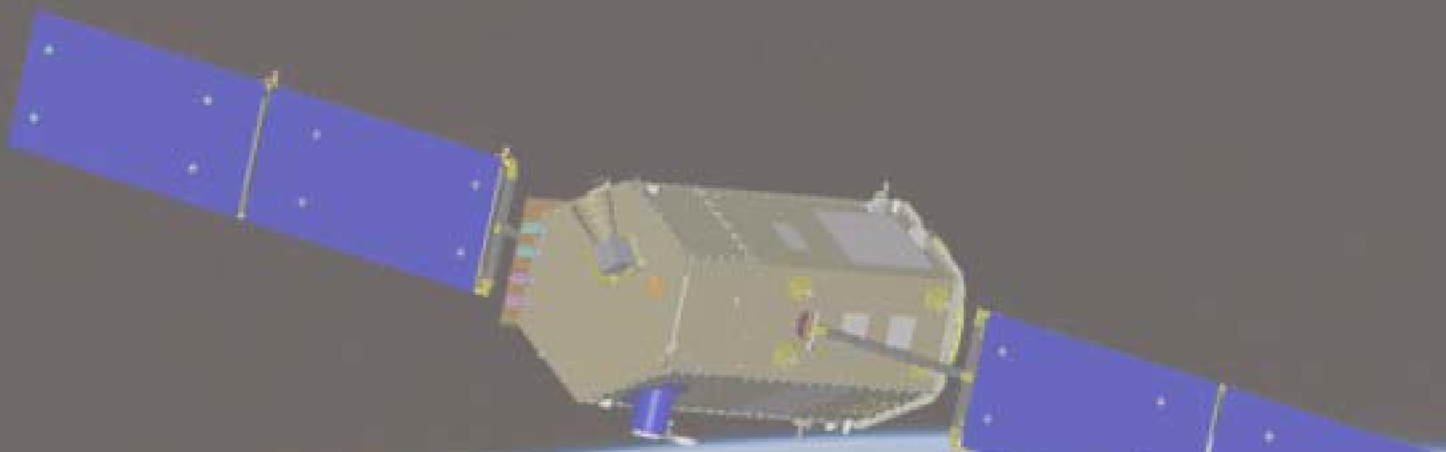


Measuring CO_2 Sources and Sinks from Space: The Orbiting Carbon Observatory (OCO)

http://oco.jpl.nasa.gov

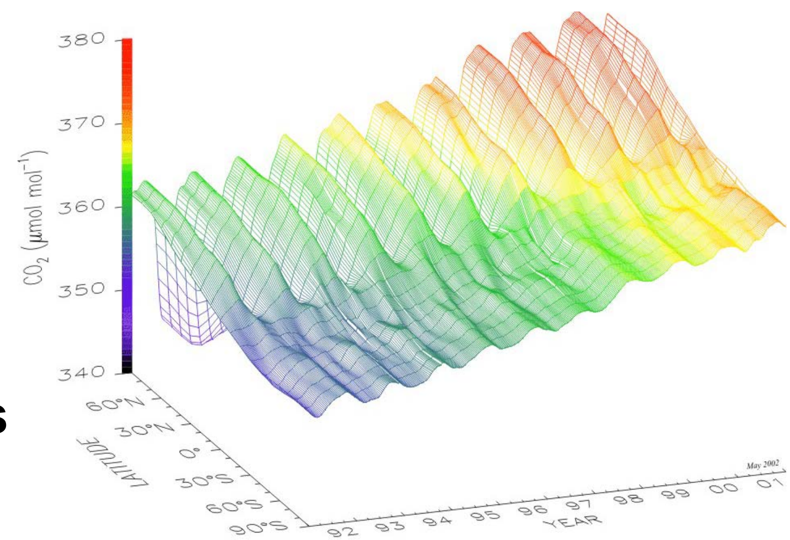
David Crisp, OCO PI

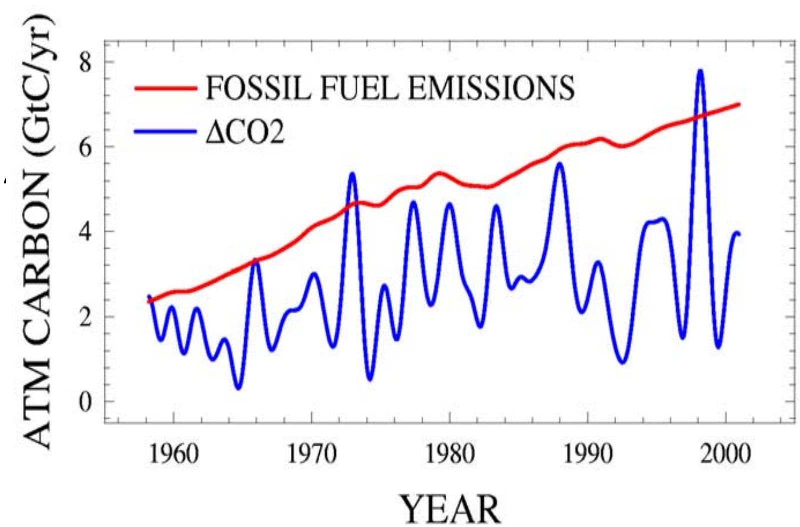
JPL/Caltech

January 2005

What Processes Control CO_2 Sinks?

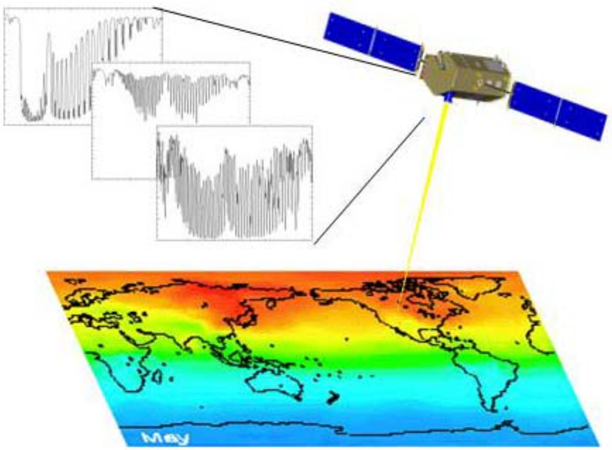
- **Carbon dioxide (CO_2) is the primary anthropogenic driver of climate change**
  - **The CO_2 concentration has increased by ~25% from ~280 to 370 ppm since the beginning of the industrial age**
- **Only half of the CO_2 produced by fossil fuel combustion in the past 30 years has remained in the atmosphere.**
  - **Where are the sinks?**
- **Outstanding Issues:**
  - **Why does the atmospheric buildup vary substantially with uniform emission rates?**
  - **What are the relative roles of CO_2 sinks**
    - Oceans vs land ecosystems
    - North American and Eurasian sinks?
  - **How will carbon sinks respond to climate change?**

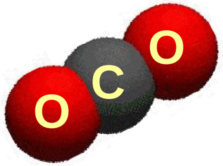


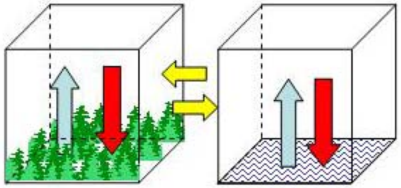


The Orbiting Carbon Observatory (OCO)

