Refined Spatial Response Functions for OCO-3

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Calibration Methods for Climate Change Measurement and Modeling Session

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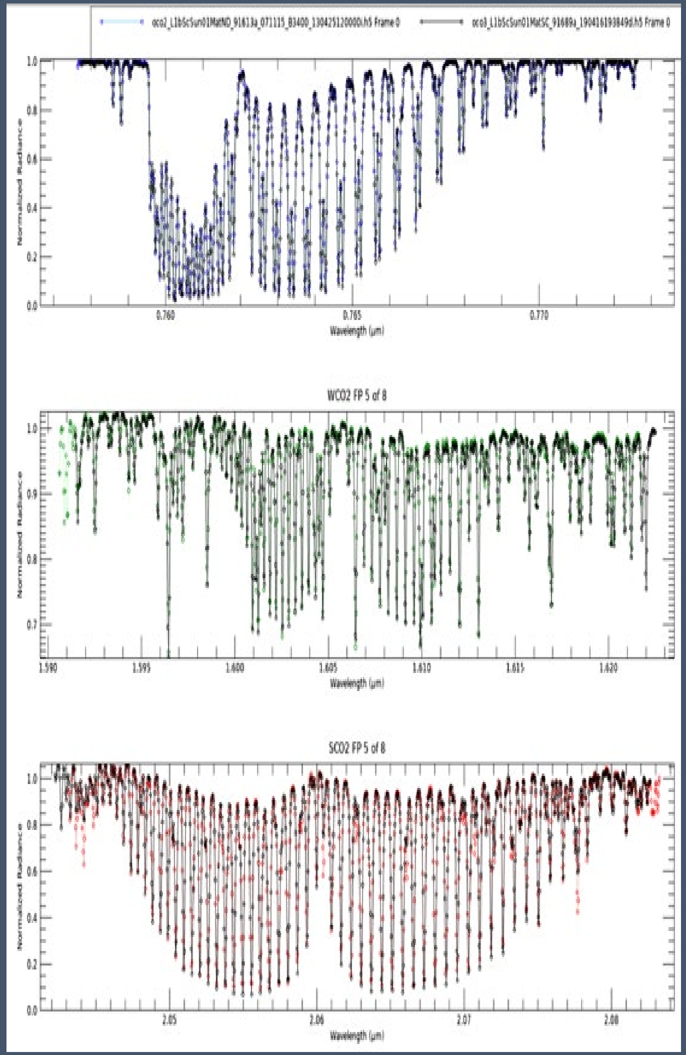
Introduction

- OCO-2 & OCO-3 have been measuring CO_2 and O_2 (inferred from absorption of reflected IR sunlight) since 2014 & 2019 respectively, at a rate of over 100K soundings/day each
- Both feature 3-channel long slit imaging grating spectrometers with common telescope, using OCO design (launch failed 2009)
- OCO-3 field of view 2.2x larger than OCO-2 due to lower orbit
- ISS altitude has increased from 350 to 410 km since OCO-3 telescope design, so OCO-3 swath is unintentionally wider
- Ancillary Geometric Product used to project footprint vertices onto Earth's surface, only updated between major versions
- Was only computed for science "superpixels" (20-row sums)
- All wavelengths assumed to have the same spatial response

