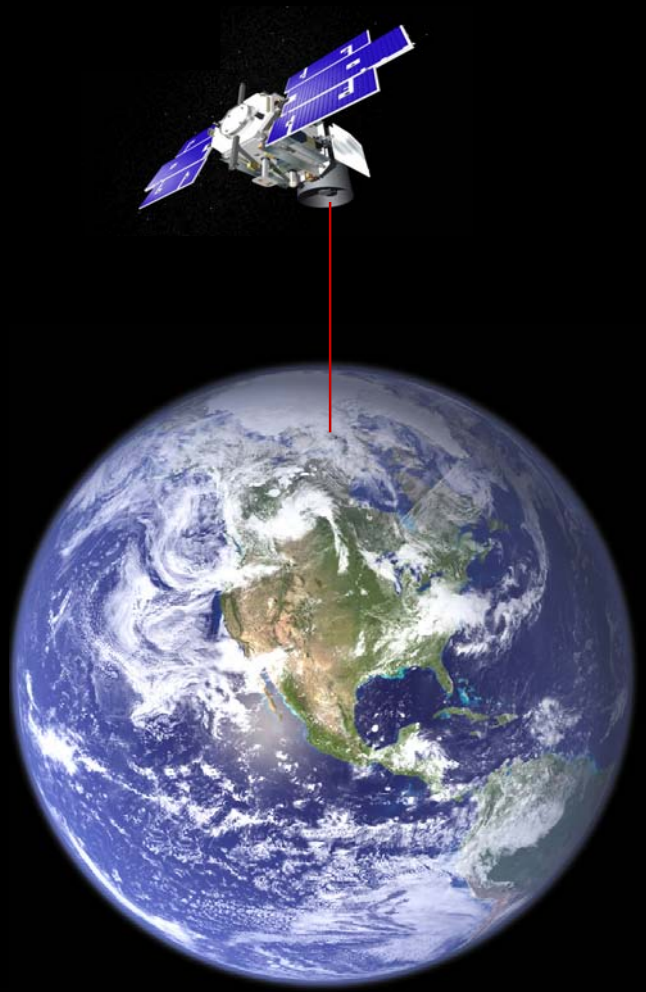
Pulsed Airborne Lidar Measurements of Atmospheric CO_2 Column Absorption & lineshapes from 3-13 km altitudes

James B. Abshire

Haris Riris, Graham R. Allan*, Clark Weaver**,

William Hasselbrack*, Xiaoli Sun, Jianping Mao**

NASA Goddard Space Flight Center,
Solar System Exploration Division, Greenbelt MD 20771
** -Sigma Space, ** GEST, Univ. of Maryland*



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James.Abshire@gsfc.nasa.gov

Laser Sounder Approach for ASCENDS Mission

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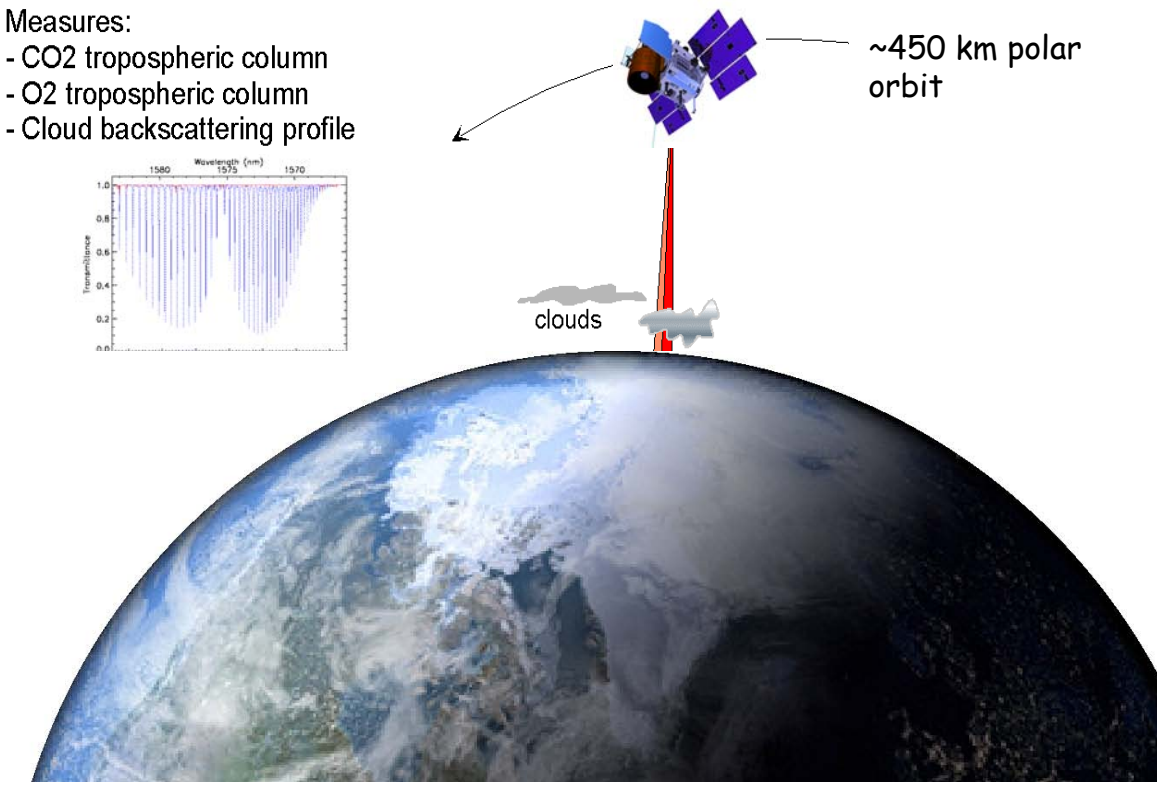
Simultaneous laser measurements:

1. CO2 lower tropospheric column
   One line near 1572 nm
2. CO2 full column (line area)
3. O2 total column (surface pressure)
   Measured between 2 lines near 765 nm
4. Altimetry & atmospheric backscatter profile from CO2 signal:
   Surface height and atmospheric scattering profile at 1572 nm



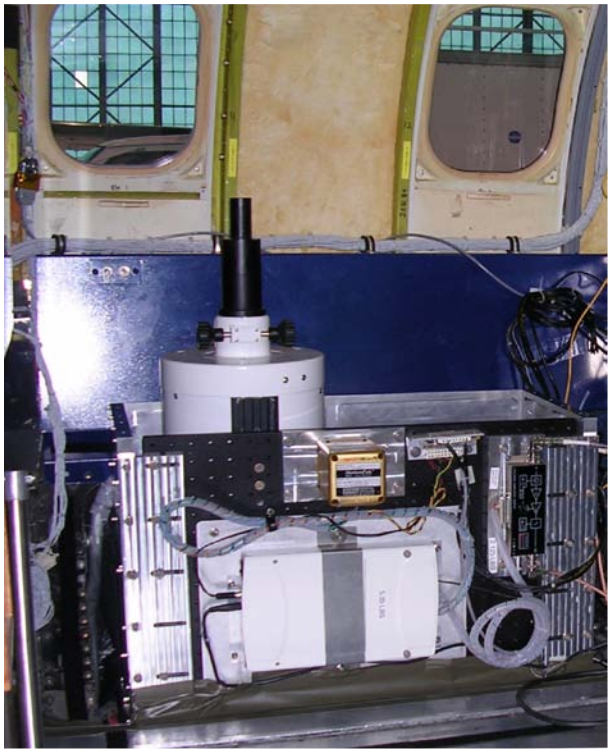
Measurements use:

