Jet Propulsion Laboratory
California Institute of Technology

Watching The Earth Breathe…Mapping CO_2 From Space.

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Key Differences in OCO-2 and OCO-3 Calibration

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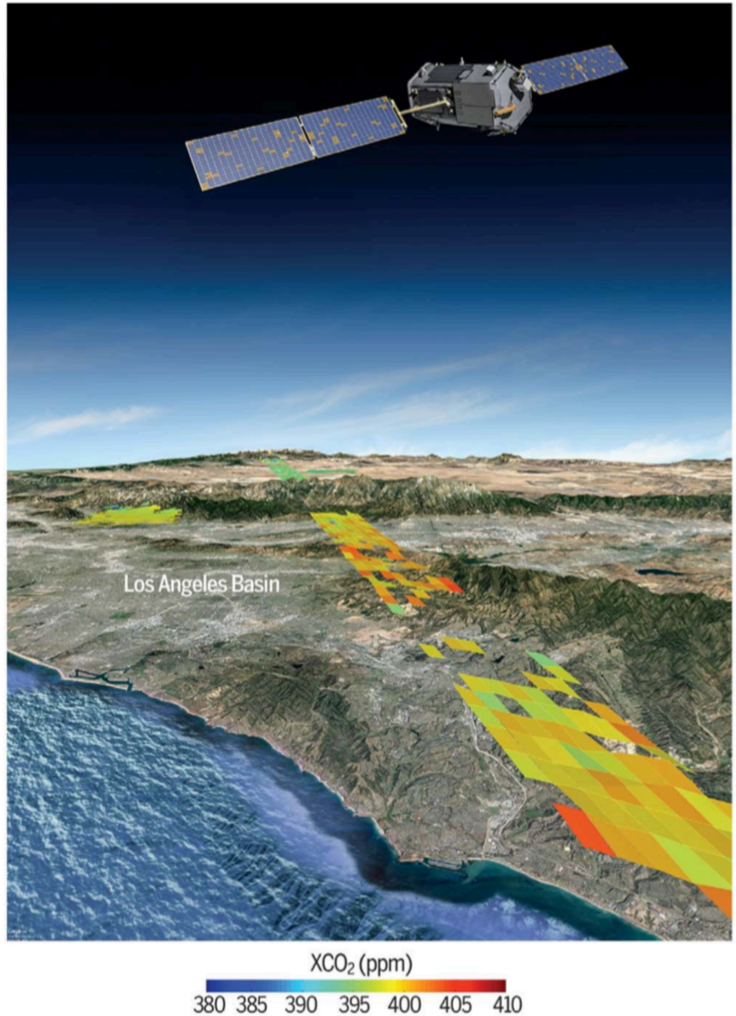
Orbiting Carbon Observatory