Prelaunch Uplooking Spectra



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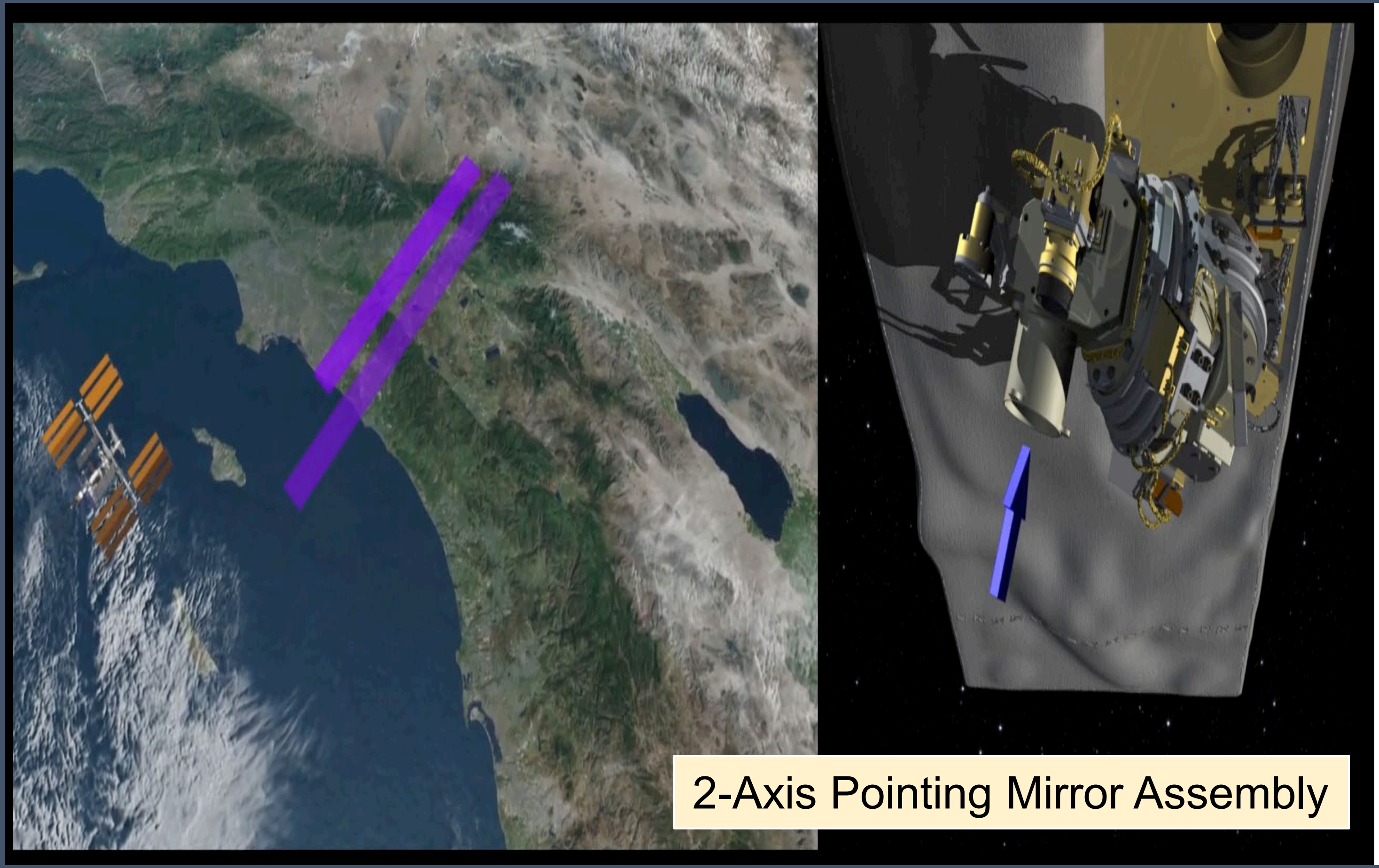
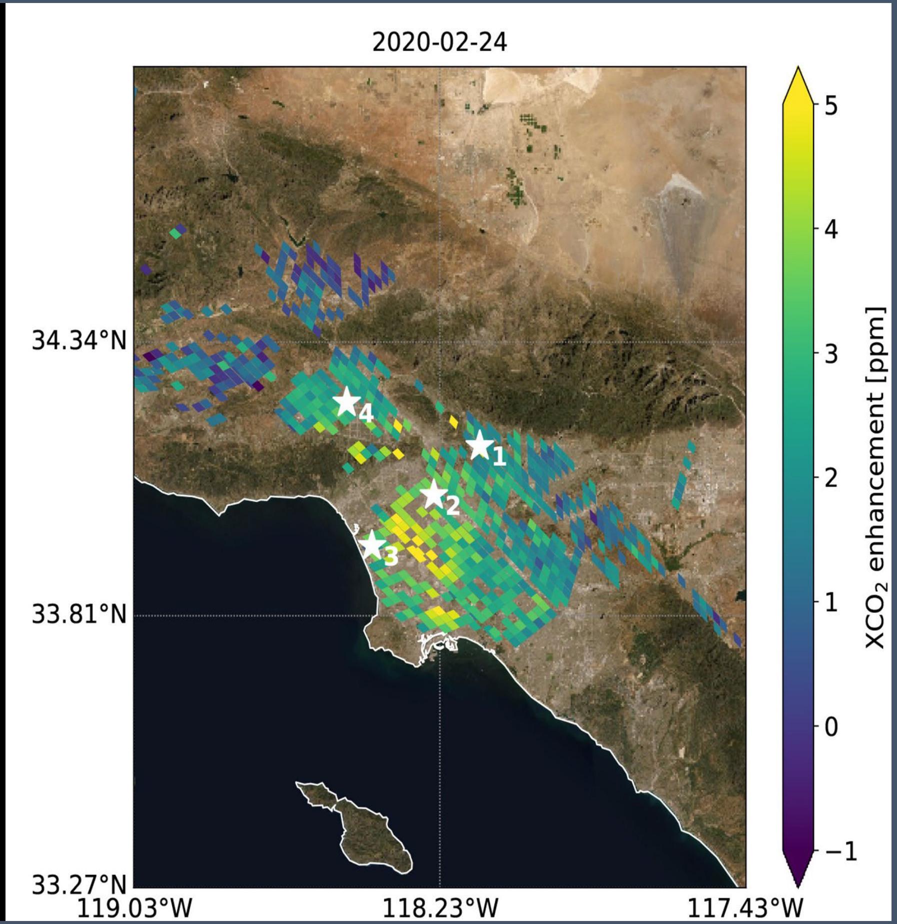
Los Angeles Snapshot Area Map Example





