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Development and Validation of CO_2 and O_2 Laser Measurements for Future Active XCO_2 Space Mission

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This paper discusses the development and validation of a unique, multi-frequency, intensity-modulated, laser absorption spectrometer (LAS) operating simultaneously in the 1.57-μm region for column CO_2 measurements and in the 1.26-μm region for column O_2 measurements. This laser system is under development for a future space mission to determine the global distribution of regional-scale CO_2 mixing ratio (XCO_2) sources and sinks, which is the objective of the NASA Active Sensing of CO_2 Emissions during Nights, Days, and Seasons (ASCENDS) mission. A prototype of this LAS system, called the Multi-frequency Fiber Laser Lidar (MFLL), is being developed by ITT and evaluated by the NASA Langley Research Center. The MFLL CO_2 measurements have been flight tested in ten airborne campaigns since May 2005. MFLL O_2 measurements using a Raman amplifier began ground testing in early 2010, and it is being integrated with the CO_2 measurement capability for combined CO_2 and O_2 measurements during flight tests this year. This paper describes the MFLL CO_2 and O_2 measurement concepts; discusses the most recent results from the 2010 flight tests of the MFLL CO_2 measurements and from ground tests of the O_2 measurements; presents the flight test plans for this year; and describes the MFLL space implementation architecture.

A major ASCENDS flight test campaign was conducted on the NASA DC-8 during 6-18 July 2010, and the MFLL CO_2 column measurements were evaluated as part of this campaign. The MFLL system and associated *in situ* CO_2 instrumentation were operated on DC-8 flights over the Central Valley of California; the desert of southeastern California/Nevada; the Pacific Ocean off of the Baja Peninsula; Railroad Valley, Nevada; and the Department of Energy Atmospheric Radiation Measurement Central Facility in Lamont, Oklahoma. Remote CO_2 column measurements were made from altitudes of 2.5 to 13 km, and *in situ* CO_2 profiles were obtained on spirals from the highest altitude on each flight to as low as 30 m at the center of the flight track. Radiosondes were also launched in conjunction with these flights to constrain the meteorological conditions for the validation of the MFLL CO_2 column measurements. The MFLL CO_2 column measurement precision from 7 km AGL with 1-s (~150-m) averaging was shown to be better than 0.2% (<0.8 ppmv XCO_2) and with 10-s (~1.5-km) averaging was better than 0.08% (<0.3 ppmv). The absolute accuracy of the MFLL CO_2 column measurements was found to have an average bias of less than 1 ppmv with a standard deviation for all the comparisons of less than 4 ppmv.

A 1.26-μm laser transmitter for MFLL has been developed at ITT for demonstrating the measurement of surface pressure through the column measurement of O_2. The first-generation 1.26-μm laser transmitter was integrated into MFLL for horizontal path tests at ITT in 2010. Results from these tests showed high correlation ($R^2 > 0.97$) between O_2 column measurements and horizontal range to target (0.7-2.8 km) and in comparison with *in situ*-predicted O_2 columns. A second generation 1.26-μm laser transmitter with more power and better efficiency is being integrated into MFLL for additional ground tests this spring and flight tests this summer on the DC-8 for validating simultaneous MFLL CO_2 and O_2 column measurements.

Several methods for removing the influence of optically thin clouds on MFLL CO_2 and O_2 column measurements are under investigation, and flight tests of the most promising techniques are being planned for this summer. These activities represent important steps toward demonstrating the needed CO_2 and O_2 column measurement precision and accuracy for a future space mission to investigate global sources and sinks of XCO_2.