NAOMI GAZL: A MULTISPECIES DIAL TESTED ON THE TADI GAS LEAK SIMULATION FACILITY

JEAN-BAPTISTE DHERBECOURT[1*], JEAN-MICHEL MELKONIAN[1], ANTOINE GODARD[1], VINCENT LEBAT[1], NICOLAS TANGUY[1], CEDRIC BLANCHARD[1], STÉPHANIE DOZ[3], PIERRE-YVES FOUCHER[3], THIERRY HUET[3], XAVIER WATREMEZ[2], DOMINIQUE DUBUCQ[2], MYRIAM RAYBAUT[1]*

[1] *DPHY, ONERA, Université Paris Saclay, F-91123 Palaiseau, France*
[2] *TOTAL, France*
[3] *ONERA/DOTA, Université de Toulouse, F-31055 Toulouse France*
**Email: jean-baptiste.dherbecourt@onera.fr*

ABSTRACT

We report on a direct detection differential absorption lidar (DIAL), designed for remote detection of CH_4 and CO_2. The system is based on a single-frequency optical parametric oscillator/amplifier system, tunable in the 1.57-1.65 µm range. The DIAL system, called NAOMI GAZL, was tested on a controlled gas release facility in October 2018.

1. INTRODUCTION

Remote detection, localization, and quantification of gaseous species is a topic of high interest in the frame of various applications, from safety to environmental or industrial monitoring. In such context, differential absorption lidars (DIAL) are promising since they can be designed to address different species, especially using emitters in the infrared where most chemicals of interest display characteristic absorption bands.

In the frame of NAOMI project (for New Advanced Observation Method Integration), Onera and Total jointly investigated different remote sensing methods, to be able to probe gases such as CO_2 and CH_4 remotely. Several systems where developed, and tested on a specific gas leak simulation facility called TADI (for Transverse Anomaly Detection Infrastructure).

Here, we present a compact, range-resolved, multi-species DIAL for both CO_2 and CH_4, based a widely tunable, single frequency emitter, with a high conversion efficiency. Indeed, only few DIAL systems have been reported lately in the literature, for this kind of applications [1,2], and here we exploit a specific emitter architecture. The emitter is based on a pulsed, nanosecond, single frequency, nested cavity optical parametric oscillator (NesCOPO) [3], amplified to 16 mJ, and implemented in a direct detection lidar system. This lidar is called NAOMI GAZL.

2. METHODOLOGY

2.1 The NAOMI GAZL DIAL

Basically, as it is well known, in a DIAL, at least two laser pulses are emitted, at two wavelengths called ON (in coincidence with one of the targeted species absorption line) and OFF (on an absorption minimum). The laser pulses are backscattered by the atmosphere, collected and detected by the DIAL receiver, and a gas plume can be localized and quantified along the line of sight by comparing the backscattered ON and OFF signals.

NAOMI GAZL emitter is based on an amplified NesCOPO. The core of the NesCOPO is a multi-track periodically-poled $LiNbO_3$ (PPLN) crystal. Given the chosen poling periods, several lines in the 1.57-1.65 µm range can be addressed for CO_2 and CH_4 measurement (Fig.1). Water vapour lines are weak but could also be addressed.

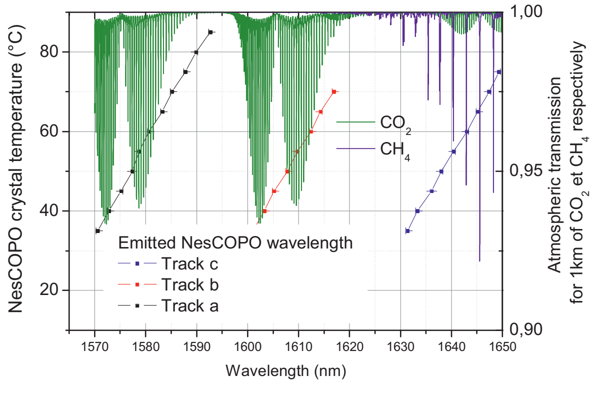


Fig. 1. NAOMI GAZL NesCOPO emitted wavelength as a function of the PPLN temperature, for three different poling periods a). The atmospheric transmission for CO_2 (for 400 ppm) and CH_4 (for 2 ppm) over 1 km are given.

