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# Advanced IMCW Lidar Techniques for ASCENDS $CO_2$ Column Measurements

Joel Campbell, bing lin, amin nehrir, fenton harrison, and michael obland
United States (joel.f.campbell@nasa.gov)

Global atmospheric carbon dioxide ($CO_2$) measurements for the NASA Active Sensing of $CO_2$ Emissions over Nights, Days, and Seasons (ASCENDS) space mission are critical for improving our understanding of global $CO_2$ sources and sinks. Advanced Intensity-Modulated Continuous-Wave (IM-CW) lidar techniques are investigated as a means of facilitating $CO_2$ measurements from space to meet the ASCENDS measurement requirements. In recent numerical, laboratory and flight experiments we have successfully used the Binary Phase Shift Keying (BPSK) modulation technique to uniquely discriminate surface lidar returns from intermediate aerosol and cloud contamination. We demonstrate the utility of BPSK to eliminate sidelobes in the range profile as a means of making Integrated Path Differential Absorption (IPDA) column $CO_2$ measurements in the presence of optically thin clouds, thereby eliminating the need to correct for sidelobe bias errors caused by the clouds. Furthermore, high accuracy and precision ranging to the surface as well as to the top of intermediate cloud layers, which is a requirement for the inversion of column $CO_2$ number density measurements to column $CO_2$ mixing ratios, has been demonstrated using new hyperfine interpolation techniques that takes advantage of the periodicity of the modulation waveforms. This approach works well for both BPSK and linear swept-frequency modulation techniques. The BPSK technique under investigation has excellent auto-correlation properties while possessing a finite bandwidth. A comparison of BPSK and linear swept-frequency is also discussed in this paper. These results are extended to include Richardson-Lucy deconvolution techniques to extend the resolution of the lidar beyond that implied by limit of the bandwidth of the modulation.