Measuring CO_2 from Space: The NASA Orbiting Carbon Observatory-2 (OCO-2)

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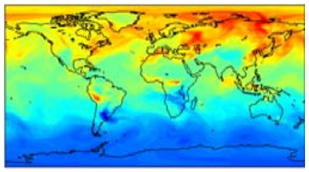
Global Measurements from Space are Essential for Monitoring CO_2 Sources and Sinks over the Globe

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

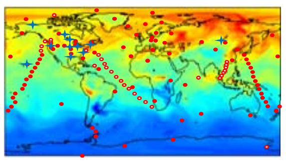
We cannot manage what we cannot measure

Plumes from medium-sized power plants (4 MtC/yr) elevate X_{CO2} levels by ~2 ppm for 10's of km downwind [Yang and Fung, 2010].

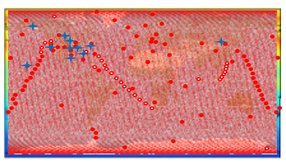


These variations are superimposed on a background of "CO_2 weather" (Kawa et al. 2010)

Space and Ground Based CO_2 Measurements are Complementary



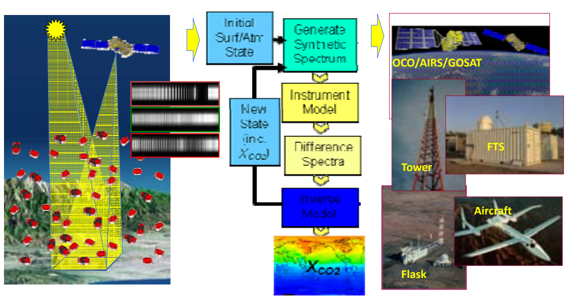
Current Surface GHG network



OCO-2 16-day ground repeat cycle

•Ground based measurements - greater precision and sensitivity to CO_2 near the surface, where sources and sinks are located.
•Space-based measurements – improve spatial coverage & resolution.
•Source/Sink models - assimilate space an ground-based data to provide global insight into CO_2 sources and sinks

Measuring CO_2 from Space



Record spectra of CO_2 and O_2 absorption in reflected sunlight

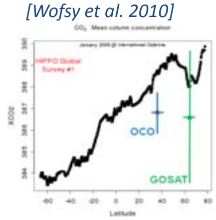
Retrieve the *column averaged CO_2 dry air mole fraction, X_{CO2}* over the sunlit hemisphere

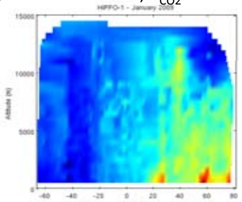
Validate X_{CO2} retrievals to ensure accuracies of 1 - 2 ppm (0.3 - 0.5%) on regional scales.

High precision is Essential for Quantifying CO_2 Sources and Sinks from Space-Based Measurements

CO_2 sources and sinks must be inferred from small spatial variations in the (390 ±5 ppm) background CO_2 distribution
- Largest variations near surface
- Space based observations of reflected sunlight constrain column averaged CO_2 dry air mole fraction, X_{CO2}

Small spatial gradients in CO_2 verified by pole-to-pole aircraft measurements [Wofsy et al. 2010]





When integrated over the column, spatial gradients in X_{CO2} are even smaller [Wofsy et al. 2010]

Coverage: Precise Measurements are Needed over Oceans as well as Continents

•The ocean covers 70% of the Earth and absorbs/emits >10 times more CO_2 than all human activities combined

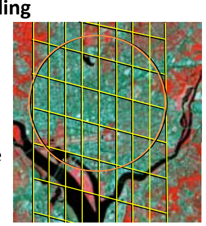
•While the oceans have few intense sources, coverage of the oceans is essential to minimize errors from CO_2 transport in and out of the observed domain

•Solar remote sensing observations over the ocean are intrinsically challenging because the ocean typically reflects only 0.5 to 1% of the incident sunlight toward the zenith.

•Clouds and optically thick aerosols contribute a larger fraction of the reflected radiance, introducing optical path length uncertainties.