The NesCOPO is pumped by less than 1 mJ of a 10 ns, 100 Hz, injection-seeded Q-switched Nd:YAG laser (Innolas). An optical parametric amplification stage, based on a PPLN crystal followed by KTA amplifiers allows to emit up to 16 mJ of single frequency radiation in the 1.57-1.65 µm range, while pumped by around 100 mJ.

NAOMI GAZL receiver unit is a custom Newtonian telescope, of 25 cm diameter, coupled to a commercial, 300 µm diameter, amplified InGaAs PIN photodiode, coupled to an 8-bits digitizer. Given the chosen amplifier, the maximum detection bandwidth is 14.5 MHz, corresponding approximately to 10 m spatial range resolution cells along the line of sight.

2.2 Preliminary testing on atmospheric CH_4

Prior to the system deployment on the TADI facility, the system was tested in ONERA facility in Palaiseau (France) in September 2018, on atmospheric CH_4. For this measurement, the photodiode alignment was optimized for long range measurement, resulting in a 200 m blind zone. A typical measurement result is displayed in Fig.2. The obtained statistical errors (due to the detection noise only) are around 3 ppm, at a 1 km range, for integration times of 250 s and a range resolution of 150 m, and less than 0.5 ppm at a 300 m range. These performances are sufficient given the simulated gas leak tests foreseen on TADI platform. For more accurate environmental monitoring, improvement of these performances via further averaging or better detection using a commercially available avalanche photodiode can be expected.

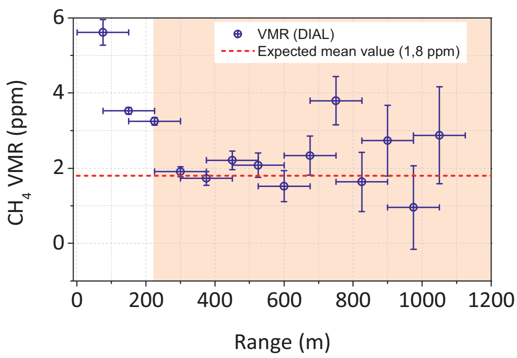


Fig. 2. NAOMI GAZL measurement for atmospheric CH_4 : volume mixing ratio (VMR) as a function of the range, for an integration time of 250 s and a measurement resolution of 150 m. The red dotted line corresponds to the expected 1.8 ppm atmospheric concentration, and the white area corresponds to the lidar blind zone.

3. OCTOBER 2018 TADI TEST CAMPAIGN

3.1 The TADI facility

Located in Lacq (France), TADI facility is an open-air site measuring 2,000 m² for qualifying systems designed to detect, localize and quantify remotely CO_2 and CH_4 releases. Equipped with surface facilities (pipelines, columns, recovered wellheads, etc.), this test area can reproduce around 30 scenarios of controlled emissions from 0.3 to 300 g/s of gas in an industrial environment.

NAOMI GAZL was deployed on the TADI facility during a test campaign in October 2018 (see Fig. 3).

