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## 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 (CH<sub>4</sub>, H<sub>2</sub>O) 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 [CH<sub>4</sub>] 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.

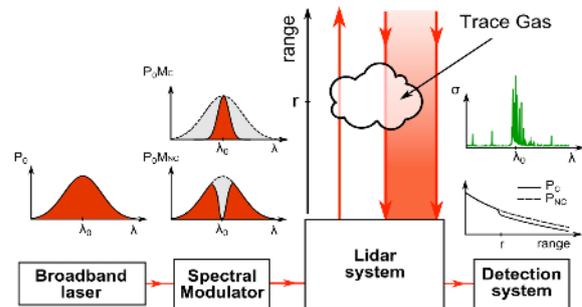


Fig. 1: Scheme of the OCS-Lidar principle.

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:

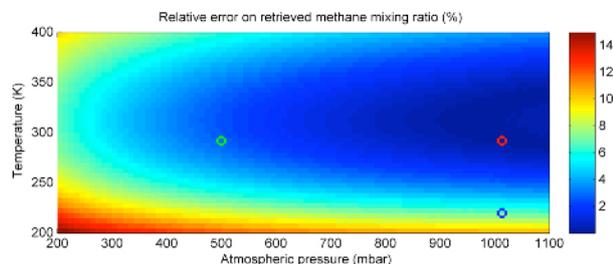
$$P_i = \frac{K(r)}{r^2} \int_{\Delta\lambda} P_0(\lambda) M_i(\lambda) \beta(r, \lambda) T^2(r, \lambda) \eta(\lambda) d\lambda \quad (1)$$

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

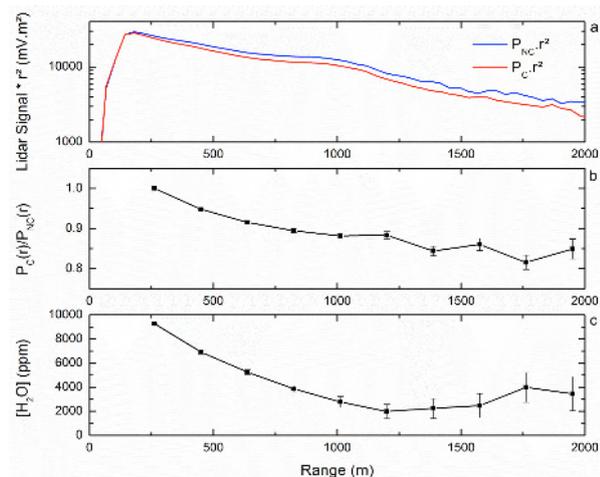
A numerical model has been developed to generate NIR OCS-Lidar signals and to evaluate the errors budget associated to  $[\text{CH}_4]$  remote sensing. It includes detector noise and variation of the Methane absorption spectral lines with the atmosphere thermodynamic changes. Fig. 2 shows, in the form 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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