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OCO-3 Science and Status for CEOS

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Jet Propulsion Laboratory, California Institute of Technology

October 2016

Comparison of OCO-2 and OCO-3 Measurements

	OCO-2	OCO-3 on ISS
Latitudinal coverage	+/- 80 degrees	+/- 52 degrees (on ISS)
Local time of day sampling and repeat	~1:30pm with 16 day routine and repeated measurements	Ranges across all sunlit hours with variable revisit (0 to multiple per day)
Land Sampling	Every day (using glint and nadir measurements)	Every day
Glint/Ocean Sampling	16 days on/16 days off (originally)	Every day
Target/mapping mode capability	Target mode achieved with spacecraft pointing	Target and mapping expanded with pointing mirror assembly
Polarization approach	Keep instrument slit in principal plane (actually 30 degrees off)	Collect data at wide range of polarization angles

As an integrated dataset:

- The OCO-2 and OCO-3 missions in series provide an extended time series of X_{CO2}
- OCO-3 has different sampling characteristics and therefore different error characteristics, this will need to be accounted for when using the datasets together
- Existing retrieval algorithm does not need to be modified for use with OCO-3 data

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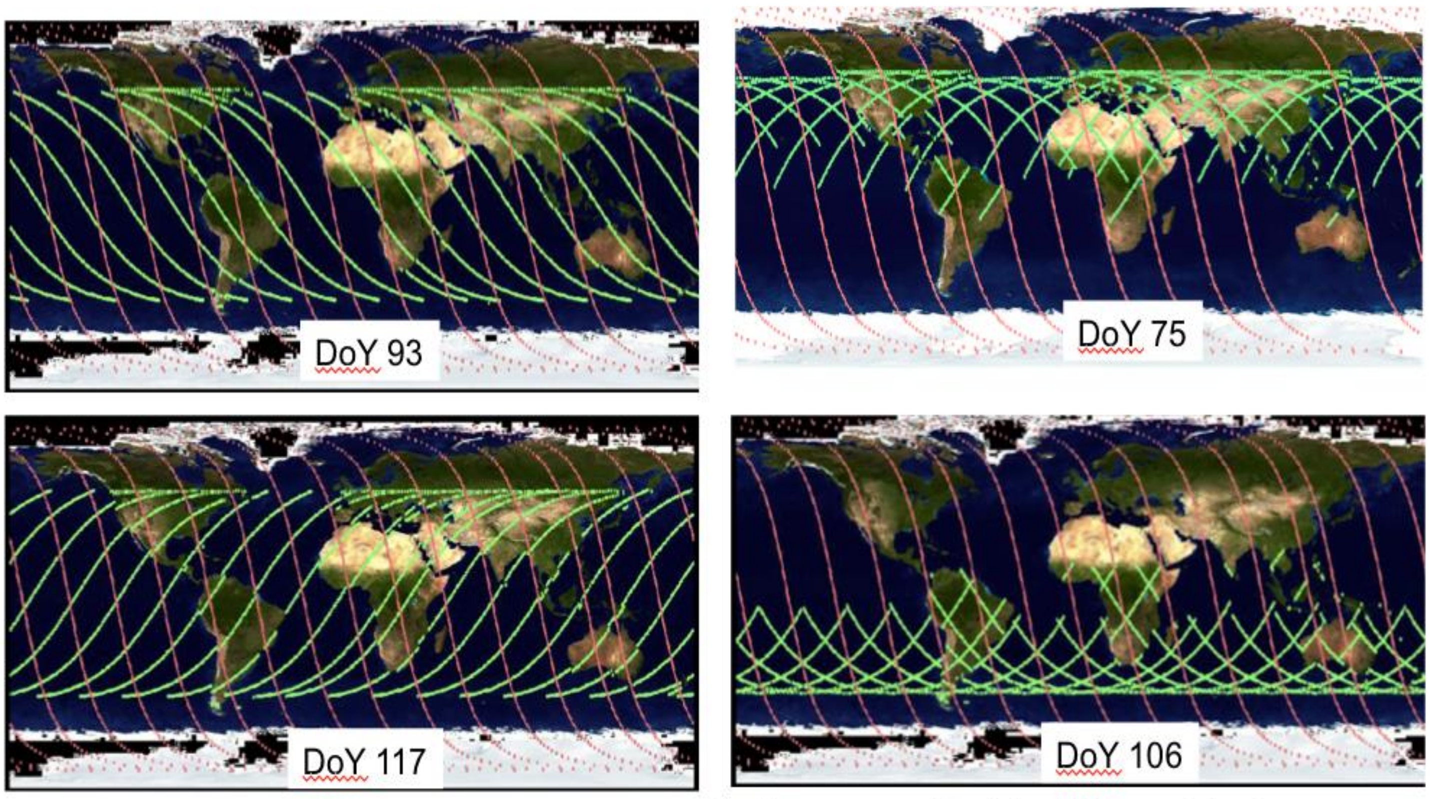
Seasonal and Latitudinal Variations of OCO-3 Sampling from ISS

- Sampling would be dense at mid-latitudes, while providing good coverage of tropics and sub-tropics
- 2-axis pointing systems would enable new operations concept with nadir *and* glint observations taken every day, effectively doubling the number of samples over oceans as compared to OCO-2



Proposed OCO-3/ISS orbits (green) and OCO-2 (pink). On “turn-around” orbits, ISS would provide better coverage of mid latitudes of one hemisphere.

OCO-3 Science Level 1 Requirements
(and differences from OCO-2)

Baseline Science Objectives: The ESSP OCO-3 Project is designed to collect the space-based measurements needed to quantify variations in the column averaged atmospheric carbon dioxide (CO_2) dry air mole fraction, X_{CO2}, with the precision, resolution, and coverage needed to improve our understanding of surface CO_2 sources and sinks (fluxes) on regional scales (≥1000 km) and the processes controlling their variability over the seasonal cycle.

Only difference in objectives: OCO-2's also states it will validate a space-based measurement approach.

	Requirement	Baseline	Threshold
Science Requirements	Estimates of X_{CO2} on regional scales (≥1000 km) collected in cloud-free scenes on monthly intervals	3 years	1 year
	Validation of X_{CO2} at ≥ 3 sites each season	< 0.3 %	< 0.5%
	Data Delivery	GSFC-DAAC	GSFC-DAAC
Instrument Requirements	Spectral Bands	A-band (0.765 µm), 1.61 and 2.06 µm	
	Range and resolving power	Resolve individual absorption lines	
	Footprint Size	≤ 4.5 km^2	

Only difference in requirements: OCO-2's requires only 80% of latitudes, due to unfavorable solar geometry at high latitudes, and OCO-3 footprint slightly larger.

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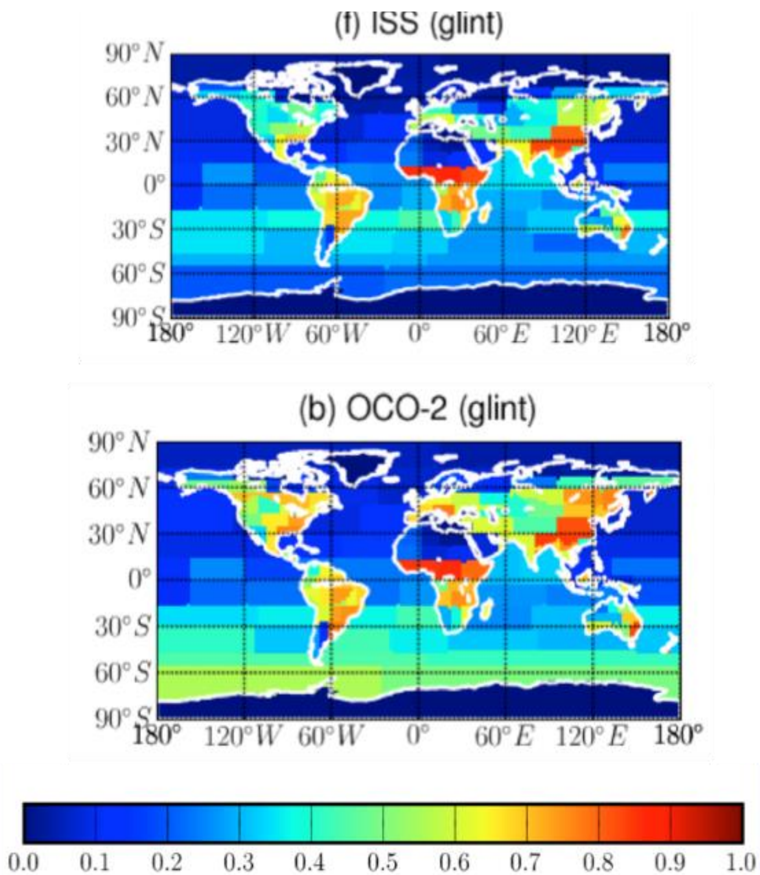
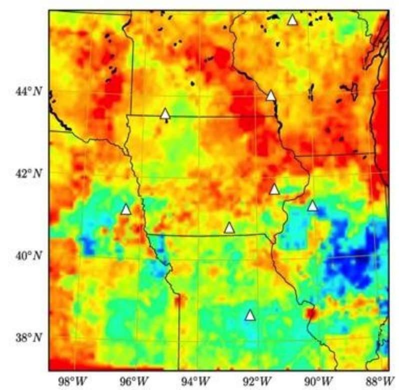
OCO-3 Science Overview

Global Flux Estimates: OCO-2 and OCO-3 impacts (simulated)



Flux error improvement for January
Palmer et al., 2011

Unique Science Opportunities with OCO-3



Midwest Carbon Flux
From Schuh et al., 2013

Terrestrial Carbon Cycle

Process studies enabled by measurements at all sunlit hours, including SIF. ISS will contain complementary instrumentation.