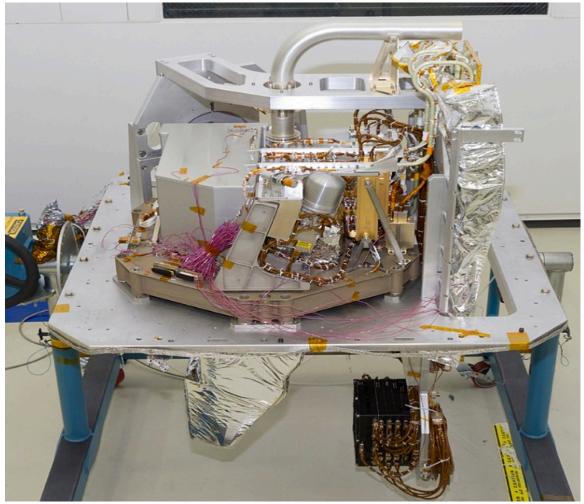
Introduction

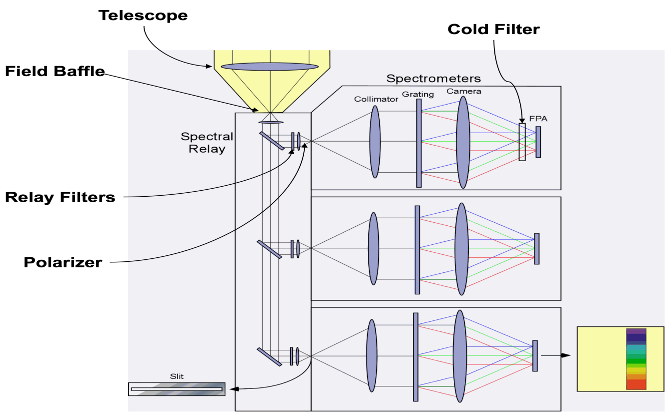
- Orbiting Carbon Observatory lost due to launch failure February 2009
- OCO-2 was launched in July 2014, completed prime mission October 2016, extended mission continues
- OCO-3 was launched in May 2019, prime mission scheduled to end August 2022
- OCO-3 was built as the OCO-2 flight spare, then modified to accommodate the change from a free flying satellite to an ISS payload
- Calibration process is largely the same, but there are several important differences that require treating them separately

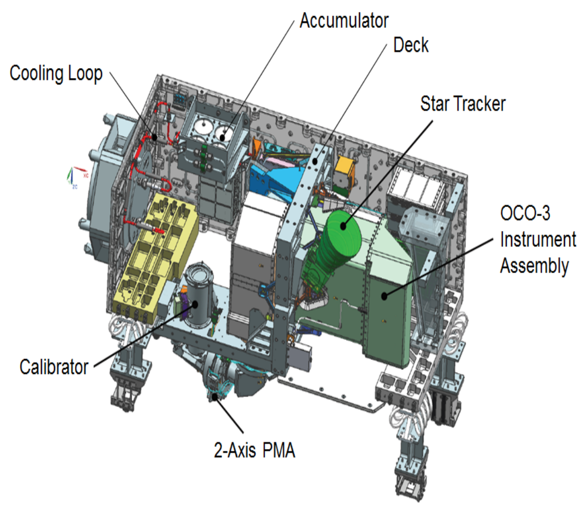


Instrument Overview

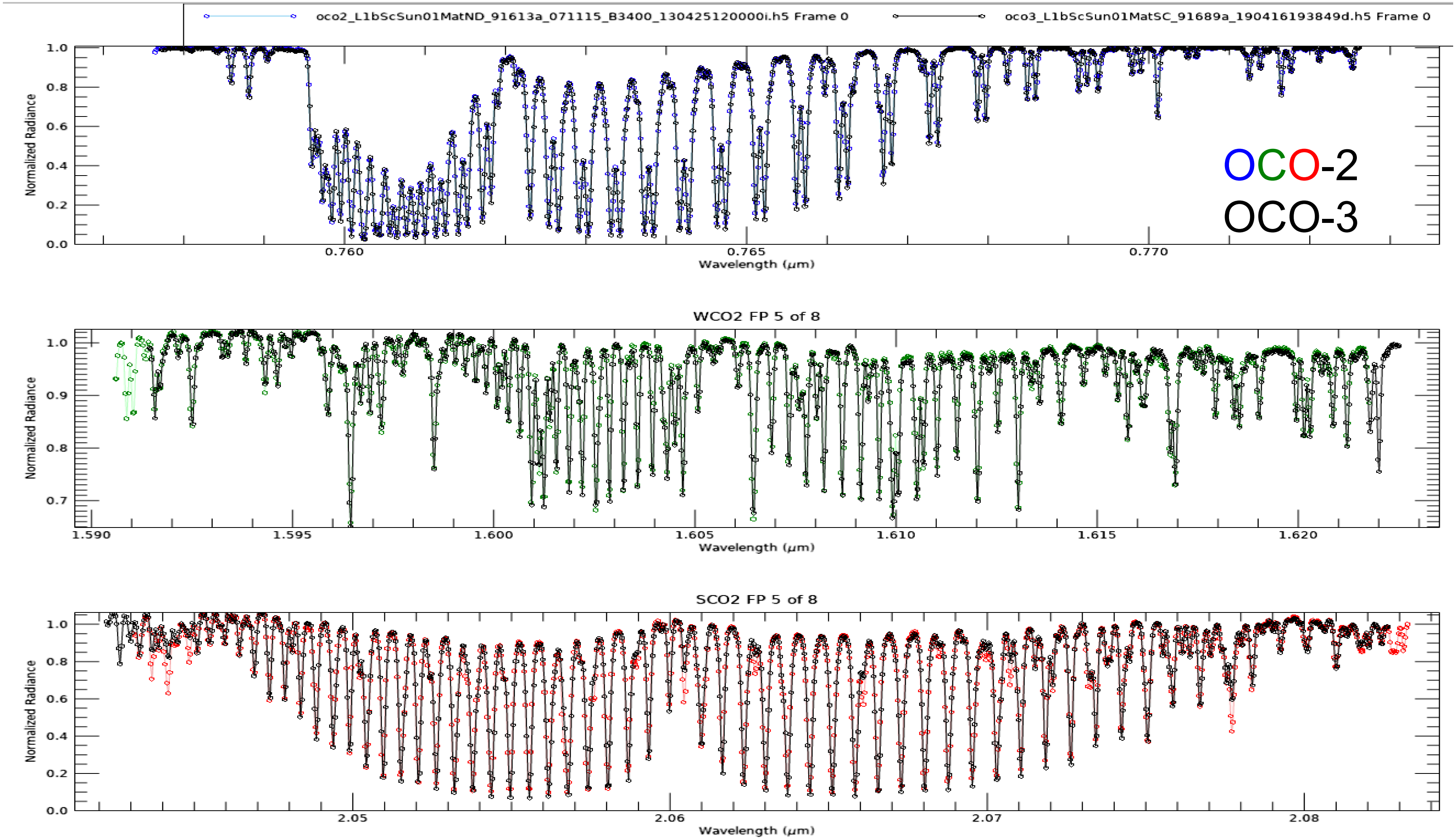
- Measures O_2 and CO_2 absorption of reflected sunlight in the near infrared using a 3 channel grating spectrometer with common entrance optics
- Each band contains 1016 spectral samples x 8 spatial footprints, and acquires 3 frames per second
- Science goals require X_{CO2} retrievals with precision better than 1 ppm (less than 0.25%), placing strict demands on preflight & inflight calibration