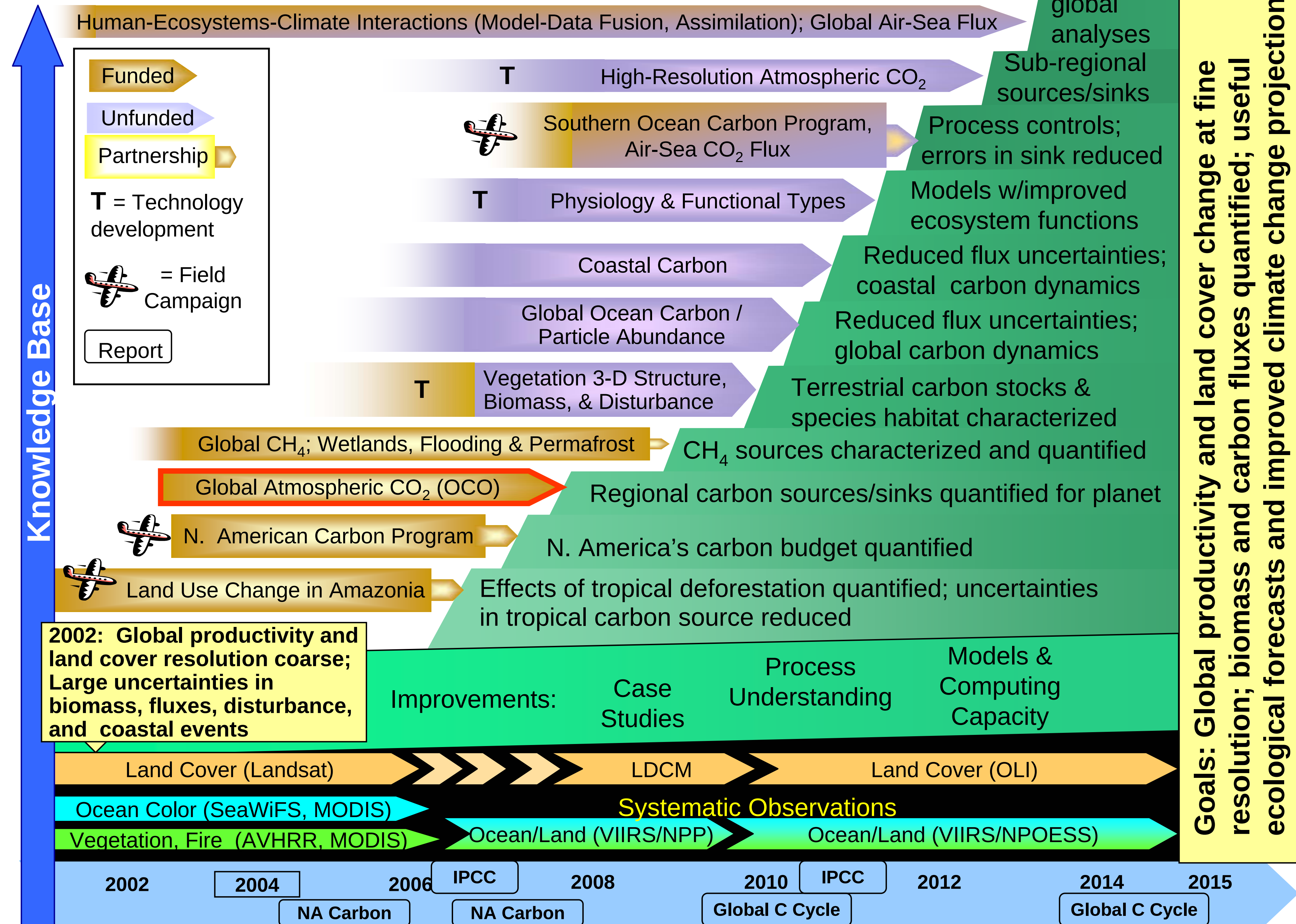
- **OCO will measure CO_2 from space with the precision, resolution, and coverage needed to quantify CO_2 sources and sinks**
  - Simultaneous spectroscopic observations of CO_2 and O_2 used to estimate the column integrated CO_2 dry air mole fraction, X_{CO2}
  - Precision: ~1 ppm (0.3%) on regional scales
  - 1:15 PM polar orbit, 16 day repeat cycle
- **Team Members**
  - Principal Investigator: David Crisp, JPL
  - Project Manager: Rod Zieger, JPL
  - Instrument provider: Hamilton Sundstrand
  - Spacecraft provider: Orbital Sciences Corp.
  - International Science Team
- **Launch date: TBD**



