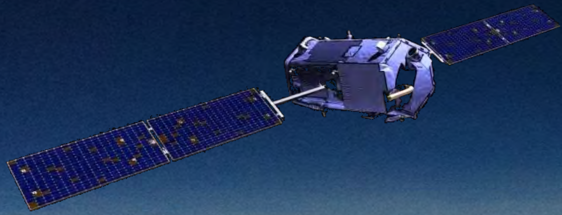


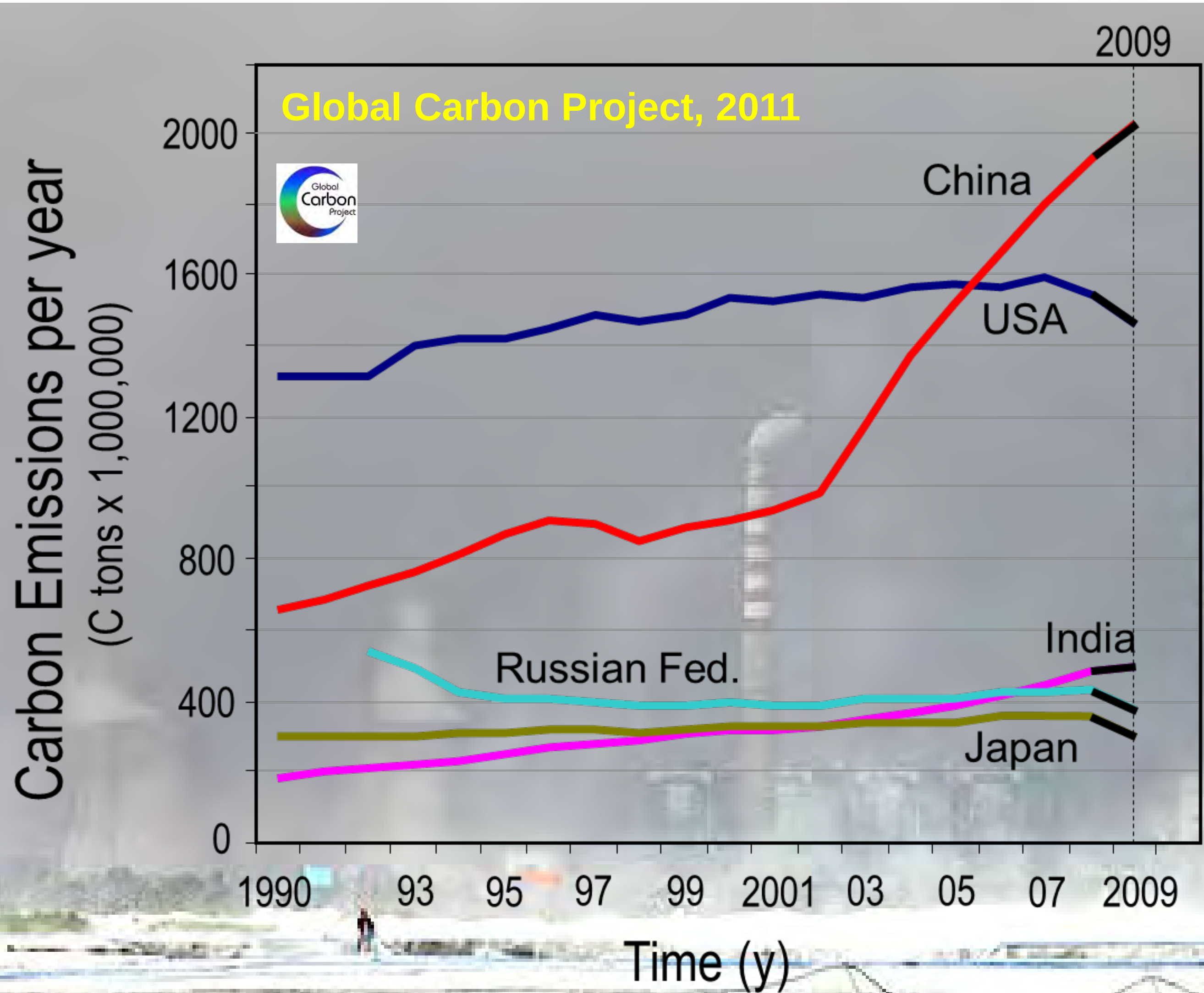
Measuring Carbon Dioxide from the A-Train: The OCO-2 Mission

David Crisp, OCO-2 Science Team Leader
for the OCO-2 Science Team

Jet Propulsion Laboratory, California Institute of Technology

March 2013

Fossil Fuel CO_2 Emissions: Top Emitters



In recent years, the largest increases in fossil fuel emissions have occurred in developing countries.

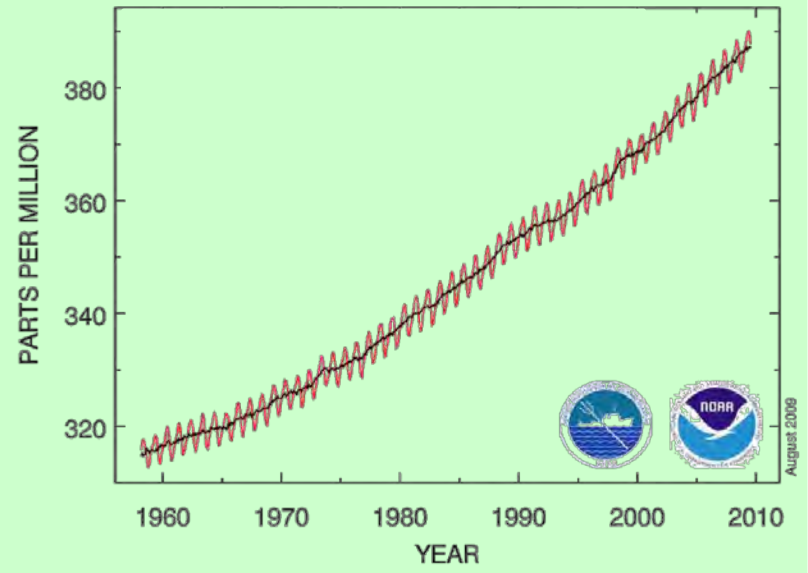
Emissions by some developed countries declined due to the global economic crisis.

China is now the largest single emitter, but its per capita emissions are still well below those in the U.S.

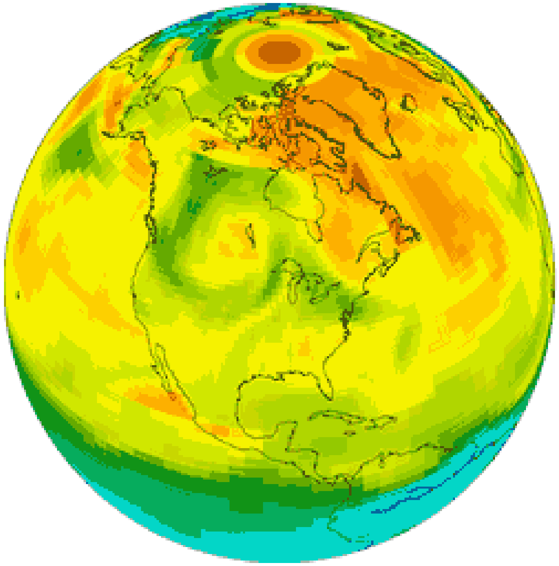
Global Measurements from Space are Essential for Monitoring Atmospheric CO_2