Example Uplooking Spectra



Calibration Data Flow

Level 1A: Uncalibrated Signal & Temperatures → **Level 1B:** Calibrated Radiance & Uncertainty → **Level 2:** Modeled Radiance & Retrieved State of Atmosphere

Level 1B Inputs: Radiometric Calibration	
Dark Correction	Function of temperature
Stray Light	Function of avg signal
Preflight Gain	Corrects nonlinearity
Gain Degradation	Linear inflight scaling

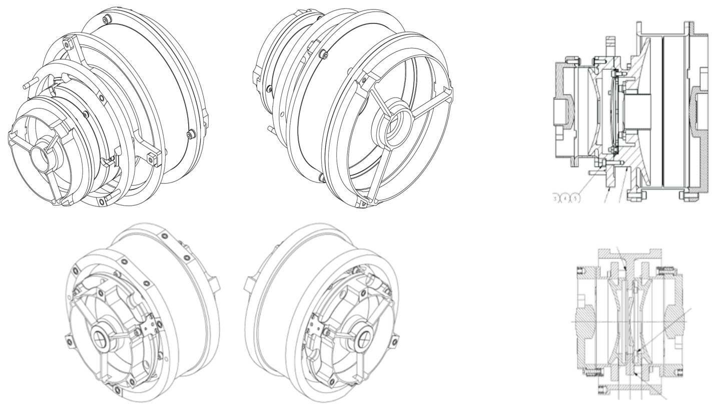
Level 2 Inputs: Calibration and More	
Dispersion	Wavelength vs column
Instr Line Shape	200 element lookup table
SNR Model	Background and photon
Bad Sample List	Remove outliers
ABSCO Tables	High resolution spectra
Geolocation	To resample meteorology
Retrieval Config	Prior, covariance, + more

New Telescope For OCO-3

- Field of view was enlarged from 0.8° to 1.8° to maintain a similar footprint size when changing from 705 km altitude orbit to ~409 km

- This had significant impacts on the preflight test program:
    - ground support equipment required modification
    - calibration sources were far less uniform over larger area
    - An additional test cycle was performed to assess the telescope changes in isolation