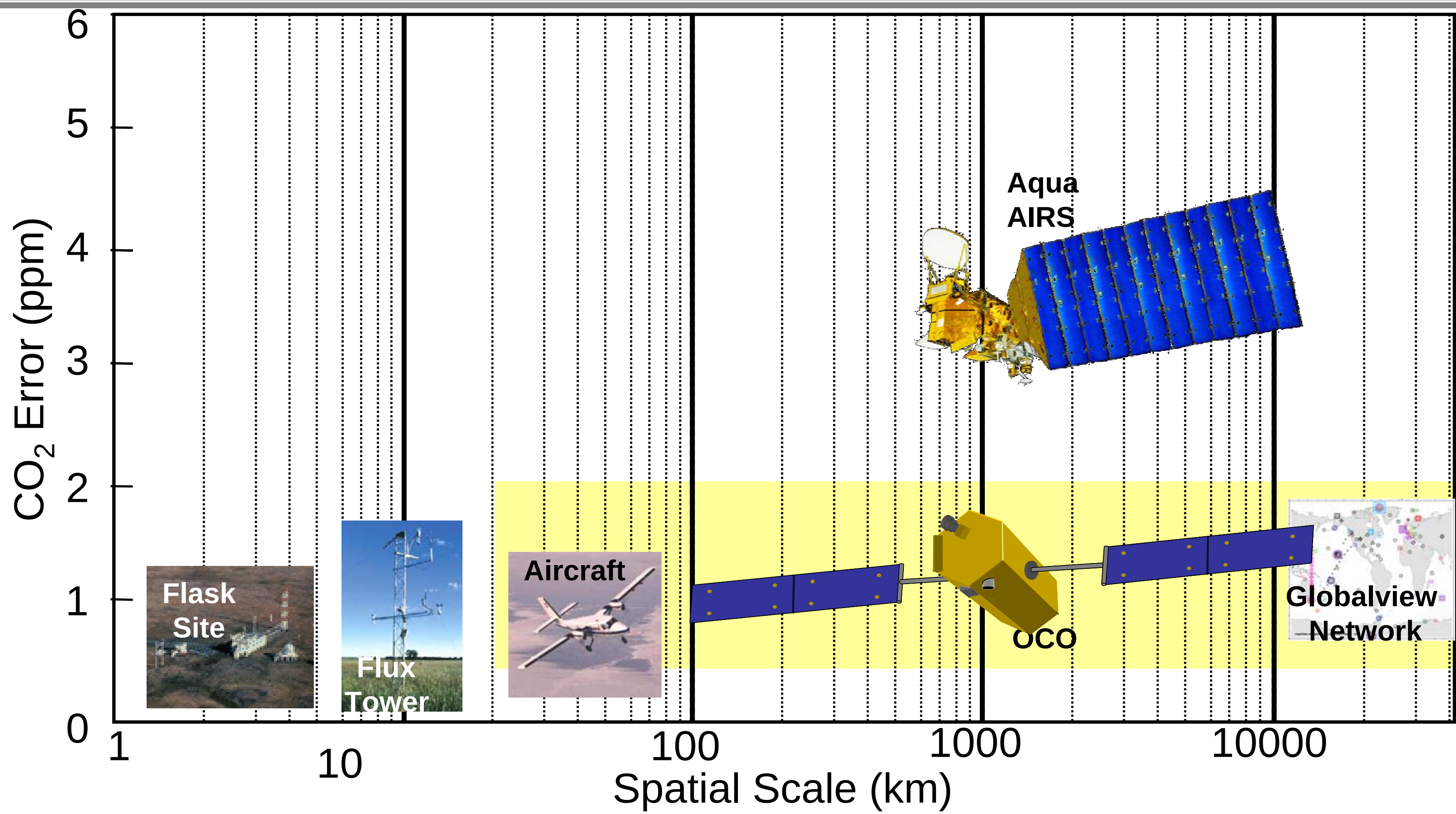




Carbon Cycle and Ecosystems Roadmap



OCO Fills a Critical Measurement Gap

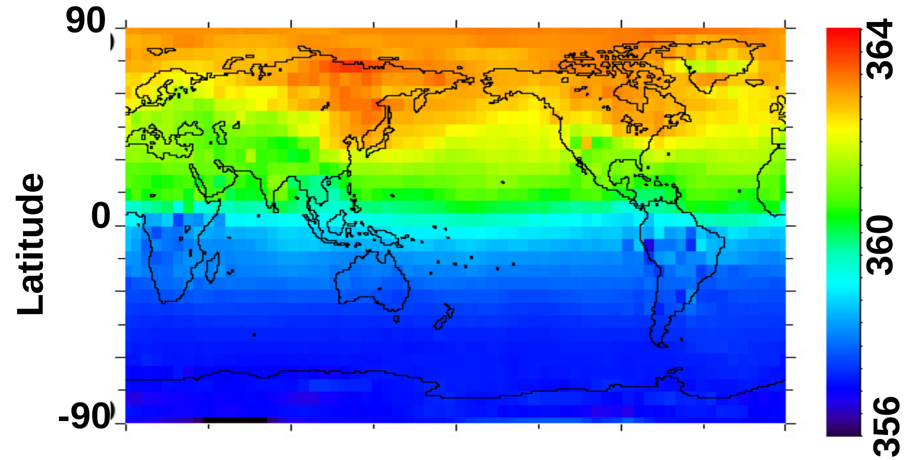


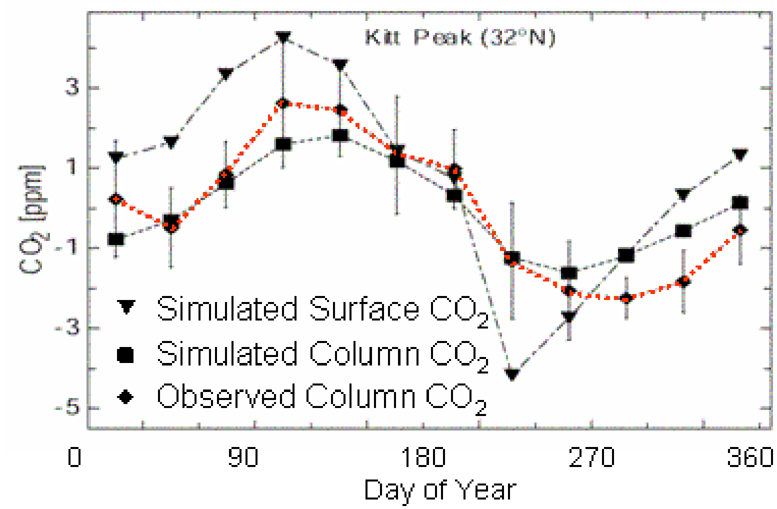
OCO will provide precise global measurements of X_{CO2} over the range of spatial scales to reduce CO_2 flux uncertainties by up a factor of 100 on regional to continental scales.

Precise CO_2 Measurements Needed to Constrain Surface Fluxes

Space-based X_{CO2} measurements with precisions of 1–2 ppm (0.3–0.5%) on regional scales will:

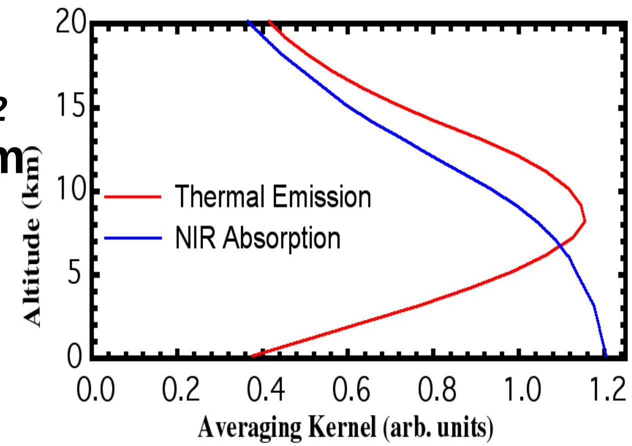
- Resolve pole to pole X_{CO2} gradients on regional scales
- Resolve the X_{CO2} seasonal cycle in the Northern Hemisphere
- Improve constraints on CO_2 fluxes (sources and sinks) compared to the current knowledge
  - **Reduce regional scale flux uncertainties from >2000 gC m^{-2} yr^{-1} to < 200 gC m^{-2} yr^{-1}**
  - **Reduce continental scale flux uncertainties below 30 gC m^{-2} yr^{-1}**



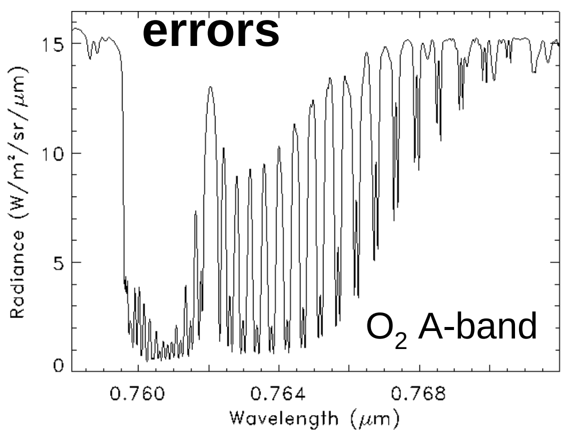


Making Precise CO_2 Measurements from Space

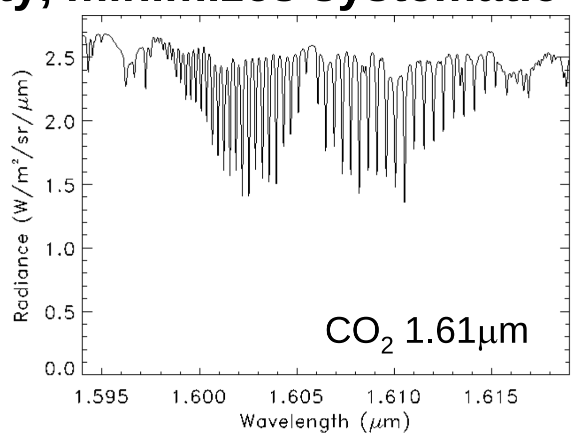
- **High resolution spectra of reflected sunlight in near IR CO_2 and O_2 bands used to retrieve the column average CO_2 dry air mole fraction, X_{CO2}**
  - **1.61 μm CO_2 bands – Column CO_2 with maximum sensitivity near the surface**
  - **O_2 A-band and 2.06 μm CO_2 band**
    - Surface pressure, albedo, atmospheric temperature, water vapor, clouds, aerosols



