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The Orbiting Carbon Observatory (OCO) Mission

Watching The Earth Breathe…Mapping CO_2 From Space.

The OCO-3 Mission: An Overview

Annmarie Eldering and the OCO-3 Team

May 2013

IWGGMS Meeting

Yokohama, Japan

OCO-3 Project Overview

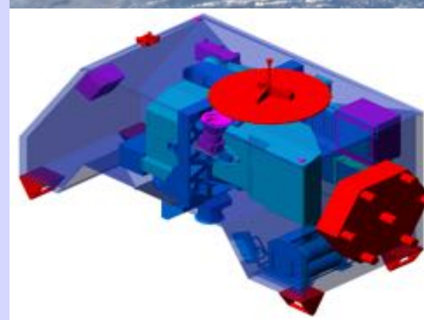
OCO-3 is a NASA-directed Climate Mission on the International Space Station

Primary Science Objective

- 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).
  - Measurement precision and accuracy requirements same as OCO-2
  - Operation on ISS allows latitudinal coverage from 51 deg S to 51 deg N

Salient Features:

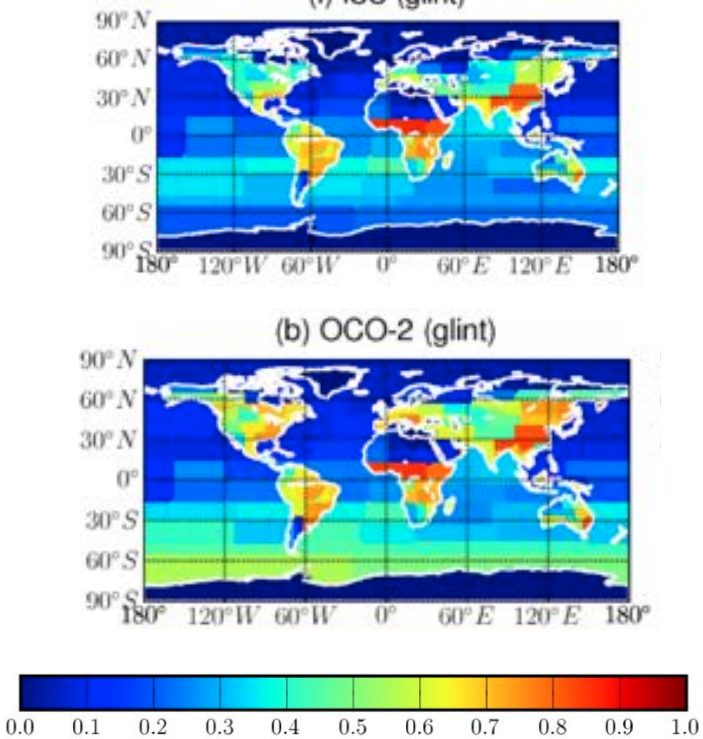
- Category 3 mission per NPR 7120.5E
- Risk classification C per NPR 8705.4
- High-resolution, three-channel grating spectrometer (JPL)
- Partnership between SMD and HEOMD
- Deployed on the International Space Station
- Payload Delivery Date: Sep 2016 at KSC
- Operational life: 3 years after 90 days In orbit Checkout
- Project Scientist: Dr. Annmarie Eldering
- Project Manager: Dr. Ralph Basilio, Deputy: Said Kaki
- JPL Program Manager: Dr. Steven Bard, Deputy: Amit Sen
- ESSP Program Director: Frank Peri, Deputy: Greg Stover
  Mission Manager: Todd Denkins
- Program Scientist: Dr. Kenneth Jucks, NASA HQ
- Program Executive: Betsy Edwards, NASA HQ



OCO-3: Science Overview

Continued Global CO_2 Flux Estimates

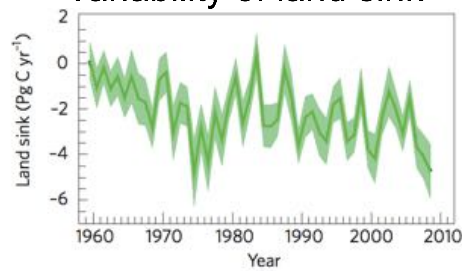
OCO-3 on
(f) ISS (glint)



Flux error improvement for January
Palmer et al., 2011

Unique Science Opportunities with OCO-3

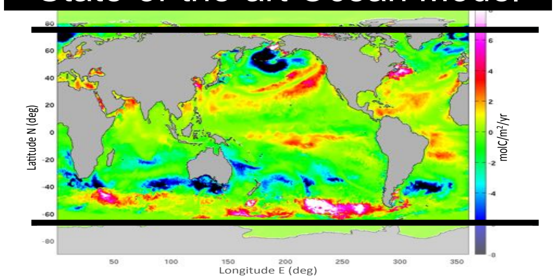
Variability of land sink



Terrestrial Carbon Cycle
Process studies enabled by measurements at all sunlit hours

From LeQuere et al., 2009

State-of-the-art Ocean Model



Oceanic Sources and Sinks
Enabled by denser glint sampling

Menemenlis et al.

Anthropogenic Emissions
Enabled by enhanced target mode using pointing mirror assembly