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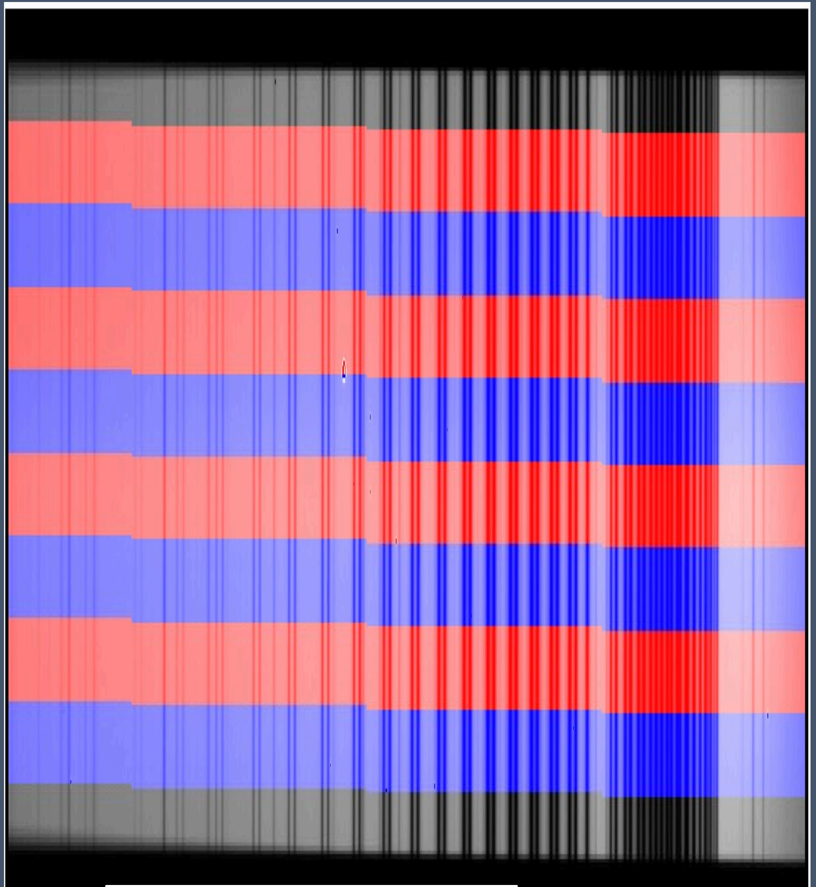
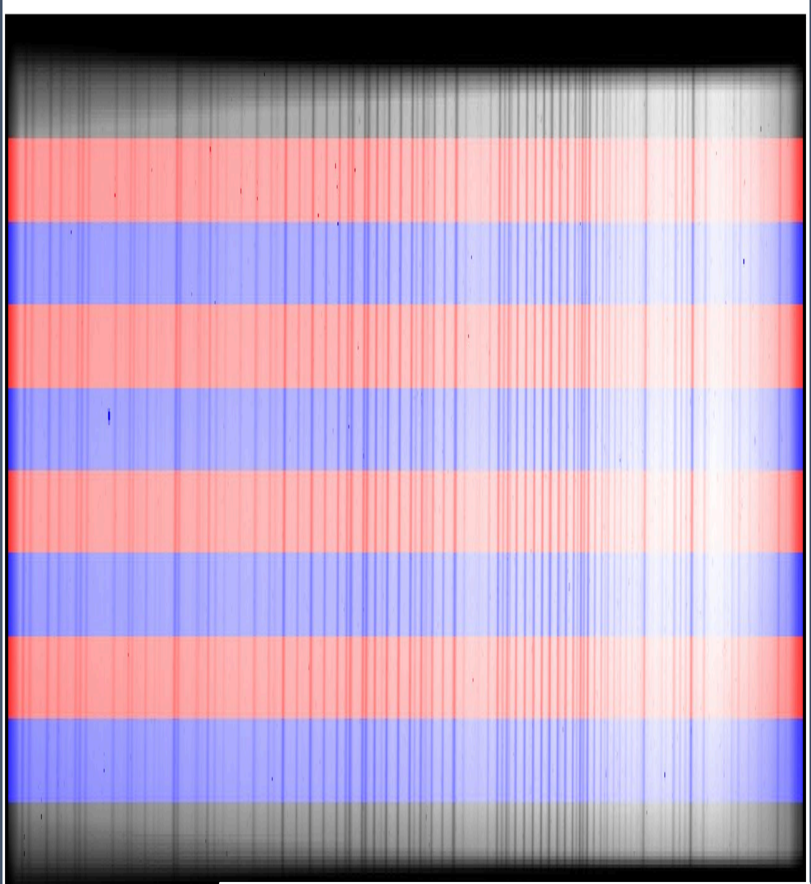
M. Kiel et al https://doi.org/10.1016/j.rse.2021.112314

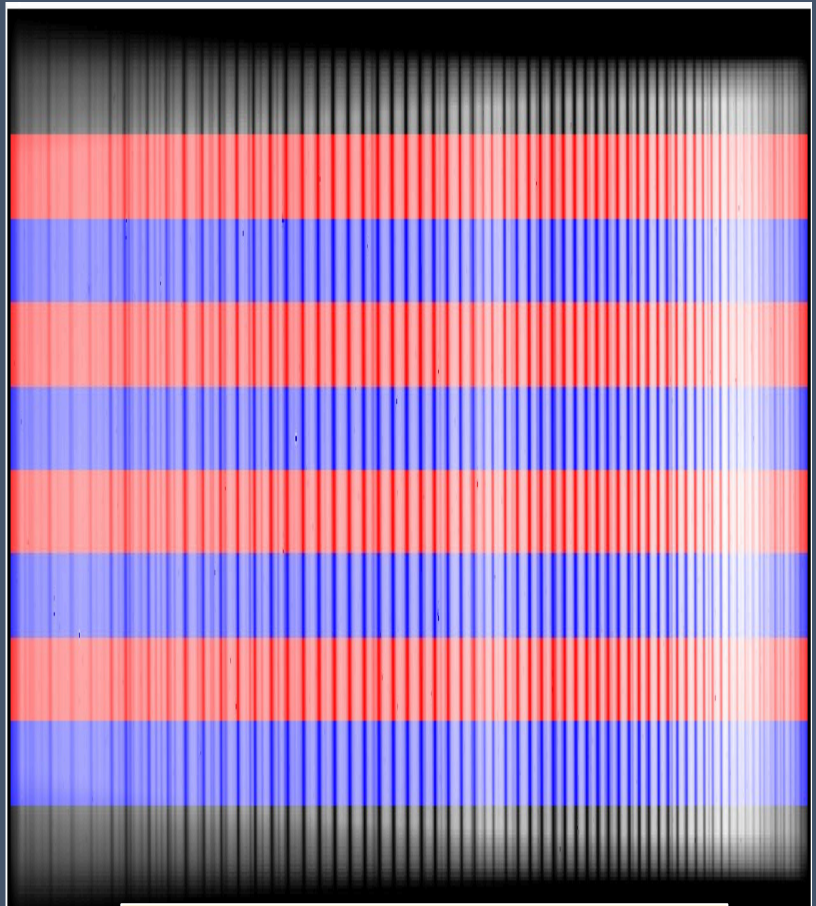
Rows & Footprints (Preflight Uplooking)