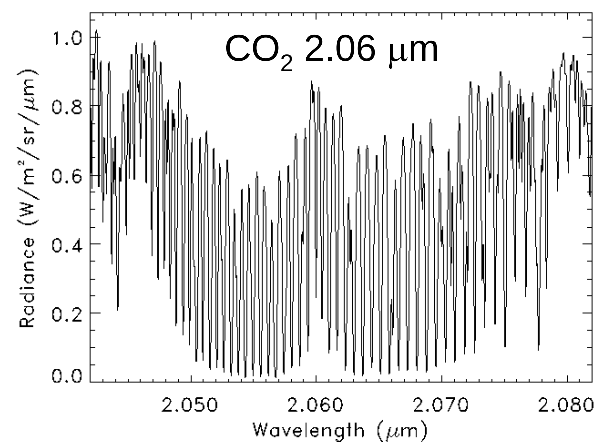
- **Why high spectral resolution?**
  - **Enhances sensitivity, minimizes systematic errors**



Clouds/Aerosols, Surface Pressure



Column CO_2

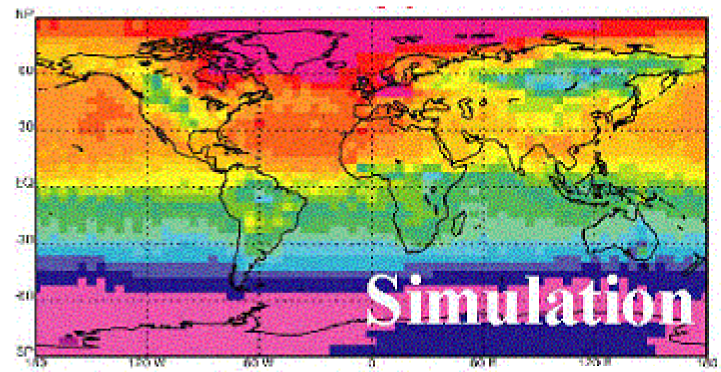


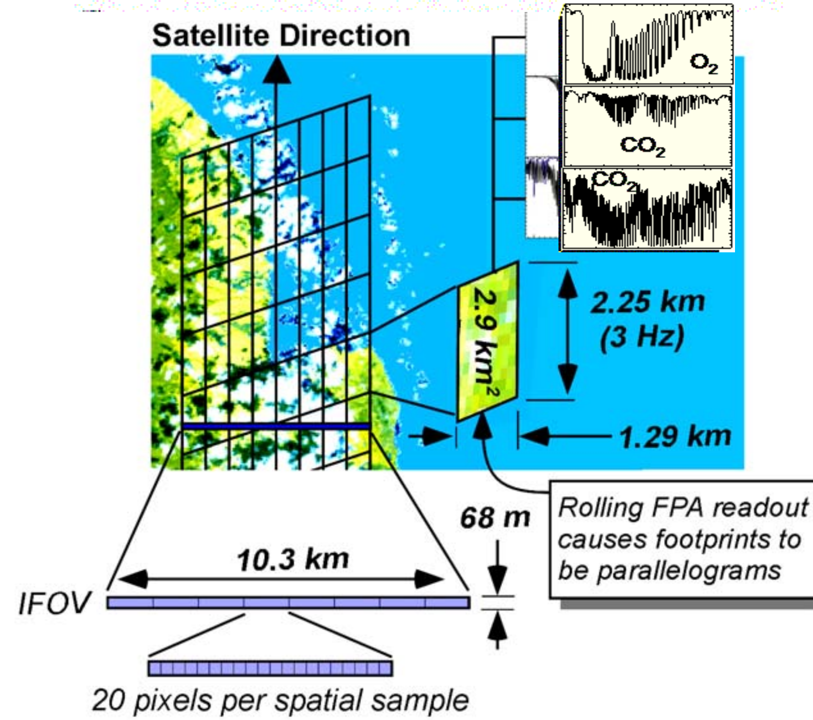
Clouds/Aerosols, H_2O, Temperature

OCO Spatial Sampling Strategy

The OCO spatial sampling strategy has been designed to provide precise, bias-free estimates of X_{CO2} on regional scales at monthly intervals

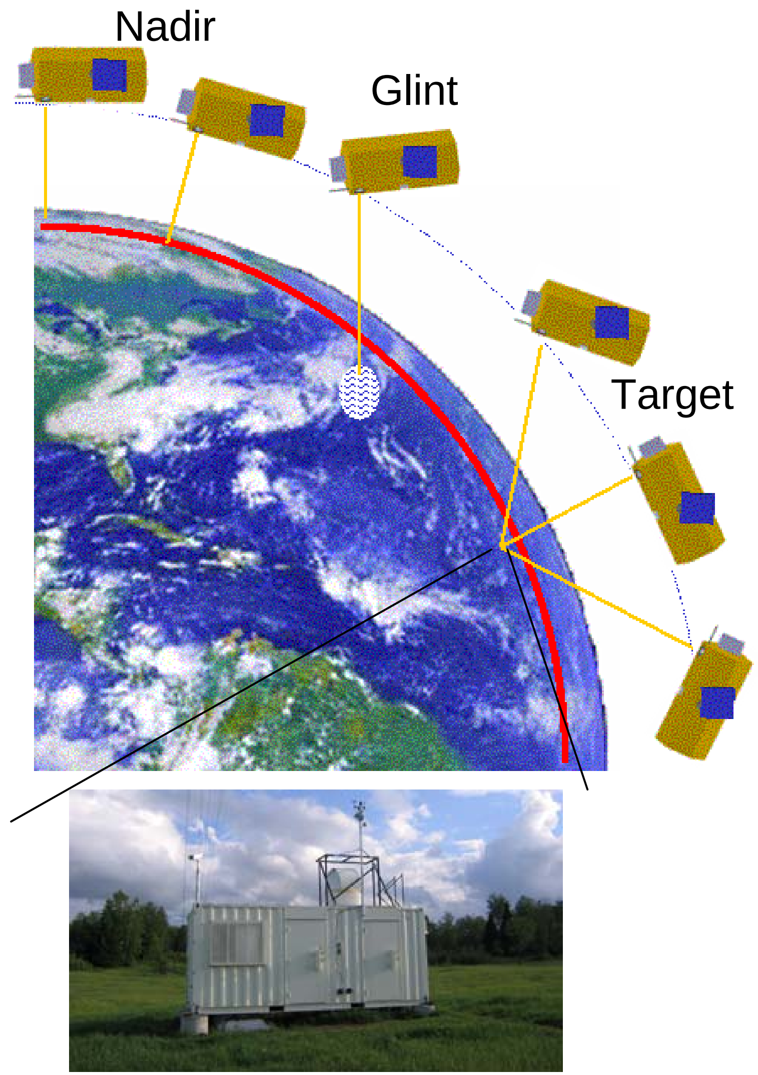
- Contiguous sampling not needed
  - **Chemical Transport Models infer sources and sinks from spatial and temporal gradients in X_{CO2}**
    - Have resolutions of 1° to 5°
  - **Winds transport CO_2 over large areas as it is mixed through the column**
- X_{CO2} soundings must be collected at high spatial resolution
  - **Maximizes the number of cloud-free samples in partly cloudy regions**
  - **Minimizes errors due to spatial inhomogeneities within each footprint**





OCO Observing Modes

- **OCO cycles between Nadir, Glint, and Target modes on monthly intervals to cross-calibrate observations**
  - **Nadir mode**
    - Footprint area < 3 km^2 to isolate cloud-free scenes and minimize other spatial inhomogeneities
  - **Glint Mode**
    - Ground track near specular point (glint spot)
    - Provides improved Signal/Noise over oceans
  - **Target Mode**
    - Tracks a stationary surface target for up to 9 minutes
    - Large numbers of observations over surface calibration sites



