OCO-3 Version 11: Better Data and More Data

Robert Rosenberg, Graziela Keller, Richard Lee, Yuliya Marchetti, Edwin Sarkissian, Gary Spiers, Vivienne Payne, Abhishek Chatterjee

Jet Propulsion Laboratory, California Institute of Technology

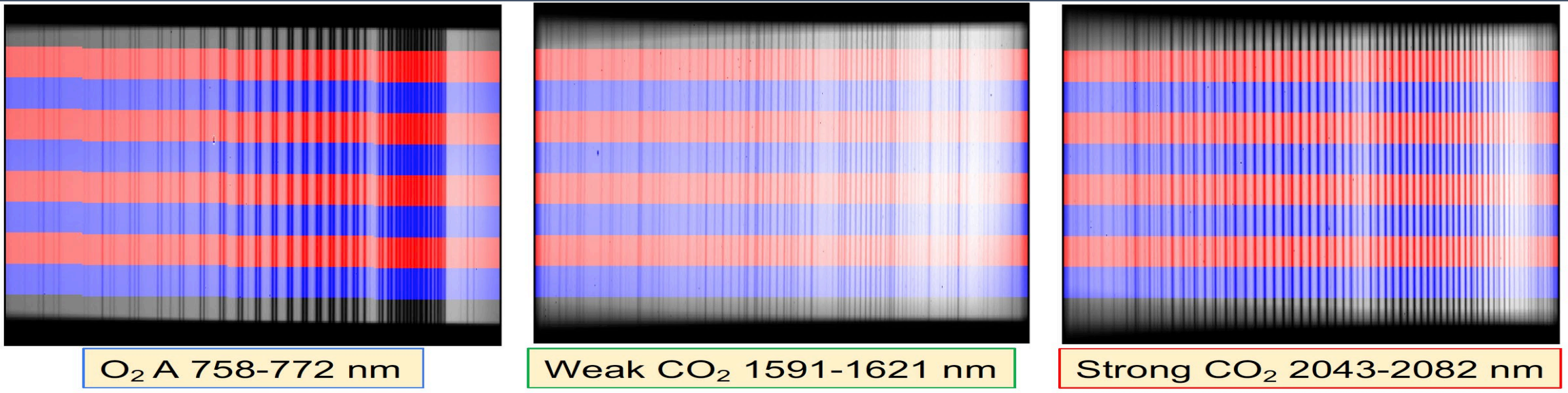
32nd CALCON Technical Meeting

Post-Launch Performance Session

Wednesday June 14, 2023 8:30-8:50 AM MDT

Introduction

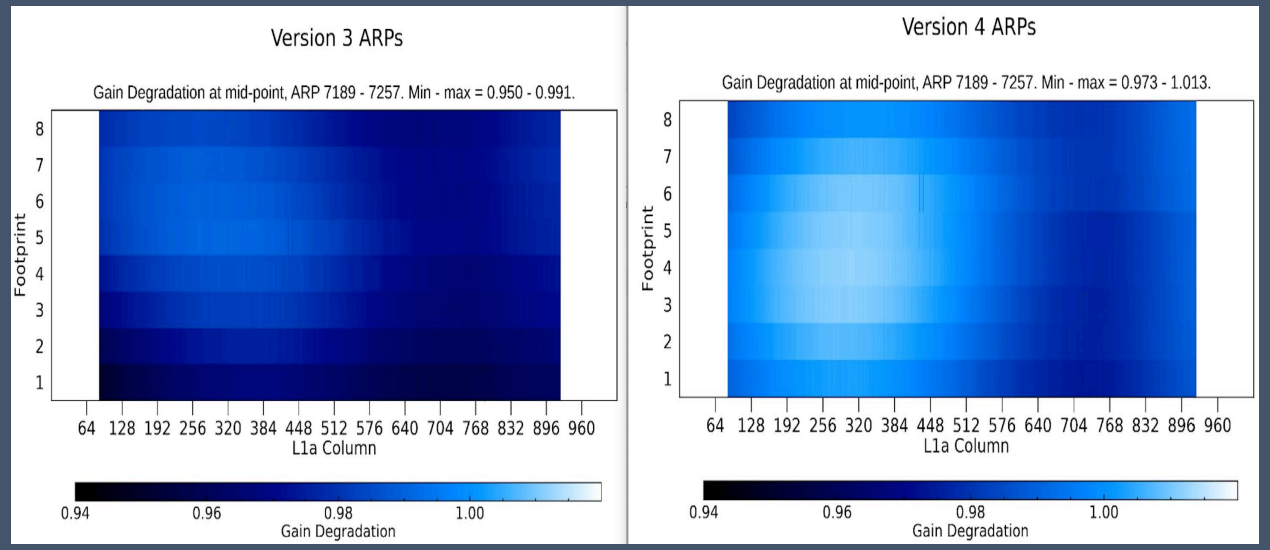
- The Orbiting Carbon Observatory 3 instrument measures O_2 and CO_2 from the International Space Station using a three-channel imaging grating spectrometer with a common telescope
- Science goals ("watching the Earth breathe") require retrievals of column-average CO_2 dry air mole fraction to have precision better than 1 ppm, less than 0.25% of the background level



