# *OCO-2 / MicroCarb Technical Interface Meeting*

## *OCO-2 / OCO-3 / GeoCarb Status*

David Crisp

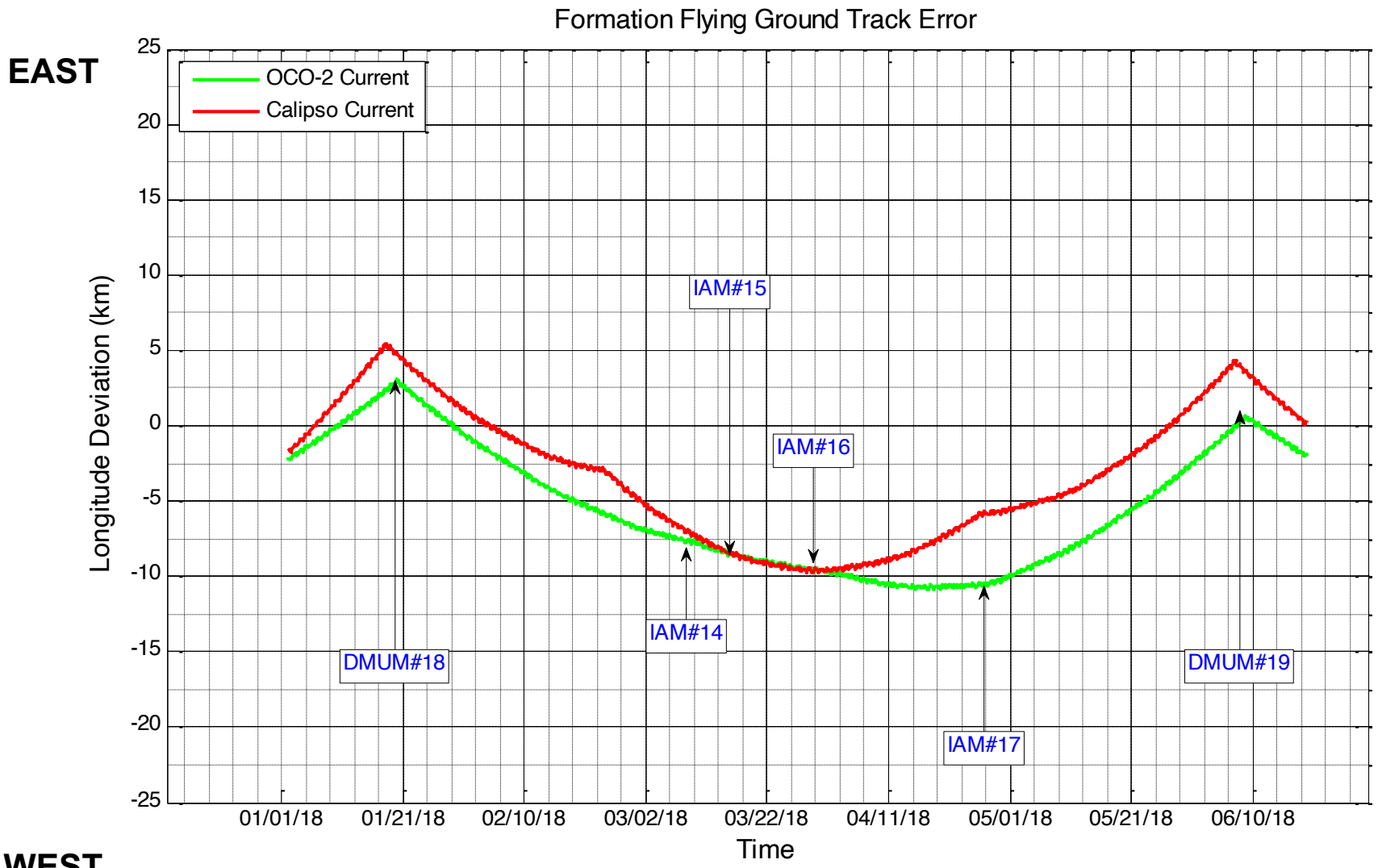
Jet Propulsion Laboratory, California Institute of Technology

June 21, 2018

# Overview

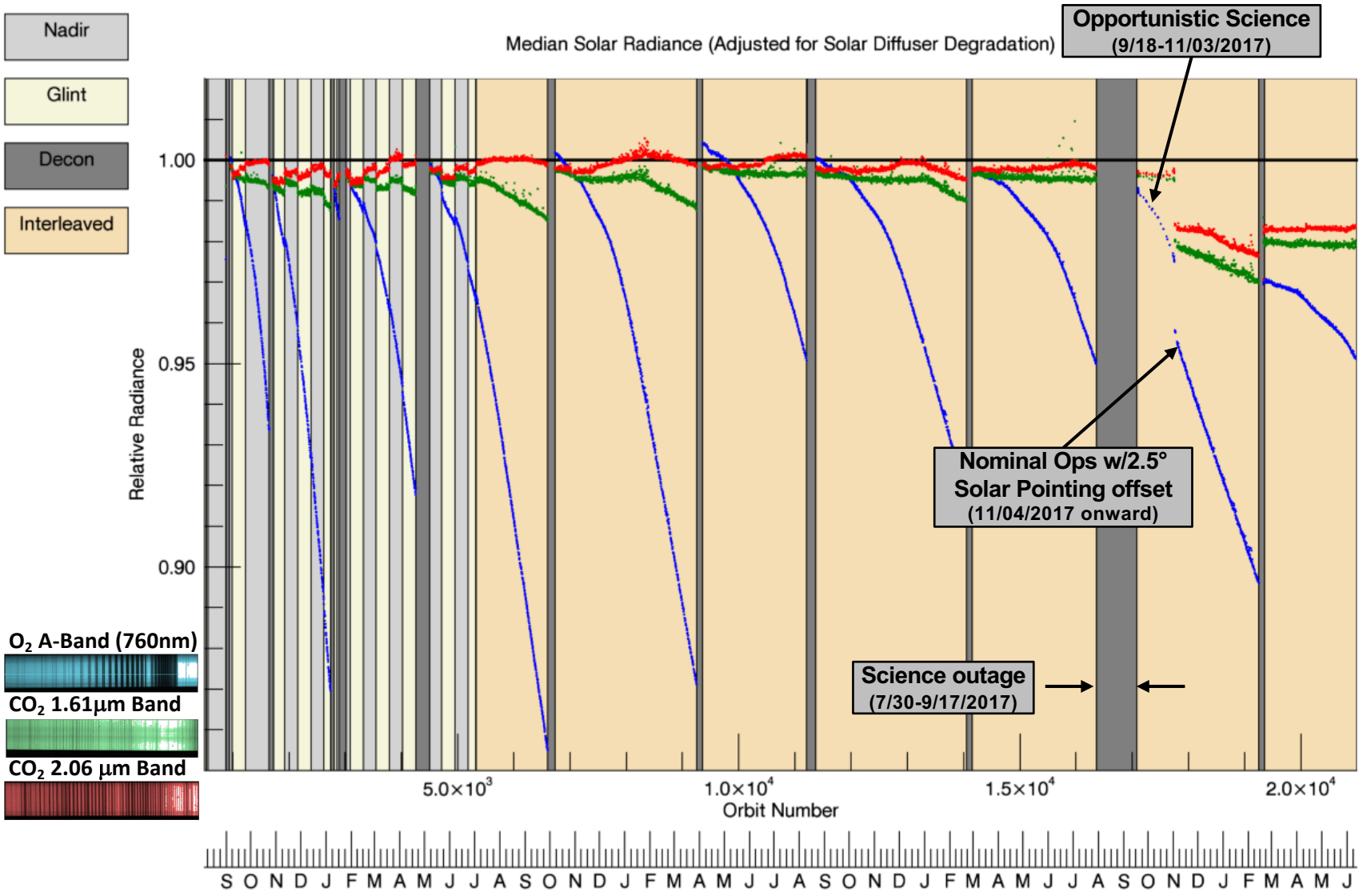
- Observatory Status: Nominal
  - Formation flying overlap 100% through 18 June 2018
  - 2018 Inclination Adjust Maneuvers completed
- Instrument Status: Nominal
  - Most recent Decontamination Cycle conducted 13-20 February
- A quick look at OCO-2 XCO2 V8 Products
  - Improvements in accuracy and coverage
  - Known issues with B8
  - The B9 Lite Files
- OCO-3 Status
- GeoCarb Status

# OCO-2 Continues to Fly in Close Formation with CALIPSO



# Contamination Trending

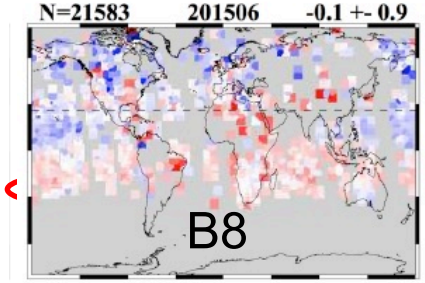
## (Periods of impact due to 2017 anomalies are highlighted)

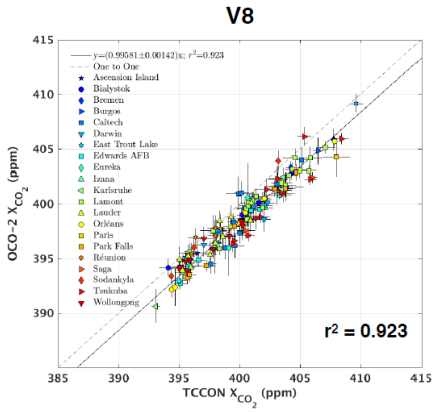


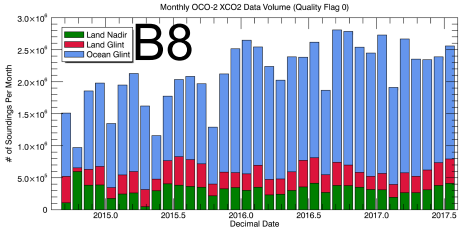
# The Latest OCO-2 Data Product: Build 8 (B8)

The entire OCO-2 dataset was reprocessed using B8:

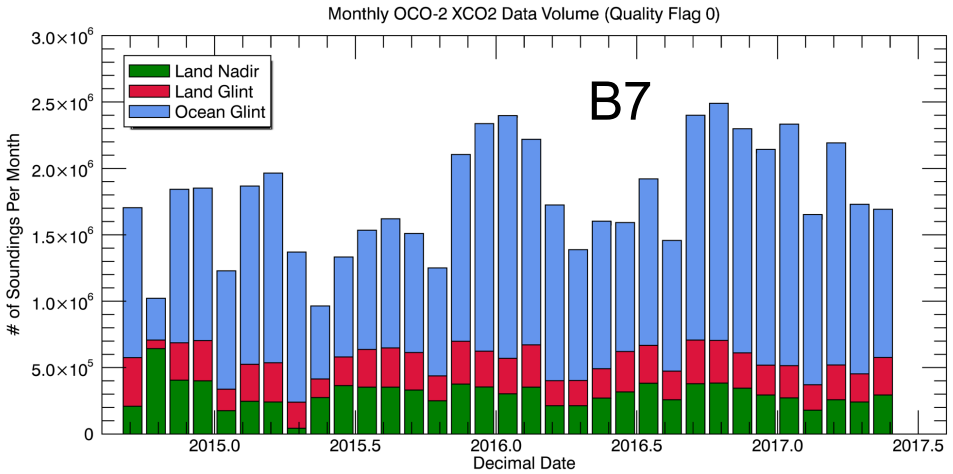
- Improved calibration of spectra (L1B)
  - Corrected throughput degradation factors
  - Corrected zero level offset A-band detector
- Retrieval algorithm updates (L2)
  - Gas absorption cross sections (ABSCO 4.2 □5.0)
  - Added an optically-thin, stratospheric aerosol type
  - More realistic land surface reflectance model (BRDF)
  - Updated cloud screening, bias correction, and warn le
  - Changes in prior meteorology, cirrus clouds
- These changes:
  - Reduced biases, especially over southern oceans
  - 10-15% better coverage over high latitude oceans