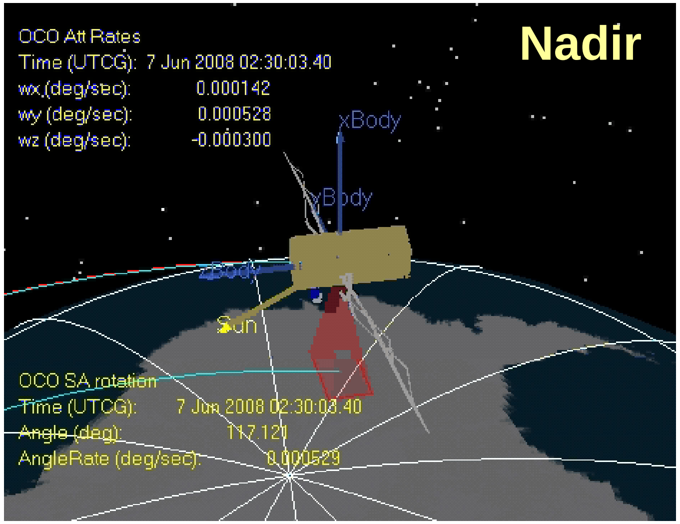
Sampling Strategy

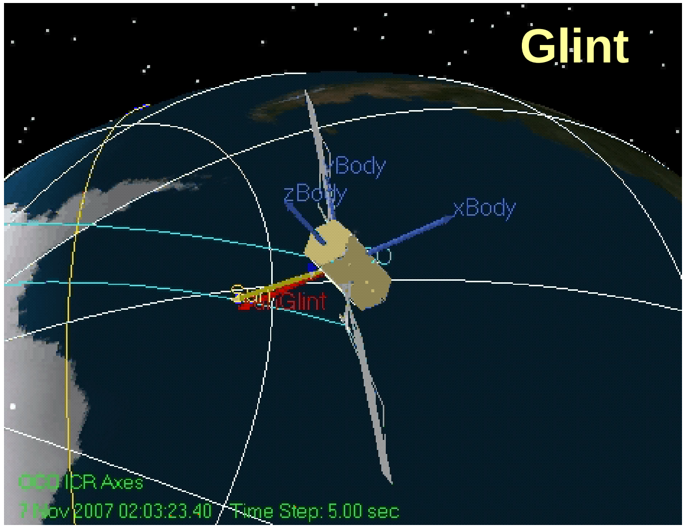
Issues:

- **Maximize solar power**
- **Minimize impact of polarization uncertainties on measurements**

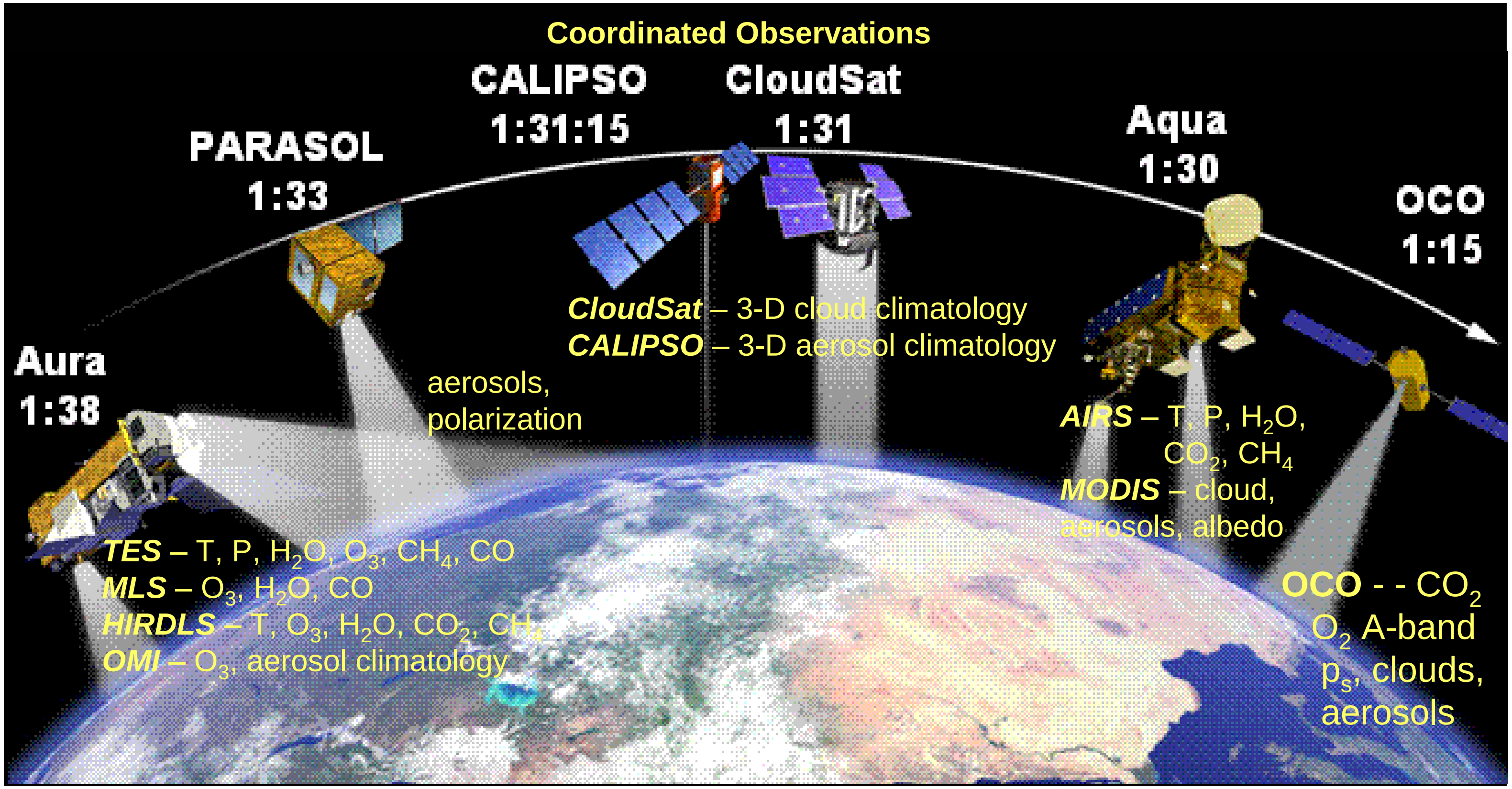
Approach:

- **Fly the spacecraft such that the Z axis is always pointing toward the solar azimuth**
  - **Maintains β ~ 0º on solar panels**
  - **Ensures slit is always aligned with major axis of polarization ellipse**
- **Modify instrument to make it a near-perfect polarization analyzer**
- **Incorporate a treatment of polarization in the OCO retrieval algorithm**





OCO Will Fly in the A-Train



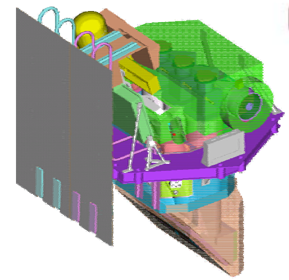
OCO files at the head of the A-Train, 15 minutes ahead of the Aqua platform