Outline

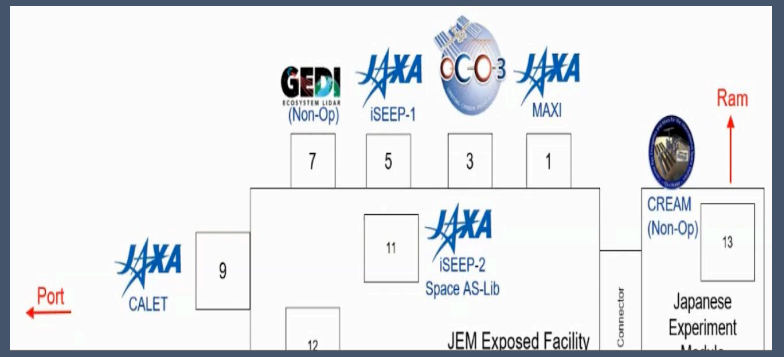
- Better Data: Version 11 contains several major radiometric improvements along with more subtle adjustments to geometric and spectral calibration
  - Band 1 Spectral Shape
  - Slow Gain Degradation
  - Signal to Noise

- More Data: Already four years since first light for what was originally a three-year mission, recently extended for several years (following interruption in 2024)



Mission Schedule & Extensions

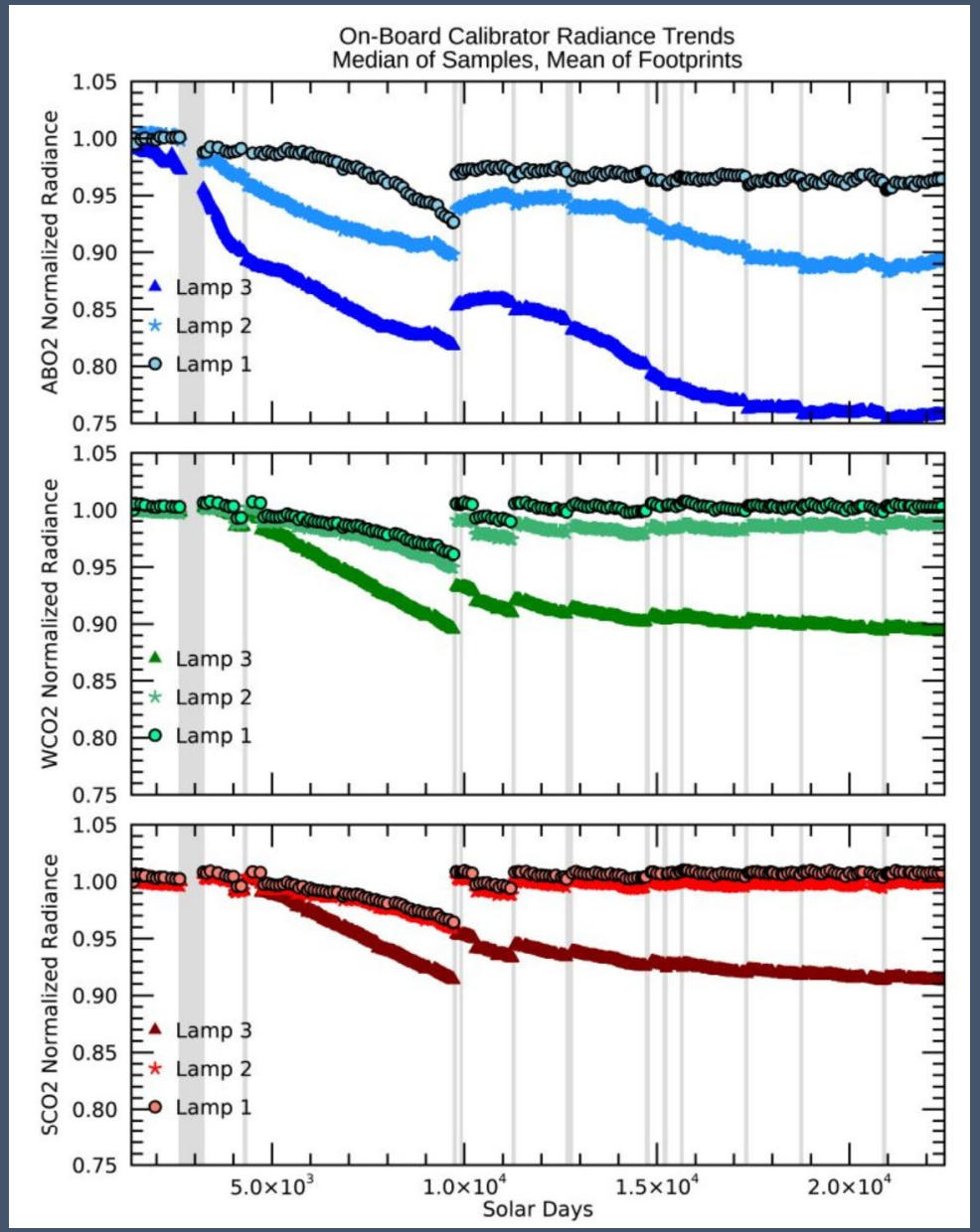
- SMD has approved a mission extension to the 2026 Senior Review
- OCO-3 will be replaced by ILLUMA-T arriving on SpX-29 (NET Dec 2023)
- OCO-3 will be removed from JEM-EF site 3 and placed in non-operational storage (site 7) while ILLUMA-T completes 6-month prime mission.
- ISS has approved position on JEM-EF site 3 through end of the ISS lifetime



Launch May 2019	IOC #1 May 2019 – Aug 2019	Phase E Sep 2019 – Aug 2022	Phase E-Ext Part 1 Sep 2022 – Dec 2023
Storage Jan 2024 – June 2024	IOC #2 July 2024 – Sep 2024	Phase E-Ext Part 2 Oct 2024 – ISS End of Life	Phase F ISS EOL 2030?