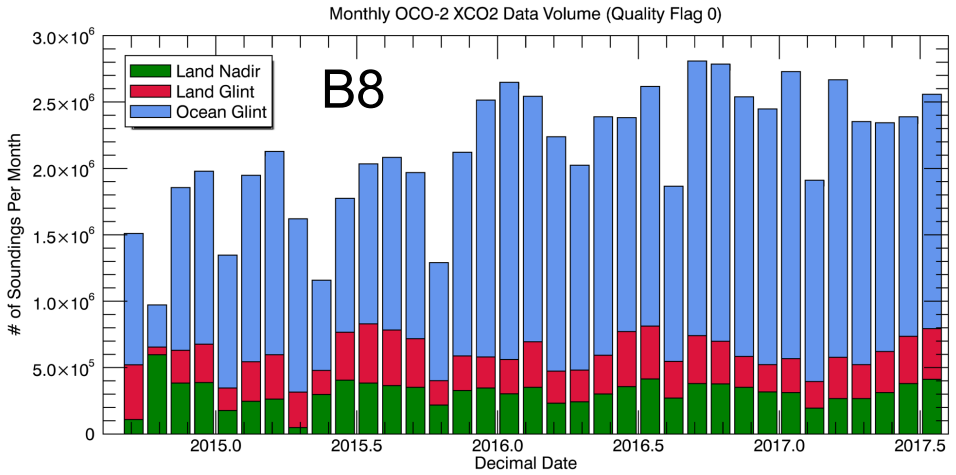



# *Improvements in Yield*



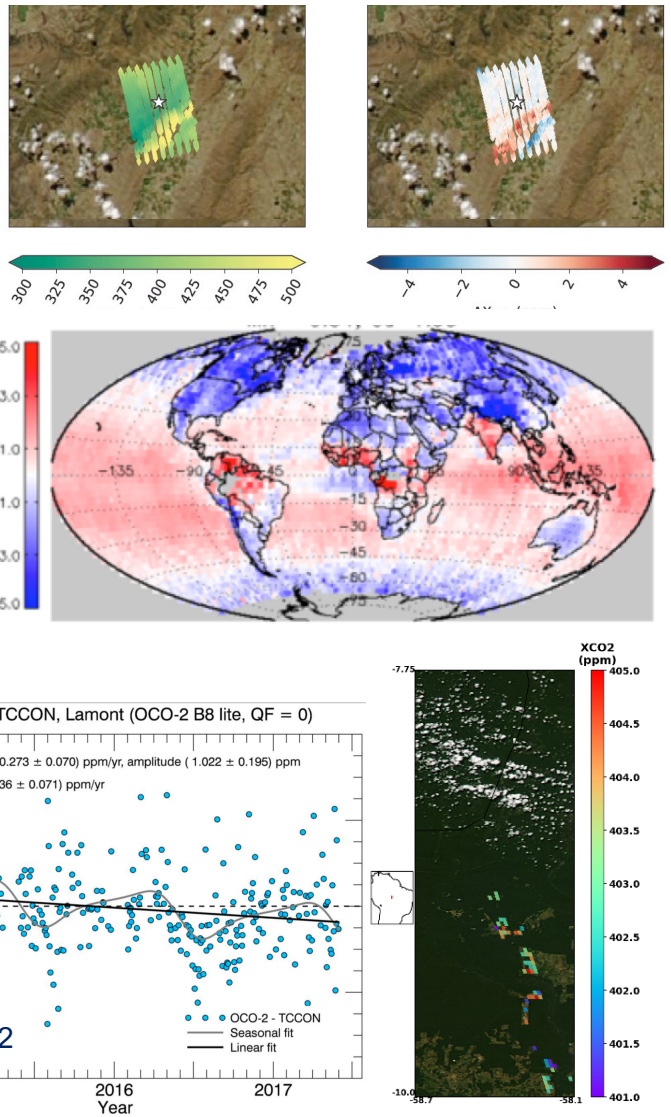

**The sounding yield for B7 was ~7% (2 million soundings/month) once the optimal observing scheme was implemented.**

**Improvements in the cloud screening algorithm and other changes in the L2 algorithm increased the B8 yield to > 8%, with the largest changes seen in the tropics and at at high latitudes**

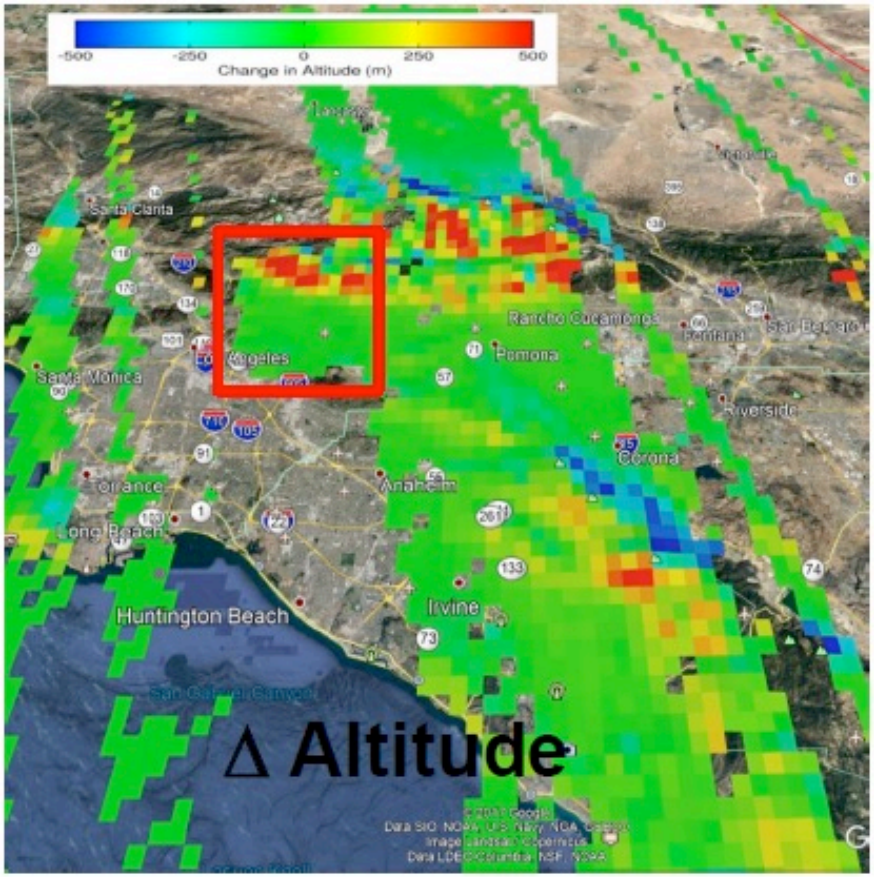


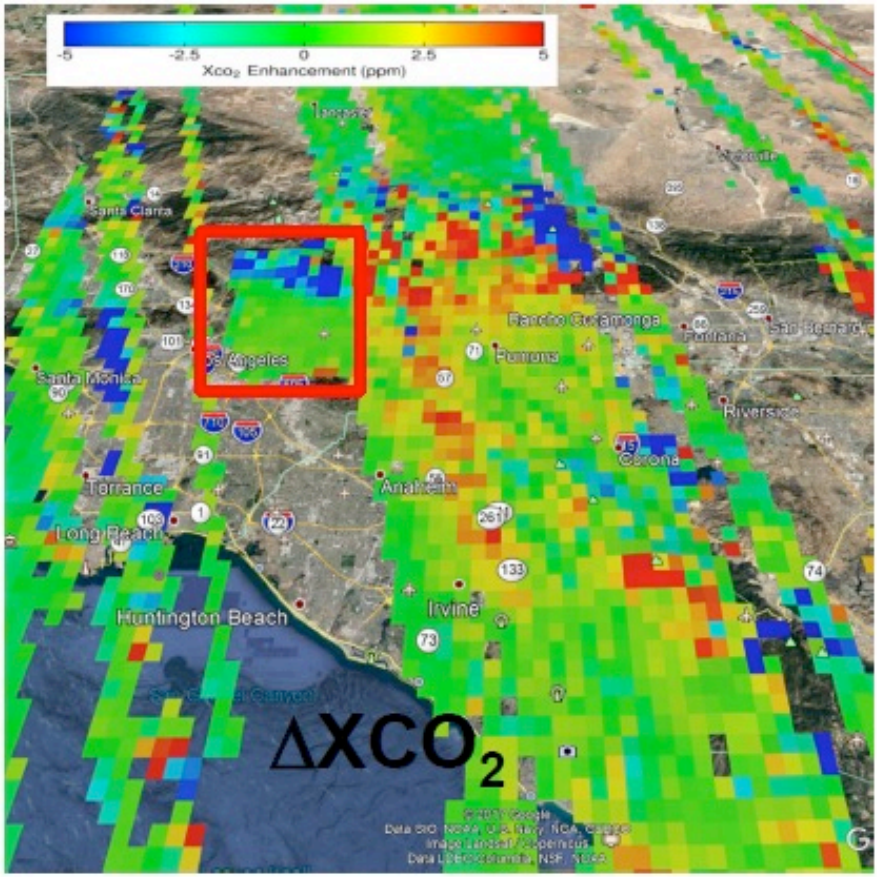
# *Known Issues with B8*

- Small (~100 arc-sec) Pointing errors introduce systematic biases in regions with significant topography
- A pole-to-pole surface pressure bias was introduced by the updated A-band gas absorption cross-sections
- Comparisons with TCCON show a long-term drift in the $X_{CO2}$ product of ~0.2 ppm/year
- Small variations in SIF indicate incomplete zero level offset correction
- Dark surface albedo screening is too aggressive, discarding many cloud free scenes



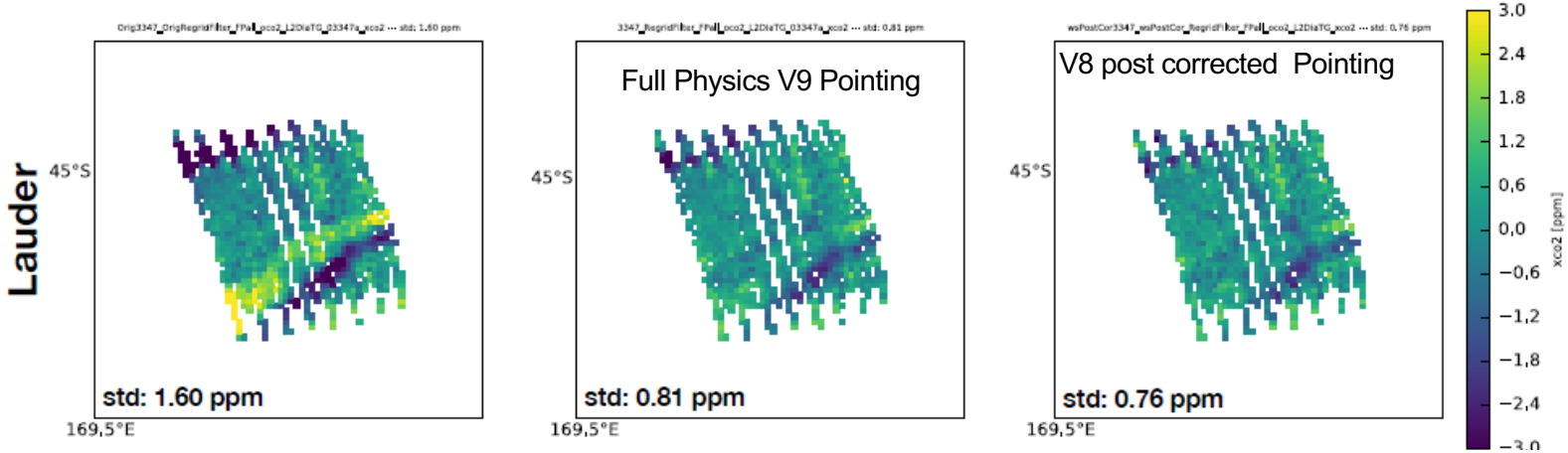
# Correlation between Surface Elevation and $X_{CO2}$ Anomaly




Maps of surface elevation (left) and $X_{CO2}$ anomaly over the LA basin show that positive anomalies are correlated with slopes with altitude increasing to the north or east. Target observations (red boxes) show the opposite correlation. These observation are consistent with a pitch error (Nassar and MacDonald).