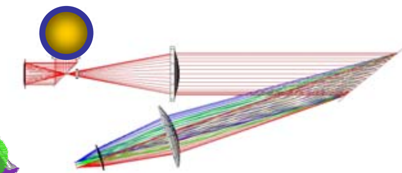
- 1:15 PM equator crossing time yields same ground track as AQUA
- Near noon orbit yields high SNR CO_2 and O_2 measurements in reflected sunlight
- CO_2 concentrations are near their diurnally-averaged values near noon
- Maximizes opportunities of coordinated science and calibration activities

Mission Architecture

Single Instrument (Hamilton Sundstrand)

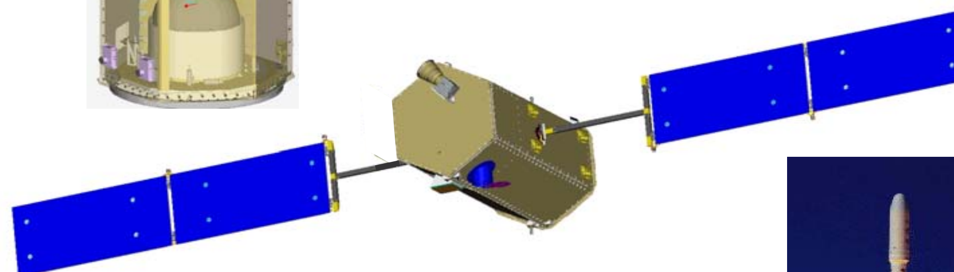
- **Incorporates 3 bore-sighted, high resolution, grating spectrometers**
  - **O_2 0.765 μm A-band, R=17,000**
  - **CO2 1.61 μm band, R=20,000**
  - **CO2 2.06 μm band R=20,000**





Dedicated Bus (Orbital LEOStar

- Heritage: OrbView 4, GALEX, SOR



Dedicated Launch Vehicle (Orbital Taurus)

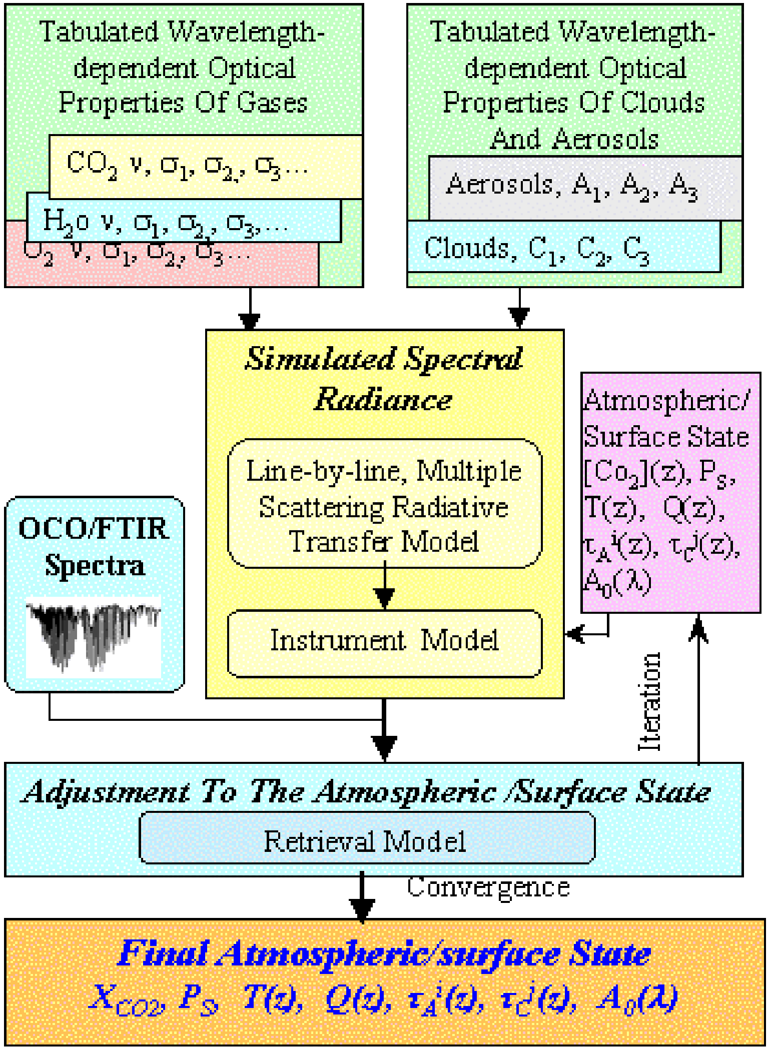
- October 2007 Launch from Vandenburg

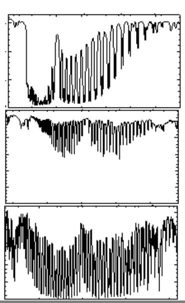
Mission Operations

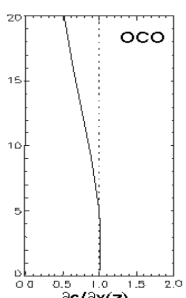
- Mission Operations (Orbital MOC)
- High latitude station for downlink station

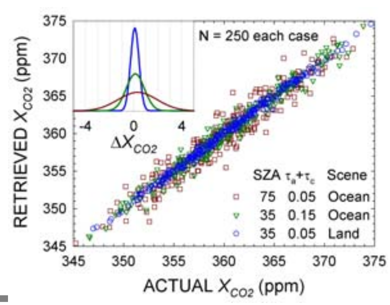
Retrieval Algorithms

- **Physics-based retrieval algorithms used to derive precise estimates of X_{CO2}**
  - **Line-by-line multiple scattering models to achieve high accuracy**
    - Spectral Mapping Methods
    - Linearized Discrete Ordinate Methods
  - **Reliable retrieval models**
    - Optimal estimation theory
  - **Comprehensive instrument models**
- **Retrieval algorithms are computationally intensive**
  - **Parallel computing architectures**



