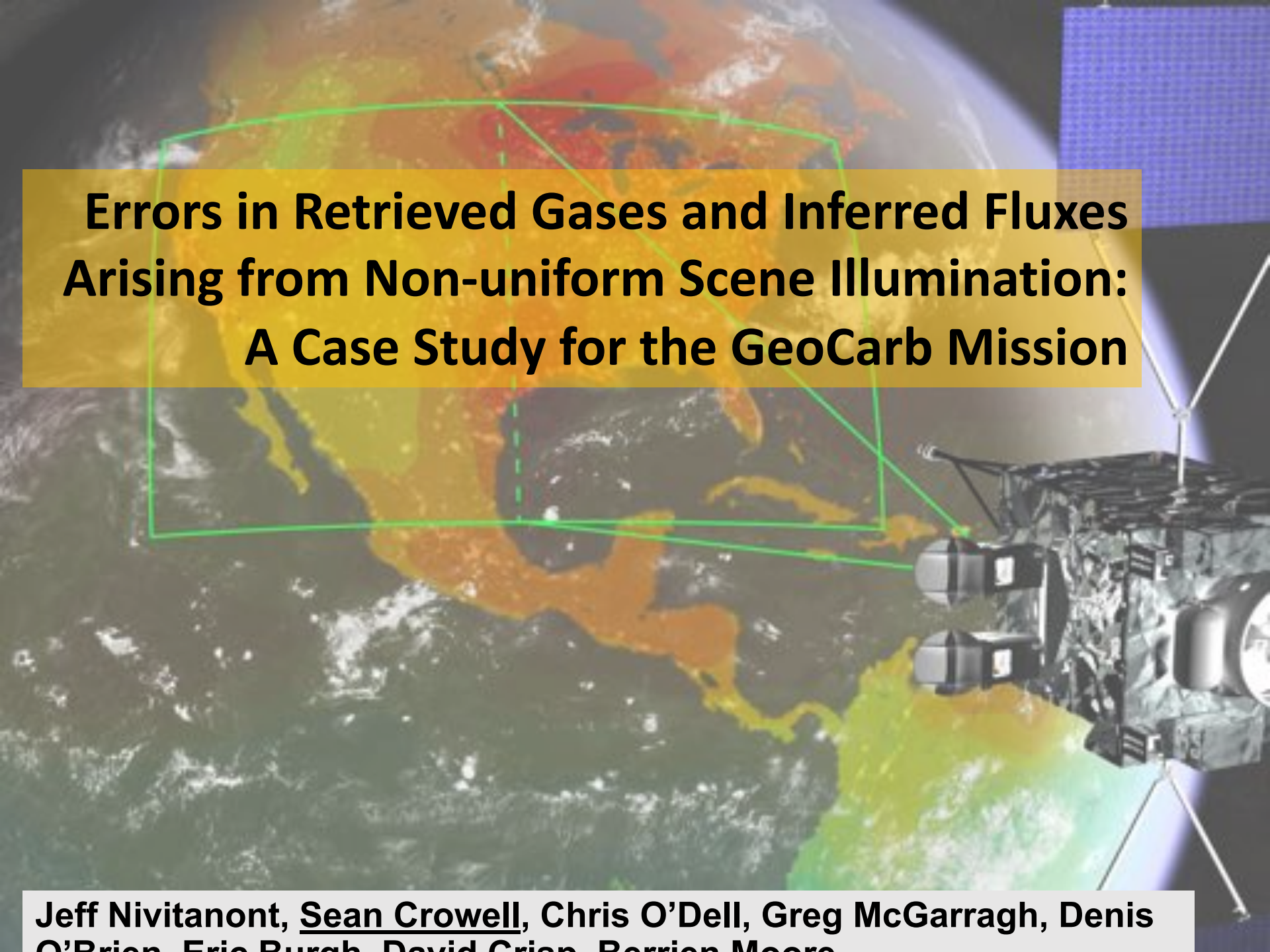
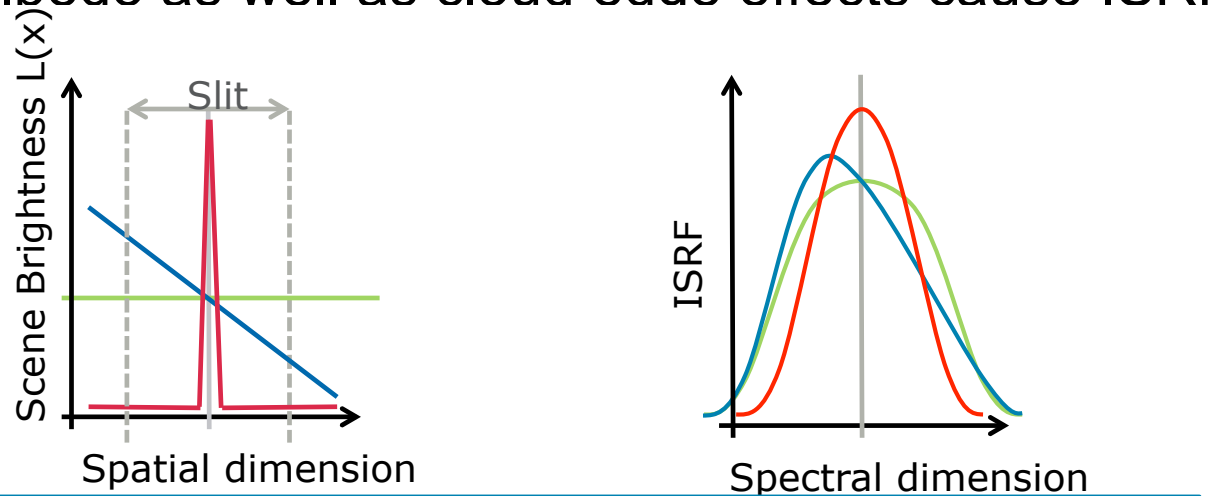


