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WaVIL : a Differential Absorption LIDAR for Water Vapor and Isotope HDO Observation in the Lower Troposphere - Instrument Design

J. Hamperl¹, C. Capitaine², R. Santagata¹, J.-B. Dherbecourt^{1,*}, J.-M. Melkonian¹, A. Godard¹, M. Raybaut¹, L. Régalia², B. Grouiez², F. Blouzon³, N. Geyskens³, C. Evesque⁴, P. Chazette⁵, J. Totems⁵, C. Flamant⁶

¹DPHY, ONERA, Université Paris Saclay, F-91123 Palaiseau, France

²Groupe de Spectrométrie moléculaire et atmosphérique (GSMA) UMR 7331, URCA, France

³Division Technique INSU (DT INSU), UPS 855, Meudon, France

⁴Institut Pierre-Simon Laplace (IPSL), FR636, Guyancourt, France

⁵Laboratoire des Sciences du Climat et de l'Environnement (LSCE), UMR 1572, CEA-CNRS-UVSQ, Gif-sur-Yvette, France

⁶Laboratoire Atmosphères Milieux et Observations Spatiales (LATMOS), UMR 8190, CNRS-SU-UVSQ, Paris, France

Author e-mail address: jean-baptiste.dherbecourt@onera.fr

Abstract: We present the design of a differential absorption LIDAR targeting HDO/H₂¹⁶O isotopic ratio measurement with high vertical resolution. This approach is enabled by infrared water vapor spectroscopy and recent high power multi-species parametric emitter developments.

1. Introduction

Stable Hydrogen or Oxygen isotopes in water are useful natural tracers of the hydrological origins of air masses and of dynamic atmospheric processes [1]. To improve the water cycle representation, bringing vertical range resolved observations of the relative abundance in HDO (δD which depends on the ratio of HDO and H₂¹⁶O) in the low troposphere (0-3 km) is expected to significantly complement the current knowledge and increase the models accuracy in the predicted magnitude of climate change [2]. To produce this type of data, the range resolved DIAL method is of prime interest, and together with the recent development efforts on multiple-species instrumentation [3–5], the technique is opening the path to co-located measurement in time and space of H₂O and HDO with high vertical resolution. In this paper we: *i*) define and characterize the proper spectral absorption lines enabling simultaneous measurement of H₂¹⁶O and HDO with a single instrument, *ii*) propose the design and the projected performances for a new LIDAR instrument capable of addressing both species.

2. Line selection for δD retrieval and DIAL set-up for low troposphere probing

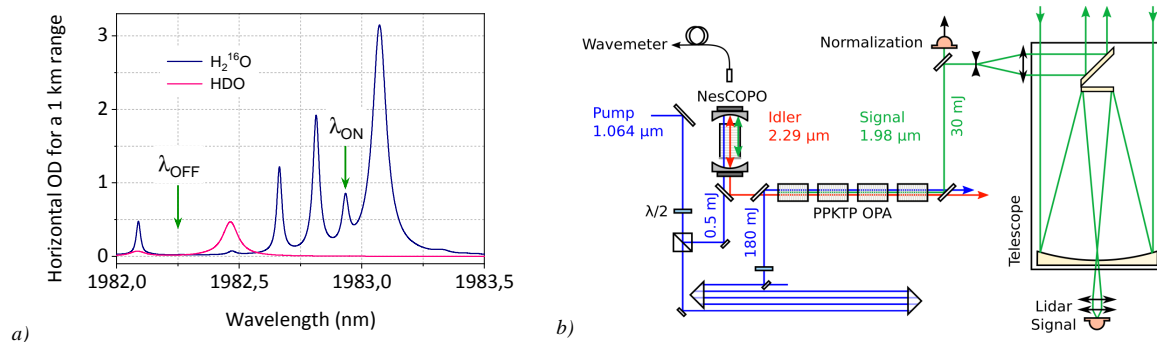


Fig. 1. *a*) Spectral region of interest for simultaneous probing of H₂¹⁶O and HDO with a long range DIAL. The optical depths are calculated for 1 km range at ground level. The marked ON and OFF wavelengths are used for sensitivity simulation on H₂¹⁶O. *b*) Schematic of the DIAL emitter (high energy OPO/OPA parametric source) and receiver (high aperture Cassegrain type telescope with InGaAs PIN photodiode).