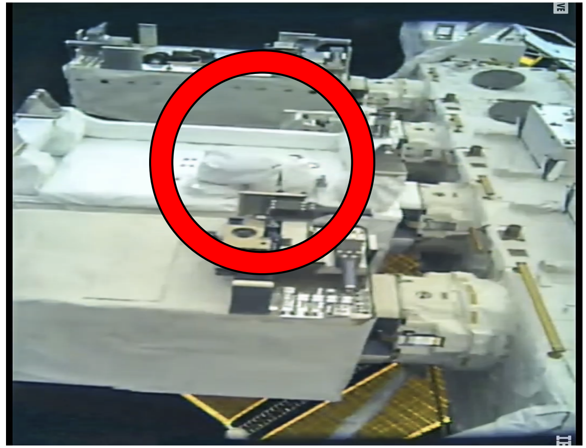
OCO-2 Entrance Optics

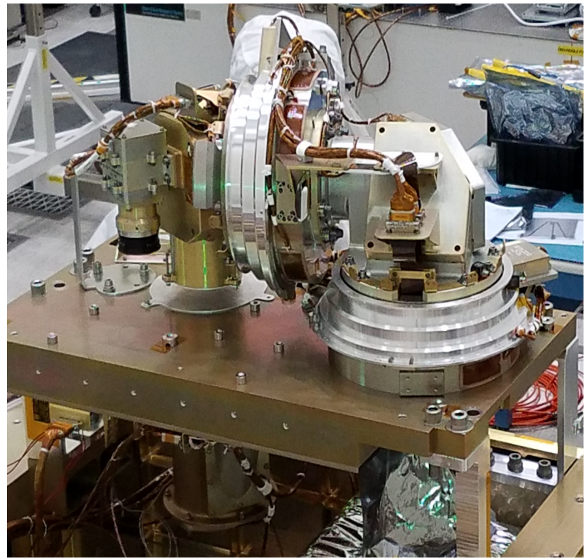


OCO-3 Telescope (same scale)

OCO-3 Pointing Mirror Assembly (PMA)

- OCO-2 calibrator has a lamp and solar diffuser that moves in front of the telescope, or to open position for science data
- OCO-2 is a dedicated satellite that changes orientation to acquire nadir, glint, or target data
- The entire ISS cannot reorient to point OCO-3, so an agile two-axis, four-mirror pointing system was installed in front of telescope
- PMA moves to new onboard calibrator containing identical lamps, but solar calibration is impossible
- Can acquire far more targets, mix nadir and glint, and has a new area mapping mode





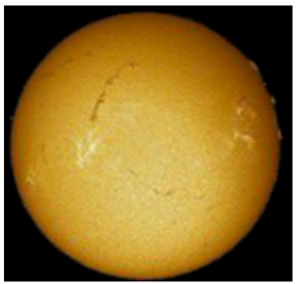
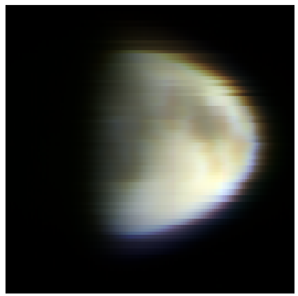
How is Radiometric Degradation Derived?

- Onboard calibration lamps provide a spectrally smooth source that is essential for correcting column-by-column artifacts, but the absolute scale is not well constrained because they age

- OCO-2: Lamp 1 -> Solar -> Lunar relative to in-orbit checkout
  - Supported by MODIS trend, RRV, Lamp 2

- OCO-3 Initial Release: Lamp 3 relative to preflight
  - Supported by OCO-2 comparisons, RRV, scaled for lamp brightening