O_2 A 758-772 nm



Weak CO_2 1591-1621 nm



Strong CO_2 2043-2082 nm

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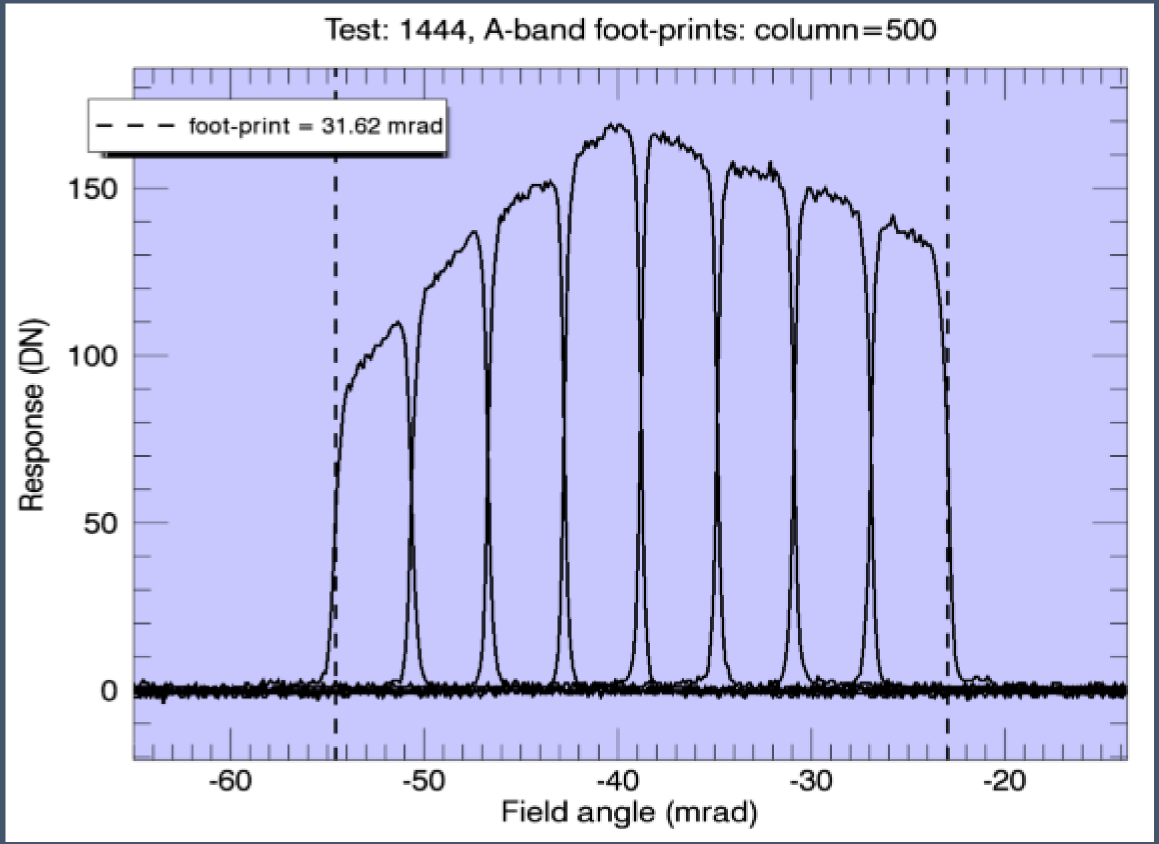
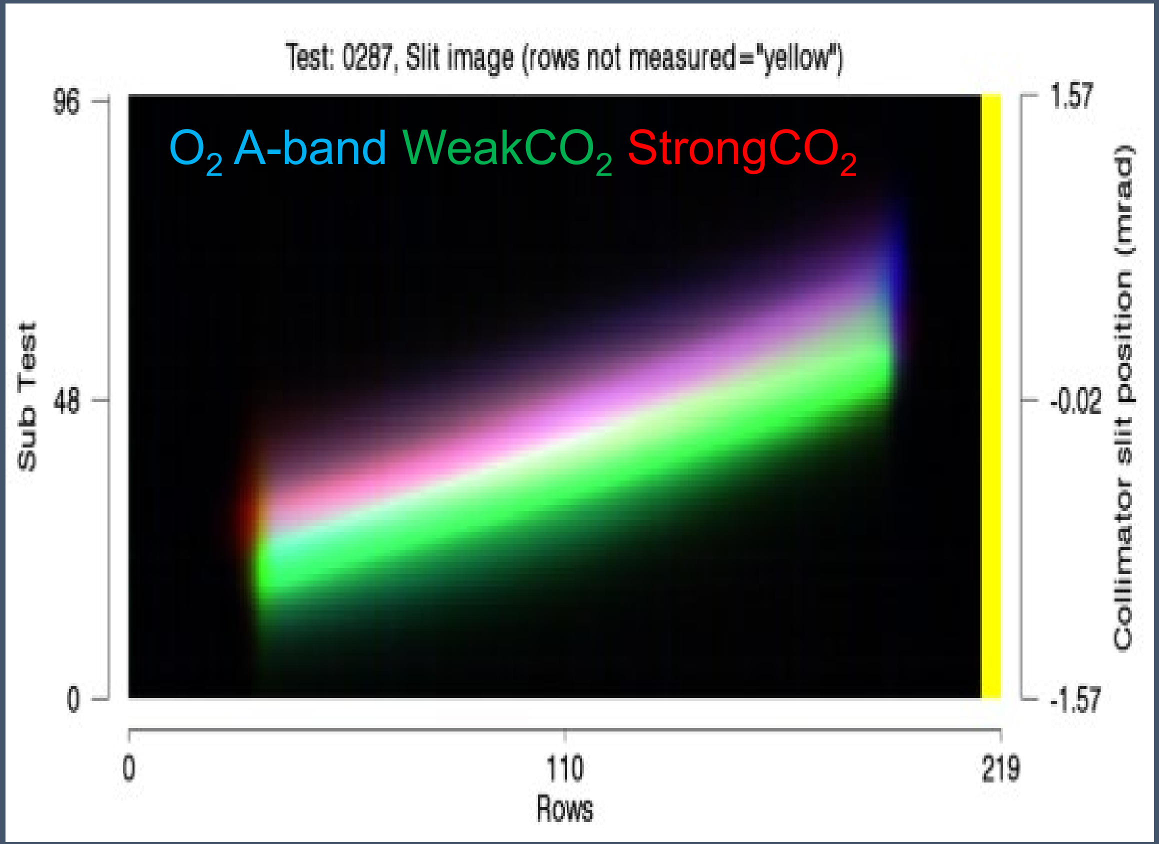
One-Dimensional Spatial Response Tests

