The NASA ASCENDS Mission to Measure Atmospheric CO_2 from Space: *A Status Report*

James B. Abshire, Kenneth W. Jucks[1]
Edward V. Browell[2], Gary Spiers[3], Jianping Mao[4]

Presentation to:
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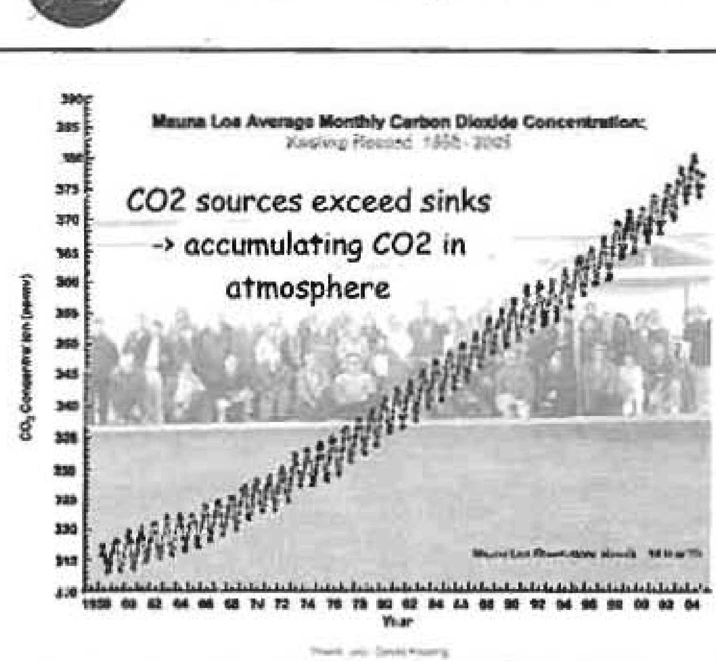
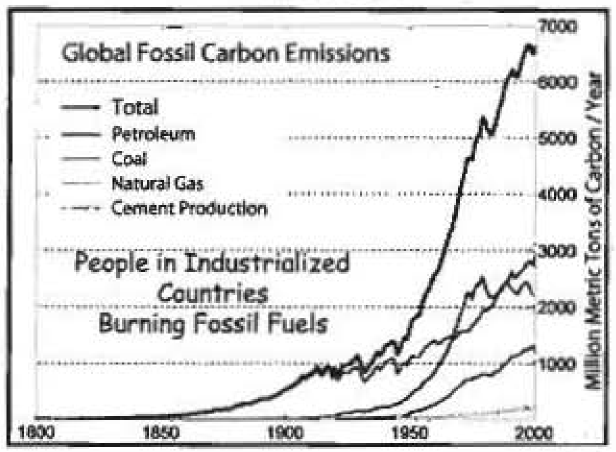
NASA - Goddard Space Flight Center ,Greenbelt MD USA
1 - NASA Headquarters, Washington DC USA
2 - NASA Langley Research Center, Hampton VA USA
3 - Jet Propulsion Lab, Pasadena CA USA
4 - GESTAR, NASA Goddard Space Flight Center, USA

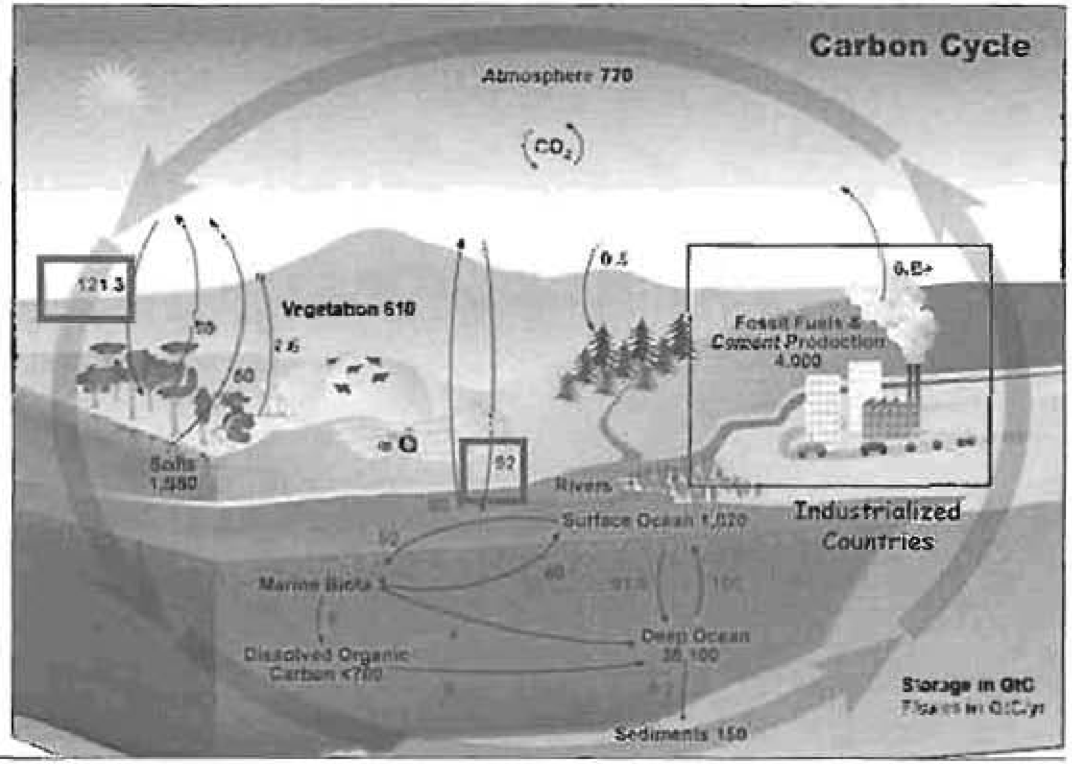
James.B.Abshire@nasa.gov

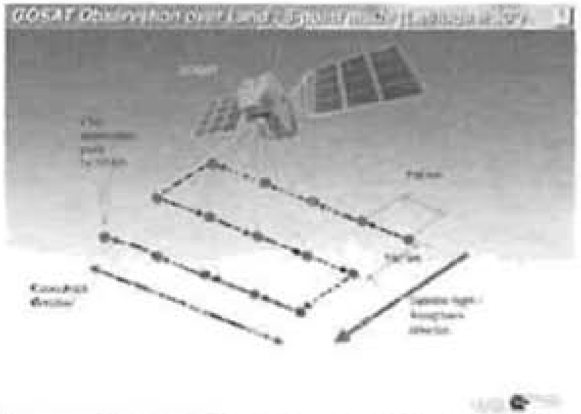
Atmospheric CO2 & Earth's Carbon Cycle

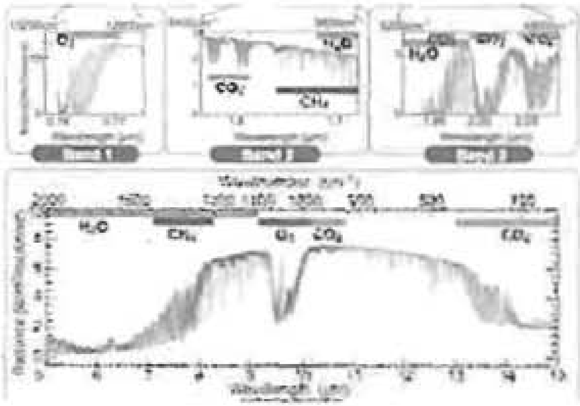


Major Questions about CO2 Sinks:
Is considerable uncertainty in locations, strengths, dynamics & evolution with time
=> Space Observations (GOSAT, OCO, ASCENDS)



