The Orbiting Carbon Observatory (OCO) Mission

Watching The Earth Breathe...Mapping CO₂ From Space.

The OCO-3 Mission: An Overview

Annmarie Eldering and the OCO-3 Team
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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 (CO₂) dry air mole fraction, X_CO₂, with the precision, resolution, and coverage needed to improve our understanding of surface CO₂ 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

Unique Science Opportunities with OCO-3

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

Continued Global CO₂ Flux Estimates

OCO-3 on (f) ISS (glint)

OCO-2 (glint)

Flux error improvement for January
Palmer et al., 2011
OCO-3 Mission Concept and Architecture

Spare OCO-2 Instrument → OCO-3 Payload → Space-X Dragon Transfer Vehicle → Falcon-9 LV → Installation on JEM-EF

Science Operations (36 months after 3 month checkout) → MOS and Ground and Space Network → Science Data Processing

EOL Payload disposal via Dragon Trunk re-entry

HEOMD contributed elements

ISS External Payload Options
OCO-3 Assigned to JEM-EF 6

<table>
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<tr>
<th>OCO-3 Resource Allocations in Payload Interface Agreement (PIA)</th>
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<tr>
<td>Mass</td>
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<tr>
<td>Power</td>
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<tr>
<td>Data Rate</td>
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<tr>
<td>Volume</td>
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<td>Thermal</td>
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OCO-3’s planned home on JEM-EF
### Comparison of OCO-2 and OCO-3

<table>
<thead>
<tr>
<th>Feature</th>
<th>OCO-2</th>
<th>OCO-3 on ISS</th>
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<tr>
<td>Land Sampling</td>
<td>Every day (using glint and nadir measurements)</td>
<td>Every day</td>
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<tr>
<td>Glint/Ocean Sampling</td>
<td>16 days on/16 days off</td>
<td>Every day</td>
</tr>
<tr>
<td>Latitudinal coverage</td>
<td>+/- 80 degrees</td>
<td>+/- 52 degrees (on ISS)</td>
</tr>
<tr>
<td>Local time of day sampling and repeat</td>
<td>~1:30pm with 16 day routine and repeated measurements</td>
<td>Ranges across all sunlit hours with variable revisit (0 to multiple per day)</td>
</tr>
<tr>
<td>Expected XCO₂ single sounding precision</td>
<td>≤ 1%</td>
<td>≤ 1%</td>
</tr>
<tr>
<td>Expected XCO₂ precision for collection of 100 cloud-free soundings</td>
<td>≤ 0.3% (1 ppm)</td>
<td>≤ 0.3% (1 ppm)</td>
</tr>
<tr>
<td>Target mode capability</td>
<td>Yes, with spacecraft pointing</td>
<td>Yes, expanded with pointing mirror assembly</td>
</tr>
<tr>
<td>Polarization approach</td>
<td>Keep instrument slit in principal plane</td>
<td>Include optical element to depolarize incoming radiation</td>
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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.
• 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
• Deployment on ISS would allow sampling across the daytime sunlit hours
• Patterns of sampling vary with latitude and season

Sampling characteristics for 30-40N

Fluorescence

Hour of the day

Day of Year
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 45° mirrors (M1-M4), 90° 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 60° of nadir
  - Scanner can also look into a calibrator box placed on the bottom of the system
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-2 (Nadir Mode)  OCO-3
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
Simulated Context Camera Image
With Simulated OCO-3 Footprints at Nadir

- Google Earth Image of Long Beach Harbor
  - Down sampled to camera resolution
  - 2 pixel diameter Gaussian blur degradation to simulate reasonable image quality for this camera
  - Note: ISS will never fly due North-South, but for this illustration it was easier to assume it does

Image sampling ~30 meters/pixel at nadir

- OCO-3 IFOV
- ~2.6 km @ 3 Hz frame rate
- ~5.5 km @ nadir from 400 km altitude
- ~26 km
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
• 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 $X_{CO_2}$ 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 $X_{CO_2}$ 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 $X_{CO_2}$ 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
What are the magnitudes, distribution, and variability of surface-atmosphere CO₂ 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
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, at all sunlit hours, 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
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 CO₂ uptake and outgassing
- Spatial patterns of CO₂ 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
How is the growth in urban population and changing patterns of fossil fuel combustion influencing atmospheric CO₂ distributions? Can we discriminate regional trends of anthropogenic CO₂ 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 provide the opportunity to characterize plumes from intense point sources of CO₂ 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.
Thank you!