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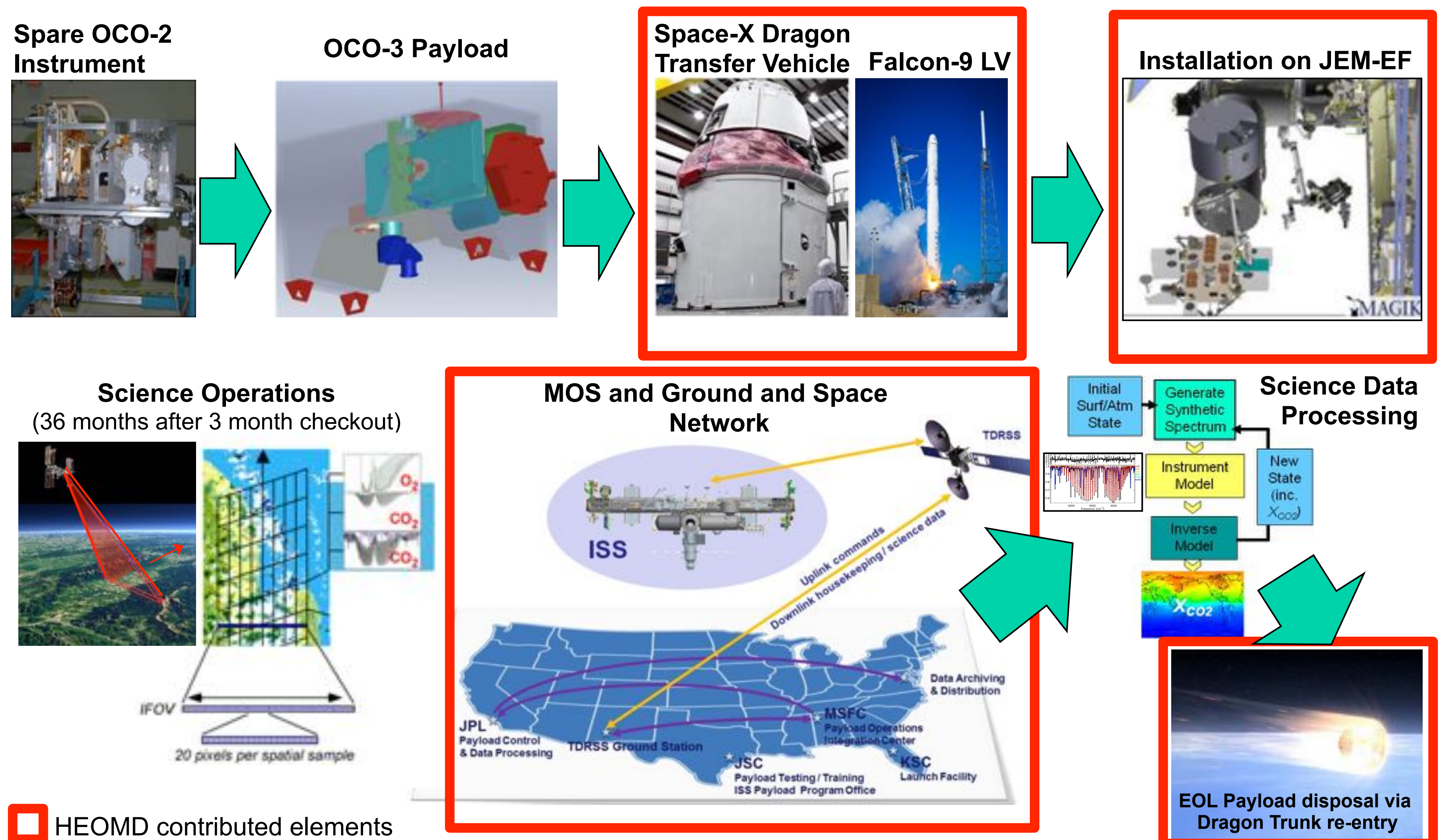
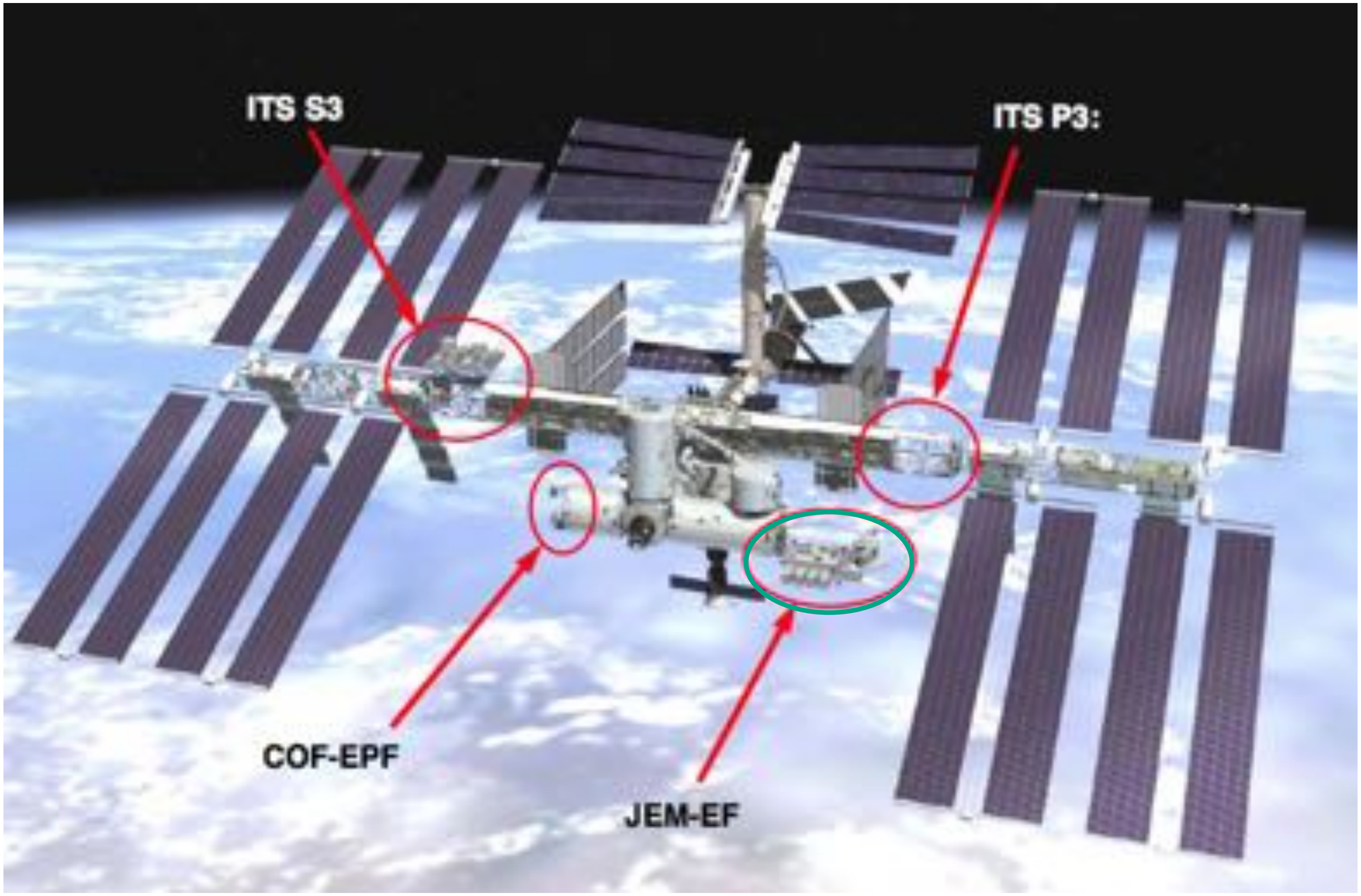
OCO-3 Mission Concept and Architecture

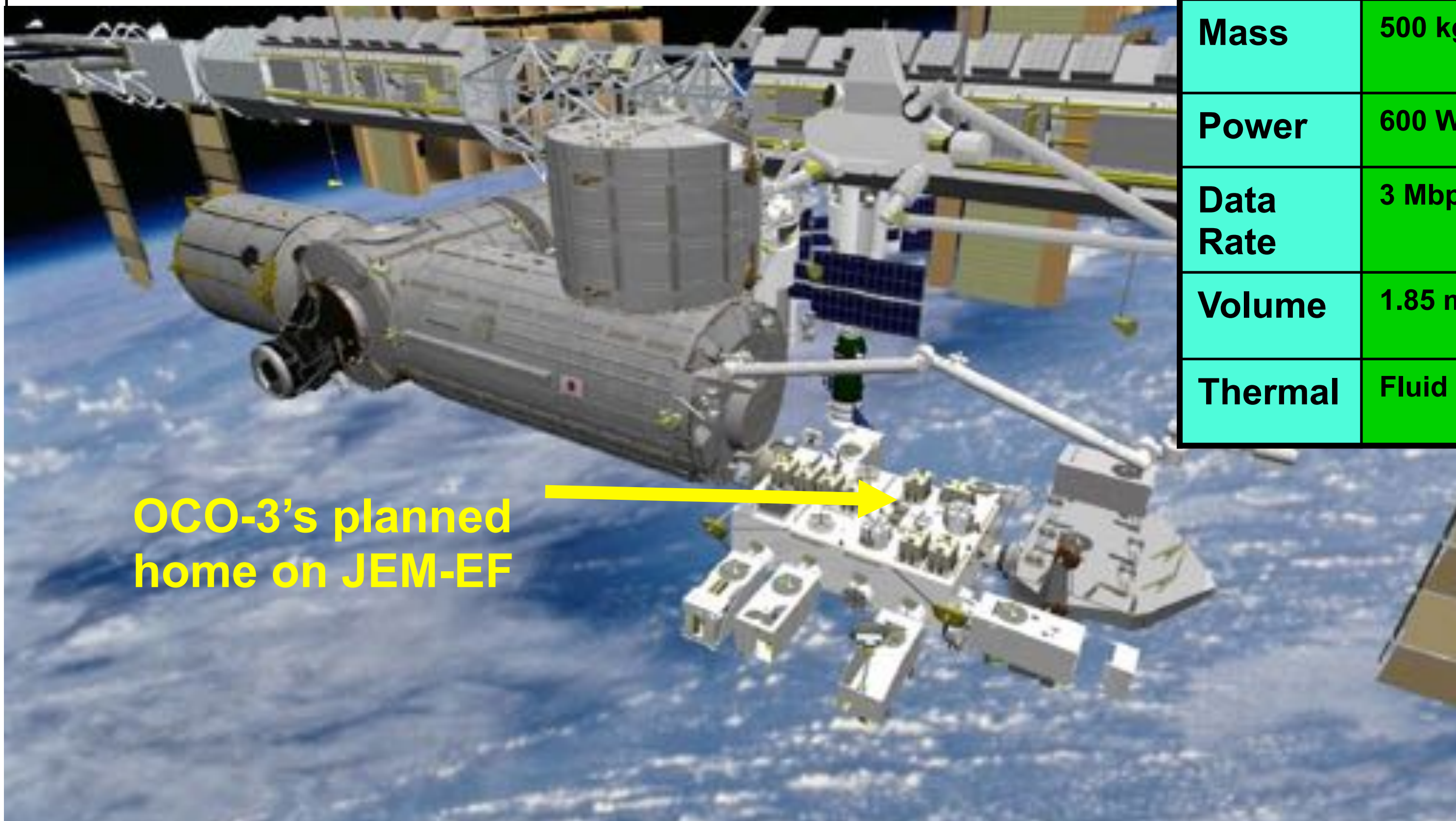


ISS External Payload Options



OCO-3 Assigned to JEM-EF 6

	OCO-3 Resource Allocations in Payload Interface Agreement (PIA)
Mass	500 kg
Power	600 W
Data Rate	3 Mbps
Volume	1.85 m x 1.0 m x 0.8 m
Thermal	Fluid Cooling Loop