Errors in Retrieved Gases and Inferred Fluxes Arising from Non-uniform Scene Illumination: A Case Study for the GeoCarb Mission

Jeff Nivitanont, Sean Crowell, Chris O'Dell, Greg McGarragh, Denis O'Brien, Eric Burgh, David Crisp, Berrien Moore

Background

- Instrument Spectral Response Function (ISRF) is characterized pre-flight, and is part of the "forward operator" in trace gas retrievals
  - Characterization is done with a uniform illumination across the slit
  - ISRF is treated as "known" in retrievals, but errors in the ISRF are a cause of errors in retrieved column gas concentrations
- Scenes with brightness variations across the slit due to gradients in surface albedo as well as cloud edge effects cause ISRF errors



$$ISRF = [(L \otimes PSF_{telescope+motion\text{-}smear}) * \Pi_{slit}] \otimes PSF_{spectrometer+detector}$$

Example Study: TROPOMI

- TROPOMI studies XCO and XCH4 errors arising from brightness variations

Hu et al.: The operational methane retrieval algorithm for TROPOMI, Atmos. Meas. Tech., 9, 5423-5440, 2016

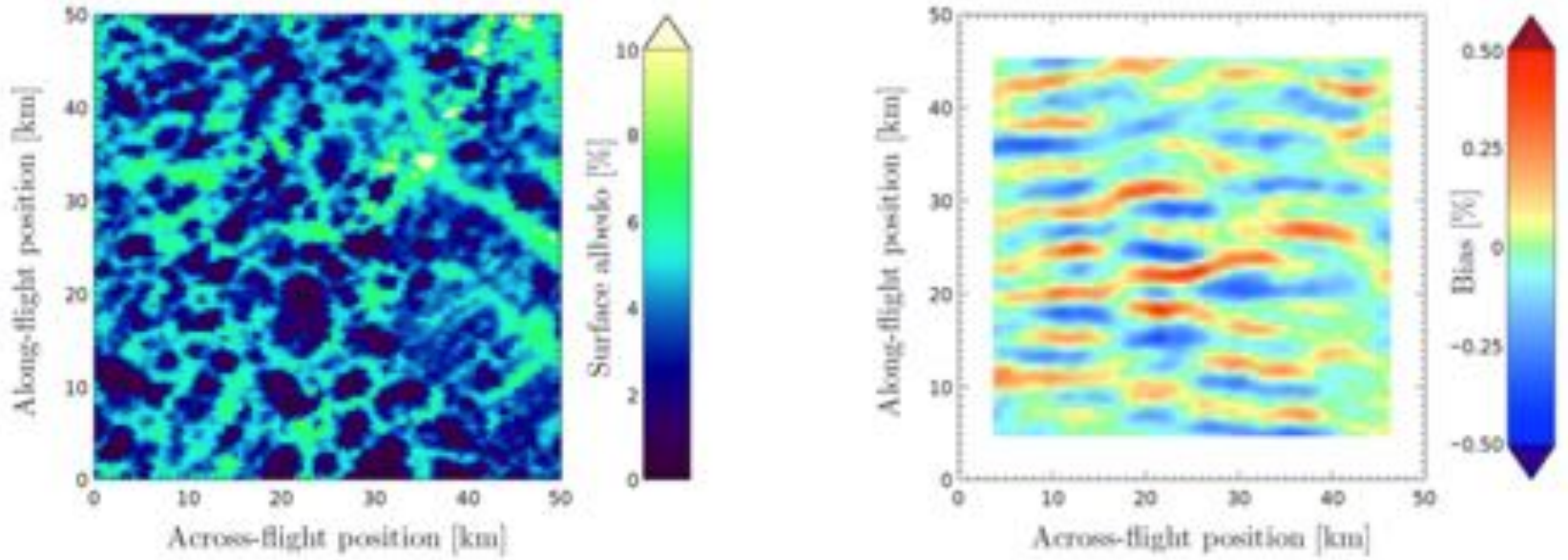


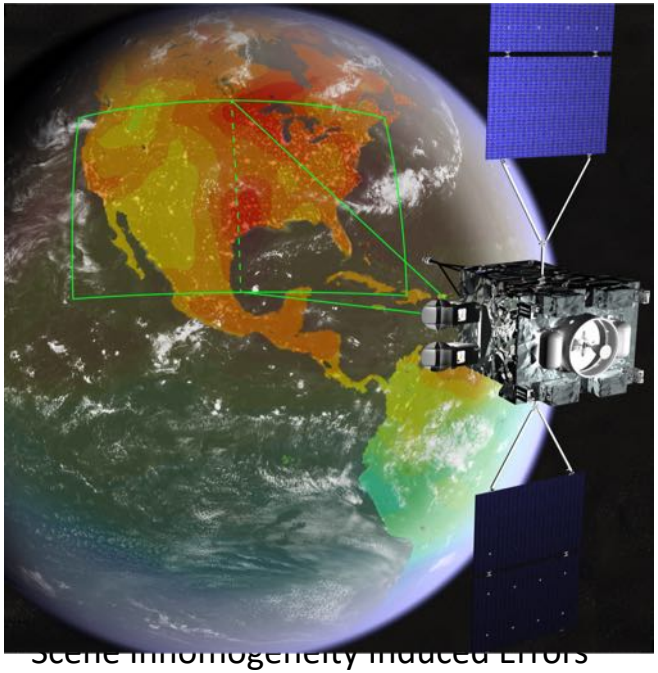
Fig. 8. Methane bias due to heterogenous slit illumination for spatially varying surface reflection over a marsh scene at Siberia close to the river Ob at latitude 62.8°N and longitude 72.1°E. Measurement simulations are performed with the instrument model by Landgraf (2016) for an instantaneous field of view of 3.4 km across the slit and 7.0 km along the slit.

- Simulation of XCH_4 retrievals over highly non-uniform scenes (Siberian swamps)
- Pseudo-random bias of +/- 0.4% (~ +/- 10 ppb XCH_4)
- Averages out over larger areas (~ 100 x 100 km)
- Would be super-imposed over maps of point sources
- Impact on XCO_2 to be studied…

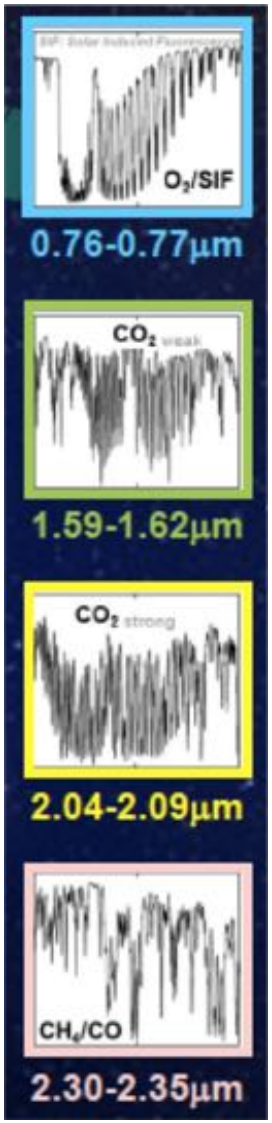
The GeoCarb Mission:

Measuring Carbon Trace Gases and Vegetation Health from Geostationary Orbit

- GeoCarb will return observations of XCO2, XCO, XCH4, and SIF with a spatial resolution of 3km N-S by 6km E-W at nadir
- "Step and stare" observing mode along a slit ~3000km N-S in length every 9 seconds
- Flexible observing sequence allows GeoCarb to plan for seasonal variations in cloud cover, intensive campaigns



Instrument	Single slit, 4-Channel IR Scanning Littrow Spectrometer
Bands	0.76μm, 1.61μm, 2.06μm and 2.32μm
Measurements	O_2, CO_2, CO, CH_4 & Solar Induced Fluorescence
Mass	155 kg (CBE)
Dimension	1.3 m x 1.14 m x 1.3 m
Power	400W (CBE)
Data Rate	10 Mbps
Daily Soundings	~4,000,000 soundings per day