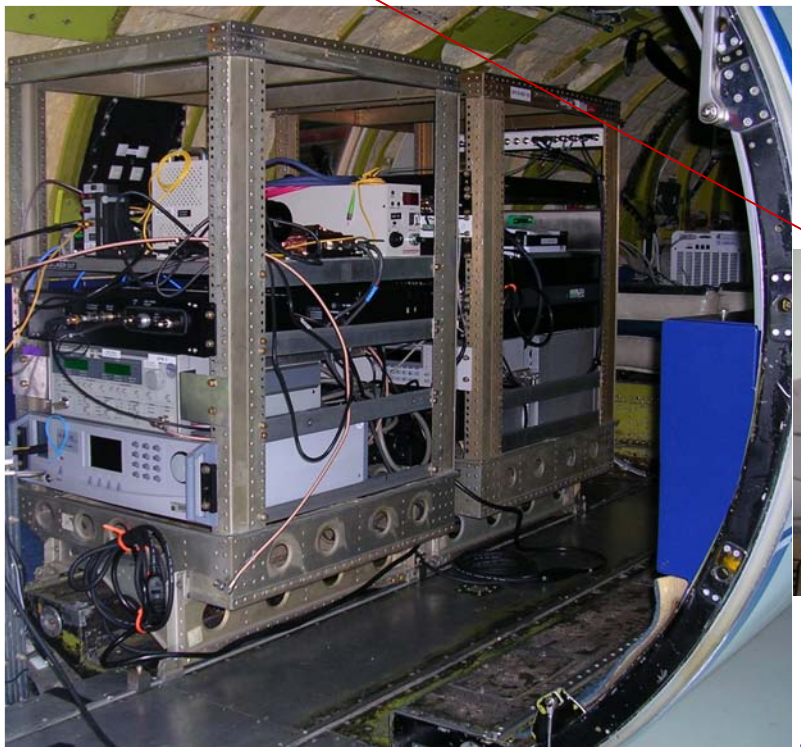
- Pulsed lasers
- 8-10 KHZ pulse rates
- ≥ 8 laser wavelengths for CO2 line
- Time gated Photon counting receiver

CO2 & O2 column measurements:

- Pulsed (time gated) signals :
  - Isolates full column signal from surface
  - Reduces noise from detector & solar background
- Target: ~ 1ppmV in ~100 km along track sample

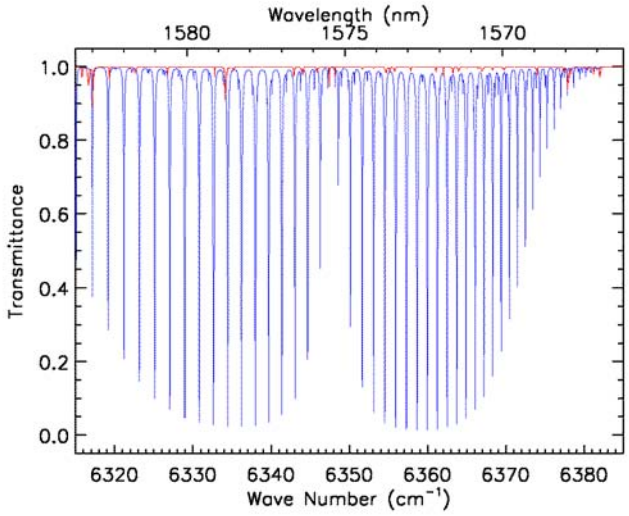
Pulsed Airborne CO2 Sounder Instrument on the NASA Glenn Lear-25 October & December 2008

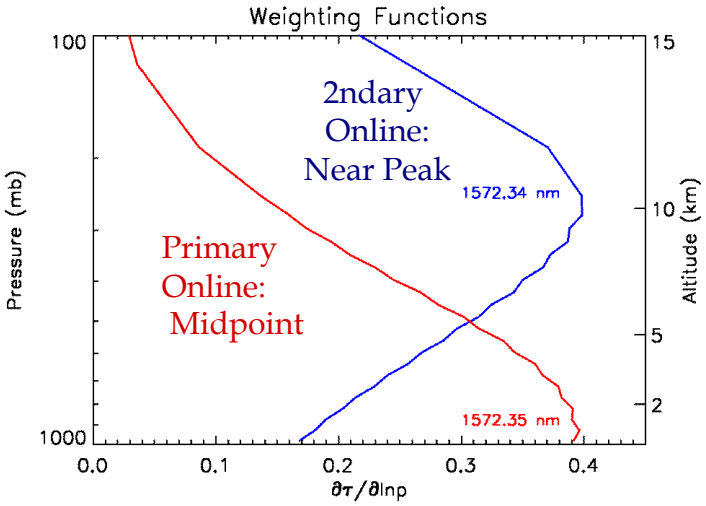




View of nadir port showing transmit and receiver windows

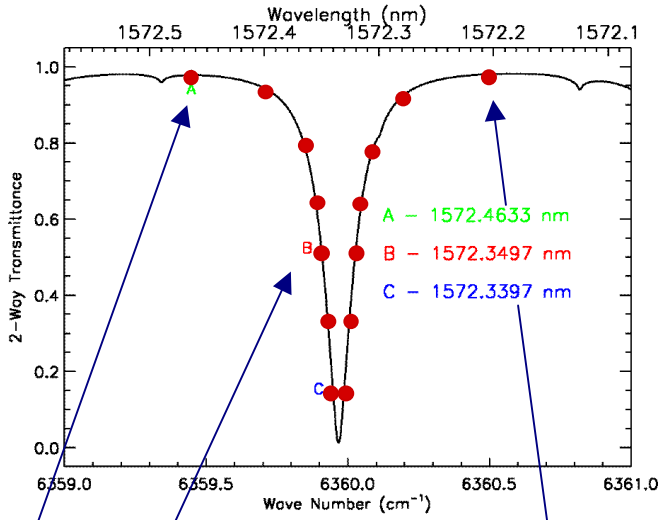
Candidate CO2 Line, Sampling & Vertical Weighting Functions

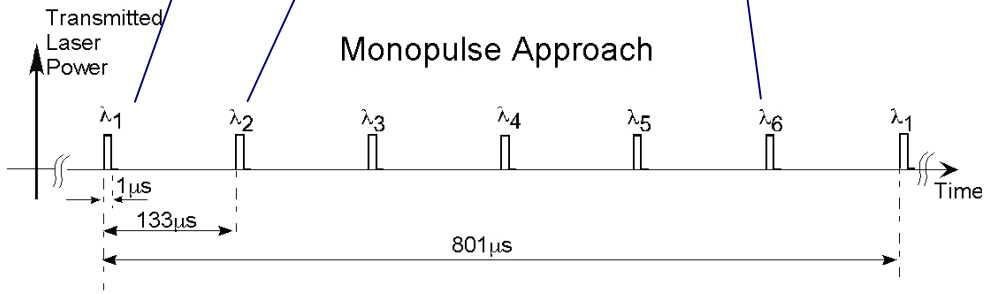




Line OD area -> total column

Airborne lidar used 10 & 20 wavelength samples across line





Multi-wavelength Line Sampling allows:

- Detection & correction of Doppler & λ errors
- Modeling -> reduces errors from varying λ response
- CO2 retrievals for: Lower troposphere
- Total column; Line shape information

Airborne Measurement Demonstrations - 2008

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Airborne CO2 column measurements demonstrated to 12 km:

- 2 flights in Ohio during 10-23, 10-24-08
- 1 flight in southwest Ohio, 12-05-08
- 2 flights above DOE ARM site, 12-07-08 (best in-situ data)
- Measurements stepped altitude (3-11 km) and thus column CO2 integral

DOE ARM Site deployment:

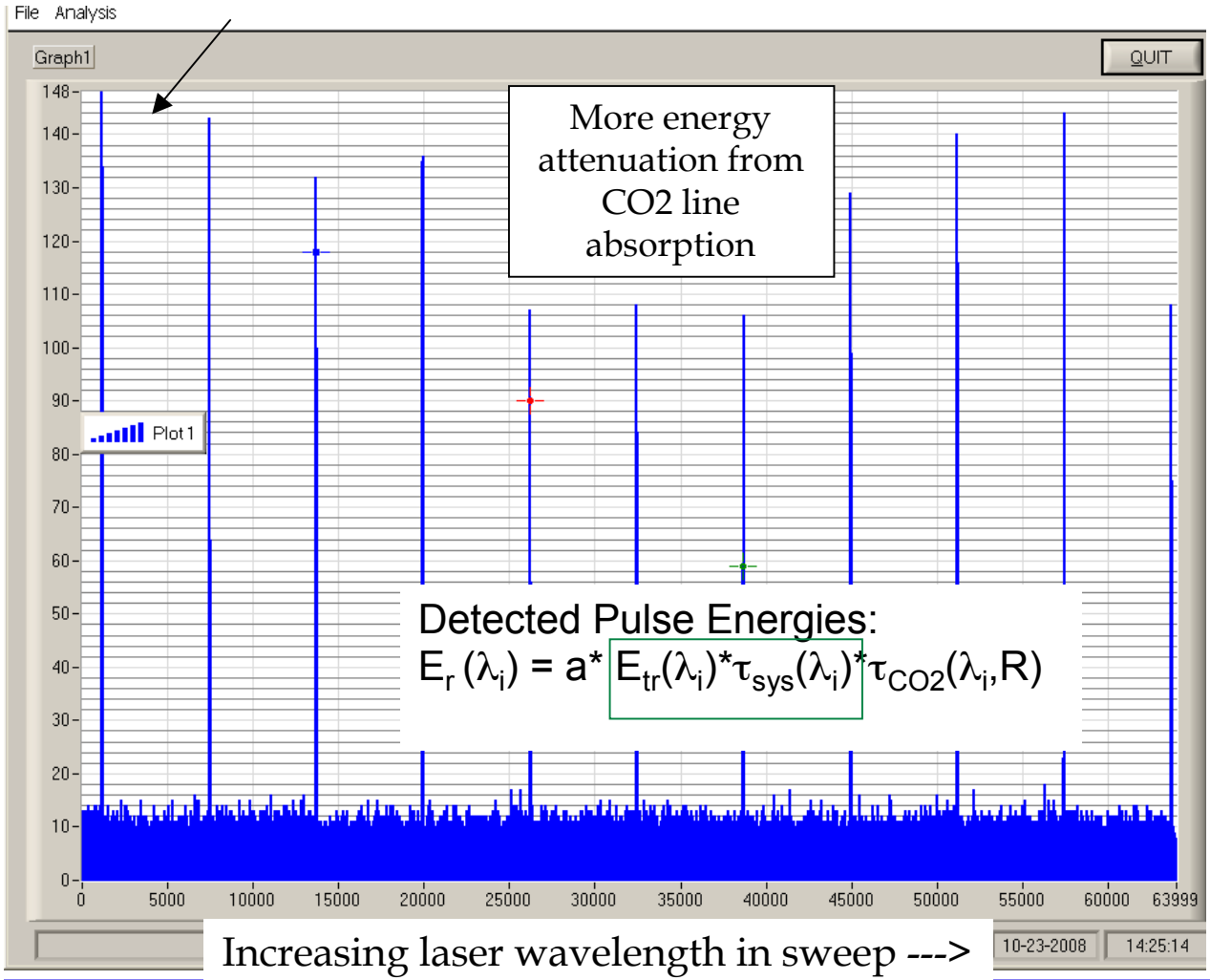
Background - NASA Glenn Lear 25 takeoff from Ponca City Airport on 12/7/08 (Graham Allan photo)

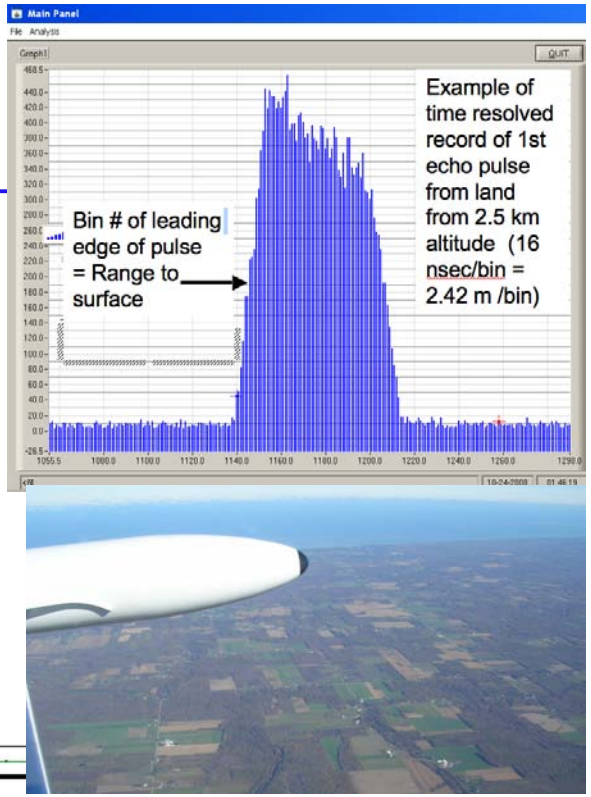
Left- Goddard field experiment team

Right - DOE Cessna aircraft with in-situ CO2 sampler (courtesy of Sebastien Biraud/LBL)

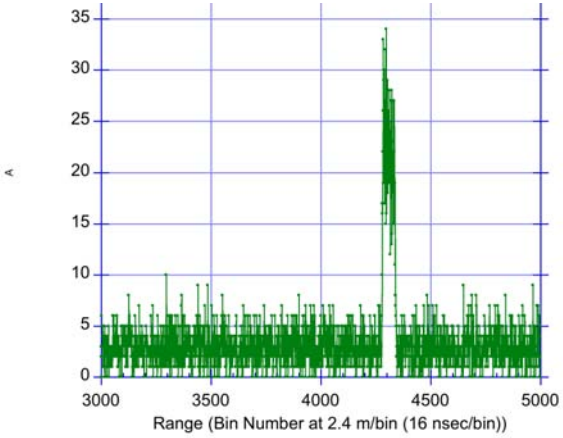
Sample wavelength Scan & Echo Pulses at 2.5 & 10 km Altitudes (1 sec averaging time)

Delay time of pulse train => range to surface
(Scattering above ground occurs before the ground echo)





Expanded view of 1st pulse reflected from Lake Erie surface at 10 km altitude

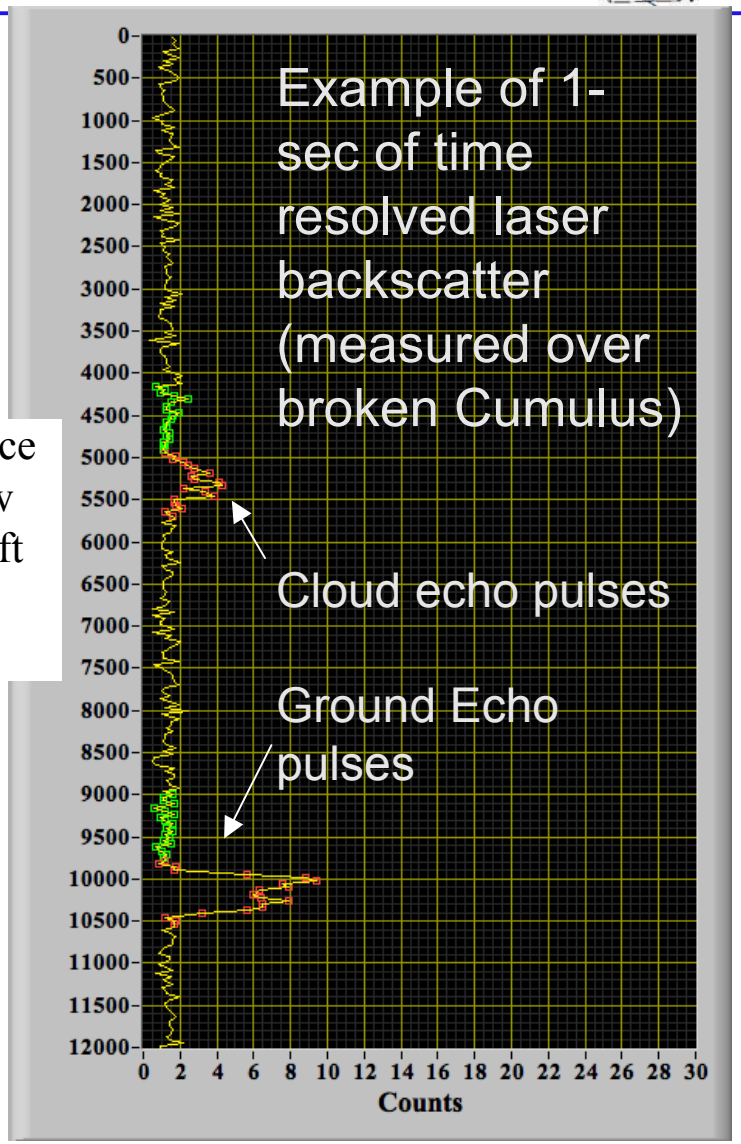


2009 Flight Example: Measuring though Cloud deck over Homer IL

Cirrus at ~32000 ft

Broken Cumulus ~5000'

Distance below aircraft (ft)