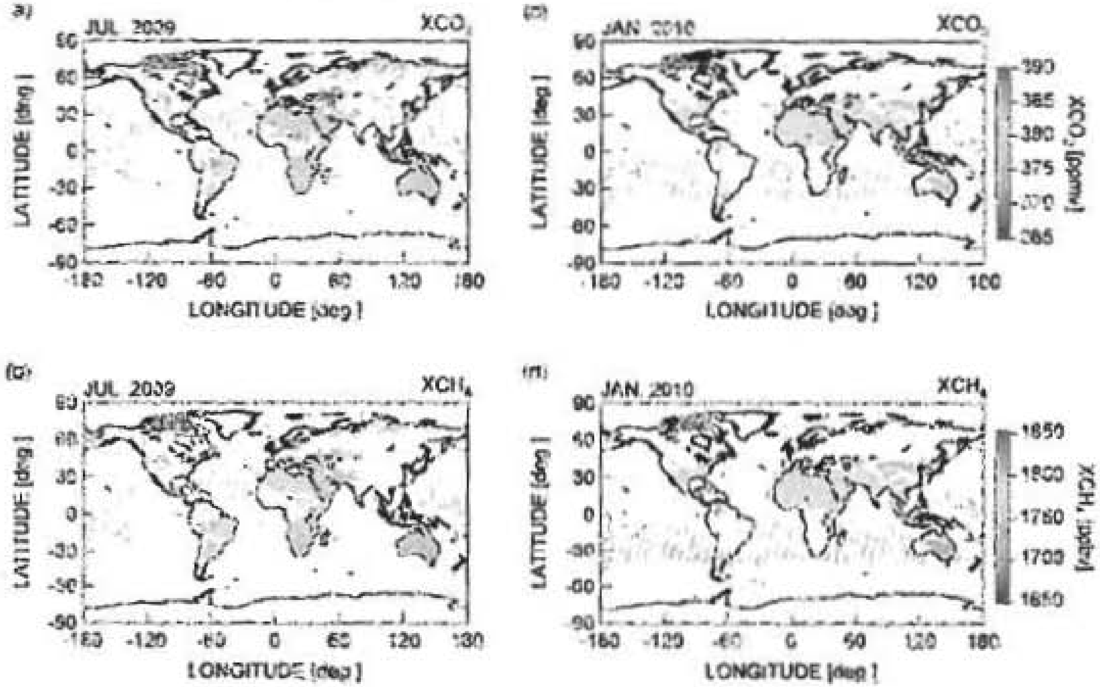






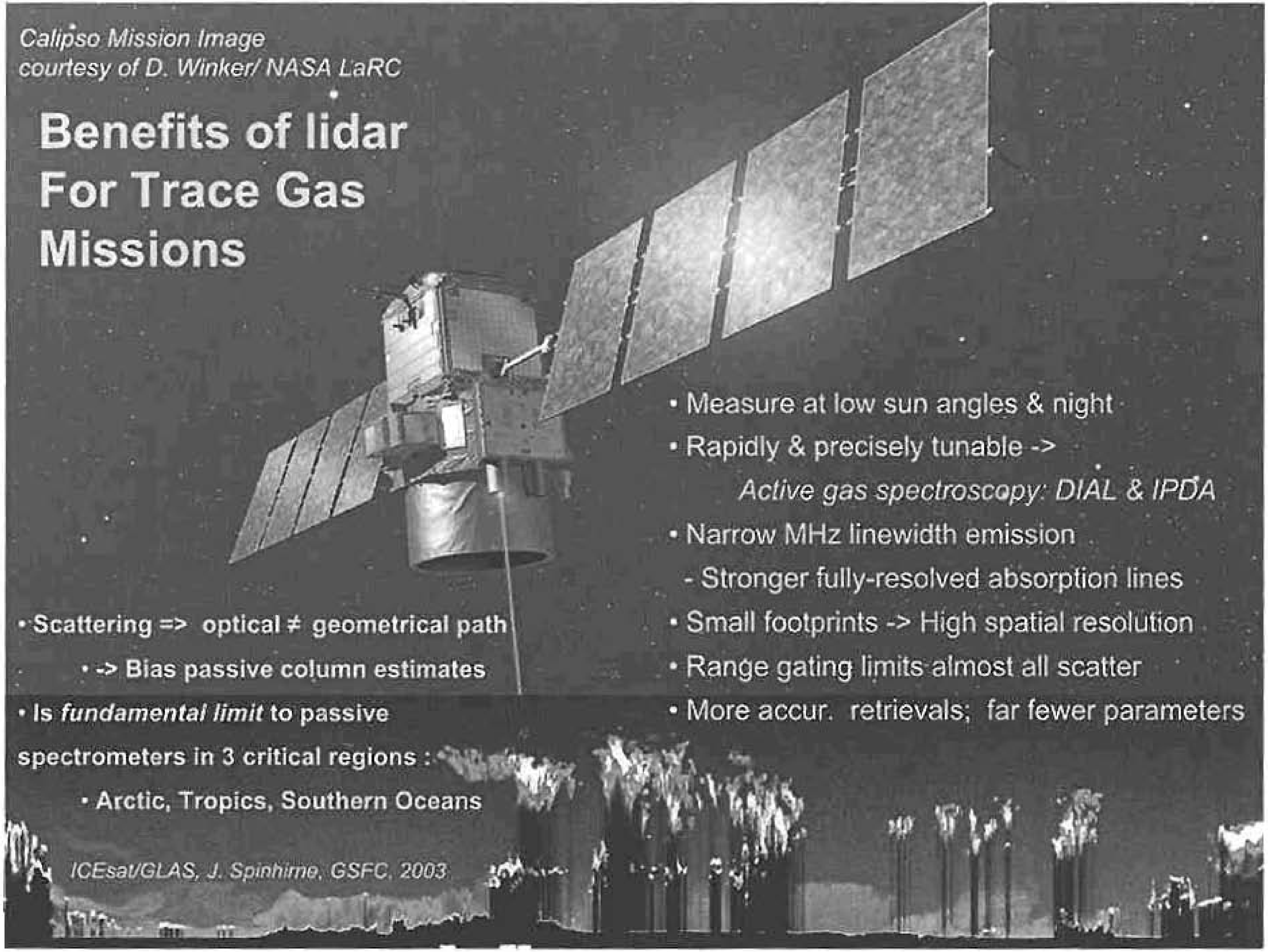
TANSO FTS Passive Optical Spectrometer 4-Bands

Retrieval algorithm for CO_2 and CH_4 column abundances from short-wavelength infrared spectral observations by the Greenhouse Gases Observing Satellite

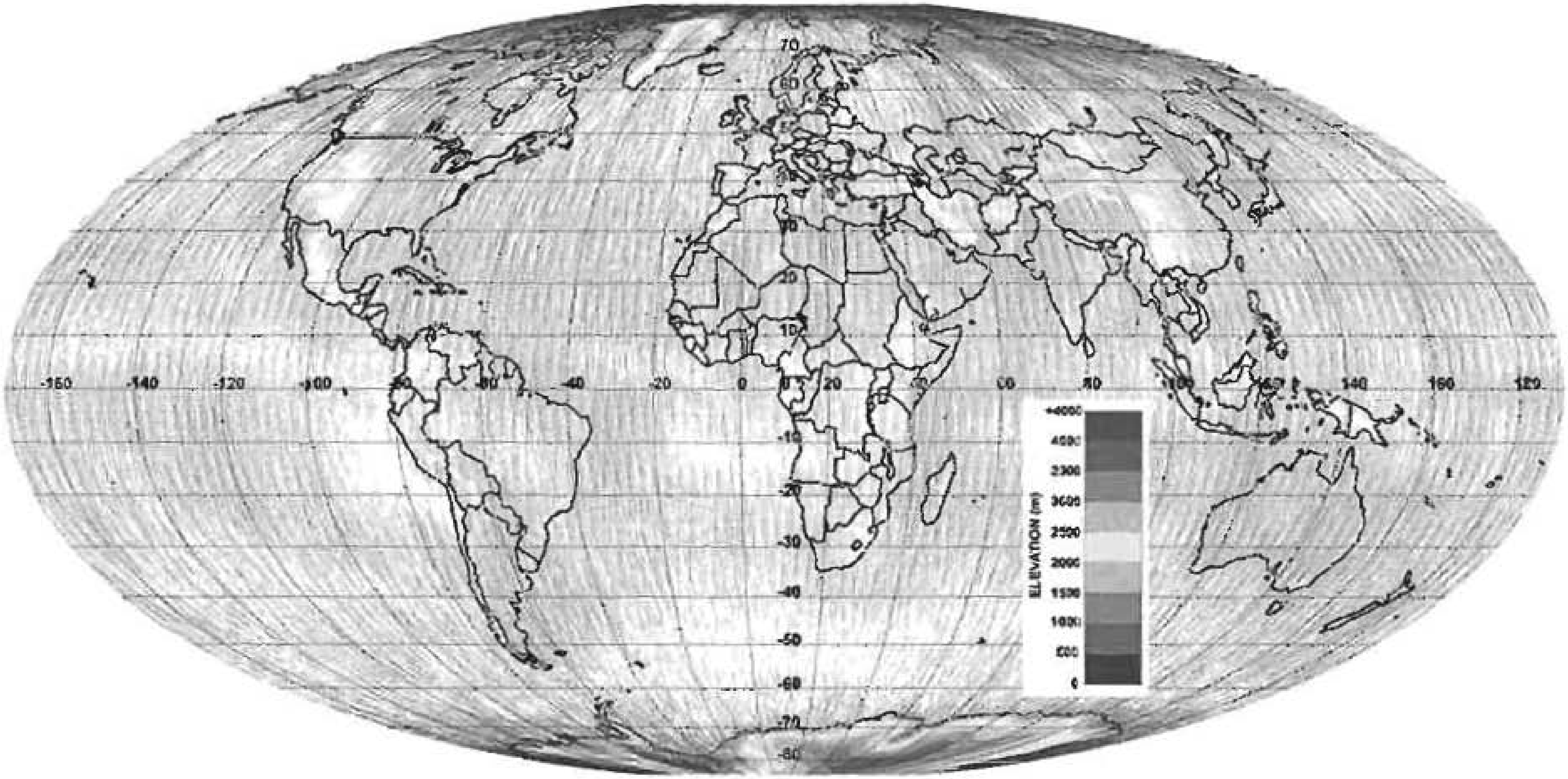


. 6. Monthly average of the retrieved XCO_2 [ppmv] (a, c) and XCH_4 [ppbv] (b, d) within a × 2.5-degree grid box. A blank indicates that no valid retrieval result was available within grid box.