Anthropogenic Emissions

Enabled by enhanced target mode using pointing mirror assembly

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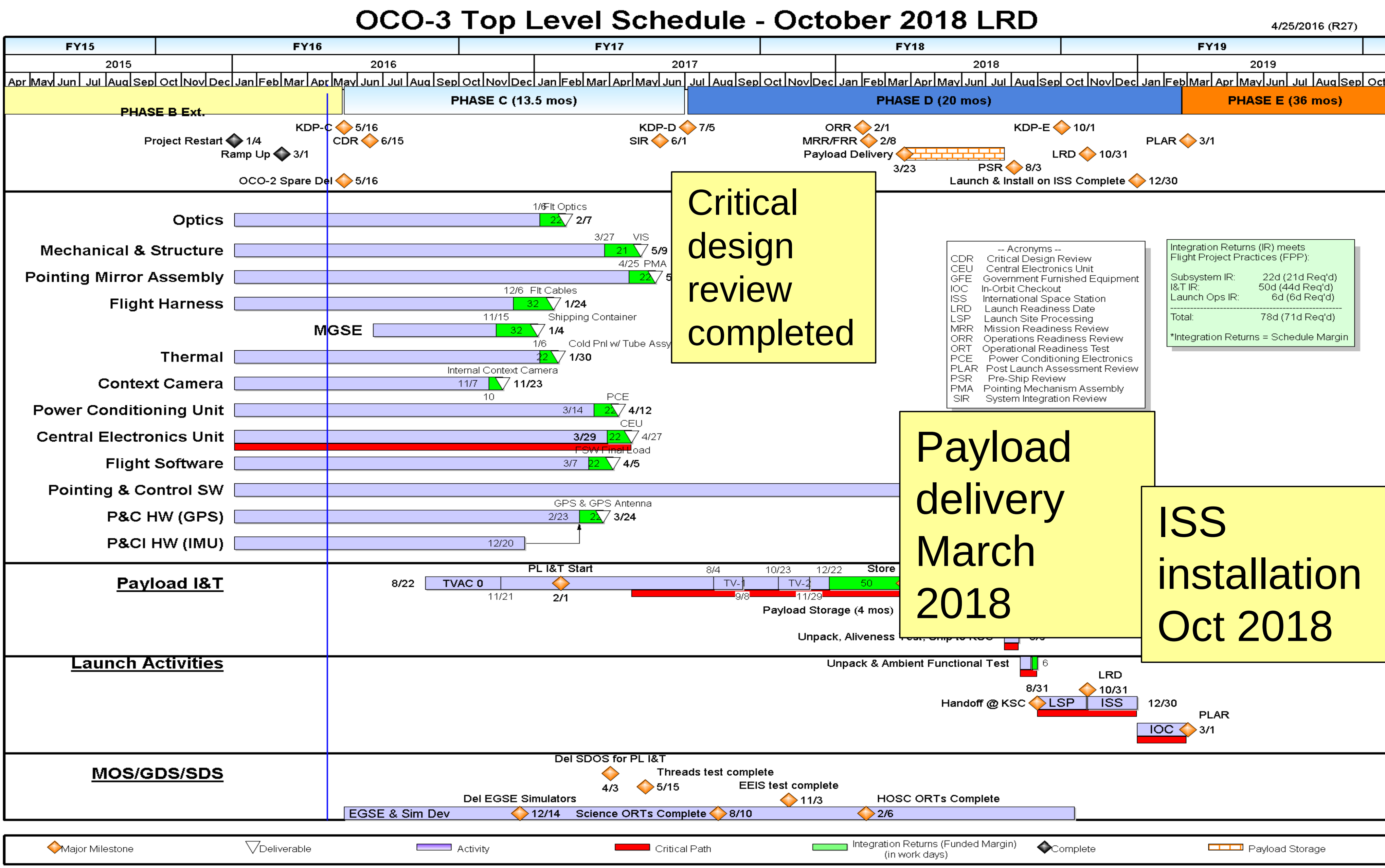
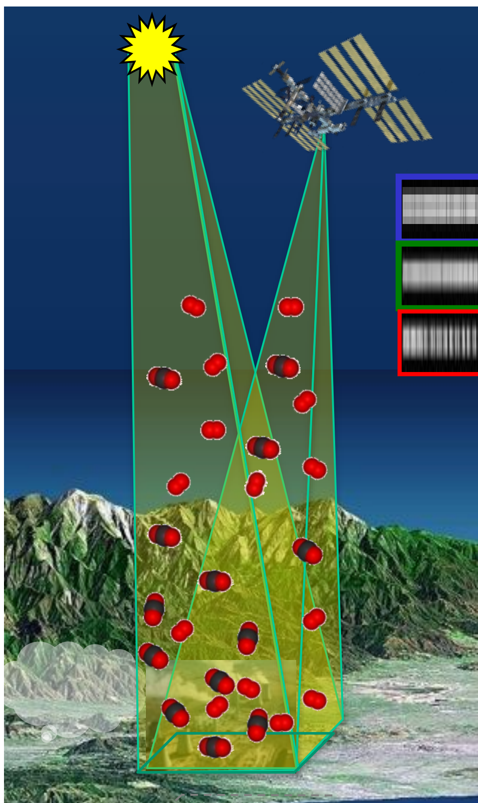
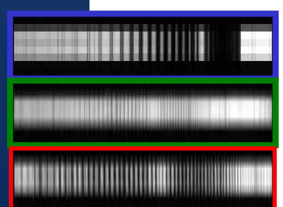
OCO-3 to be installed in ISS in late 2018



Measurement Approach – Same as OCO-2

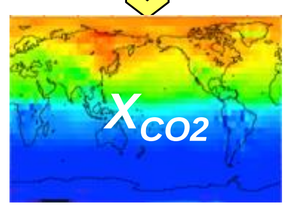
Collect spectra of CO_2 & O_2 absorption in reflected sunlight over the globe





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

Initial Surf/Atm State → Generate Synthetic Spectrum → Instrument Model → Difference Spectra → Inverse Model → New State (inc. X_{CO2}) → Generate Synthetic Spectrum



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

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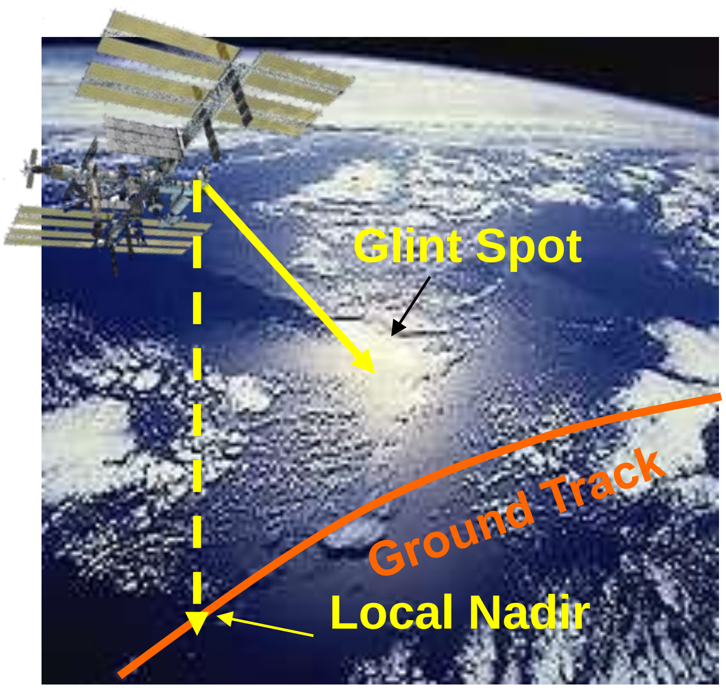
OCO-3 Observation and Science Modes