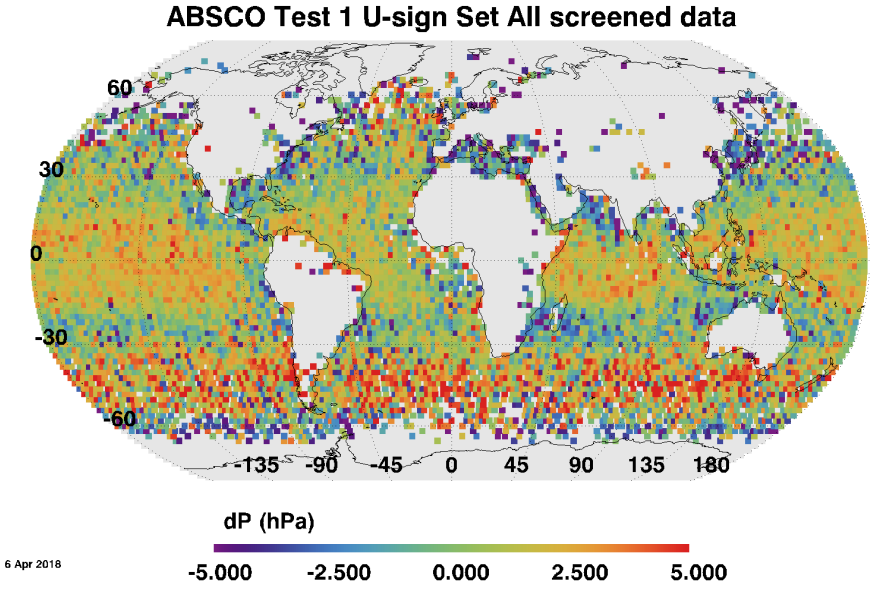
# OCO-2 Pointing Refinement

- Recent B8 validation efforts identified $X_{CO2}$ anomalies that were strongly correlated with topographic slopes
- This issue was traced to a small pointing offset (much below the requirements)
- Members of the OCO-2 Science Team (Kiel, Wennberg, Fisher, Nassar, MacDonald, et al.) used nadir, glint, and target data to diagnose the problem, quantify the pointing offset, and validated the ~100 arc-second
- 

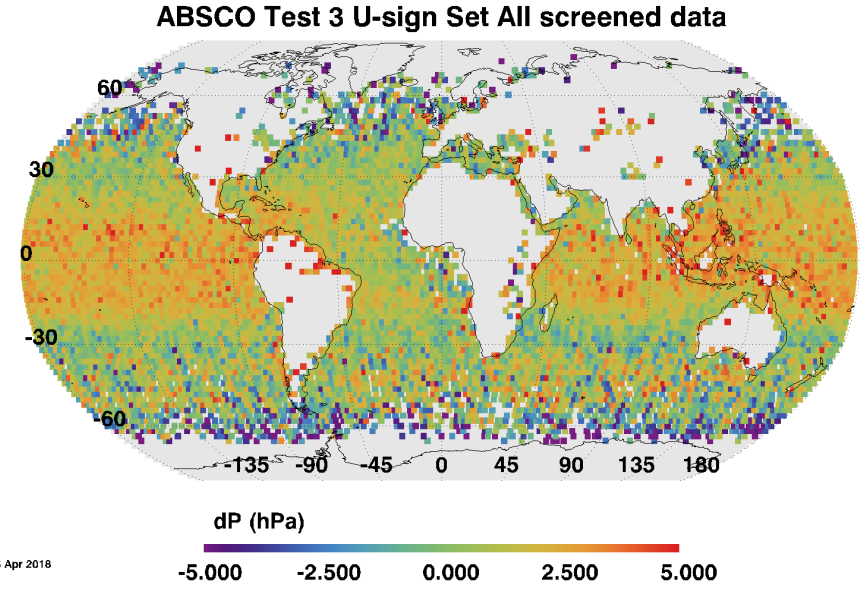

Amplitude of spurious XCO2 anomalies over the Lauder TCCON station (left) are reduced by more than 50% by proposed pointing correction.

# *Surface Pressure Bias due to Uncertainties in $O_2$ Absorption Cross Sections*

V7 Baseline with Version 4.2 ABSCO




V7 Baseline with Version 5.0 ABO2 ABSCO



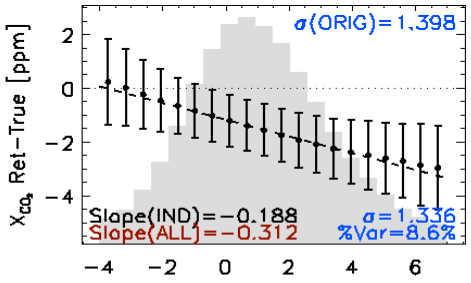

- Version 5 $O_2$ gas absorption coefficients (ABSCO, right) substantially reduced the amplitude of land/sea and ocean glint surface pressure biases and scatter seen in Version 4.2 ABSCO (left).
- However, it apparently introduced a larger, more coherent pole-to-pole bias.
- This difference is well compensated in the bias-corrected $X_{CO2}$ data included in the V8 Lite files.

Brendan Fisher and Vivienne Payne

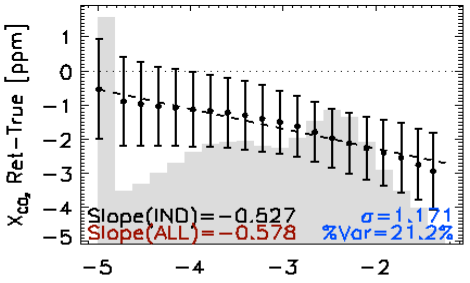
# XCO2 Bias Correction Process (OCO-2)

$$X_{CO2}^{BC} = \frac{X_{CO2}^{Raw} - c_1 P_1 - c_2 P_2 - \cdots - FPbias}{global\_offset}$$

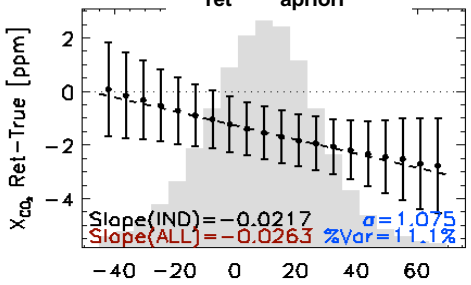
## Step 1: Regress vs. Bias Predictors




$P_{ret}$ - $P_{apriori}$




Log AOD(Dust+Water+SS)

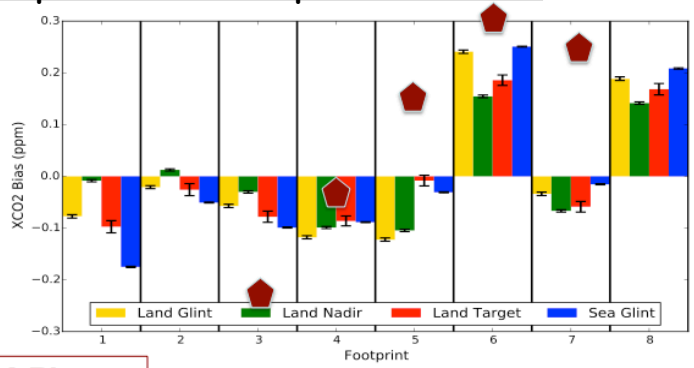



$\Delta CO_2$ Vertical Gradient

Predictors:

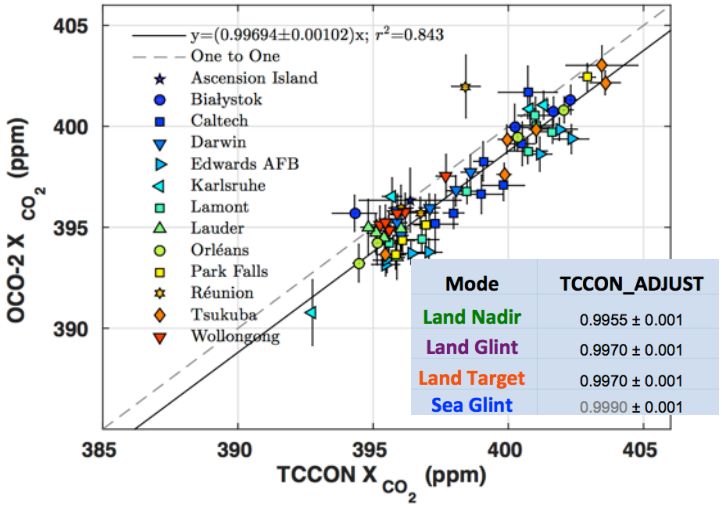
- Surface Pressure Error
- CO2 Vertical Gradient
- Large Aerosol+Water Clouds (land only)

