Abstract

In collaboration between NASA GSFC and GWU, a new, low-cost, surface instrument was being developed that can continuously monitor key carbon cycle gases in the atmospheric column: carbon dioxide (CO₂) and methane (CH₄). The instrument is based on a miniaturized, laser heterodyne radiometer (LHR) using near infrared (NIR) telecom lasers. Despite relatively weak absorption line strengths in this spectral region, spectrally-resolved atmospheric column absorptions for these two molecules fall in the range of 60-80% and thus sensitive and precise measurements of column concentrations are possible.

In the last year, the instrument was deployed for field measurements at Park Falls, Wisconsin; Castle Airport near Atwater, California; and at the NOAA Mauna Loa Observatory in Hawaii. For each subsequent campaign, improvement in the figures of merit for the instrument has been observed. In the latest work the absorbance noise is approaching 0.002 optical density (OD) noise on a 1.8 OD signal.

An overview of the measurement campaigns and the data retrieval algorithm for the calculation of column concentrations will be presented. For light transmission through the atmosphere, it is necessary to account for variation of pressure, temperature, composition, and refractive index through the atmosphere that are all functions of latitude, longitude, time of day, altitude, etc. For temperature, pressure, and humidity profiles with altitude we use the Modern-Era Retrospective Analysis for Research and Applications (MERRA) data. Spectral simulation is accomplished by integrating short-path segments along the trajectory using the SpecSym spectral simulation suite developed at GW. Column concentrations are extracted by minimizing residuals between observed and modeled spectrum using the Nelder-Mead simplex algorithm.

We will also present an assessment of uncertainty in the reported concentrations from assumptions made in the meteorological data, LHR instrument and tracker noise, and radio frequency bandwidth and describe additional future goals in instrument development and deployment targets.

Simulating Spectra

Atmospheric spectra are simulated for the column using the SpecSym spectral simulation package developed at The George Washington University (GWU). This software uses physical parameters from the HITRAN spectral databases (2004 edition) to model CO₂ spectra. The integrated path absorption spectrum is calculated using the initial sun angle and pressure and temperature profiles taken from Modern-Era Retrospective Analysis for Research and Applications (MERRA). Instrument broadening is then added to the simulated spectrum, with an initial assumption of 3 GHz (0.025 nm). The experimental spectrum is then fit to the instrument-broadened simulated spectrum using a Nelder-Mead simplex algorithm. Figure 3 shows data for a typical synthetic spectrum (blue line) and measured spectrum (red symbols).

Background

Laser heterodyne radiometry (LHR) is a technique for detecting weak signals that was adapted from radio receiver technology. In a radio receiver, a weak input signal from a radio antenna is mixed with a stronger local oscillator signal. The mixed signal (beat frequency) has a frequency equal to the difference between the input signal and the local oscillator. The intermediate frequency is amplified and sent to a detector that extracts the audio from the signal. In a laser heterodyne radiometer, the weak input signal is light that has undergone absorption by a trace gas. The local oscillator is a laser at a near-by frequency - in this case a low-cost distributed feedback (DFB) telecommunications laser. These two light waves are superimposed in either a beamsplitter or in a fiber coupler (as is the case in this design). The two signals are then mixed in the detector, and the RF beat frequency is extracted. Changes in the column concentration of the trace gas are read out by analyzing changes in the beat frequency amplitude. By bandpass filtering the RF and tuning the laser through an absorption feature, trace gas concentrations can be found as a function of altitude.

Affect of Absorbance Noise

To estimate the uncertainty in this fitting algorithm, absorbance noise was added to a simulated spectrum and the resulting "experimental" spectrum was fit. This process was repeated for 100 trials at several absorbance noise levels. The results of these Monte Carlo trials, shown above, indicate that a noise level of 0.01 OD leads to an uncertainty of just 1 ppmv in CO₂ column mixing ratio.

Future Plans

New opportunities for mini-LHR deployment are currently being explored including:

- A multi-disciplinary, multi-scaled study to measure methane (CH₄) and carbon dioxide (CO₂) above thawing permafrost at Park Falls, Wisconsin in 2020.
- A regional network of sensors in the Washington DC area to help validate higher resolution grid simulations of GEOS-5 data.
- Cubesat deployment of a mini-LHR system for limb measurements of CO₂ in arctic regions.

Acknowledgements

At NASA Goddard: This effort was made possible by the Goddard Internal Research and Development (IRAD) Program. Thanks to Brent Holben and the GSFC AERONET team for their continued support of this project and for the use of their AERONET sun trackers. The following people provide ongoing collaboration for this effort: Ted Koskiola, Bill Heaps, Jim Abshire, Judd Wolton, and Jim Garbin. At GWU, The Ball Atlantic Graduate Fellowship has supported Ms. Melroy during 2011-2012.