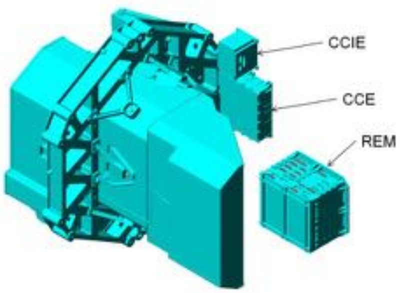


Comparison of OCO-2 and OCO-3

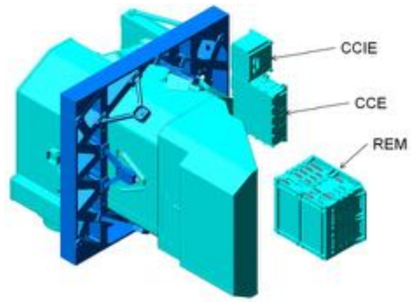
	OCO-2	OCO-3 on ISS
Land Sampling	Every day (using glint and nadir measurements)	Every day
Glint/Ocean Sampling	16 days on/16 days off	Every day
Latitudinal coverage	+/- 80 degrees	+/- 52 degrees (on ISS)
Local time of day sampling and repeat	~1:30pm with 16 day routine and repeated measurements	Ranges across all sunlit hours with variable revisit (0 to multiple per day)
Expected XCO_2 single sounding precision	≤ 1%	≤ 1%
Expected XCO_2 precision for collection of 100 cloud-free soundings	≤ 0.3% (1 ppm)	≤ 0.3% (1 ppm)
Target mode capability	Yes, with spacecraft pointing	Yes, expanded with pointing mirror assembly
Polarization approach	Keep instrument slit in principal plane	Include optical element to depolarize incoming radiation

OCO-3 Payload Concept

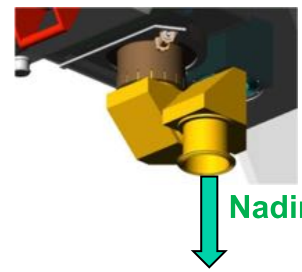
Inherit OCO-2 spare instrument



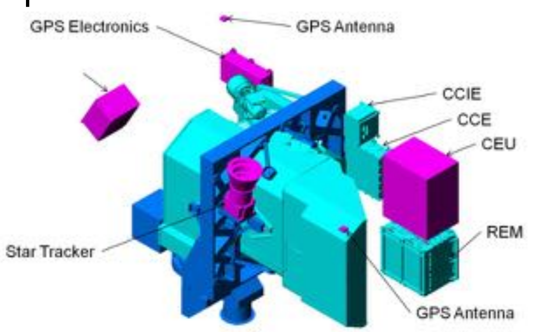
Replace instrument deck



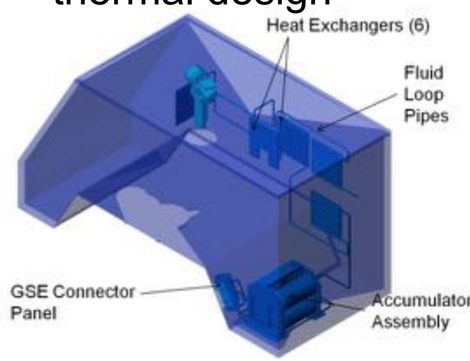
Add 2 axis Pointing Mirror Assembly



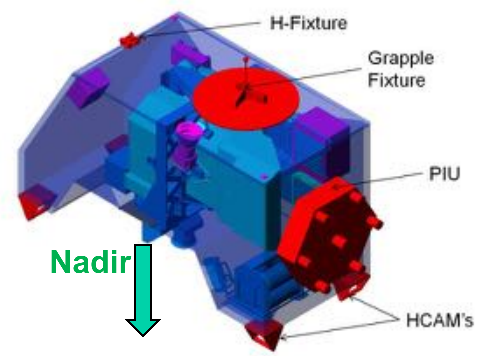
Pointing and control hardware, power and data interface to ISS