Perpendicular



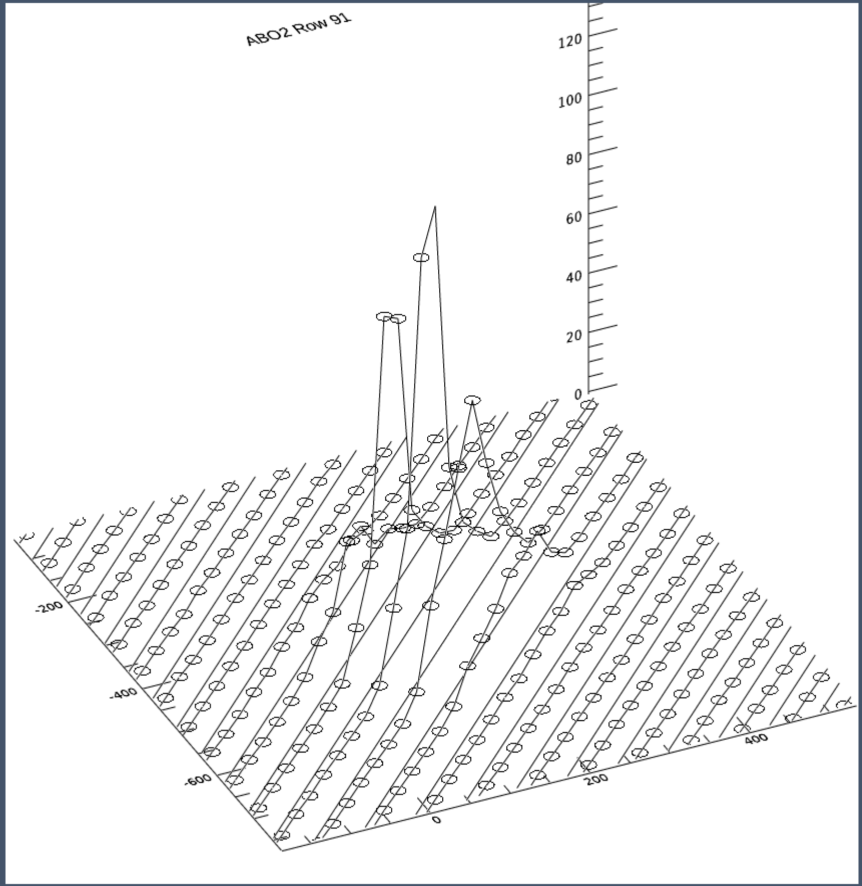
Parallel



Two-Dimensional Spatial Response Test

- Moved a pinhole in front of collimator white light source on a stage in a raster scan across FOV
  - 35 [cross slit] x 173 [along slit] grid
  - procedure duration ~18 hours

- Rotated stage coordinates to AGP coordinate system using Internal Context Camera measurements



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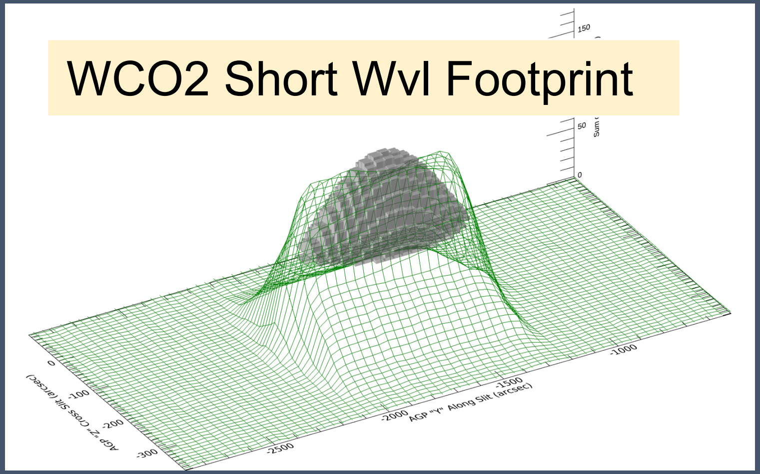
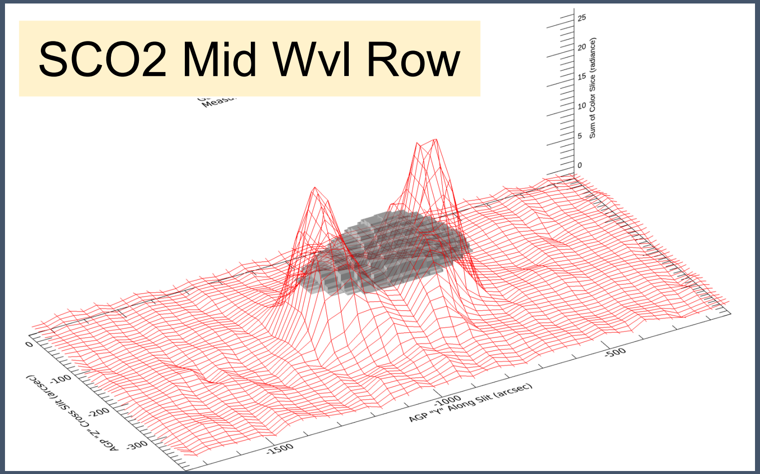
Spatial Response Shape & Defocus

- OCO-2 & OCO-3 vEarly/v10 determined footprint centroids and widths by fitting 2D Gaussians to dark-subtracted pinhole data

- In focus: rows gaussian, footprints “flat top”
- Defocused: rows double-peaked, FPs wide

- Defocus varies by wavelength within each band, SCO2 long wavelengths worst by far





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Lunar Images: Feb 15 2022 (Orbit 15752)