Solar Induced Fluorescence, O_2, Clouds, Aerosol

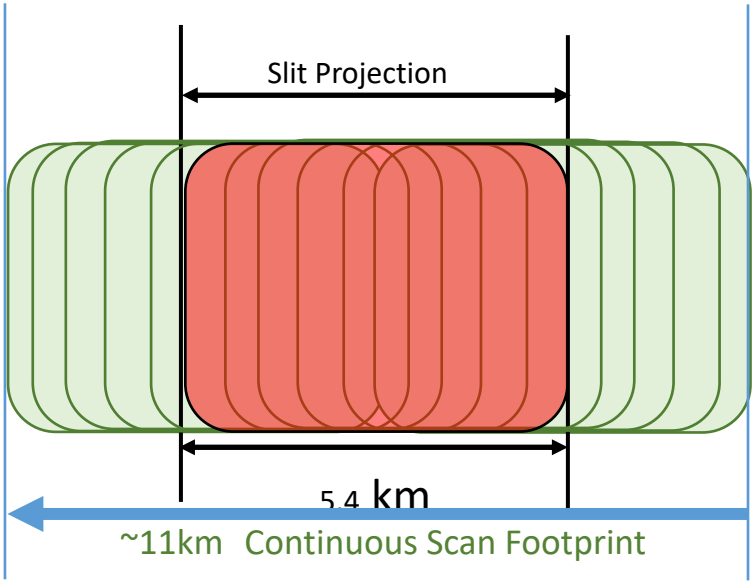
CO_2

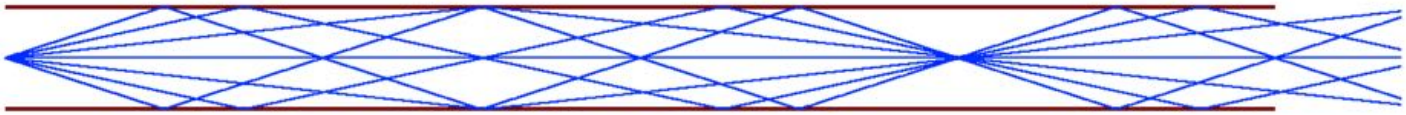
CO_2, H_2O, Clouds, Aerosol

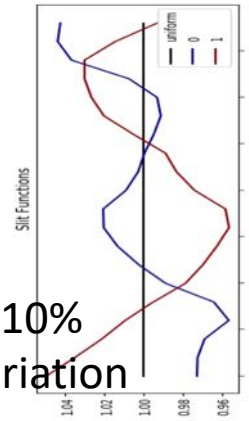
CH_4, CO, H_2O

Mitigation Approaches

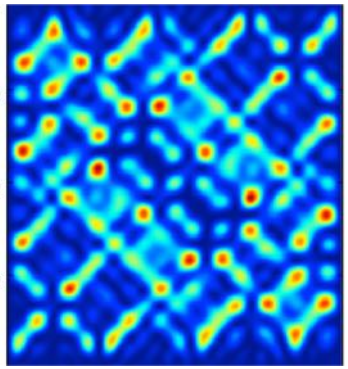
- One mitigation is to scan across the slit, effectively "blurring" the sharp gradients in brightness
- Another is to employ a "slit homogenizer": a hardware solution that scrambles the direction of the incoming light and removes the gradients across the slit