New Structure and thermal design

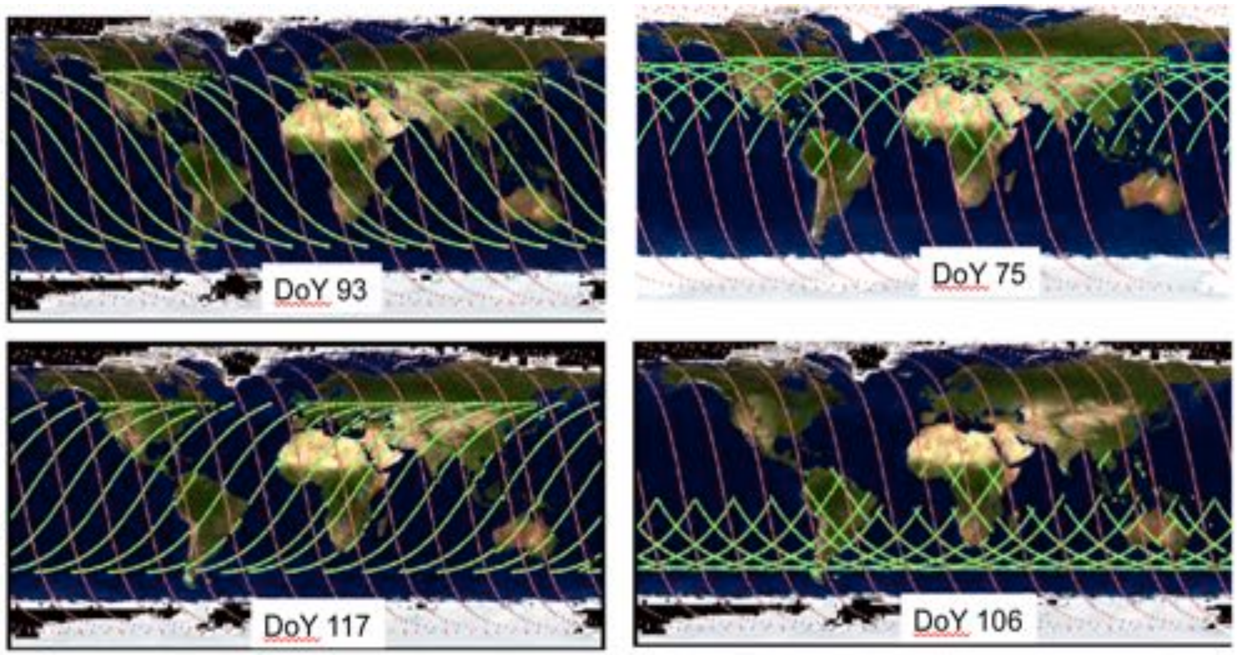


LV and ISS Interface GFE



Seasonal and Latitudinal Variations of OCO-3 Sampling from ISS

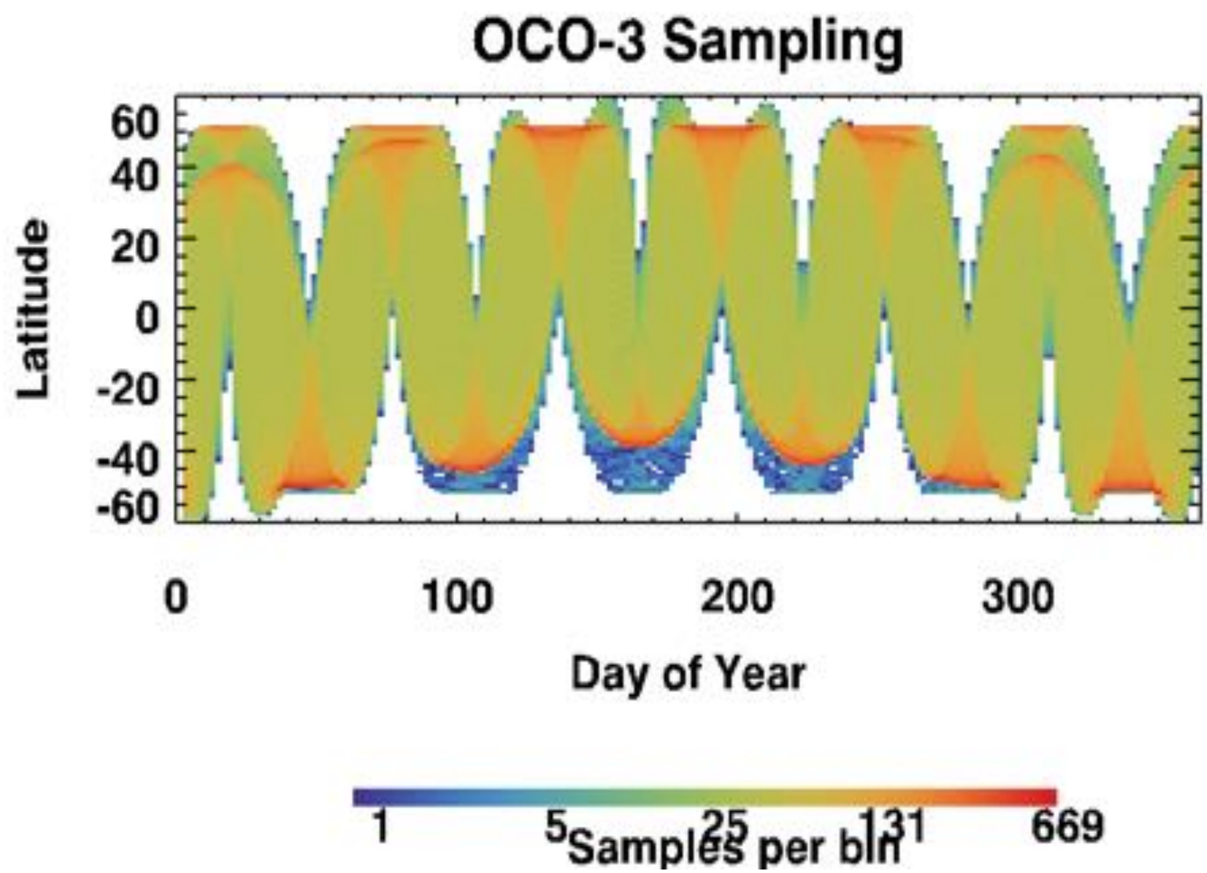
- Sampling would be dense at mid-latitudes, while providing good coverage of tropics and sub-tropics
- 2-axis pointing systems would enable new operations concept with nadir *and* glint observations taken every day, effectively doubling the number of samples over oceans as compared to OCO-2



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.

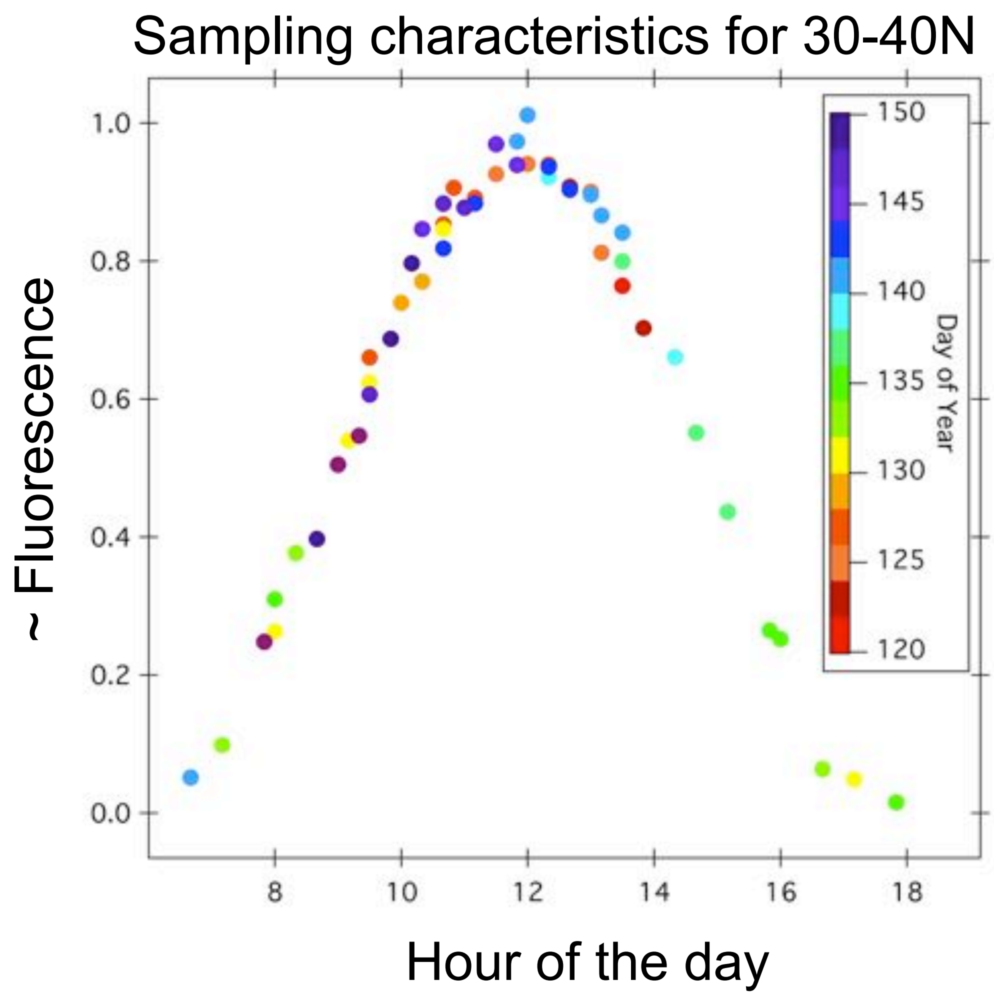
Spatial Characteristics of OCO-3 Sampling

- 2D histogram, with log scale
- There are periods where the northern and southern latitudes have sampling gaps, alternating with very dense sampling
- No simple formula for describing these
- Tropics have consistent, dense sampling, yet clouds will reduce yield



OCO-3 Temporal Sampling Characteristics

- Deployment on ISS would allow sampling across the daytime sunlit hours
- Patterns of sampling vary with latitude and season