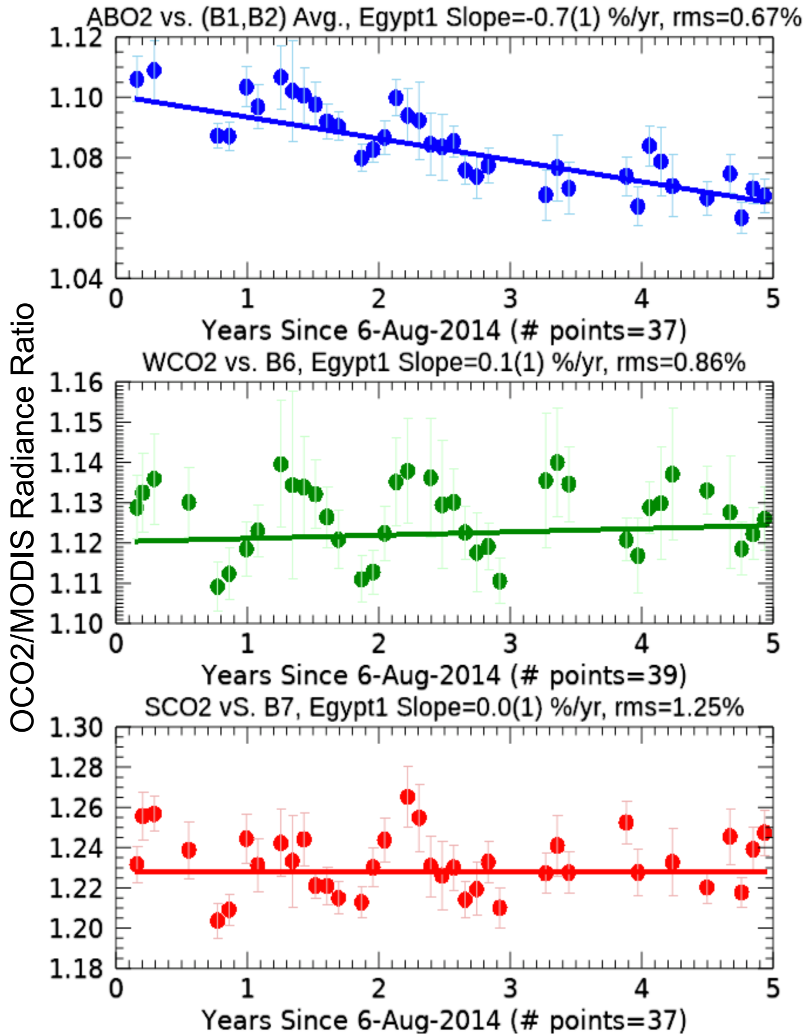
- OCO-3 Future Builds: Lamp 3 -> Lamp 2 -> Lunar
  - Supported by Lamp 1, OCO-2 comparisons, RRV


