Measuring Carbon Dioxide from Space Using Lidar: An Update from the NASA ASCENDS Science Definition Team

S. R. Kawa, J. B. Abshire, D. F. Baker, E. V. Browell, A. Chatterjee, D. Crisp,
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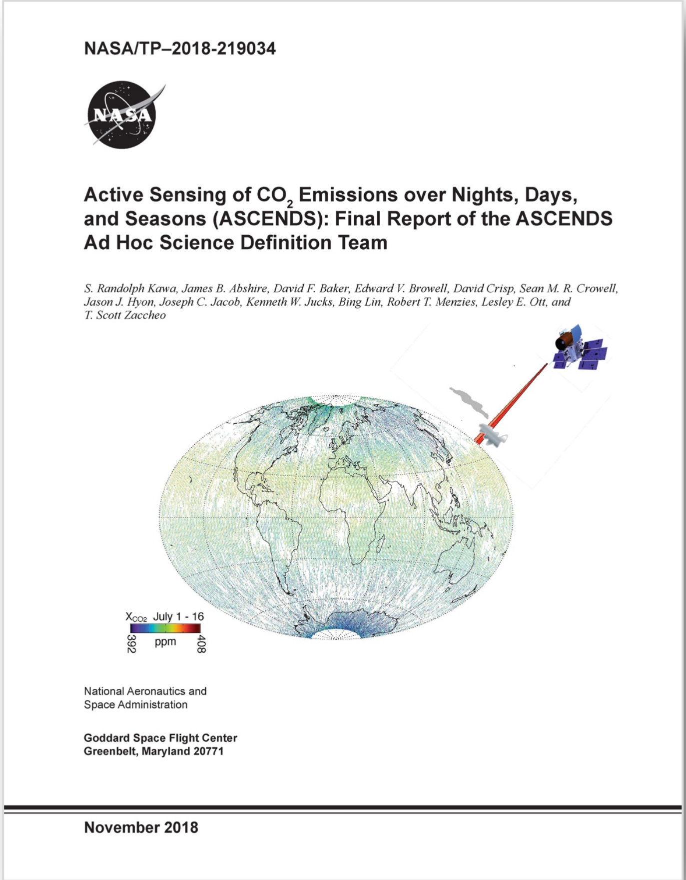
- Why Lasers?
- CO_2 Flux Inference
- Measurement Technology
- Pathway to Space
- Whither Hence?

IWGGMS-15
Jun 5, 2019

ASCENDS Study Team Final Report



NASA/TP–2018-219034

Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS): Final Report of the ASCENDS Ad Hoc Science Definition Team