GOSAT's Measurements of XCO2 (1 Month)


Calipso Mission Image
courtesy of D. Winker/ NASA LaRC
Benefits of lidar For Trace Gas Missions
• Measure at low sun angles & night
• Rapidly & precisely tunable ->
Active gas spectroscopy: DIAL & IPDA
• Narrow MHz linewidth emission
- Stronger fully-resolved absorption lines
• Small footprints -> High spatial resolution
• Range gating limits almost all scatter
• More accur. retrievals; far fewer parameters
• Scattering => optical ≠ geometrical path
• -> Bias passive column estimates
• Is fundamental limit to passive spectrometers in 3 critical regions :
• Arctic, Tropics, Southern Oceans
ICEsat/GLAS, J. Spinhirne, GSFC, 2003

Example of Lidar Measurements to Surface (ICESat/GLAS)



ICESat/GLAS Laser 2a Global Elevations: 9/25 to 11/19/03 (~45 days)

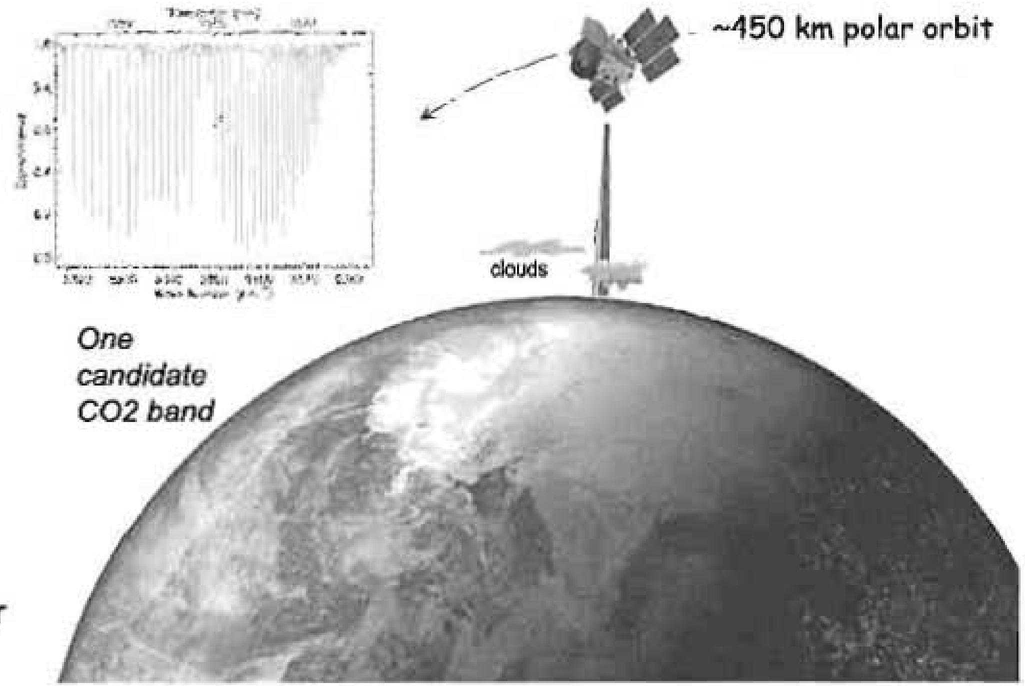
The NASA ASCENDS Mission

Some Notional Measurement Requirements
(under development)

1. CO_2 lower tropospheric column
   One line in 1575 or 2060 nm bands
2. O_2 total column (surface pressure)
   Measure doublet near 764 or 1260 nm
3. Mean Range to surface to a few m

Under the conditions of:

- To rough or smooth bare land & with crop cover
- To scattered trees to closed forests
- To snow surfaces
- To ocean surface, for wind speed not too high
- Through thin clouds and aerosols
- Through holes in broken cumulus clouds

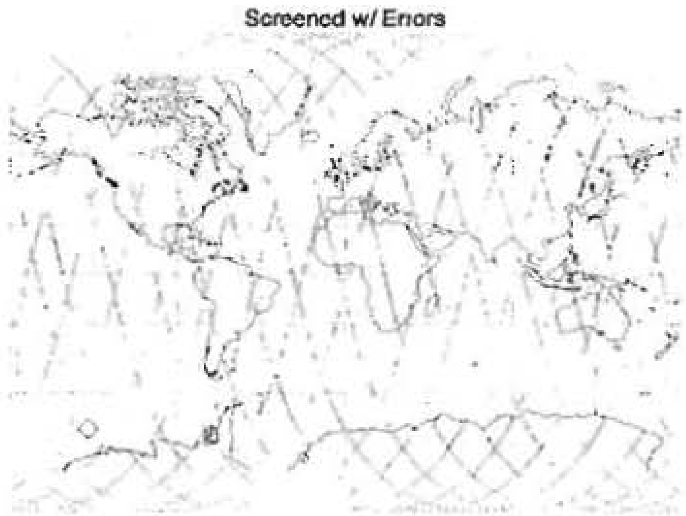


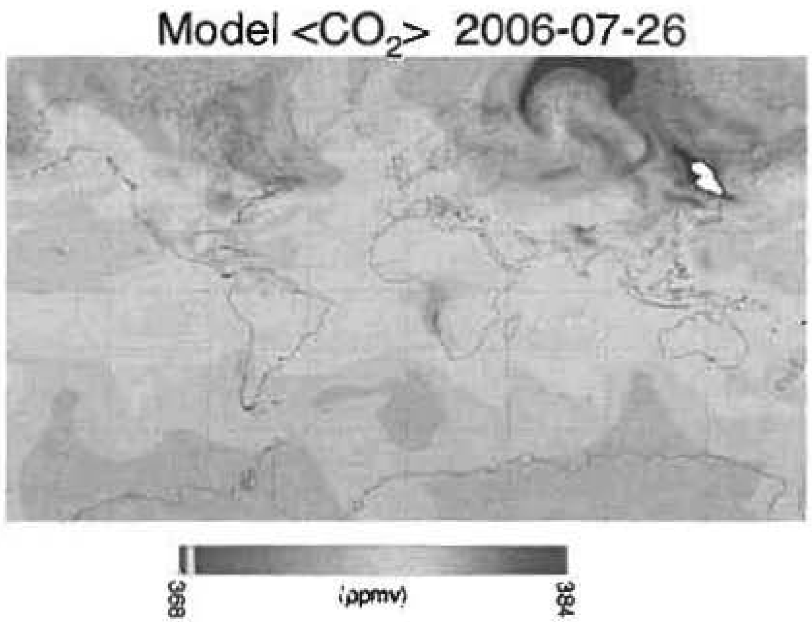
Space measurements require:

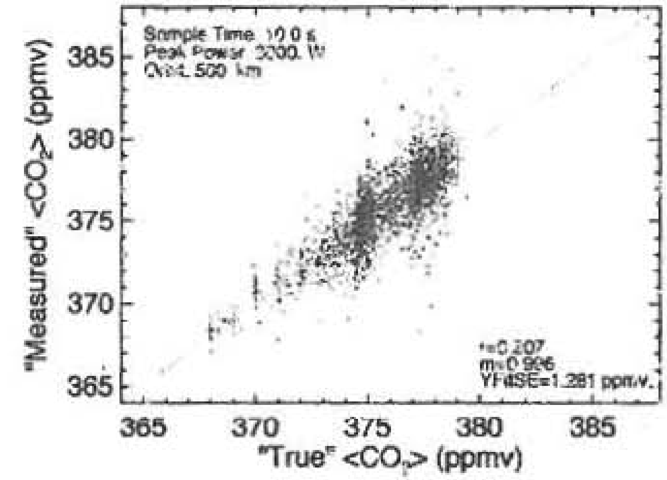
- 1ppm in ~100 km along track sample:
  => ~3 m Range (ave height of surface)
  => ~0.2% measurements of CO_2 & O_2 DODs
  in ~10 sec
  => "low" bias (<0.5 ppm)

Some Initial Ascends Simulation Results

(Kawa et al., GSFC)







- Single-sample errors average 1.3 ppmv for this instrument configuration (3mJ/pulse, 30 W average)
- Appear ~ consistent with nominal ASCENDS requirements.
- More extensive & improved simulations, using improved more generic lidar error model, being performed in 2011
- Results will help establish ASCENDS requirements

