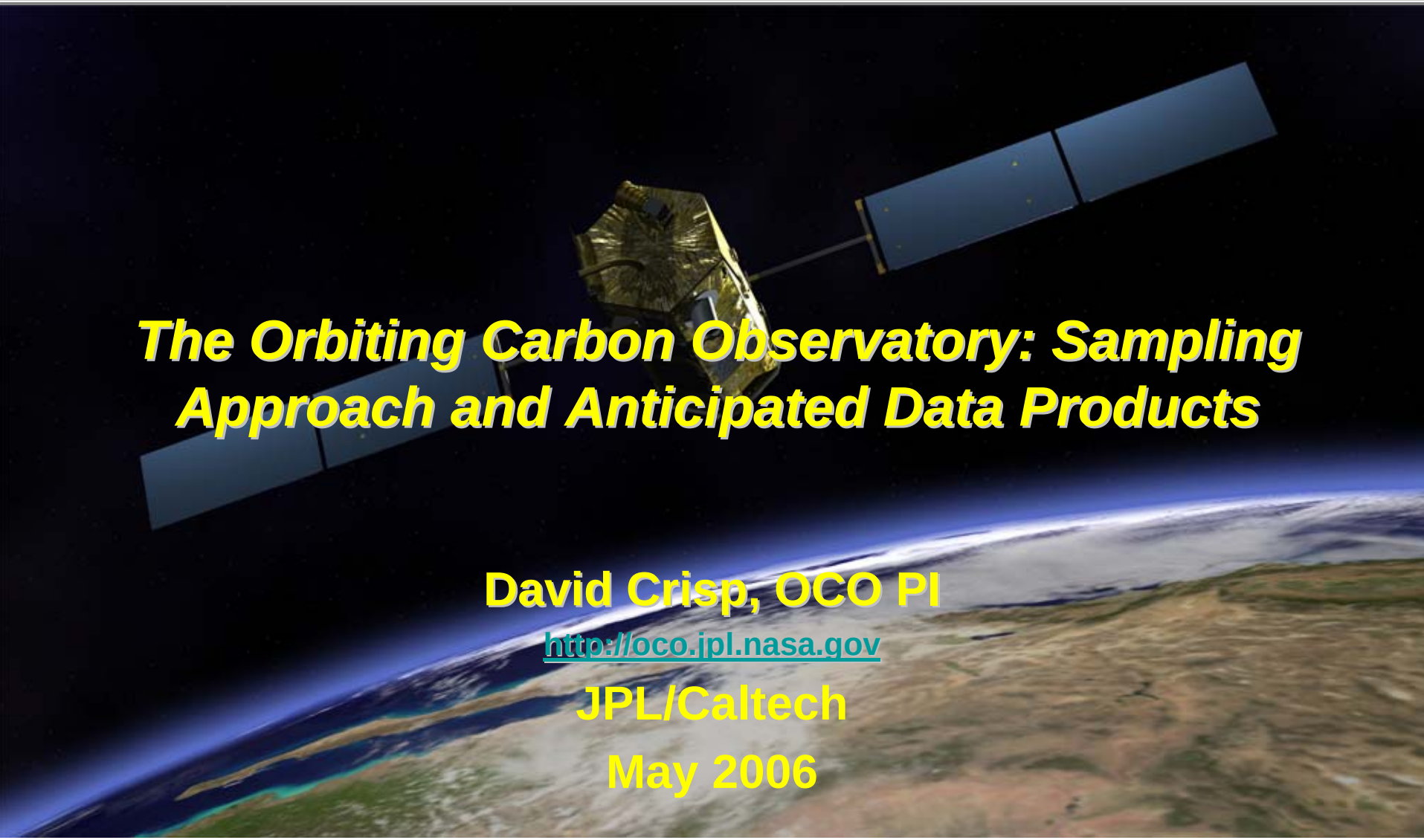


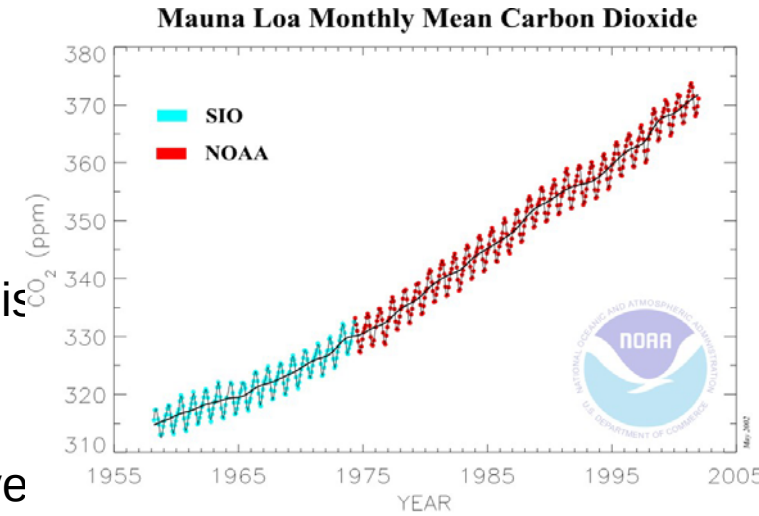
The Orbiting Carbon Observatory: Sampling Approach and Anticipated Data Products

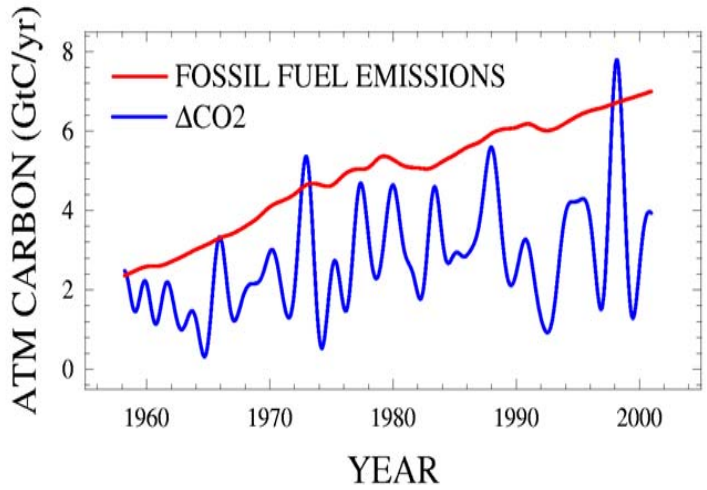
David Crisp, OCO PI
http://oco.jpl.nasa.gov
JPL/Caltech

May 2006

What Processes Control Atmospheric CO_2?