To limit the rate of atmospheric carbon dioxide buildup, we must
- Control emissions associated with human activities
- Understand & exploit natural processes that absorb carbon dioxide

We can only manage what we can measure

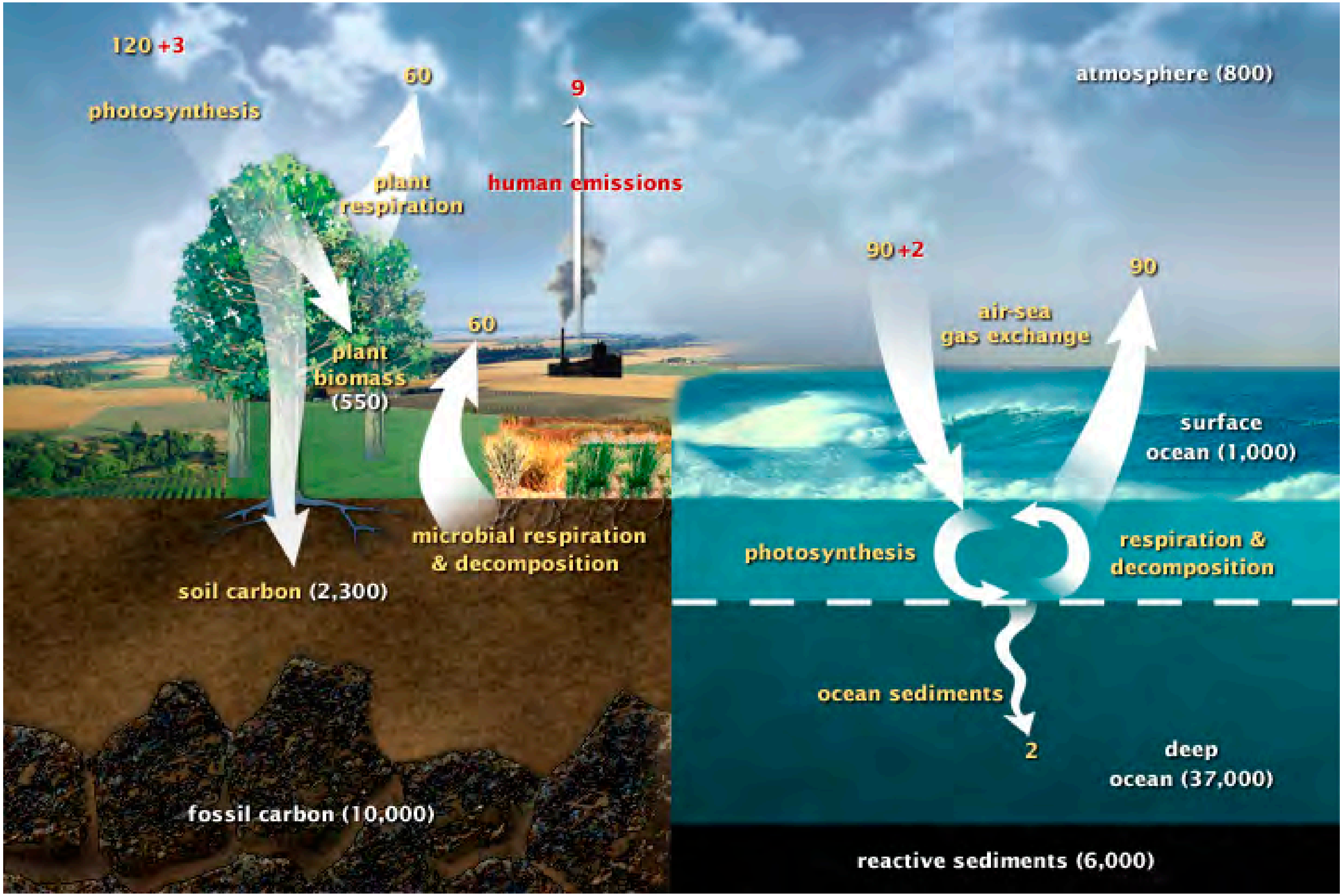


Ground-based measurements describe the global CO_2 trends.

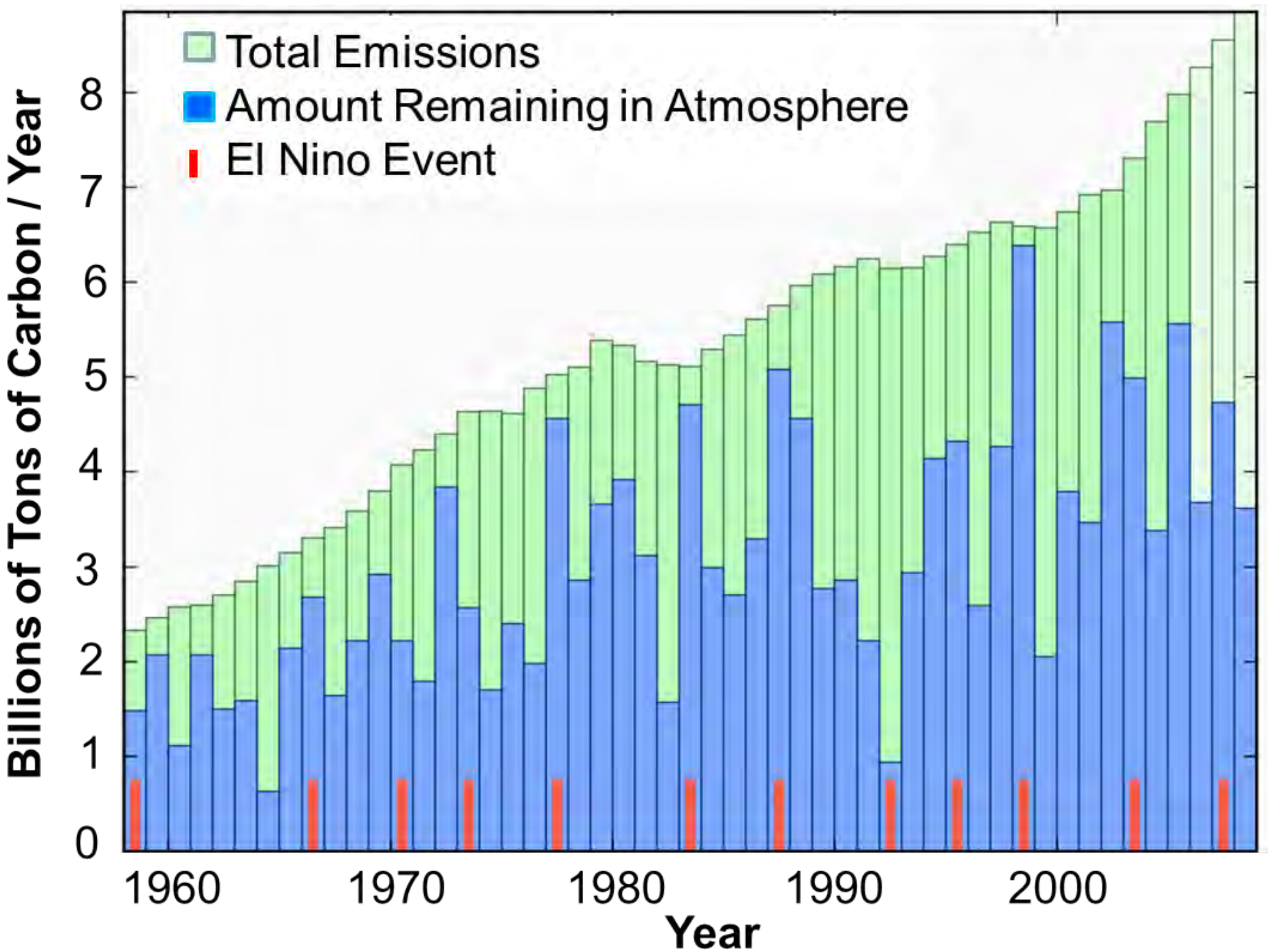


High resolution, space-based measurements are needed to discriminate its sources and sinks.

