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Updated Performance Simulations for a Space-Based CO_2 Lidar Mission

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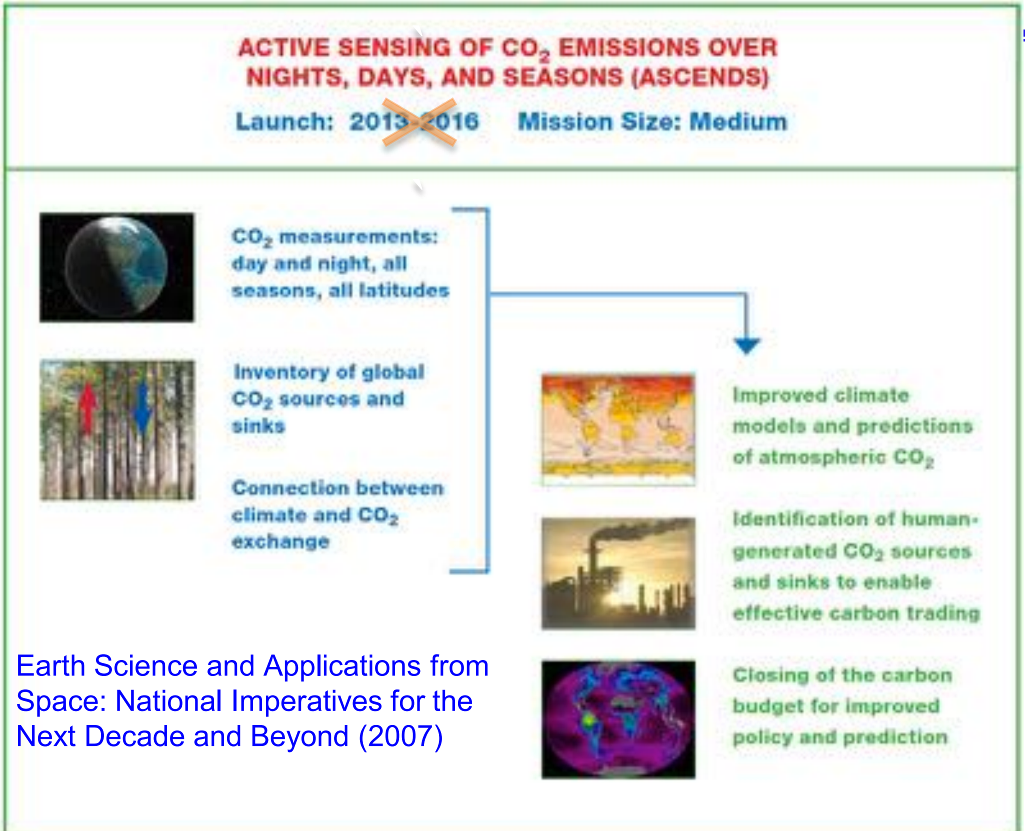
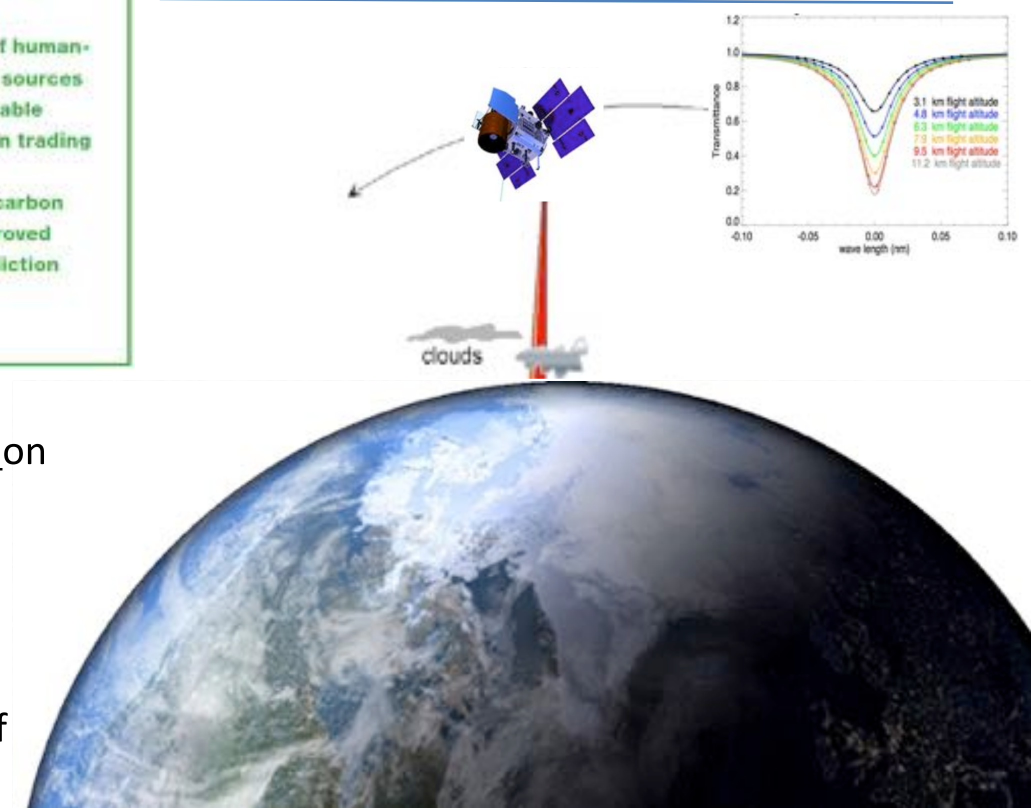
- Motivation and Overview
- Mission Simulation
- Random Error Estimates
- Toward Level I Requirements
- Summary

ASCENDS



Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (2007)