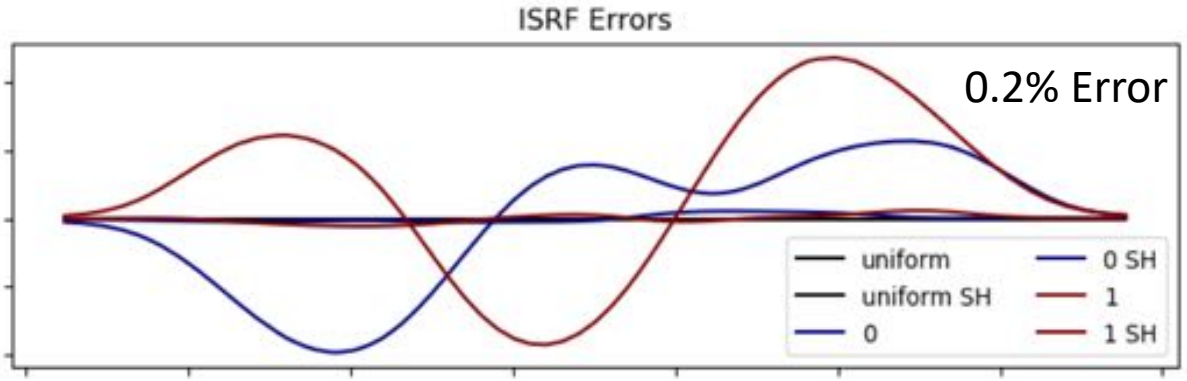




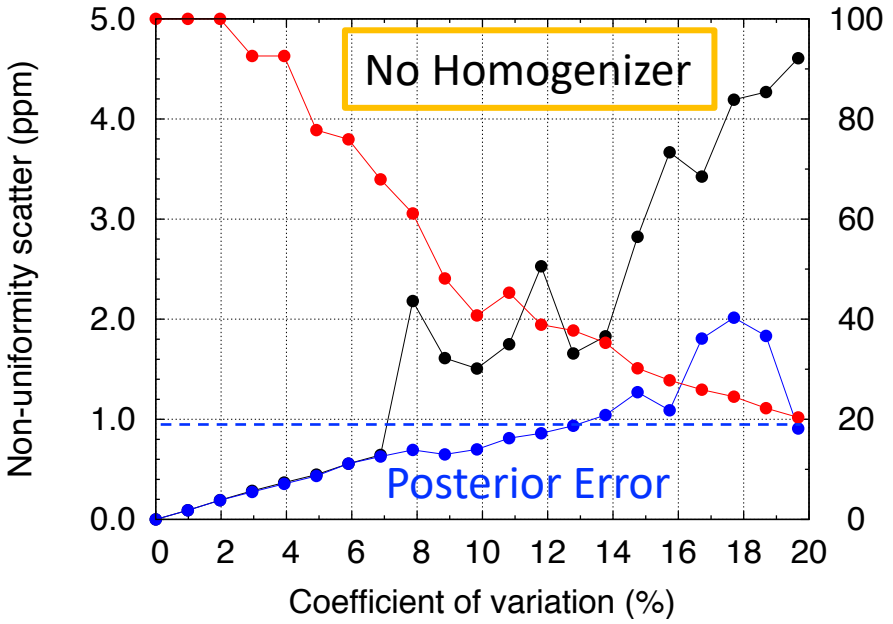


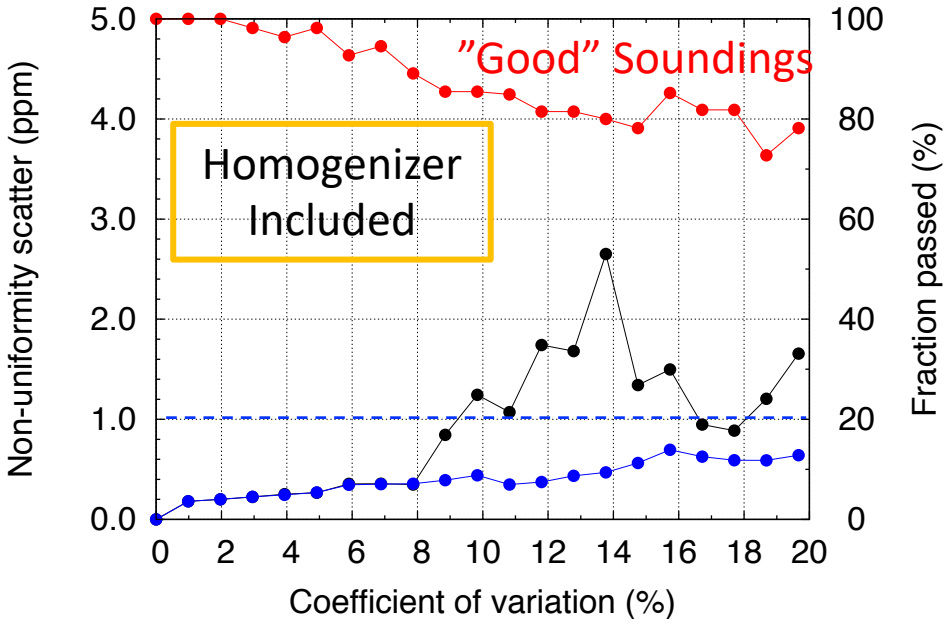
10% Variation

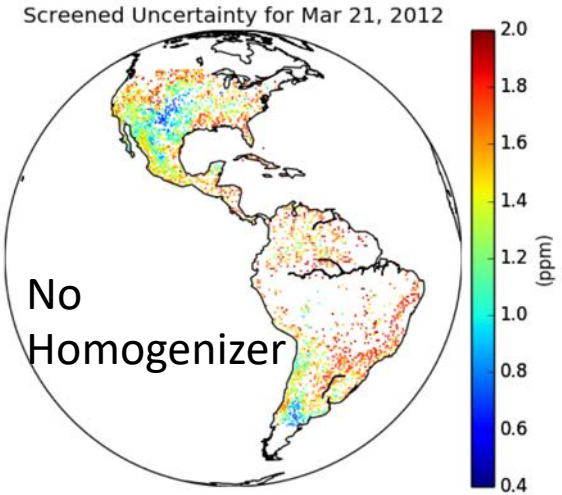


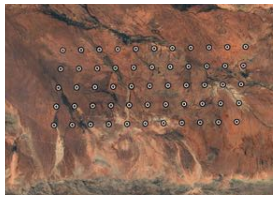