CO_2 is a Component of the Carbon Cycle



What Processes Regulate CO_2 Absorption?



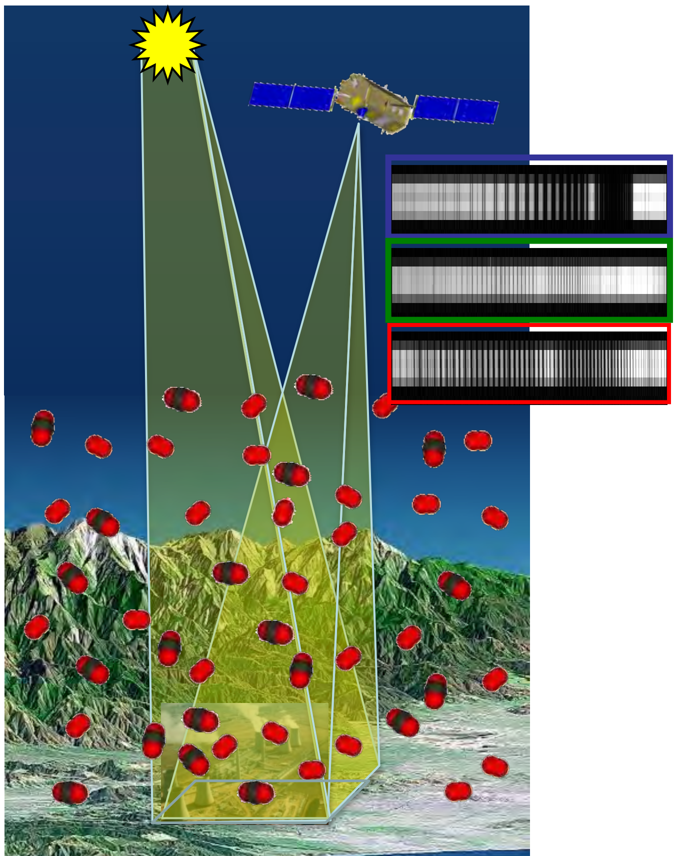
What natural processes are currently absorbing almost half of the CO_2 emitted by human activities?

Why does the amount of CO_2 that stays in the atmosphere change so much from year to year?

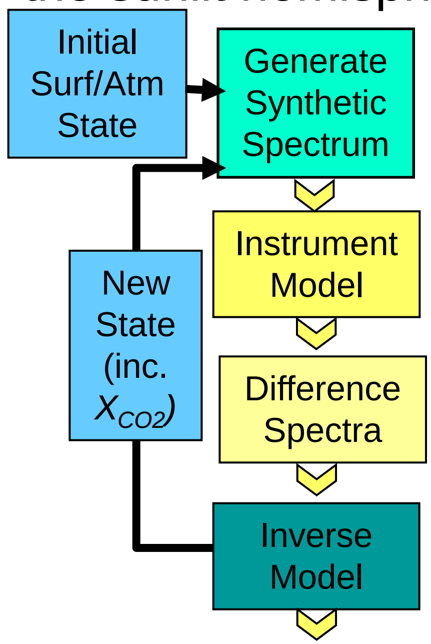
We don't know.

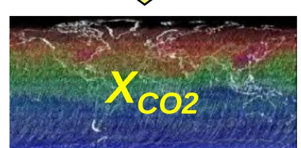
Measuring CO_2 from Space

- **Record** spectra of CO_2 and O_2 absorption in reflected sunlight



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

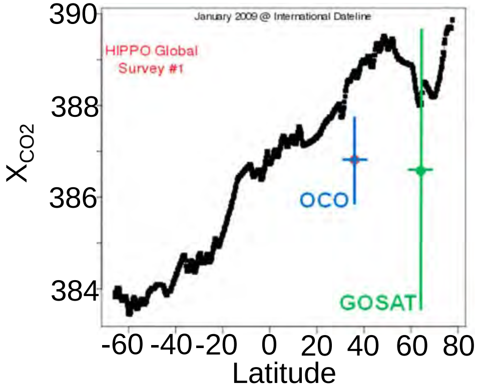


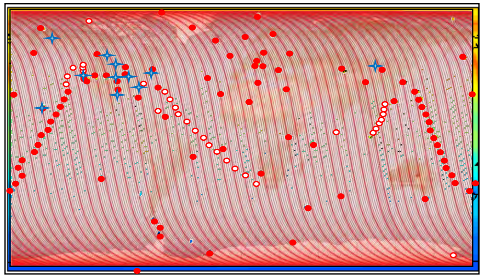


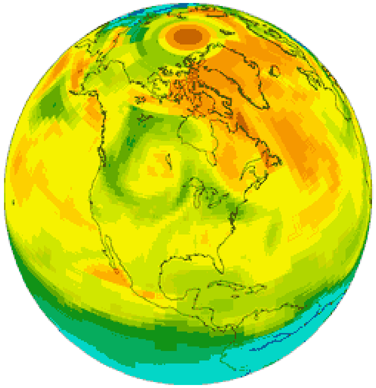
- **Validate** measurements to ensure X_{CO2} accuracy of 1 - 2 ppm (0.3 - 0.5%)

Driving Requirements for Space-based CO_2 Measurements

- Precision and accuracy
  - High precision required to resolve small (0.2-0.3%) variations in CO_2 associated with sources and sinks
  - High accuracy essential to avoid regional-scale biases
- Spatial coverage
  - Nadir and glint observations are needed to yield useful observations over both continents and ocean
- Spatial resolution and sampling
  - Sensitivity to point sources scales with area of footprint
  - Small measurement footprints reduce data losses due to clouds
- Temporal sampling
  - Monthly measurements required over > 1 year to resolve seasonal and inter-annual variability in CO_2







The Pioneers: GOSAT and OCO

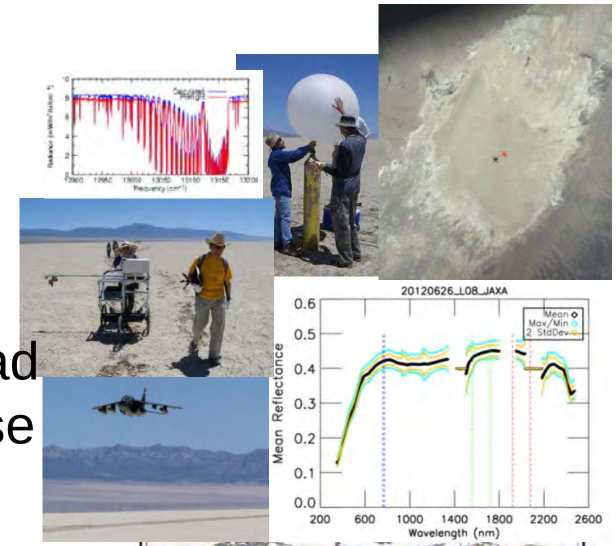
GOSAT launched successfully on 23 January 2009

