Performance Simulation of a Raman Lidar for the Retrieval of CO2 Atmospheric Profiles

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02 - Emerging lidar techniques, methodologies, and discoveries

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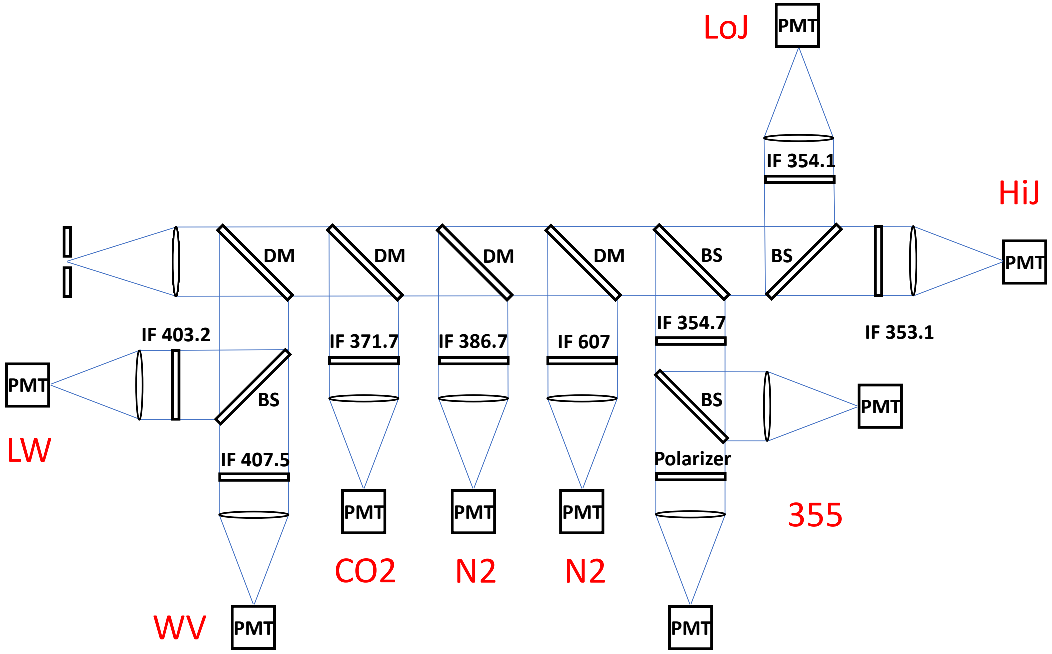
Introduction

In the frame of the project **CONCERNING** (COmpact RamaN lidar for atmospheric CO_2 and thERmodyNamic profilING), a Raman lidar capable to provide accurate and high-resolution measurements of the vertical profiles of CO_2, water vapor mixing ratio, temperature, and particle backscattering/extinction profiles is being developed.
The **performance** of the lidar system was investigated through a set of **numerical simulations**. The possibility of exploiting both **CO_2** Raman lines of the v1:2v2 resonance was explored. An accurate evaluation and quantification of the contribution of the Raman O_2 lines on the signal and other (e.g., aerosol, absorbing gases) disturbance sources was carried out. The signal integration over the vertical and over time required to reach a useful signal to noise ratio both in day-time and night-time needed for a quantitative analysis of carbon dioxide sources and sinks was evaluated.

Figure 1 (left): Work in progress assembly of the CONCERNING lidar prototype.

Figure 2 (right): Schematics of the CONCERNING lidar optical system.



Simulator

The numerical model calculates the various terms of the lidar equation. The Raman backscattering term is calculated **line-by-line** for the different molecular species of the atmosphere (**O2**, **N2**, **H2O**, **CO2**). The first four more intense CO2 Raman lines (among which the Fermi doublet with 2v2 at 1285.4 cm^{-1} and v1 at 1388.2 cm^{-1}) were simulated.

Pressure broadening (i.e., Lorentzian) was applied for a rough estimation of the impact of the tails of the O2/N2 broadened lines on the CO2 measurements at low altitudes. A fixed value of 0.05 cm^{-1} HWHM was used for the Lorentzian broadening function.

Molecular scattering and absorption was calculated using the **AFGL** atmospheric constituent profiles. A fixed value of **415 ppm** was used for the CO2. Gas absorption was calculated for **O3**, **NO2**, and **SO2**. Aerosol extinction was computed with a highly parametrized representation based on aerosol optical depth, angstrom exponent and scale height.

Background was calculated at 371.7 nm and 382.7 nm in single scattering approximation for different solar zenithal angles and summed to the signal.

Noise is assumed as the square root of the signal including the background.