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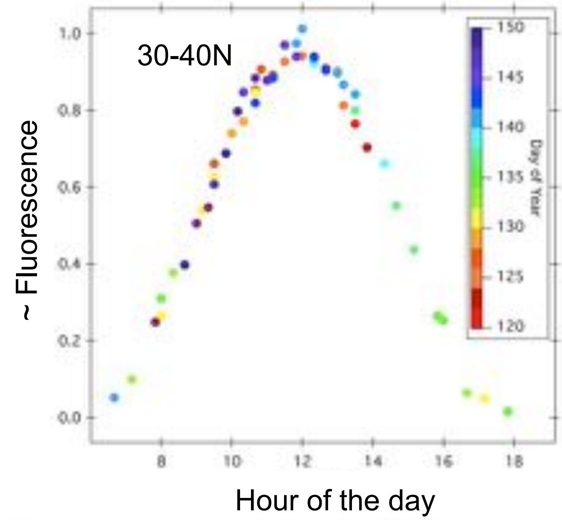
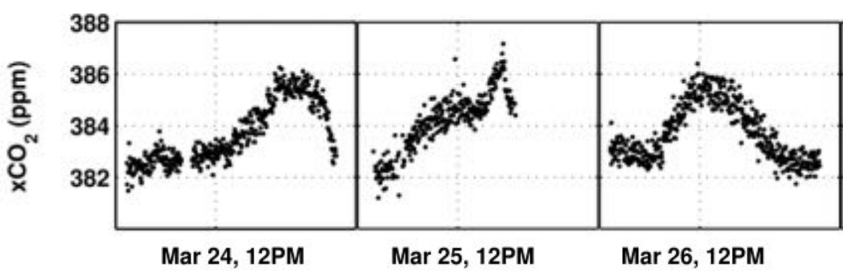
Measurements over the Diurnal Cycle

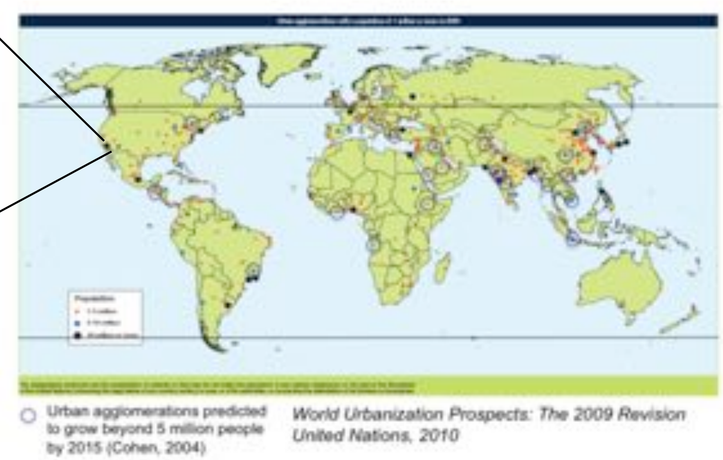
- Deployment on ISS allows sampling across all sunlit hours, facilitating studies of diurnal variations in
  - Chlorophyll fluorescence
  - Detection limits for diurnal variations in emissions from mega cities



Fluorescence amplitude vs. hour of day and season at 30 – 40 N.



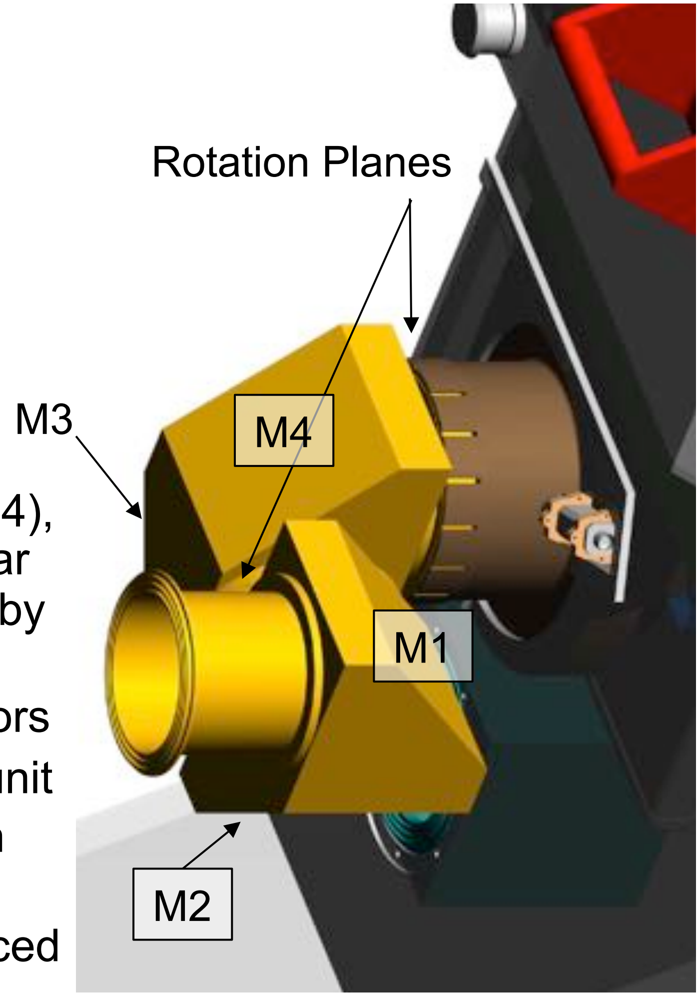
TCCON observations of emission plumes at Caltech.



Fastest growing mega cities.

Pointing Mirror Assembly (PMA)

- OCO-2 Pointing is controlled by spacecraft
  - Nadir, Glint, and Target observations
- OCO-3* Pointing
  - Same as above plus City Mode
- OCO-3 Pointing Concept
  - 2-Axis pointing mirror system
  - Each axis is made up of two 45º mirrors (M1-M4), 90º out of alignment with each other – any linear polarization created by one mirror is cancelled by the second
  - Two ring motors control the rotation of the mirrors
  - Outer mirror and motor is carried by the inner unit
  - Two axes provide ability to look in any direction within 60º of nadir
  - Scanner can also look into a calibrator box placed on the bottom of the system



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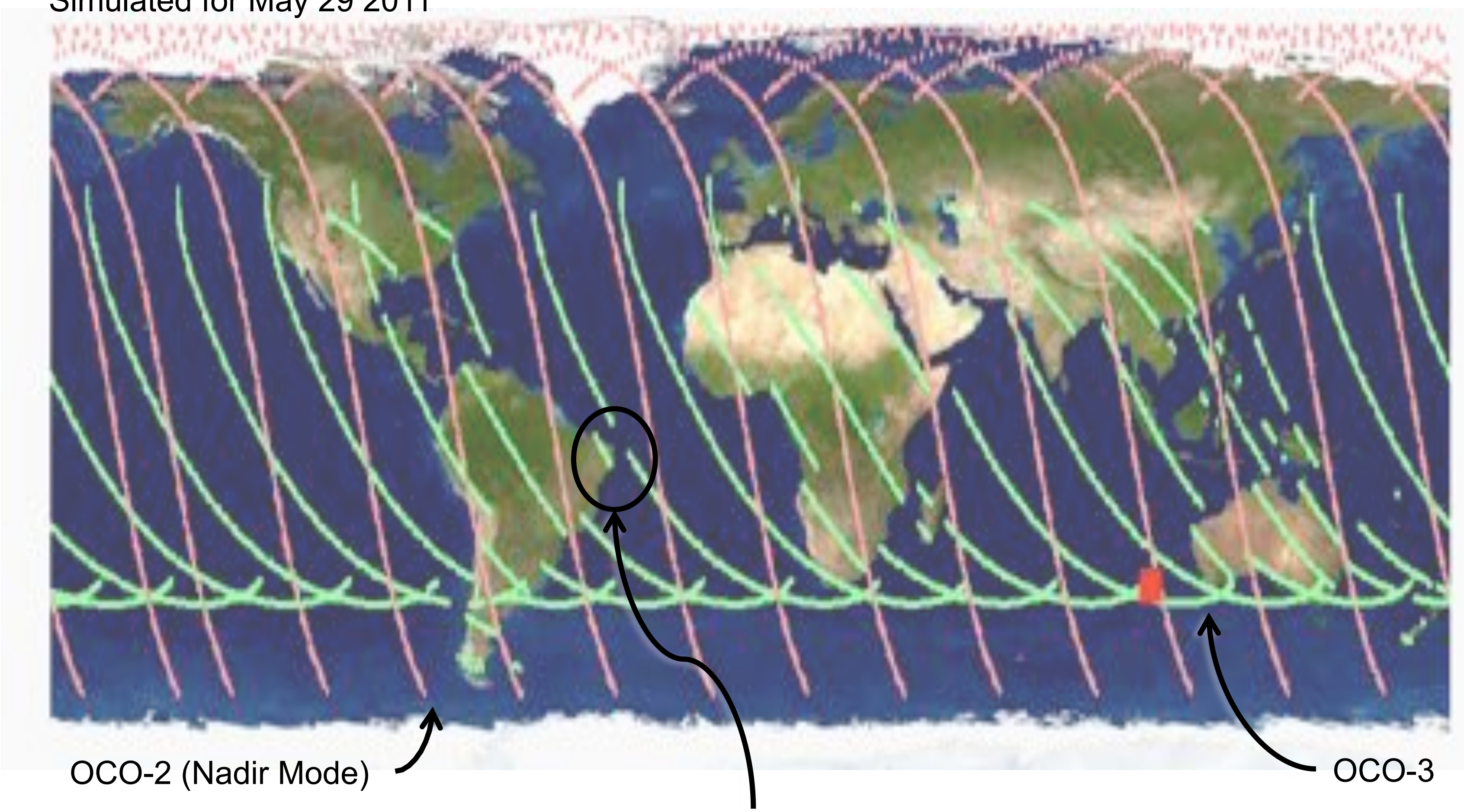
PMA Operations Concept For Science Data