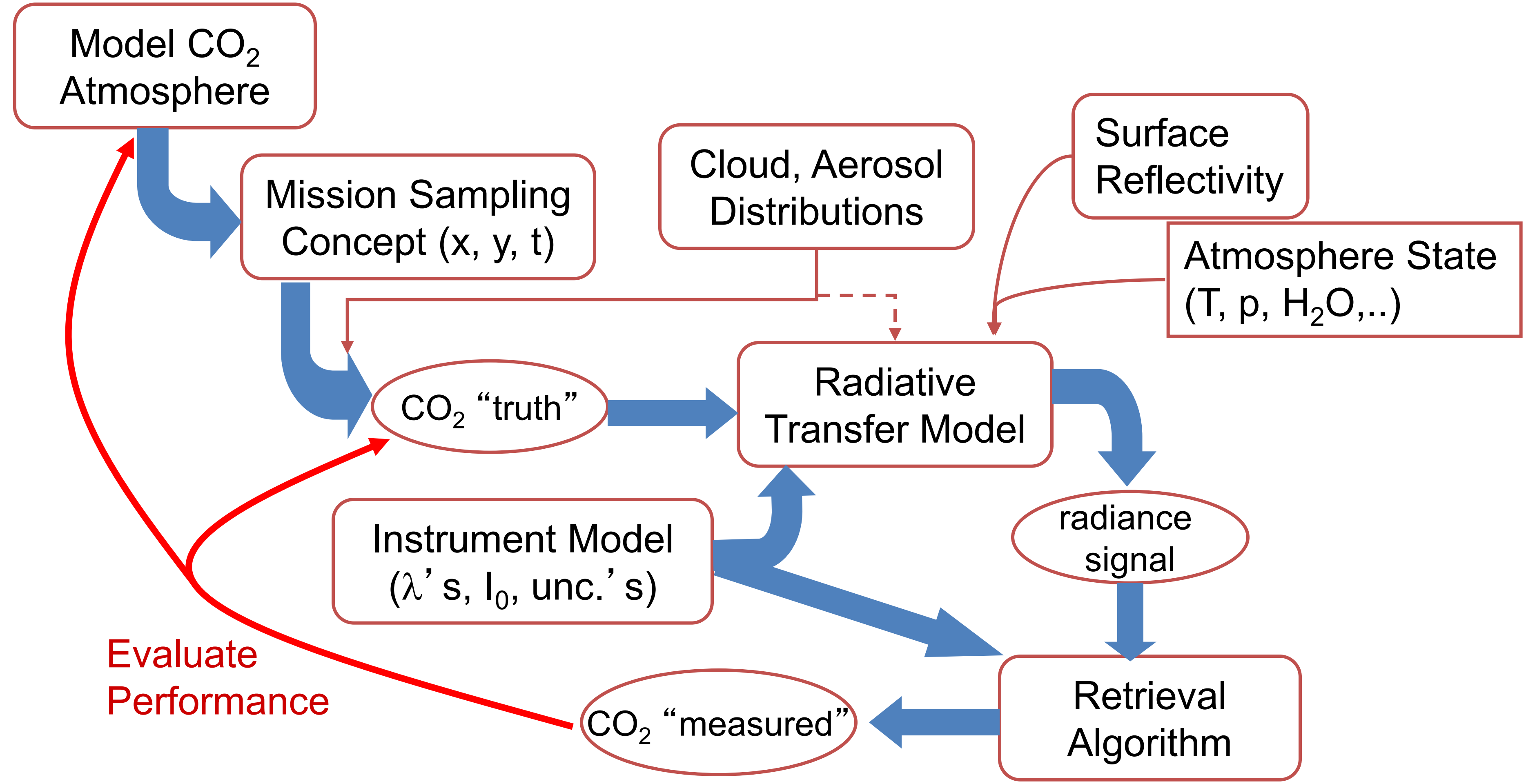
Space-based Lidar for Atmospheric CO_2



Science Objectives:

1. Quantify global distribution of atmospheric CO_2 on scales of weather models in the 2010-2020 era
2. Quantify global distribution of terrestrial and oceanic sources and sinks of CO_2 on 1° grids weekly
3. Provide a scientific basis for future projections of CO_2 sources and sinks through data-driven

Mission Simulation Overview



➔ Test sensitivity of inferred CO_2 distributions to varying mission and instrument design parameters (Kawa et al., Tellus-B, 2010).