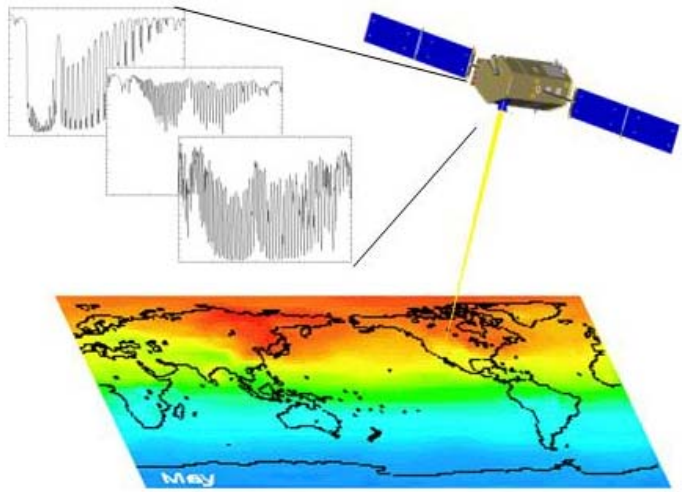
- Atmospheric Carbon dioxide (CO_2)
  - Primary man-made greenhouse gas
  - Mixing ratios have increased by ~25% since the beginning of the industrial age (280 to 375 ppm)
  - Only half of the CO_2 from fossil fuel combustion is staying in the atmosphere – the rest is being absorbed by the oceans and land biosphere
  - The current measurement network does not have the spatial coverage or sampling to resolve sinks
- Outstanding Issues:
  - Where are the CO_2 sinks?
    - Oceans vs land ecosystems
    - North American and Eurasian sinks?
  - Why does the atmospheric buildup vary with uniform emission rates?
  - How will carbon sinks respond to climate change?





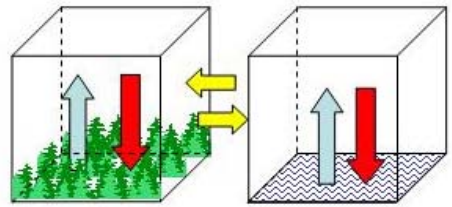
The Orbiting Carbon Observatory (OCO)

OCO will acquire the space-based data needed to identify CO_2 sources and sinks and quantify their variability over the seasonal cycle



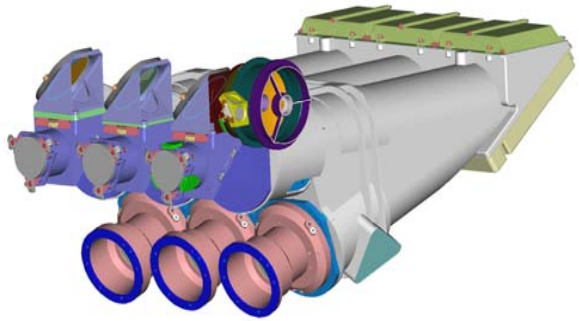
Approach:

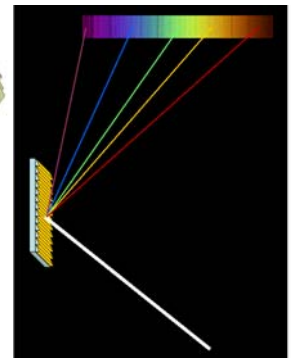
- Collect spatially resolved, high resolution spectroscopic observations of CO_2 and O_2 absorption in reflected sunlight
- Use these data to resolve spatial and temporal variations in the ***column averaged CO2 dry air mole fraction, X_{CO2}*** over the sunlit hemisphere
- Employ independent calibration and validation approaches to produce X_{CO2} estimates with random errors and biases no larger than 1 - 2 ppm (0.3 - 0.5%) on regional scales at monthly intervals



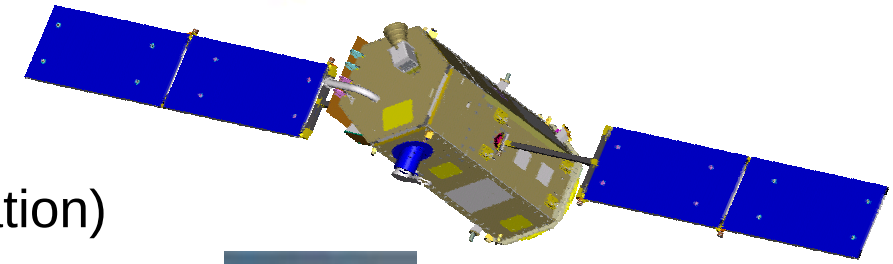
Mission Architecture

Project Management (JPL)
- Science & Project Team
- Systems Engineering, Mission Assurance
- Ground Data System





Single Instrument (Hamilton Sundstrand)
- 3 high resolution grating spectrometers