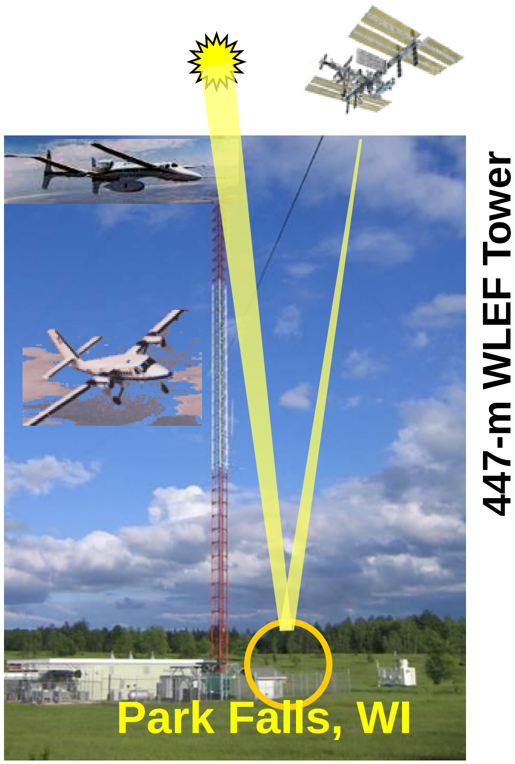
Nadir/Glint Observations:

- Nominal science measurements
- Nadir over land, glint over ocean during daylight → more data collected than OCO-2



Target/ Area map Observations:

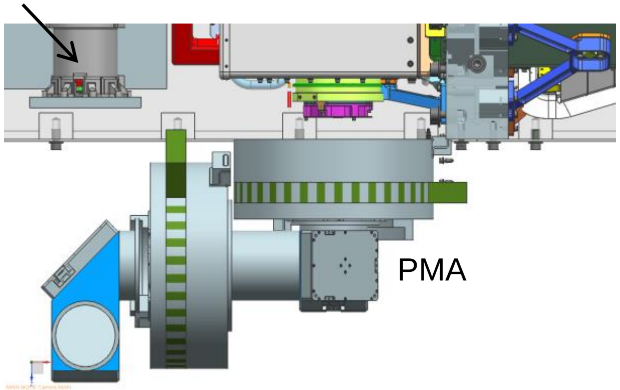
- Validation over ground based FTS sites, field campaigns, other targets
- Snapshot map variant for area mapping



Calibration Measurements:

- Dark and calibrator measurements for radiometric calibration
- Lunar calibration goal for geometric calibration

Calibration System



Lunar view from ISS

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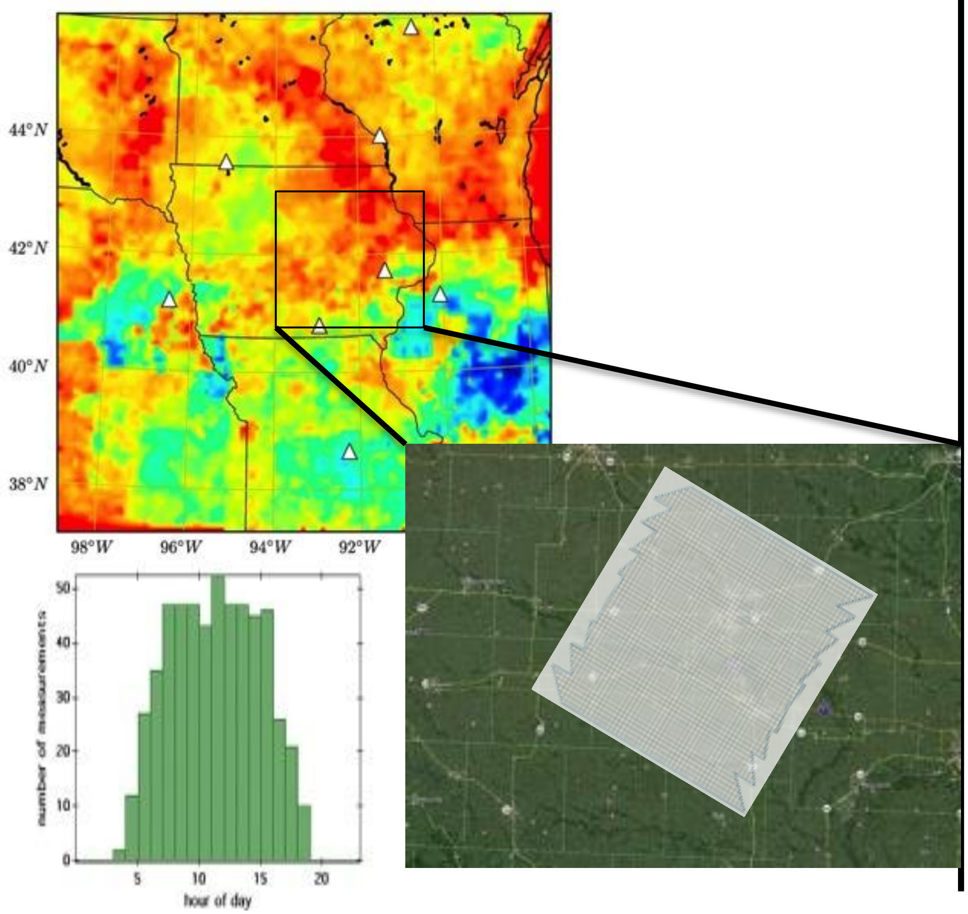
Terrestrial Carbon Cycle Processes can be Studied with Mapping Mode

The Mid-Continent Intensive was a field campaign to study the uptake of CO_2 by crops. OCO-3 measurements would add a dense dataset at varying times of day to such process studies.



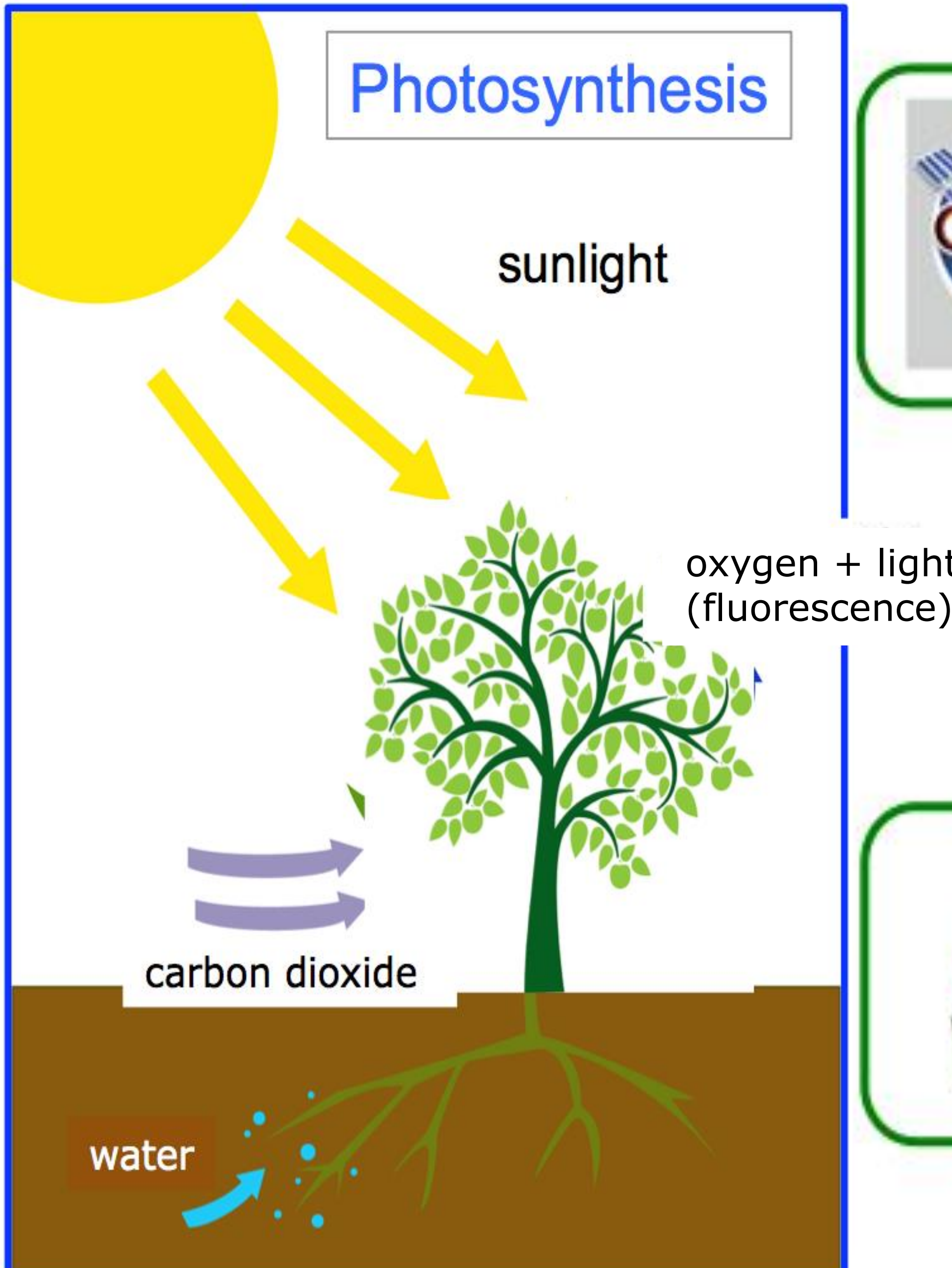
OCO-2 fluxes estimates are the size of states. Process studies are on scale of 1km. OCO-3 can aid in bridging between the process scale and the global scale

Targeted measurements of the Amazon would be possible every day, covering all sunlit hours over a month. We could cover a wide area, or collect repeated measurements over a smaller region.