Orbit Sampling and Cloud Data

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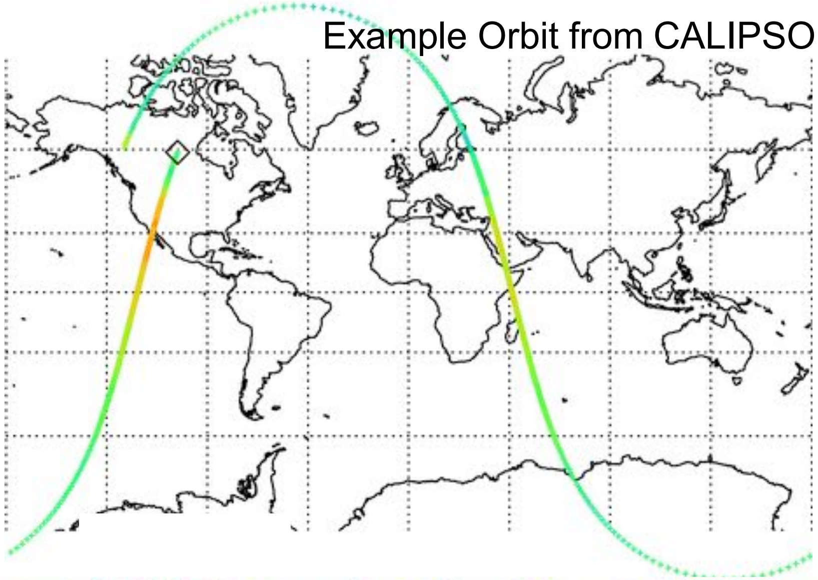
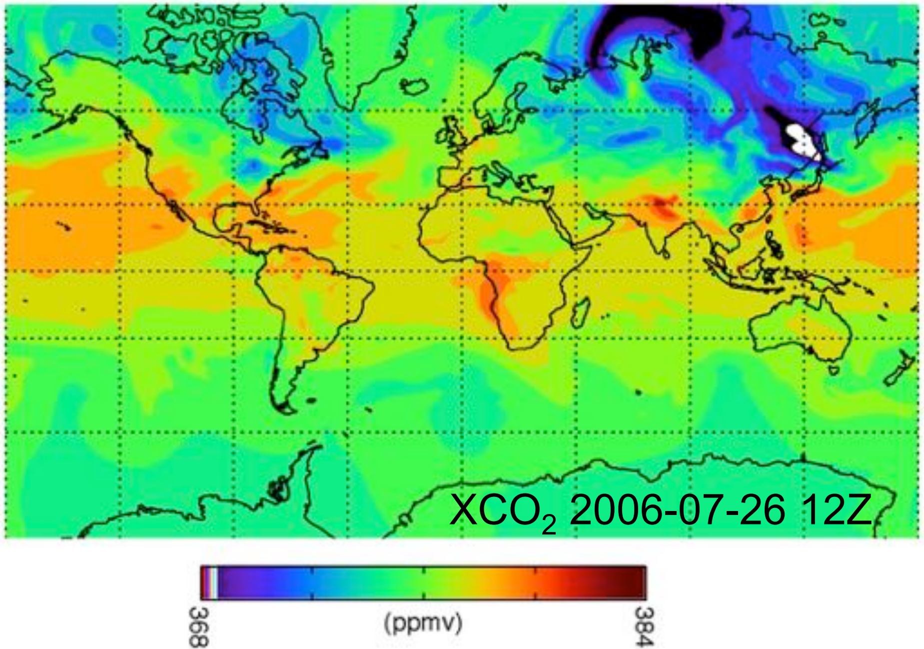
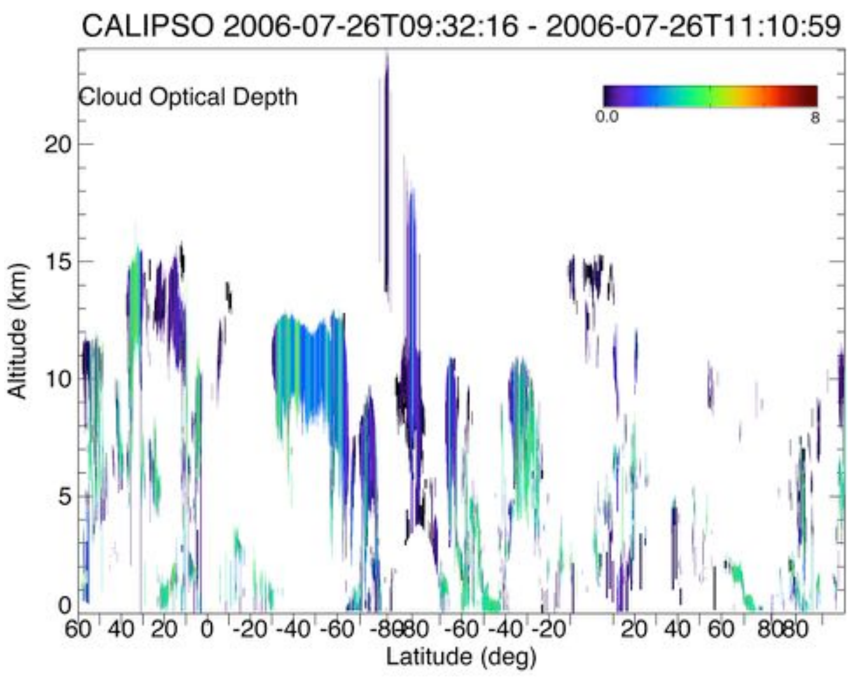
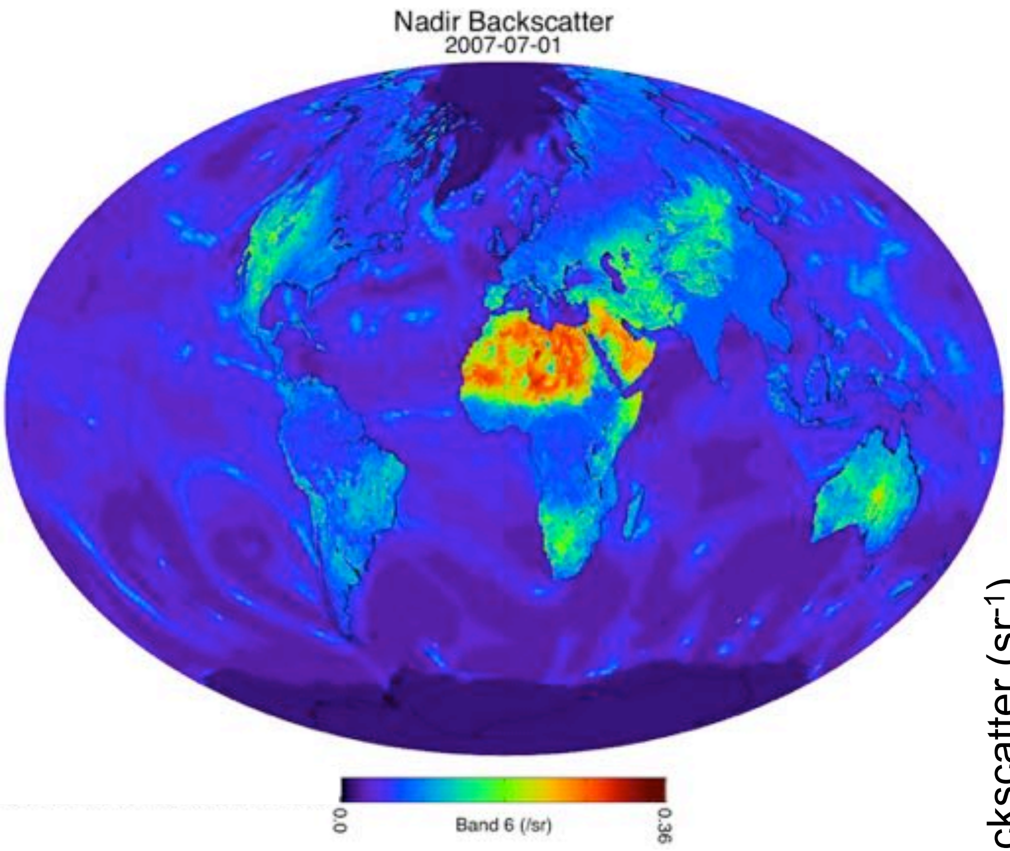


- CALIPSO orbit defines sampling
- Model driven by MERRA meteorology provides realistic distribution of CO_2 ($1^o \times 1.25^o \times 56$ levels, hourly)
- Measured cloud plus aerosol optical depth used to attenuate laser radiances
  - samples with optical depth > 1 are screened (~50% accepted)