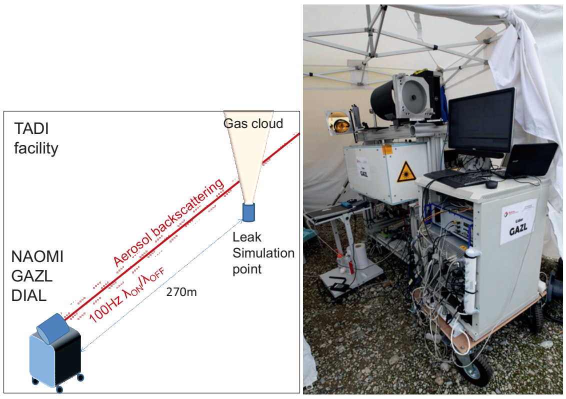
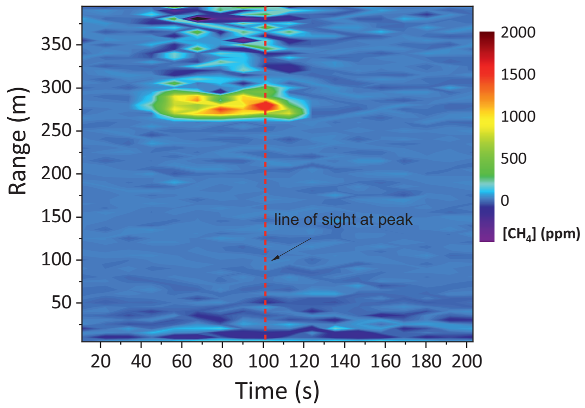


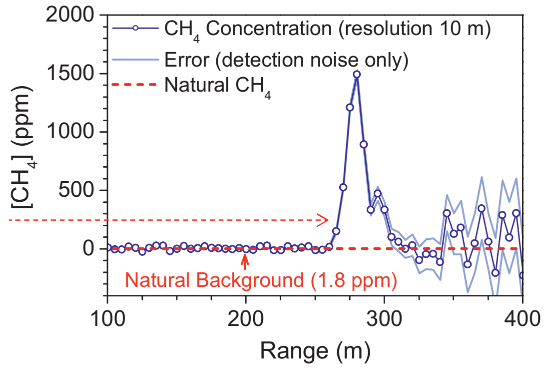
Fig. 3. NAOMI GAZL deployment scheme on TADI and picture of the system.

3.2 Example of measurement results

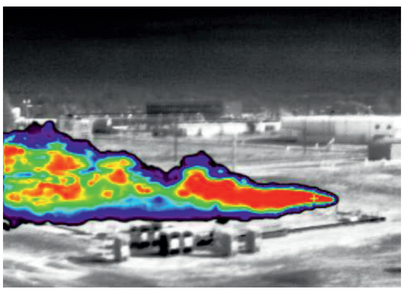
The NAOMI GAZL DIAL was located 250 m away from the gas release system. It was operated in a high resolution mode, i.e. with a spatial range resolution of 10 m (corresponding to the maximum detector amplifier bandwidth). Given the wind condition during these measurements, it was also operated on a high speed temporal mode with 10 s temporal averaging. Fig.4 a) and b) show an example of remote detection, quantification and localization of a CH_4 plume, generated by TADI, using GAZL. The system was tested for different fluxes of CH_4 and CO_2. Comparisons with integrated concentration in ppm.m retrieved from LWIR imaging hyperspectral data acquired during this campaign can also be used then to analyse and validate GAZL results (Fig.4 c).



a)



b)



c)

Fig. 3. a) Example of measurement performed using GAZL DIAL, on TADI facility: a gas plume is generated 250 m away from the DIAL. The estimated CH_4 plume concentration with a 10 m range resolution and a 10 s temporal resolution is shown on the left curve. In b), we can see a zoom of the CH_4 concentration along the line of sight, with error bars corresponding to the detection noise. c) Methane plume quantitative image (range: 0-200.000 ppm.m) from hyperspectral LWIR data at a distance of 100 m from the leak with a 5 s temporal resolution and a 15 cm spatial resolution.

ACKNOWLEDGEMENTS

This development was carried out in the frame of TOTAL and Onera NAOMI project.

REFERENCES

[1] G.A. Wagner, D.L. Plusquellic, Optics Express Vol.26, n°15,19420-19434 (2018)

[2] A. Amediek, G. Ehret, A. Fix, M. Wirth, C. Büdenbender, M. Quatrevalet, C. Kiemle, and C. Gerbig, Appl. Opt. **56**, 5182-5197 (2017)

[3] A. Godard, M. Raybaut, M. Lefebvre, Encyclopedia of Analytical Chemistry (2017)