Inflight Radiometry

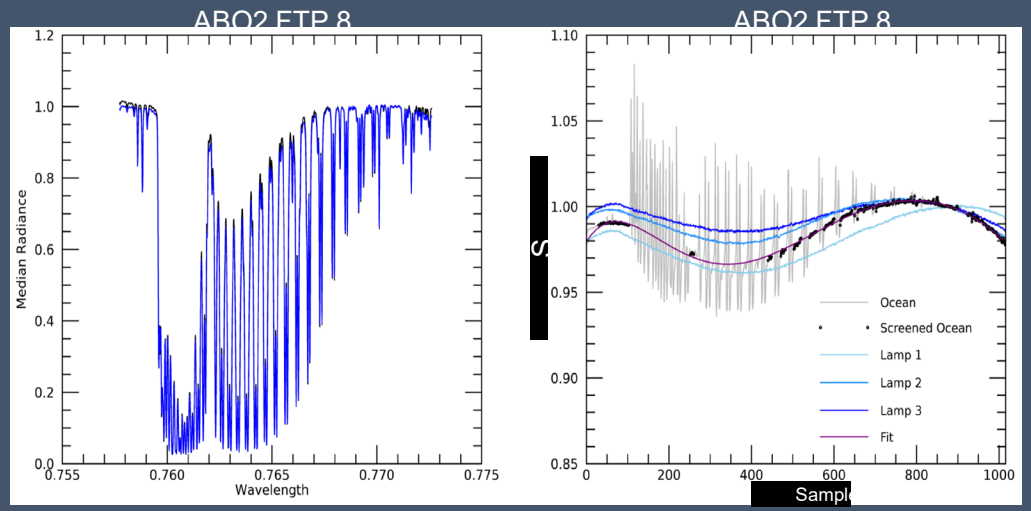
- OCO-3 directs its pointing mirror assembly into an onboard calibrator to collect dark data, or view a diffuser illuminated by one of three lamps, every orbit
- With no solar calibration and less reliable lunar calibration than OCO-2, the lamps are used at different cadences and age at different rates
  - L1: 1%, L2: 19%, L3: 80%
- High contamination from Jun 2020 to Jan 2021

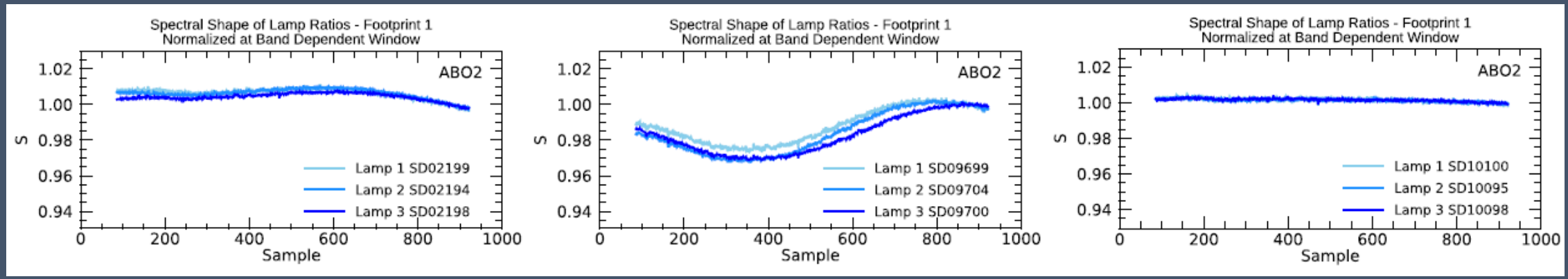


G. R. Keller *et al.*, "Inflight Radiometric Calibration and Performance of the Orbiting Carbon Observatory 3 for Version 10 Products," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1-18, 2022, Art no. 5413518, doi: 10.1109/TGRS.2022.3216825.

Radiometry: In-Band Spectral Shape

- During max-contamination period, not only did Band 1 lamp spectra change, but they diverged from one another (Bands 2/3 did not)
- Pattern varied significantly in spatial dimension
- This is also when Level 2 biases were largest prior to additional “ad-hoc” correction in V10.4