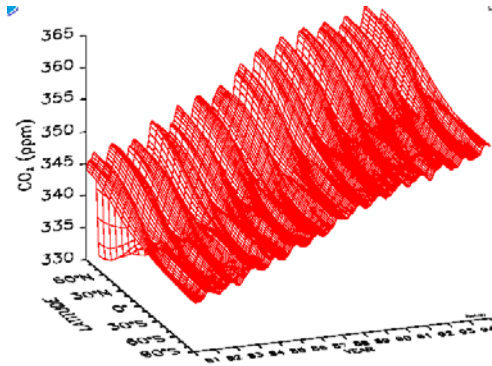


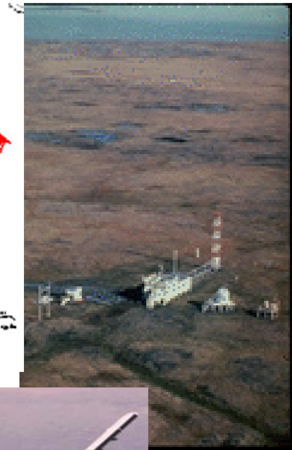


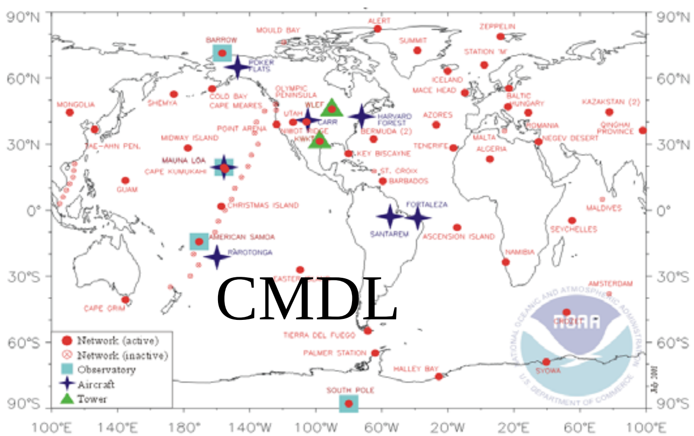


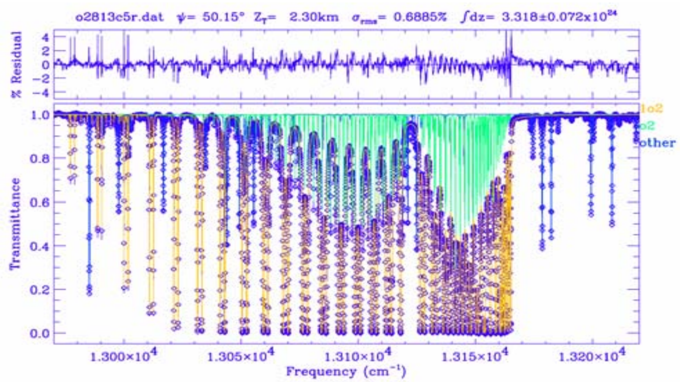
Validation Program Ensures Accuracy and Minimizes Biases

- **Ground-based in-situ measurements**
  - **NOAA CMDL Flask/Tower Network**
  - **International Partners**
- **Aircraft measurements of CO_2 profile**
  - **Wofsy (US), Ciais (CNRS Aerocarb)**
- **Uplooking FTS measurements of X_{CO2}**
  - **3 funded by OCO**
  - **4 upgraded NDSC instruments**
- **Laboratory spectroscopy**