758 nm

1591 nm

2043 nm

765 nm

1606 nm

2063 nm

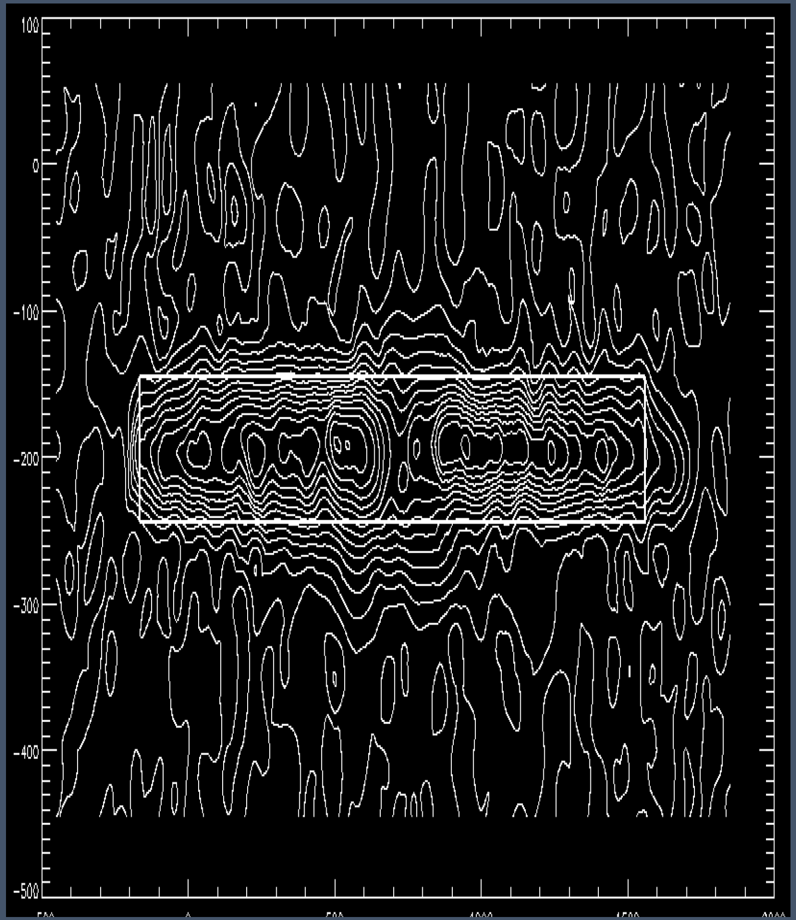
772 nm

1621 nm

2082 nm

New Approach: Rectangles around SRF

- Optimal “rectangle” with sides parallel to ABO2 slit minimizes ”area” (solid angle) while enclosing a pre-specified fraction of spatial response
  - Compute centroids in separate earlier step
  - Remove outliers: along-slit uses linear fit, cross-slit quadratic because slit curved
  - Had to account for time-dependent drift to perform an accurate background subtraction
  - Slight improvement from applying radiometric gain before fitting (telescope throughput)



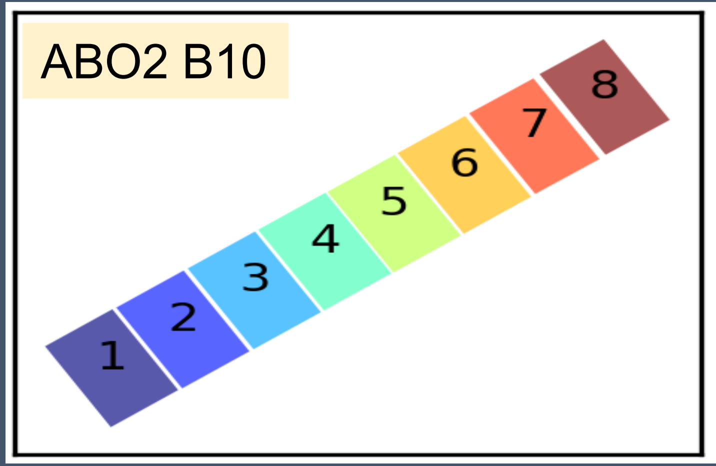
Nonlinear Least Squares Optimization

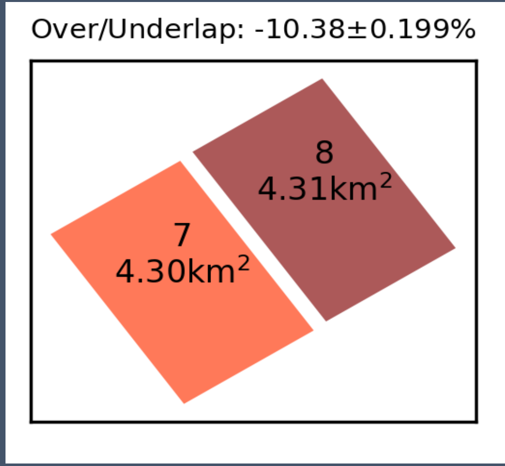
- Interpolate SRF to a fine, regular grid to compute ”volume” using a continuous 2D Riemann summation

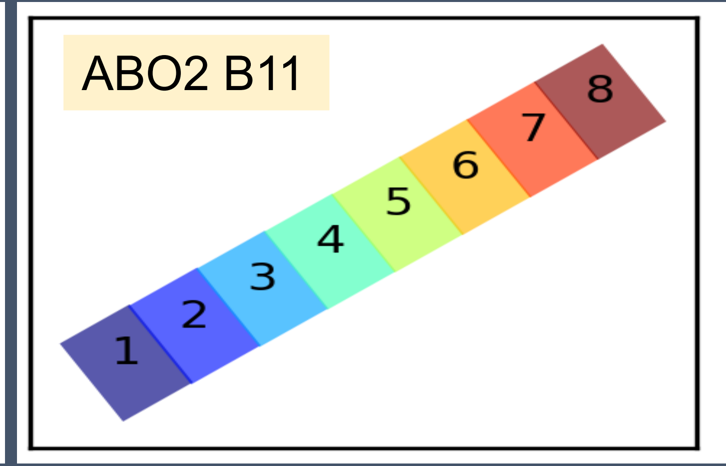
- Cost function to be minimized is weighted sum of “area” & difference between “volume” and desired volume
  - Uses a version of Levenberg-Marquardt algorithm developed at JPL
  - Need continuous, differentiable, continuous partial derivatives
  - When it diverges, perform SVD on interpolated SRF, smooth by eliminating high frequency variations associated with small singular values