Early mission | Just before decontamination | Just after decontamination

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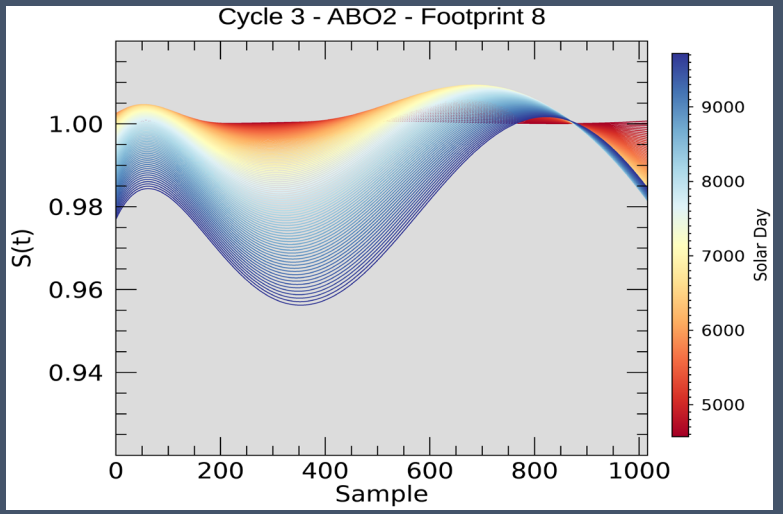
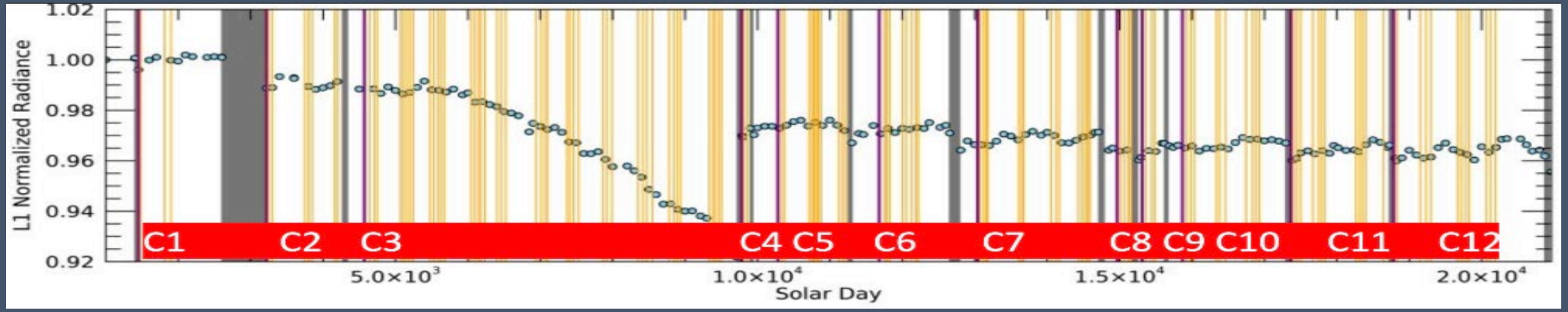
Radiometry: Clear Ocean Correction

- Corrected the spectral shape of lamps using ratios of thousands of clear ocean spectra between high- and low-contamination periods using polynomial fits in column and in time
- Spectral residuals from ACOS Level 2 Full Physics retrieval show considerable improvement in V11