Simulated for May 29 2011



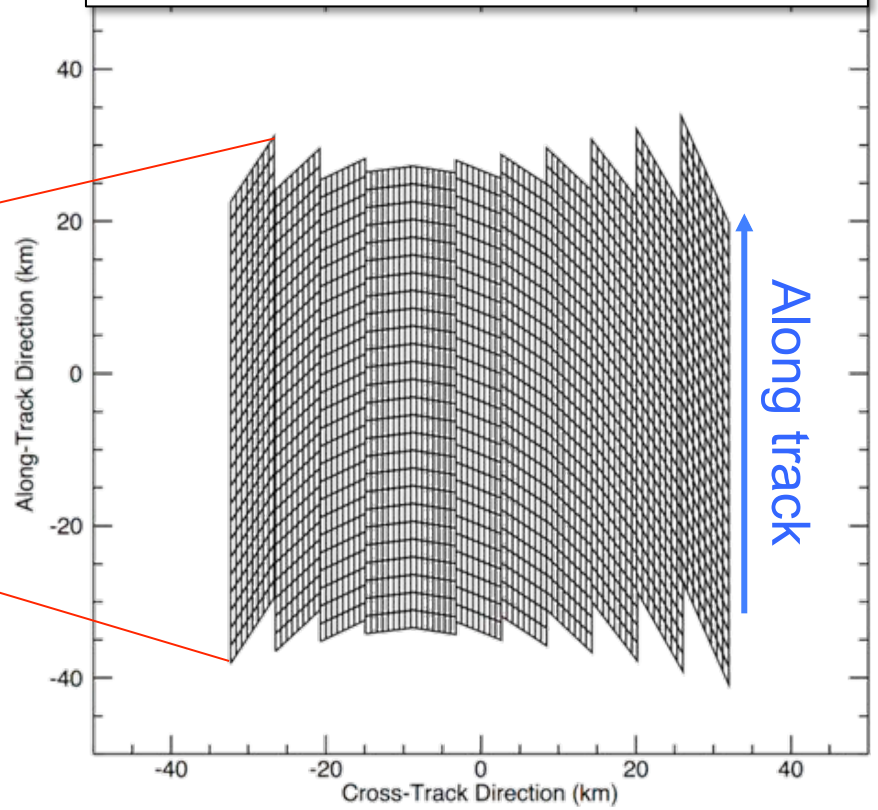
Note the OCO-3* observing track discontinuities at land/ocean boundaries – nadir observations when over land / glint when not over land

OCO-3 City Mode

- Scan starts when azimuth angle is ~50°
- PMA pointed to right of track and held steady for 8-9 seconds (50-60 km)
- PMA rotates quickly backwards and slightly left, waits 2 seconds to settle, then holds steady for 8-9 second scan
- Repeat until target is ~50° behind ISS

Best Case (ISS passes straight overhead) provides ~65 km x 65 km scan area
Typical will be 50 km to 60 km 'squares'

OCO-3 target mode raster-scan (~3600 samples per 3 minute pass in ~50km by ~50km region, several passes per month at different times of day



City Mode is an expanded case of Target Mode

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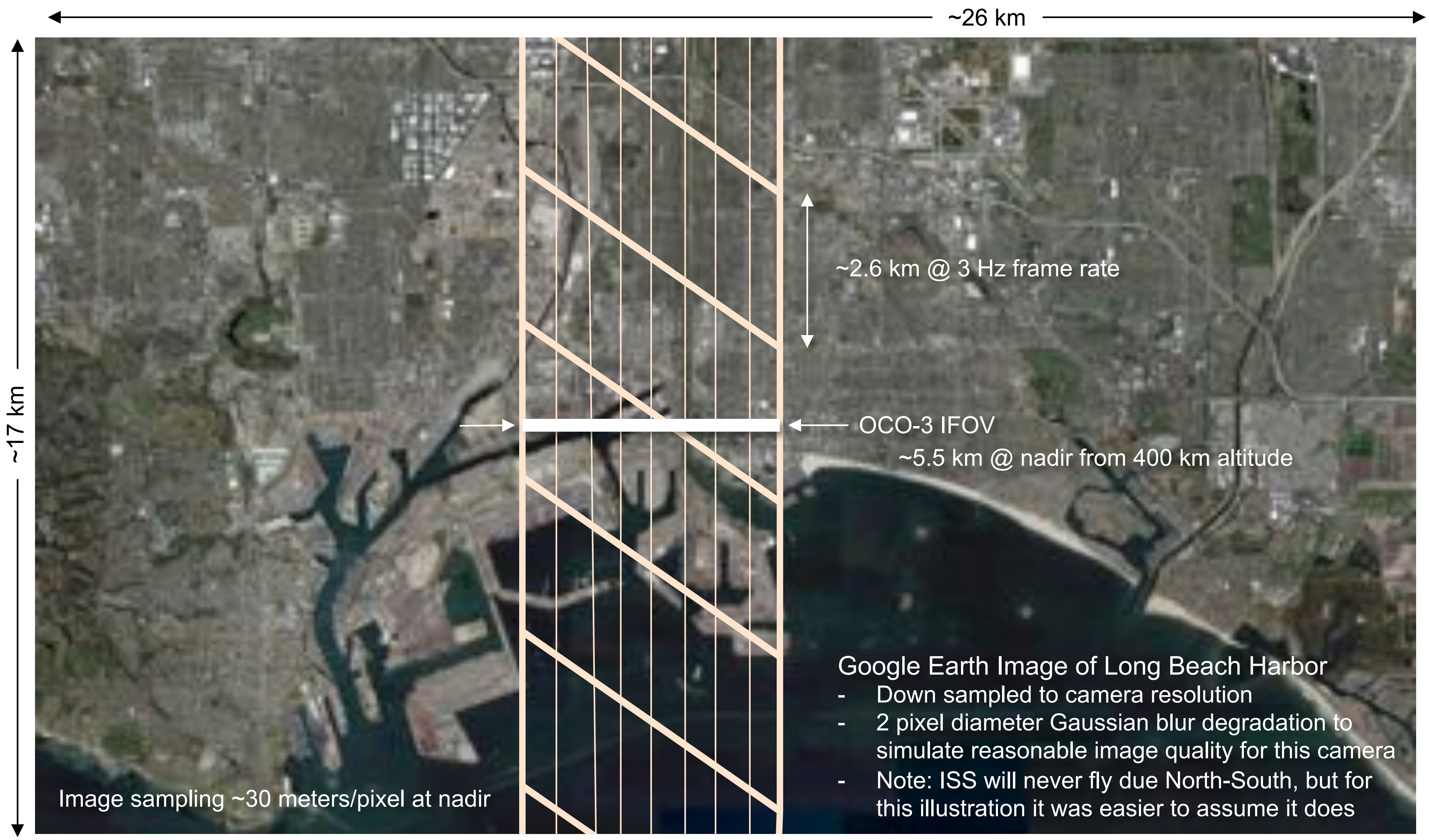
Simulated Context Camera Image With Simulated OCO-3 Footprints at Nadir