Airborne Measurements through higher partially transmissive cirrus Clouds

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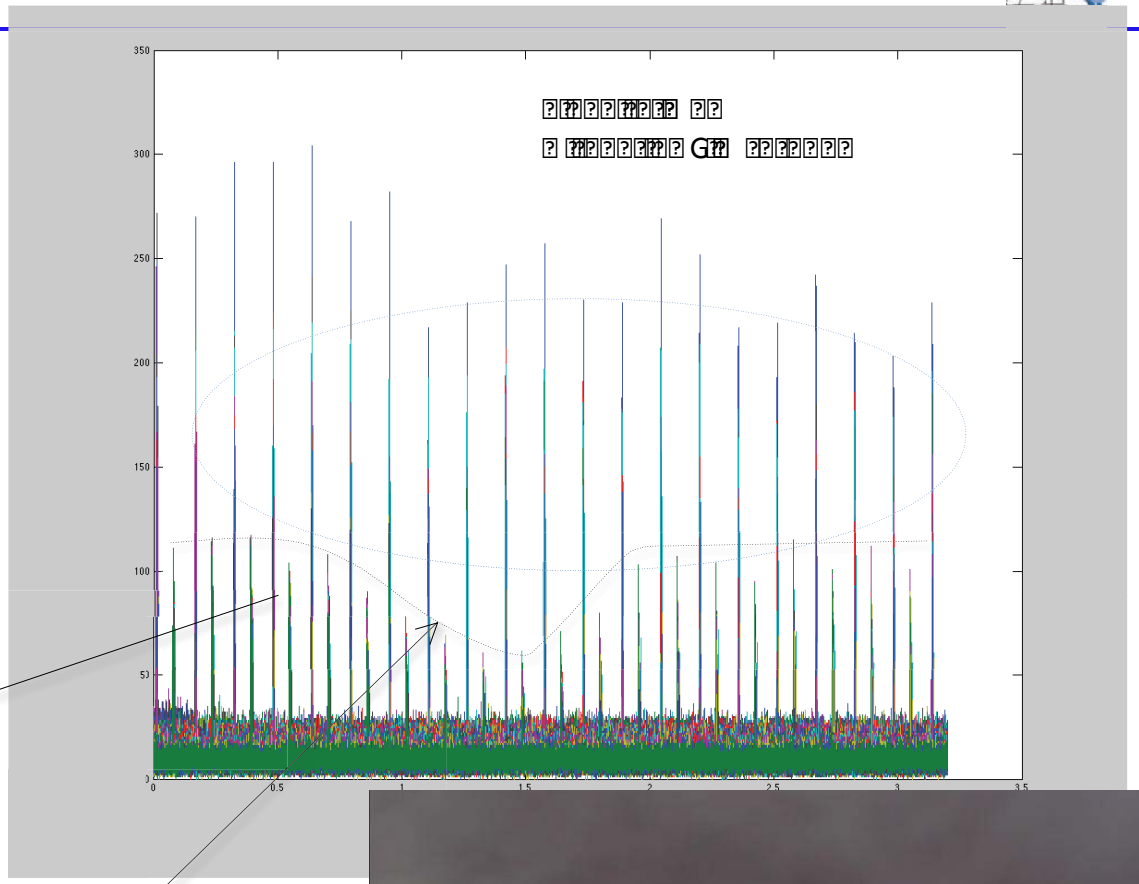
12/7/08 Flight, 8km altitude

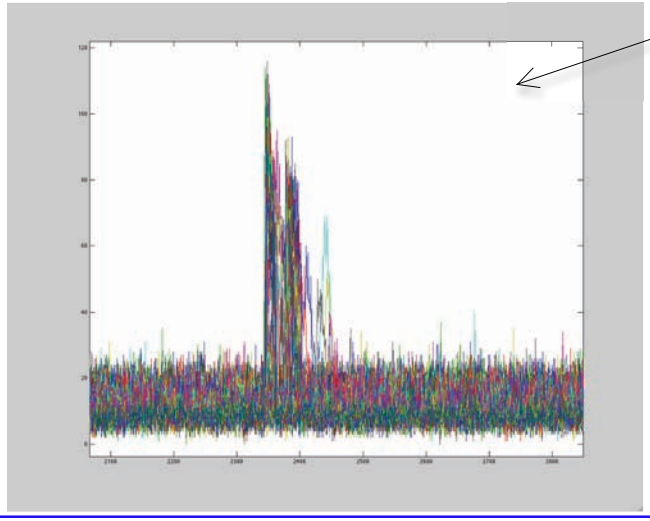
100 traces overlaid,
Each trace is the sum of 450 scans.

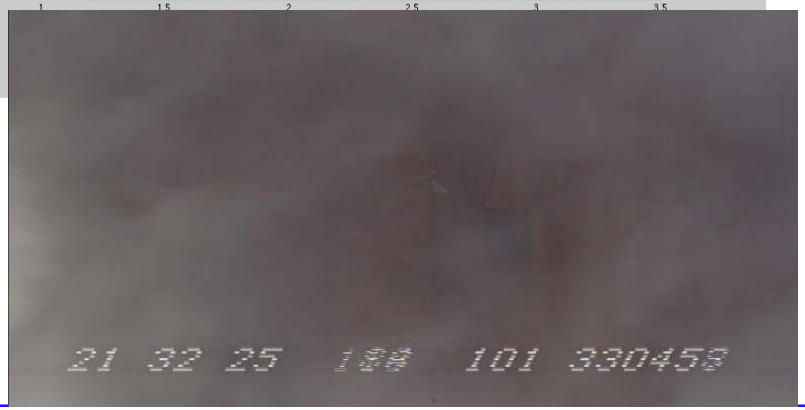
Each scan consists of 20 laser pulses
at 10 kHz or 2ms/20 pulses
0.9sec/trace

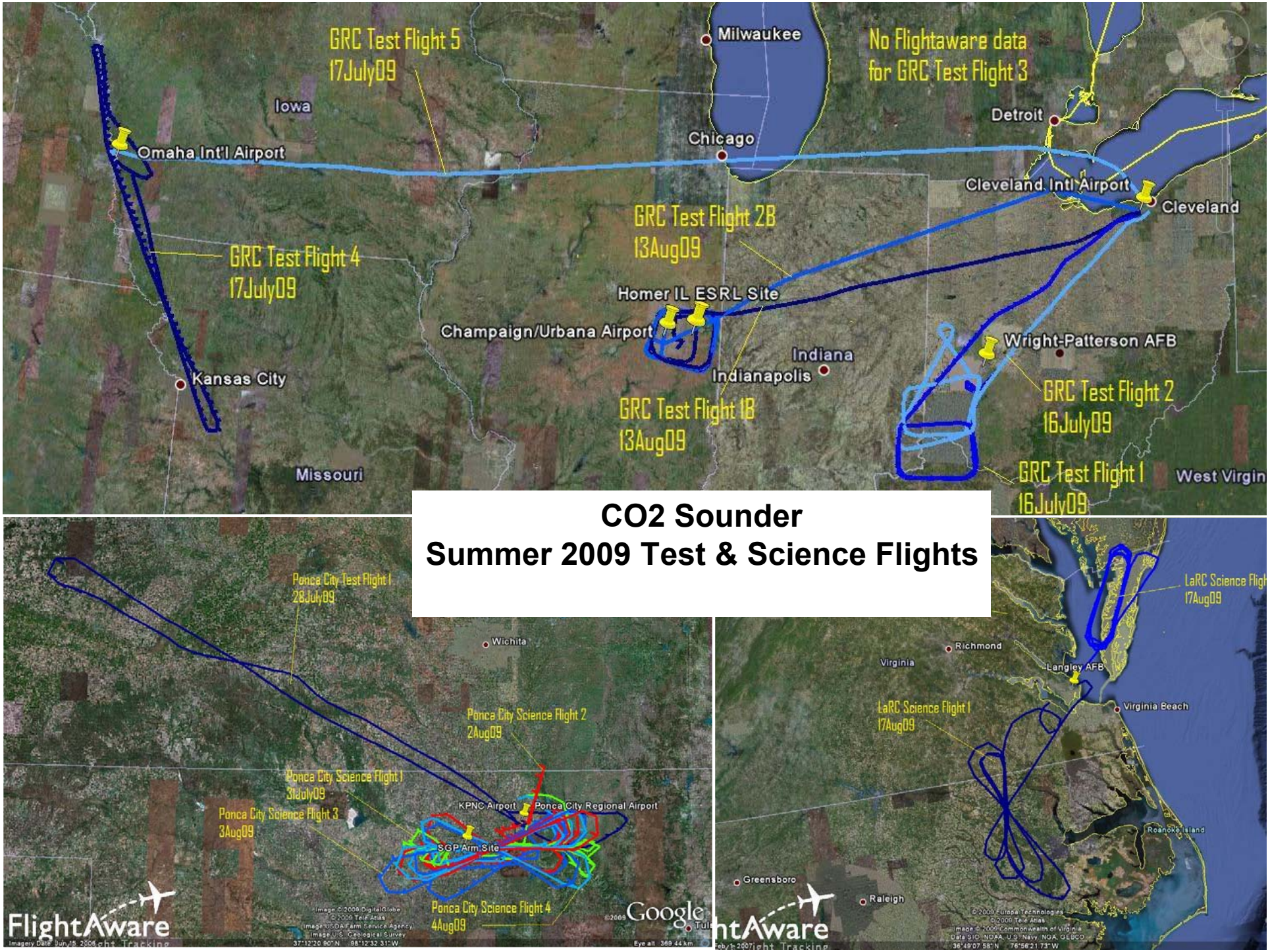
Each pulse is 1 us wide

Each range bin = 64 ns (0.9 sec/450 scans)