## Step 2: Per-Footprint Offset



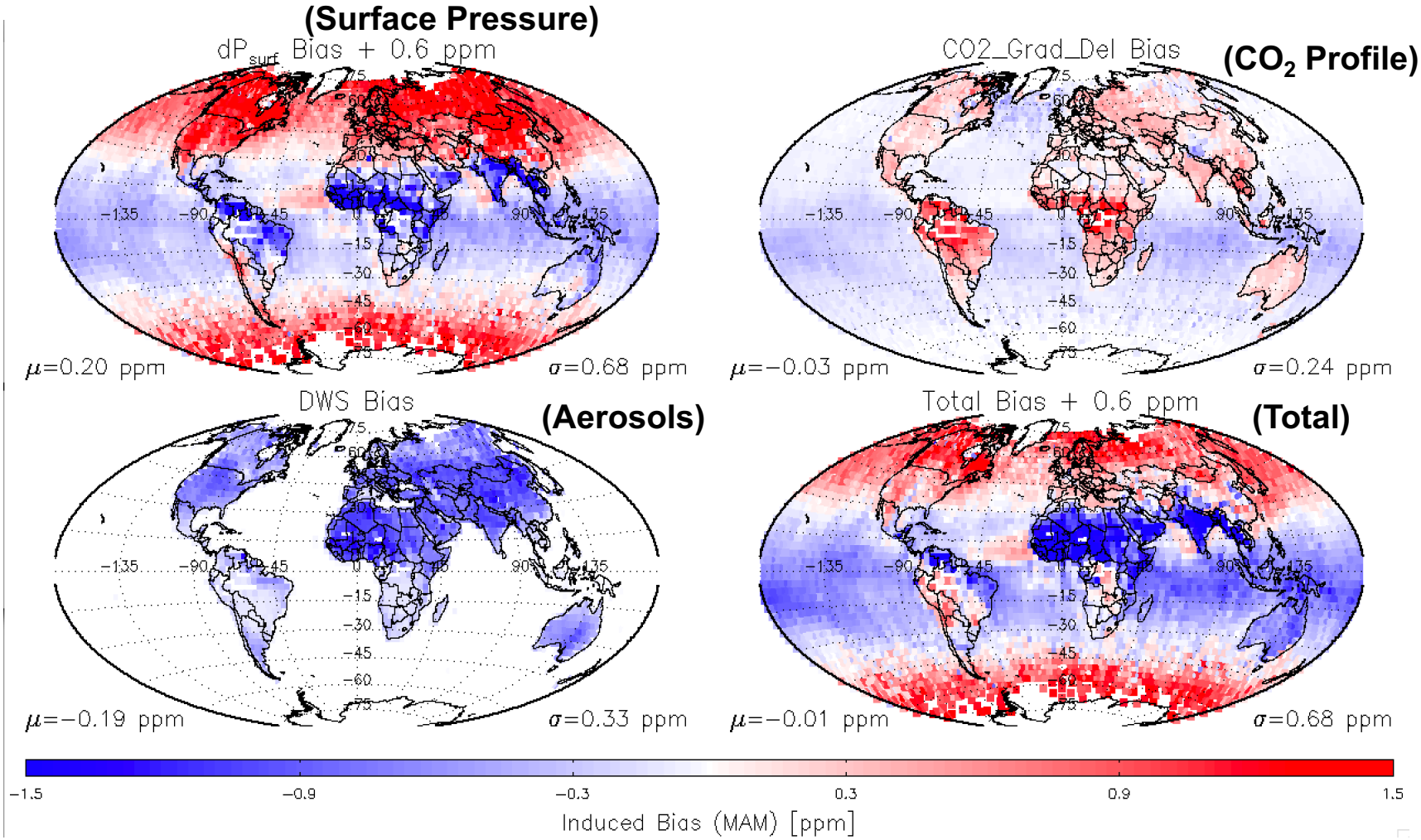

**B6.0 Biases**

## Step 3: Global Multiplier



# B8 Bias Correction Patterns

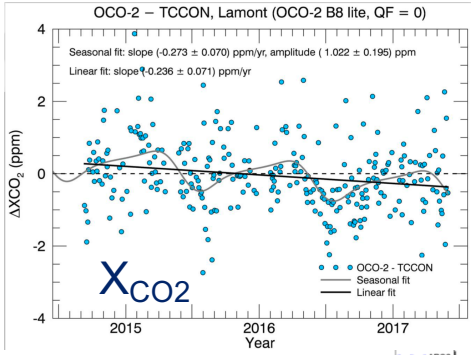
Chris O'Dell

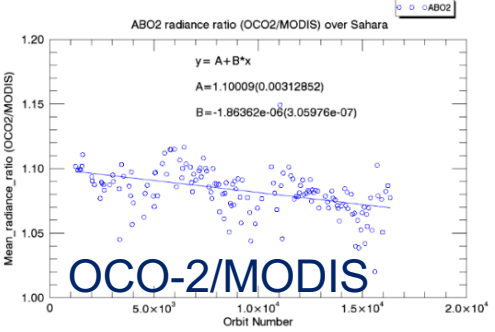


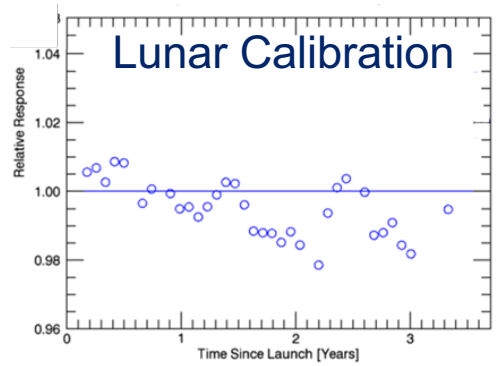

Psurf now dominates the bias correction (+/- 1.5 ppm).

# Long Term $X_{CO2}$ and Radiometric Drifts

- Comparisons of the OCO-2 V8 product with TCCON indicate a long-term drift (0.1 ppm/yr)
- This drift is correlated with a long term drift in the radiometric calibration of the V8 L1b product
  - OCO-2 was cross calibrated against MODIS Aqua over the Sahara
    - Location box: 15° -23° N, 5° -17.5° E
  - Differences in viewing geometry (BRDF) and spectral interpolation may account for overall biases (based on RRV experience)
  - Comparisons indicate ABO2 ($O_2$ A-band) channel has a drift of -0.9% / year
- Similar drifts seen in lunar calibration trends
- These changes will corrected in the next major reprocessing effort.

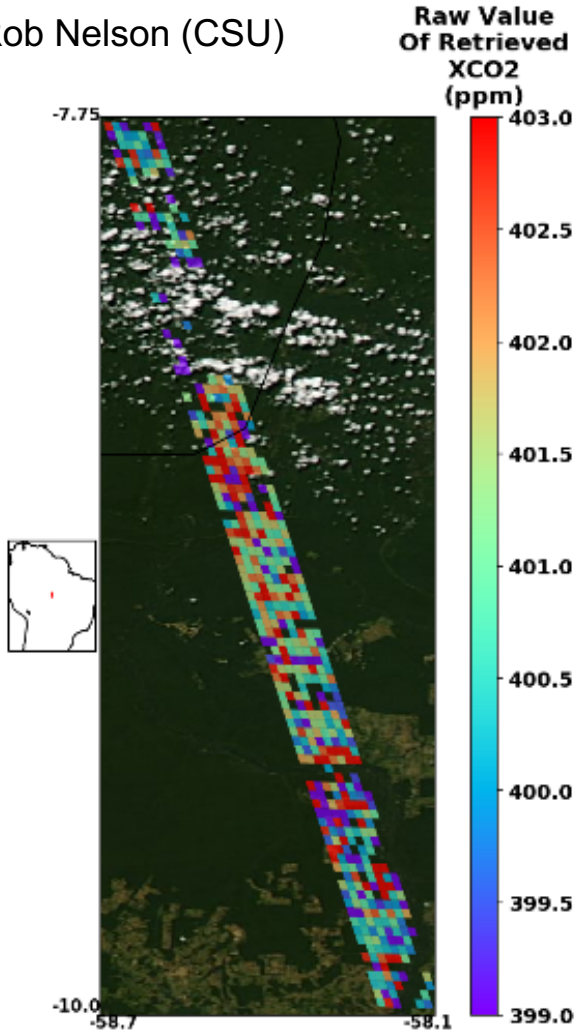


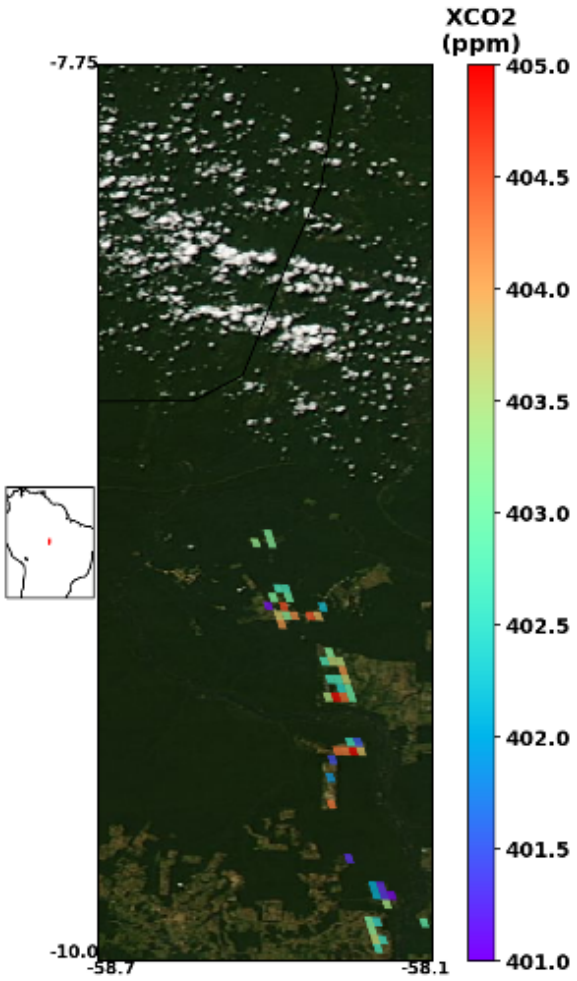



# Why is the OCO-2 Yield so Low over Tropical Land?

Rob Nelson (CSU)




All Data (B8, latest lite files)

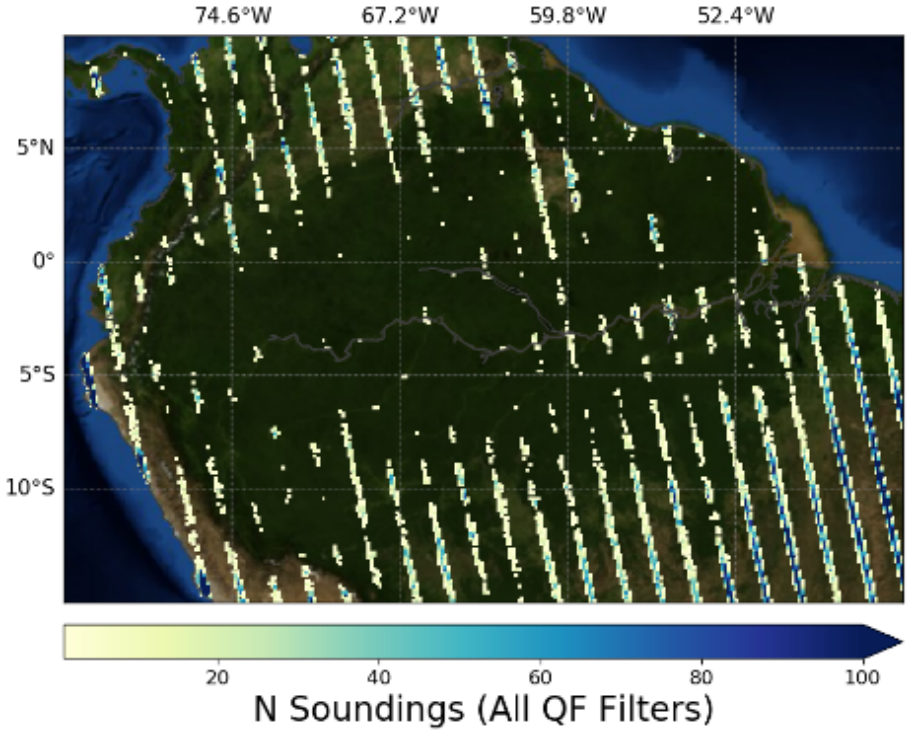



Quality Flagged (B8, latest lite files)

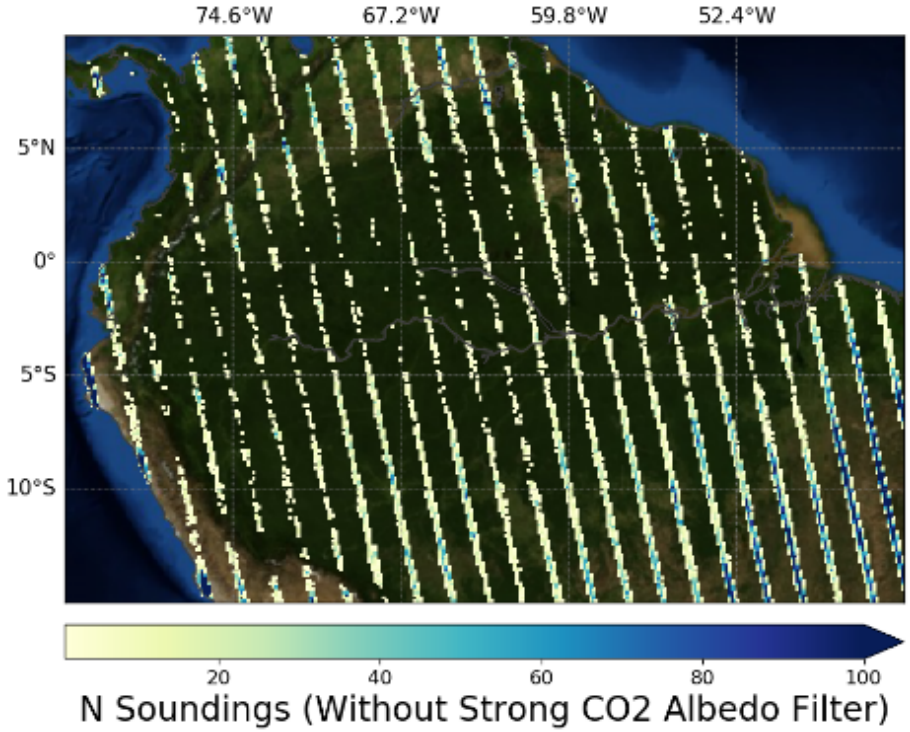
- Rob Nelson found that the quality flag is removing clear-sky dark forest retrievals
- Most of the cloud-free soundings that are being lost over the Amazon are being removed by the strong $CO_2$ low albedo land filter
- We will review the settings used for this filter in the V9 Lite Product.