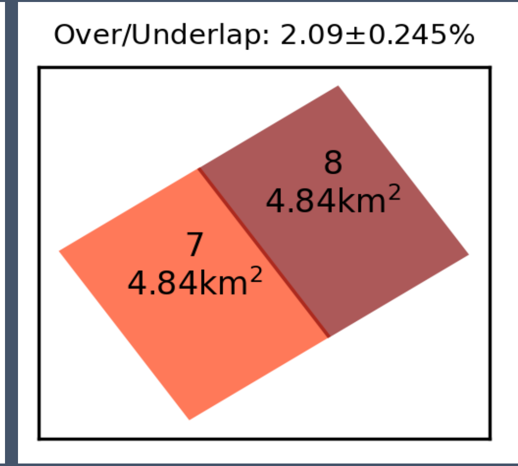
Footprint Overlap & Ensquared Energy %

- Detector is continuous, so ”underlap” was clearly unphysical
- 80% rectangles yield favorable overlap in ABO2 (best focused)
  - This may not be ideal for “solid angle of pixel” calculations for Lunar!
- Ensquared energy of 2D Gaussian within $\pm \sigma_x$ & $\pm \sigma_y$ = 57.9%









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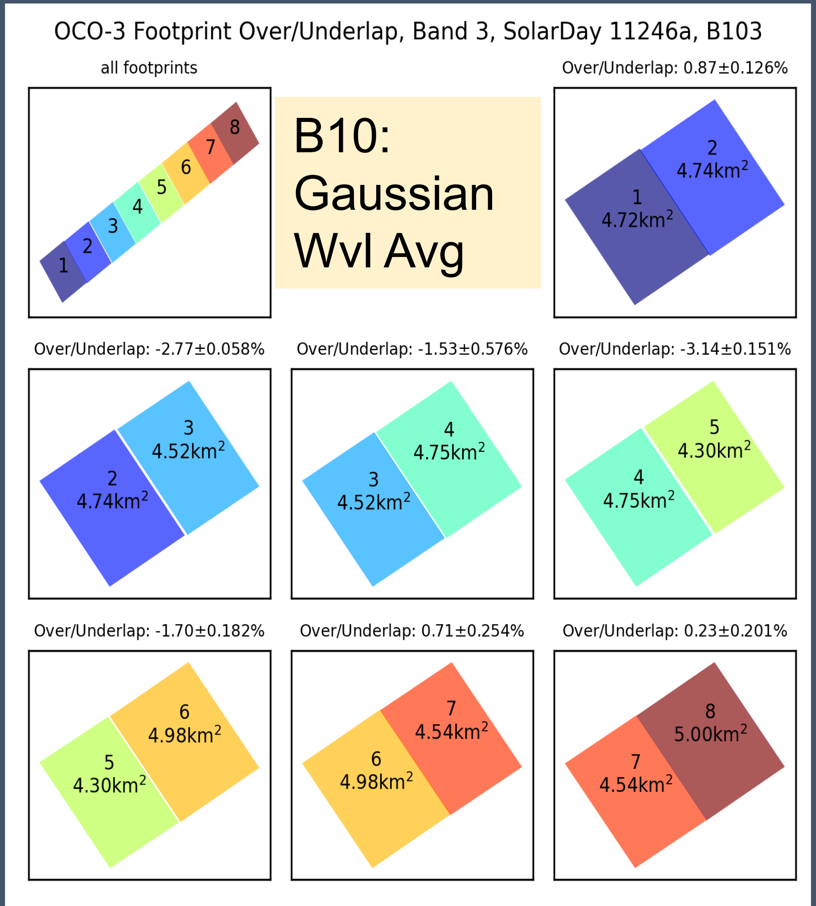
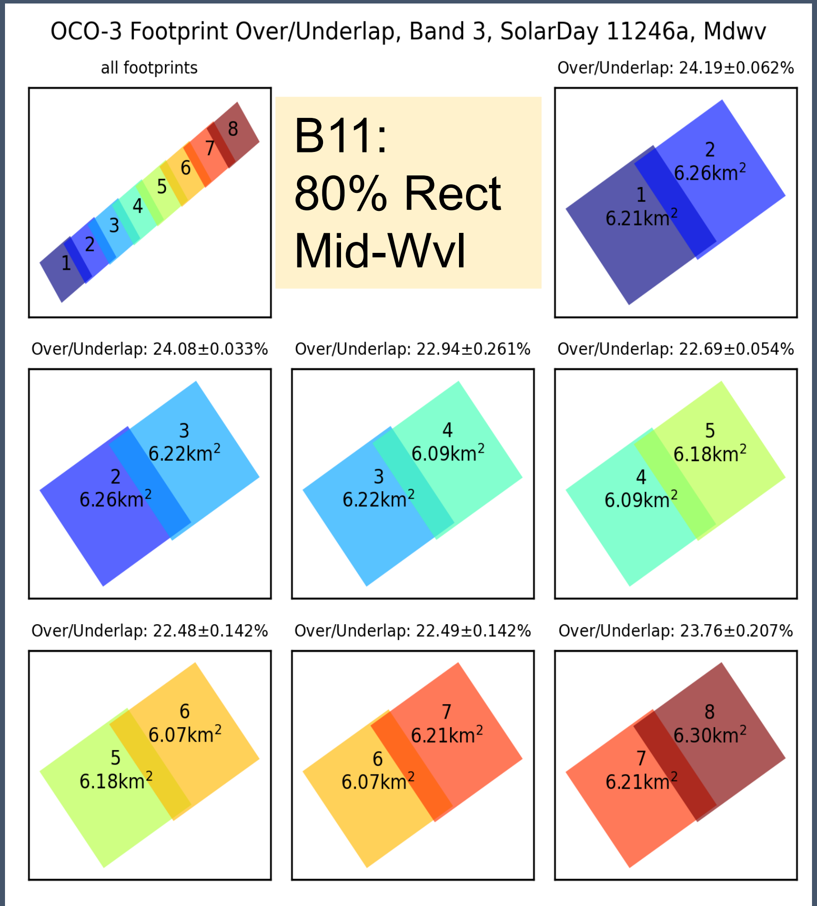
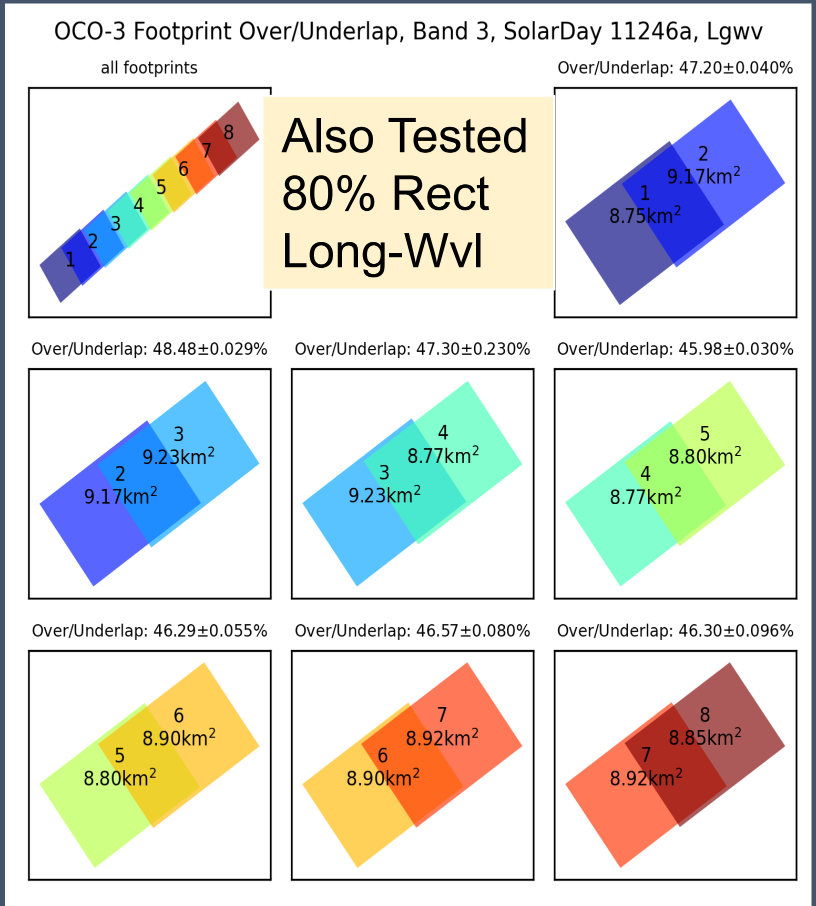
SCO2 Overlap Comparison