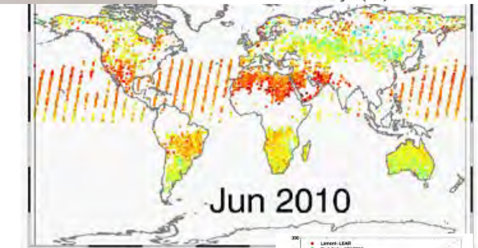
OCO was lost a month later when its launch system failed

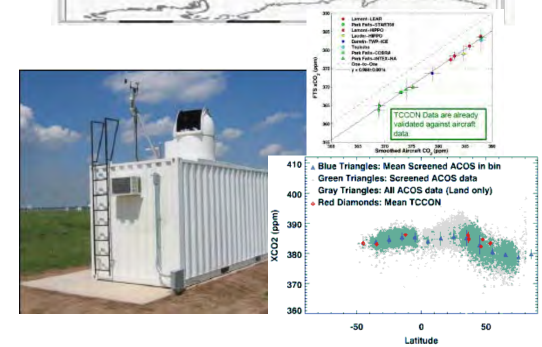
The ACOS/GOSAT Collaboration

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

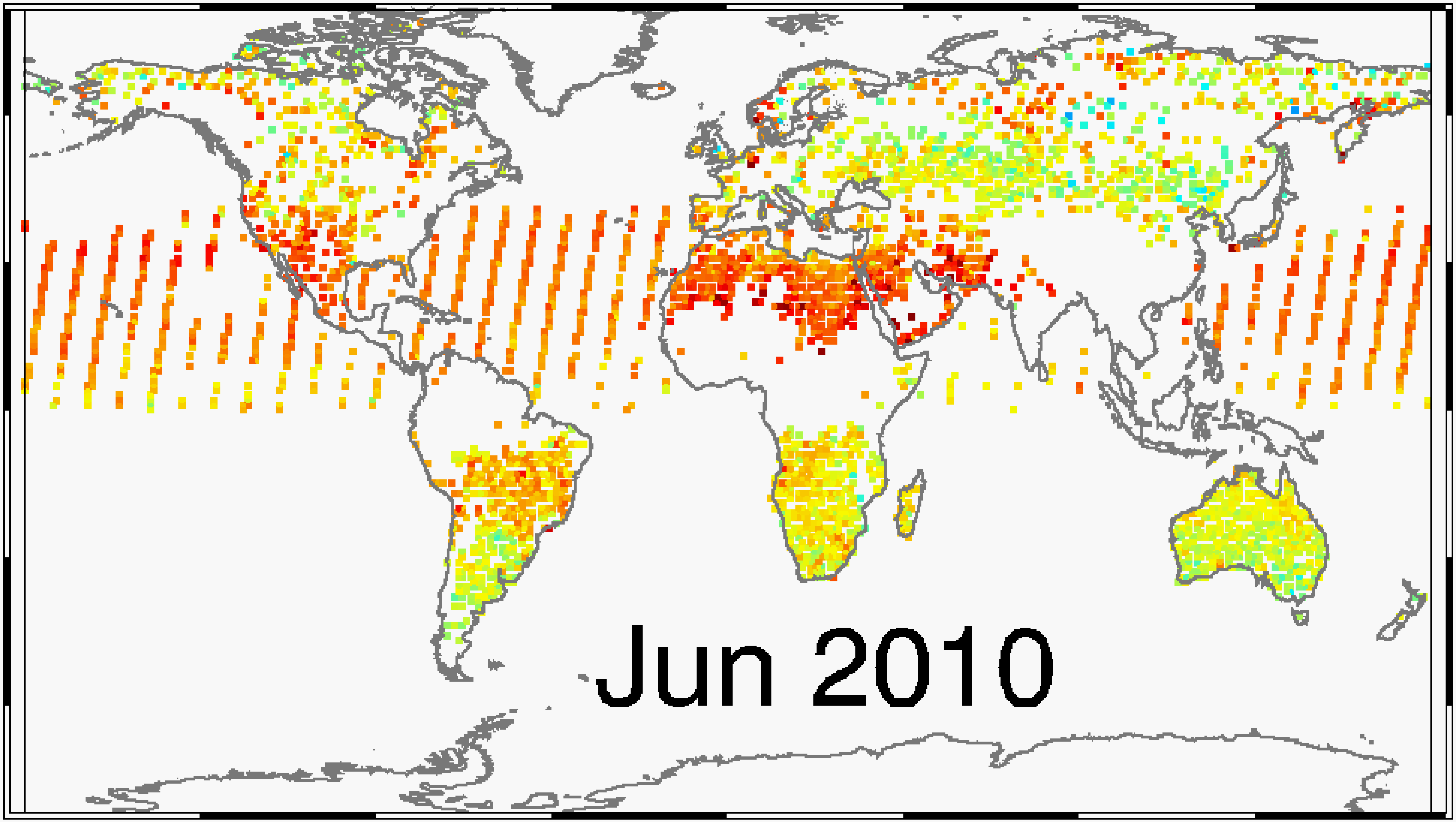
- Conduct vicarious calibration campaigns in Railroad Valley, Nevada, U.S.A. and analyze results of those campaigns
- Retrieve X_{CO2} from GOSAT spectra
  - Model development, and testing
  - Data production and delivery
- Validate GOSAT retrievals by comparing
  - GOSAT retrievals with TCCON measurements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