GRC Test Flight 5
17July09
Milwaukee
No Flightaware data
for GRC Test Flight 3
Iowa
Detroit
Chicago
Omaha Int'l Airport
Cleveland Intl Airport
Cleveland
GRC Test Flight 2B
13Aug09
GRC Test Flight 4
17July09
Homer IL ESRL Site
Champaign/Urbana Airport
Wright-Patterson AFB
Indiana
Indianapolis
Kansas City
GRC Test Flight 2
16July09
GRC Test Flight 1B
13Aug09
Missouri
GRC Test Flight 1
16July09
West Virgin
CO2 Sounder
Summer 2009 Test & Science Flights
Ponca City Test Flight 1
28July09
Wichita
Ponca City Science Flight 2
2Aug09
Ponca City Science Flight 1
31July09
KPNC Airport
Ponca City Regional Airport
Ponca City Science Flight 3
3Aug09
SGP Arm Site
Ponca City Science Flight 4
4Aug09
FlightAware
Google
LaRC Science Flight
17Aug09
Richmond
Virginia
Langley AFB
Virginia Beach
LaRC Science Flight 1
17Aug09
Roanoke Island
Greensboro
Raleigh
FlightAware

1. Cessna Takeoff

2. Twin Otter Takeoff

3. Lear Takeoff

Coordinated Airborne Experiments to Measure CO2 column densities in support of ASCENDS Mission Definition

(August 2009)

4. UC-12 Takeoff

0. Checkout on ground
Ponca City Airport, OK

Examples of Line shapes vs Altitude
OK SGP ARM Site Flight 4 (Up) - August 4, 2009

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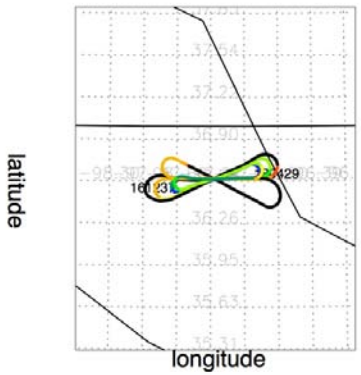
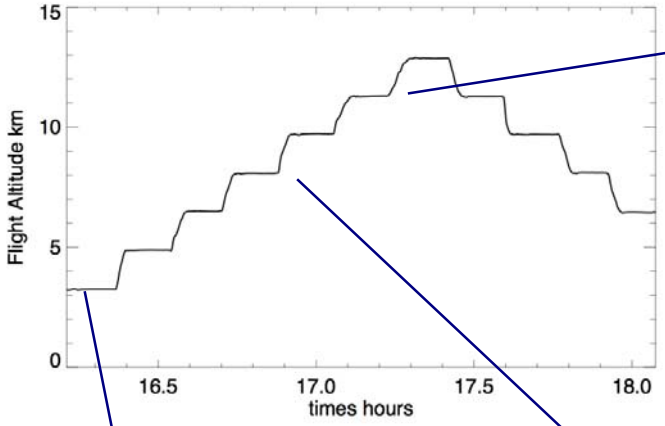
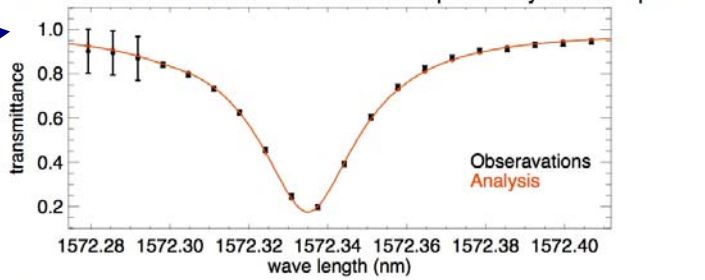
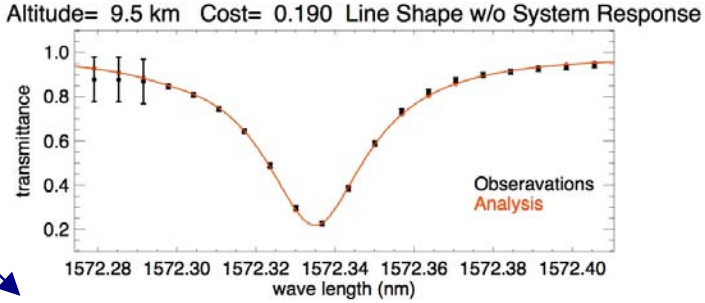
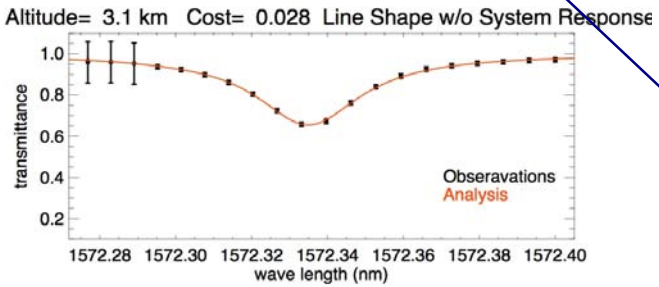
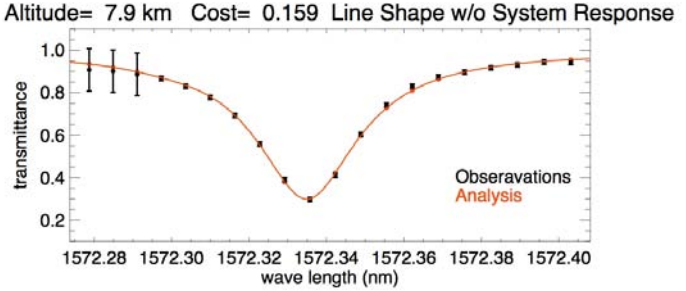