# Getting Amazon Data Back

Rob Nelson



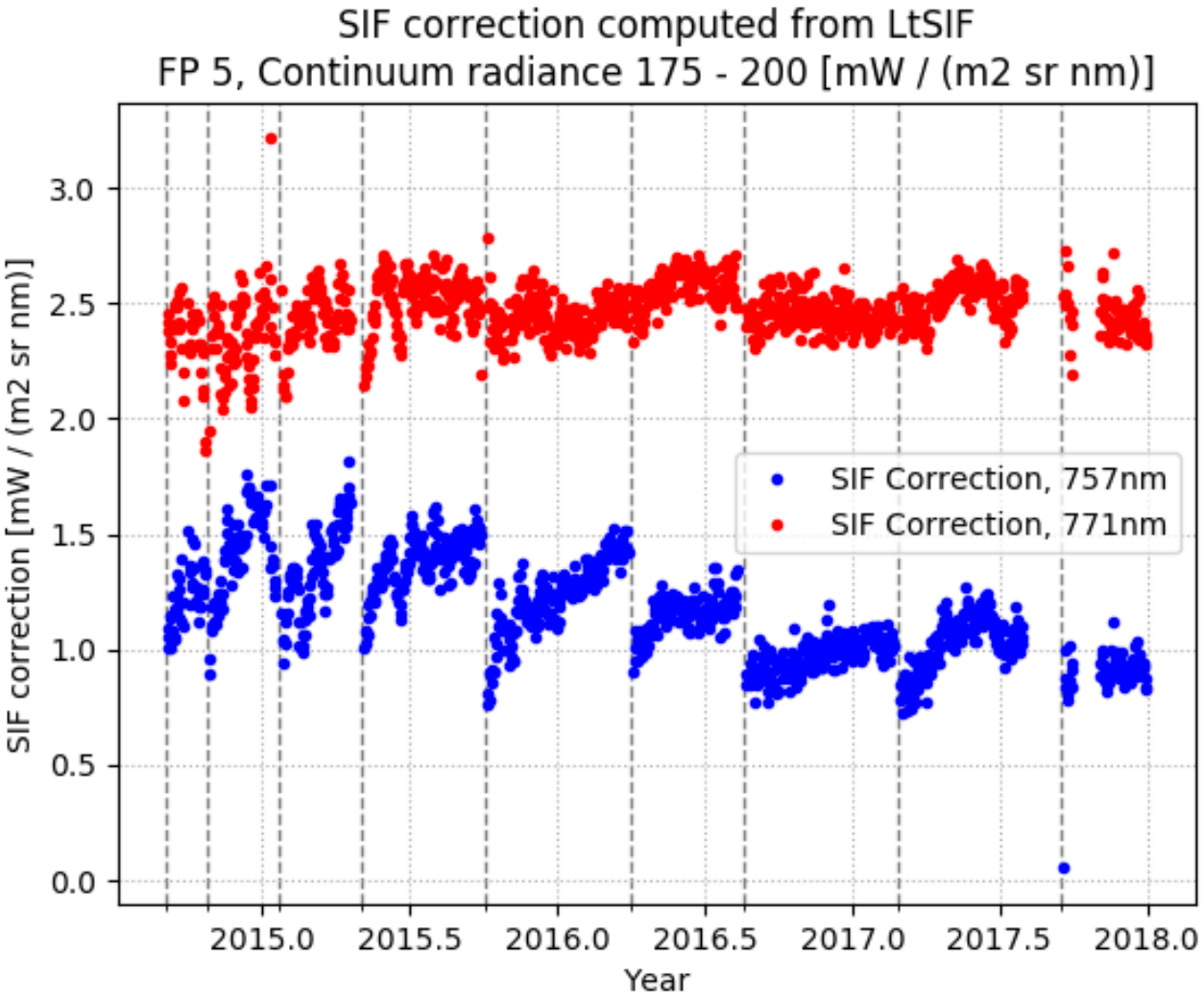

Number of soundings remaining after QF is applied




Number of soundings remaining after QF is applied (except for SCO2 albedo filter)

We may be able to salvage these data in the Version 9 Lite File development

# SIF Time Series Show Evidence for Uncorrected Zero Level Offsets




B8 zero level offset correction fixed 771 nm SIF, but did not fully correct 757 nm .

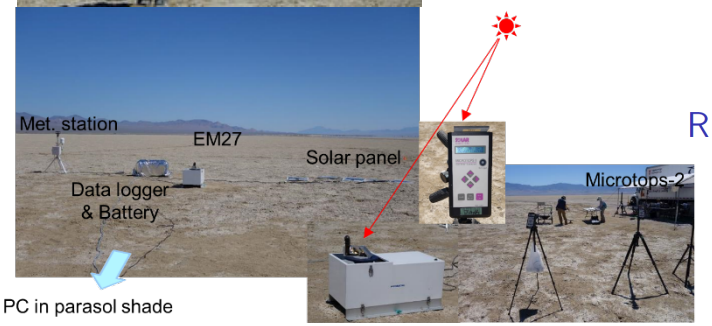
# *Updated Lite Files: B9*

- The OCO-2 data products that are routinely delivered to the Goddard Earth Science Data and Information Services Center (GES DISC) are
  - L1B - calibrated, geolocated spectral radiances
  - L2 Standard products - $X_{CO2}$, SIF, other geophysical variables, consisting of 14.5 orbit-based "granules/day
  - L2 $X_{CO2}$ "Lite files" – a streamlined version of the $X_{CO2}$ products that include both raw and bias corrected values as one file/day
  - L2 SIF "Lite files" – a streamlined version of the SIF product consisting of one file/day
- Updated Lite Files will delivered during summer of 2018
  - Corrected pointing/geolocation biases
  - Refined surface pressure bias correction
  - Possible corrections in the SCO2 dark surface screen

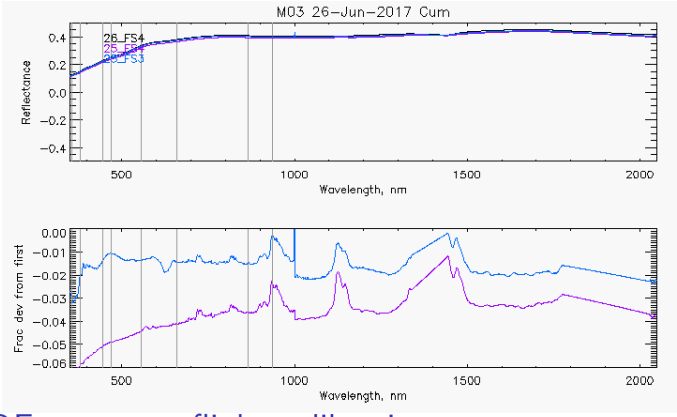
# 2017 Railroad Valley Campaign

*[Kuze et al.]*

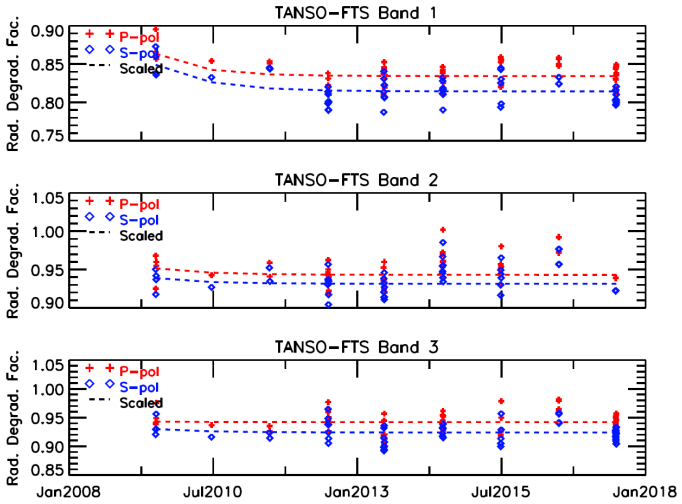
RRV_20:53:59(L1B)
GOSATTFTS201706232053036
0242_1BSPOD201202.01 05
RRV_20:54:02(CAM)

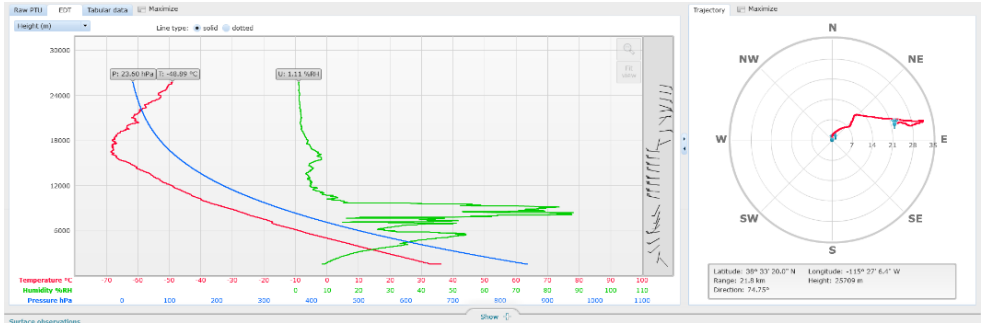



PC in parasol shade



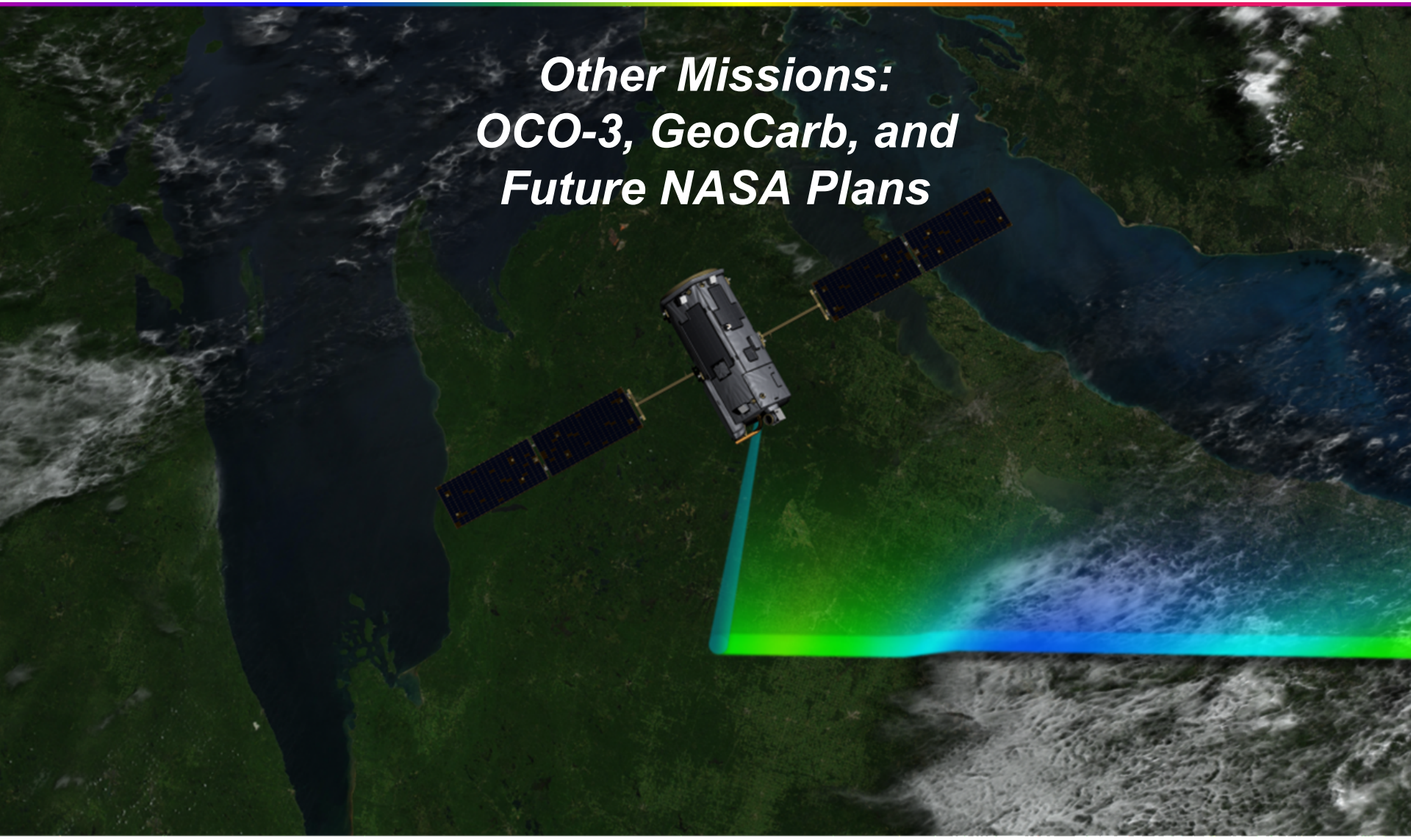

RDF versus preflight calibration



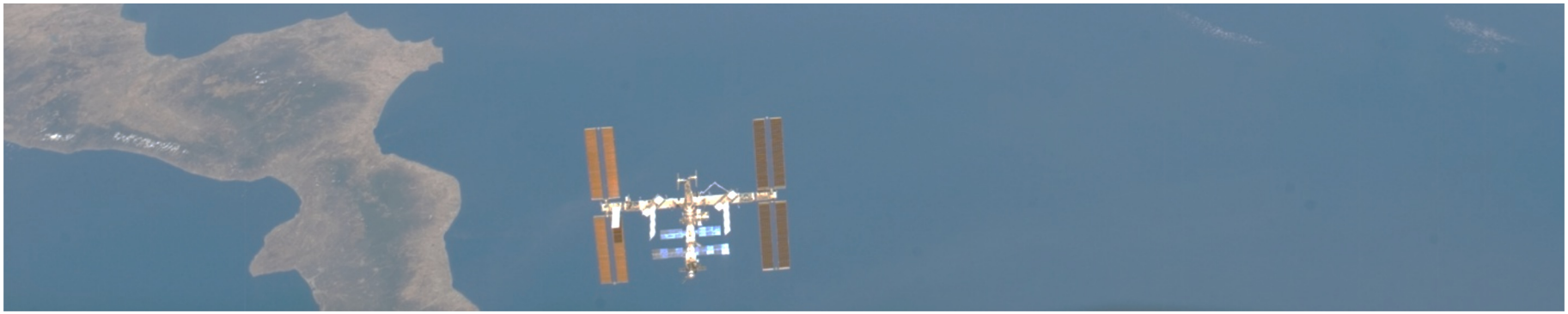



Clear skies prevailed, providing high quality data during GOSAT and OCO-2 overpasses.