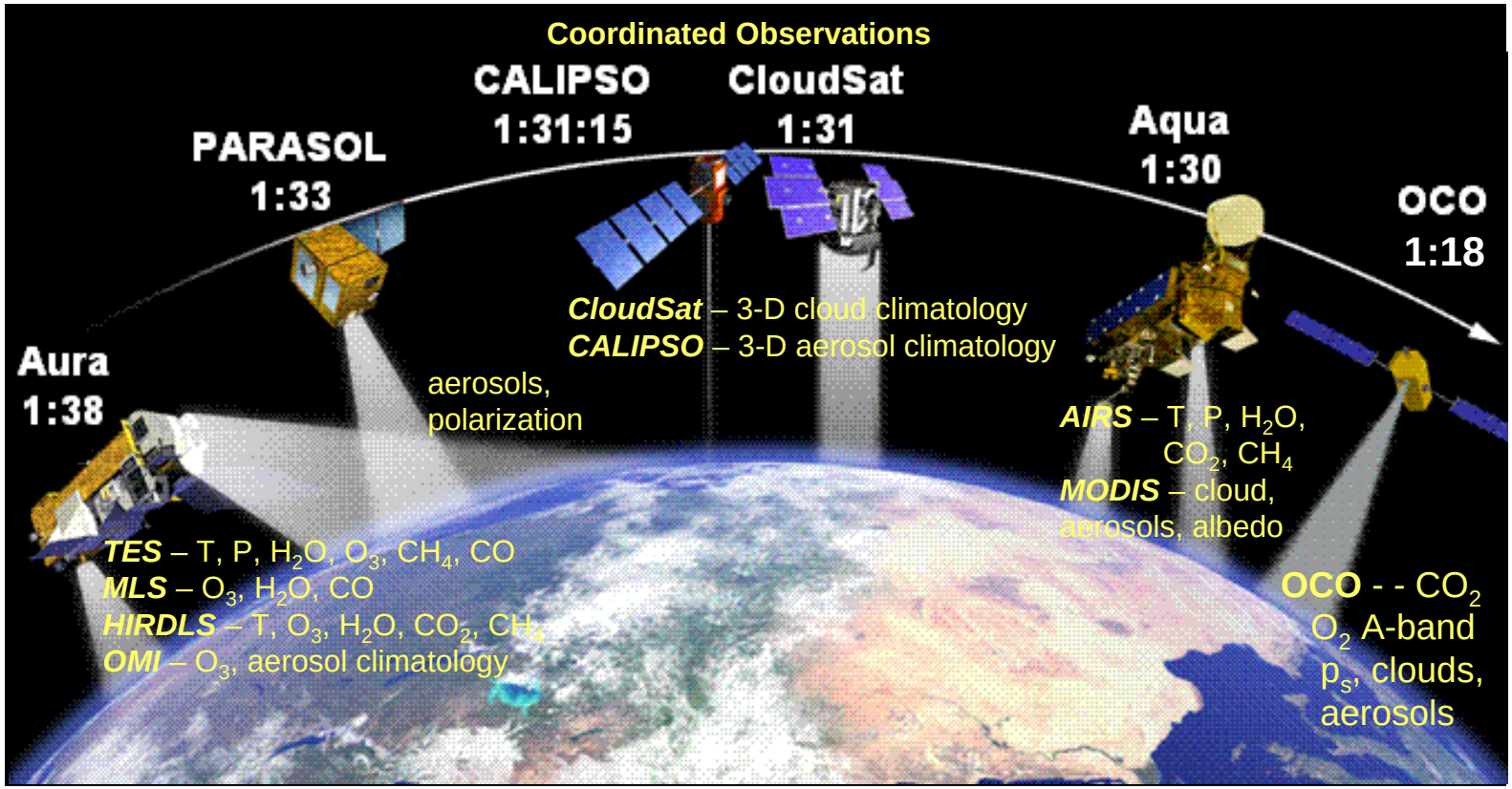


Dedicated Bus (Orbital Sciences Corporation)
- LEOstar2: GALEX, SORCE, AIM

Dedicated Launch Vehicle (Orbital Taurus 3110)
- September 2008 Launch from Vandenberg AFB

Mission Operations (JPL)
- NASA Ground Network, Poker Flats, Alaska

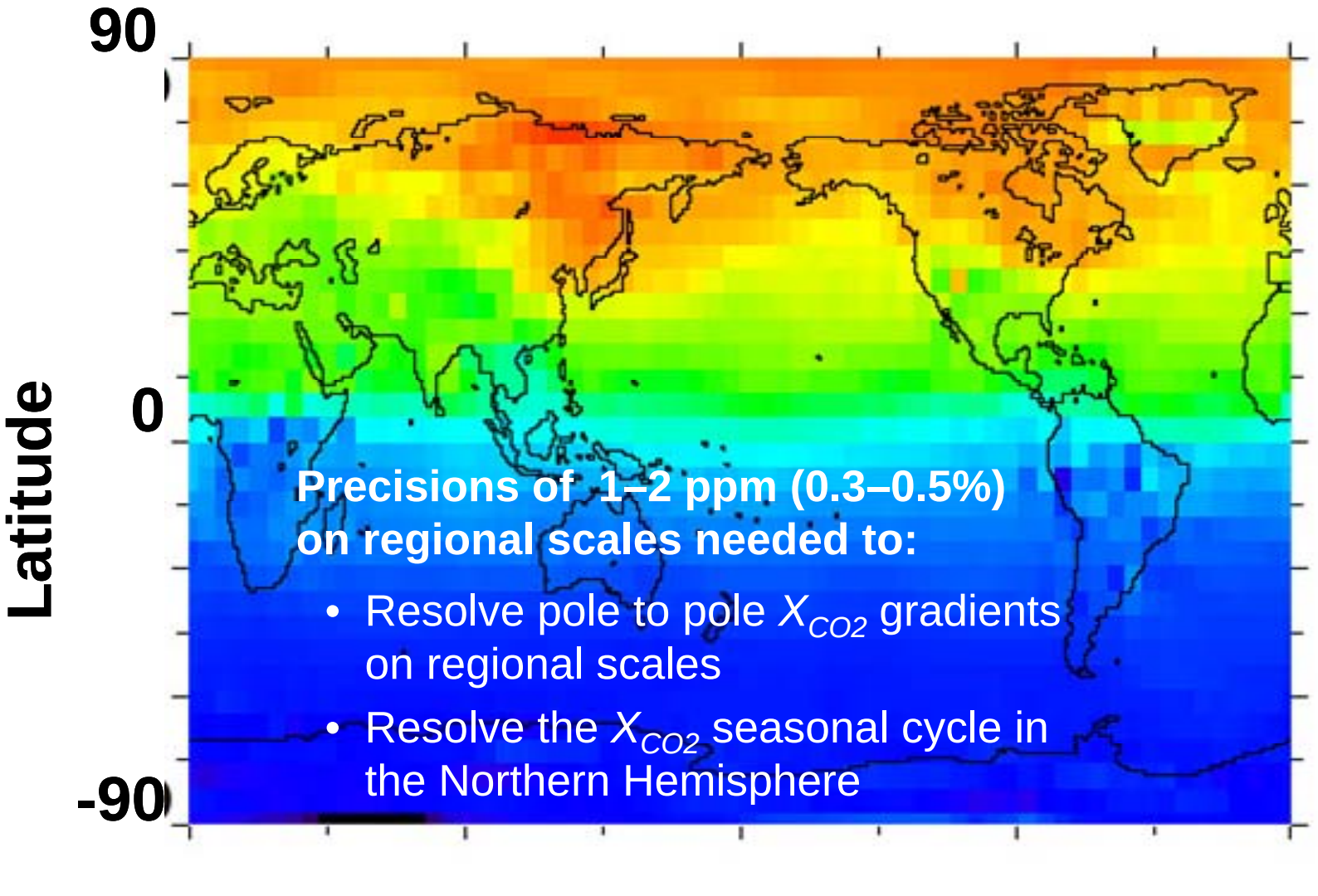
OCO Will Fly in the A-Train



OCO files at the head of the A-Train, 12 minutes ahead of the Aqua platform

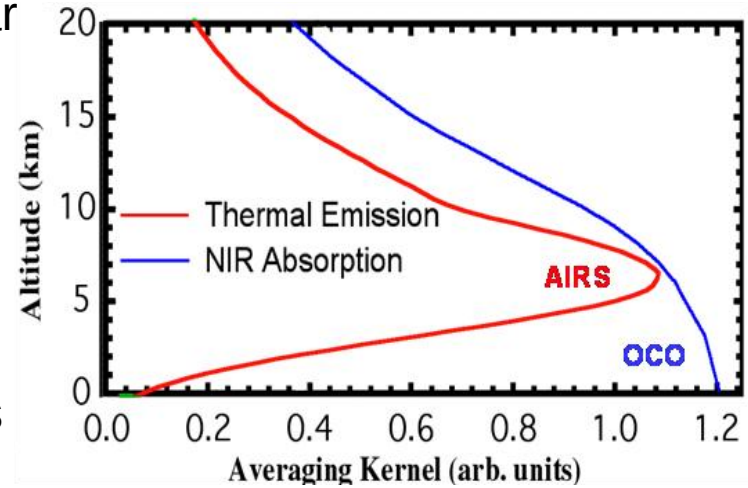
- 1:18 PM equator crossing time yields same ground track as AQUA
- Near noon orbit yields high SNR CO_2 and O_2 measurements in reflected sunlight
- CO_2 concentrations are near their diurnally-averaged values near noon
- Maximizes opportunities of coordinated science and calibration activities

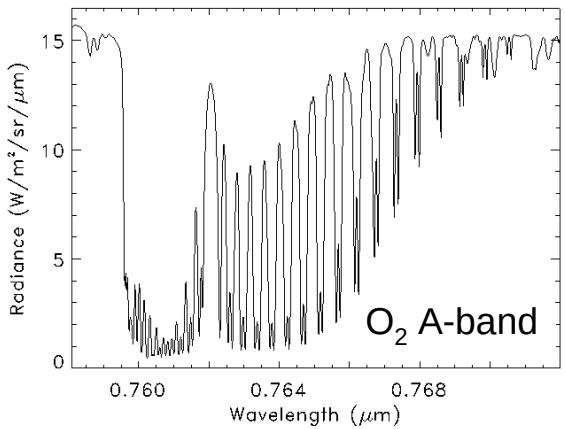
Precise CO_2 Measurements Needed to Constrain Surface Fluxes