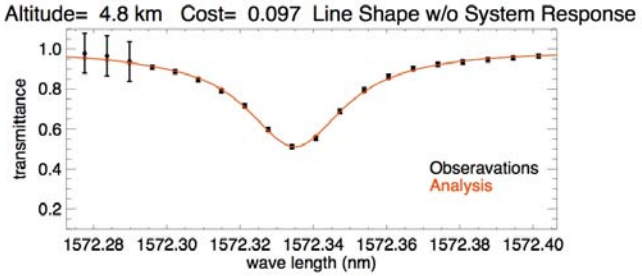


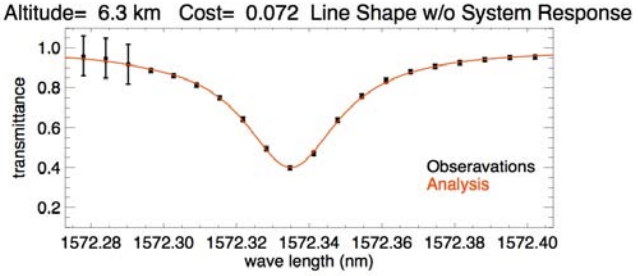










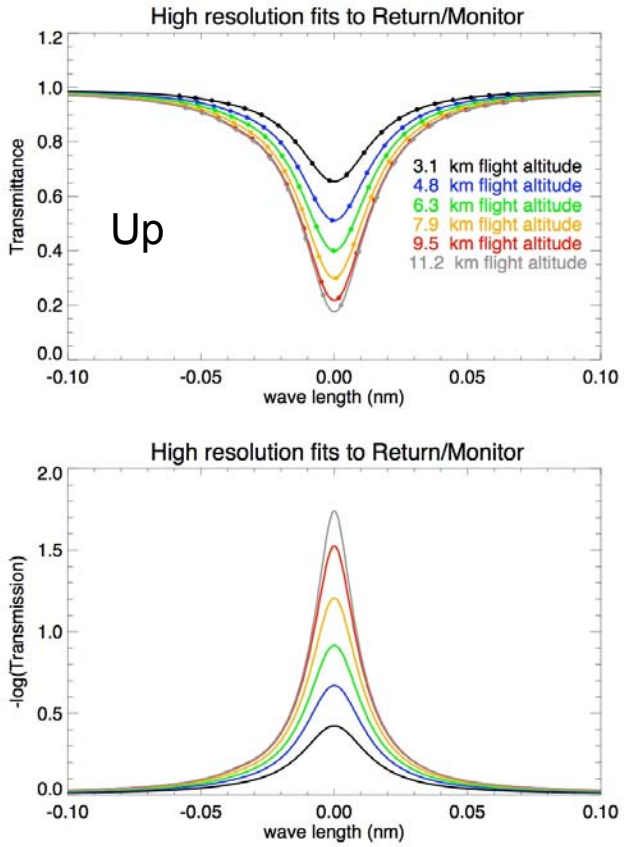


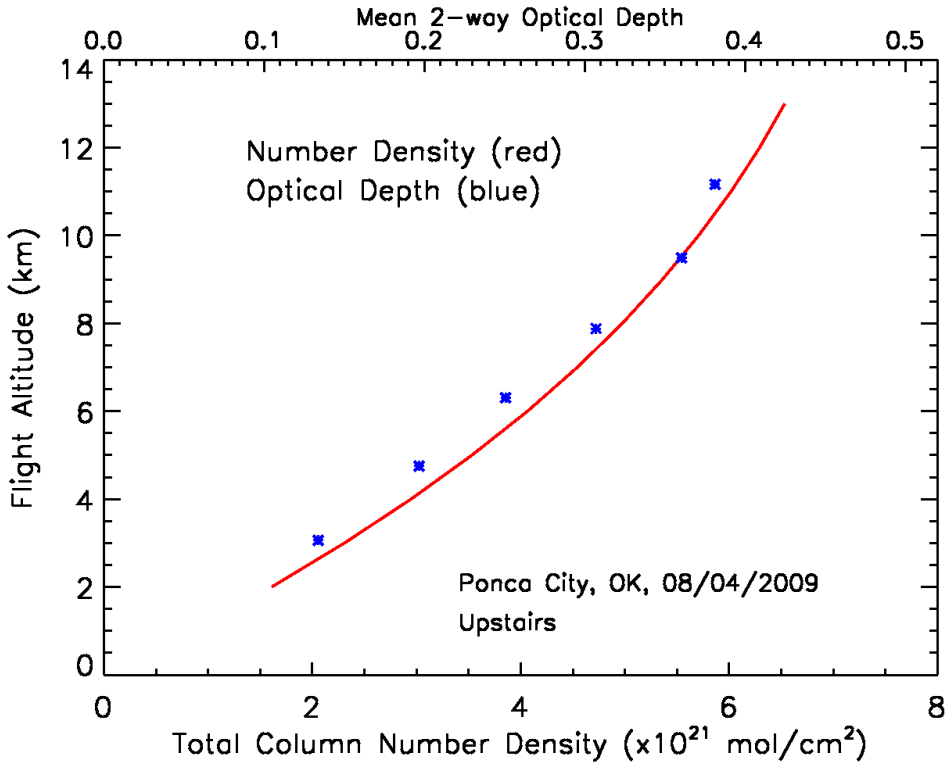
- Black dots - sampled line shape from lidar
- Typ. 60 sec ave time

- Red curves - best fit line shapes (based on HITRAN) from retrieval process

- Absorption increases with altitude
- Smooth line shapes at all altitudes !

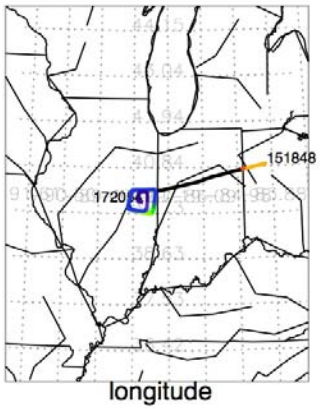
Line Optical Density & # Density vs Altitude
Oklahoma SGP ARM Site - Flight 4: August 4, 2009

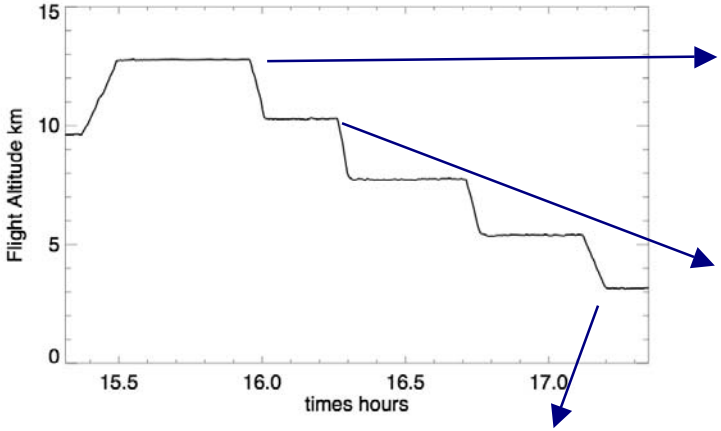


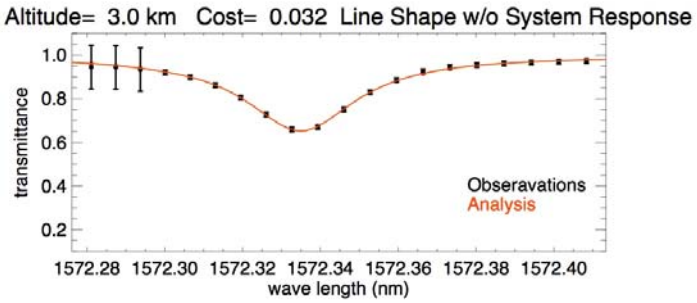


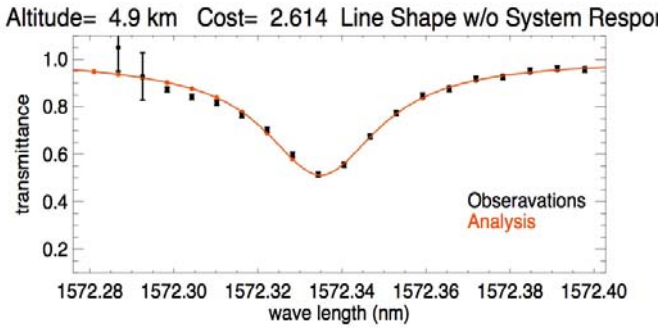
- Mean Optical Depths from line fits to CO2 Sounder measurements
- # Densities calculated from LaRC in-situ sensor and radiosonde readings

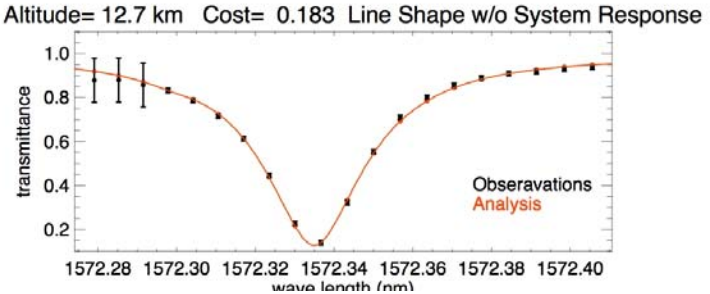
Examples of Line shapes vs Altitude
Homer IL - August 13, 2009