Airborne Experiments to Measure CO_2 & O_2 Column Densities Summer 2010 & 2011

ASCENDS

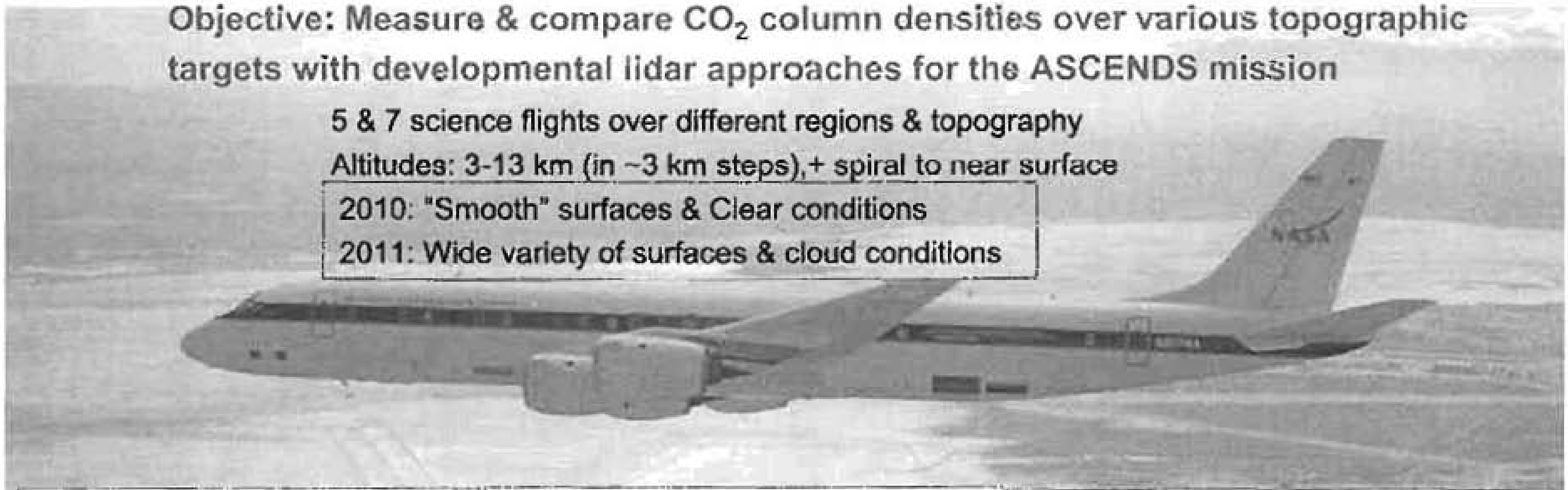
Objective: Measure & compare CO_2 column densities over various topographic targets with developmental lidar approaches for the ASCENDS mission

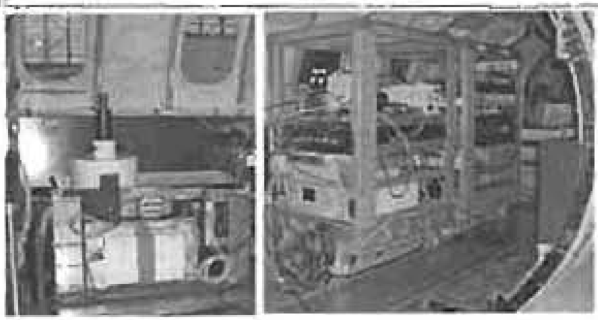
5 & 7 science flights over different regions & topography

Altitudes: 3-13 km (in ~3 km steps),+ spiral to near surface

2010: "Smooth" surfaces & Clear conditions

2011: Wide variety of surfaces & cloud conditions



LaRC/ITT instrument	GSFC instrument	JPL/LMCT instrument
		

LaRC/ITT instrument

- Multi-functional Fiber Laser Lidar (MFLL)
- Ed Browell/LaRC, Team Leader
- Instrument development via ITT IRAD, NASA AITT funding, LaRC IRAD

GSFC instrument

- CO_2 Sounder lidar with O_2 measurement experiment
- Jim Abshire/GSFC, Team Leader
- Instrument development via NASA ACT & IIP programs, GSFC IRAD

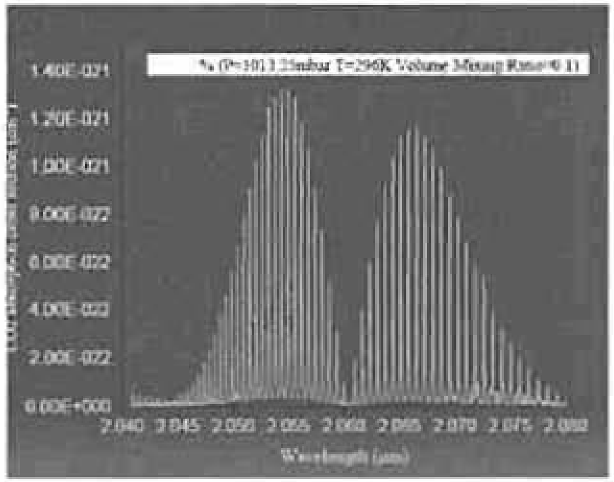
JPL/LMCT instrument

- CO_2 laser absorption spectrometer (CO_2LAS)
- Gary Spiers/JPL, Team Leader
- Instrument development via NASA ACT, IIP & AITT programs, JPL IRAD

JPL CO_2 LAS Airborne Instrument & Campaigns
(2051 nm line, 2 wavelength, CW Heterodyne)

ASCENDS

Parameter	Value
CO_2 line center wavelength	4875.749 cm^{-1}
JPL LAS ON wavelength JPL LAS OFF wavelength	4875.882 cm^{-1} 4875.225 cm^{-1}
Laser output power	75 mW
Transmit/Receive Telescope apertures	10 cm diameter
Receiver FOV (diffraction limited)	60 µrad
Photomixer type	InGaAs
Receiver heterodyne frequency window	10-20 MHz
Signal Digitization	5H[illegible] / [illegible]



Spiers et al.

Flight Campaigns:

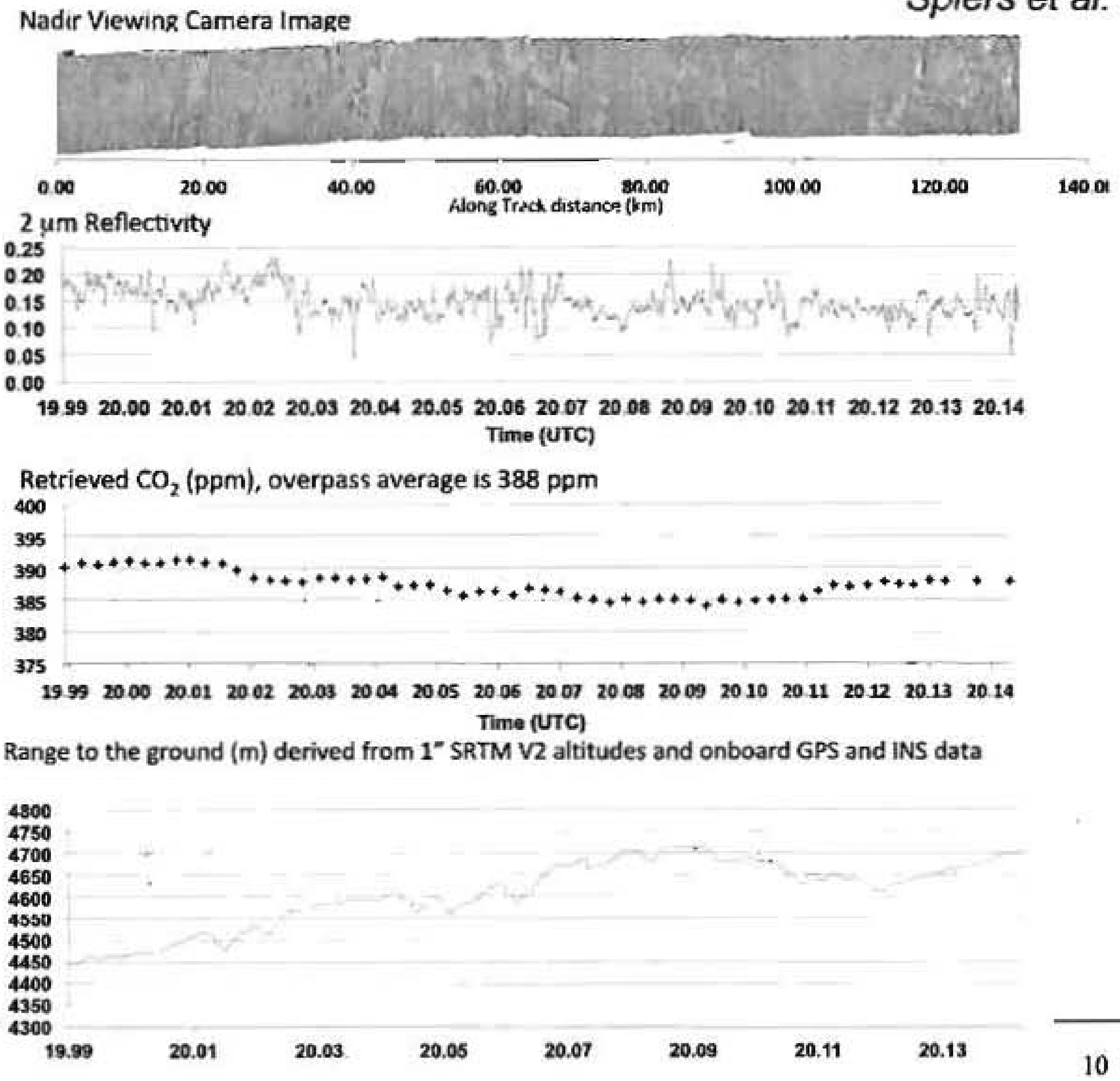
- California: checkout flights over Mojave desert & Pacific Ocean - Summer 2006.
- Virginia: 5 flights in October 2007, joint campaign with LaRC/ITT
- California: El Mirage, April, 2009.
- Oklahoma: 4 flights near ARM SGP site, July/August, 2009 – joint campaign with LaRC/ITT and GSFC airborne instruments.
- DC-8: 5 flights over California, Pacific, NV, Oklahoma), July, 2010.
- DC-8: 7 flights: Pacific, western & mid-western states, British Columbia, July & August, 2011.

