A Lidar Approach to Measure Atmospheric CO_2 Concentration from Space for NASA ASCENDS Mission

Jianping Mao[1], S. Randolph Kawa[2], James B. Abshire[2], and Haris Riris[2]

[1] Goddard Earth Sciences and Technology Center, University of Maryland at Baltimore County; [2]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

EGU2010-14603 (XY77 on May 4)

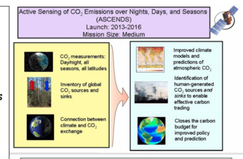
GSFC

NASA's ASCENDS Mission

Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS)

Why lasers ?

- Measures at night & all times of day
- Constant nadir/zenith path
  - Illumination = observation path
  - Continuous "glint" measurements over oceans
- Measurements at high latitudes
- Small measurement footprint
- Measure through broken clouds
- Measure to cloud tops
- Very high spectral resolution and accuracy

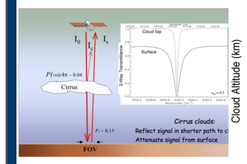


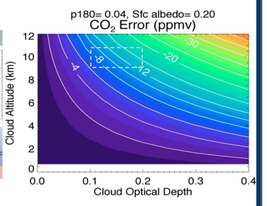
Are several lidar approaches for CO2 column:

Broadband laser - 1570 nm band - λ tuned receiver
1 line - 2 um band - pulsed - direct detection
1 line - 2 um band - CW heterodyne detection
1 line - 1570 nm band - synchronous direct detection
1 line - 1570 nm band - pulsed direct detection

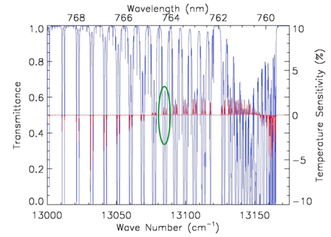
This approach →

Scattering from thin cirrus clouds must be reduced via techniques like time gating



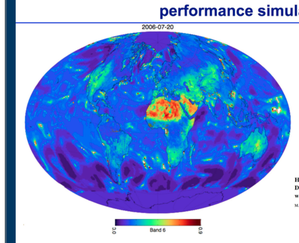


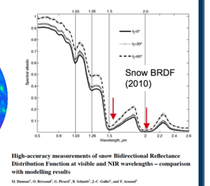
Oxygen A-band Temperature Sensitivity to +1K in PBL



- Doublet at 764.7 nm has the minimal temperature sensitivity
- Clear line separations for both off-line and on-line frequencies

Global surface reflectance used in measurement performance simulations

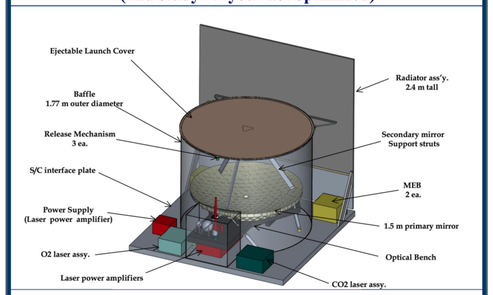




High-accuracy measurements of snow Bidirectional Reflectance Distribution Function at visible and NIR wavelengths – comparison with modelling results

- Reflectance over land from MODIS 16-d composite BRDF-adjusted nadir reflectance. Missing data =0.2.
- Over water, Fresnel reflectance is calculated at nadir using 10-m wind speed from the meteorological analysis.
- Reflectance over ice that is not available from MODIS (e.g., in the polar dark) is assumed to be 0.1.
- Ice cover extent is determined from the GEOS-4 analysis.

A possible ASCENDS Lidar Configuration (2nd study - layout not optimized)

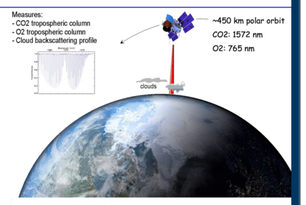


Laser Sounder Approach for ASCENDS Mission

Simultaneous laser measurements:

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

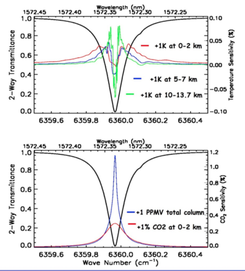
Measures:
- CO2 tropospheric column
- O2 tropospheric column
- Cloud backscattering profile



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

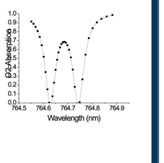
CO2 & O2 column measurements:
- Pulsed (time gated) signals :
  - Isolates full column signal from surface
  - Reduces noise from detector & solar background
- Target: ~ 1ppmV in ~100 km along track sample