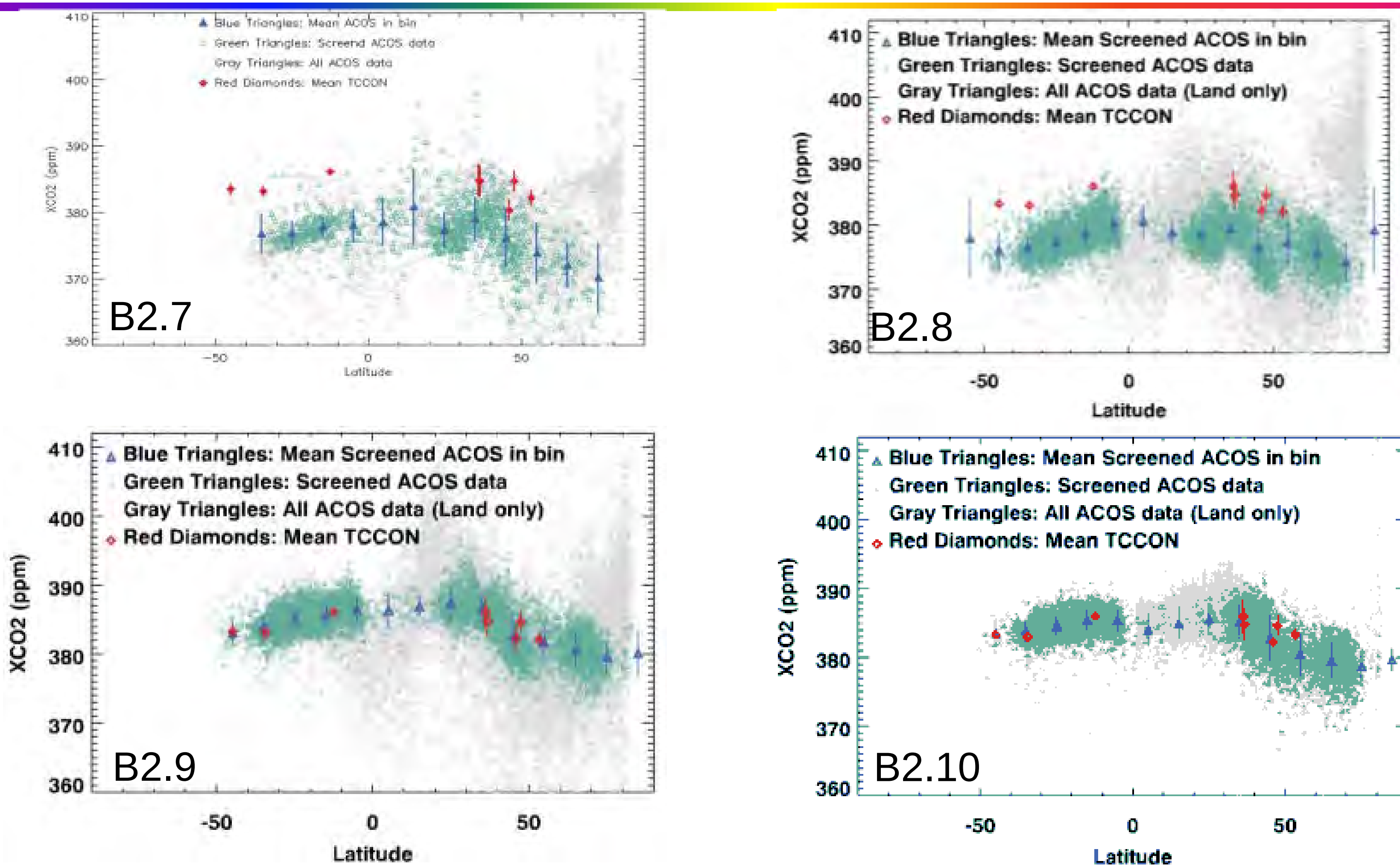




ACOS GOSAT B2.10 XCO2 Retrievals

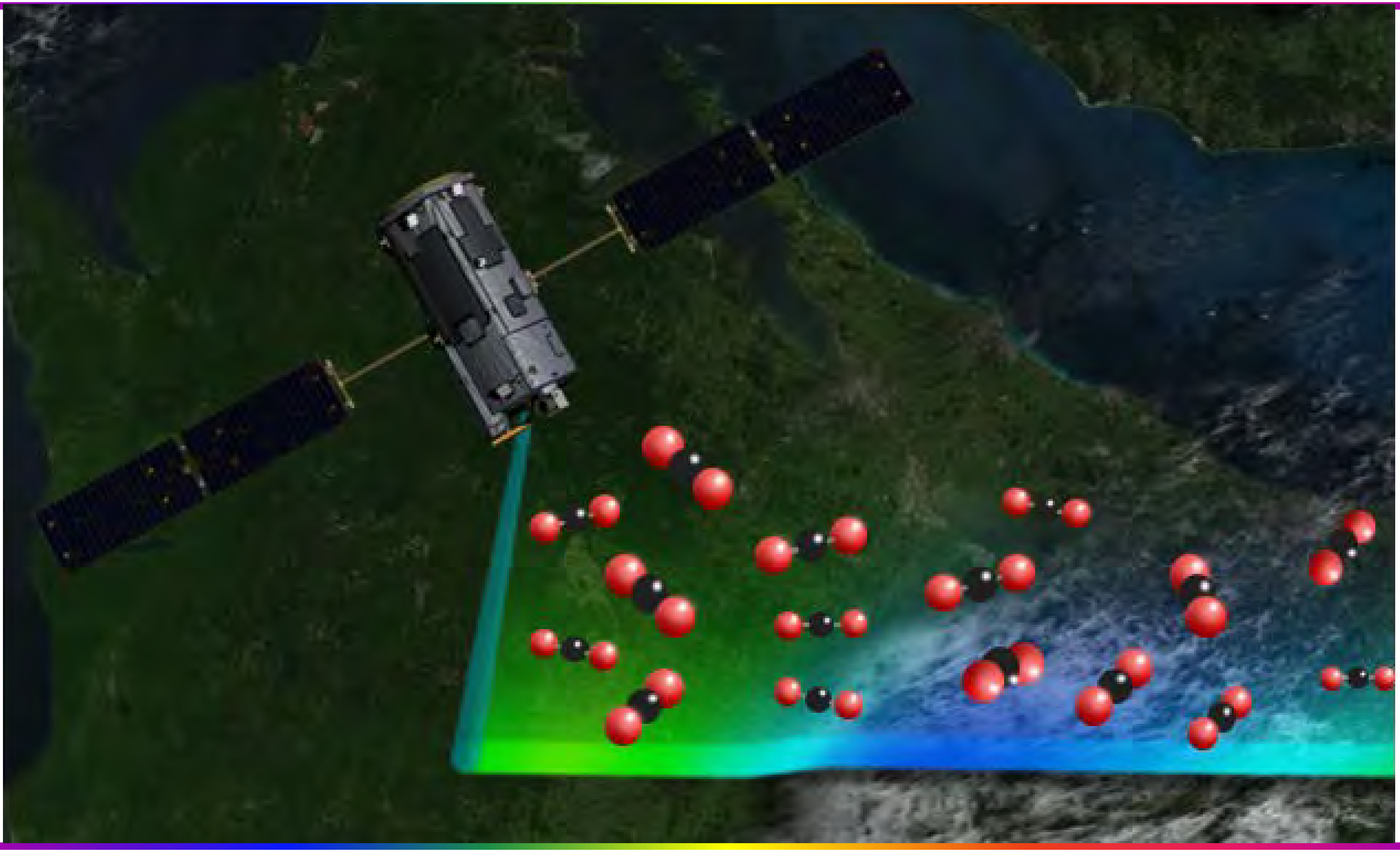


TCCON Comparisons Show Improvements in ACOS GOSAT X_{CO2} Bias and Random Error



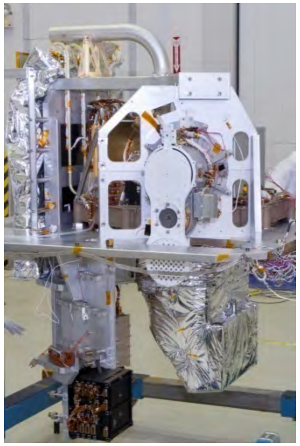
Zonal profiles of ACOS/GOSAT XCO2 estimates (green and grey triangles) are compared to the monthly mean XCO2 estimates from TCCON stations (red diamonds) for July 2009. The precision (scatter), bias, and yield of the ACOS/GOSAT products have improved over time (Crisp et al. 2011).

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



The OCO-2 Mission Overview

3-Channel Grating Spectrometer (JPL)



Dedicated Spacecraft Bus (OSC)

Delta-II Launch Vehicle

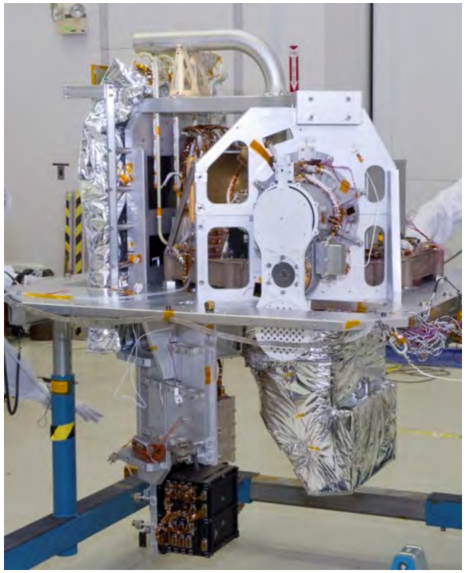
Mission Operations (OSC)