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

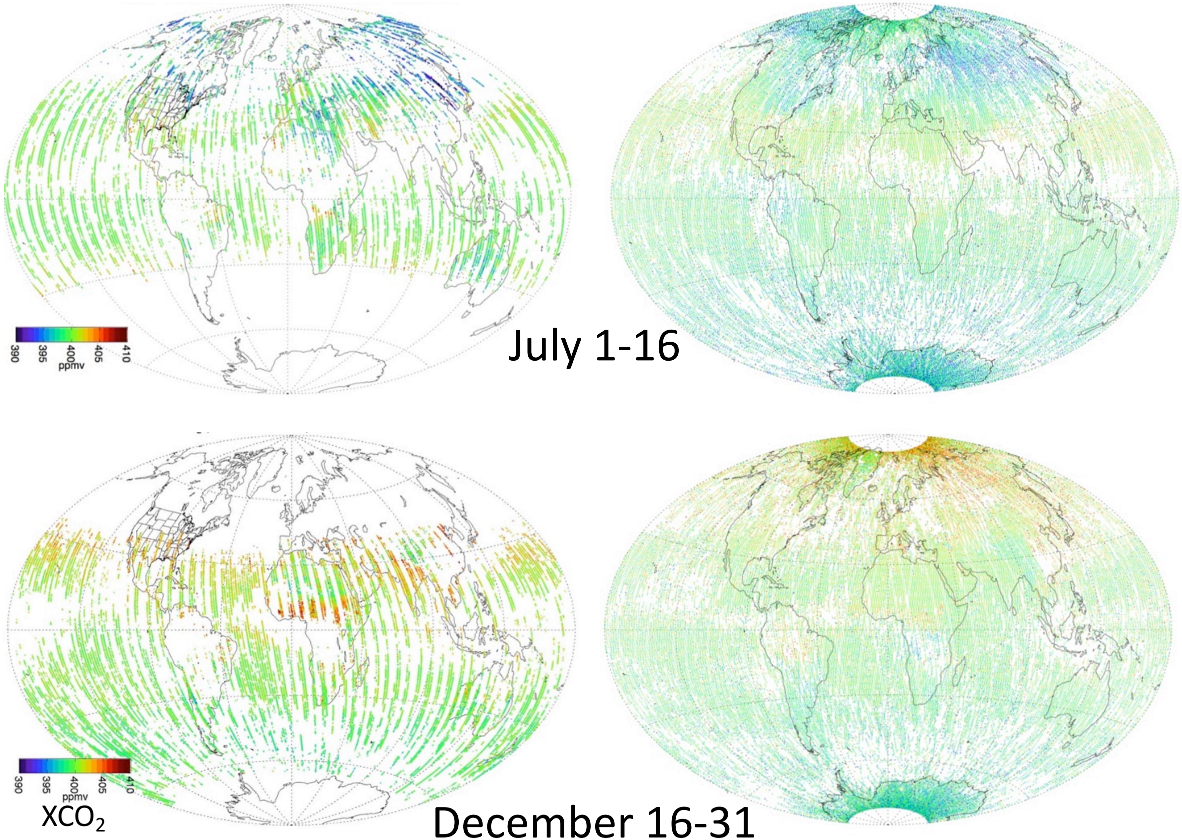
November 2018

https://ntrs.nasa.gov/search.jsp

Why Lasers?

- Day/night all-latitude, land/ocean <u>coverage</u>
- <u>Reduced</u> cloud/ aerosol/view angle <u>biases</u>

OCO-2 ASCENDS (10-s)

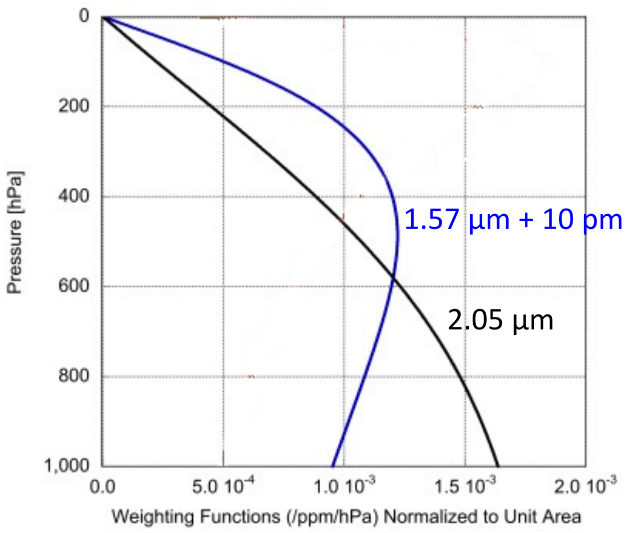


July 1-16

December 16-31

Observing System Simulation Experiments

1. Estimate range of baseline errors and vertical weighting functions across instrument models.
2. Apply global error scaling to generic instrument models
   - random error scaled to observed spectral reflectance, clouds and aerosol
   - including potential bias errors
3. Introduce simulated data and errors into inverse and forward atmospheric transport models
4. Assess impacts of ASCENDS data on CO_2 surface flux inference