JPL LAS: Observation of CO2 Drawdown over Eastern Colorado Plains 8/10/2011

ASCENDS

- Opportunity to detect/measure CO2 drawdown near the surface due to photosynthetic activity in vegetated areas;
- Transit from Denver area eastward to Iowa at constant altitude; stable a/c attitude, gradual ground elevation change during transit
- On-board *in situ* sensor data during spiral over western Iowa agricultural area showed ~ 15 ppm reduction in boundary layer;
- Visible and IR reflectance data indicate reflectance variability depending on surface material

Spiers et al.

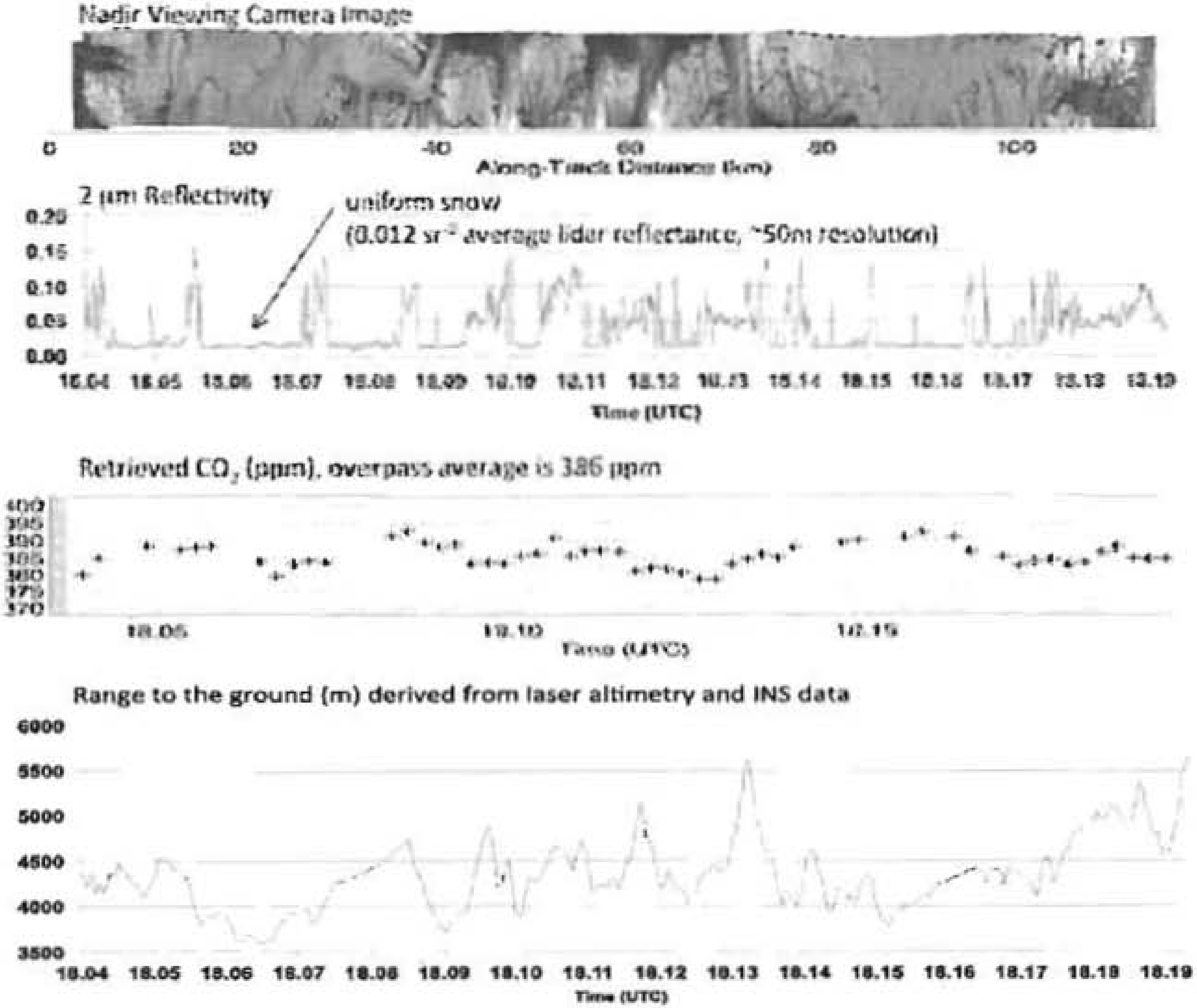


ESTO

JPL LAS: Reflectance & CO2 Retrievals over BC Mountain "Snowline" Segments, 8/7/2012

Spiers et al.

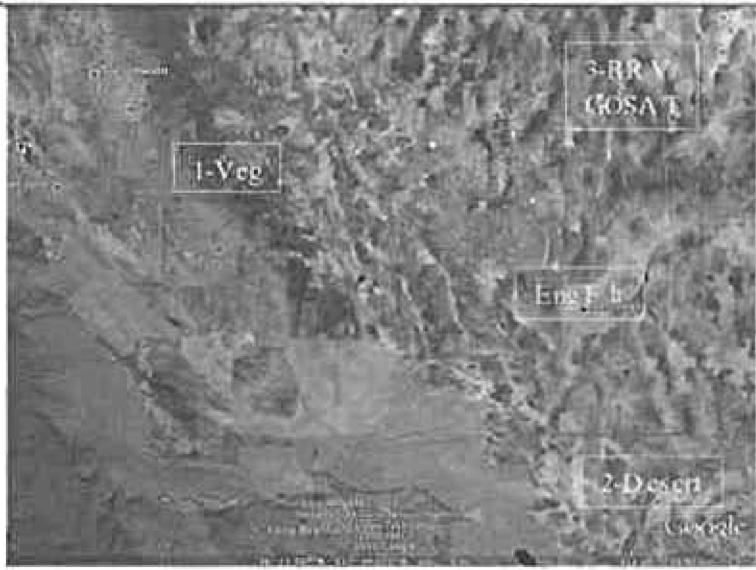
- Allowed measuring lidar reflectance from snow;
- the opportunity to assess CO2 retrieval capability over snow-covered mountainous terrain
- Reflectance data indicate a wide dynamic range, depending on surface material (e.g., snow, ice, rock, dirt, shrub)
- Minimizing range-to-ground component of the overall error budget in mountainous terrain is a major challenge, particularly with partial snow cover;
- High sampling rate is essential, with reflectance-weighted averaging;

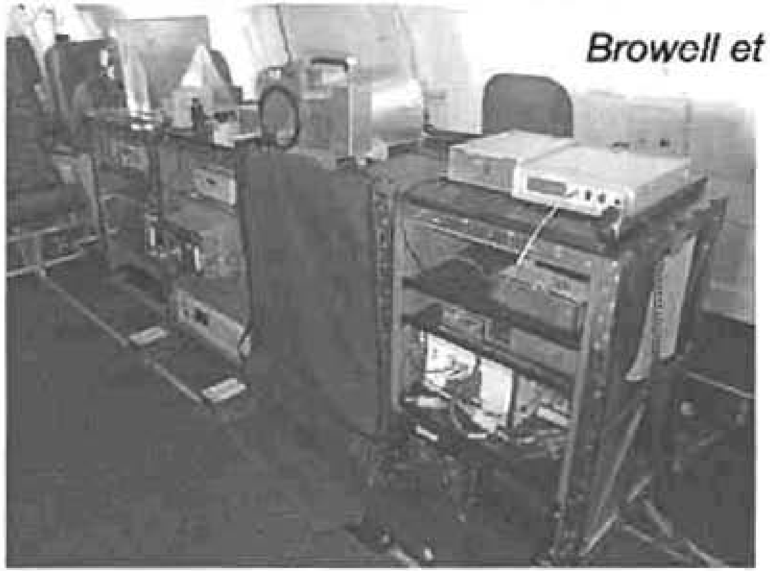


– Normalized rms ΔCO2: Snowline Out: 3.6 ppm; (1) speckle fluctuation component: 0.4 % normalized rms (i.e. ~ 1.6 ppm); (2) Dominant source of variability is range-to-ground (air mass) estimation uncertainty as non-co-boresighted laser altimeter

LaRC/ITT MFLL: ASCENDS DC-8 Flights

(1571 nm line, 3 λ, sine-wave modulation, direct detection)





Browell et al.