# *Other Missions: OCO-3, GeoCarb, and Future NASA Plans*



# OCO-3 Status

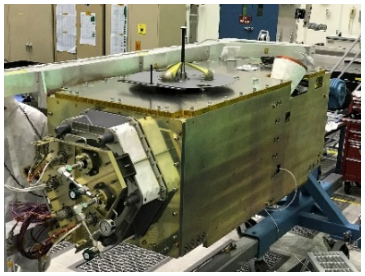


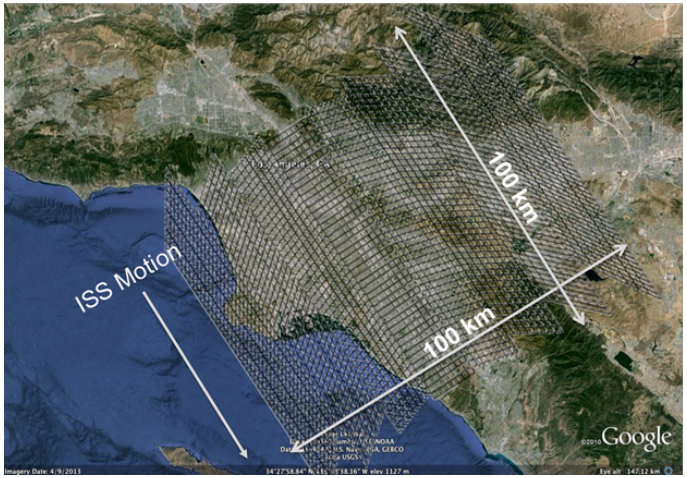
- JPL has been instructed to complete the preflight testing, deliver, and prepare for a launch to the International Space Station (ISS) in early 2019
- The OCO-3 team has completed the “final” thermo vacuum (TV) test at JPL in April/May of 2018
- Currently analyzing data a preparing for a pre-ship review

# The NASA Orbiting Carbon Observatory-3 (OCO-3)

- OCO-3, will be deployed on the International Space Station, ISS
  - OCO-3 integrates the OCO-2 flight spare spectrometers with an agile pointing mechanism.
- That pointing mechanism, combined with the low inclination orbit of the ISS will facilitate new types of investigations of CO2 sources and sinks
  - acquisition of 100 km x 100 km maps of large urban areas and other targets
  - unique opportunity to improve our understanding of the role of diurnal variations the global carbon cycle.