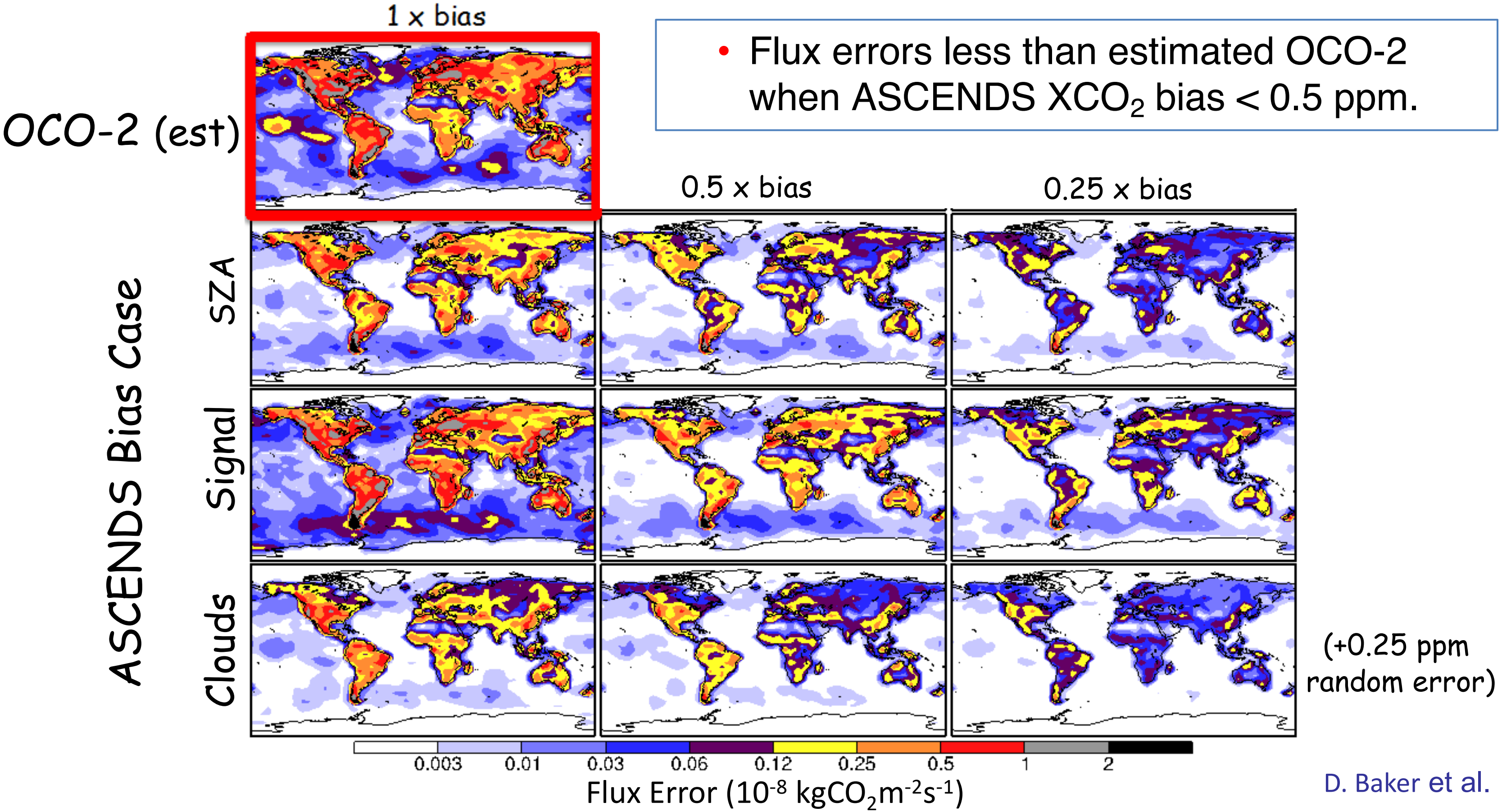


ASCENDS OSSE Summary

Hypothesis/Scenario	ASCENDS Result
Permafrost thawing CO_2 emissions	detection of spatial gradients at high latitudes on seasonal time scale (better than even unbiased passive observations)
Fossil fuel emissions change	identify foreseeable shift in annual and seasonal emissions at the scale of Europe and China
SH Ocean sink variability	reduce uncertainty in fluxes and provide constraint on spatial and temporal variability
Tropical land sinks	constrain large sinks as well as some weaker Northern mid-latitude regional land sinks
Biome and finer scales (e.g., 100 km)	- reduce biome flux uncertainties substantially, toward understanding long-term carbon sinks - discern fossil fuel emissions patterns from largest-emitting sub-continental regions over N America (particularly with the 2.05 μm weighting function)
Global flux uncertainty	detect fluxes with high SNR and resolve temporal/spatial gradients for process attribution that passive observations cannot