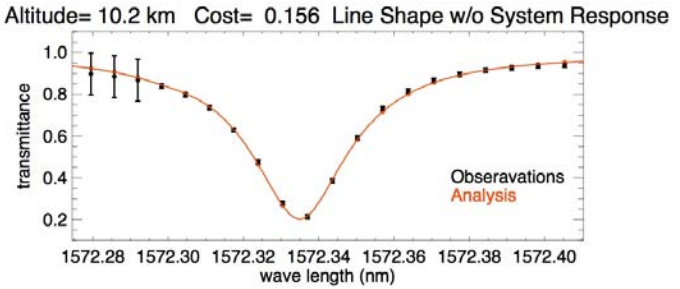


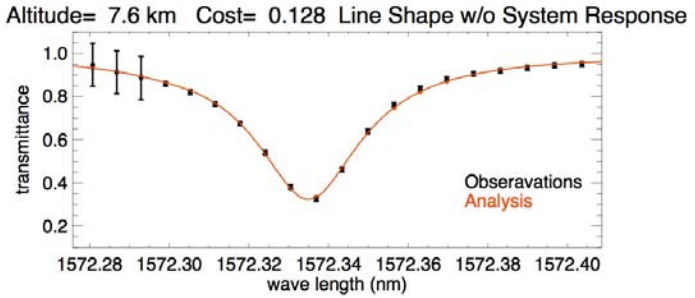


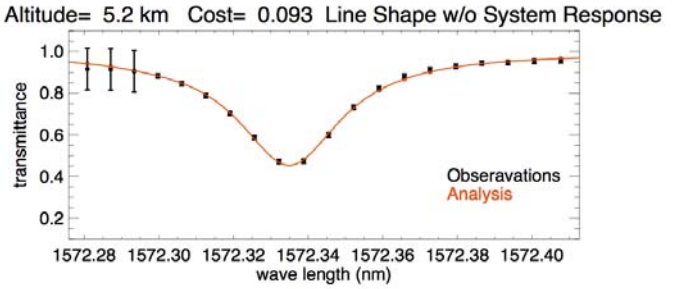






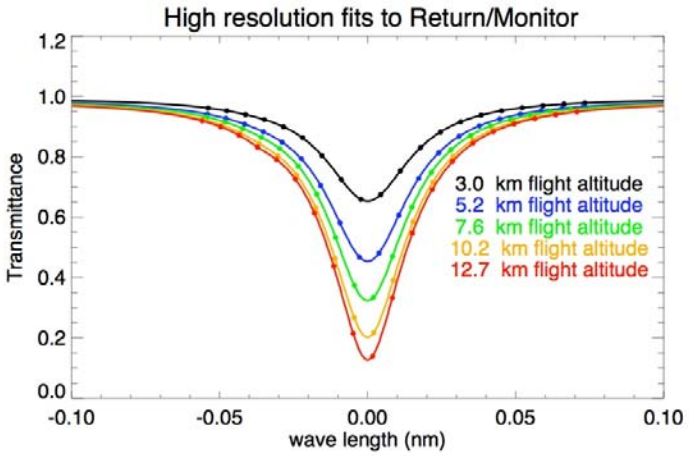


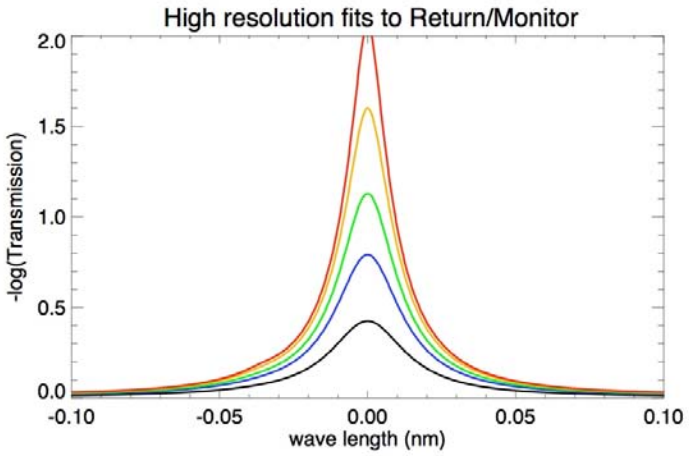


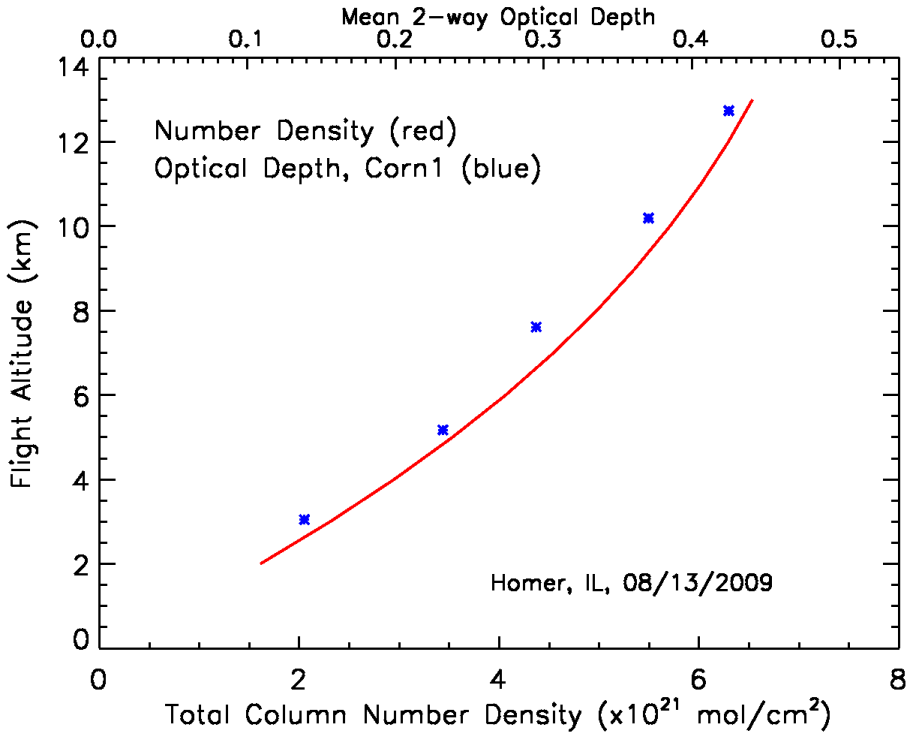


- Depth increases with altitude
- Smooth line shapes at all altitudes !

Line Optical Density & # Density vs Altitude
Homer IL Flight - August 13, 2009







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Examples of Line shapes vs Altitude
North Carolina Flight - August 17, 2009

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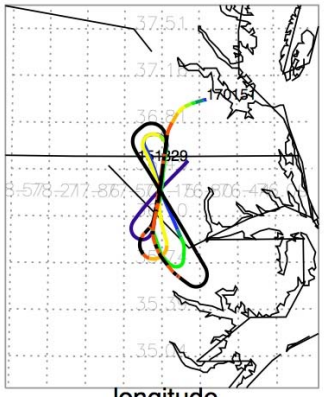