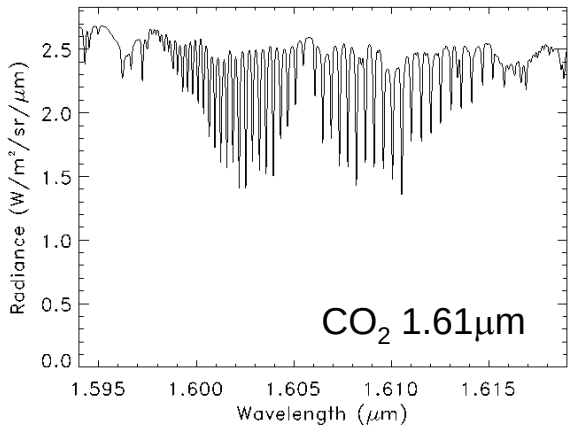
Making Precise CO_2 Measurements from Space

- 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}
  - 1.61 μm CO_2 bands – Column CO_2 with maximum sensitivity near the surface
  - O_2 A-band and 2.06 μm CO_2 band
    - Surface pressure, albedo, atmospheric temperature, water vapor, clouds, aerosols
- Why high spectral resolution?
  - Enhances sensitivity, minimizes biases

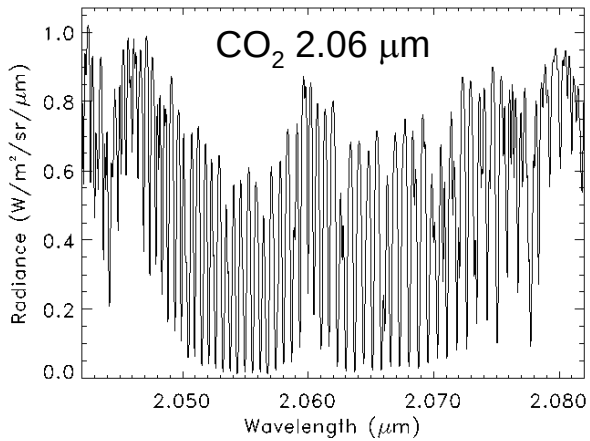




Clouds/Aerosols, Surface Pressure



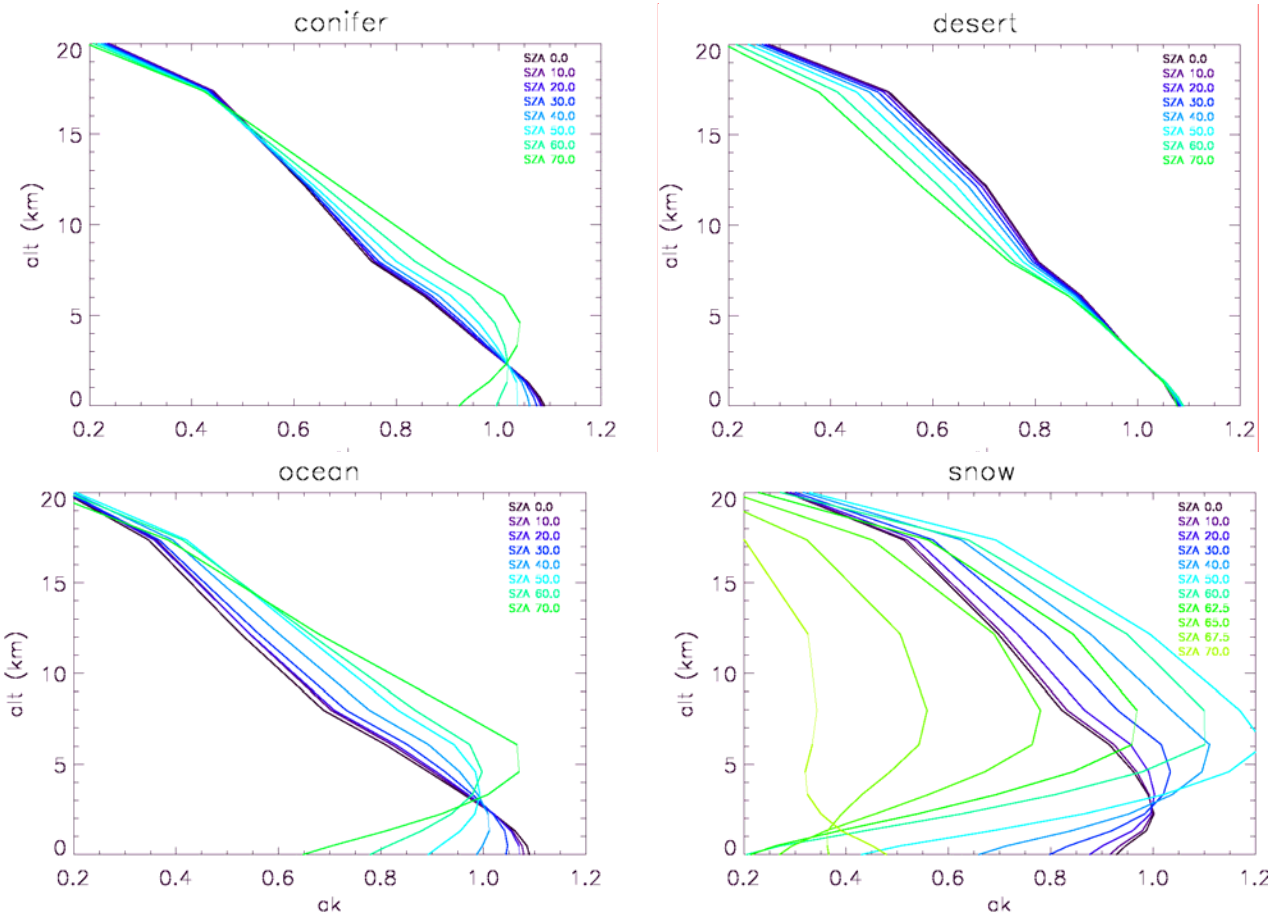
Column CO_2



Clouds/Aerosols, H_2O, Temperature

Early Support for Source/sink inversions

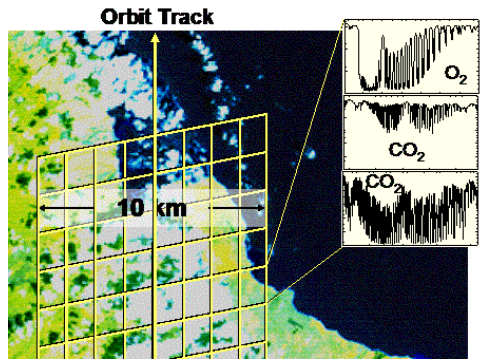
OCO characterization for Key Environmental Parameters (SZA, surface type)