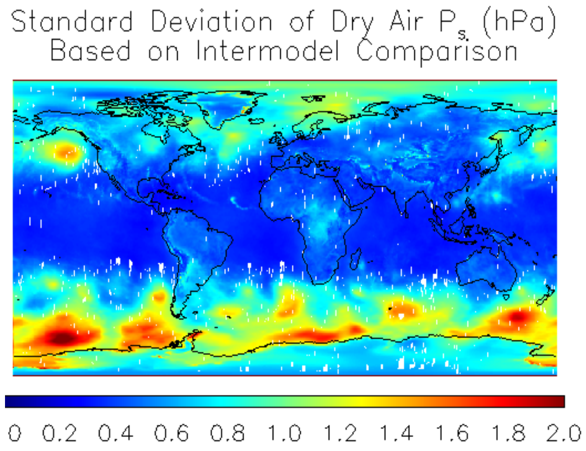
Impact of Systematic Errors

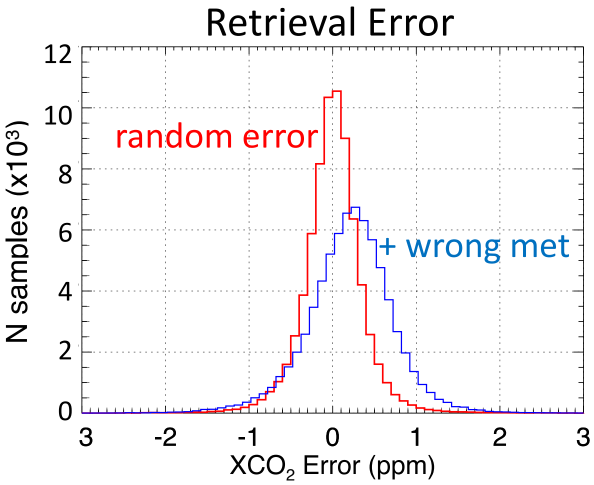
- Flux errors less than estimated OCO-2 when ASCENDS XCO_2 bias < 0.5 ppm.

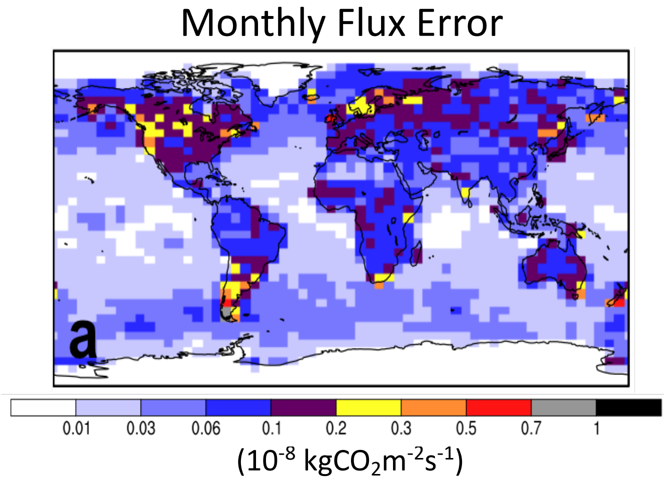


D. Baker et al.

Impact of Meteorological Errors







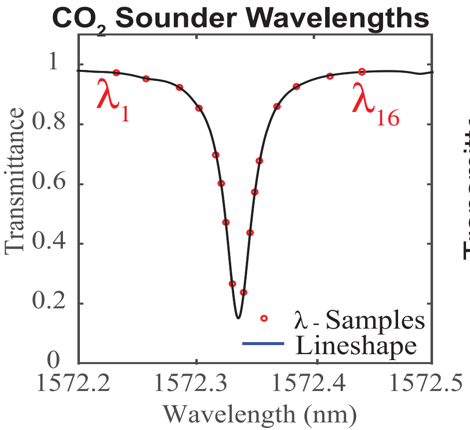
- ➢ Co-aligned lidar measurement of O_2 is not cost effective.
- Meteorological re-analyses together with ASCENDS precise laser altimetry meet dry air mass requirement.
- Met errors in XCO_2 retrieval have small impact on flux error vs. other factors.
- Laser measurements of O_2 A-and B-bands were demonstrated in flight.