Trends of OCO-2 vs. Aqua MODIS

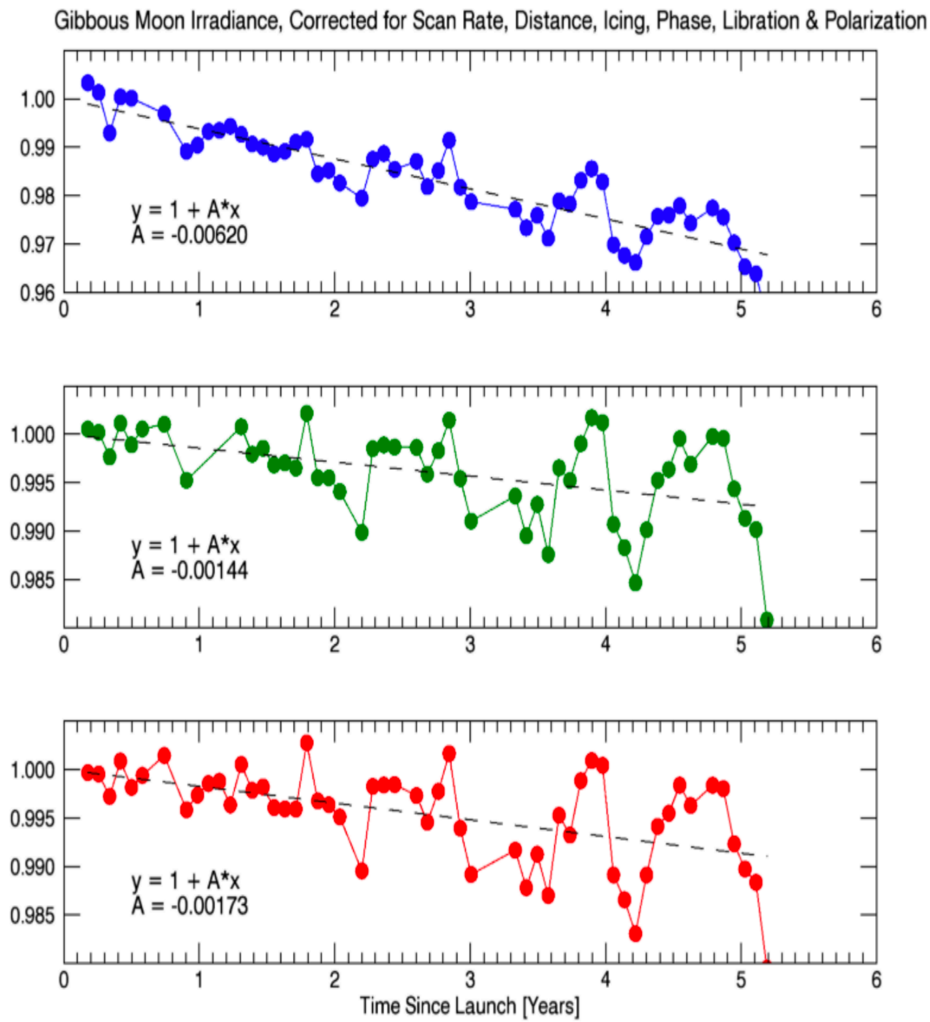
- Select clear OCO-2 nadir soundings in 0.9˚ x 0.9˚ region, MODIS 500m within 1 km circle around OCO-2 footprint
- ~7 minute delay, ~15º view zenith diff
- ABO2 mean drift -0.9±0.2 %/year, no measurable trend for the other bands
- Working to remove seasonal trend

Site	Slope (% per year)			# points in 5 years
	ABO2	WCO2	SCO2	
Algeria1	-1.0±0.1	0.1±0.1	0.4±0.1	17
Algeria2	-0.8±0.2	0.0±0.1	-0.2±0.2	19
Algeria4	-1.1±0.2	0.1±0.1	-0.5±0.2	17
Arabia1	-0.9±0.1	0.1±0.1	-0.4±0.1	33
Egypt1	-0.7±0.1	0.1±0.1	-0.0±0.1	37
Libya1	-1.2±0.1	-0.1±0.1	-0.3±0.1	18
Libya2	-0.9±0.1	0.0±0.1	-0.4±0.1	31
Mauritania1	-1.0±0.1	-0.1±0.1	-0.5±0.1	16



Lunar Calibration

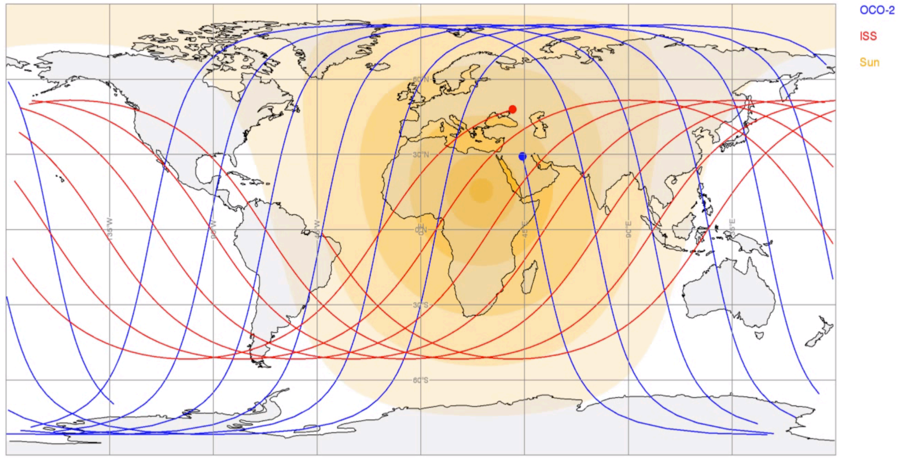
- OCO-2 observes the waxing gibbous each month, and through May 2019 also observed a near-full moon
- Correlated patterns among the three bands are assumed to be sampling artifacts
- OCO-3 has a limited field of regard available for lunar calibration, and initial attempts were delayed due to pointing control system updates