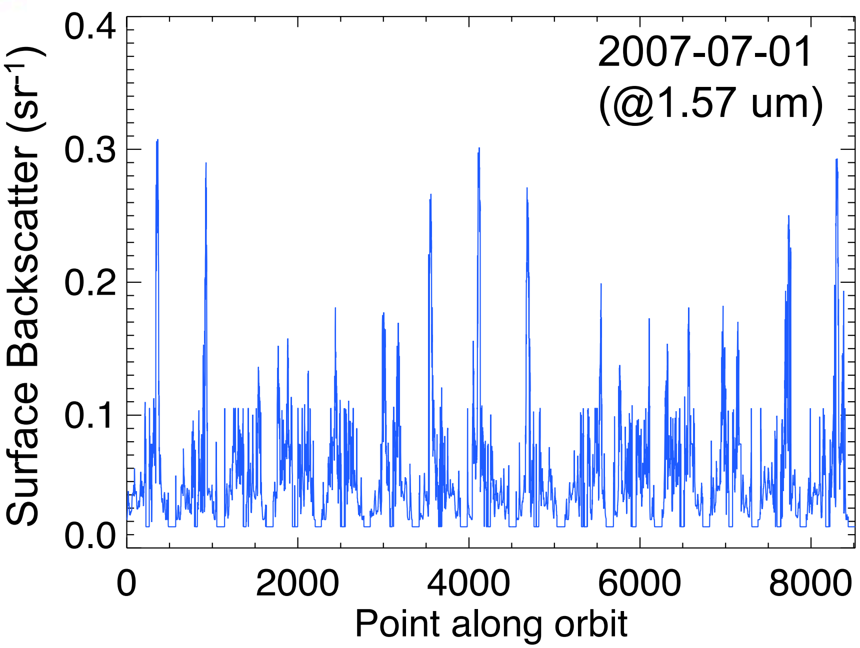




Surface Reflectance, Backscatter



- MODIS 16-d composite nadir reflectance over land
  - ‘hot spot’ enhancement
- Ice, snow default reflectance (updated)
- Ocean glint nadir backscatter from 10-m analyzed wind speed



in conjunction with ASCENDS definition team

Measurement Noise Model

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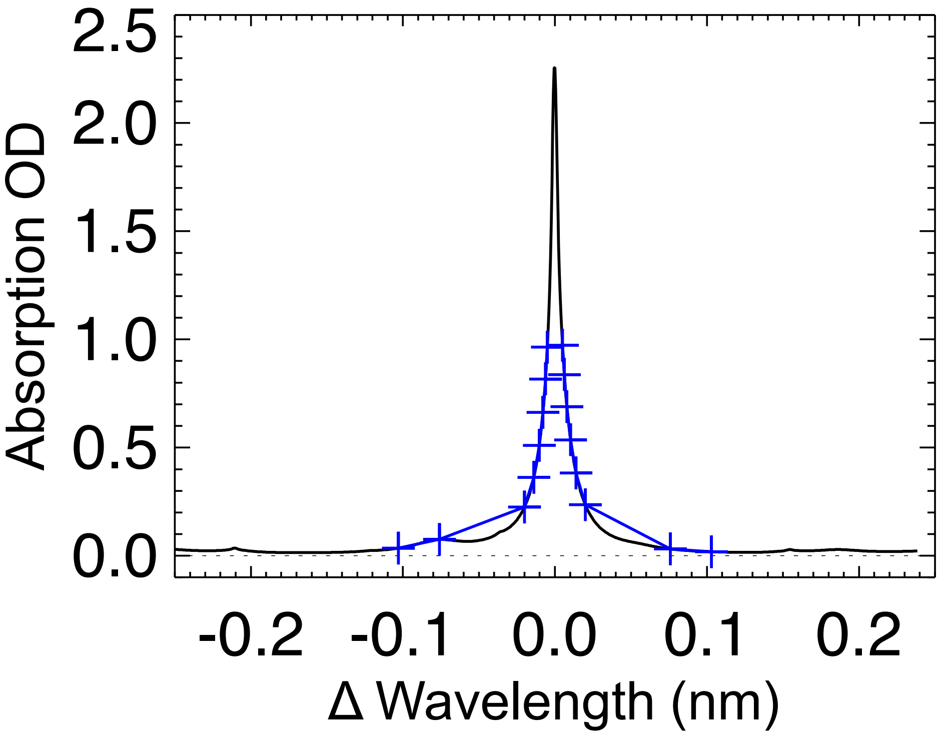
Lidar Instrument Model Specifications

Design Parameter	Value
Orbital Altitude	450 km
Laser Peak Power	2700 W
Laser Pulse Width	1 μs
Laser Pulse Rate (all wavelengths)	7500 Hz
CO_2 line center wavelength	1572.33 nm
Receiver Telescope Diameter	1.5 m
Telescope and Receiver Transmission	0.5
Receiver optical bandwidth	0.4 nm
Detector Efficiency	68%
Measurement Integration Time	10 s

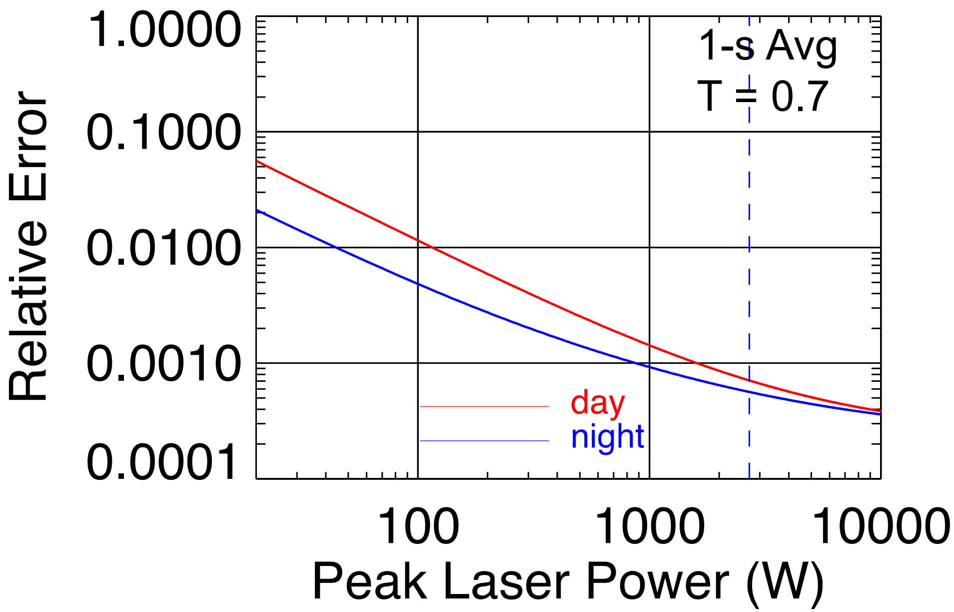
- Instrument parameters all readily achievable
- Laser transmitter in lab tests for TRL
- Verified in airborne simulator tests