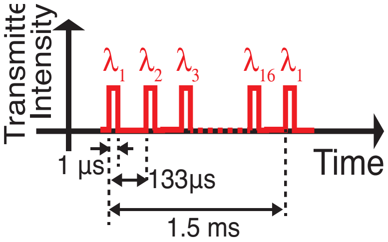
Airborne Instrument Prototypes

- NASA has supported several different lidar approaches for ASCENDS
  - to optimize measurement capability and technology readiness
- Examples from 3/4 follow with snapshots of data
  - demonstrate measurements across wide variety of conditions
- Results documented in publications and presentations

Pulsed 1.57 µm Approach

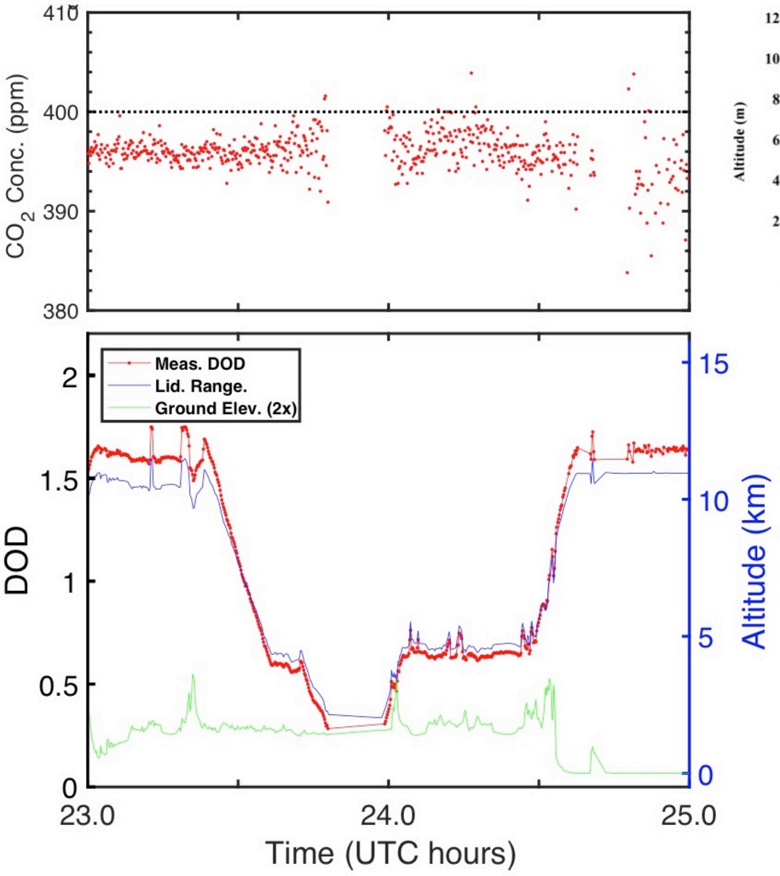
DC-8 Installation

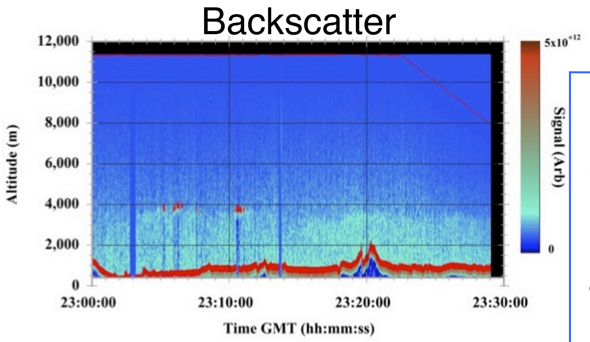


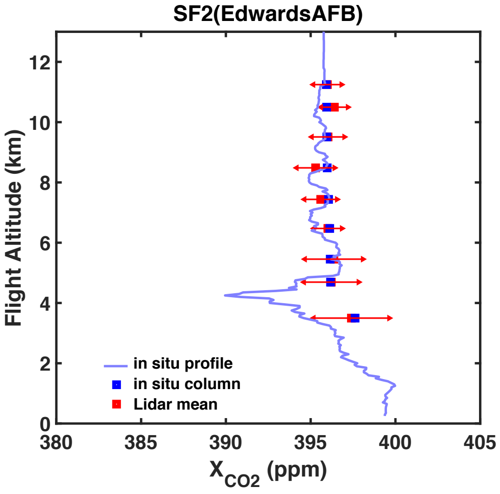


- Multiple (15-30) wavelength pulses tuned across CO_2 absorption line