CHARACTERISTICS

Characteristics of the simulated lidar:

- **354.74 nm** monochromatic laser source,
- **0.1 J** per laser impulse,
- **100 Hz** repetition rate,
- **0.90** optical transmission efficiency,
- **0.43** receiving quantum efficiency,
- **0.46** CO2 interference filter peak transmission and FWHM of 0.15 nm,
- **0.25 m** telescope radius,
- **0.1 mrad** field of view (full angle),
- lidar altitude of 0 m AMSL,
- full overlap assumed for the whole atmosphere.

Results

Preliminary calculations indicate that the broadened Rayleigh/Raman signal due to the **tails**, integrated over the filter A window (2v2 line), has an intensity **comparable to the CO2 signal**. This should be an overestimation of the real expected Rayleigh and Raman tail contribution and the simulation should be performed with more accurate broadening coefficients.

Due to the difficulty of modelling the broadened tails, in order to have accurate measurements at low altitudes this contribution to the signal should be **better investigated** experimentally with measurements slightly below the 2v2 wavelength (e.g., with the same filter shifted in frequency with angle tuning or with a scanning spectrometer).

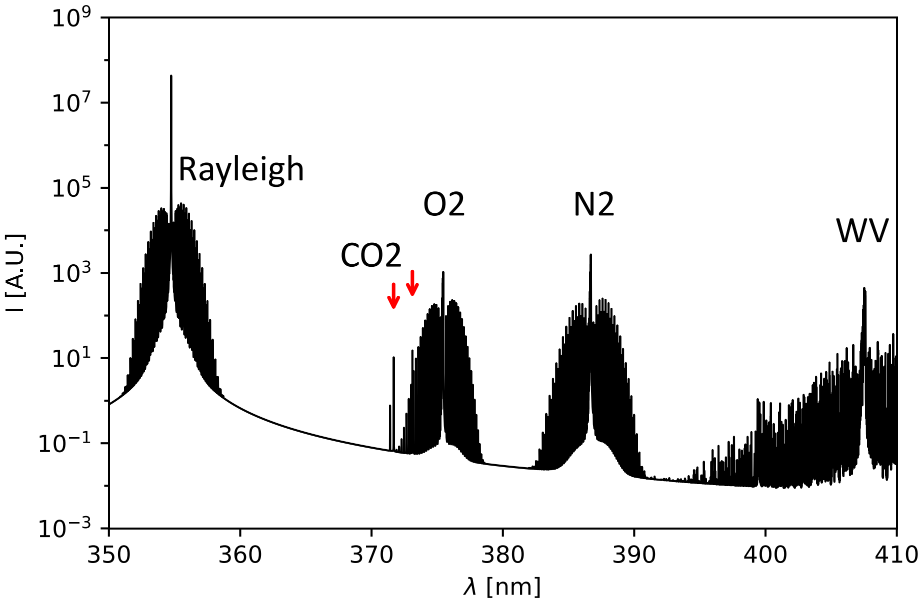
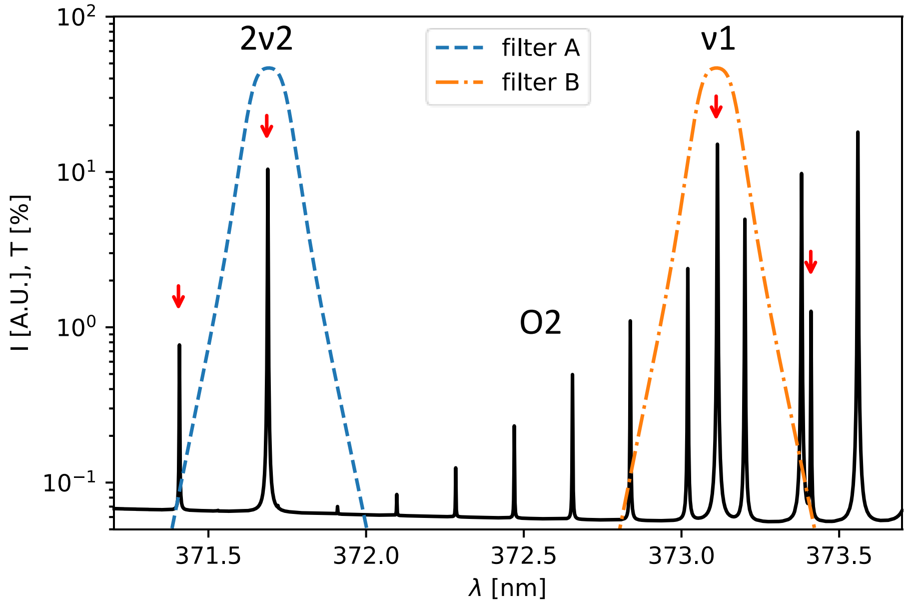


Figure 3 (left): Simulated "full" Rayleigh and Raman spectrum at 1013 hPa and 288 K. The CO2 lines are indicated by the red arrows.