Major Improvements

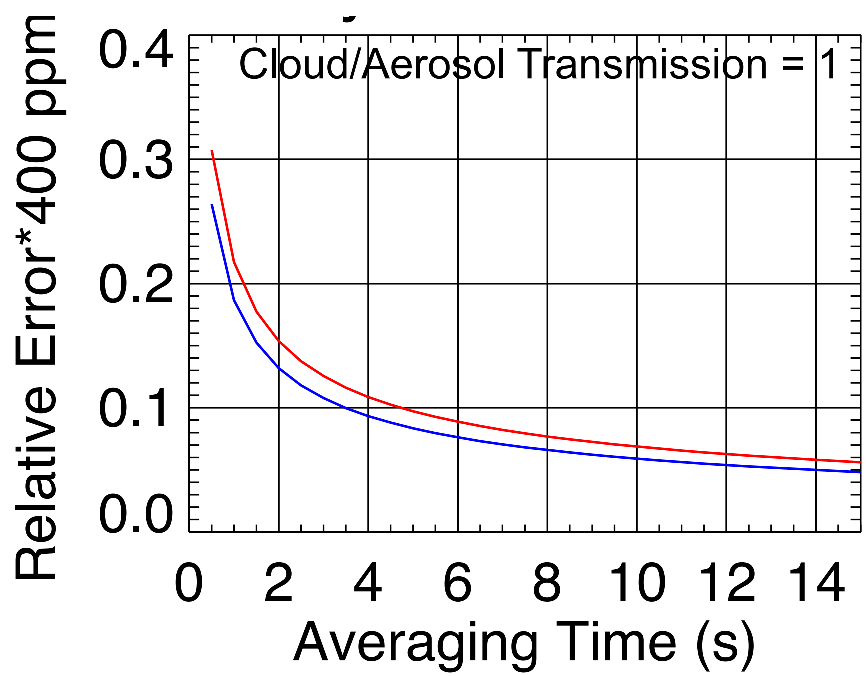
- Detector efficiency
- Faster laser pulse rate
- Linear least-squares fitting optical depth across 16 points



Random Error Characteristics

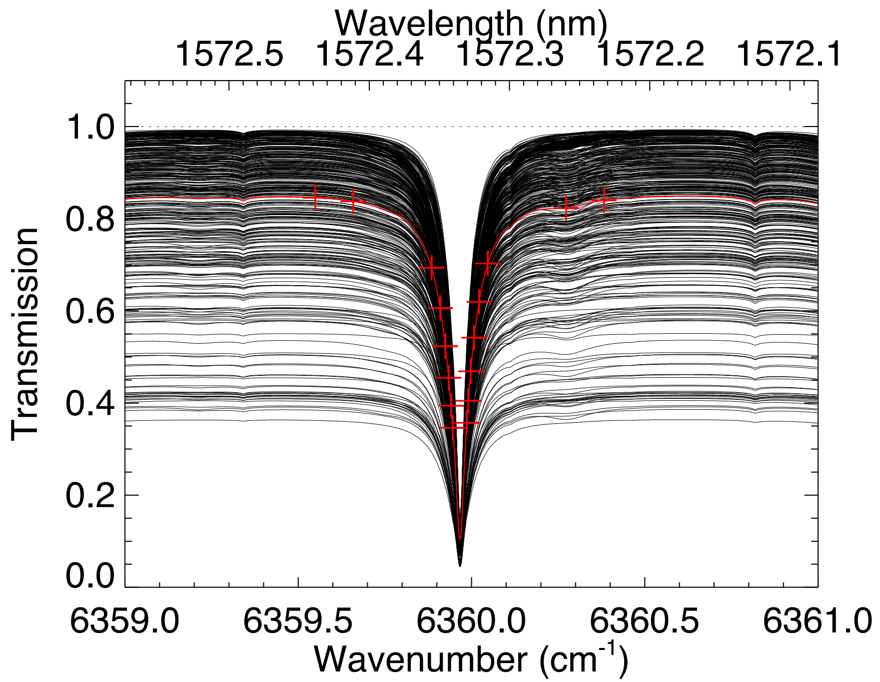


- Consider shorter nominal averaging times (50 Hz reported)
- Cloud slicing, partly cloudy scenes retrievals more feasible
- Take another look at detecting diurnal differences in XCO_2



- Random errors from photon counting noise become near-negligible
- Other error sources now dominate

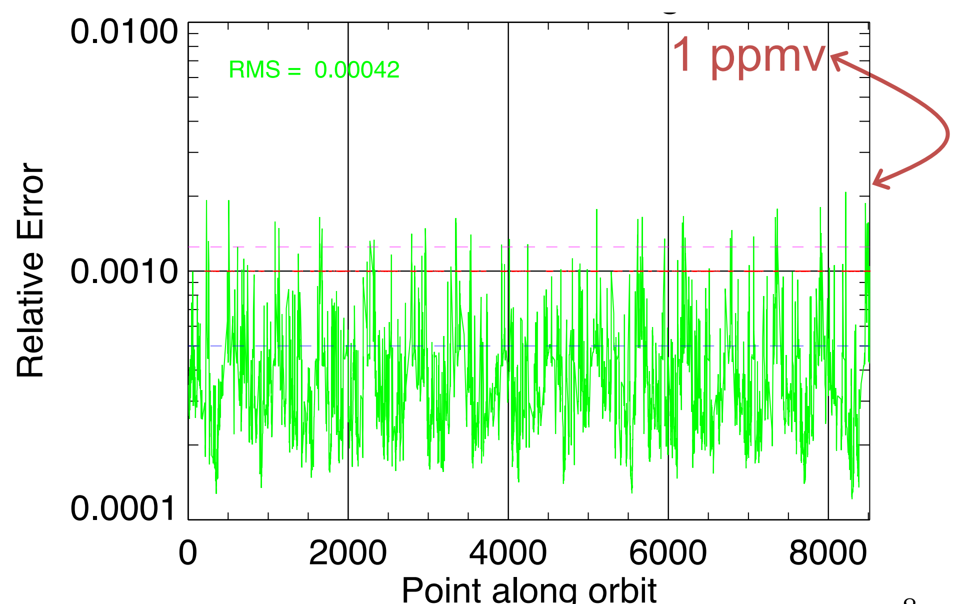
Global Error Distribution



- Forward model transmission calculated for each profile sample.
- Most variability results from cloud attenuation.
- Average spectrum and candidate laser measurement wavelengths in red.