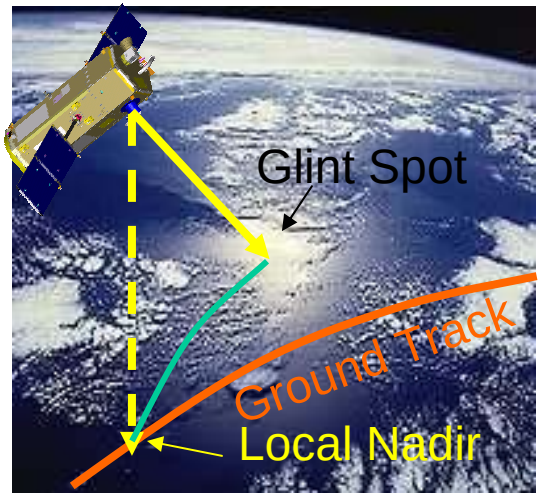


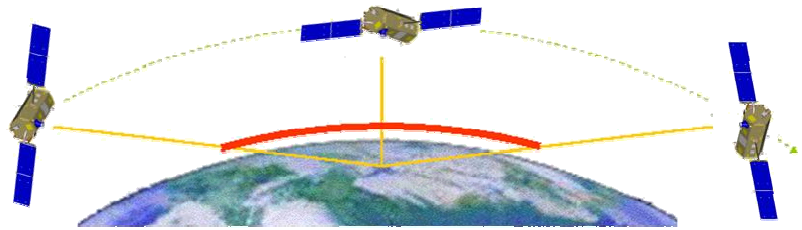
- Study effect on X_{CO2} biases on CO_2 source/sink inversions
- Rehearsal of ingesting OCO X_{CO2} (early feedback on L2 product)

OCO Observing Strategy

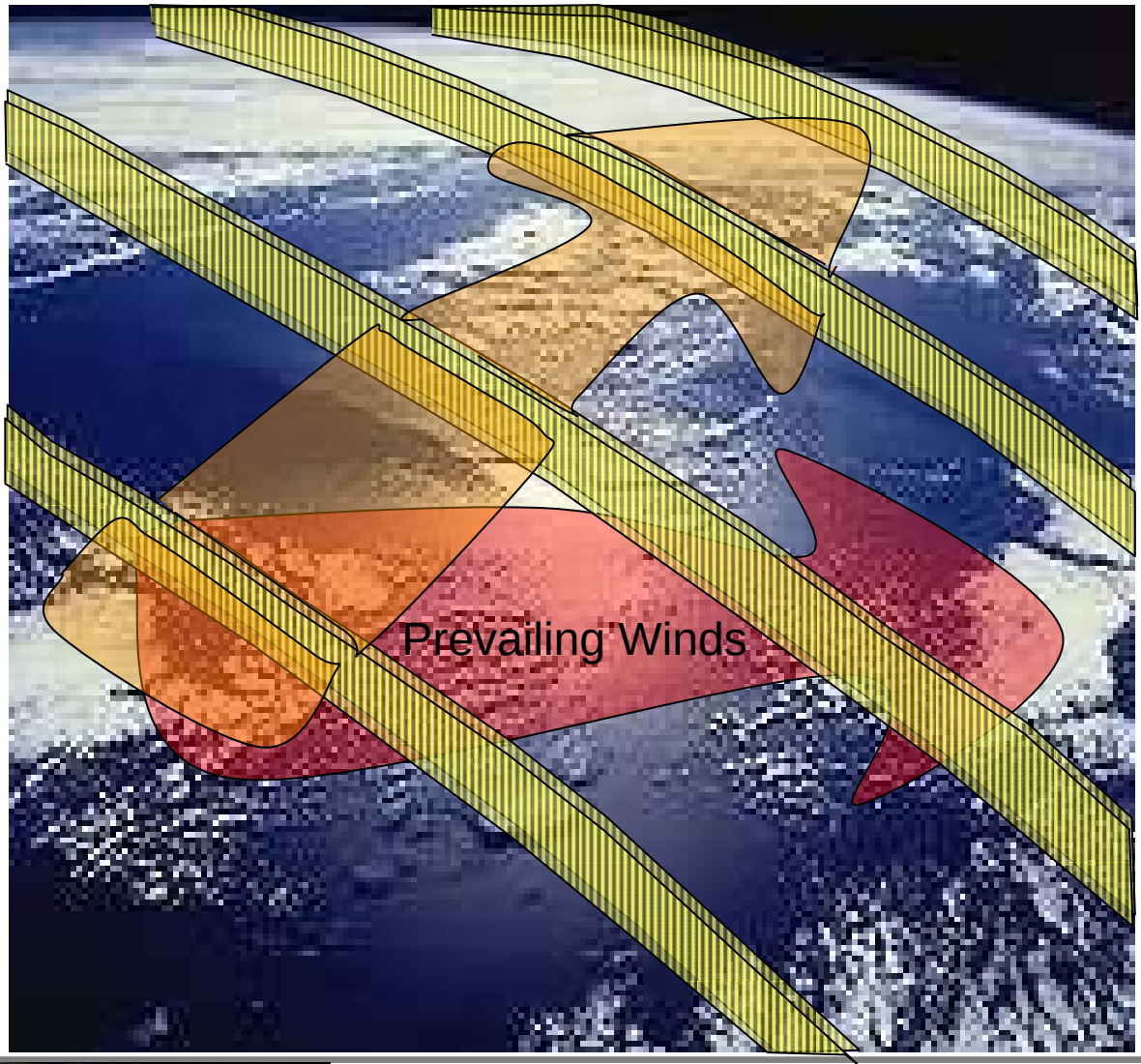
- Nadir Observations: tracks local nadir
  - + Small footprint (< 3 km^2) isolates cloud-free scenes and reduces biases from spatial inhomogeneities over land
  - Low Signal/Noise over dark ocean
- Glint Observations: views "glint" spot
  - + Improves Signal/Noise over oceans
  - More interference from clouds
- Target Observations
  - Tracks a stationary surface calibration site to collect large numbers of soundings
- Data acquisition schedule:
  - alternate between Nadir and Glint on 16-day intervals
  - Acquire ~1 Target observation each day