OCO-3, ECOSTRESS and GEDI: the ISS Carbon Cycle Opportunity

Plant species distribution and physiology

Evapo-transpiration



CO_2 & Fluorescence

Biomass

Growth of Fossil Fuel CO_2 AND Its Uncertainties in the global CO_2 budget

- How OCO-3 reduces uncertainties in the global carbon cycle budget
  - OCO-2 and OCO-3 measurements will reduce uncertainty in global terrestrial carbon fluxes, and the magnitude of the land use change flux.
  - Fossil fuel emissions are increasing, as are the relative uncertainties on these emissions.
  - The fossil fuel uncertainty is beginning to compromise our ability to retrieve natural fluxes, especially in some critical regions.
- By 2020 the absolute uncertainty in global total FFCO2 will likely exceed the absolute uncertainty in the terrestrial land sink (i.e., > 1 GtC/year), with particularly high uncertainty in rapidly increasing source regions
- Flexible measurements from OCO-3 and snapshot mapping allow frequent revisit over strong source regions. Many targets could be visited 10 times per year, resulting in significant decreases in fossil fuel uncertainty.

- OCO-3 measurements are needed before this crossover happens, to maintain the overall $FFCO_2$ uncertainty at an acceptable level.

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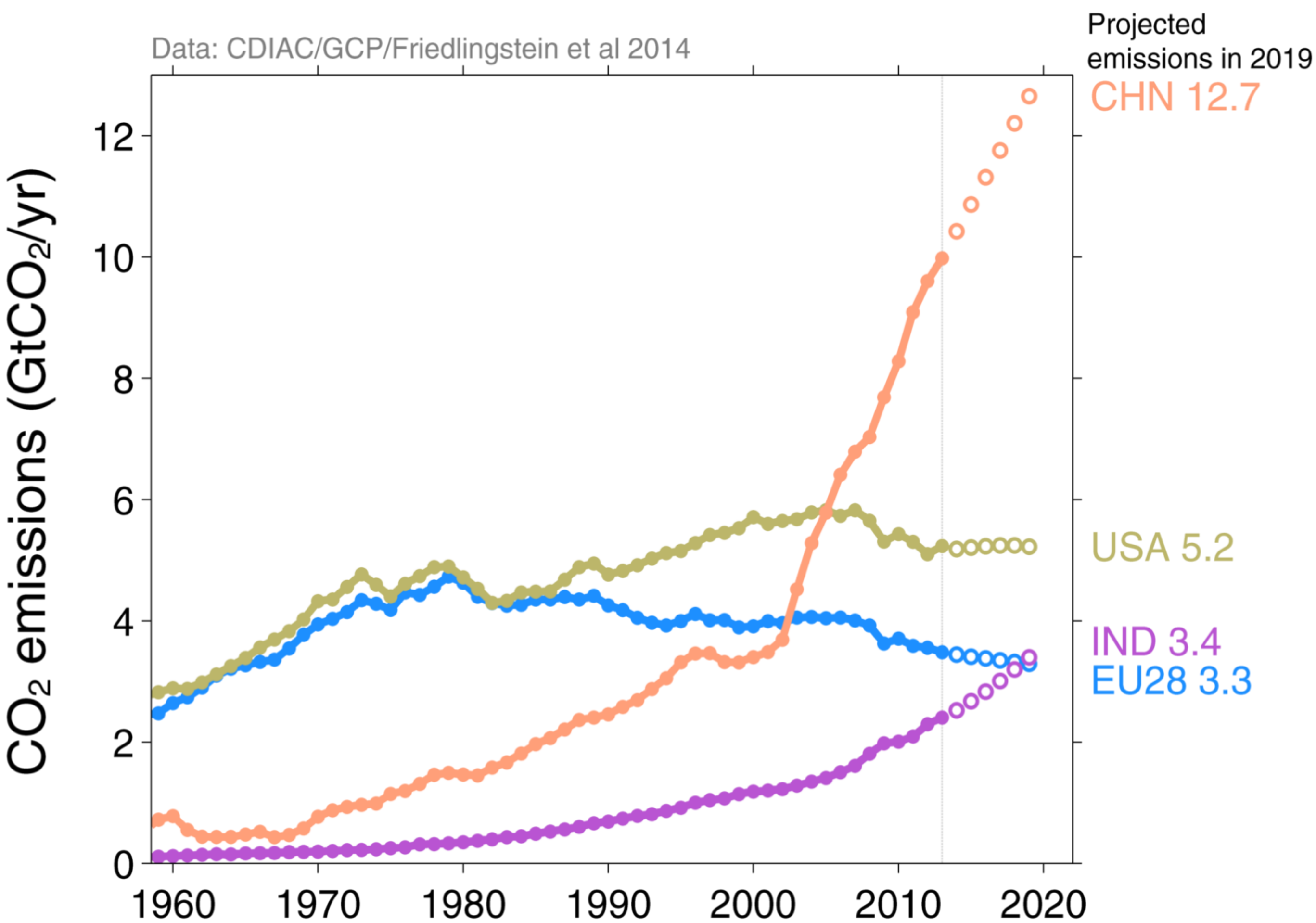
Anthropogenic Emissions: Growth is Large and Uncertain

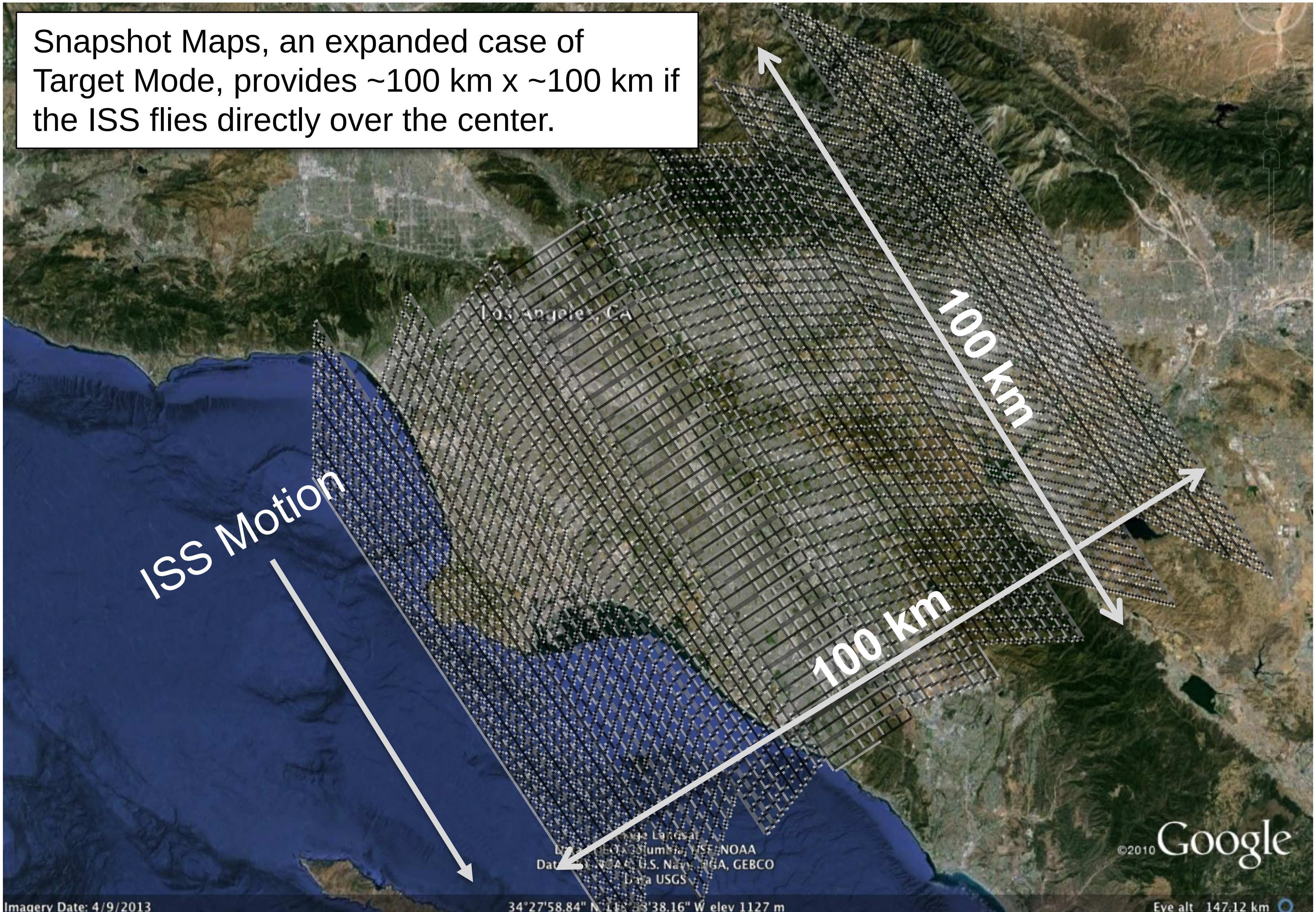
Rapid emissions growth with large uncertainty at regional and local scales