Simplified Retrieval:

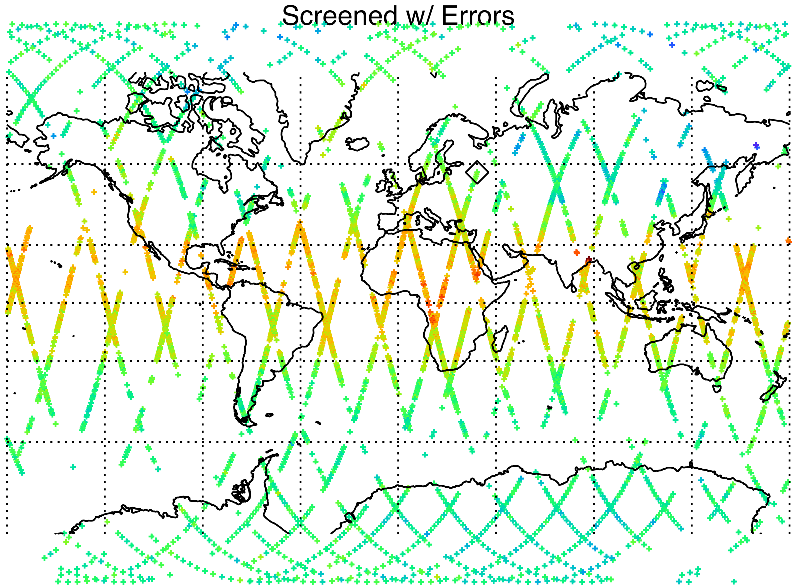
XCO_2 error equals relative error in fitted optical depth plus uncorrelated error in surface pressure plus minor terms.

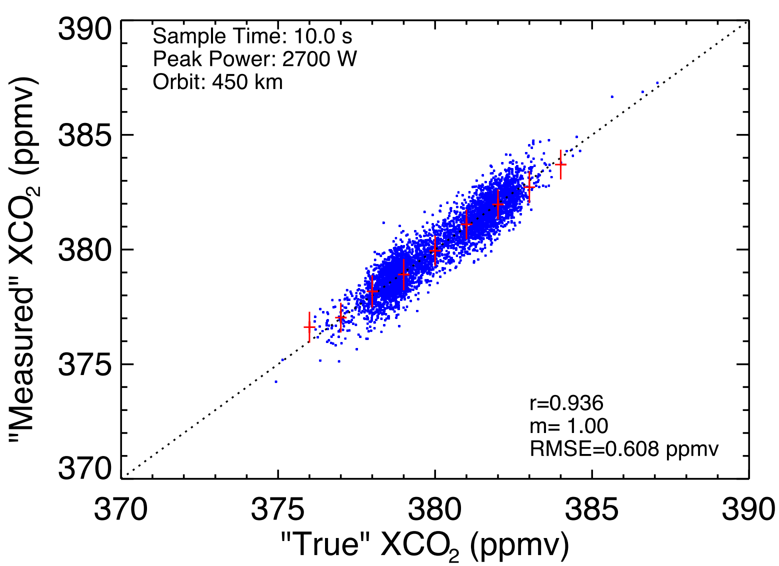


Error Budget

Error Term	Current Form	Next Level
Random Error	f (cld + aerosol OD, β, CO_2, λ, instr. spec)	✔
Solar Background	f (SZA, instrument)	✔
Representation	(0.05 + 0.1)%	Fine-scale model, a/c data
Surface Pressure/Airmass	1.25 mbar	f (met analyses)
State Error (T, H_2O)	Incl. in surface pressure error	Impose δT, δH_2O in 'retrieval'
Instrument Bias	none	f (instrument, measurement state)
Spectroscopy	none	Line shape, mixing, …

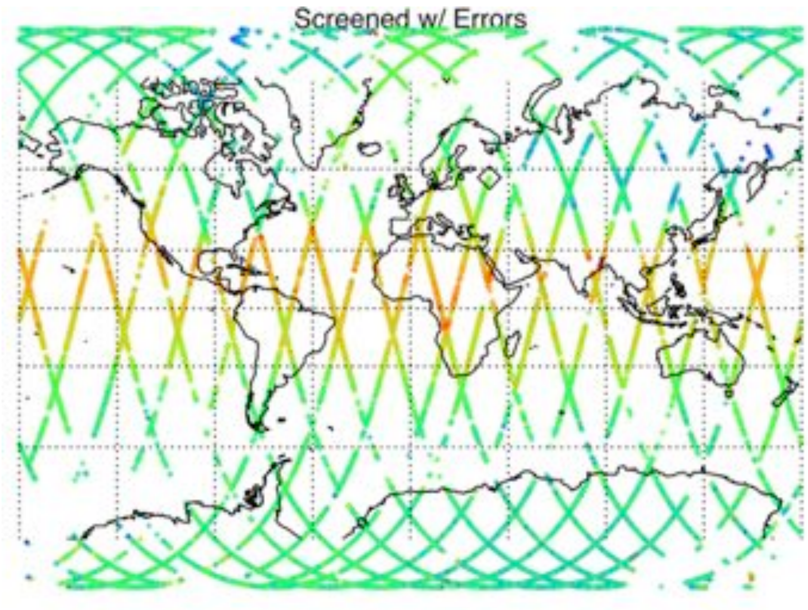
Design Point Error Estimate

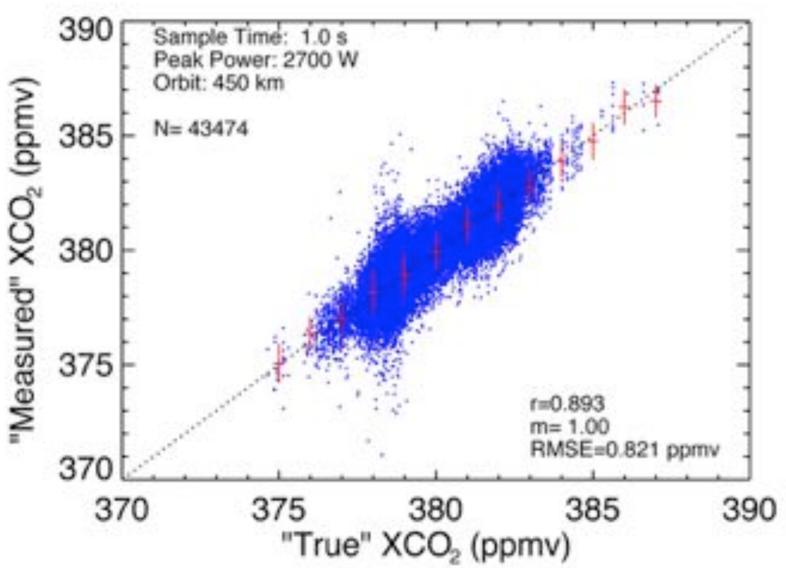




- Single-sample errors average 0.6 ppmv for this instrument configuration (10-s avg).
- Exceeds ASCENDS measurement requirements.