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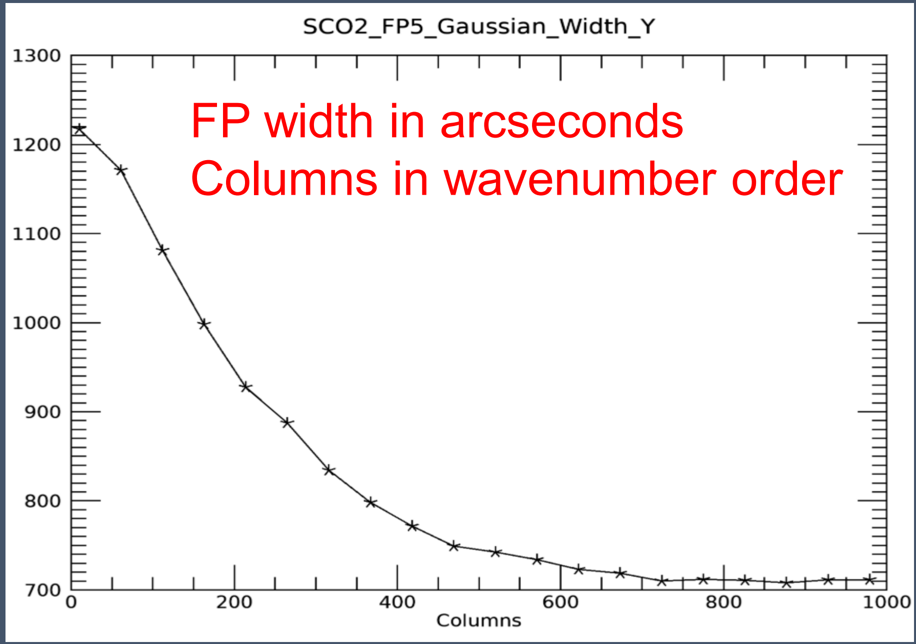
Conclusion

- Upcoming B11 will have more accurate FP vertices due to improved approach for calculating spatial response
- NL least squares optimized 80% rectangle instead of 2D gaussian, computed separately for spectral columns
  - Also determined for spatial rows, important for Lunar Cal
- ACOS Level 2 retrieval cannot easily account for in-band variations in along-slit width, used median column
  - Effectively no variation in centroids or cross-slit widths
  - Minor change in sounding selection, negligible change to XCO2



"You May Also Like":

- Fu et al., "Vicarious Calibration of Orbiting Carbon Observatory 2 and 3" (Session 7, 5:25 pm tomorrow)
- Keller et al., Inflight Radiometric Calibration and Performance of the Orbiting Carbon Observatory 3 (OCO-3) for Version 10 Products, Manuscript in Review, IEEE Transactions on Geoscience and Remote Sensing