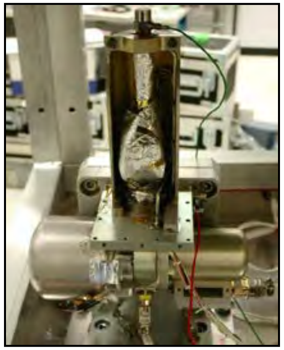
Formation Flying as Part of the A-Train Constellation

NASA NEN (GSFC) and SN (TDRSS)

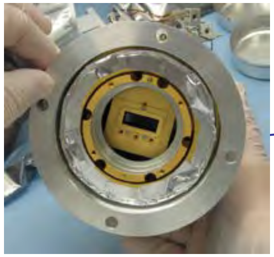
The OCO Instrument – Optimized for Sensitivity

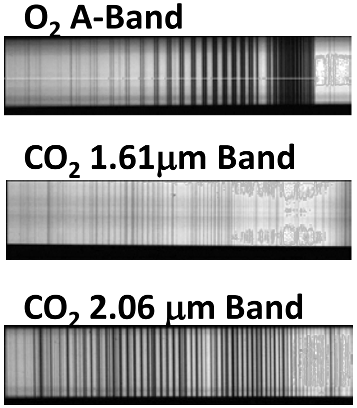
- 3 co-bore-sighted, high resolution, imaging grating spectrometers
  - Resolving Power ~20,000
  - High Signal-to-Noise Ratio
  - Collects 4 to 8 cross-track footprints at 3 Hz

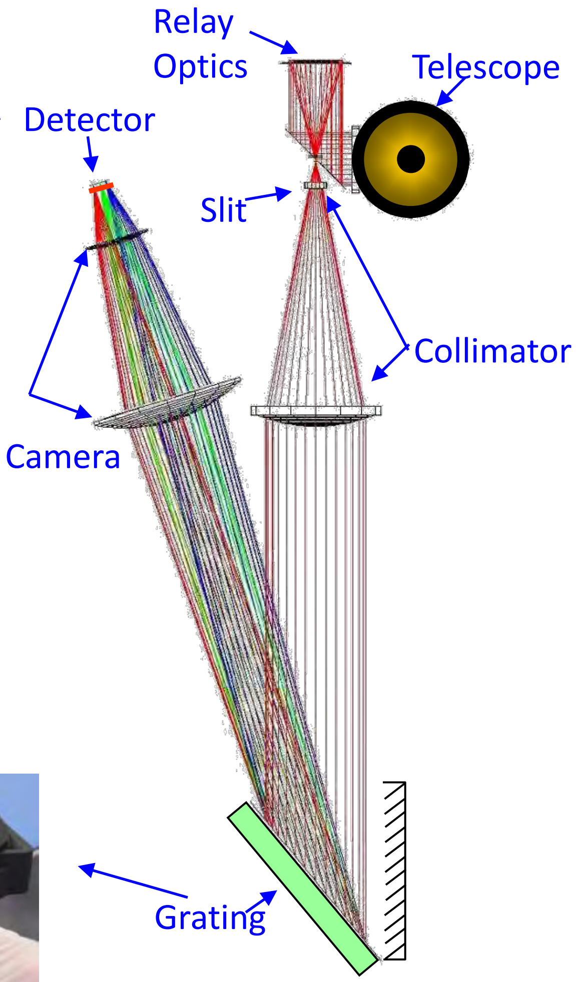


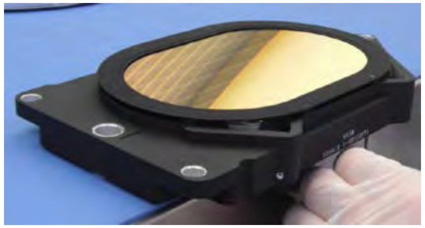


Cryocooler





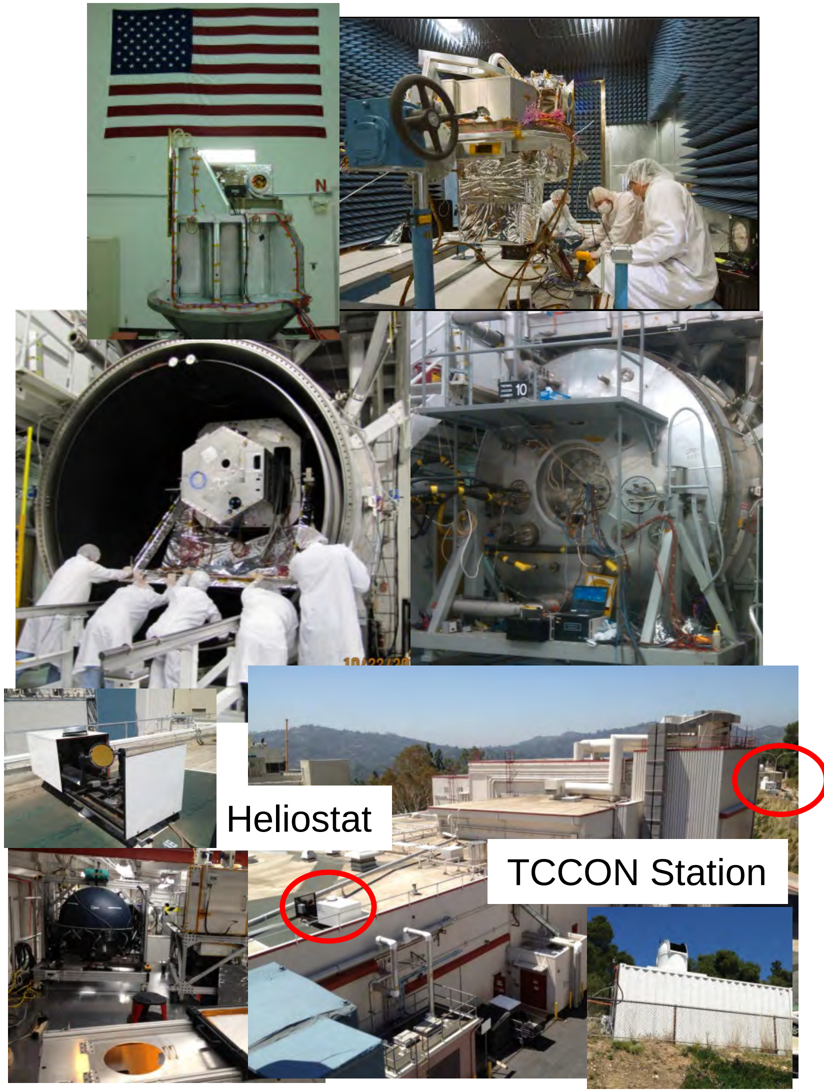




key components of each channel.

Pre-Flight Instrument Calibration and Characterization

- Pre-flight testing quantifies key Instrument performance and knowledge parameters
  - Geometric
    - Field of view, Bore-sight alignment
  - Radiometric
    - Zero-level offset (bias)
    - Gain, Gain non-linearity
  - Spectroscopic
    - Spectral range, resolution, sampling
    - Instrument Line Shape (ILS)
  - Polarization
  - Instrument stability
- Pre-flight instrument characterization and calibration completed in April 2012



Observatory I&T Activities Ongoing

The instrument has now been integrated with the spacecraft bus to produce the Observatory. The first Observatory thermo-vacuum test was completed in 2012.