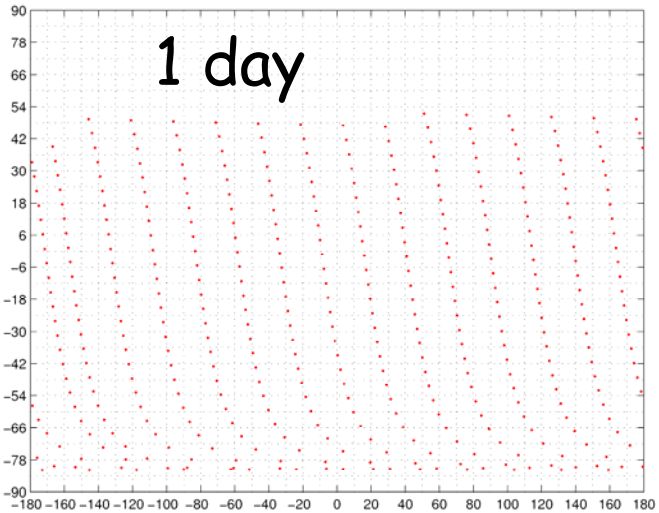
OCO Sampling over a 16-Day Repeat Cycle

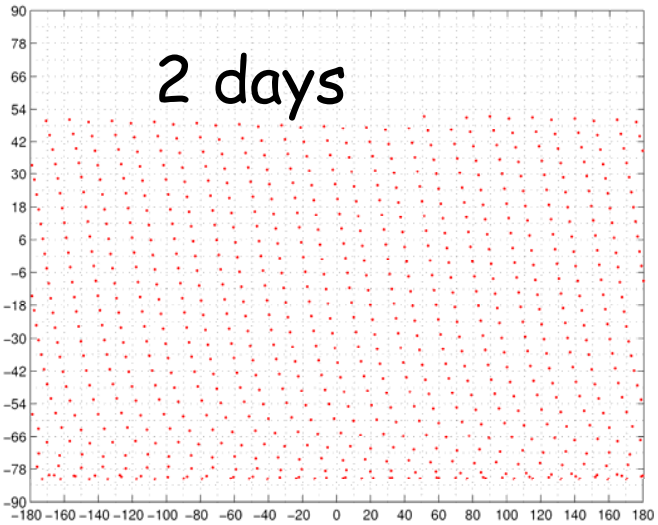


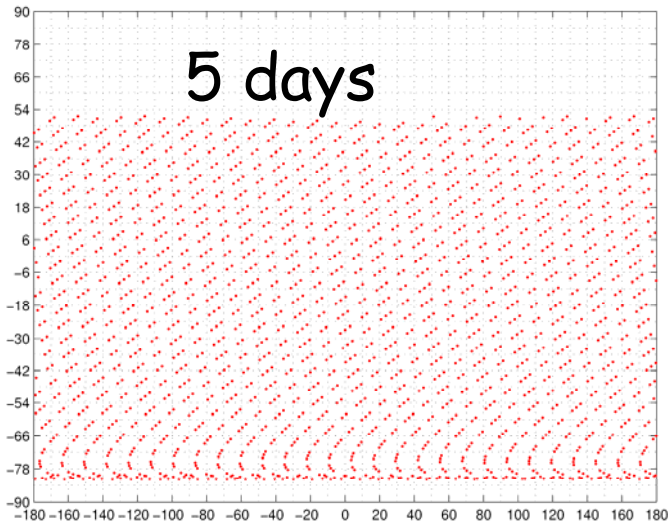
- OCO collects ~7-14 million soundings per 16-day cycle
  - 10-25% cloud free
- Sampling Rate/Coverage
  - 12-24 samples/second collected along track over land and ocean
  - Glint: ±75o SZA
  - Nadir: ±85o SZA
  - Longitude resolution 1.5^{o}

- CO_2 column measurements complement surface measurement network.
  - CO_2-rich (poor) air carried over surface sites will not be missed by high density column measurements.

OCO Sampling

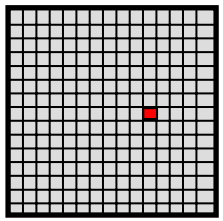




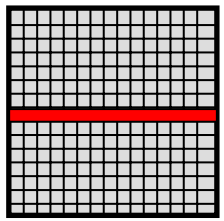


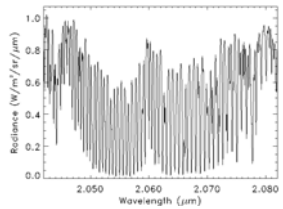
OCO orbit ground tracks and 6°x10° grid boxes (January)