Trace Gas Errors as a Function of CoV

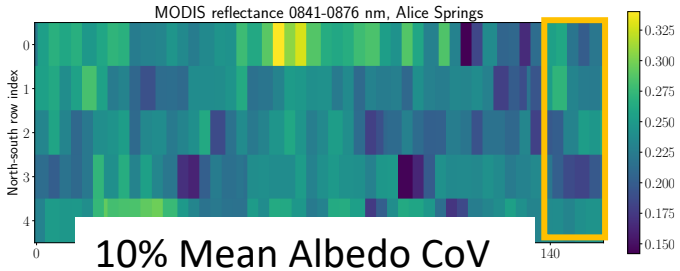




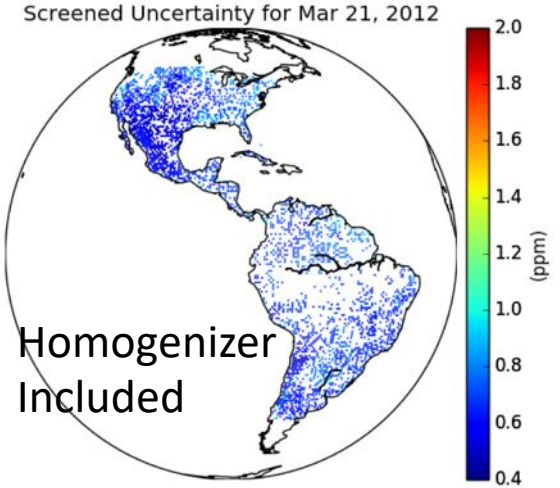




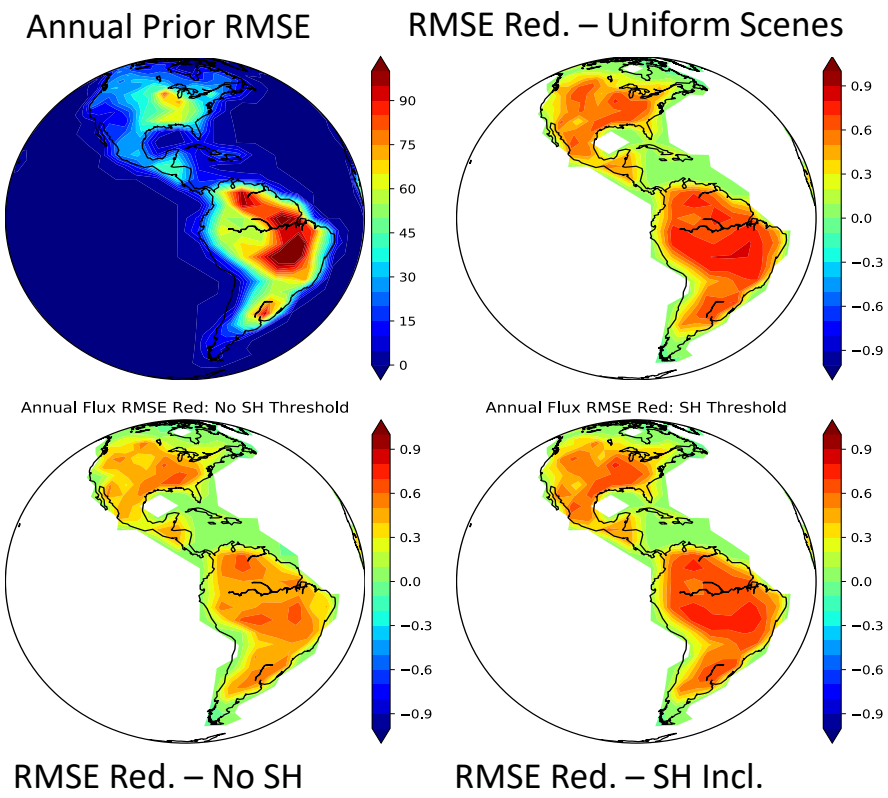
McDonnell Range near Alice Springs



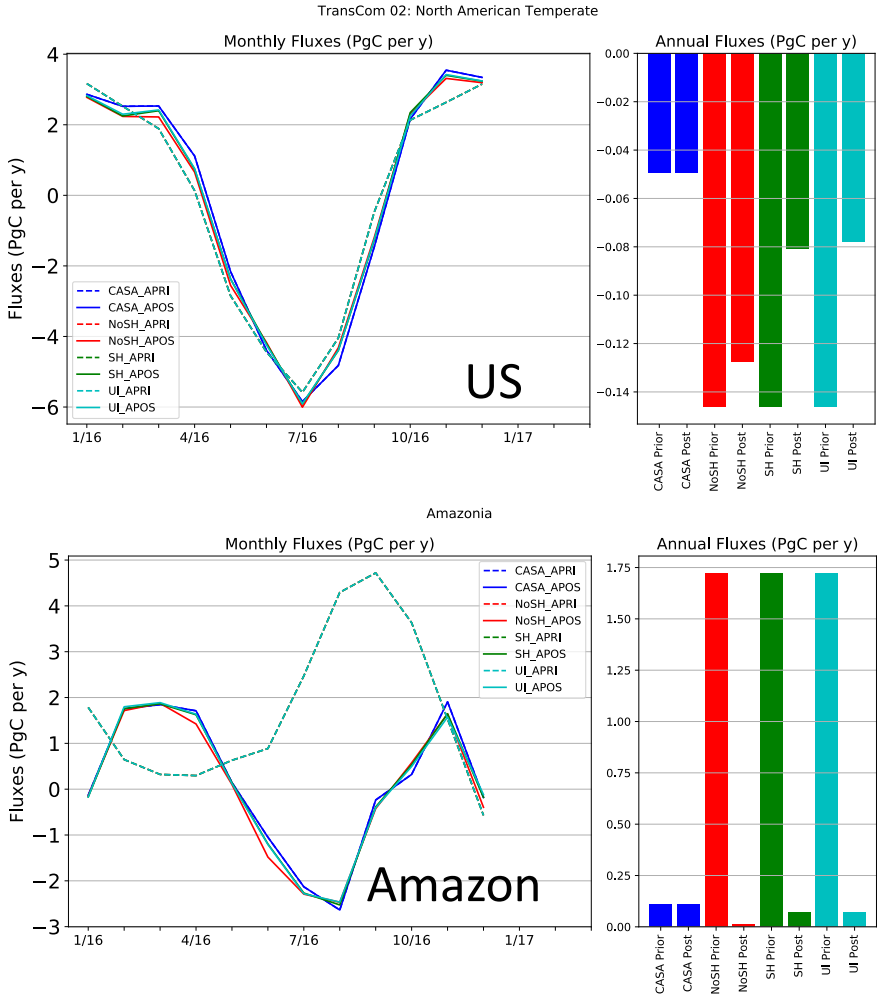
10% Mean Albedo CoV



Both Concepts Constrain Regional Fluxes



- GeoCarb will be able to constrain <u>regional</u> fluxes even in the absence of a slit homogenizer due to the <u>persistent daily coverage</u>