- 3%/year average global growth rate
- Locally much larger growth rates (50-100% for developing cities, power plants etc)
- Uncertainty at continental scale ranges from 5 to 20%/year
- Uncertainty at process-relevant scales (individual cities and power plants) can be as large as 50-100%

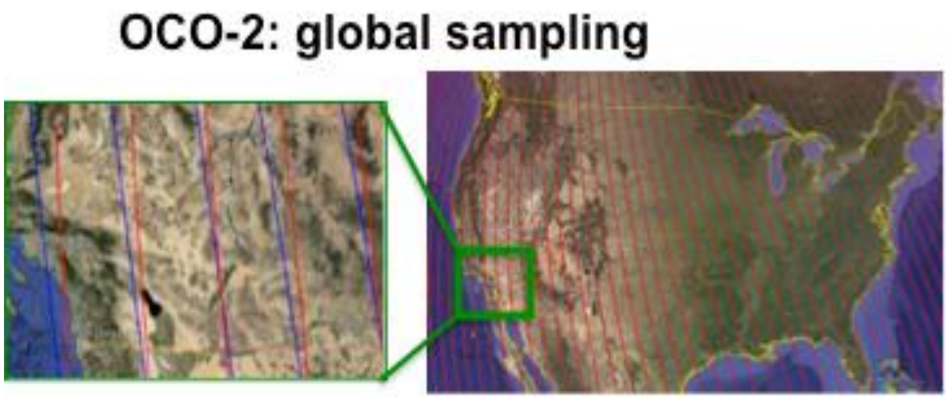
Economic growth based on IMF projections, fossil fuel intensity based on 10-year trend
Source: CDIAC; Friedlingstein et al 2014

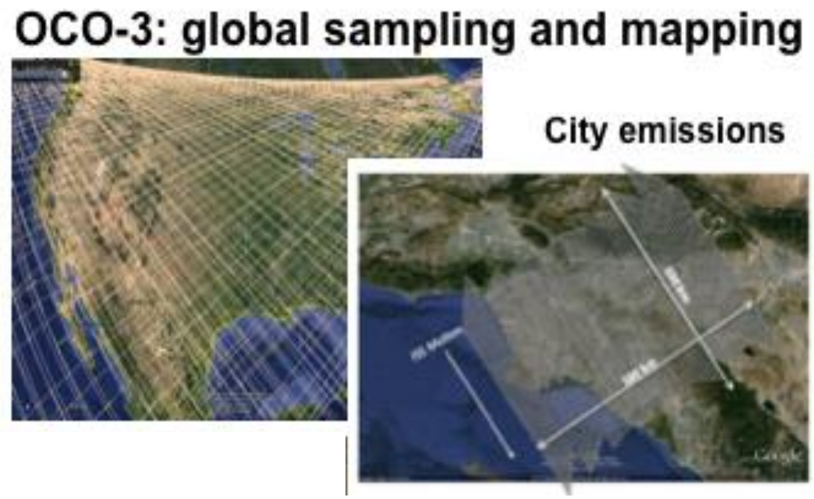
OCO-3 Snapshot Maps

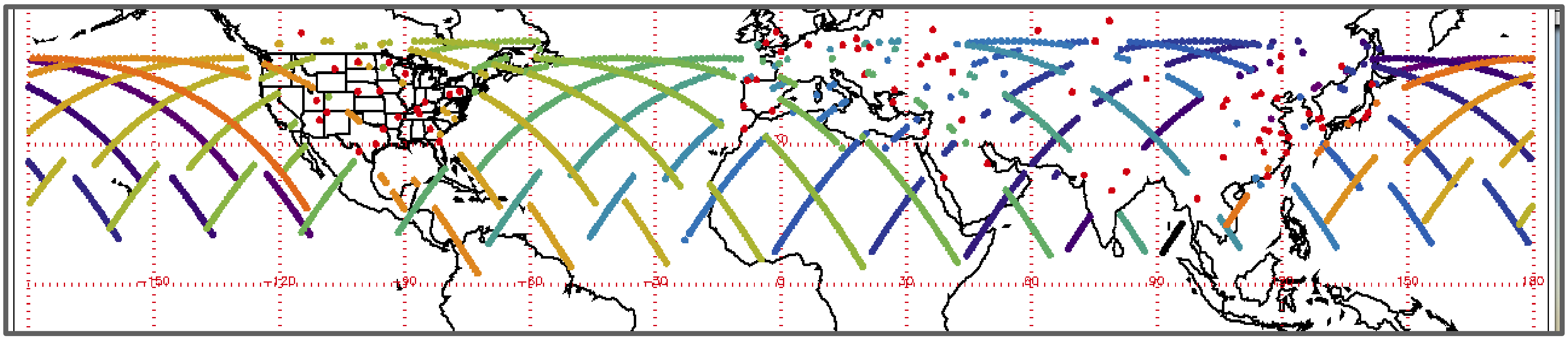


Courtesy of Lars Chapsky

Snapshot Maps Integrate Easily into Global Sampling on OCO-3







- OCO-3's snapshot mapping mode can be used to focus on localized source emissions
- These maps show maximum usage of snapshot maps (red points) interwoven with standard glint and nadir sampling (other colors)

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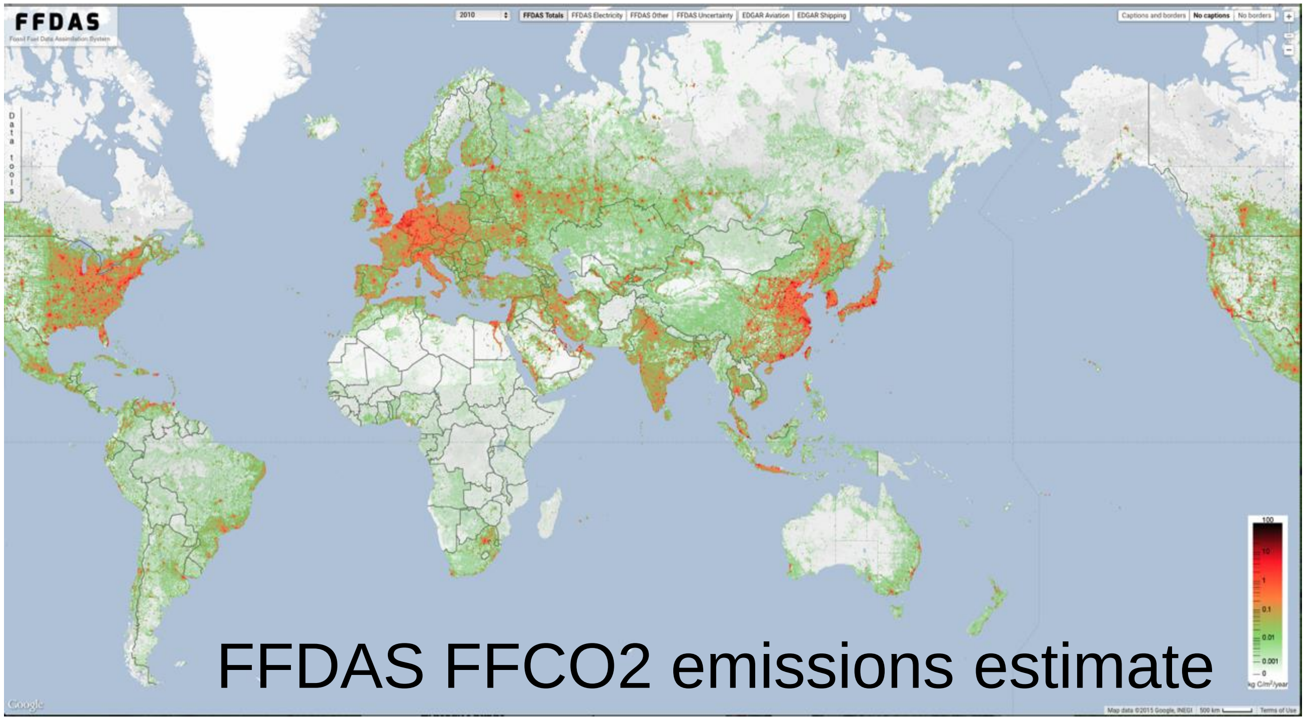
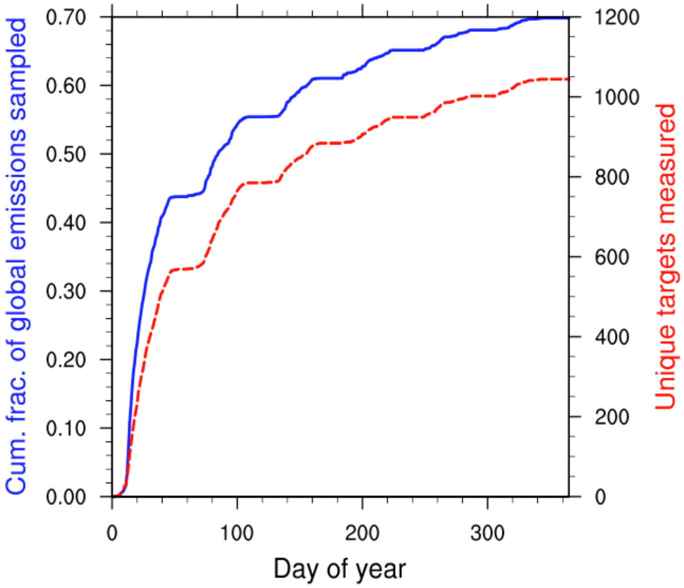
Designing FFCO2 Sampling for OCO-3