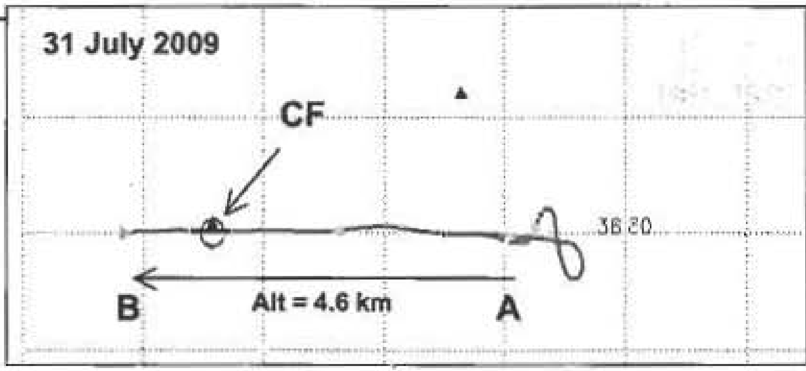
2010 Surface Reflectances & CO_2 Measurement Precision (7-km alt)

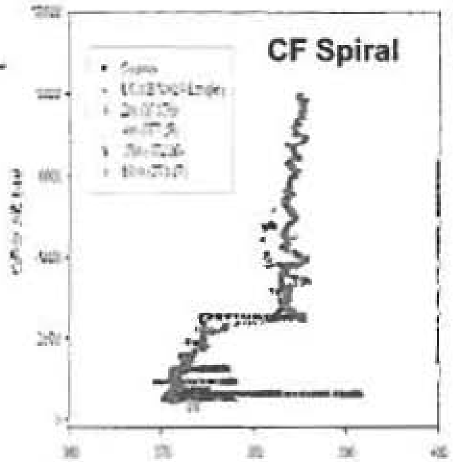
Surfaces	Desert	Desert	Vegetation	Vegetation	Ocean[3]
Location	Railroad Valley, NV	Needles, CA	Central Valley, CA	DOE ARM, Lamont, OK	Pacific off Baja
Median Surface Reflectance[1] [sr^{-1}]	0.143	0.118	0.098	0.080	0.019 (0.03-0.06)[4]
1-s CO_2 SNR[2] (CO_2 [ppmv])	630 (0.59)	612 (0.59)	545 (0.68)	560 (0.65)	~186 (2.87)
10-s CO_2 SNR[2] (CO_2 [ppmv])	1347 (0.27)	1443 (0.25)	1236 (0.30)	1460 (0.25)	~531 (0.72)

LaRC/ITT MFLL CO_2 Remote Measurements

ASCENDS

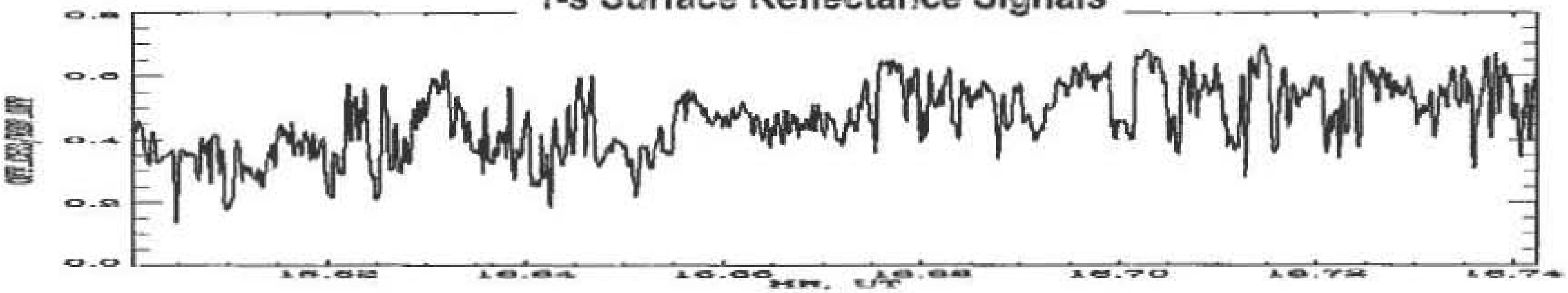
Browell et al.

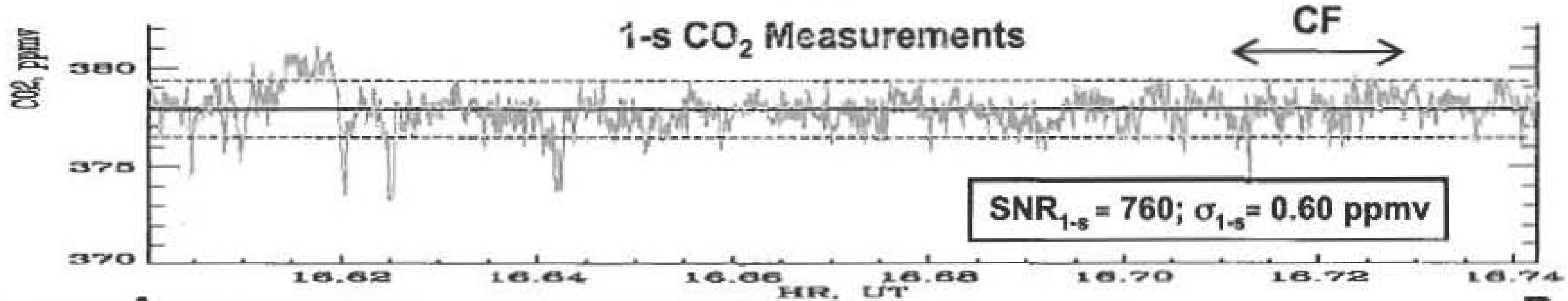




A

B





A

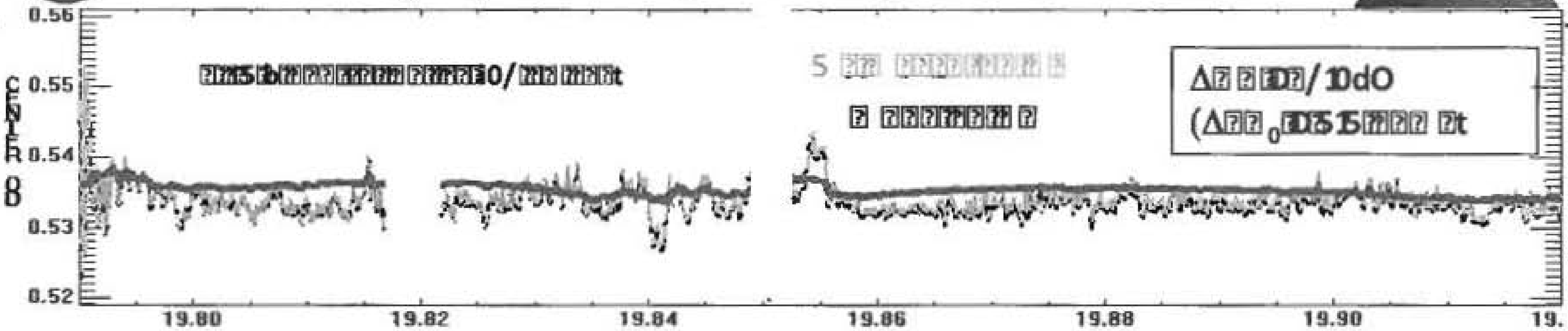
B

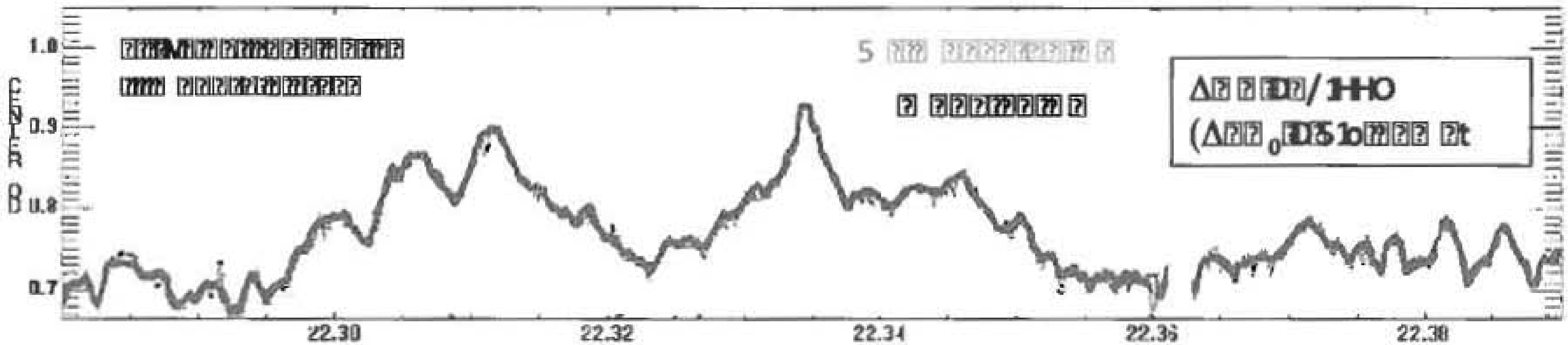
ESTO

10-s CO_2 Measurements: $SNR_{10\text{-}s}$ = 2002; $\sigma_{10\text{-}s}$ = 0.20 ppmv