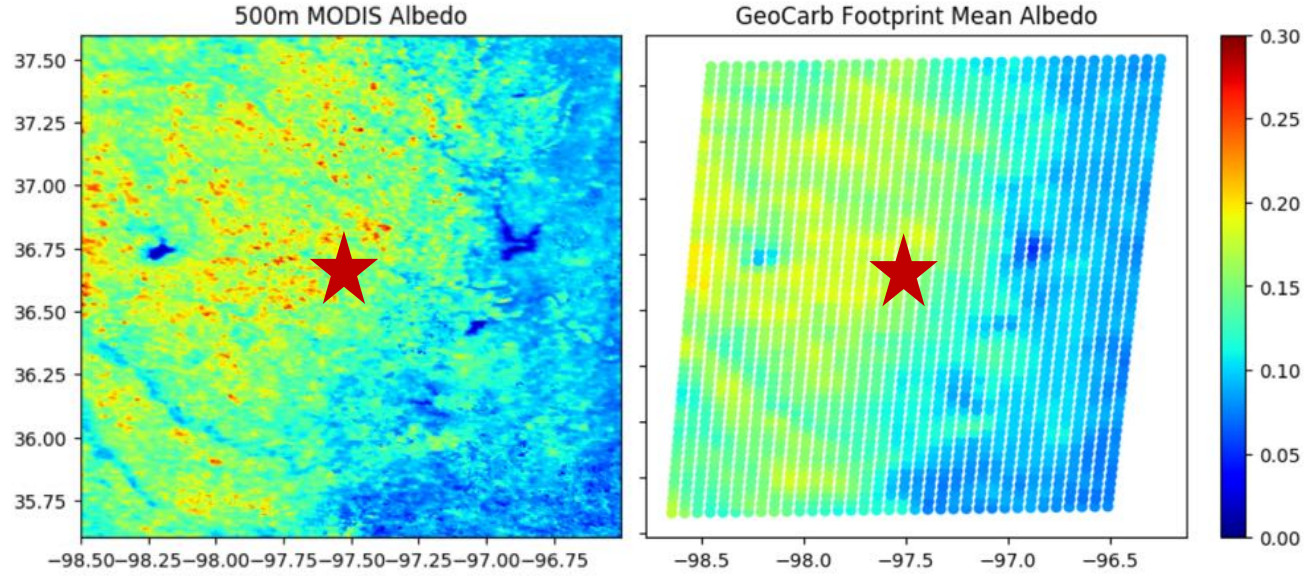
Truth Homogeneous scene

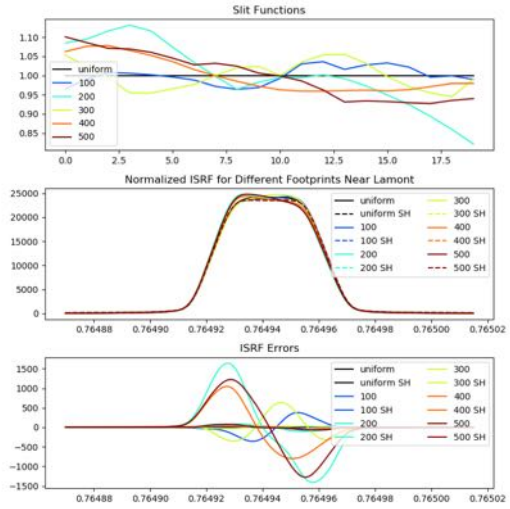
No SH SH included

Comments

- The slit homogenizer reduces scatter in our parametric approach – this suggests an increased ability to
  - Remove systematic errors more effectively (visible above the noise)
  - Constrain surface fluxes on smaller spatial and temporal scales
- Even without the homogenizer, we are able to constrain regional scale fluxes well, assuming
  - No systematic errors, and
  - No transport errors
- What about spatially coherent errors? These are the limiting factor in terms of constraining fluxes.