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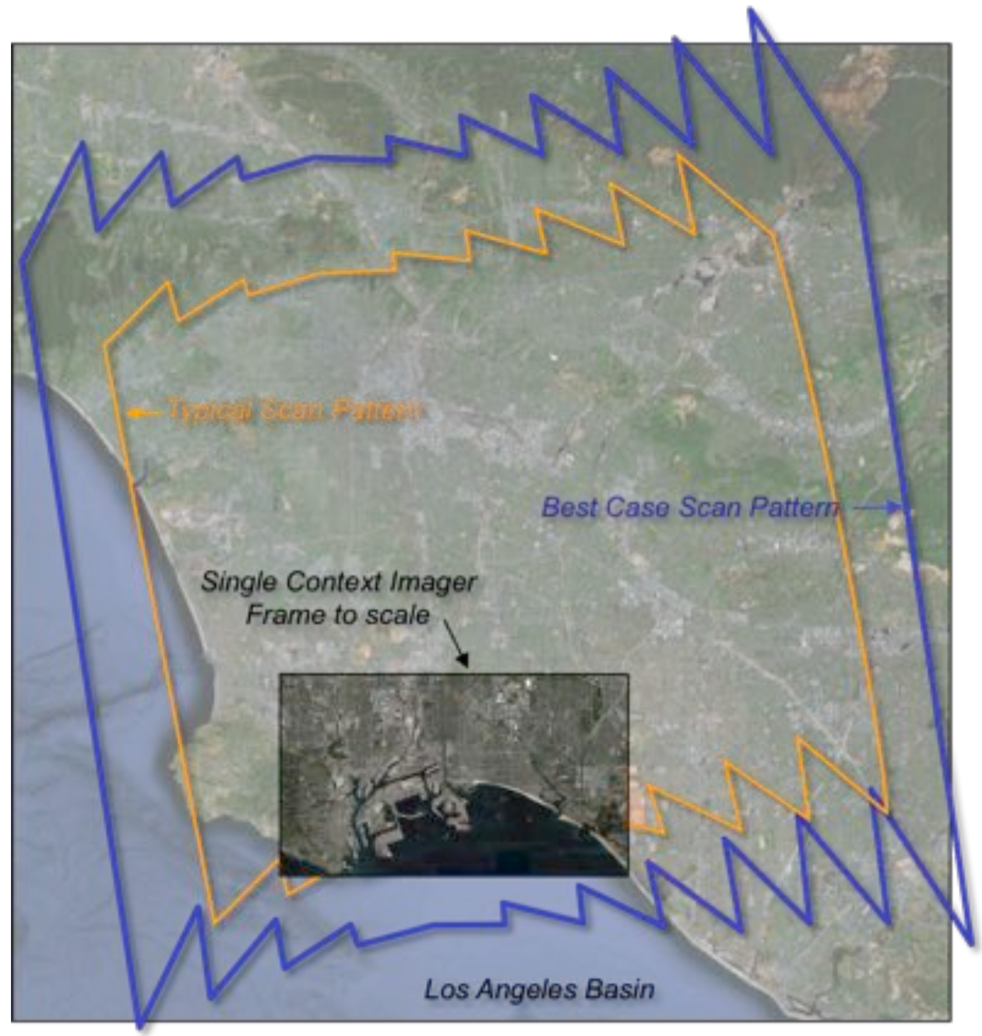
OCO-3 City Mode Plus Context Camera

- During City Mode scan, the context imager will take pictures every 2 seconds
  - Provides an overlapping set of images that will extend ~15-20 km outside X_{CO2} scan pattern
- Science opportunity
  - Large industrial plumes will be clearly visible in the imagery
  - X_{CO2} field can be compared to plume – especially when visible plume disappears



Benefits of OCO-3 Carbon Cycle Science

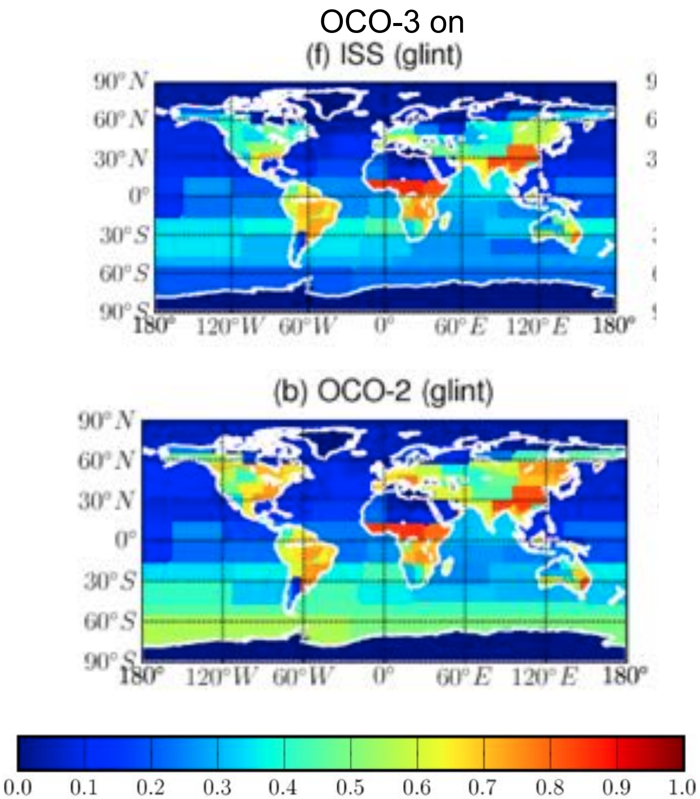
- The OCO-2 spare instrument will become OCO-3 after OCO-2 is launched
- OCO-3 on ISS has proposed to:
  - **Advance carbon cycle science and build on the capability to determine regional sources and sinks**
  - **Provide X_{CO2} data bridging the potential gap between the OCO-2 and ASCENDS missions, with highest data density at mid-latitudes**
  - Reduce errors of the carbon cycle flux in the **terrestrial biosphere** with measurements of X_{CO2} and chlorophyll fluorescence across all sunlit hours
  - Investigate the small scale **patterns of ocean carbon flux** suggested by eddy-resolving models with dense sets of glint X_{CO2} measurements
  - Detect and quantify the **spatial variability of fossil fuel emissions** in rapidly developing urban centers as opportunistic science

OCO-3 transitioned into Phase-A in Nov 2012, and will be ready for installation on ISS in early 2017

OCO-3: Global CO_2 Flux Estimates

What are the magnitudes, distribution, and variability of surface-atmosphere CO_2 fluxes and their uncertainties over the relevant range of spatial and temporal scales?