Temperature Sensitivity of 1572.33 nm line



- ✓ Less sensitivity to atmospheric temperature
- ✓ Greater sensitivity to atmospheric CO2 amount

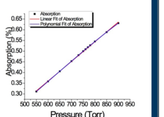
O2 absorption measurements from laboratory



Airborne O2 Lidar Parameters:
- Seed Wavelength: 1530 nm
- Custom NP Photonics EDFA
- Output Wavelength: 764.5 nm
- Output Energy: ~1 uJ/pulse
- Detector: SPCM
- Scan over the absorption with 20-40 Pulses (variable) at 450 Hz

Distance to target: 1.5 km
Target illuminated by green alignment laser

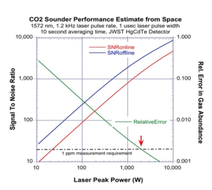
B33 Room F411
"Truth:" Weather station on top of B33



Space: SNR & Relative Measurement Errors

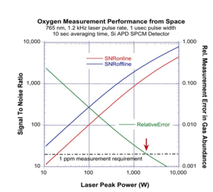
(10 seconds observing time, 500* km orbit, 1.5m telescope)

CO2 column measurement



~ 3 mJ/pulse energy (HgCdTe detector*)
Ave optical power ~25-30W

O2 column measurement



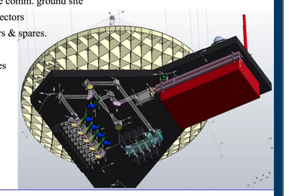
~ 3 mJ/pulse energy (SPCM detector)
6 mJ energy from 1530 nm amp, 50% doubling
Ave optical power ~25-30 W

* - Same performance at 3 mJ/pulse with PMTs at 400 km orbit

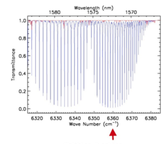
Rel Measurement Errors scale as (laser pulse energy)$^{-1}$*(T)$^{-1/2}$

2nd study - Aft view of optical bench

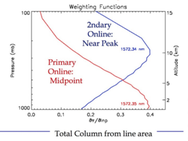
- Conducted studies of this approach for ASCENDS space lidar in 4/08 and 9/09
- Several aspects can be further optimized in design studies
- Straightforward space lidar design:
  - Mass: ~ 400 Kg (can be reduced via more efficient layout)
  - Power: ~ 850W (3dB margin); driven by SNR needs
  - Data rate: ~1.9 Mbit/sec; high latitude comm. ground site
- Low risk: Space qualified telescope, O2 detectors
- Detectors -> reliability via multiple detectors & spares.
- Primary power draw: lasers
- Lasers: high efficiency & reliability & spares

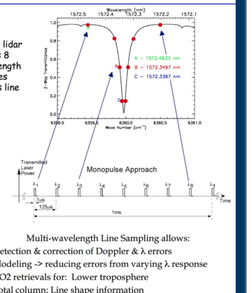


Candidate CO2 Line, Sampling & Vertical Weighting Functions



Space lidar plan is 8 wavelength samples across line

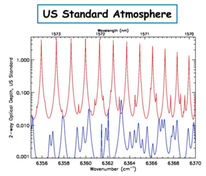




Multi-wavelength Line Sampling allows:
- Detection & correction of Doppler & λ errors
- Modeling -> reducing errors from varying λ response
- CO2 retrievals for: Lower troposphere
- Total column; Line shape information

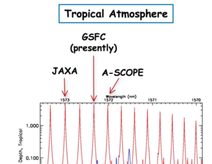
Water Vapor Absorption in tropics will influence CO_2 line selection

US Standard Atmosphere



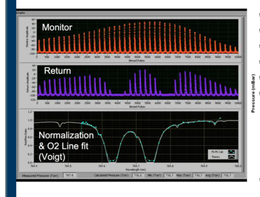
Tropical Atmosphere

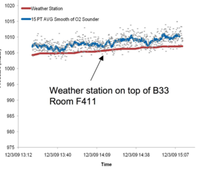
GSFC (presently)
JAXA
A-SCOPE



- Water vapor influence is usually small
- Measurements in tropics mean
- Choose CO_2 line and wavelengths *carefully !*

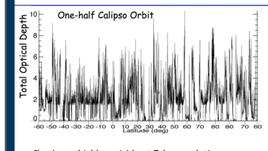
Sample O2 Measurements made over 1.5 km horizontal path with photon counting detector

