

REMOTE SENSING OF GREENHOUSE GASES BY COMBINING LIDAR AND OPTICAL CORRELATION SPECTROSCOPY

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ABSTRACT

In this contribution, we present recent work on the ability to achieve range-resolved greenhouse gases concentration measurements in the Earth's atmosphere (CH₄, H₂O) by combining broadband optical correlation spectroscopy (OCS) with lidar. We show that OCS-Lidar is a robust methodology, allowing trace gases remote sensing with a low dependence on the temperature and pressure-variation absorption cross section. Moreover, we evaluate, as an experimental proof, the water vapor profile in the planetary boundary layer using the 4v 720 nm absorption band.

1. INTRODUCTION

As underlined in the latest IPCC report [1], there is a need for determining the spatial and temporal concentrations of atmospheric constituents. Therefore, Lidar is an efficient monitoring device to probe trace species [2] and also particulate matter [3] coupled with complex atmospheric processes [4]. We have recently developed the OCS-Lidar, a novel instrument that is based on coupling a Lidar with Optical Correlation Spectroscopy (OCS). Its principle and the theoretical approach have then been established [5] leading to a comprehensive study on OCS-Lidar errors budget in the NIR [6]. Moreover OCS-Lidar based on a femtosecond broadband laser source has been successfully applied to retrieve water vapor in the lower atmosphere using the 4v 720 nm absorption band [5].

This abstract is organized as follows. The OCS-Lidar methodology and the formalism aimed at retrieved the TG concentration are presented in Section 2. Numerical simulations of [CH₄] remote sensing for extreme pressure and temperature conditions are presented in Section 3. Finally, a field measurement of OCS-Lidar dedicated to water vapor in the planetary boundary layer is presented. The abstract ends with a conclusion.

2. METHODOLOGY

OCS-Lidar is an active optical remote sensing method able to monitor atmospheric trace using broadband laser pulse. Its principle is displayed in figure 1.

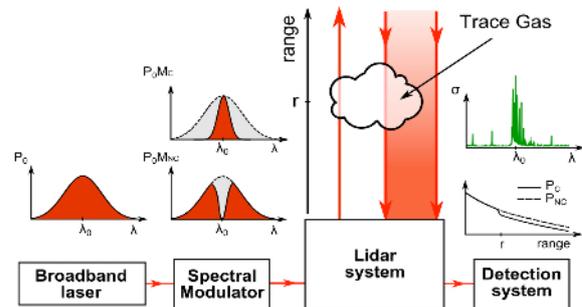


Fig. 1: Scheme of the OCS-Lidar principle.

The broadband laser pulse power density $P_0(\lambda)$ is spectrally shaped by alternatively applying two different amplitude modulations M_C and M_{NC} . A spectral modulator is used to custom one emission laser pulse to be spectrally correlated (C) with the trace gas absorption spectrum while a second one, which is a non-correlated (NC) laser pulse, serves as OCS-Lidar reference signal.

The target gas (TG) concentration profile is retrieved from the signals without the requirement of a permanent calibration gas cell. However a calibration cell could serve to reveal experimental biases. The backscattered OCS-Lidar signal $P_i(r)$ can be written as follows:

$$P_i = \frac{K(r)}{r^2} \int_{\Delta\lambda} P_0(\lambda) M_i(\lambda) \beta(r, \lambda) T^2(r, \lambda) \eta(\lambda) d\lambda \quad (1)$$

where M_i is the modulator transmission which ensures the correlation ($i = C$) or not ($i = NC$). $\Delta\lambda$ is the spectral bandwidth of the optical set-up. $\beta(r, \lambda)$ is the atmosphere backscattering coefficient, while $K(r)$ depends on the receiving optics geometry and $\eta(\lambda)$ is the optical set-up efficiency. Finally, $T(r, \lambda)$ is the transmission of the atmosphere which includes the trace gas (TG) concentration profile. From the ratio of OCS-Lidar signals $P_C(r)$ and $P_{NC}(r)$, we retrieved an analytical expression of [TG](r) by approximating the TG transmission present in $T(r, \lambda)$ with a Taylor expansion series of the Lambert Beer equation. The mathematical description can be found elsewhere [5].