- Time-gated receiver for range

Example Data







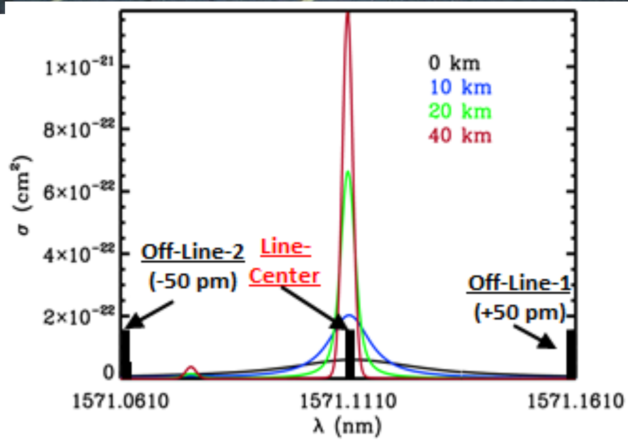
Measurements near Edwards AFB (desert):

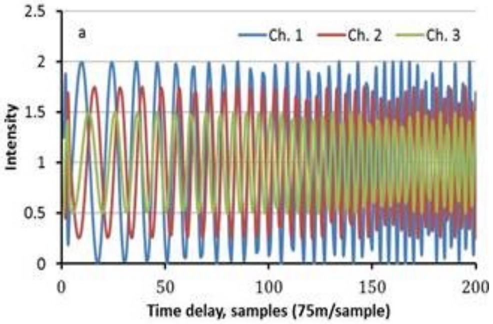
- High quality measurements through aerosol haze and scattered cloud
- Min XCO_2 variability ~ 0.7 ppm for 1-s samples at altitude, low bias wrt in situ profile.

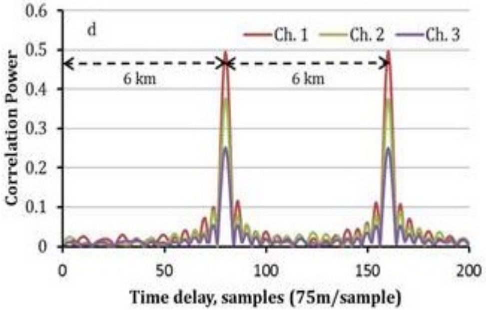
Intensity-Modulated Continuous-Wave (IM-CW) 1.57 μm Approach

Langley Research Center

- 3-wavelength IM-CW lasers
- Intensity modulated to get range
- 13 flight campaigns since 2005
- Also participating in NASA ACT-America Project