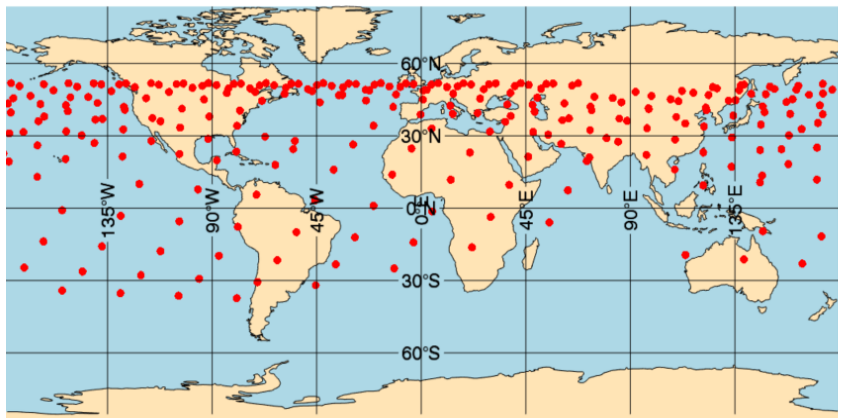
OCO-2/3 Intercomparison Opportunities

- OCO-2 / A-Train in sun-synchronous orbit, repeats the same 233 paths every 16 days
- OCO-3 / ISS in precessing orbit, time of day varies, restricted to [51° S, 51° N], latitude coverage shifts on 63 day cycle
- 262 daytime simultaneous nadir overpasses found (within 30min) for August 2019
  - Represents an upper bound, no screening applied
  - Concentrated near "turnaround" point in the ISS orbit

Sat Aug 10 10:21:00 UTC 2019



Day Time SNOs within 30 minutes. August, 2019.

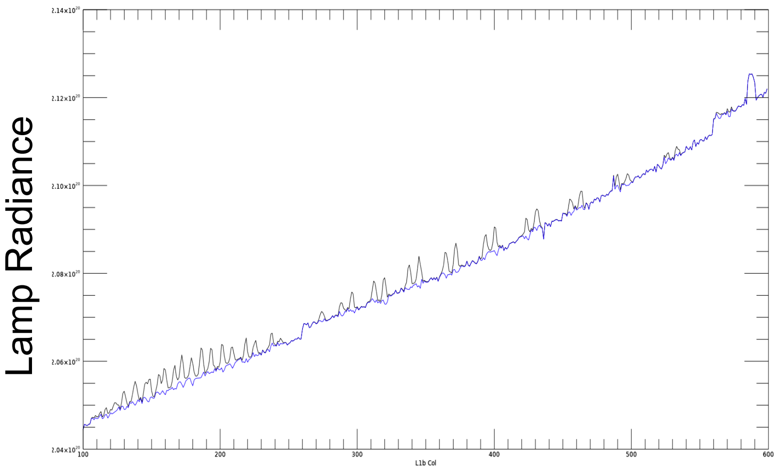


https://sips.ssec.wisc.edu/orbnav/#/tools/snotimes

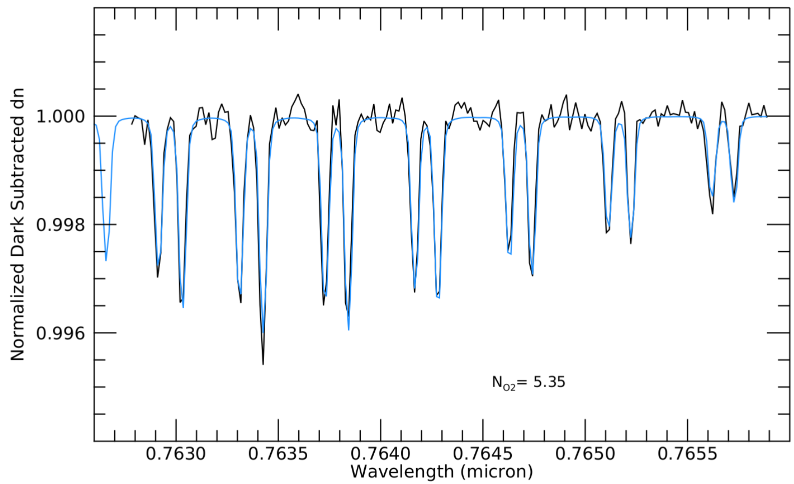
Oxygen Corrections

- Integrating sphere source under N_2 purge, but OCO-3 still observed residual O_2
- Using high resolution absorption coefficients, instrument line shape, and assumptions for temperature and pressure, estimated the number of molecules along the path
- Gains were refit with corrected radiances, which changed by up to 0.4%