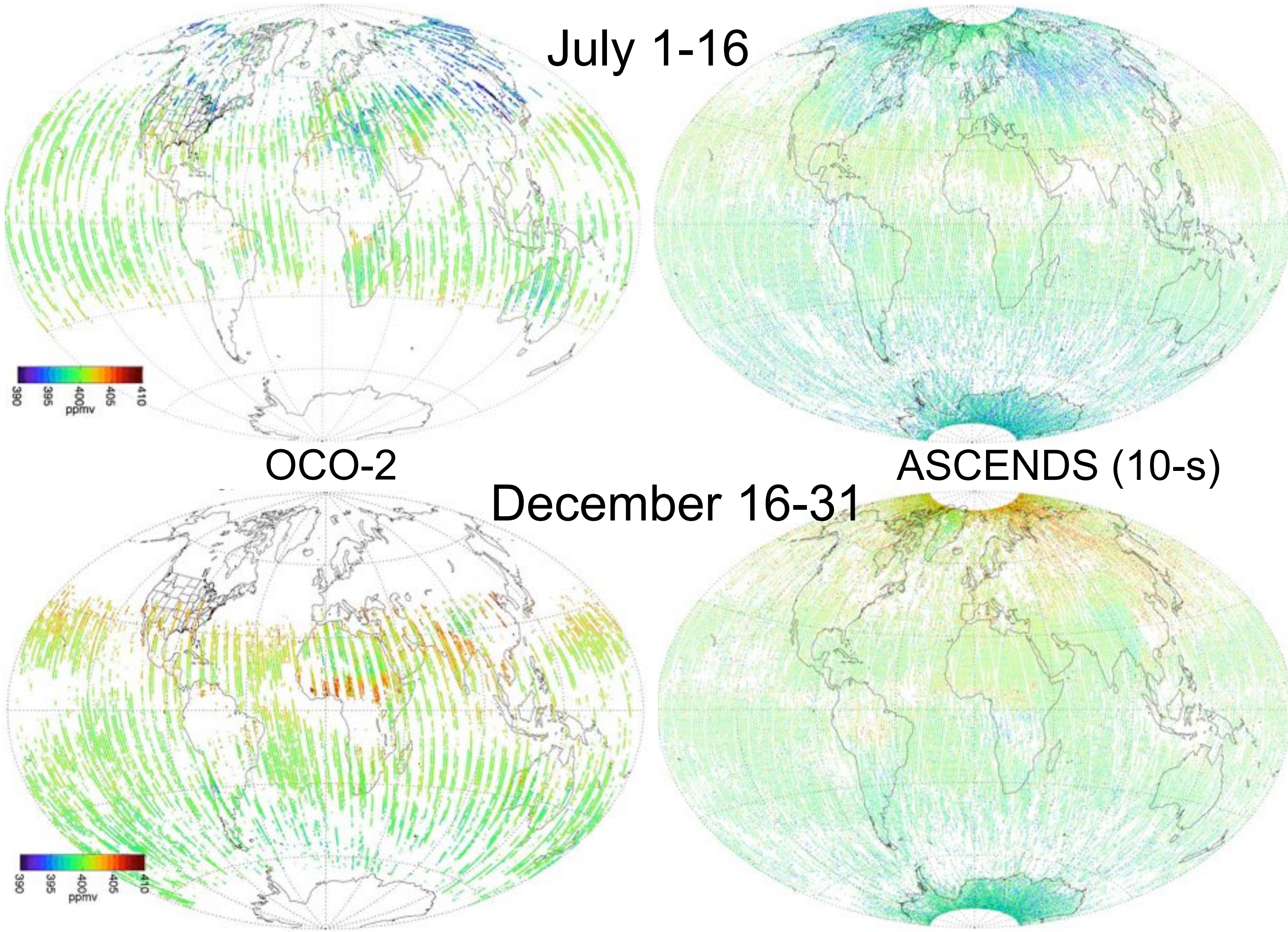
Design Point Error Estimate





- Single-sample errors average ~0.8 ppmv for this instrument configuration (1s avg).
- Meets ASCENDS requirements with enhanced spatial resolution.