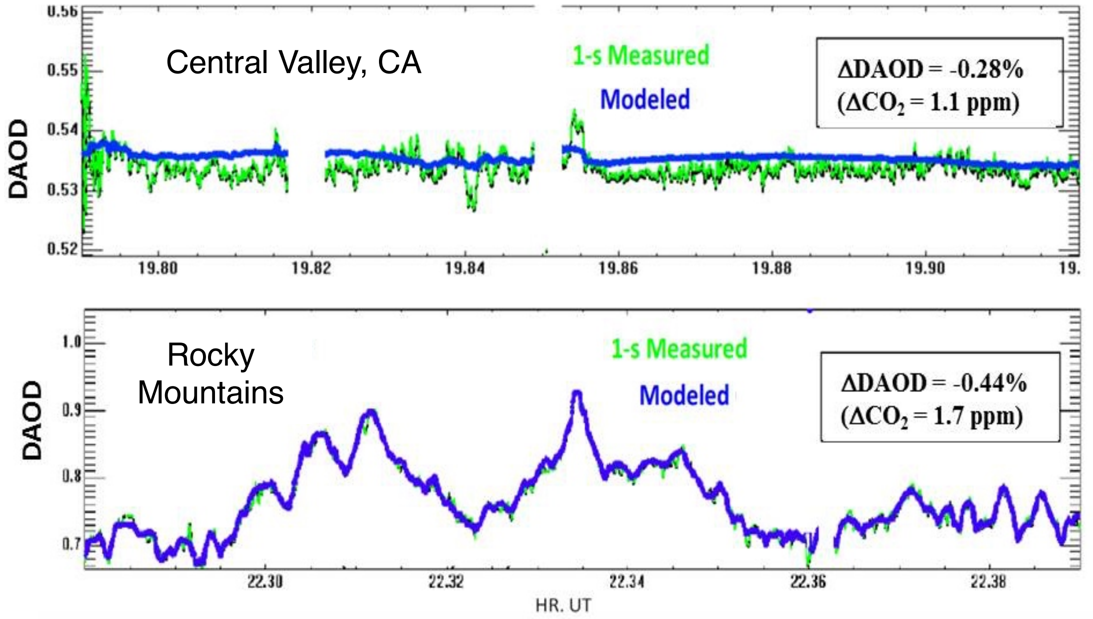




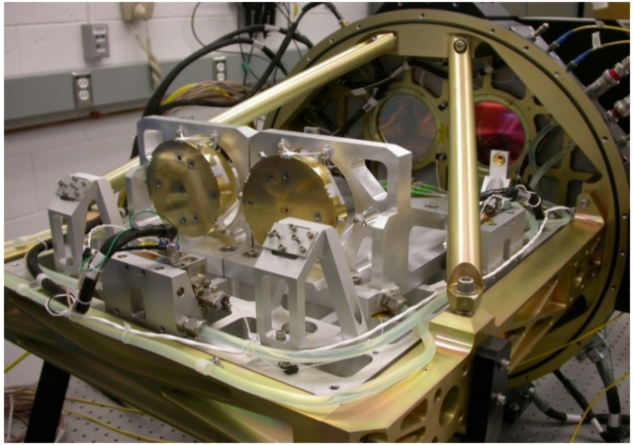


IM-CW Example Results

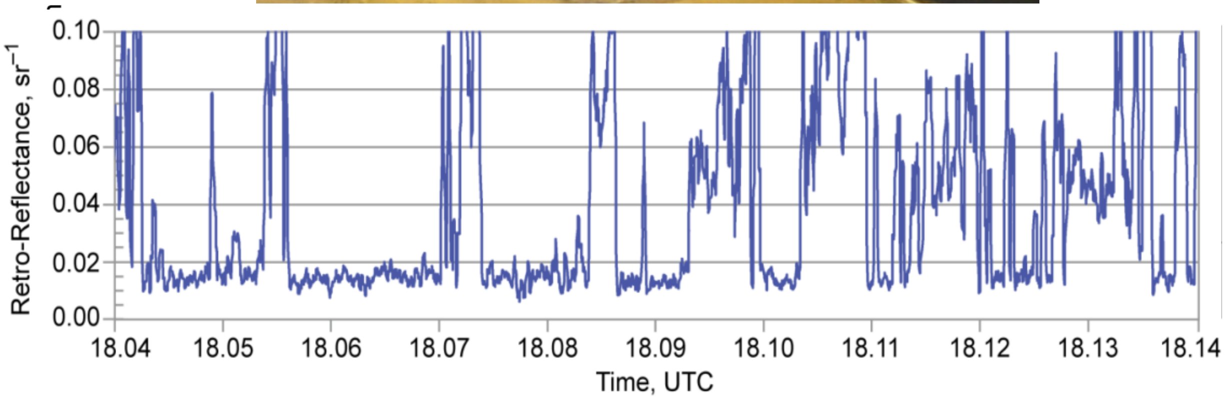
- Lidar measurements agree with calculations from in situ CO_2 profile to ~1 ppm.
- Data over complex terrain correspond closely to expected variations with elevation change.