OCO Data Hierarchy

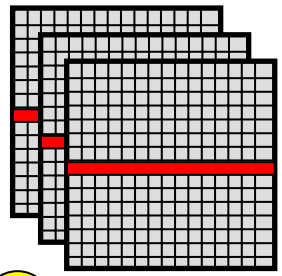


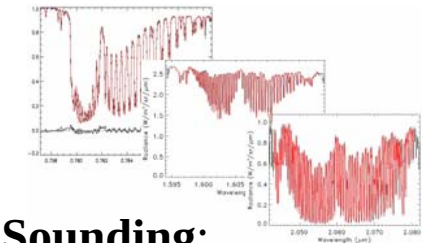
1 **Pixel**



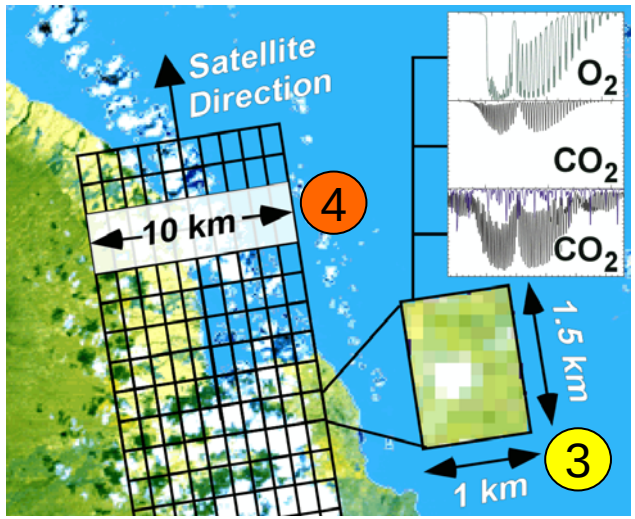


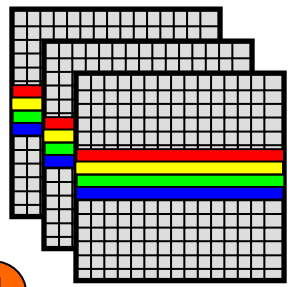
2 **Spectrum**



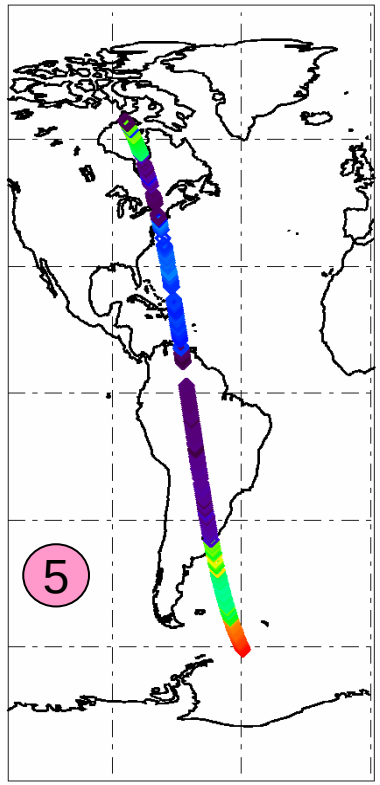


3 **Sounding**: 3 Collocated Spectra





4 **Frame**: 4 (8) Cross-Track Soundings



Granule: All ~30,000 Soundings recorded each orbit

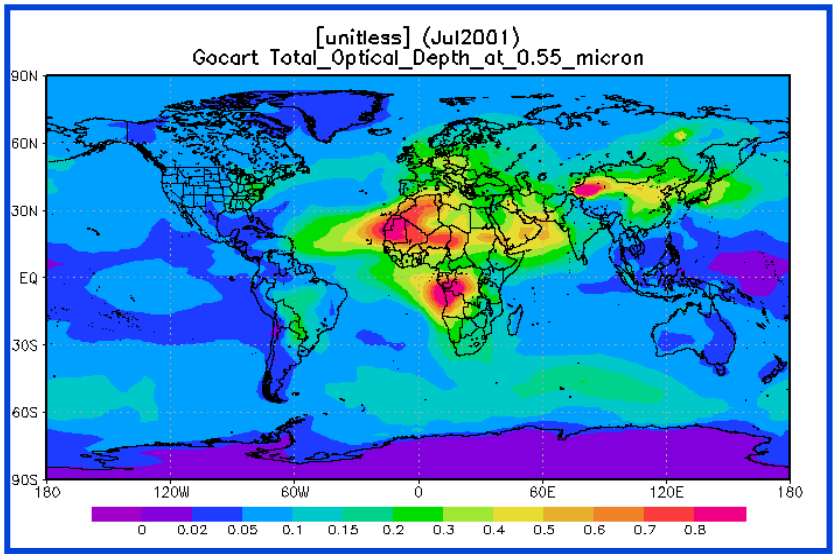
Current Best Estimate Signal / Noise

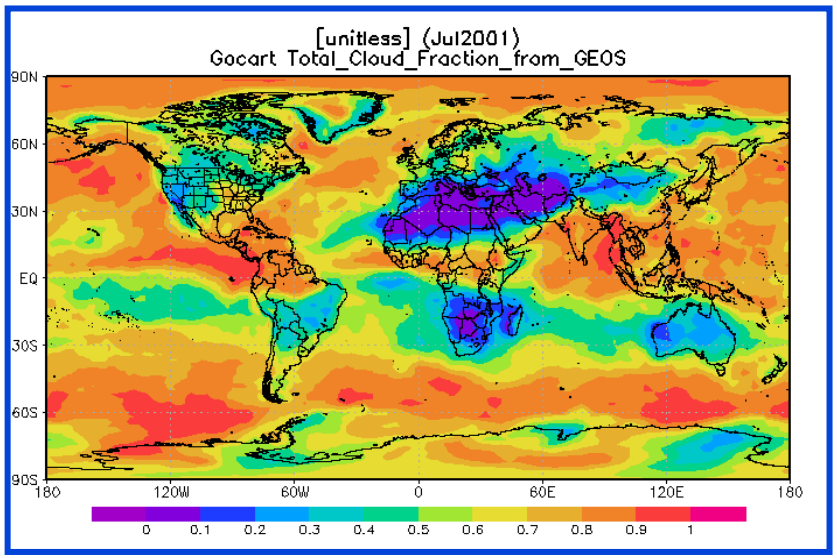
	Wavelength	Minimum Detectable Signal			Nominal Signal		
	microns	*e-/pixel/ frame*	*SNR*	*Margin*	*e-/pixel/ frame*	*SNR*	*Margin*
O_2 A-Band	0.758	14.3	4.63	363%	4971	474	32%
	0.765	12.1	4.24	324%	4210	467	30%
	0.772	9.4	3.70	270%	3280	455	26%
1.61 μm CO_2	1.594	10.7	3.65	265%	3429	364	46%
	1.607	9.3	3.40	240%	2982	361	44%
	1.619	7.6	3.05	205%	2433	353	41%
2.06 μm CO_2	2.042	15.5	4.07	307%	2699	304	69%
	2.062	15.1	4.31	331%	2636	325	80%
	2.082	9.6	3.12	212%	1683	279	55%

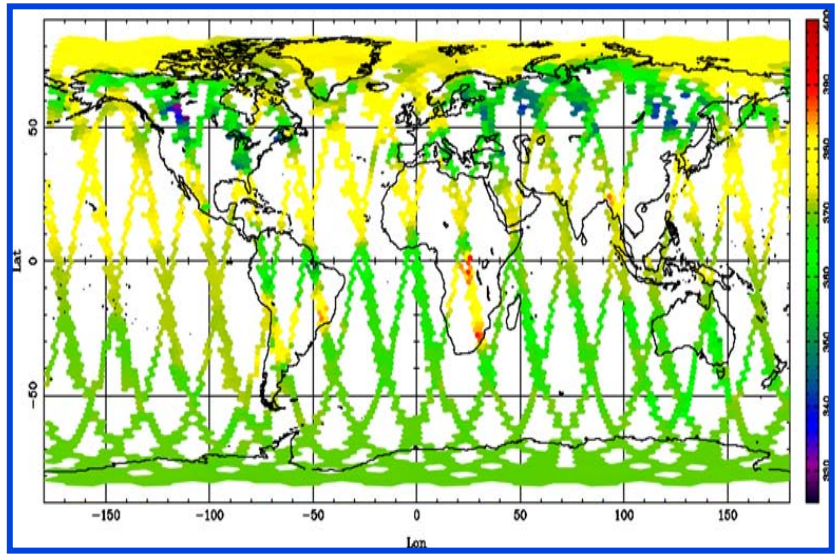
Read-noise Limited
margin is ~linear in read-noise

Photon Limited
Transmission Margin Proportional to Margin Squared

Sampling Constraints



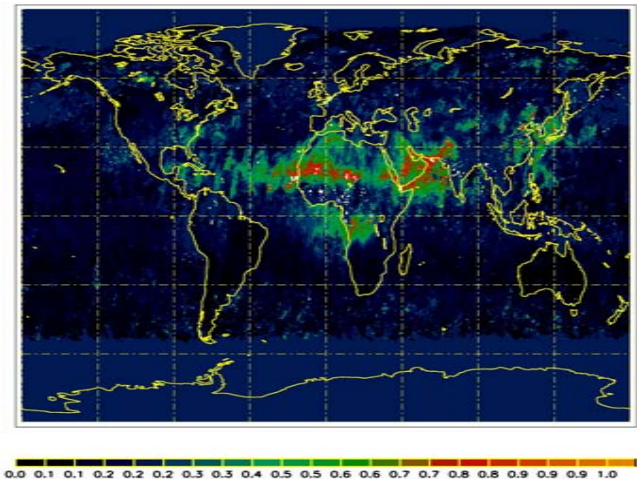




- Aerosols
- Clouds
- Satellite track
- Maximum (sub)sampling rate
- Albedo
- Measurement error
- Temporal aggregation
- Others?

