Field Results From Three Campaigns To Validate the Performance Of The Miniaturized Laser Heterodyne Radiometer (Mini-LHR) For Measuring Carbon Dioxide And Methane In The Atmospheric Column

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Abstract

In a collaboration between NASA GSFC and GWU, a low-cost, surface instrument is 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’s 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 Development (MERRA) data. Spectral simulation is accomplished by integrating short-path segments along the trajectory using the SpecSyn spectral simulation suite developed at GWU. 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.

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 nearby 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 signals are mixed in the detector, and the RF beat frequency is extracted. Changes in the column concentration of the trace gas are revealed through analyzing changes in the beat frequency amplitude. By bandpass filtering the RF and tuning the laser through an absorption line, the absorbance nose levels. The results of these Monte Carlo trials, shown above, indicate that a noise level of 0.01 OD leads to an uncertainty of absorbance noise of about 0.003 for 45 minutes of averaged data. Over the three field campaigns at Mauna Loa Observatory, the scan time was further reduced to reach an absorbance noise of 0.0004 was reached in about 6 scans (~6 minutes of data). Once again referring to Figure 4 an estimated precision of ±0.2 ppmv is determined.

Simulating Spectra

Atmospheric spectra are simulated for the column using the SpecSyn spectral simulation package developed at The George Washington University (GWU). This software uses physical parameters from the HITRAN Spectral database (2008 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) data. The simulated spectrum is then fit to the laboratory-measured spectrum using a Nelder-Mead simplex algorithm. Figure 3 shows data for a typical synthetic spectrum (blue line) and measured spectrum (red symbols).

Affect of Absorbance Noise

Figure 4: To estimate the uncertainty in this fitting algorithm, absorbance noise was added to a simulated spectra 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 and carbon dioxide (CO₂) above thawing permafrost in three sites near Fairbanks, AK.
- 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.

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