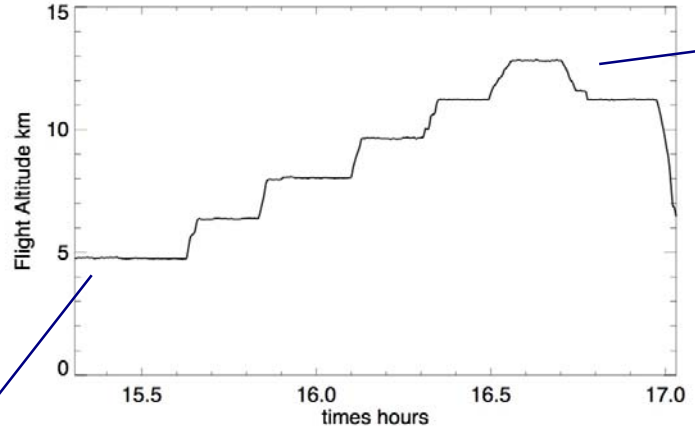

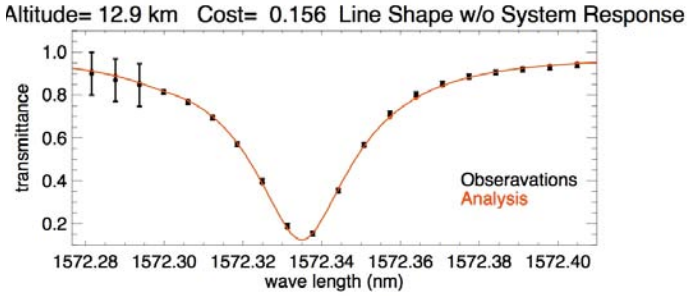

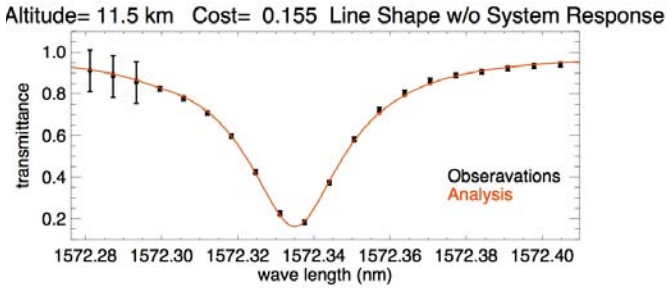

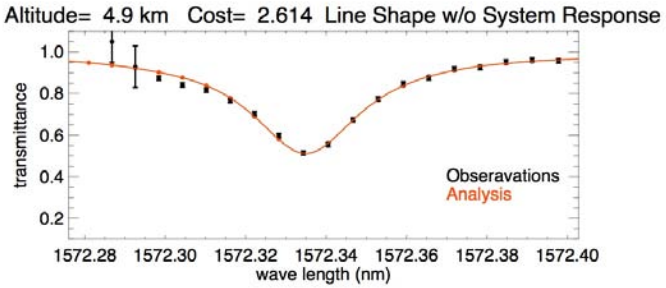

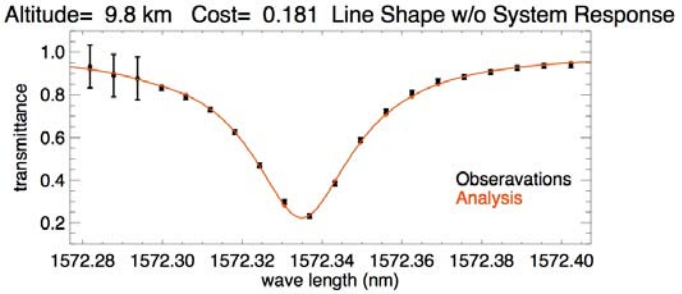

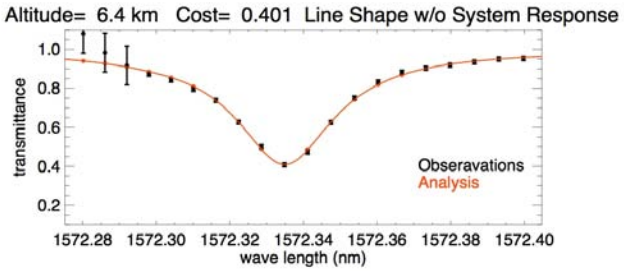

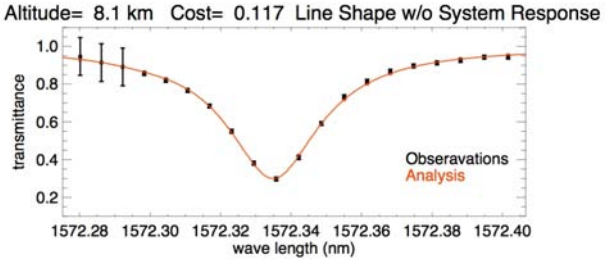

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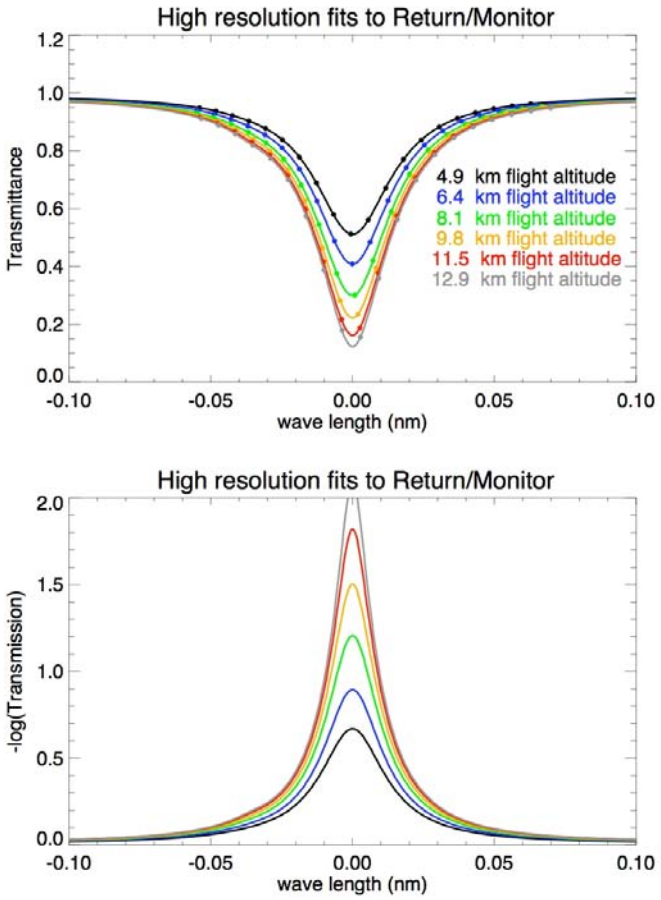
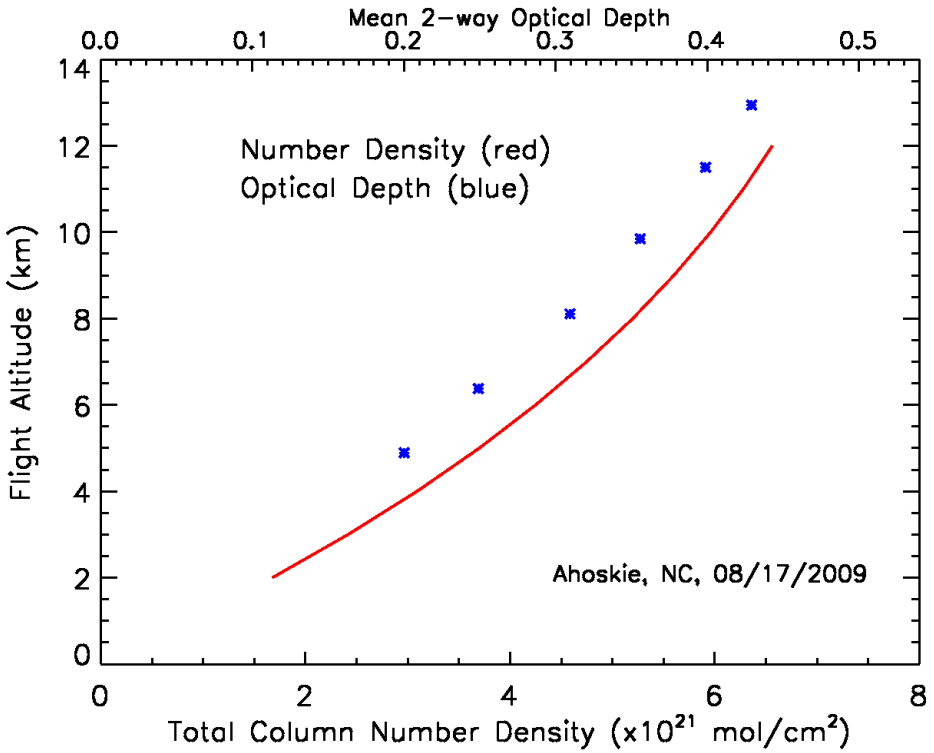
Line Optical Density & # Density vs Altitude
North Carolina Flight - August 17, 2009





- Mean Optical Depths from line fits to CO2 Sounder measurements
- # Densities calculated from LaRC in-situ sensor and radiosonde readings

Summary

- Airborne CO2 Lidar worked quite well in multiple flights, 3-13 km
- Measured optical depths increased with altitude, consistent with calculations
- Altimetry measurements & SNR consistent with theory
- CO2 calibrations and evaluations are ongoing

More information - A41C Poster Session, Thursday 8 am

A41C-0118. Signal to Noise Ratio Analysis of the Pulsed Airborne CO2 Lidar Measurements. *X. Sun et al.*

A41C-0119. Retrievals of column CO2 mixing ratio from airborne pulsed lidar measurements. *C. J. Weaver; et al.*

A41C-0121. Simulation Studies of Satellite Laser CO2 Mission Concepts. *S. R. Kawa et al.*

Acknowledgements

- NASA Headquarters - ASCENDS Mission definition
- NASA ESTO IIP-7 program; Goddard IRAD program
- NASA Glenn Aircraft Operations Office
- NASA LaRC & ACCLAIM group (Ed Browell, Yonghoon Choi)

Thank you !