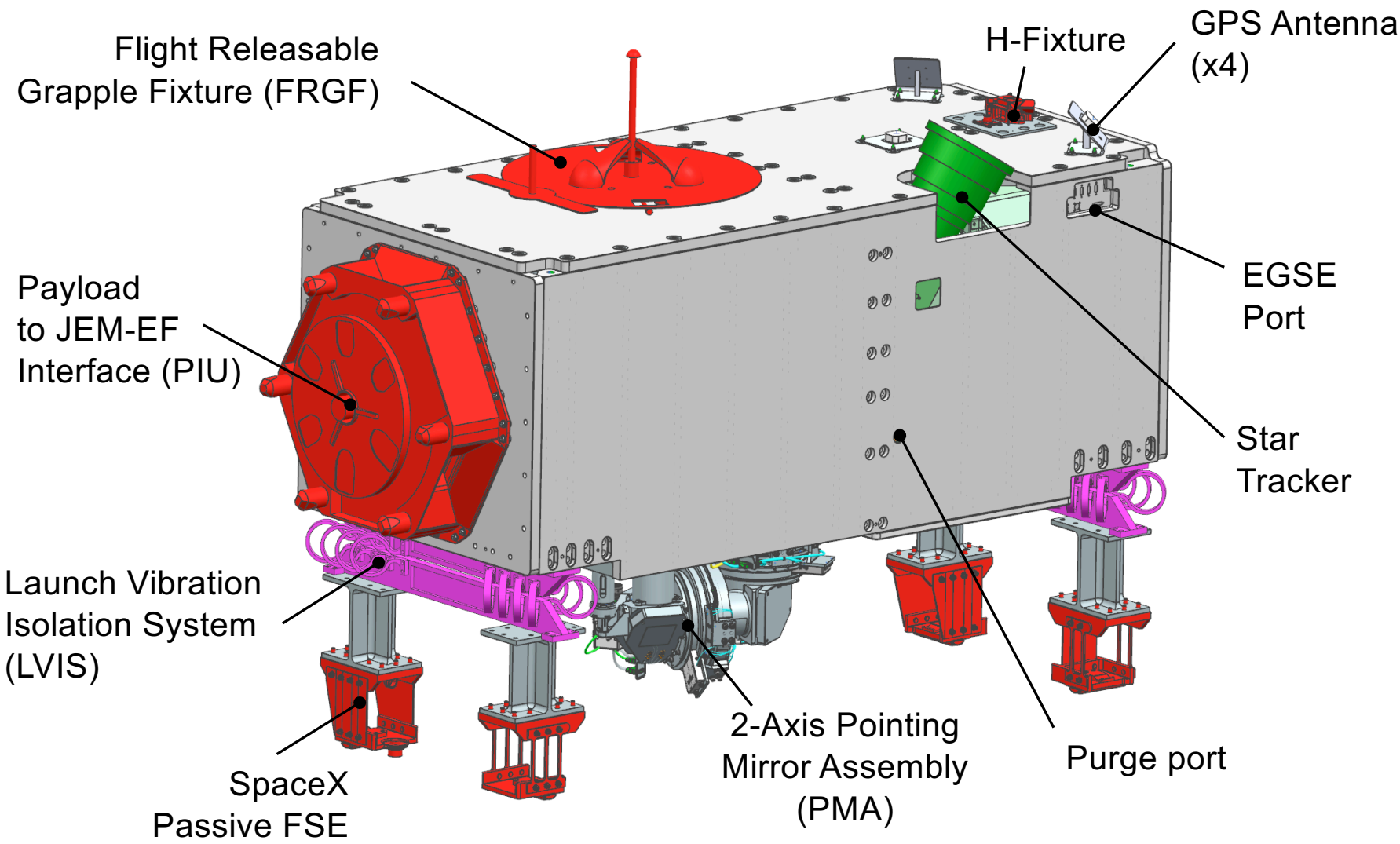
OCO-3 Instrument

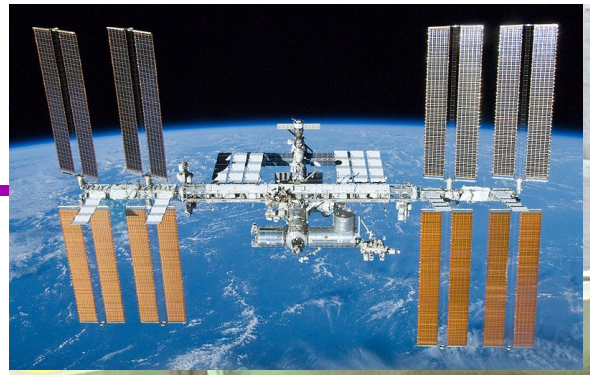





OCO-3 be used to map out large urban areas like Los Angeles

# OCO-3 Payload Exterior

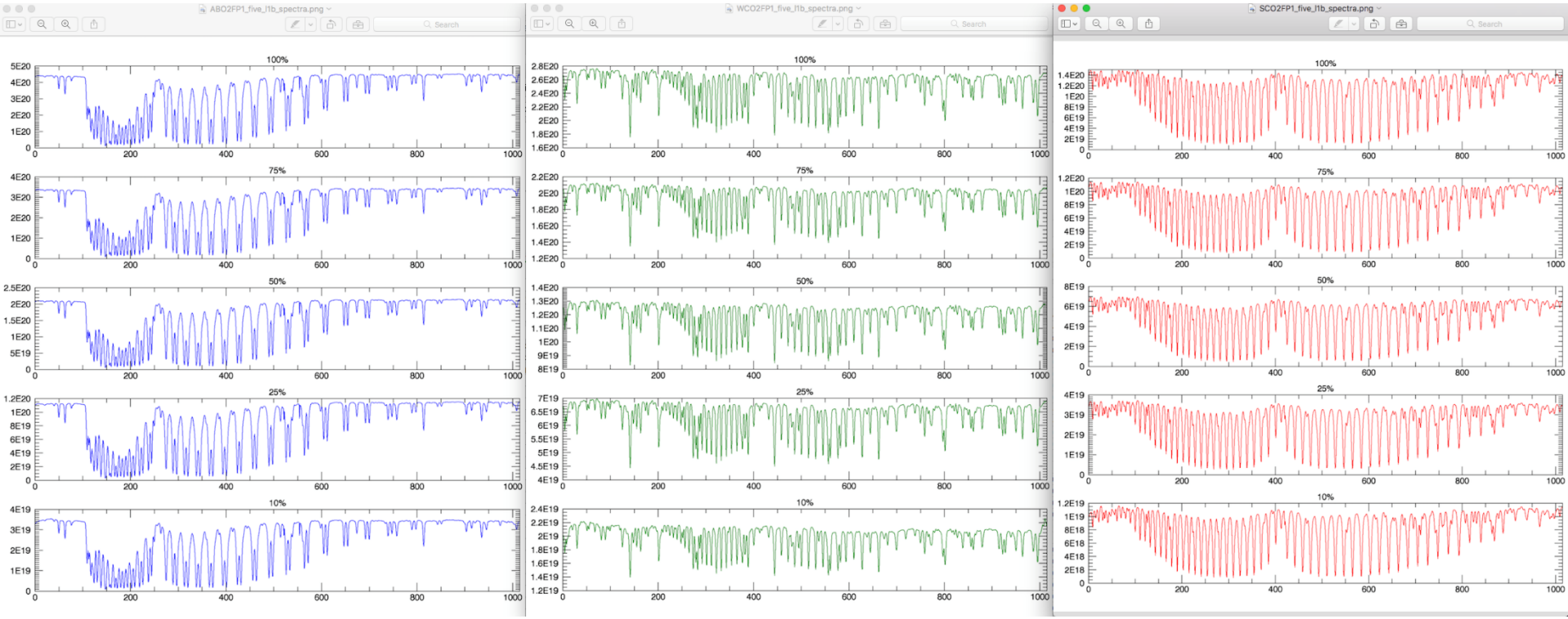




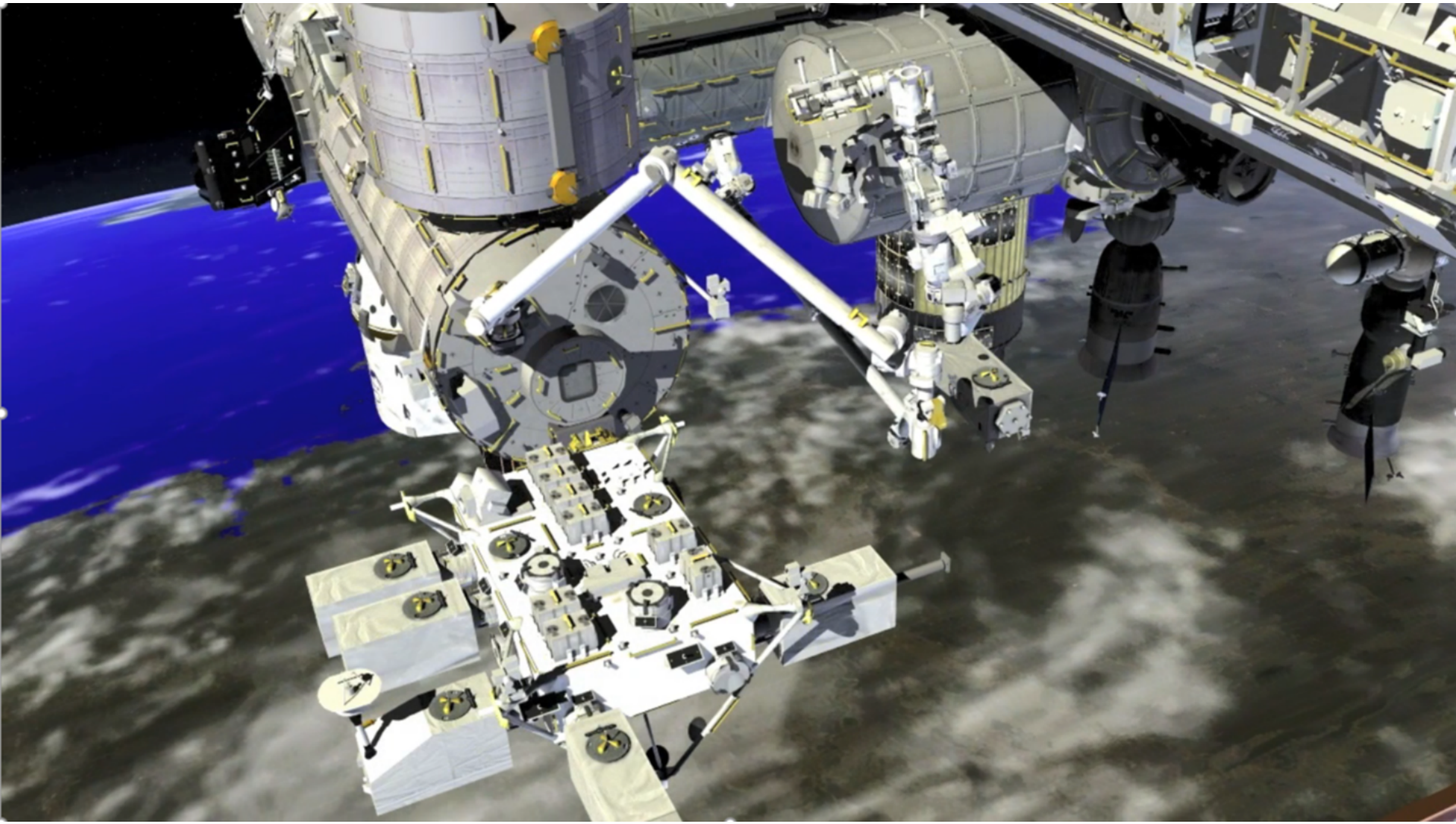

EXIT
THIS DOOR

# OCO-3 Heliostat Spectra

- Like OCO-2, the OCO-3 instrument observed direct sunlight through a heliostat installed above the TV chamber
- Preliminary results from OCO-3 look very good due to a much lower number of bad pixels



# OCO-3 Installation on the ISS



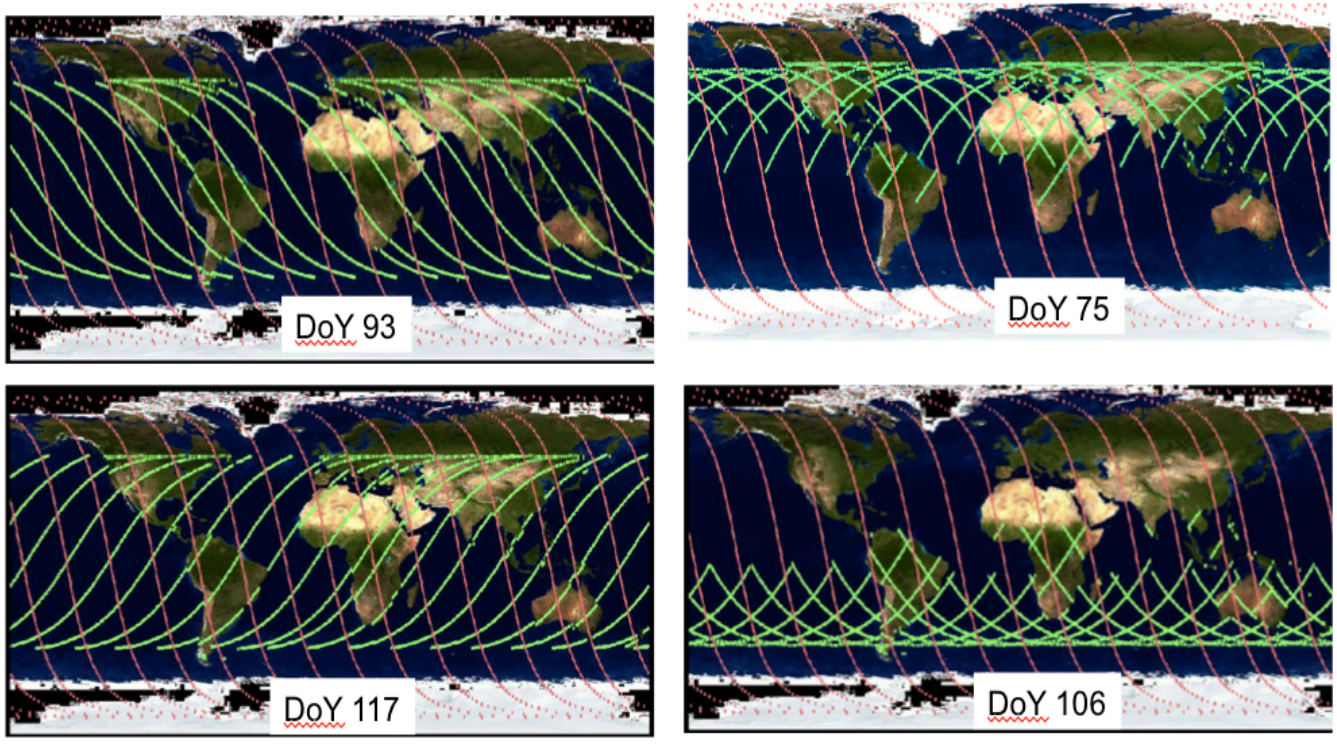
# Comparison of OCO-2 and OCO-3 Measurements

| | 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 |

- 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

# Seasonal and Latitudinal Variations of OCO-3

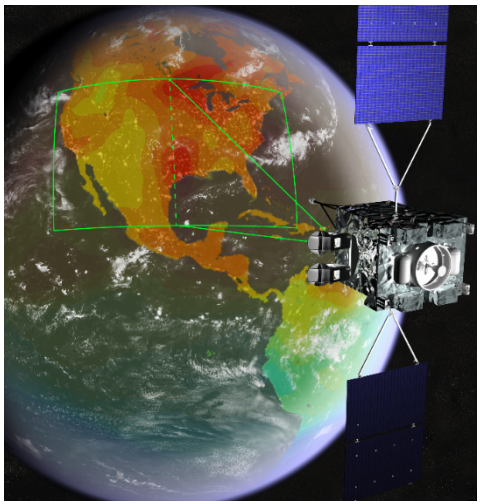
- Sampling would be dense at mid-latitudes, while providing good coverage of tropics and sub-tropics
- The 2-axis pointing system would enable new operations concept with nadir *and* glint observations taken on every orbit, increasing the number of useful samples over oceans as compared to OCO-2

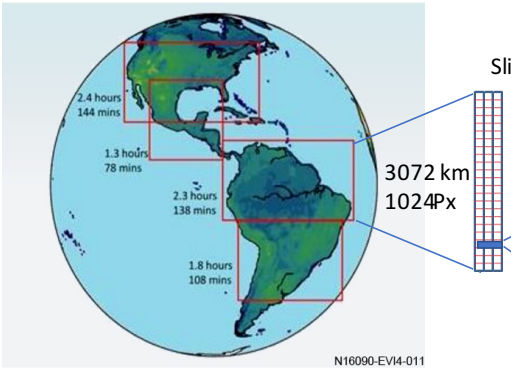



OCO-3/ISS orbits (green) and OCO-2 (pink). On "turn-around" orbits, ISS would provide better coverage of mid latitudes of one hemisphere.

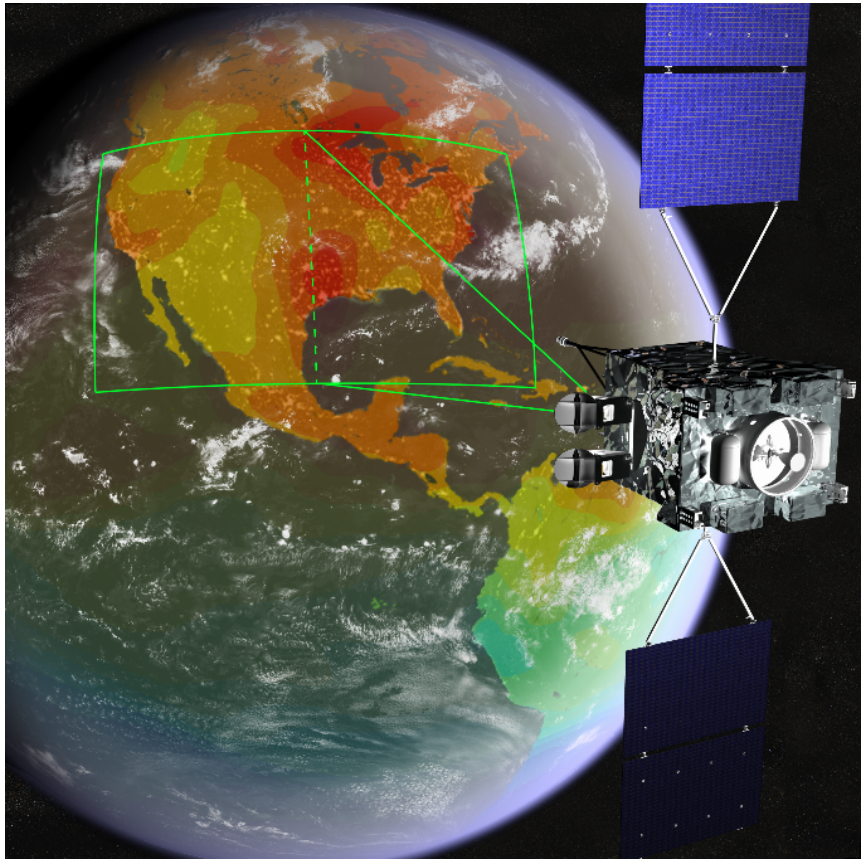
# *The NASA GeoCarb Mission**

- In December 2016, NASA selected the Geostationary Carbon Cycle Observatory (GeoCarb) as the second complete mission in the NASA Earth Ventures series.
- GeoCarb will be the first mission to acquire spatially resolved observations of greenhouse gases and solar induced chlorophyll fluorescence (SIF) at high spatial resolution (5 to 10 km) from geostationary orbit (GEO).
- GeoCarb will fly on a commercial communications satellite and carries an imaging grating spectrometer
  - $O_2$ (765 nm) $CO_2$, (1610 and 2060 nm), methane ($CH_4$) and carbon monoxide (CO; 2300 nm)
- It will launch in 2022 and be stationed between 75˚ and 100° West longitude in 2023.
- It will map these properties over North South America two or more times each day.