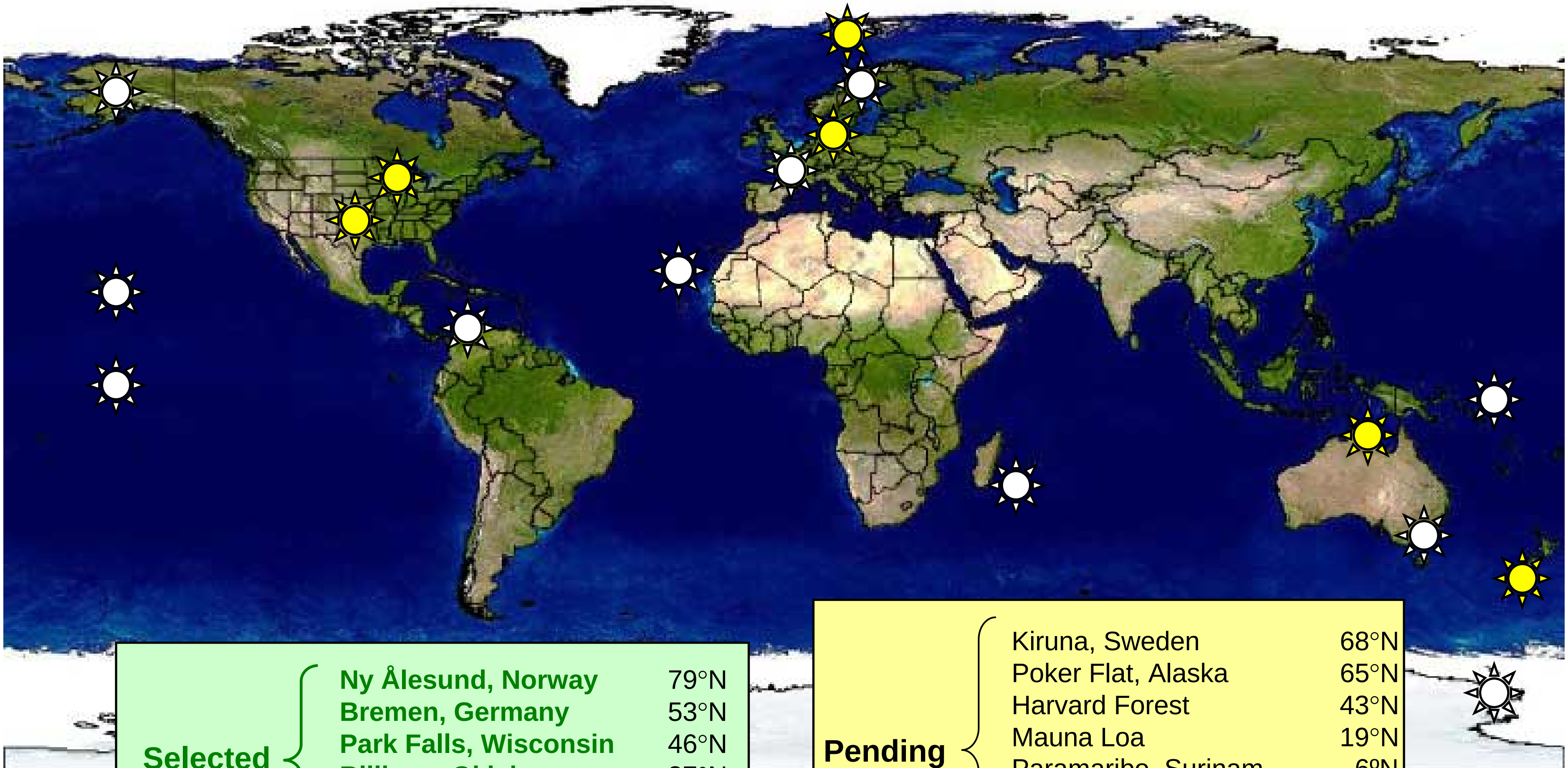








Global X_{CO2} FTS Network



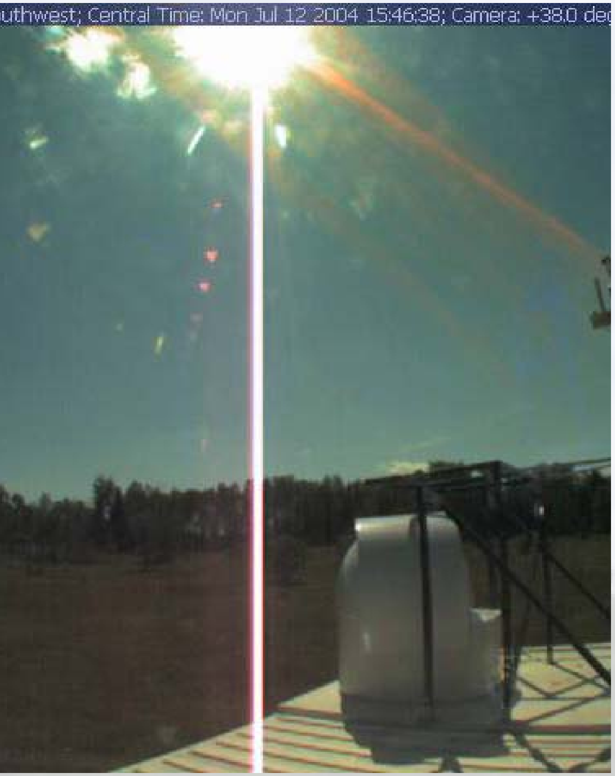
Selected

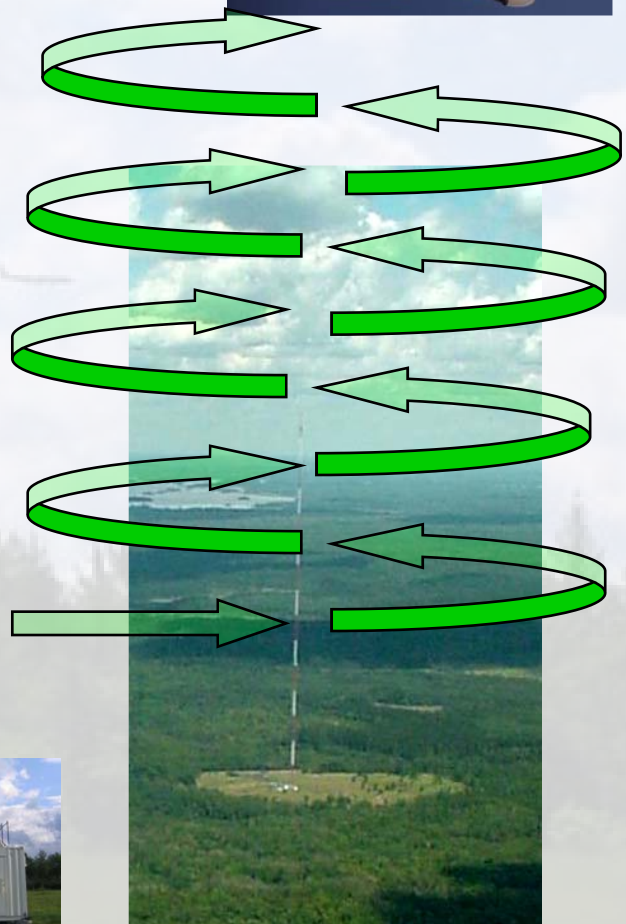
Ny Ålesund, Norway	79°N
Bremen, Germany	53°N
Park Falls, Wisconsin	46°N
Billings, Oklahoma	37°N
Darwin, Australia	12°S
Lauder, New Zealand	45°S

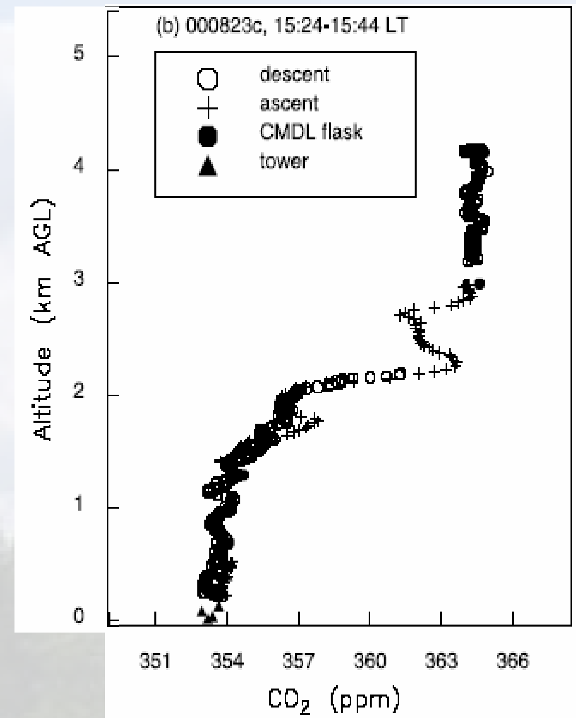
Pending

Kiruna, Sweden	68°N
Poker Flat, Alaska	65°N
Harvard Forest	43°N
Mauna Loa	19°N
Paramaribo, Surinam	6ºN
Nauru	0°S
Wollongong, Australia	34°S
Arrival Hts, Antarctica	78°S

OCO Validation Concept Demonstrated with Aircraft Overflights of Park Falls Tower





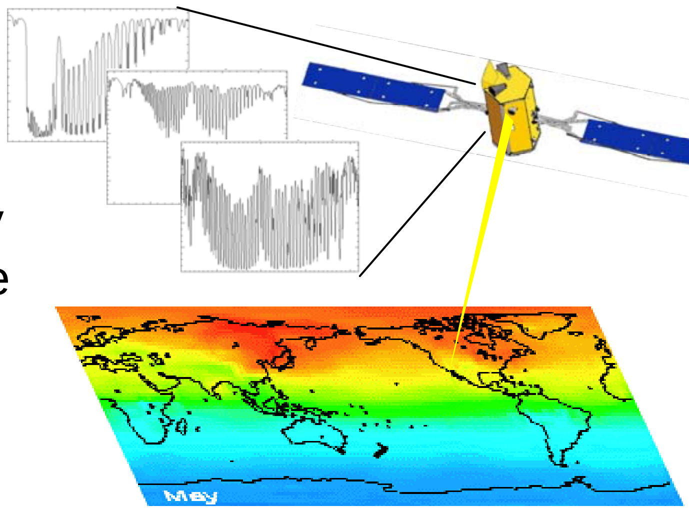


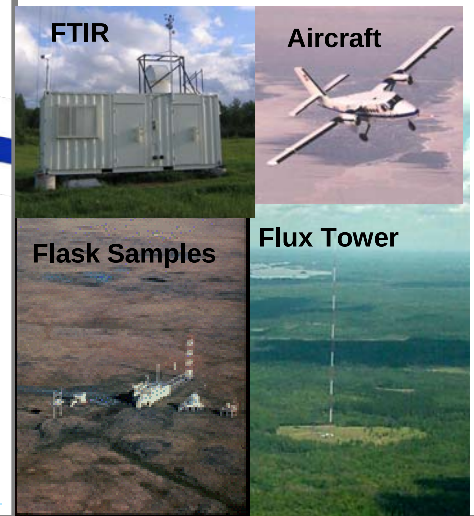
OCO Mission Highlights

- **Selected through a rigorous competitive process**
  - – Top rated mission among 33 competing mission concepts
- **Addresses NASA's highest priority carbon cycle measurement requirement**
  - – Global, space-based measurements of atmospheric carbon dioxide
- **OCO validates essential technologies**
  - – Long-lived, low-cost passive system for greenhouse gas and pollution monitoring
    - Most sensitive near surface, where sources and sinks are located
    - Can be deployed from MEO, GEO, or even L1
  - – Spinoff: First global space-base measurements of surface pressure
    - Could dramatically improve weather forecasts over oceans and other sparsely sampled regions

Summary of the OCO Mission

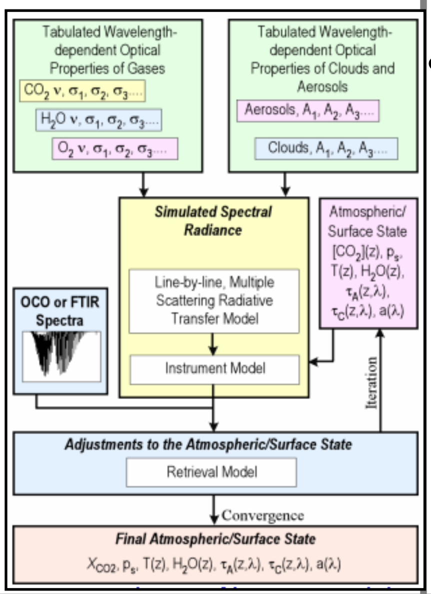
- OCO will measure CO_2 and O_2 globally from space





- The OCO Validation program ensures accuracy and reduces biases

- Sophisticated retrieval algorithms will be used to estimate the column averaged CO_2 dry air mole fraction with accuracies of 0.3 % on regional scale.



- OCO data will be used in tracer transport models describe sources and sinks