Airborne IPDA Lidar Measurements using the Oxygen A-Band

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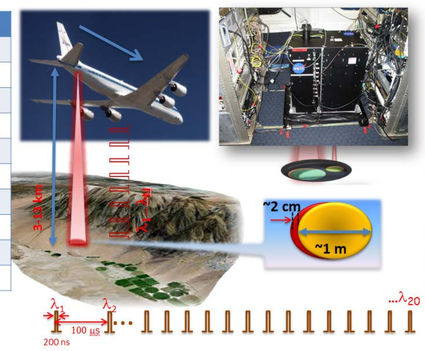
- **Why Oxygen? We need to measure the dry air column in order to estimate the dry mixing ratio of CO_2 for ASCENDS.**
- **Meteorological models can provide surface pressure but there are concerns about global coverage and co-location of the measurements.**
- **The GSFC Integrated Path Differential Absorption (IPDA) lidar uses a tunable fiber laser, doubling crystal, and flight qualified single photon counting detectors to measure Differential Optical Depth (DOD) at 765 nm for the dry air column.**

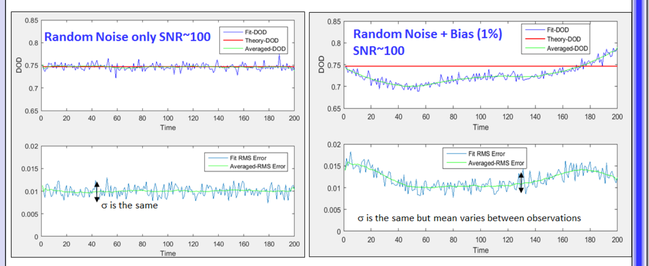
GSFC O_2 Airborne IPDA Lidar

Parameter	Value (2014)*
Center l	764.685 nm
PRF	10 KHz
Pulsewidth	200 ns
Energy	~ 1.5-2.0 µJ
Bin Width	32 ns (10 ns)
Divergence	~110 µrad
FOV	200 µrad
Bandpass	0.5 nm (0.8 nm)
Averaging T	1 s (125 ms)
Detector QE	~ 50%

*2014 values in parenthesis



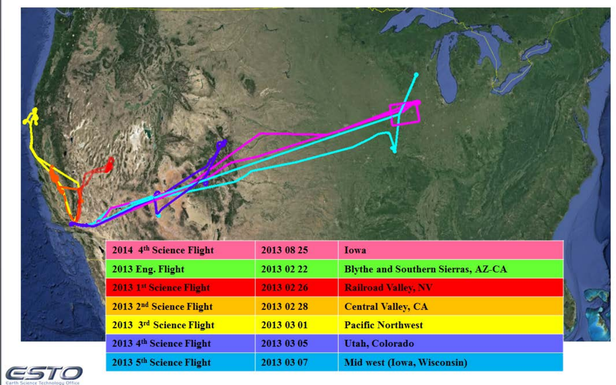
Simulation of instrument bias errors on retrievals



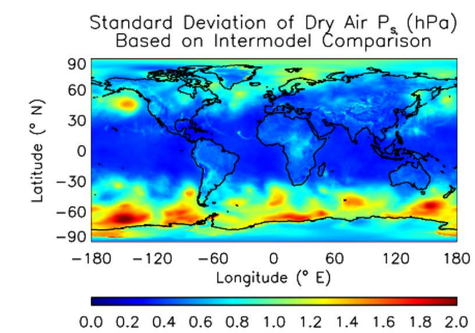
- Time dependent bias errors (non-stationary noise) will bias the retrievals. These biases cannot be filtered or averaged out and their impact will not be apparent solely from the SNR and/or RMS error. The standard deviation may be held constant, but the mean varies over time. They need to be adequately sampled in order to asses their impact.

References: P. Werle, Applied Physics B, Volume **102**, pp 313-329, (2011); John von Neumann et al. , Ann. Math. Stat. **12**, 153 (1941)

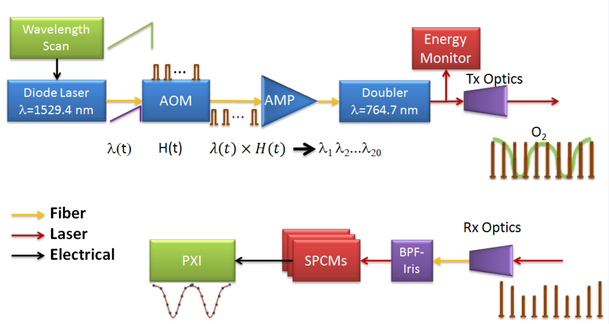
2013-2014 Flights



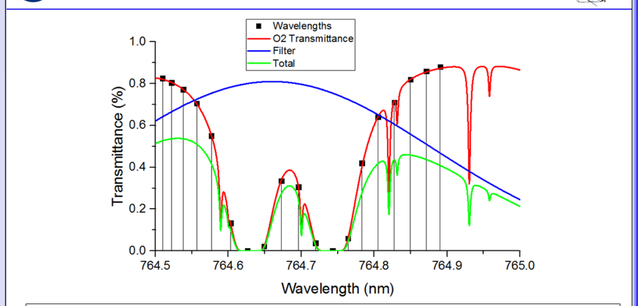
Surface pressure from meteorological analyses