3. EXPERIMENT

3.1 Methane

A numerical model has been developed to generate NIR OCS-Lidar signals and to evaluate the errors budget associated to $[\text{CH}_4]$ remote sensing. It includes detector noise and variation of the Methane absorption spectral lines with the atmosphere thermodynamic changes. Fig. 2 shows, in the form of a color plot, the relative error on the retrieved $[\text{CH}_4]$ by considering the temperature and pressure variations in the troposphere. There, for the input of the model, we consider a 20 ppm Methane peak concentration located at a 1000 meters distance with a 100 meters width range. This numerical simulation [6] shows that the error on $[\text{CH}_4]$ does not overcome 14 % when the temperature and pressure respectively vary by 200 K and 900 mbar.

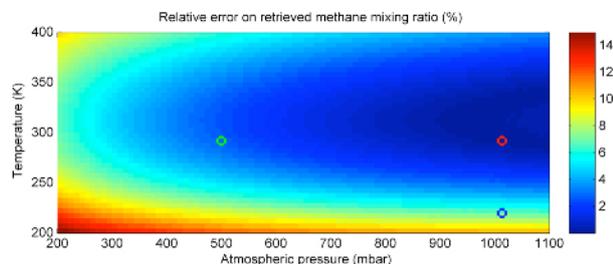


Fig. 2: Relative error in % on retrieved Methane mixing ratio assuming initial atmosphere temperature and pressure of 292 K and 1013 mbar respectively.

3.2 Water Vapor

The first experimental proof of OCS-Lidar has been performed on the measurement of the water vapor content in the PBL [5].

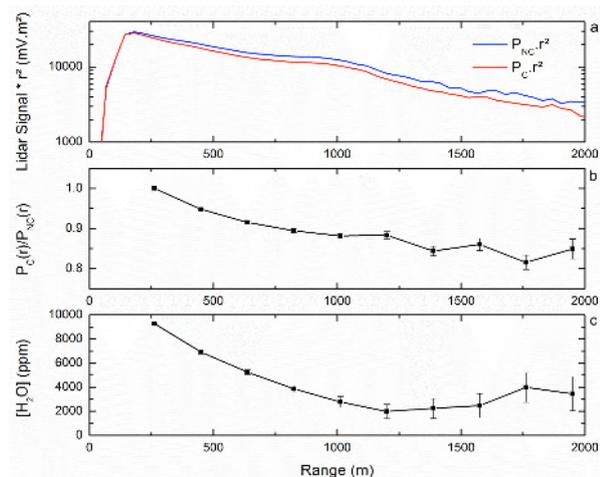


Fig. 3: OCS-lidar water vapor measurement in the PBL. (a) Range-corrected OCS-lidar signals. (b) The ratio P_C / P_{NC} (c) Retrieved water vapor mixing-ratio profile.

We also demonstrate the ability to realize the experiment using two different configurations of M_i (see Eq. 1): on the laser emission or on the reception part. Fig. 3 shows the results of the field experiment when achieving the amplitude modulation $M_i(\lambda)$ on $P_o(\lambda)$. The water vapor concentration profile in the PBL could be retrieved up to a 2000 meters distance with a 200-m range resolution. The retrieved water vapor mixing-ratio profile starts at $(7,850 \pm 55)$ ppm at a 260-m range and reaches $(3,500 \pm 1,000)$ ppm at the maximum range of 1900 meters. These first experimental results show water vapor mixing-ratio values in agreement with standard atmosphere. Moreover, near ground level (30 m), in situ hydrometer measurement shows similar values within 15 %.

4. CONCLUSIONS

We here present the OCS-Lidar based broadband laser source, which is a novel optical methodology to remotely retrieve the concentration of atmospheric greenhouse gases. We demonstrate the ability of this methodology to achieve water vapor filed measurements. Moreover, based on a numerical model, we demonstrate that the OCS-Lidar applied to $[\text{CH}_4]$ detection is almost insensitive to changes in absorption cross-section due to extreme temperature and pressure variations. Future work on $[\text{CH}_4]$ and on other traces gases remote sensing are in progress.

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