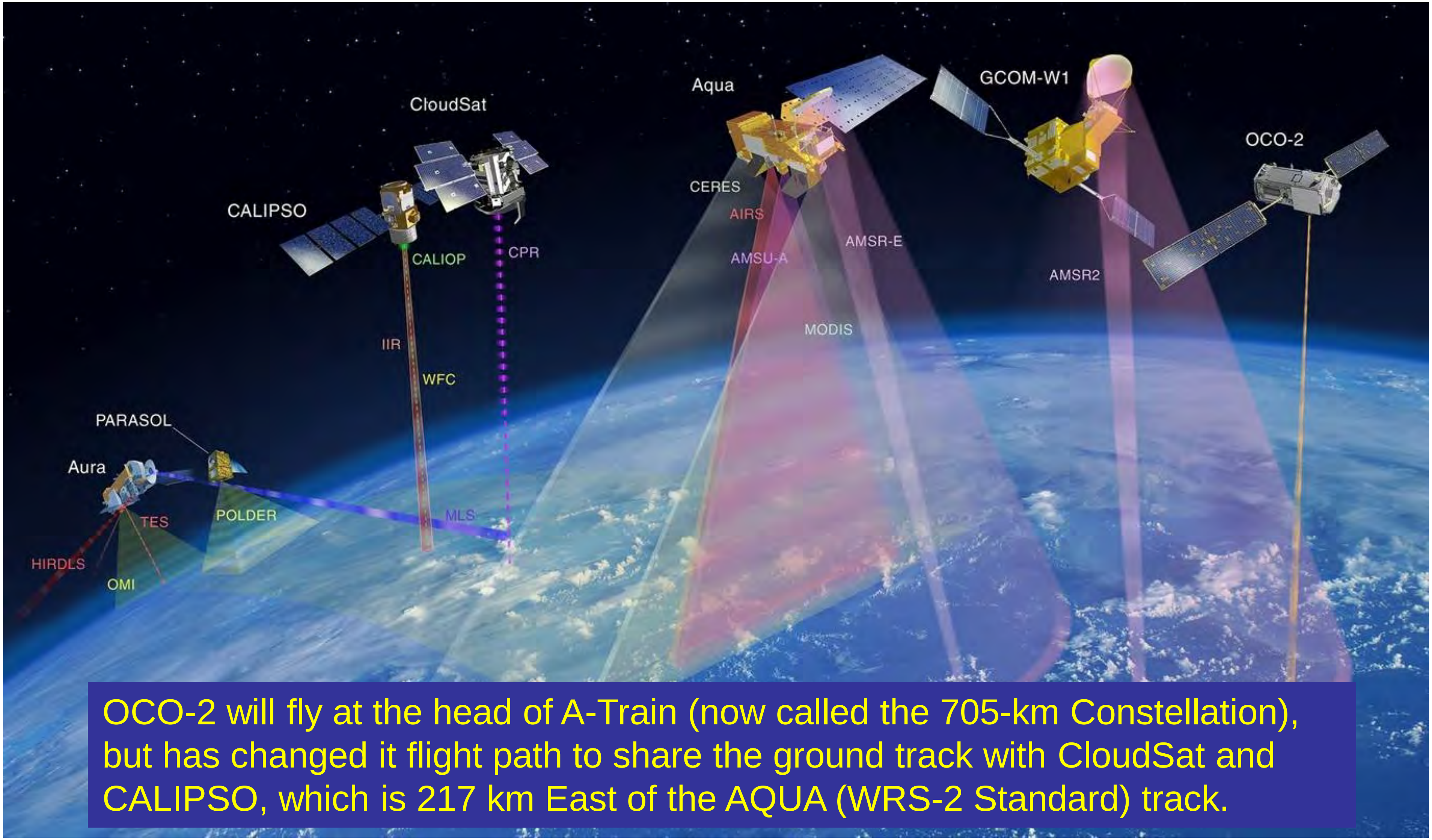
Launch Date Driven by Launch Service Availability

- OCO-2 will fly on a United Launch Alliance (ULA) Delta II 7320
  - Selected by NASA in July 2012, (along with launch vehicles for SMAP, JPSS-1, and Jason-3)

- The OCO-2 Team is currently working closely with ULA to accommodate OCO-2 on the Delta-II vehicle
  - Substantially different interface and launch environment
  - New plans are being made for ascent navigation and A-Train entry

- The nominal OCO-2 launch date is “no earlier than 1 July 2014”

Flying in Formation in the A-Train



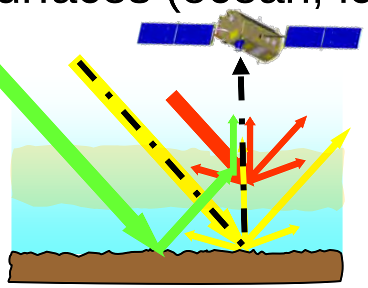
OCO-2 will fly at the head of A-Train (now called the 705-km Constellation), but has changed it flight path to share the ground track with CloudSat and CALIPSO, which is 217 km East of the AQUA (WRS-2 Standard) track.

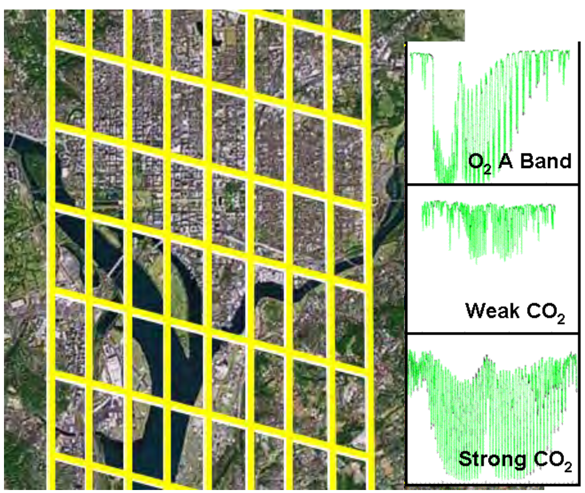
Observation Modes Optimize Sensitivity and Accuracy

Nadir Observations:

+ Small footprint (< 3 km²)

– Low Signal/Noise over dark surfaces (ocean, ice)

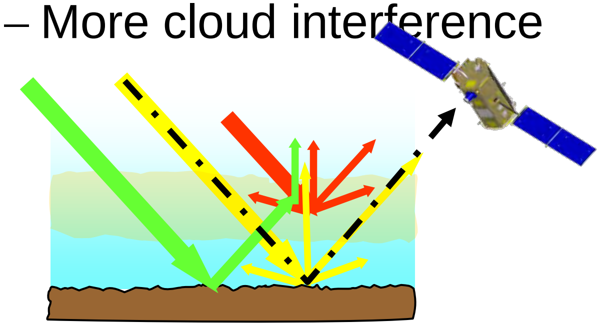


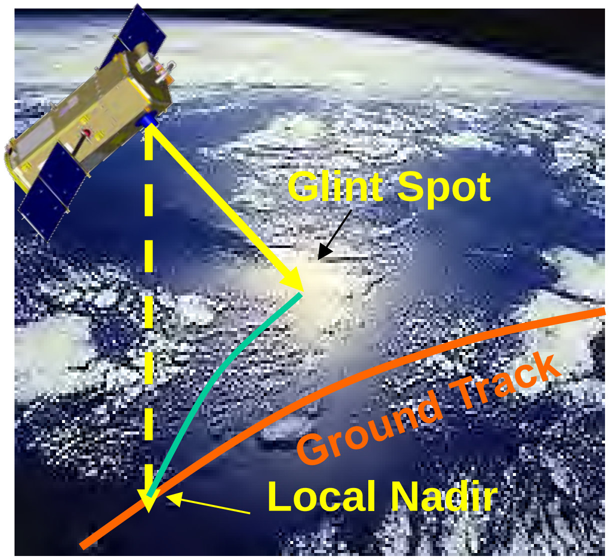


Glint Observations:

+ Improves Signal/Noise over oceans

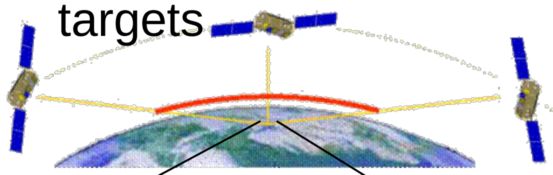
– More cloud interference

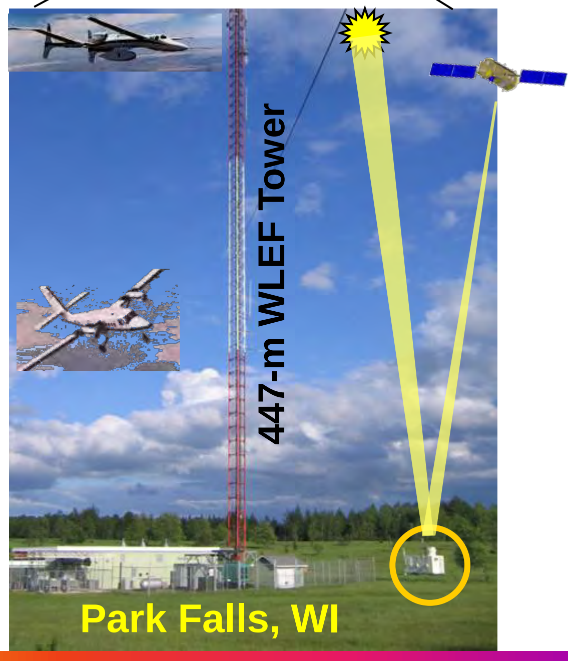




Target Observations:

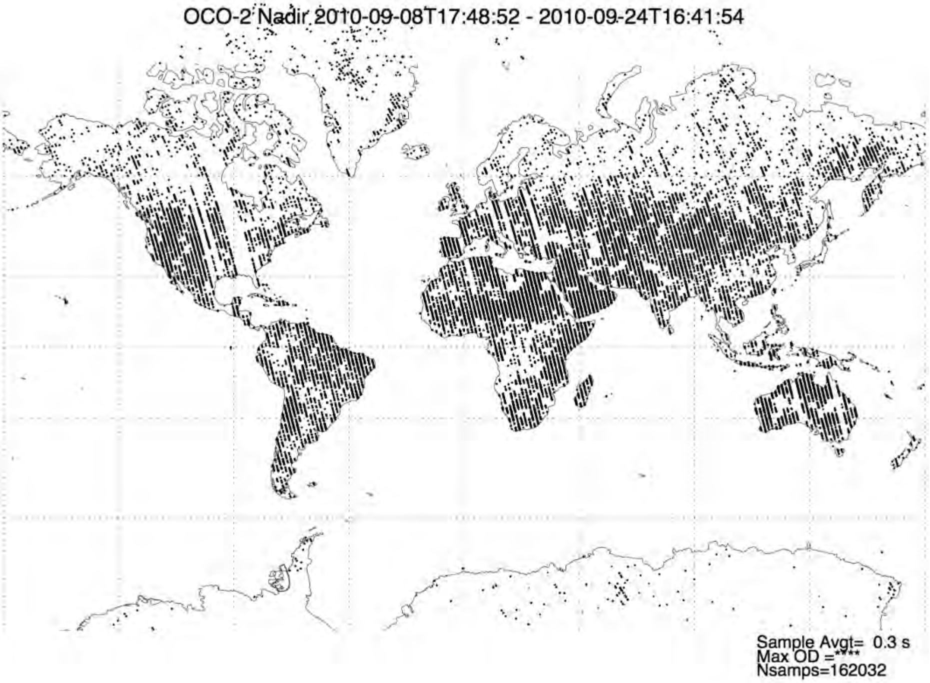
- Validation over ground based FTS sites, field campaigns, other targets



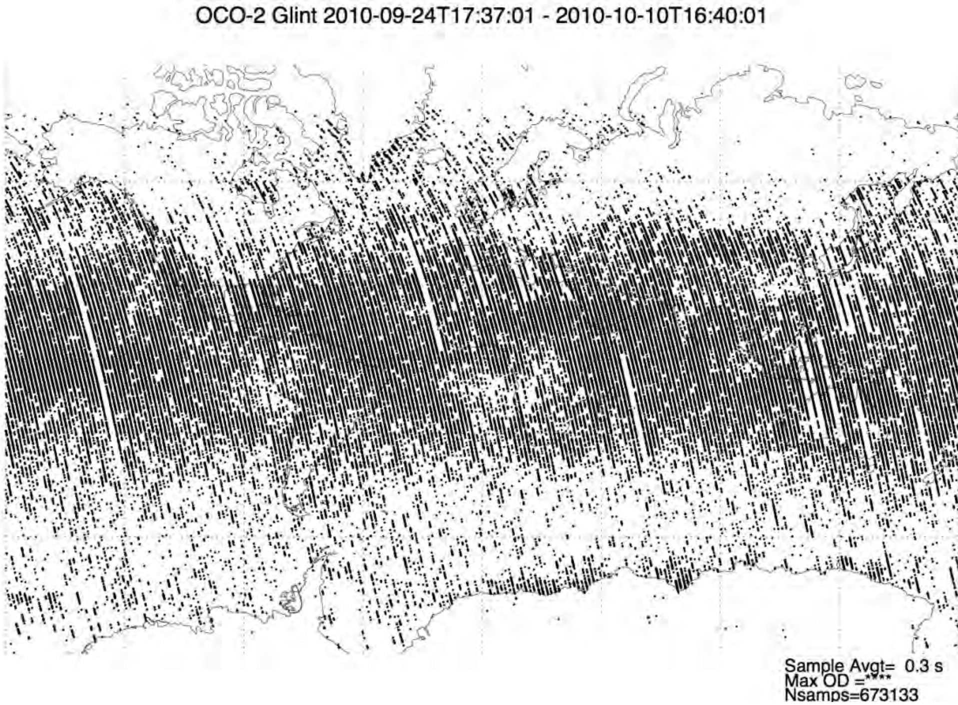


Glint vs. Nadir Coverage

- OCO-2 will obtain Nadir and Glint observations of the sunlit hemisphere on alternate 16-day ground track repeat cycles.
- The mission plan has been modified to return all 8 cross-track footprints, yielding ~380 Soundings/degree of latitude or 10^6 soundings/day.



Nadir observations provide better coverage over continents



Glint observations provide better coverage over oceans

Conclusions

- Space-based remote sensing observations hold substantial promise for future long-term monitoring of CO_2 and other greenhouse gases
  - These measurements will complement those from the existing ground-based greenhouse gas monitoring network with increased: spatial coverage and sampling density

- The principal challenge is the need for high precision (~0.3% or 1 ppm)

- The Japanese GOSAT mission (Nicknamed “Ibuki”) has provided a valuable pathfinder for analysis techniques

- Once it is launched in 2014, the NASA OCO-2 mission will demonstrate the measurement precision, coverage, and resolution needed to:
  - Quantify CO_2 sources on the scale of an average-sized nation
  - Find the natural “sinks” that are absorbing over half of the CO_2 emitted by human activities