Functional Block Diagram

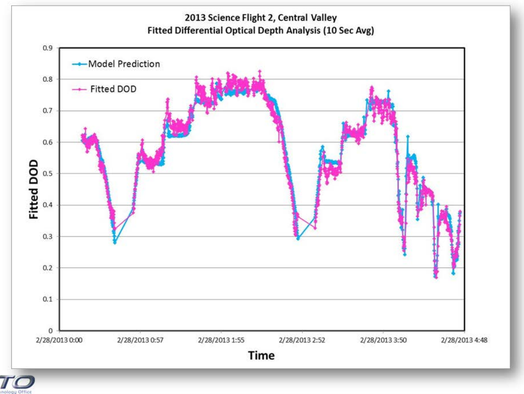


Example of a Systematic Error



- Narrow Filter severely distorts the lineshape.
- Correction (calibration) is possible but difficult to implement to < 0.1%
- ➢ Using a wider filter (0.8 nm) should minimize distortion but increase solar background
- ➢ Using an isotope line may also be a viable alternative
- ✓ **Both implemented in 2014 flights.**

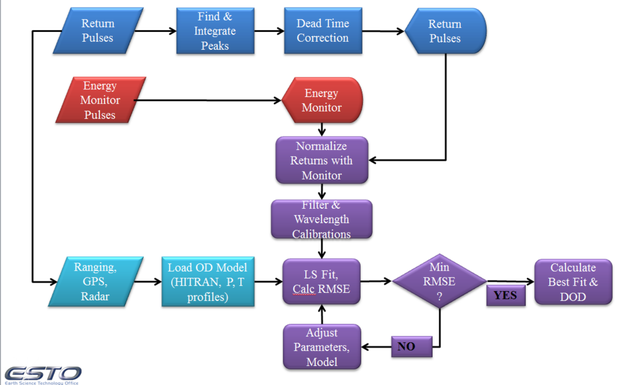
2013 Flight 2 Central Valley, CA



Model Surface Pressure Uncertainty

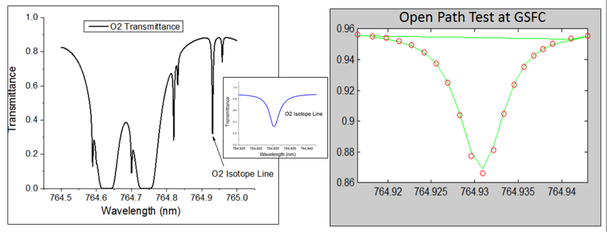
- The uncertainty of surface pressure from meteorological analyses was estimated by comparing fields from the Modern Era Retrospective-analysis for Research and applications (MERRA), the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis, and NOAA's Climate Forecast System Reanalysis (CFSR). The range of reanalysis surface pressure values was computer every 6 hours during 2009, and means and standard deviations of the surface pressure range computed. In most regions, intermodel differences are less than 1 hPa. The largest differences among reanalyses exist in data sparse regions where, in the absence of a strong observational constraint, model physics tend to dominate. Over much of the Southern Ocean, large surface pressure uncertainties translate to 0.5-0.8 ppm XCO2. This uncertainty exists because the remote Southern Ocean is virtually unobserved by conventional in situ observations, and assimilation of satellite observations is limited by persistent cloudiness.

Retrieval Algorithm

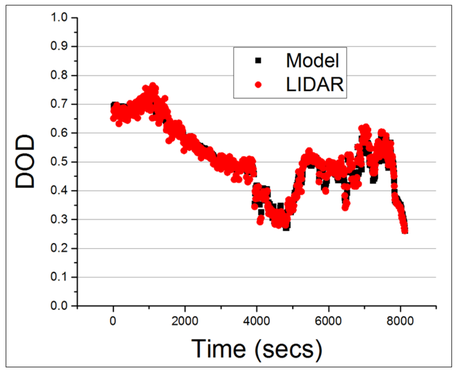


An alternative Isotope Line

- *Why consider an isotope line?* The narrow bandpass filter and large scanning range severely distort the O_2 lineshape making post-processing calibrations and subsequent retrievals difficult. An O_2 isotopic line at 764.93 nm was identified and tested as a possible candidate.



2014 Iowa Flight



O2 LIDAR Summary

- Meteorological analyses and models need to be validated by independent surface pressure measurements at the relevant spatial scales.
- Impact of co-location of the meteorological models and ASCENDS CO_2 observations needs to be evaluated.
- O_2 LIDAR Improvements:
  - Increase laser energy to ~ 2-4 mJ for space.
    - Increased laser energy by a factor of 5-6 since 2013 with new amplifier
- Improve dynamic range
  - Increased dynamic range by a factor of 8 since 2013
- Control Bias errors
  - Several hardware and software changes were implemented to control bias errors and improve stability.

- ✓ **The GSFC O_2 IPDA lidar has flown on NASA's DC-8 airborne laboratory since 2010 and the retrievals track atmospheric models over a wide range of topography and ground cover from altitudes of 3 km and 13 km.**
- ✓ **Our total random error is currently 8-10 mbar (with 60 secs averaging) and is limited by the laser energy and receiver dynamic range.**
- ✓ **We increased the dynamic range of the receiver for the 2014 flights by a factor of ~ 8 but had a laser power supply failure in our engineering flight. The lidar was operational for only one flight in 2014.**
- ✓ **Following the 2014 flights we have increased the laser pulse energy by a factor of 6. We anticipate the random error to be reduced further.**