- OCO-3 flexibility allows for a highly customized sampling design
- We consider these items when designing data collection: emissions magnitude, emissions uncertainty, desired number of revisits, opportunity cost with respect to other sources
- We defined 1308 sample regions that represent 77% of global emissions (~6 PgC/year) and 55% of FFDAS uncertainty



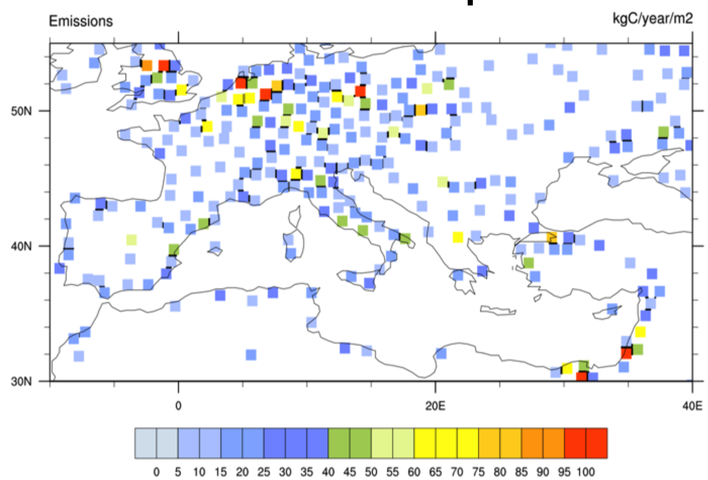


Courtesy of Ryan Pavlick

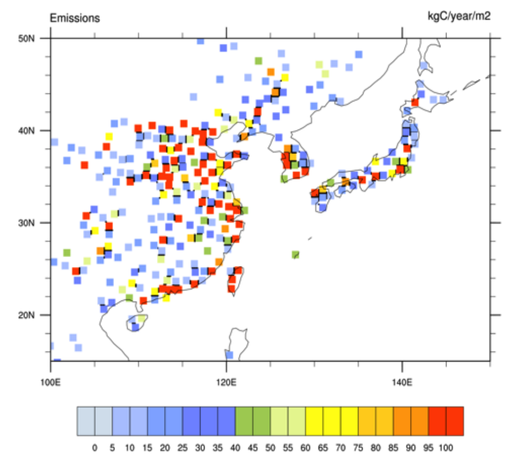
Where to Focus Area Mapping Mode

- The OCO-3 Mission Operations team designed a flexible system that can accommodate up to 100 special observations in a day. A prioritization system was developed to optimize selection. We are developing an automated system to update selected targets based on weather data.

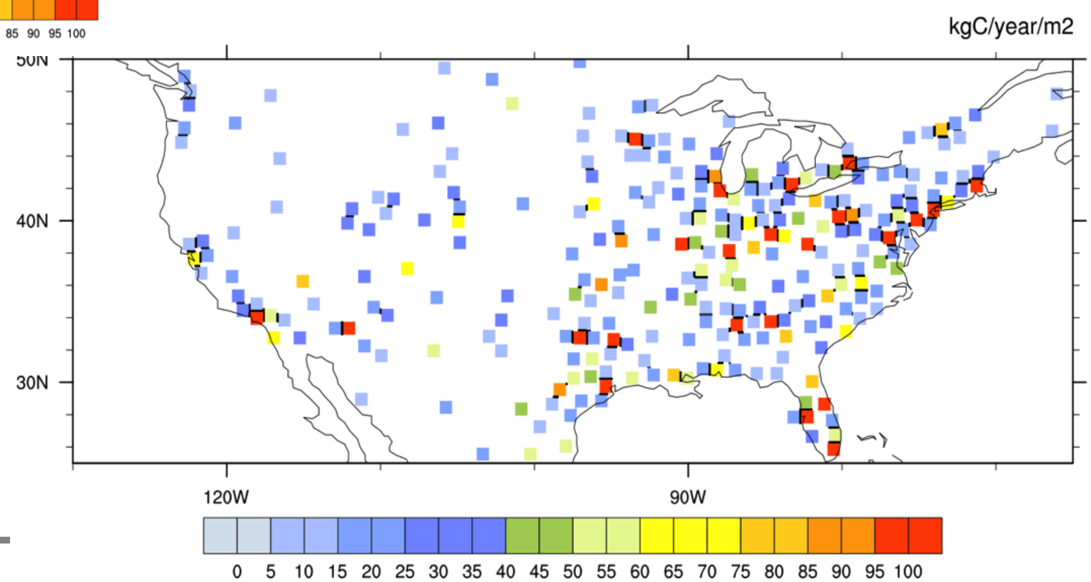
Emissions - Europe



Emissions -Asia



Emissions – North America



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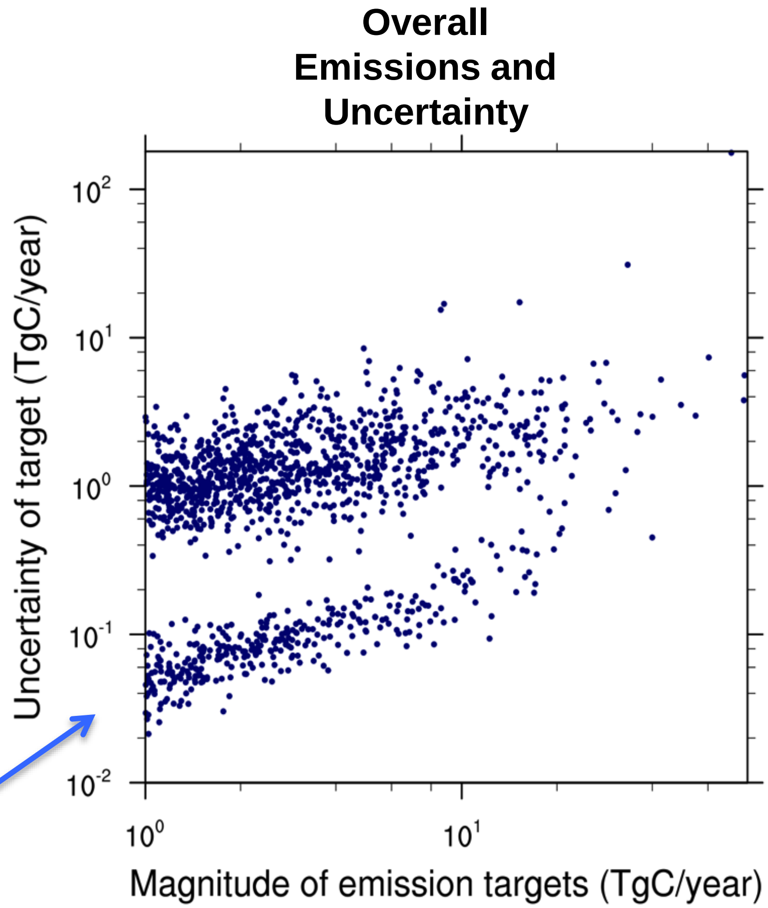
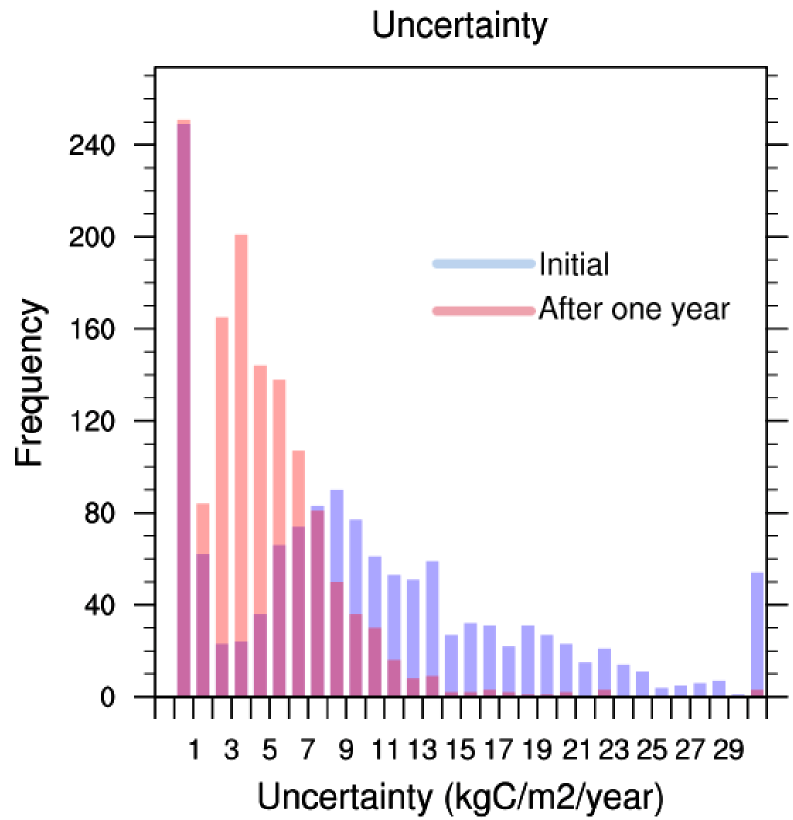
Estimated Uncertainty Reduction