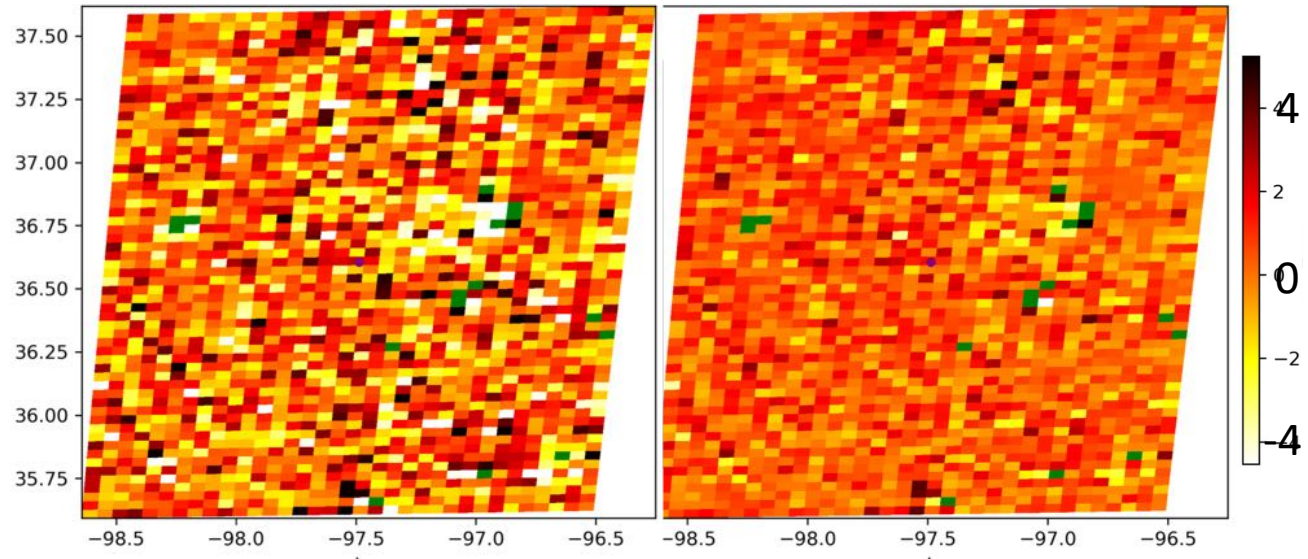
Lamont, Oklahoma Study

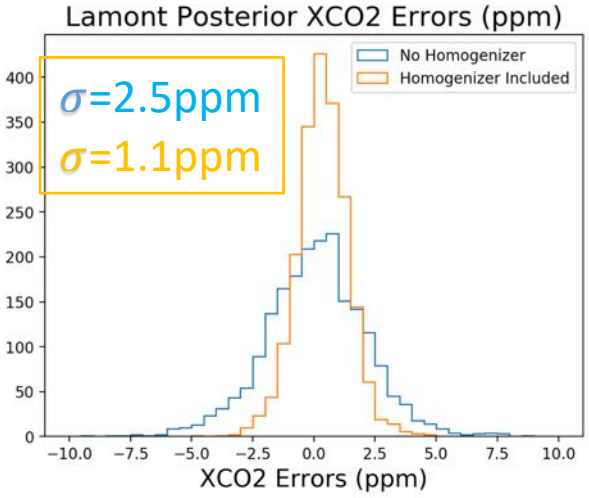




XCO2 Errors: No Homogenizer

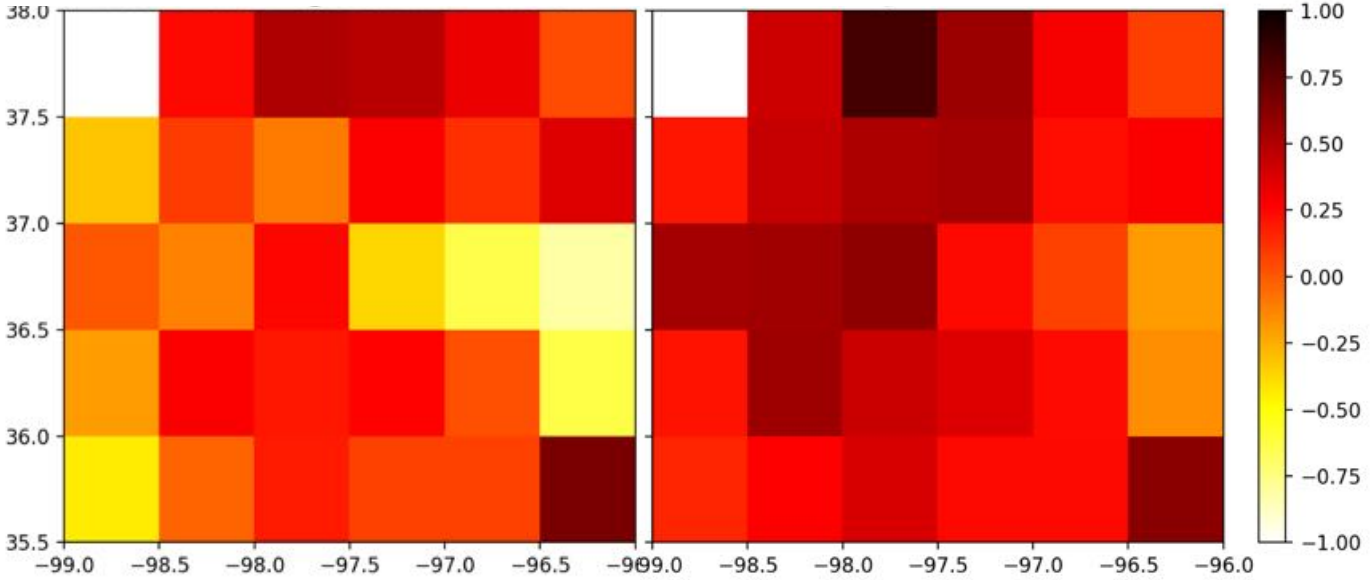
Homogenizer Included

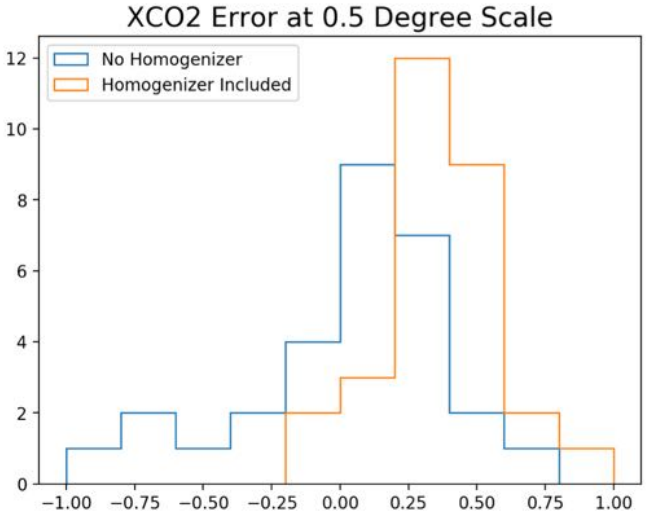




How Do Errors Reduce With Averaging?

XCO2 Errors: No Homogenizer Homogenizer Included





- Scatter Reduces for Both
- Homogenizer reduces outliers, but has a slight high bias – looking for covariates
- Expect this to be highly scene dependent – exploring other times of year as well as scenes in the Amazon

Summary

- Non-uniform illumination leads to errors that are important to characterize
  - Increased Scatter in Trace Gas Retrievals
  - Local effects may be tough to detect
- Errors can (and should) be mitigated with a slit homogenizer
  - 1-D Version is a simple piece of hardware that is well understood
  - 2-D Version is under development for the next generation of imagers
- Bias can be coherent on smaller spatial scales due to persistent albedo gradients – the slit homogenizer seems to remove these effects
- Future work: expand the analysis to include aerosol scattering as well as more challenging scenes