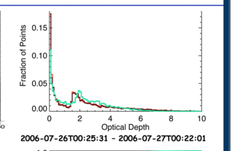




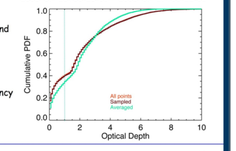
Weather station on top of B33 Room F411

Using Calipso measurements to Representing Clouds in Error Model



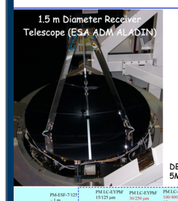


2006-07-26T00:25:31 - 2006-07-27T00:22:01



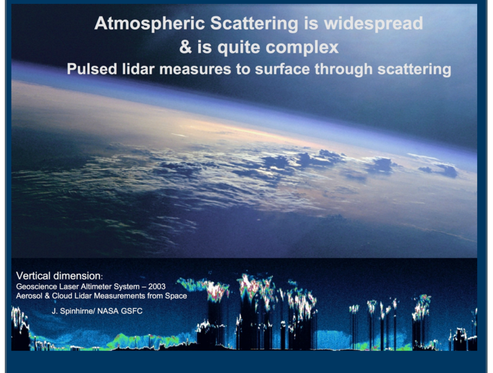
- Clouds are highly variable at 5-km resolution.
- Along-track averaging narrows the PDF (fewer high and low values).
  - fewer samples at a given optical depth cutoff
  - greater overall CO_2 measurement uncertainty
- Expect cloud-clearing will be done at a sample frequency greater than 1 Hz.
  - conditionally sampled average optical depth significantly less than the 10-s average

Some key space lidar components

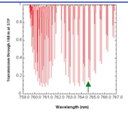


Atmospheric Scattering is widespread & is quite complex

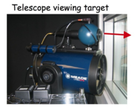
Pulsed lidar measures to surface through scattering



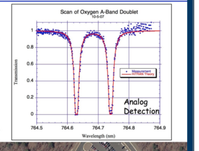
Oxygen - Open path measurement of absorption lines near 765 nm

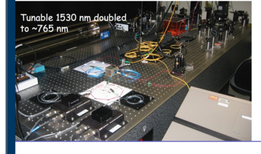


Oxygen A band: Atmospheric transmission for 100 m path at STP



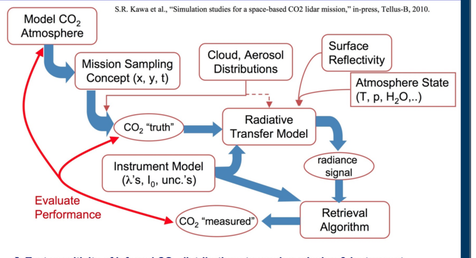
Peak optical power ~ 50 mW
Attenuation for round trip was ~10^6





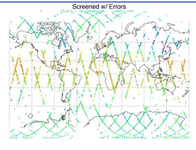
Measurement Model & Mission Performance Simulation

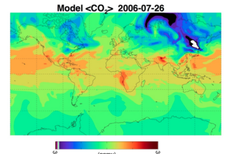
S.R. Kawa et al., "Simulation studies for a space-based CO2 lidar mission," in-press, Tellus-B, 2010.

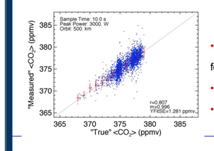


➔ **Test sensitivity of inferred CO_2 distributions to varying mission & instrument design parameters.**

Nominal Design Point Error Estimate

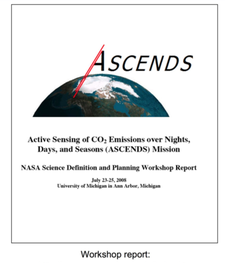






- Initial results: Single-sample errors average 1.28 ppmv for this instrument configuration.
- Consistent with ASCENDS requirements.
- Work is ongoing

Summary



Workshop report:
http://cce.nasa.gov/ascends/index.htm

CO2 Sounder approach has key capabilities:

- CO2 and O2 (pressure) measurements
- Column height measurements
- Clean spectral regions
- Lower and upper tropospheric CO2 column measurements
- Robust against cloud & atmospheric scattering errors
- CO2 measurements demonstrated from aircraft
- Ground-based O2 measurements demonstrated (airborne ones in prep.)
- Lidar Power*Area product needed for space has been assessed
- Space instrument studies show technology is practical