Sample Coverage



Sample/Error Distributions

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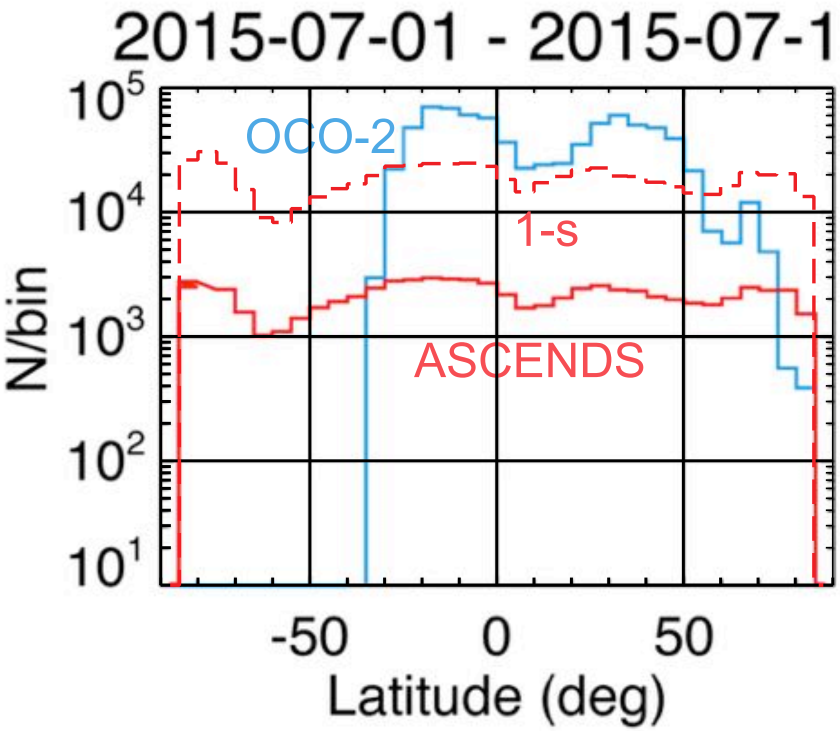
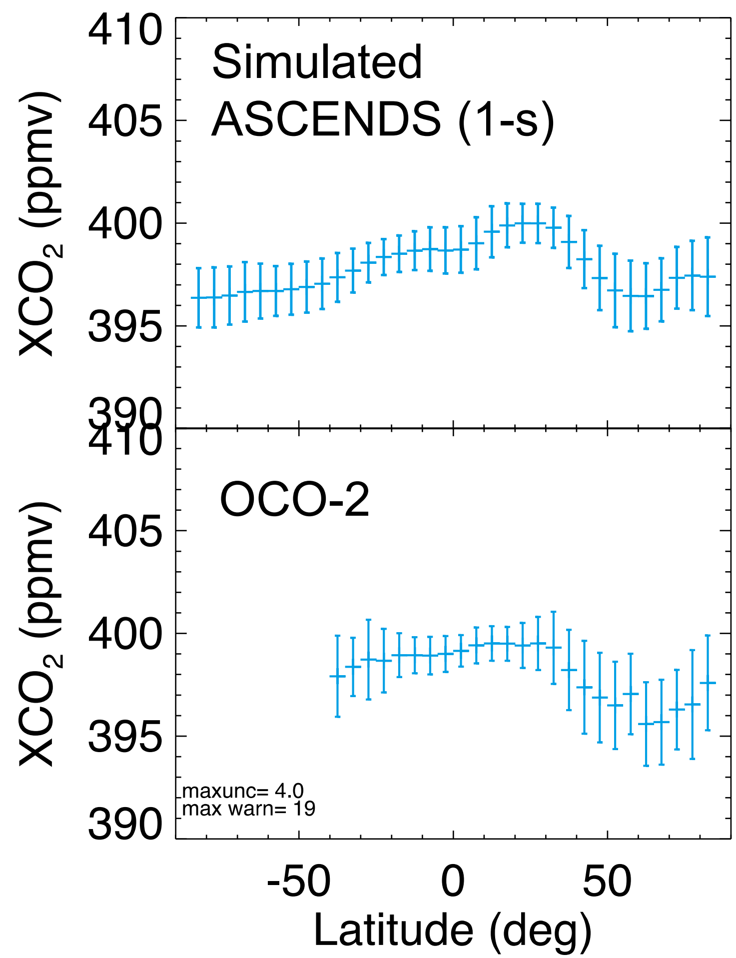
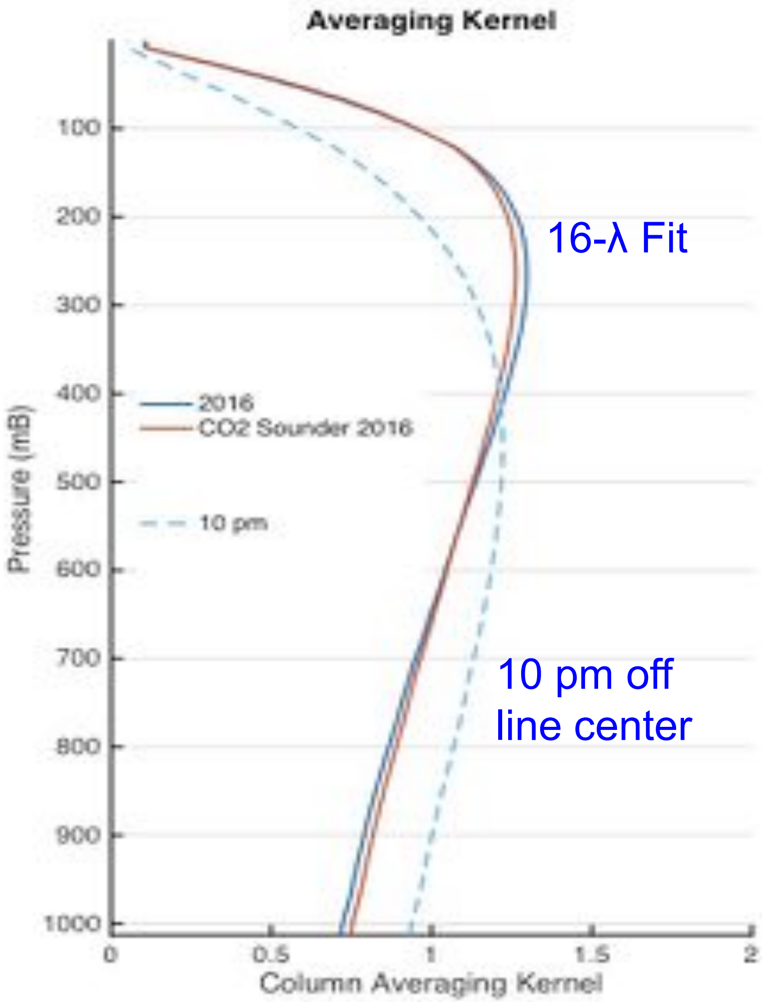


- ASCENDS will greatly improve sampling at high latitudes and in cloudy regions
- Total number of samples and random error levels can be comparable to OCO-2
- Expect reduced bias errors



Vertical Weighting Functions



$$XCO_2 = \int X_p \, WF \, dp \, / \int WF \, dp$$

- Minimum variance OD fitting shifts WF higher relative to 2-λ solution.

  - Optimize wavelength sample distribution/weighting to enhance WF.

  - Optimize for 2 pieces of info in vertical?

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Summary

- Updated instrument model and pulsed multi-wavelength fitting approach for ASCENDS simulator produce much-reduced random error estimates
  - other error sources dominate photon measurement uncertainty
  - current instrument design point exceeds ASCENDS performance requirements from Decadal Survey
  - revisit L1 measurement requirements

Next Steps

- Evaluate retrieval errors
- Incorporate bias distributions
- Include errors in knowledge of atmospheric state
- Test in inverse model(s) for source/sink uncertainties
  - including cloud-top retrieval samples

Acknowledgements

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