FFDAS predicts low uncertainties in US



The FFCO2 uncertainty reduction is estimated to be 40%. The optimization was successful - after a year of sampling only a few sources had predicted uncertainty larger than 15 $kgC/m^2/year$.

Conclusions

- OCO-3 is a critical element in the continuation of global CO2 measurements focused on understanding the regional sources and sinks of CO2.

- OCO-3 can also contribute to focused study of how space based measurements can constrain rapidly changing anthropogenic emissions. Anthropogenic emissions could be the largest source of uncertainty in the global carbon budget as OCO-2 measurements reduce uncertainty of natural fluxes.

- OCO-3 measurements can be combined with evapotranspiration and biomass measurements to study process details of the terrestrial ecosystem.

- OCO-2 has demonstrated the atmospheric XCO2 can be measured from space with precision of better than 1 ppm.

- OCO-3 has differences including measuring at all polarizations. Much of the data should be of similar quality as OCO-2.

Near Term Activities

TVAC-0 late Aug 2018

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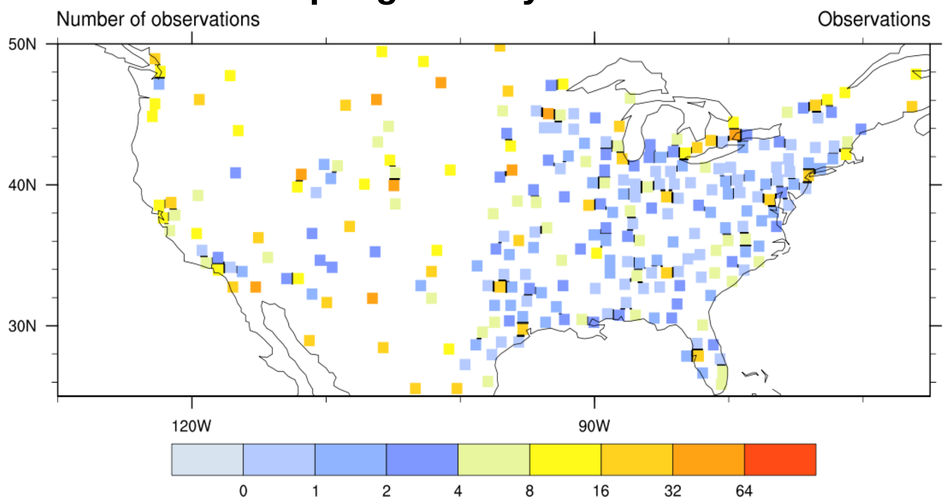
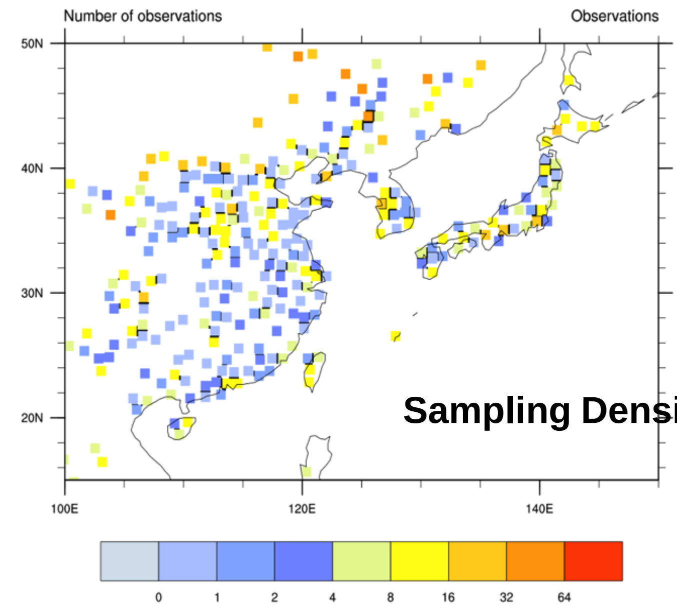
Simulated OCO-3 Snapshot Mapping