LaRC MFLL: 2011 Ascends Flights
CO_2 Optical Depth Comparisons & SNR

ASCENDS

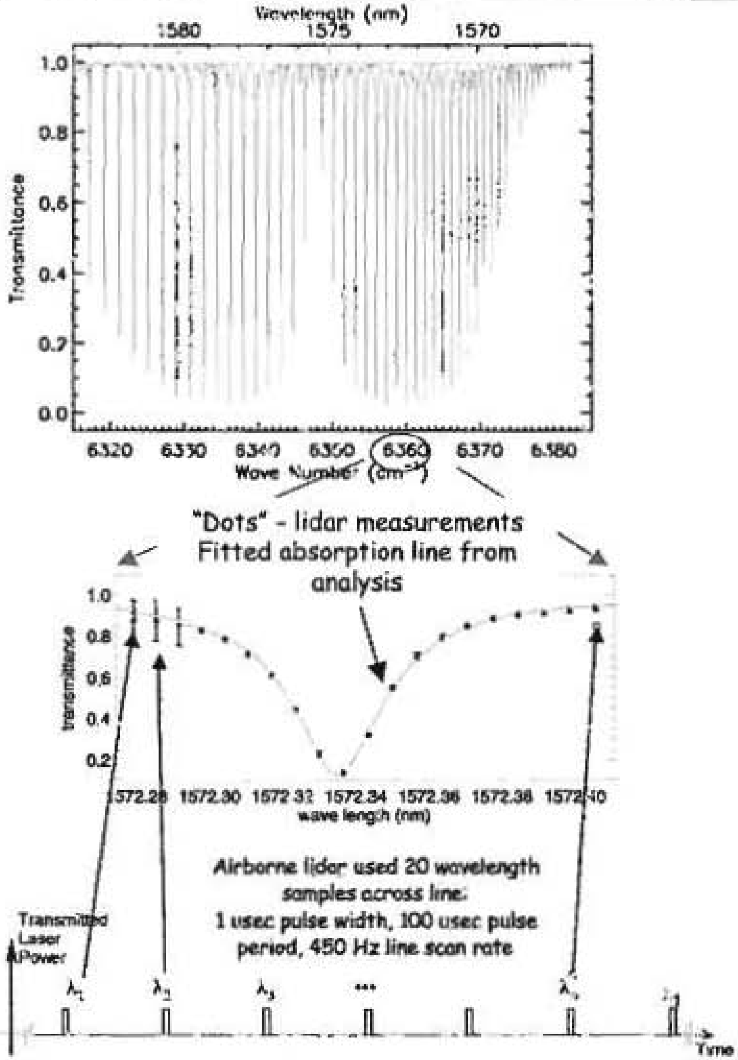




SNR Comparisons

Flight #	Start Hour	End Hour	Delta Time, sec	Nadir Range, m	Optical Depth	CO2, ppmv	1-s SNR	1-s σ, ppmv	10-s SNR	10-s σ, ppmv
1	20.07	20.08	198.0	6406	0.708	389.7	433	0.90	1264	0.31
3	20.03	20.06	211.0	6593	0.755	394.5	517	0.76	1510	0.26
4	15.63	15.70	396.0	6360	0.704	387.1	460	0.84	1325	0.29
5	20.00	20.02	180.0	8063	0.924	391.8	418	0.94	1274	0.31
7	17.21	17.23	79.2	5805	0.632	379.2	396	0.96	1237	0.31
		Avg:		6645	0.745	388.5	445	0.88	1322	0.29

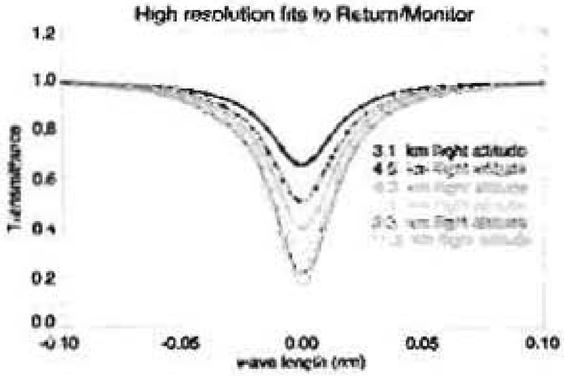
GSFC CO_2 Sounder Approach: 1572 nm line, Pulsed, Stepped λ's (8-30), direct detection



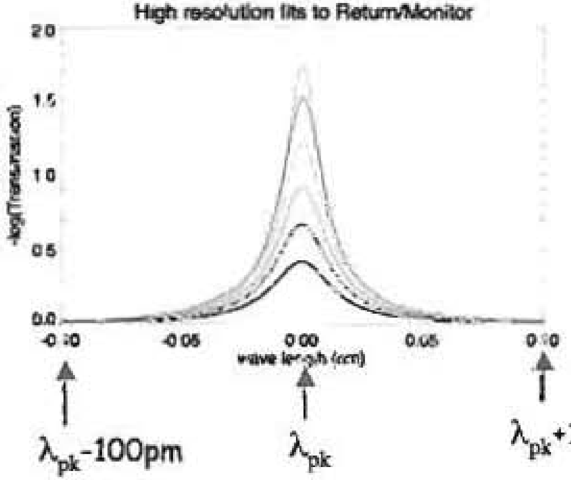
Airborne Lidar: 30 λ's (oversampling)

Space Lidar : 8 λ's

Line Transmission vs wavelength at increasing alt.'s



Optical Depth of fitted lines at increasing alt.'s



Note: Other λ's may be chosen for analysis

Retrieved Values:

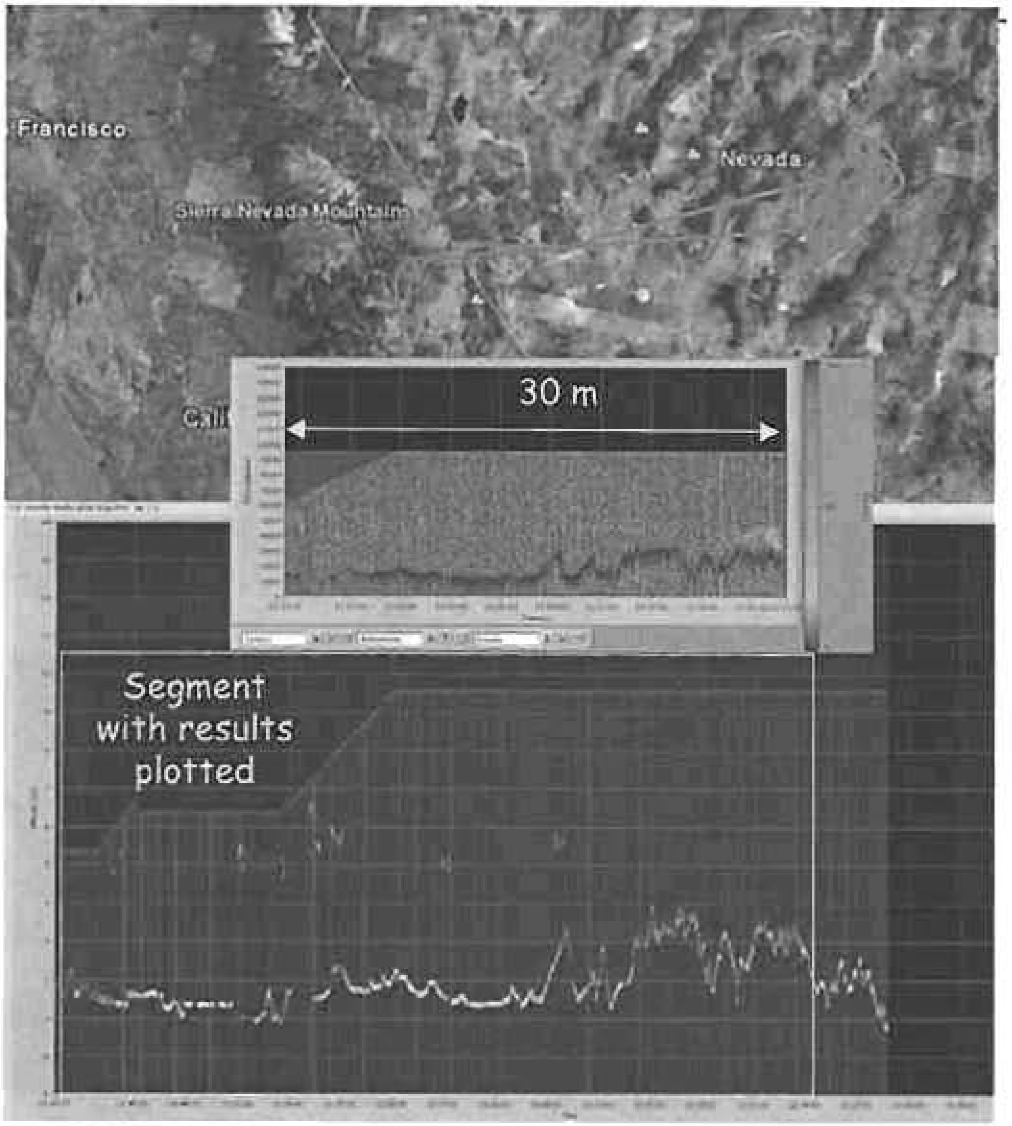
Differential Optical Depth:

