Low-power, Portable, Wireless Laser Spectroscopic Sensor for Atmospheric CO_2 Monitoring

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Motivation

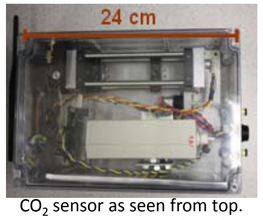
The CO_2 impact on the greenhouse gas effect requires global and local monitoring capability which would greatly benefit from availability of sensors that are:

- Lightweight, portable, and robust
- Highly sensitive
- Low-power/battery operated
- Wirelessly networked and autonomous

Background

We have developed a compact, wireless, tunable diode laser absorption spectroscopic (TDLAS) CO_2 sensor, which:

- Is housed within a 24x16x9 cm NEMA enclosure for environmental protection
- Is equipped with a 3.5 m path Herriott multi-pass cell within a physical space of ~20 cm
- Employs a 2 µm VCSEL & uncooled InGaAs photodetector
- Is based on the openPHOTONS platform[1]
- Is powered by an integrated 10 Ah Li-ion polymer battery



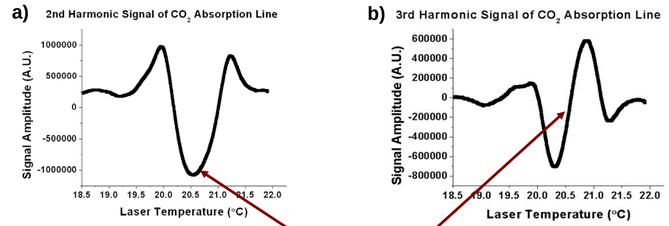
CO_2 sensor as seen from top. The total size is less than that of a shoebox.

Conclusion

- A robust, portable, wireless, low-power CO_2 sensor based on TDLAS with a custom Herriott multi-pass cell was demonstrated to have:
  - 2f SNR of 2530; Gaussian white noise performance to 100 sec; ultimate minimum detectable absorption of ~$6x10^{-7}$
- Lab and field performance tests compare well with the commercial Vaisala GMP343 CO_2 sensor
- The calibration is performed in the laboratory using calibration gas mixtures
- New modules for sensor calibration in the field based on Beer-Lambert law are currently under development

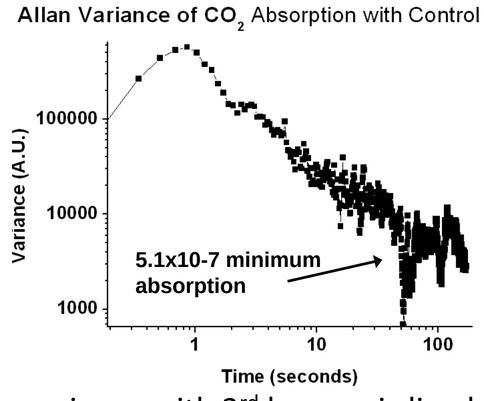
CO_2 Sensor Operation

- Laser temperature and drive current and signal processing are controlled by custom PHOTONS electronics with USB and wireless interface
- Sensor uses TDLAS with wavelength modulation at 10 kHz
- Temperature total tuning range of 5 cm^{-1}
- 2nd & 3rd harmonics of the modulation frequency yielded SNR's of 2530 & 1052, respectively



Continuous CO_2 monitoring is performed using the maximum of the 2f signal and line locking performed with the 3f signal at zero-crossing

CO_2 Sensor Allan Variance

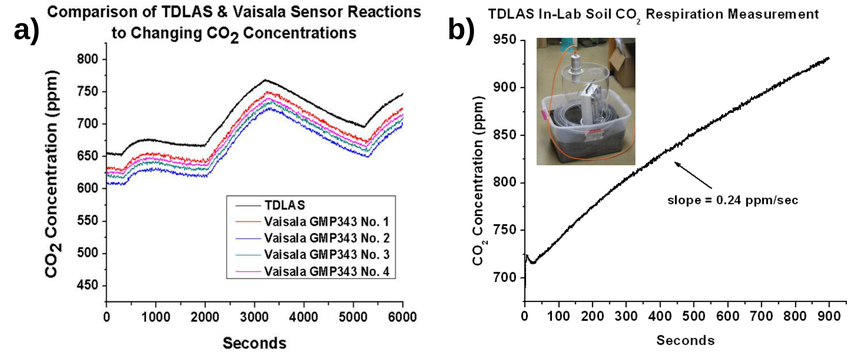


- Allan variance with 3rd harmonic line locking at 4987 cm^{-1} absorption line showed:
  - Gaussian white noise performance up to 100 sec.
  - Sensitivity of 0.113 ppm in 1 sec averaging time
  - Minimum detectible absorption of $7.4x10^{-6}$ in 1 sec.
  - Ultimate minimum detectable absorption of ~$6x10^{-7}$ has been achieved with 100 sec. averaging

References:

[1] www.openphotons.org, "openPHOTONS repository."

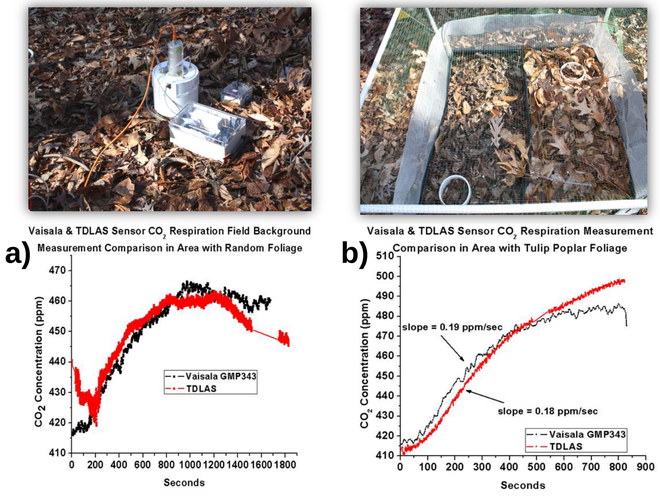
Lab Tests: Comparison with Vaisala CO_2 Sensor & Soil Respiration Measurement



- Testing at 0 °C (Figure (a)) shows nearly identical behavior between TDLAS and Vaisala GMP343 sensors
  - When the CO_2 concentration was varied, the TDLAS sensor showed the same concentration trends
- Soil CO_2 respiration at room temperature was measured to have a typical concentration increase slope of 0.24 ppm/sec

Field Tests: Forest Floor Respiration

- Soil respiration measurements performed at the Smithsonian Environmental Research Center
  - TDLAS and Vaisala produced nearly identical measurements in the control area with random foliage makeup (Figure (a))
  - In an area with just Tulip Poplar leaves (Figure (b)), TDLAS and Vaisala measured soil CO_2 respiration slopes of 0.18 ppm/sec. and 0.19 ppm/sec, respectively



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