Atmospheric Absorption Spectroscopy using Supercontinuum Lasers

Perry S. Edwards, David M. Brown, Andrea M. Wyant, Zhiwen Liu, C. Russell Philbrick
Department of Electrical Engineering,
The Pennsylvania State University, University Park, PA 16802
pse104@psu.edu

Abstract: A supercontinuum absorption spectroscopy (SAS) approach for measurement of atmospheric constituents is extended to offer increased capability of detecting concentrations of gaseous species. An atmospheric path length greater than 600 m is utilized in the multi-wavelength differential absorption setup. A multi-wavelength algorithm for analysis of the spectra measurements obtained from the return of the supercontinuum source is used to determine the concentrations of species, with comparison to MODTRAN™ 5 simulation spectra. Further developments to the SAS approach and measurements are presented.

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1. Introduction and Experimental Setup

Supercontinuum absorption spectroscopy was developed to offer a multi-wavelength approach for detection of gaseous atmospheric species utilizing a single laser rather than traditional methods of multiple laser differential absorption lidar (DIAL) [1]. The supercontinuum source used in the SAS experimental setup is generated by coupling a 1064 nm, nanosecond pump laser into a photonic crystal fiber which spreads the pump wavelength through the non-linear four wave mixing process to create a wide spectral range [2]. The source is transmitted across the 600 m atmospheric path and the backscatter signal is collected by a 10 inch Newtonian telescope with a focal length of 1270 mm for analysis by an optical spectrum analyzer. The transceiver system is located on the roof laboratory and a retro reflector, positioned on an adjacent building, is used to provide the target return.

2. Data Analysis Approach

A multi-wavelength DIAL algorithm was adapted and further developed to analyze the collected return from the supercontinuum source after passing through the 600 m path. The algorithm implements a least squares fit inversion approach [3, 4] developed using methods described by Warren [5] and Yin and Wang [6] for determining concentration path length (CPL) for DIAL pairs by iterating over hundred's of wavelengths. The multi-wavelength algorithm determines the CPL of multiple vapors by simultaneously solving the noise covariance matrix, $\hat{\Lambda}$, in equation 1, where α is an array of wavelength-specific target vapor absorption parameters, $\hat{H}$ is the simulated signal from MODTRAN™ 5 spectral data [7], and $\overline{Q}(j)$ is average SAS integrated measurements.

$$CPL_l = \frac{1}{n-1}\sum_{M=n-x}^{n}\left\{\frac{\sum_{j=1}^{M}\left[\alpha_{jl}\hat{\Lambda}_1^{-1}(j,j)\left[\hat{H}_1-\overline{Q}(j)-\sum_{l=1,l\neq 1}^{L}\alpha_{jl}CPL_l\right]\right]}{\sum_{j=1}^{M}\left[\alpha_{jl}\hat{\Lambda}_1^{-1}(j,j)\alpha_{jl}\right]}\right\}\left[ppm\cdot m\right] \qquad (1)$$

3. Absorption Measurements

The supercontinuum source provides the capability to detect species with absorption bands located within the wide spectral bandwidth of the source (i.e. water vapor, oxygen, carbon dioxide). An absorption measurement of oxygen utilizing the previously reported SAS configuration [4,8] but with increased path length to 600 m path is shown in Figure 1 with arbitrary intensity values. As an example, the spectral data of the oxygen measurement

when run through the SAS multi-wavelength algorithm resulted in a mean atmospheric oxygen concentration of 209180 ppm ± 47 ppm, and compares favorably with the standard atmospheric value of 20.95%.

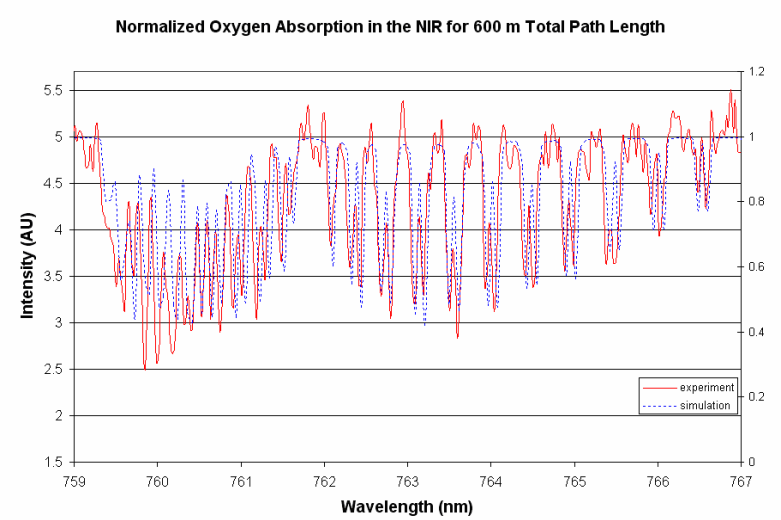

Fig. 1. MODTRAN™ 5 simulation compared with raw experimental data for oxygen.

4. Conclusions

A supercontinuum source is demonstrated as a useful technique for measuring near infrared absorption of atmospheric constituents over a 600 m path. The system utilizes an improved transceiver system and increased path length over previous experimental configurations to achieve better measurement sensitivity. The SAS technique offers a unique approach for detecting and quantifying gaseous species in the atmosphere with direct applications to pollution and chemical monitoring.

6. References

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