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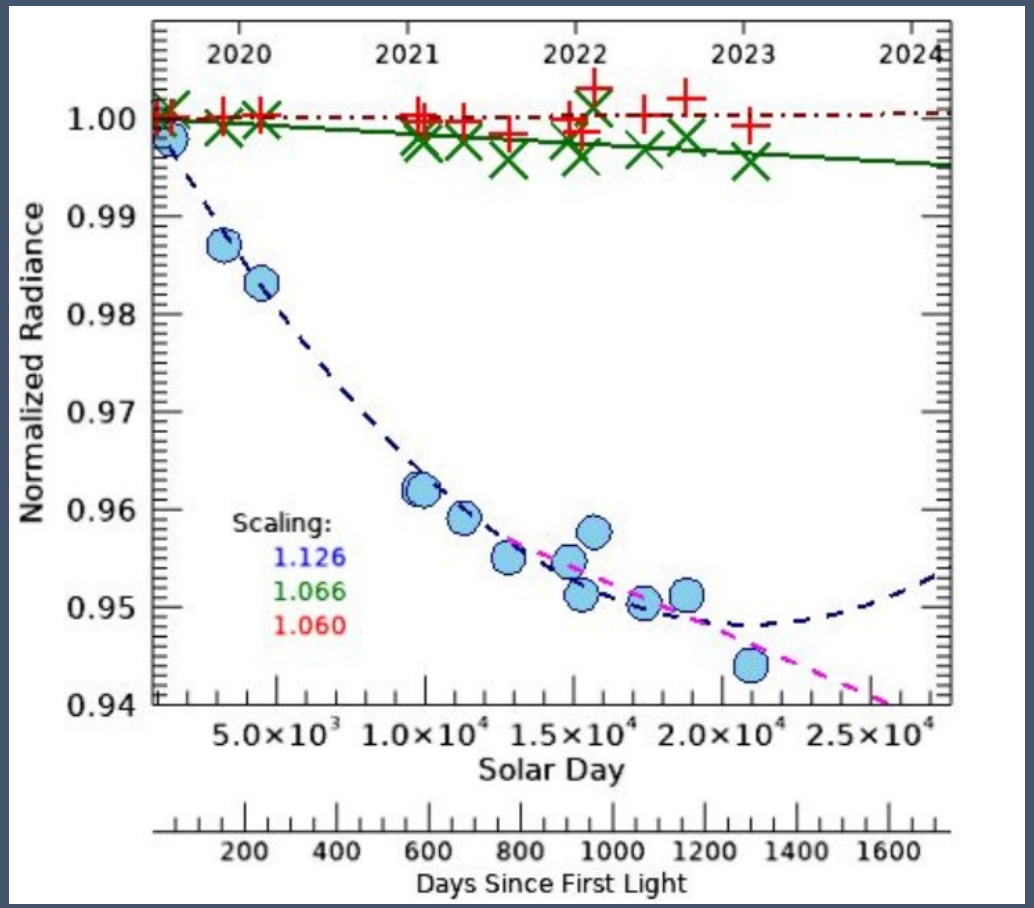
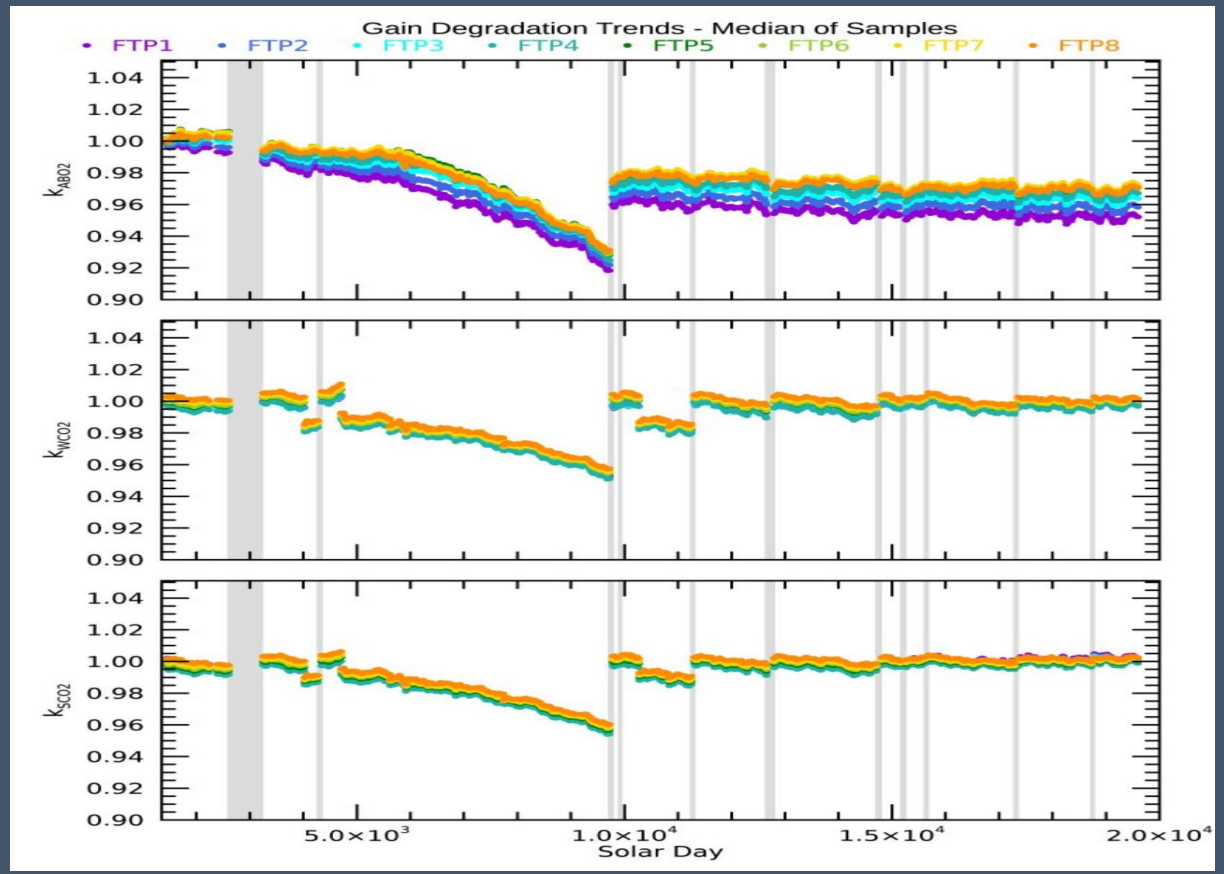
Radiometry: Slow Degradation

- The first Lamp 1 measurement after each decontamination is “clean” and the trend represents the combination of both lamp aging and instrument sensitivity changes
- V10 assumed that L1 did not age at all, causing bias of up to 1 %/year
- V11 implements a quadratic fit for past cycles and will extrapolate using a linear fit for future
- These curves, along with the scaling to account for lamp brightening during IOC, are now calculated separately for each spatial footprint
- “Day 0” moved from end of IOC (Aug 2019) to First Light (Jun 2019)