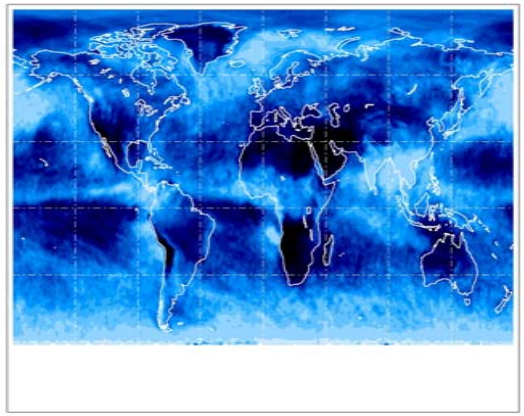
Aerosol and Clouds

MISR Aerosol Product

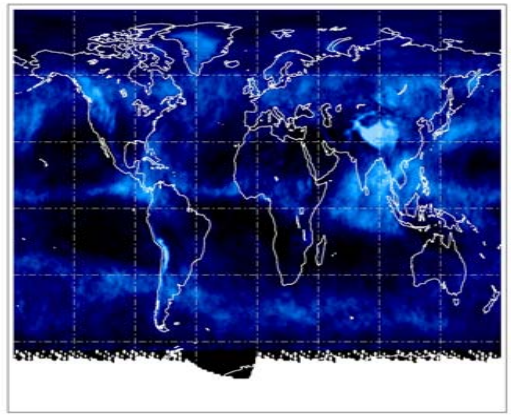


Monthly Mean Aerosol Optical Depth

MODIS Cloud Product



Monthly Mean Water Cloud Fraction



Monthly Mean Cirrus Cloud Fraction

- **Improved scheme:** Aerosol optical depth and thin cirrus will have significant impact on characterization and error budget (adds more complexity to scheme)
- **Statistics:** OCO soundings will not be retrieved in the presence of clouds and aerosol optical depth > 0.3 (large variability in amount of retrievable OCO spectra)

Data Product Definition

- **Four major products in the process**
  - **Level 0 - Packetized science and optical housekeeping data**
    - Removed spacecraft packet information for data transfer to ground
  - **Level 1A - Parsed and merged science and instrument housekeeping telemetry**
    - Data subdivided into discretely named elements
    - Corresponding data from all three spectrometers correlated in a single frame
    - Corresponding temperature and voltage measures from housekeeping merged into appropriate frame
  - **Level 1B - Spatially ordered, Earth located, calibrated spectra**
    - Software Interface Specification Document (JPL D-27861)
  - **Level 2 - Geolocated retrieved state vectors with CO_2 column averaged dry air mole fraction**
    - Software Interface Specification Document (JPL D-27862)

Current OCO Data Product Volumes

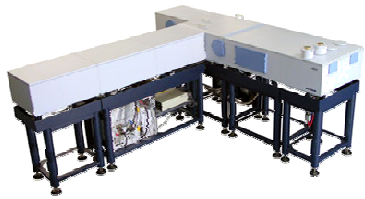
Product	Single Product Volume (MBytes)	Daily Volume (Gbytes)	Mission Volum (Tbytes)
Science Telemetry		4.843	3.455
Housekeeping Telemetry		0.186	0.133
OCO Level 0	310.281	4.406	3.141
OCO Level 1A	315.429	4.479	3.193
OCO Level 1B	640.184	9.090	6.480
Level 2	15.922	0.226	0.161
Total		23.230	16.563

- **The above estimates assume that the GDS retains just a single instance of each data product**
  - **Recognizing that multiple versions of the data are inevitable, the estimated volume required for OCO products alone is about 30 TBytes.**
  - **Level 2 Product volume reflects the size of the distributable product**
    - Product for Science Team expert will include spectral residuals
    - Expert product is about 55.7 Gbytes per orbit, or about 0.79 Gbytes per day

Space-based X_{CO2} Validation Strategy

Validate space-based X_{CO2} using:

- Measurements of X_{CO2} from ground based Fourier transform spectrometers (FTS)
- FTS and space-based X_{CO2} processed using same retrieval code

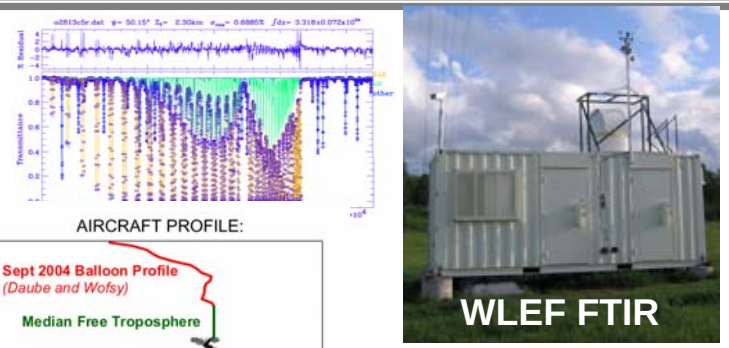


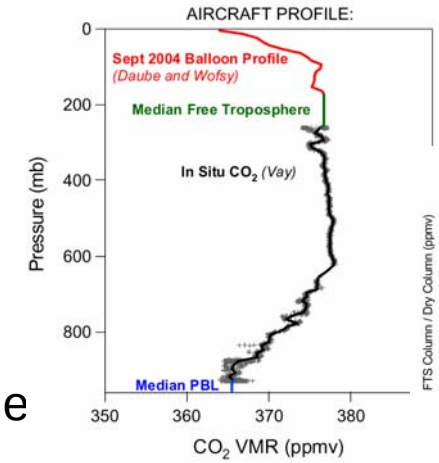
FTS X_{CO2} compared to:

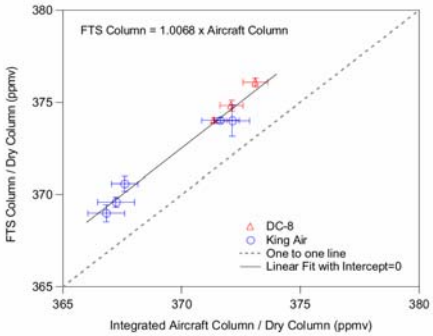
- Surface in situ CO_2
- Tall tower in situ CO_2
- Column CO_2 integrated from in situ profile

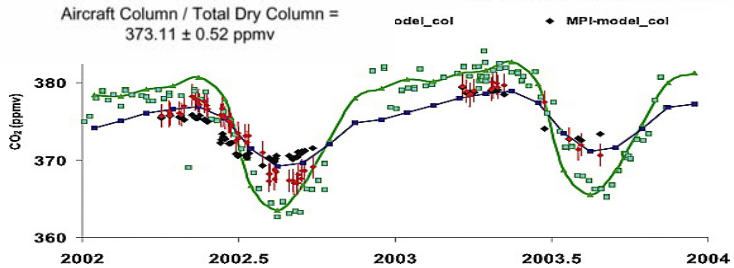
FTS X_{CO2} performance tracked via monitoring of:

- Instrument Line Shape (HCl gas cell)
- Pointing (Doppler shift, telluric vs solar features)
- XO_2, surface pressure and H_2O









Observations at 79°N (Spitsbergen) FTS
Notholt et al., GRL, 2005

It is essential that OCO and GOSAT use a common validation network

Summary and Schedule

- 7/2001: Step-1 Proposal Submitted
- 2/2002: Step-2 Proposal Submitted
- 7/2003: Selected for Formulation
- 7/2004: System PDR
- 5/2005: Mission Confirmed for Implementation
- 10/2005: Instrument CDR
- 2/2006: Spacecraft CDR < ESA 3rd Party Mission
- 7/2006: MOS/GDS CDR
- 8/2006: System CDR
- 2-4/2007: Instrument Testing
- 5/2007: Instrument Delivery to SC
- 10/2007: Observatory Integration begins
- 6/2008: Launch Vehicle Integration begins
- 9/2008: Launch from VAFB
- 10/2010: End of Nominal Mission