Black: Uncorrected   Blue: O_2 Corrected



Black: Measured Ratio   Blue: Model



Bad Pixels and Samples

- OCO-2 detectors are OCO flight spares, and the instrument was stored warm for > 2 years after the final ground test due to a launch vehicle change

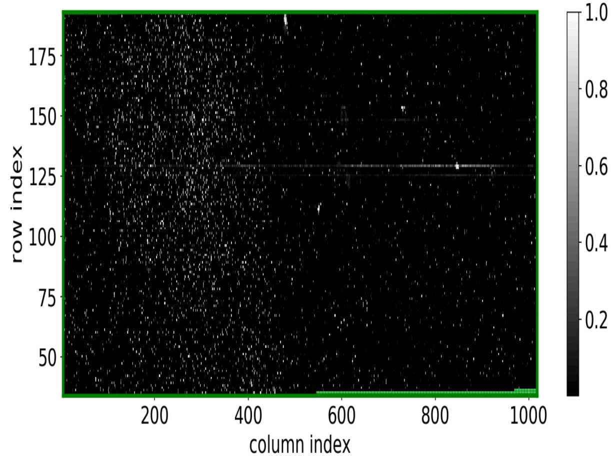
- Dramatic increase in the number of bad pixels from test to flight, concentrated on one side of WCO2 and SCO2 detectors

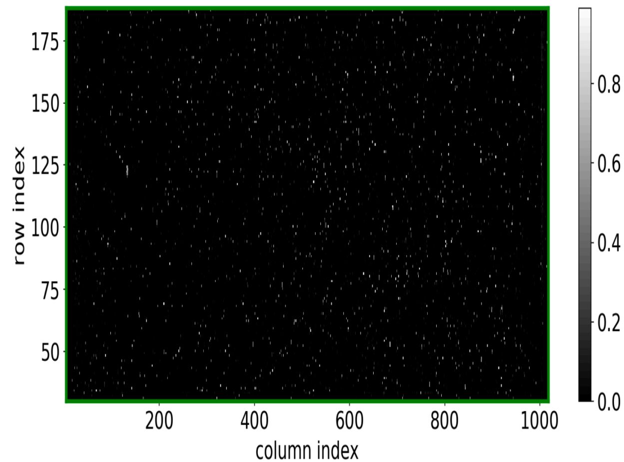
- Machine learning classifier to identify bad pixels was used for OCO-3 test in Apr 2018, OCO-2 flight in Aug 2019, and OCO-3 flight in July 2019

- Bad pixels are irreversibly removed in flight software, but entire samples (sums of 20 px) can be removed from the retrieval in ground processing

- Bad samples can be identified from Level 1A calibration data, Level 1B calibration data, and spectral residuals from the Level 2 algorithm

OCO-2 WCO2: 5262 bad pixels





OCO-3 WCO2: 1936 bad pixels

Conclusion

- Absolute radiometric scaling remains a challenge for both missions, but fortunately those errors impact retrieved albedo more than retrieved X_{CO2}
- Spectral calibration is essential, but harder to track ILS on orbit
- OCO-2 has benefited from a 5+ year data record, and OCO-3 has benefited from mature OCO-2 algorithms and calibration processes
- OCO-2 Build 8 will complete with January 2020 data
- OCO-2 Build 10 has been finalized and is under production
- OCO-3 Level 1B data will be released soon

You might also like…"Remote Sensing of CH_4 and CO_2 From Space"
Sessions A52H, A53F, A54G, Friday 10:20-12:20, 13:40-15:40, 16:00-18:00