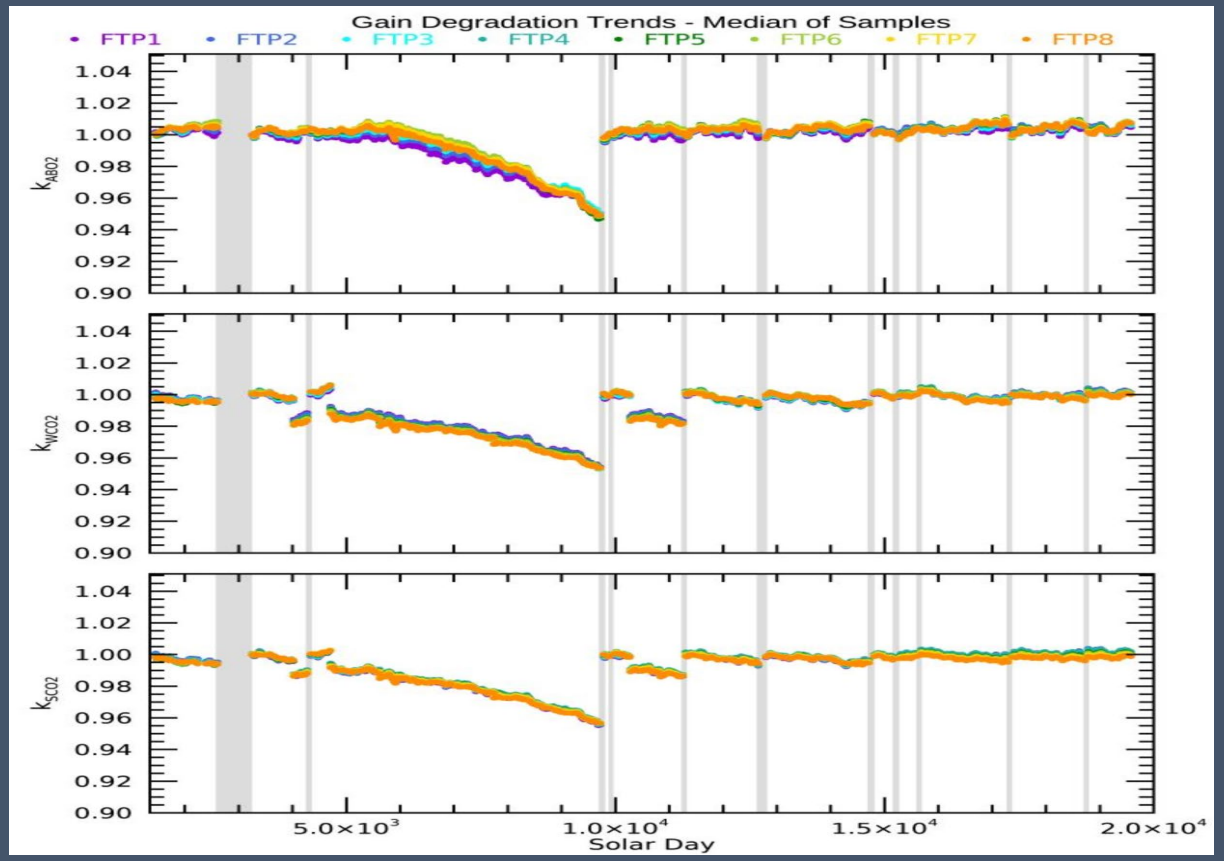


Radiometry: Median Gain Degradation

Version 10

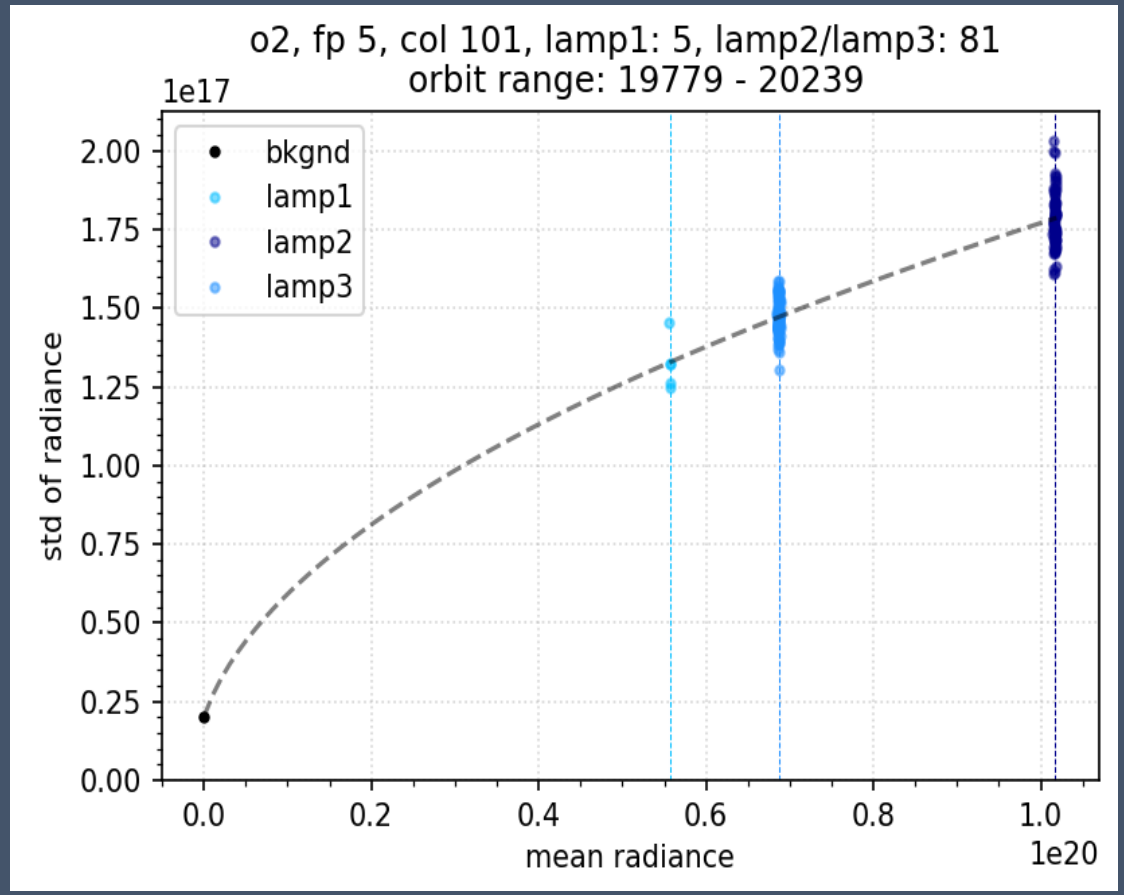


Version 11



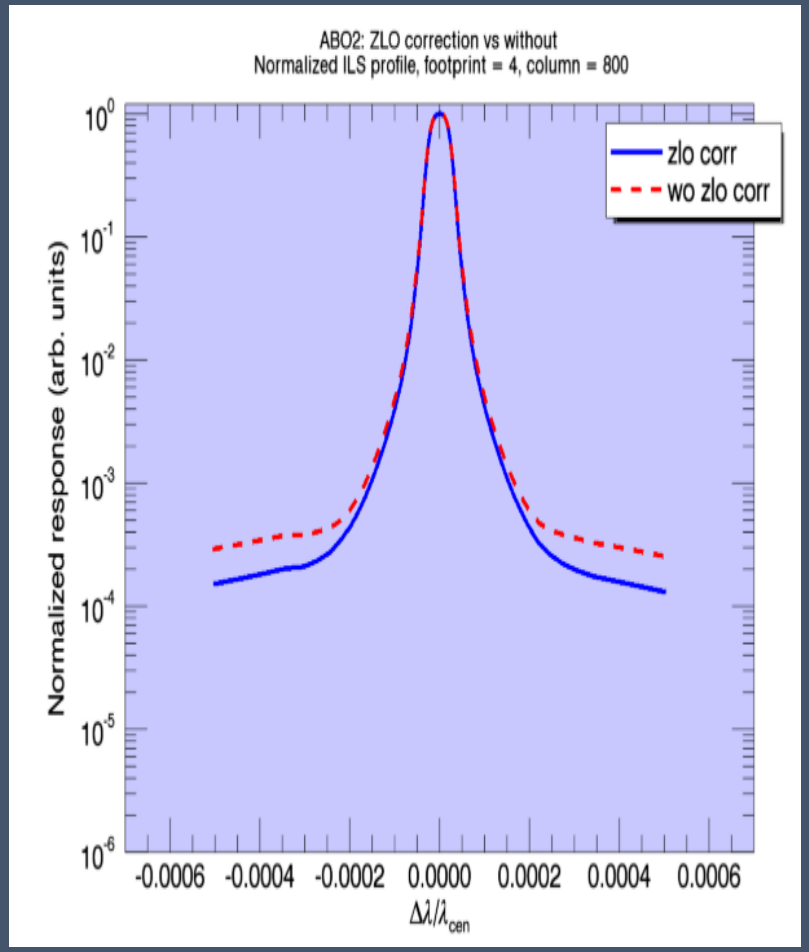
Radiometry: Noise Model

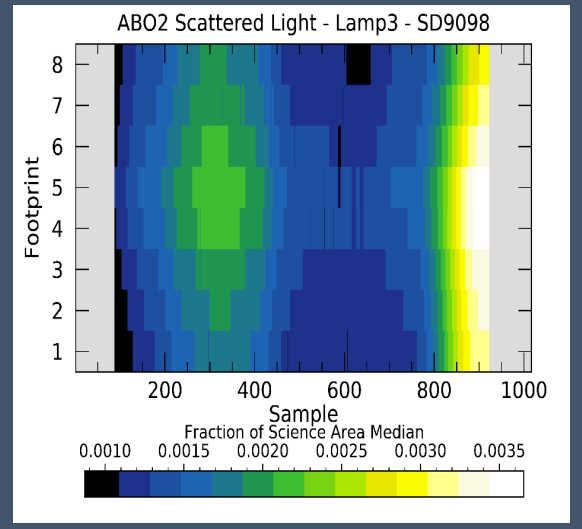
- Two components:
  - Constant “background”
  - Photon proportional to $L^{0.5}$
- V10 used a fit of inflight data from 2019 that was applied to the entire mission
- Background noise now fit from inflight dark measurements (dozens per day) for each period of 3-7 days
- Photon noise now fit from inflight lamp measurements for each calendar month to allow sufficient L1 to constrain fit