The key to independent measurement of HDO and H₂O concentration is to properly select a spectral region where the two molecules display well separated lines, while preserving a similar and sufficient differential absorption in order to make the LIDAR works in equivalent dynamic and relative precision ranges for both isotopes. This makes the line selection extremely limited since δD values range from a few 10 ‰ to a few 100 ‰. The spectral window between 1982 – 1984 nm is well suited for all these purposes as illustrated in Fig.1 (*a*). To support the end-to-end simulation of the LIDAR performances and gas concentration retrieval, the spectroscopic line parameters have been experimentally measured with high accuracy in the GSMA laboratory with an IFS 125HR.

The DIAL system is based on a generic OPO/OPA architecture for the emitter depicted in Fig. 2(b), which has been developed at ONERA in the recent years. The approach relies on the combination of a doubly resonant Nested Cavity Optical Parametric Oscillator (NesCOPO) and Optical Parametric Amplifier (OPA), which intrinsically delivers single frequency high energy pulses with adequate tunability for multiple-species probing as demonstrated in the 2 μm range [3]. The latest design has been simplified for the OPA line thanks to the recent advent of high aperture (up to 5x5 mm²) PPKTP nonlinear crystals [6], which combine high nonlinearity ($d_{\text{eff}} > 9 \text{ pm/V}$) and high damage threshold ($>10 \text{ J/cm}^2$). With 180 mJ energy pulses at 1 μm pumping a combination of four PPKTP (total interaction length of 40 mm), an extracted signal energy of 30 mJ at 1982 nm is expected at the emitter output. The receiver part is based on a 40 cm diameter primary mirror, and the detection part is a combination of PIN InGaAs photodiode and low noise amplifier, with a 0.6 pW/ $\sqrt{\text{Hz}}$ NEP over a 1.8 MHz bandwidth at ambient temperature.

3. Sensitivity analysis

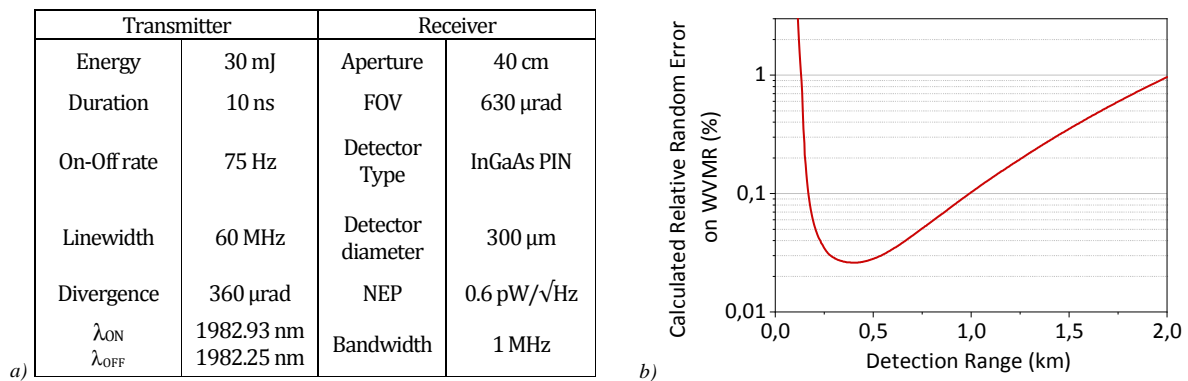


Fig. 2. a) Example of parameters set for the simulation. b) Expected relative random error on WaterVapor Mixing ratio (WVMR) in the vertical direction over a 2 km range. The dominant noise source is the detector electronic amplifier. The bandwidth is limited by a 1 MHz low-pass filter.

The main LIDAR parameters are summarized in Fig. 3(a). The simulation is performed by considering a vertical probing and a simplified atmospheric configuration in order to give a first glance estimate of the expectable sensitivity. Pressure and temperature variations follow the US standard atmospheric model. The vertical distribution of aerosols is supposed to bring a uniform backscattering coefficient of $\beta_{\pi} = 4.10^{-7} \text{ sr}^{-1} \cdot \text{m}^{-1}$, and relative humidity (RH) is also taken uniformly equal to 50 % over the first 2 km, which corresponds to a Water Vapor Mixing Ratio (WVMR) varying from 6 g/kg (at 0 km) to 3 g/kg (at 2 km). Finally, the signal averaging is performed for 10 min accumulation time (90 000 laser shots in total), and a 1 MHz bandwidth (150 m range resolution). With these parameters, the expected relative random error on WVMR is expected to be lower than 1 % in the first 2 km of the atmosphere. Given the absorption of HDO at 1982 nm similar relative random error levels are to be expected on HDO mixing ratio, and thus finally on the retrieved value of δD .

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3. References

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