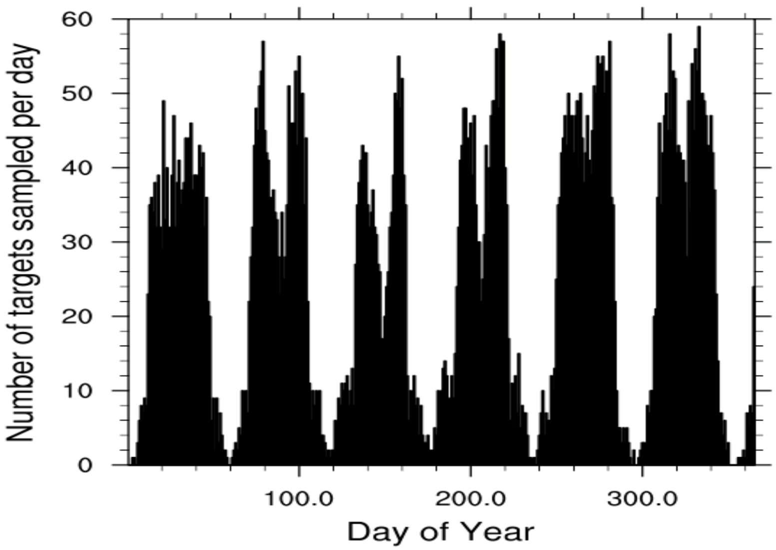
Sampling Density – North America



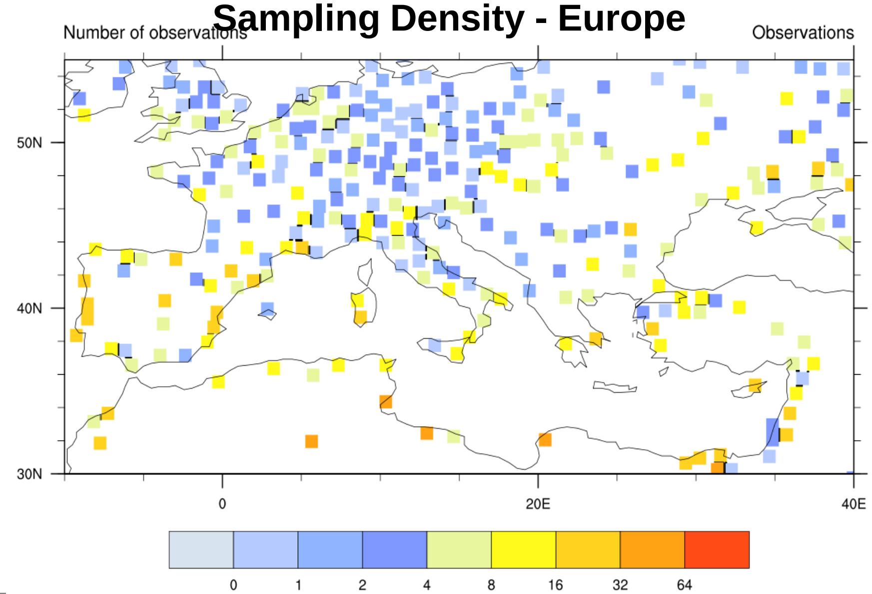
Sampling Density - Asia



Sampling Density over the year



Sampling Density - Europe



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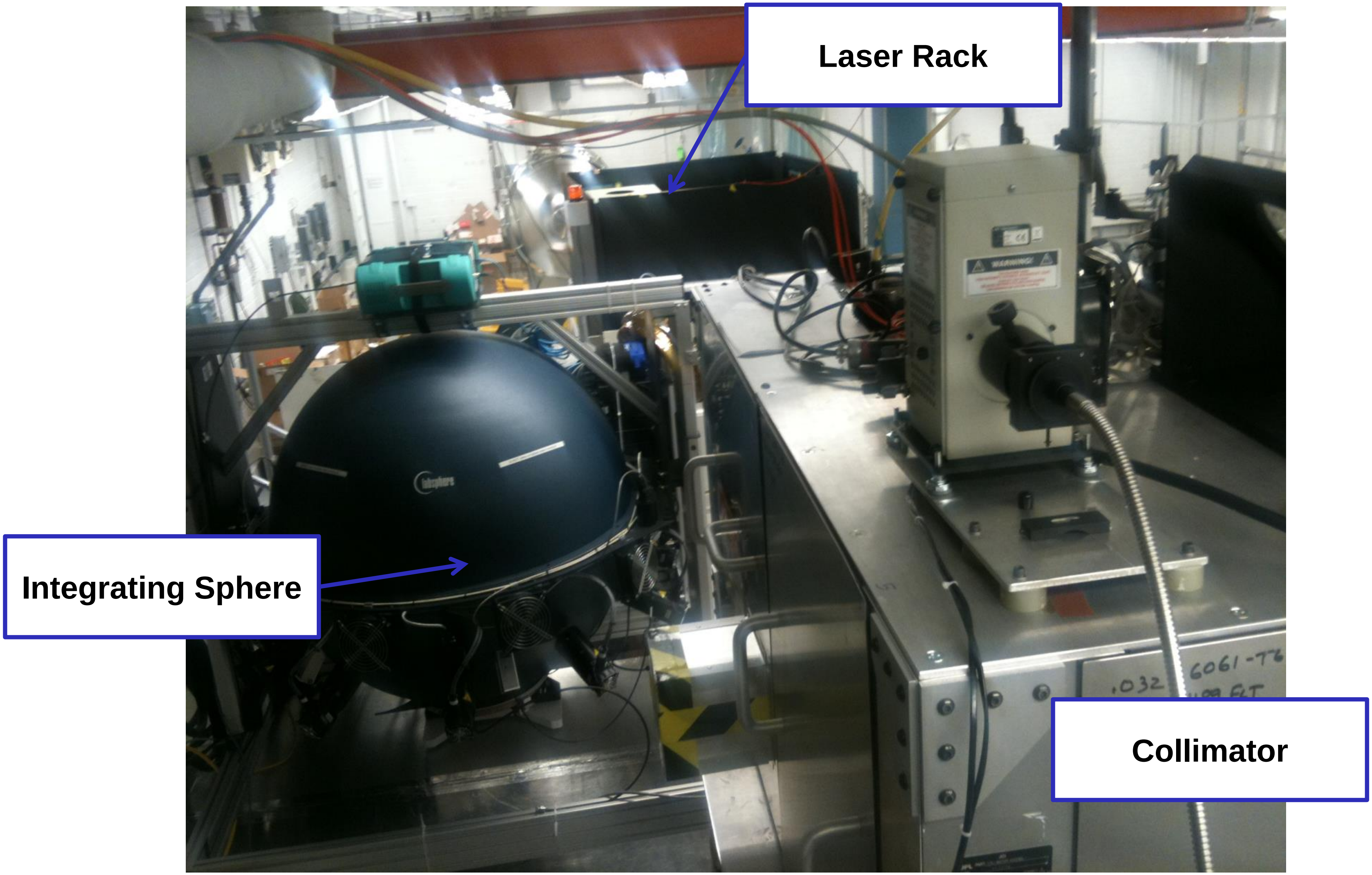
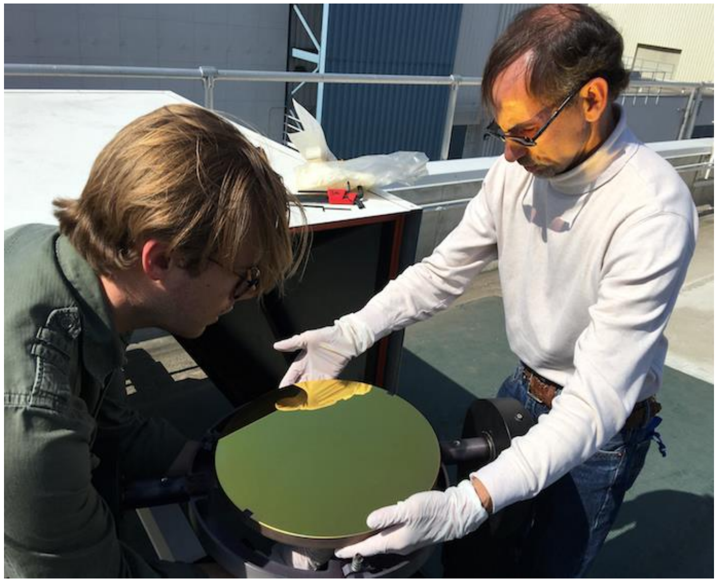
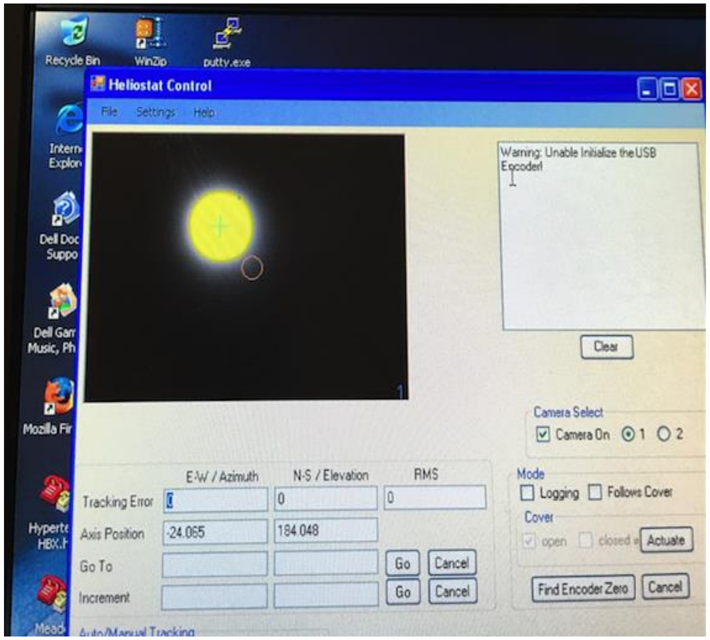
OCO-2 Optical Ground Support Equipment Used for OCO-3 Testing



Optical Ground Support Equipment Refurbished for TVAC-0

- Integrating Sphere
  - Reintegrate ASD spectrometer (currently backup for OCO-2 vicarious calibration)
  - Retest functionality (stages, light bulbs, LabView code, etc)
  - Recalibrate sphere in-situ to capture chamber window transmission
- Collimator
  - Replenish spares used during last Tvac (e.g. two optical fibers broken during test)
  - Recalibrate various components (wavemeters, power supplies, etc.)
  - Realign and validate internal alignment (e.g. polarizer positions)
  - Retest functionality (stages, light bulbs, LabView code, etc.)
- Vacuum Chamber Heliostat
  - Re-install hardware removed from roof to protect from the environment
  - Retest functionality of the tracking system

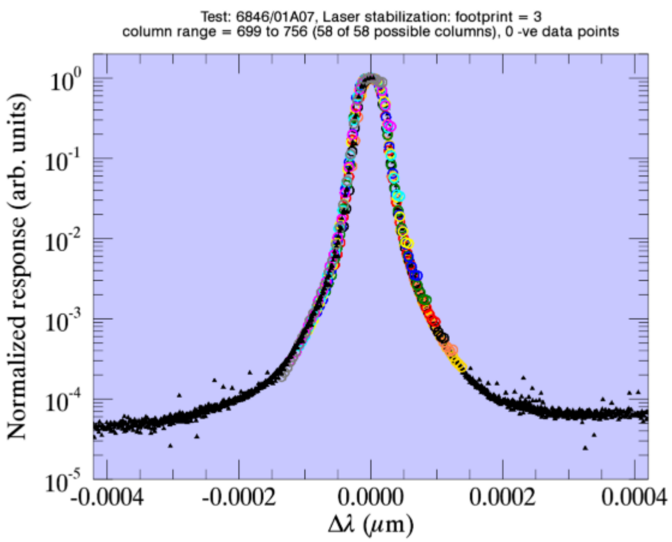




Successful TVAC0!

- The OCO-3 TVAC0 test showed that the instrument is performing virtually the same now as it did just before storage 3 years ago.
- THIS SLIDE WILL BE UPDATED
- Similarity of instrument lineshape in the two measurements

TVac1C



TVac0b