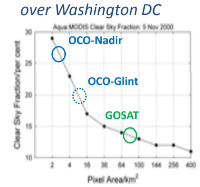
Spatial Resolution and Sampling

A Small Footprint:
- Increases sensitivity to CO_2 point sources
  - The minimum measureable CO_2 flux is inversely proportional to footprint size
- Increases probability of recording cloud free soundings in partially cloudy regions



GOSAT (circle) and OCO-2 (parallelogram) footprints over Washington DC

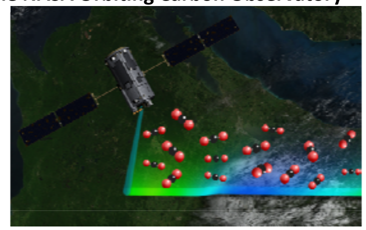
- Reduces biases over rough topography



MODIS Cloud studies indicate that a smaller footprint yields more cloud free soundings.

High Sampling Rate:
- Soundings can be averaged along the track to reduce single sounding random errors

The NASA Orbiting Carbon Observatory



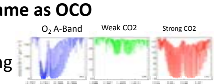
NASA's Orbiting Carbon Observatory (OCO) was designed to provide estimates of atmospheric carbon dioxide (CO_2) with the sensitivity, accuracy and sampling density needed to quantify regional scale carbon sources and sinks over the globe and characterize their behavior over the annual cycle.

The Loss of OCO and the Birth of OCO-2

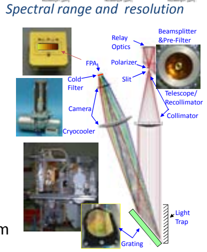
- February 2009: The OCO spacecraft was lost when its Taurus XL launch vehicle's fairing failed to deploy
- December 2009: The U.S. Congress added funding to the NASA FY2010 budget to restart the OCO Mission
- The OCO-2 mission is currently on track for a launch as early as 2013

The OCO-2 Instrument – same 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
- Narrow Swath: < 0.8°
  - 8 cross-track footprints sampled @ 3 Hz
  - Footprint: < 1.29 x 2.25 km at nadir (< 3 km²)
- Mass: 144 kg, Power: 105W



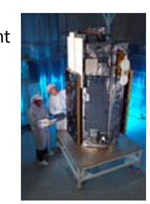
Spectral range and resolution



Optical layout of each spectral channel and major components

OCO-2 Spacecraft Bus – same as OCO

The spacecraft bus is used to:
- Support and point the instrument
  - No pointing mechanism needed
  - Facilitates Nadir/Glint/Target Obs
- Formation fly in the A-train
  - Facilitates synergy with other missions
- Record and downlink the data

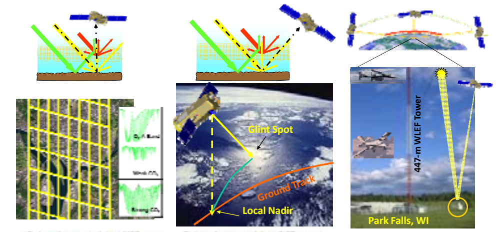


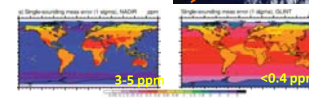
OCO-2 Observation Modes Optimize Sensitivity and Accuracy over Land & Ocean

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





OCO single sounding random errors for nadir and glint [Baker et al. ACPD, 2008].

Experience gained working with the Japanese Greenhouse gases Observing Satellite, GOSAT

- The ACOS/OCO-2 team is retrieving global maps of X_{CO2} from GOSAT
- Close collaboration between calibration, validation, and retrieval algorithm teams has led to rapid progress in data analysis
  - Vicarious Calibration campaigns in Railroad Valley, NV provided data need to identify and correct instrument calibration changes
  - Validation against Total Column Carbon Observing Network (TCCON) measurements and other data sets being used to detect and correct large scale biases

Conclusions

- Space-based remote sensing observations hold substantial promise for future long-term monitoring of CO_2 and other greenhouse gases, providing:
  - Spatial coverage (especially over oceans and tropics)
  - sampling density (needed to resolve CO_2 weather)
- The principal challenge is the need for high precision
- To reach their full potential, space based CO_2 measurements must be validated against surface measurements to ensure their accuracy.
  - The TCCON network is providing the transfer standard
- A coordinated global network of surface and space-based CO_2 monitoring systems as well as sophisticated models that can assimilate these data are needed to provide insight into the processes controlling atmospheric CO_2