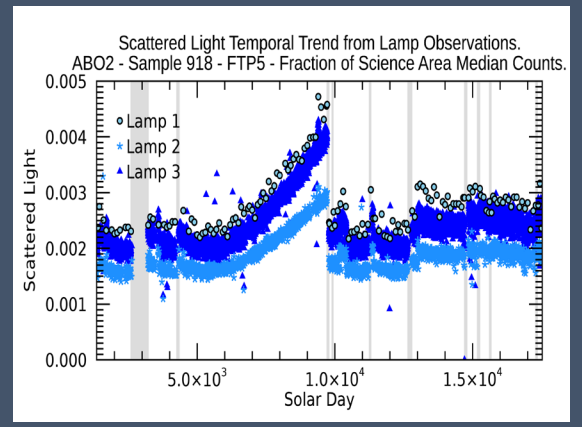


Spectral: Instrument Line Shape

- Stray light scattered by FPA increases with contamination, low but nonzero in thermal-vacuum tests
- From B10.2 to B10.3 an error was corrected in the stray light model
- Preflight spectral and radiometric tests (sphere, laser, heliostat) reprocessed with correct stray light
- New instrument line shape has lower “wings”, better agreement with uplooking FTS







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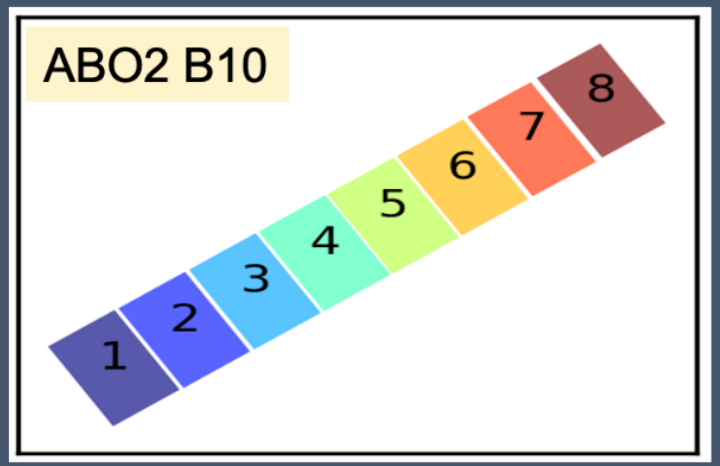
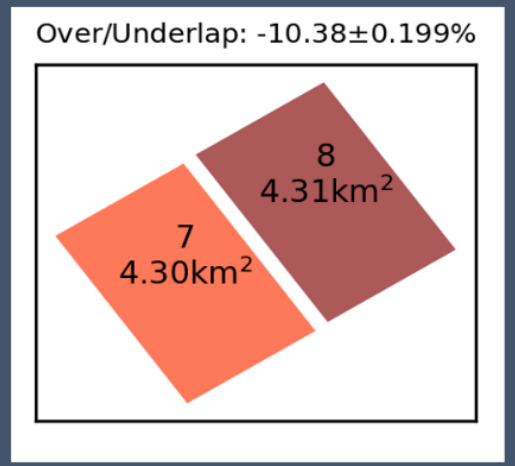
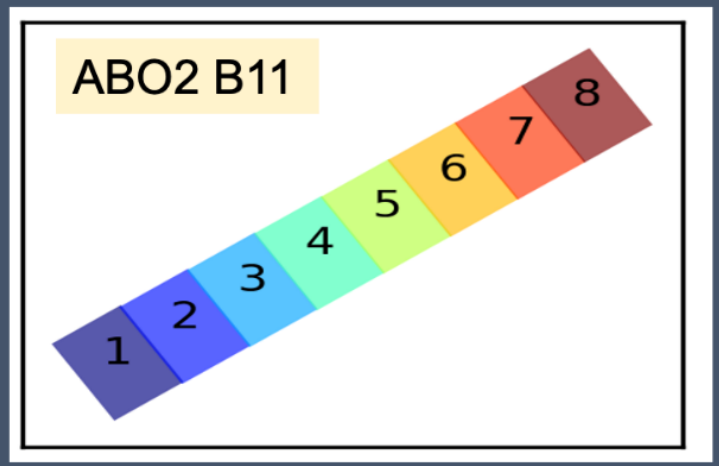
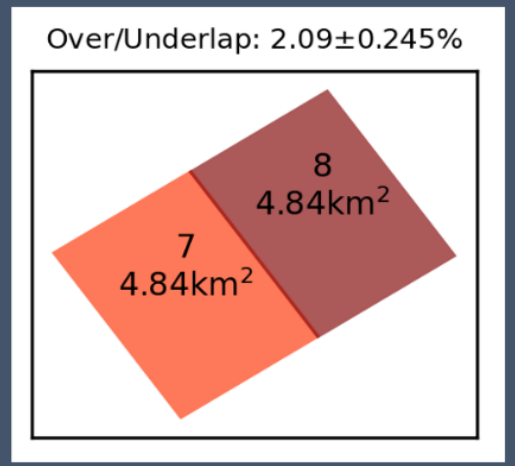
Geometric: Footprint Vertex Coordinates

- Spatial response function poorly characterized because 2D Gaussian shape assumed
- New approach: nonlinear least-squares optimization calculated rectangles with 80% ensquared energy – band centers used for science ops but also done for separate rows/cols
- Eliminated unphysical “gaps” or “underlaps” between footprints, areas larger in all bands
- Band 3 footprints now overlap by up to 24% - better estimate of defocus









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Conclusion

- Excited that OCO-3 has opportunity to deliver a longer-term climate data record
- New partnerships / simultaneous measurements in second half of decade?
- 2nd In-Orbit Checkout critical to ensure pre- and post-storage data can be used together
- In addition to the calibration improvements, Version 11 will also feature improved timing/attitude/geolocation and retrieval algorithms
- Reprocessing campaign complete & data available next year