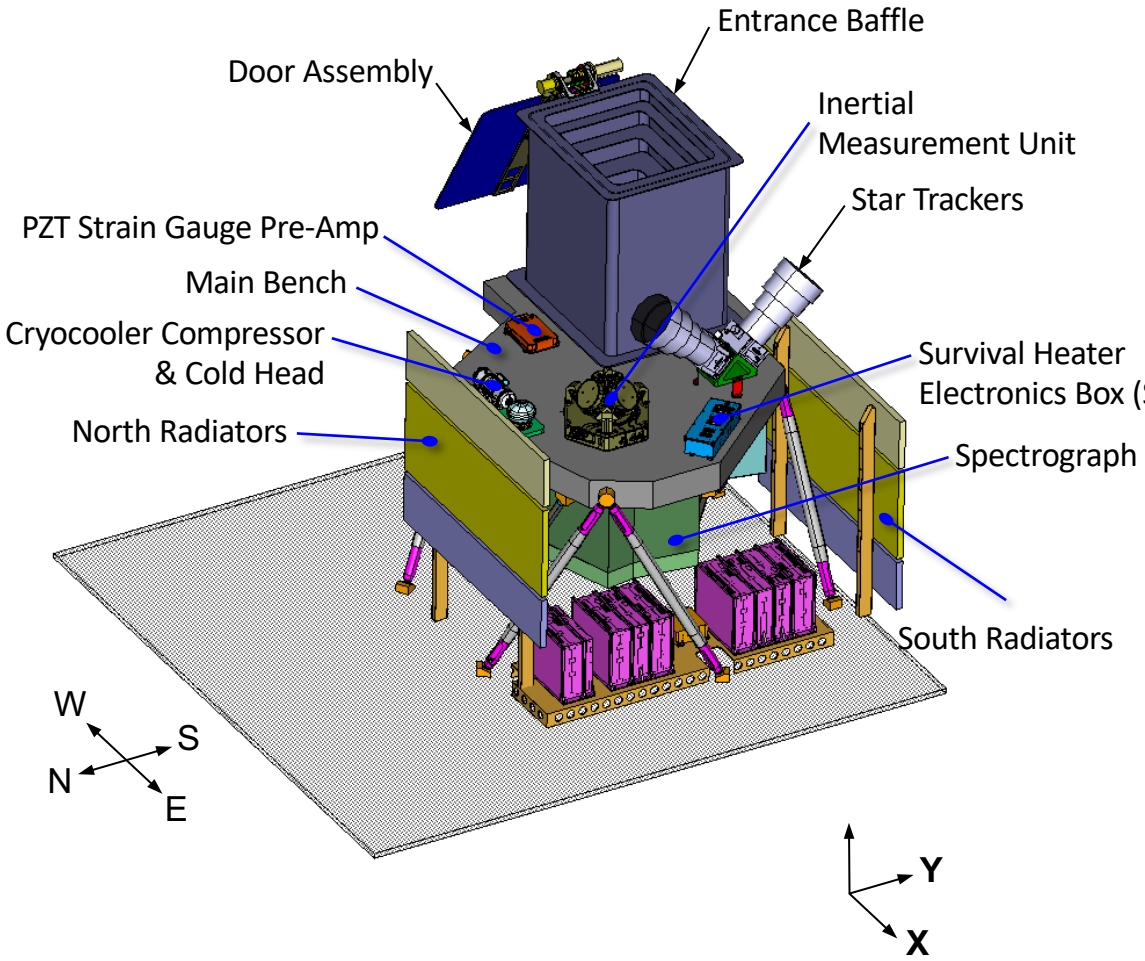


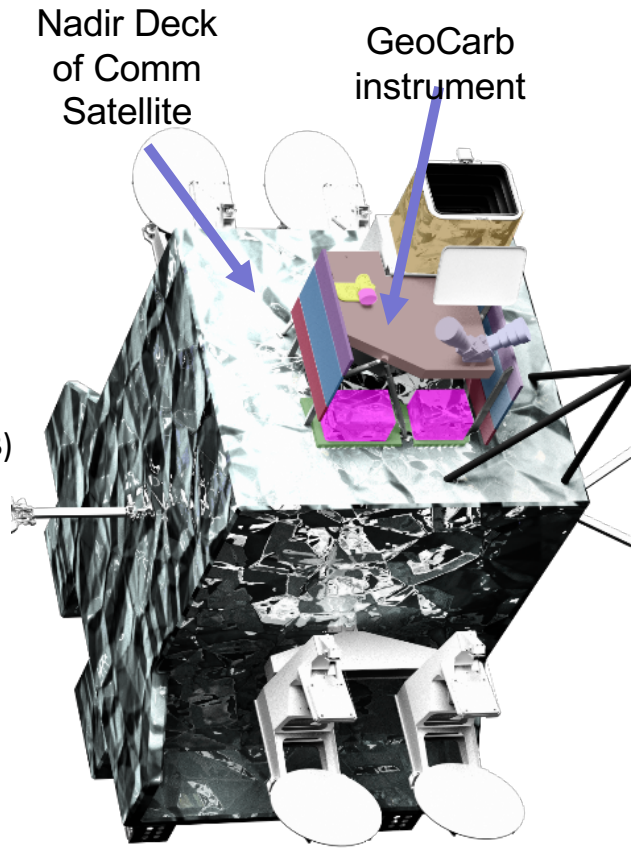
# GeoCarb Overview



| | |
|---|---|
| Principal Investigator | Berrien Moore, University of Oklahoma |
| Technology Development | Lockheed Martin Advanced Technology Center |
| Host Spacecraft & Mission Ops | SSE Government Solutions |
| Instrument | Single slit, 4-Channel IR Scanning Littrow Spectrometer |
| Bands | 0.76$\mu$m, 1.61$\mu$m, 2.06$\mu$m and 2.32$\mu$m |
| Gases | $O_2$, $CO_2$, CO, $CH_4$ & Solar Induced Fluorescence |
| Mass | 138 kg (CBE) |
| Dimensions | 1.3 m x 1.14 m x 1.3 m |
| Power | 128W (CBE) |
| Data Rate | 10 Mbps |
| Daily Soundings | ~10,000,000 soundings per day CONUS > once per day |

# GeoCarb Instrument

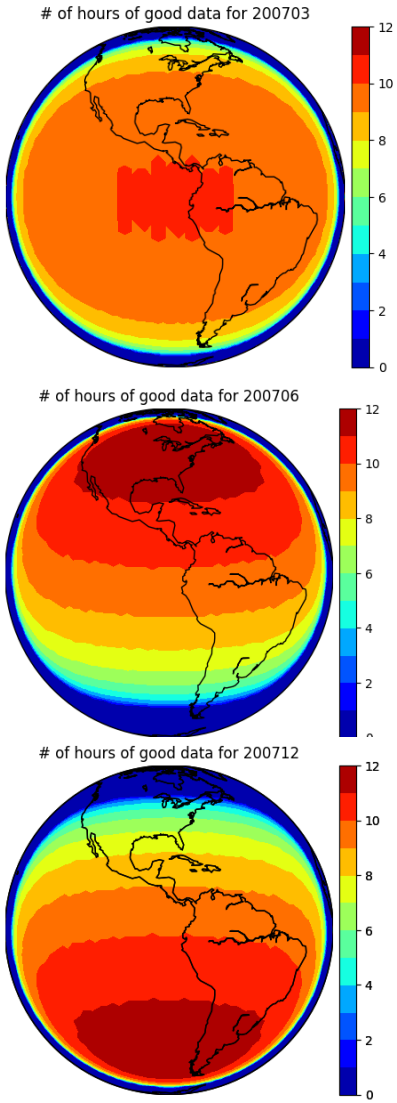


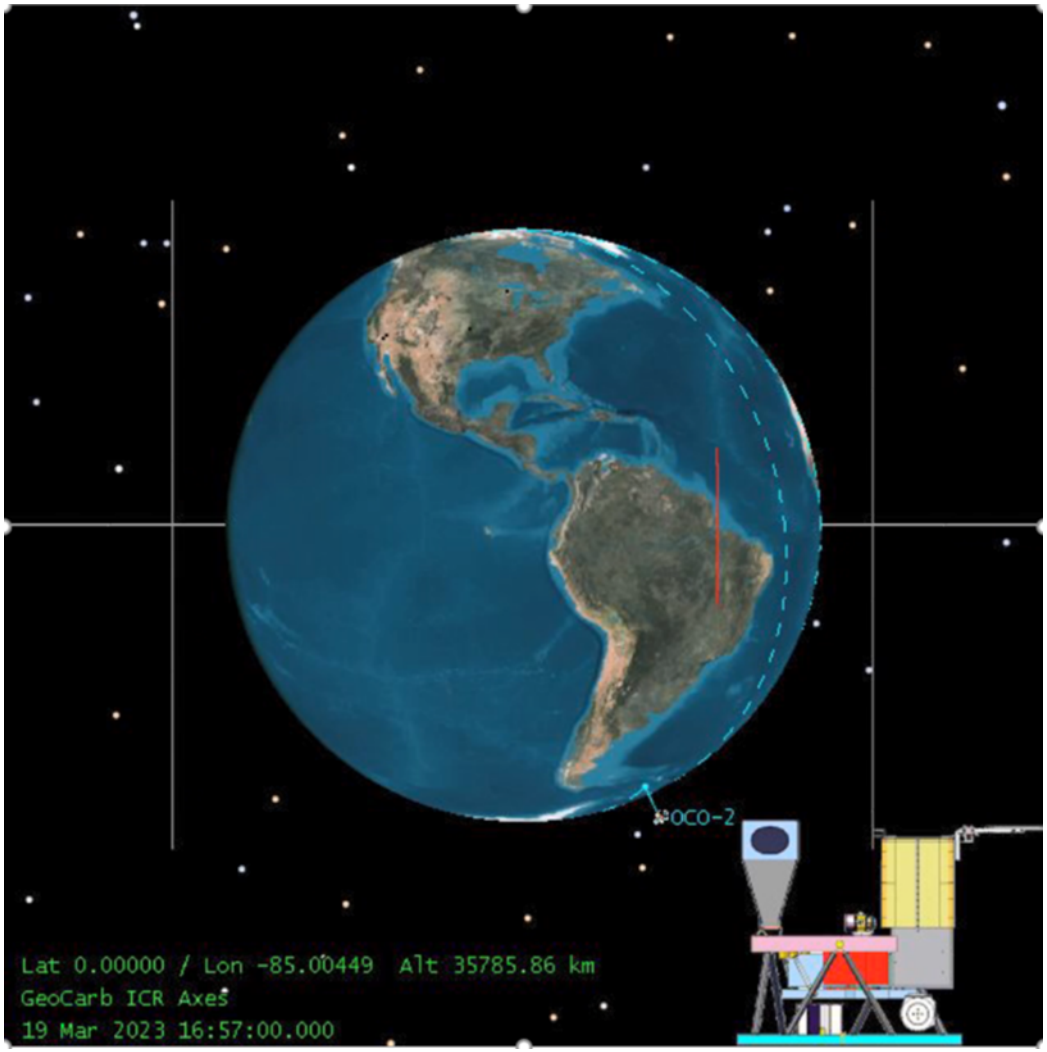
# Field of Regard

- GeoCarb will view North and South America 2 or times each day
  - ±10.0 degrees East/West, ±9.25 degrees North/South

- Implemented by an adaptable 2-axis spatial scanning mechanism that enables:
  - Executes East-West rectangular scans in science coverage areas
  - Star sighting calibrations near E and W limbs
  - Area coverage rate: 37M km$^2$ in 6 hours
  - 4.4625 sec cadence (12 co-added soundings)
  - Slit length: 4.4° or 2800 km at SSP
  - Slit width: 5.4 km at SSP,
  - 2340 km/hr E/W at SSP



# A Day in the Life of GeoCarb



# Summary

- OCO-2 finished its nominal mission in September 2016, and started its first extended mission with a healthy spacecraft and instrument

- All planned pre-launch testing of OCO-3 has been completed. Final review of test results is underway in preparation for a early 2019 launch to the ISS

- The GeoCarb design is progressing well as the team prepares for the Preliminary design Review in August of 2018.