- OSSE study show that OCO-3 has the same sounding accuracy as OCO-2 – in most regions flux error reduction is similar, although OCO-3 does not sample Southern Ocean.
- The benefit of the denser sampling of OCO-3 is not reflected in this study
- The combined OCO-2 and OCO-3 measurements would be used to:
  - reduce flux uncertainties by 50% on length scales of 400km for the combined data, as compared to 950km for OCO-2 alone.
  - perform weekly rather than monthly flux inversions of OCO-2 alone.
- Flux error improvement = 1-(final error /initial error). Flux error improvement – 0.9 means a factor of 10 improvement, 0 is no improvement



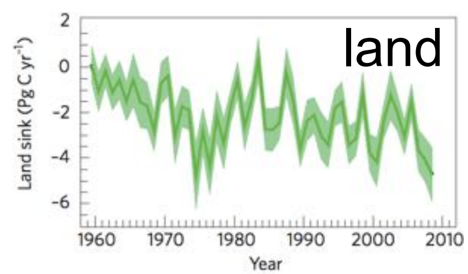
Flux error improvement for January
Palmer et al., 2011

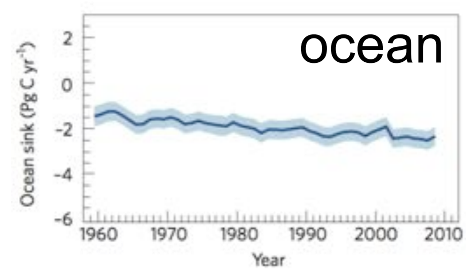
OCO-3: Terrestrial Carbon Cycle

What are the inter-annual, seasonal, and diurnal changes in uptake and release of CO_2 on sub-regional and regional scales in the terrestrial biosphere?

- The behavior of the terrestrial biosphere is one of the largest sources of uncertainty in quantifying the carbon cycle (LeQuere et al, 2009)
- The X_{CO2} and fluorescence measurements of OCO-3, <u>at all sunlit hours</u>, will provide insight into key terrestrial carbon processes.
- Reducing uncertainties requires sub-regional fluxes, the scale provided by combining OCO-2 and OCO-3.
- As with OCO-2, chlorophyll fluorescence is co-retrieved as part of the standard algorithm (to reduce error of X_{CO2})
- Current GOSAT-based dataset is at a single local time, yet there is a strong diurnal signal in fluorescence, valuable for process studies and provided by OCO-3

Year to year changes in land uptake/terrestrial biosphere are large and variable



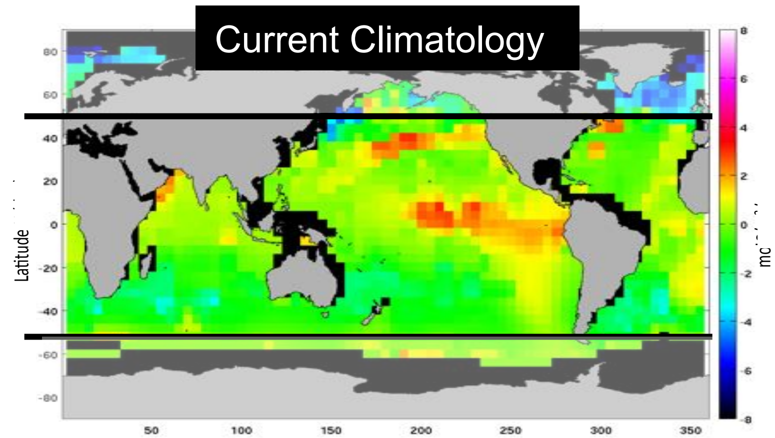


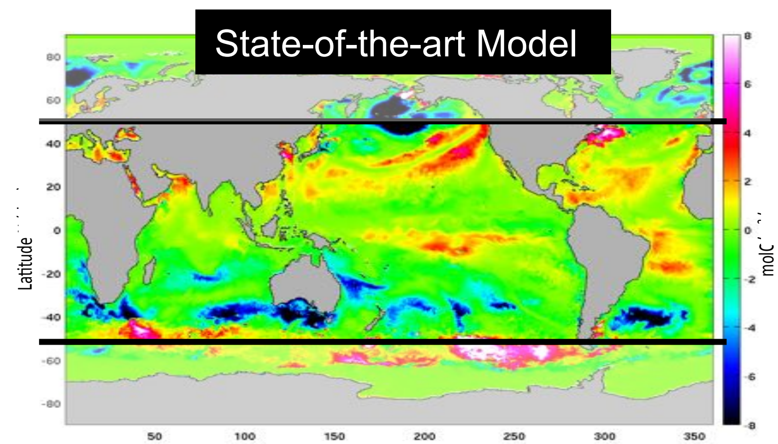
From LeQuere et al., 2009

OCO-3: Oceanic Sources and Sinks

How do the regional oceanic sources and sinks of atmospheric carbon dioxide change with sub-seasonal to inter-annual variability, e.g., synoptic forcing and ENSO?

- The ENSO cycle is thought to be a key driver of the variability of ocean CO_2 uptake and outgassing
- Spatial patterns of CO_2 exchange are predicted to have fine structures, which are not represented in ship-based climatologies
- The OCO-2 glint (16 days on and off) and the denser OCO-3 glint (every day) measurements would provide flux estimates on the scales required to investigate the patterns of ocean flux suggested by state of the art ocean models
- The combined OCO-2 and OCO-3 missions should span a complete ENSO cycle





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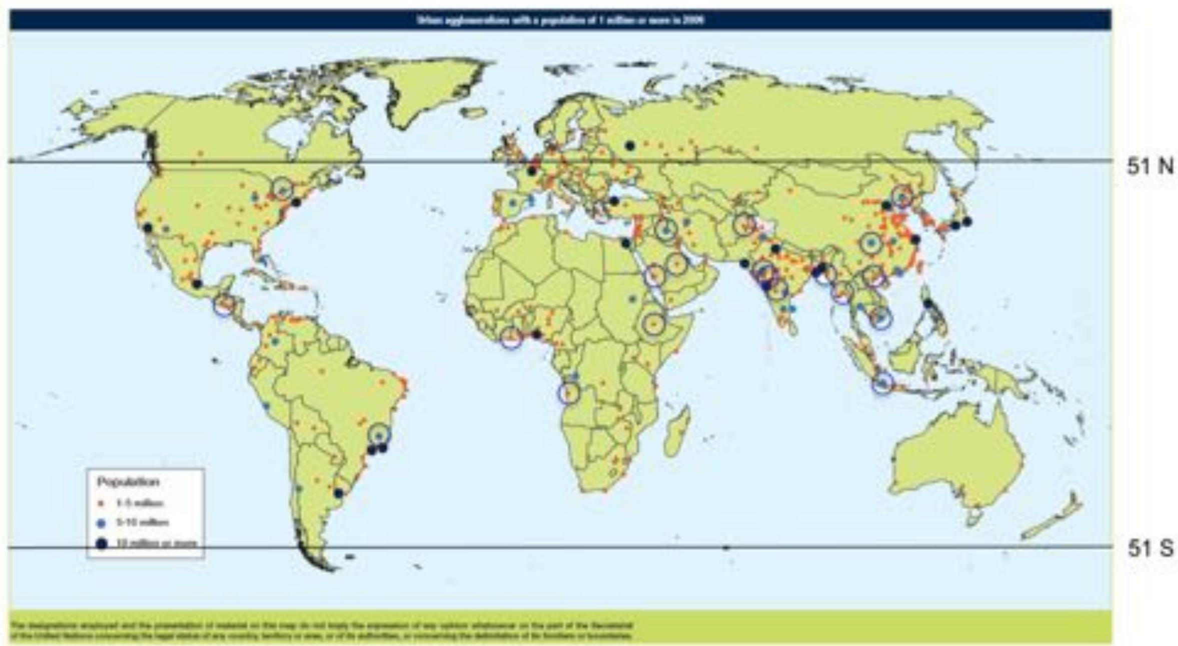
OCO-3 Opportunistic Science: Trends in Anthropogenic Emissions

How is the growth in urban population and changing patterns of fossil fuel combustion influencing atmospheric CO_2 distributions? Can we discriminate regional trends of anthropogenic CO_2 emissions against the backdrop of natural variability?

- Reducing uncertainty of the largest terms of the carbon cycle, anthropogenic fossil fuel emissions, is critical to quantifying the complete carbon cycle
- OCO-3 target mode measurements of cities provides the opportunity to characterize plumes from intense point sources of CO_2 such as power stations, and urban centers.
- Urban center growth of 10% per year is detectable by sampling once or twice a month over 2 to 3 years.



○ Urban agglomerations predicted to grow beyond 5 million people by 2015 (Cohen, 2004)

World Urbanization Prospects: The 2009 Revision United Nations, 2010

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Thank you!