2.05-µm LAS Using Heterodyne Detection



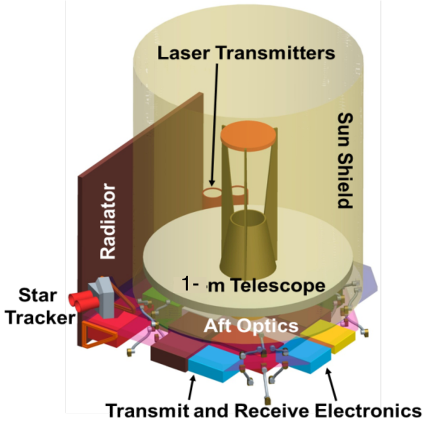
- 2-wavelength heterodyne detection at 2.05-µm
- Flight campaigns since 2006
- Example quantifying power plant emission from XCO_2 plumes

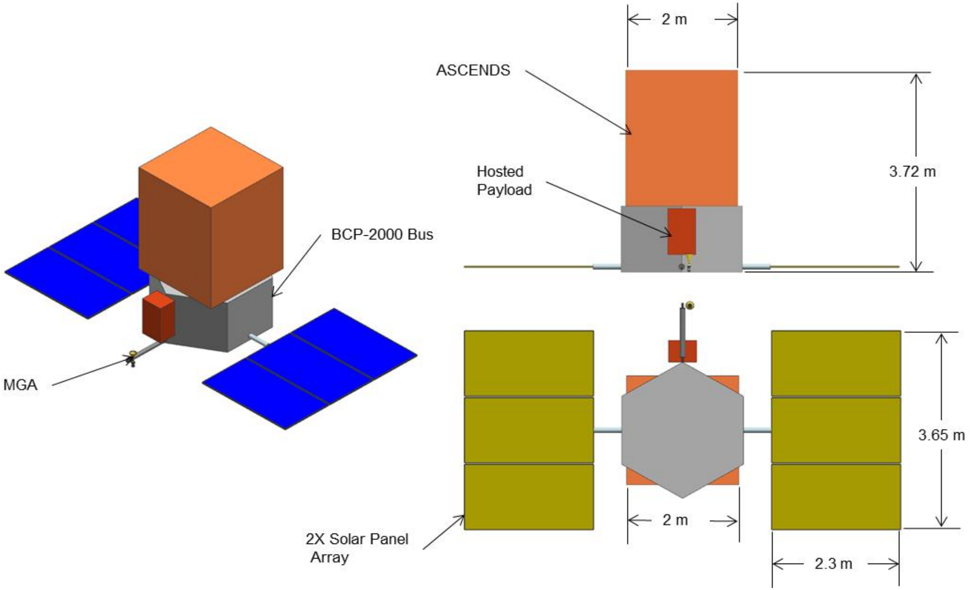


Pathway to Space

Technology progress has been substantial

- Improved SNR/averaging times are possible
- Take another look at detecting diurnal differences in XCO_2
- Measurement requirements are summarized in report





Instrument and mission design studies

- No major impediments
- Needed lidar technologies are available
- Nominal bus and launch requirements

Where Do We Go From Here?

- ✓ Technology development, airborne campaigns, measurement simulations, and inverse modeling demonstrate that ASCENDS concept will meet requirements of the 2007 Decadal Survey, and will produce substantially improved characterization of global CO_2.
- ➢ Report recommends a number of activities to carry possible ASCENDS development forward in the future.
- ❑ The 2017 NAS Decadal Strategy for Earth Observation from Space relegated greenhouse gas measurements to Explorer-class missions with unspecified priority or implementation approach.
- $ Explorer cost cap at $350M to NASA presents a challenge for a space lidar.
  - Explore international partnerships to enable.
  - Assess technology advances and accommodations for lidar as secondary payload.
- ➢ Active $CO_2 + CH_4$?

Acknowledgements

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