Figure 4 (right): Simulated Raman spectrum (solid line) and filter transmittance T for filter A (dashed line) and filter B (dash-dotted line). The CO2 lines are indicated by the red arrows.



Results

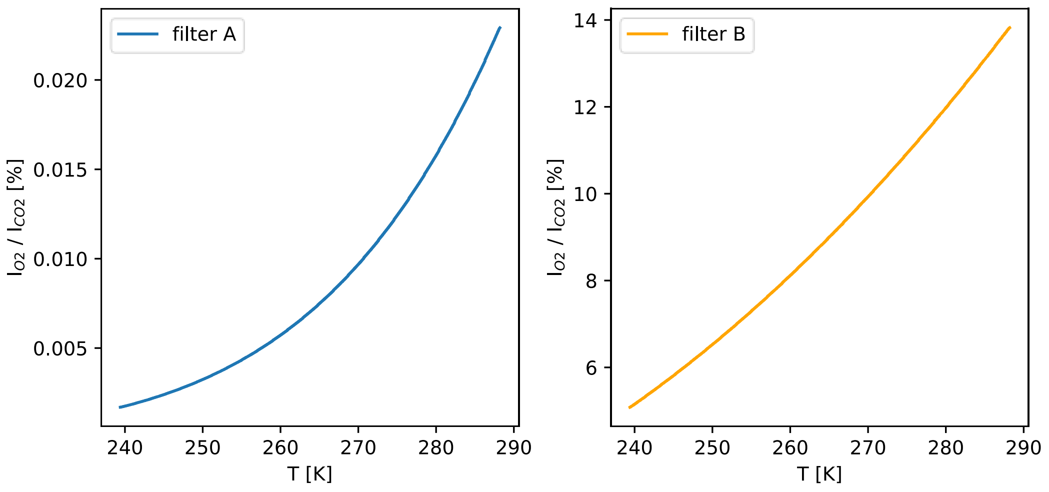


Figure 5: Temperature dependence of the contribution of the O2 lines relative to the CO2 signal for Filter A (left) and Filter B (right).

The impact of the unbroadened **O2 lines** falling inside the filter transmission ranges was evaluated. The O2 **contribution** on filter A signal is **less than 1%** and on filter B signal is in the order of 10-15 %. Line modeling paired with simultaneous temperature measurements should decrease the uncertainty to less than 1 ppm/K.

The **spatial and temporal integration** necessary to reach a sufficient SNR for filter A during night-time and day-time was calculated. The results (Figure 6) indicate that the simulated lidar system, provided to have a low overlap height, could perform measurements on the low troposphere CO2 gradients with sufficient precision **both in day-time and night-time** with an integration time of **1-3 h**.

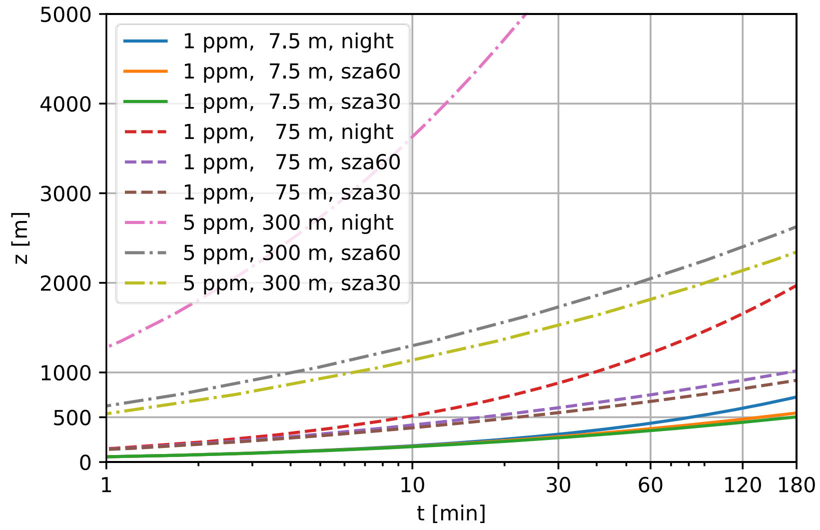


Figure 6: Integration time t required to reach a given altitude z for different background conditions (night, SZA=60°, SZA=30°), vertical resolutions (7.5 m, 75 m, 300 m) and measurement precisions (1 ppm, 5 ppm).

CONCLUSIONS

Preliminary results confirm that a state-of-the-art Raman lidar system dedicated to the measurements of CO2 profiles **could perform measurements in the low troposphere with sufficient precision to estimate gradients due to carbon sources and sinks**.

Both 2v2 and v1 lines could be used and the signal contamination attributed to the O2 Raman lines could be mitigated via line modeling.

NEXT STEPS

- accurate theoretical or experimental estimation of the signal contamination due to line broadening
- estimation of the uncertainty for different aerosol types and atmospheric profiles