DOD(pk) =

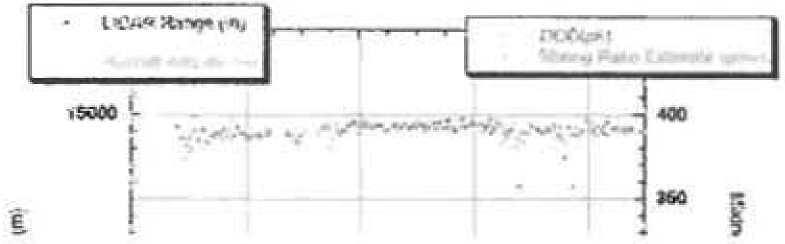
$OD(\lambda_{pk}) - [OD(\lambda_{pk}-100) + OD(\lambda_p+100)]/2$

GSFC CO2 Sounder: 2011 Ascends Flight 3
RRV, NV with Mountains on return leg

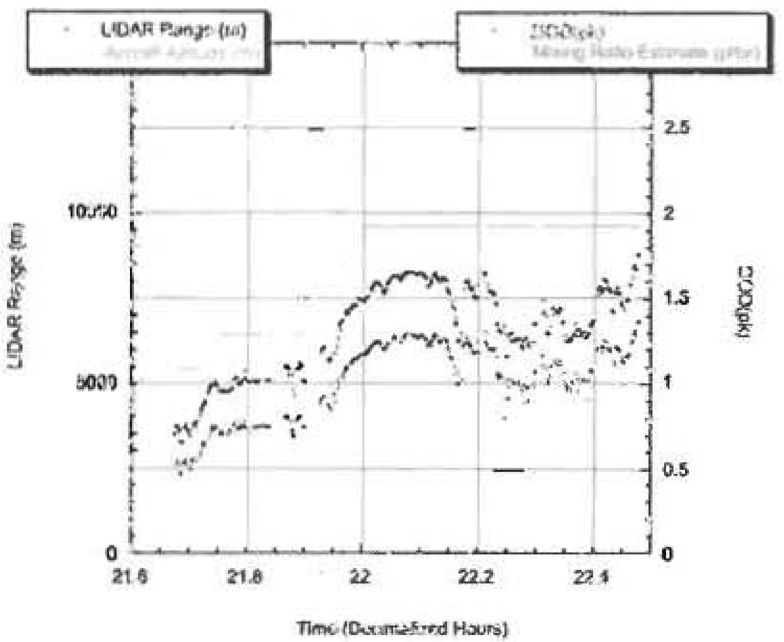
ASCENDS



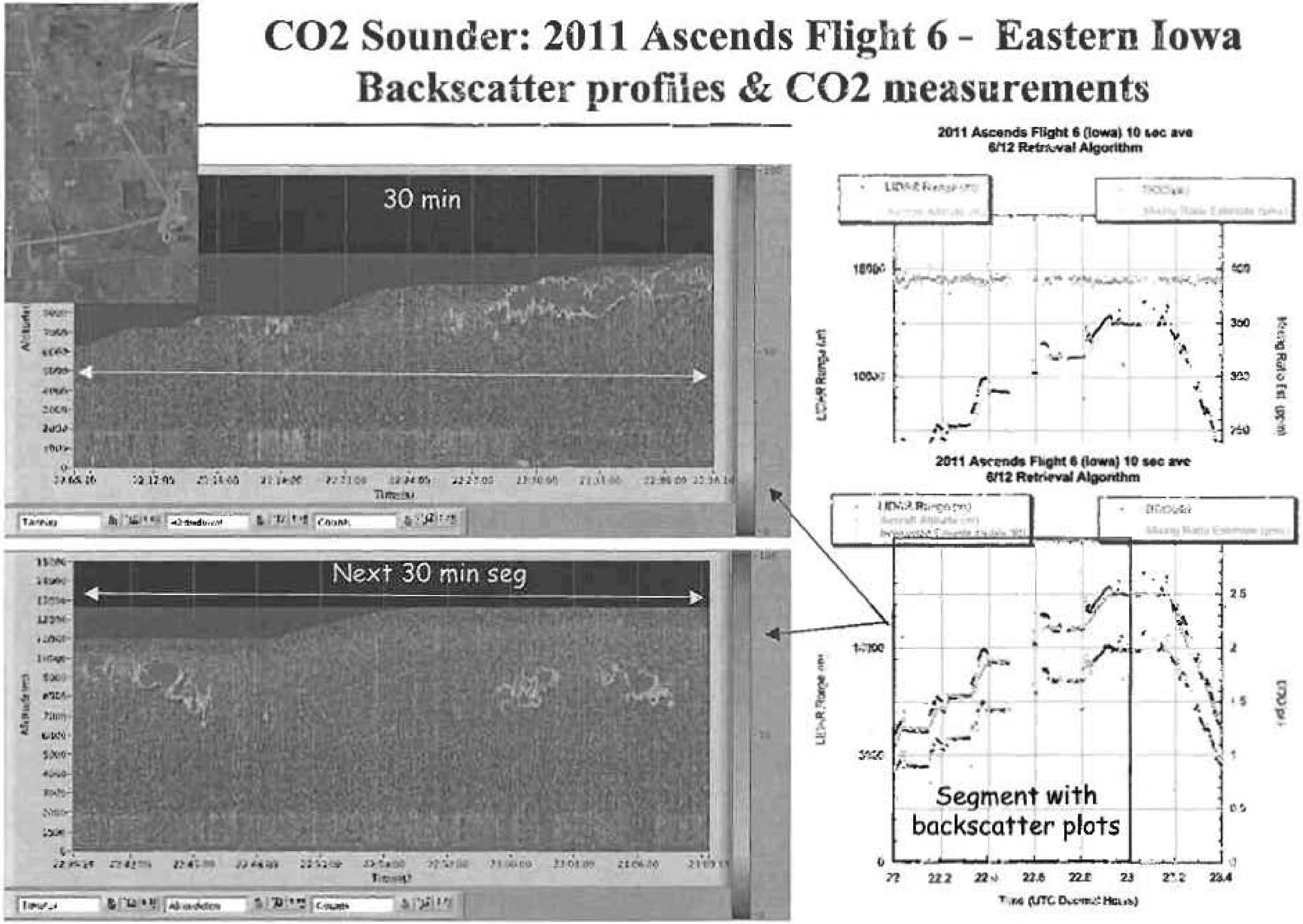
2011 Ascends Flight 3 (Railroad Valley) 10 sec ave
6/12 retrieval algorithm



2011 Ascends Flight 3 (Railroad Valley) 10 sec
6/12 retrieval algorithm



CO2 Sounder: 2011 Ascends Flight 6 - Eastern Iowa
Backscatter profiles & CO2 measurements



Summary - Ascends Mission Status

- **Develop Mission Measurement Requirements**
  - *Now: Working to complete initial set of OSSE measurement simulations*
- **Demonstrations of measurement techniques**:
  - 2009: 4-6 airborne flights Midwest - separate aircraft, clear conditions
  - 2010: 6 flights, CA and midwest - all on NASA DC-8, clear conditions
  - 2011: 7 flights - variable clouds & surface conditions
  - *Now: Complete 2011analysis, improve retrievals*

    Improve airborne lidar (CO2 & O2 measurements)

    Prep. for Feb 2013 flights - emphasis: measurements over snow & trees
- **Development of enabling *lidar technology* for space (NASA ESTO)**
  - *Now - Develop & demonstrate key instrument components in 2014*

More information & updates:

- Presentations at 8th IWGGMS (June 2012): https://sites.google.com/site/iwggms8/
- Fall AGU Meetings: "Greenhouse Gas Measurements Using Active Optical Remote Sensing"
- NASA ESTO ESTF conference: http://esto.nasa.gov/

Thank you !

4th
International
Workshop on
CO2/CH4 DIAL
Remote Sensing

3-5 November 2010 Oberpfaffenhofen, Germany

Contributors, Advocates, & Community Members

Backup