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NEWSLETTER N°4
NOVEMBER 2021

Welcome to the LEMON project newsletter n°4

The overall objective of LEMON is to provide a new Differential Absorption Lidar (DIAL) sensor concept for greenhouse gases and water vapour measurements from space, based on a versatile transmitter.

Editorial by the Coordinator

Less travel restrictions allowed us this year to perform a first differential absorption lidar (DIAL) ground-based validation campaign. The LEMON instrument itself is currently being manufactured, and this first campaign was realized with its laboratory test-bed experiment WAVIL. We hope that the analysis of the errors and biases will allow us to comfort LEMON design or to perform some adjustments if necessary. The first article of this newsletter gives you an overview of this campaign.

These last months were also marked by several publications, for example one on the instrument design [https://doi.org/10.3390/atmos12030402] and one on the expected instrument performances versus various atmosphere scenarii [https://doi.org/10.5194/amt-14-6675-2021], which is described in the second article of this newsletter.

Finally, we wanted to focus on the work carried out by Post-docs in the LEMON project, so we propose an interview with Daniele Zannoni, who is working at the University of Bergen. Enjoy reading us!

Dr. Myriam Raybaut
Research engineer at ONERA – France

NEWS & EVENTS

Check the news article about the radiation tests performed within the LEMON project:
>> Read the article

The LEMON project leaflet is available:
>> Downlaod the pdf

The LEMON project poster is available:
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This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement N° 821868.

Focus on the first differential absorption lidar (DIAL) instrument ground-based validation campaign, performed by LEMON partners in September 2021.

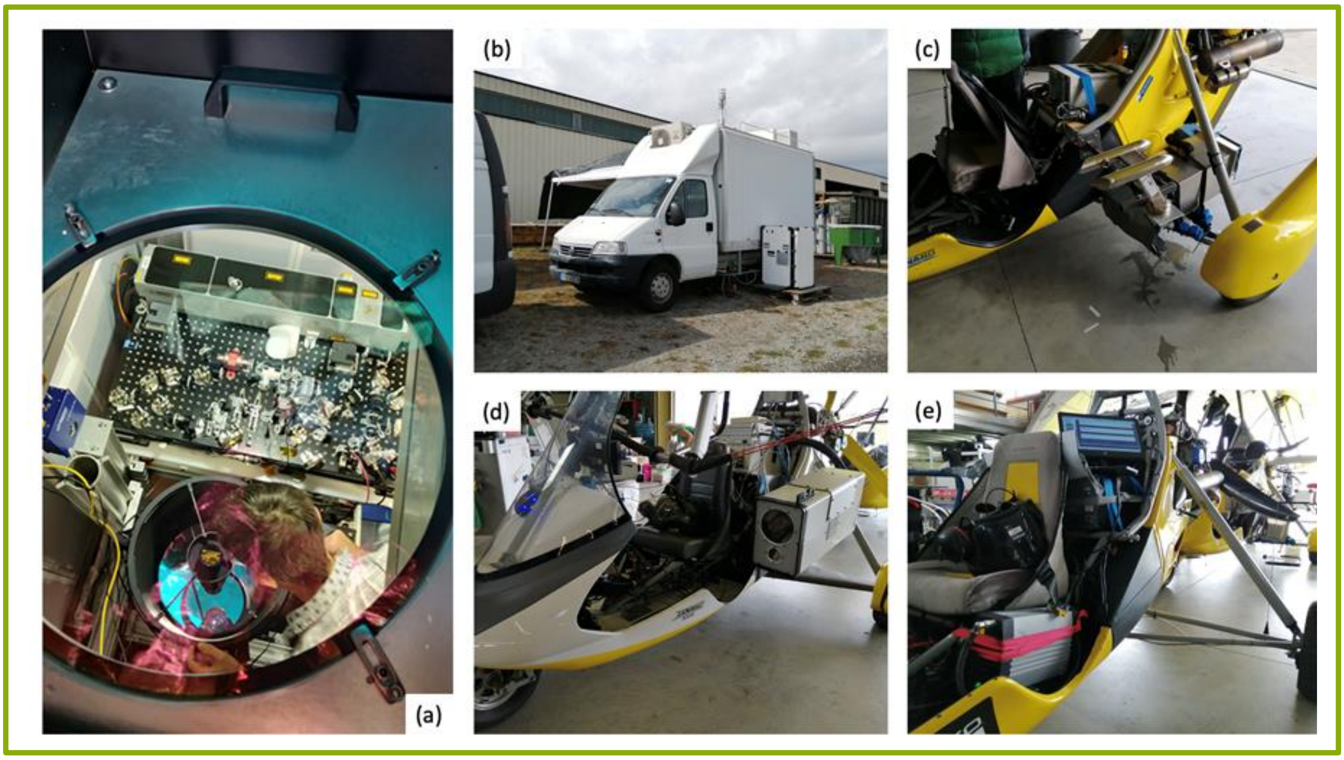

Figure 1: An overview of the instrumentation involved in the campaign. (a, b) the lidar truck, (c) the cloud ULA, (d) the lidar ULA and (e) the water vapor ULA.

Between the 13th and the 24th of September, LEMON partners **ONERA**, **CNRS** and **University of Bergen** (UiB) have conducted a first differential absorption lidar (DIAL) instrument ground-based validation campaign. The main objective of the campaign was to measure humidity and water vapor isotopic composition in the lower troposphere in order to provide validation data to ground-based water vapor lidars. Tropospheric measurements were performed using three different Ultralight aircrafts (ULAs). The campaign was conducted near Aubenas, in southern France. This site was chosen because of several interesting geographical features, including the proximity of the Rhone valley. The campaign headquarter was set up inside the Air Création factory, which is located next to the Aubenas Ardèche méridionale Aerodrome, thus providing an important logistic advantage. In total, 20 people took part in the campaign, including ONERA, CNRS-INSU (LSCE, LATMOS, DT, LaMP), UiB, AMU and the ULA pilots. The equipment deployed during the campaign consisted of (see Figure 1):

- 3 ULAs:
    - The water vapor ULA, operated by UiB and equipped with a Cavity Ring-Down Spectroscopy water isotopes analyzer and an iMet-XQ2 PTU probe.
    - The lidar ULA, operated by LSCE, equipped with the Airborne Lidar for Atmospheric Studies (ALiAS) and a Vaisala PTU probe.
    - The cloud chemistry ULA, operated by AMU and equipped with a cloud droplets size analyzer, two cloud water samplers and an iMet-XQ2 PTU probe.
- The lidar truck (LSCE, ONERA), equipped with two lidars, the Weather Atmospheric Lidar (WALI) and the Water Vapor and Isotope Lidar (WAVIL), which is a preliminary test bed experiment for LEMON lidar.
- A complete radiosonde station mainly operated by DT and LATMOS with the help of Météo-France.

All the flying instrumentation worked properly during the campaign. The water vapor ULA conducted 16 flights for a total flight time of ~20 hours. The flight plans of the water vapor ULA were specifically designed (1) to get meaningful profiles of the water vapor column in the lower troposphere, (2) to get precise estimates of the humidity and water vapor isotopic composition at specific altitude levels and (3) to describe the vertical and horizontal structure (and the temporal evolution) of the water vapor isotopic composition in the lower troposphere.

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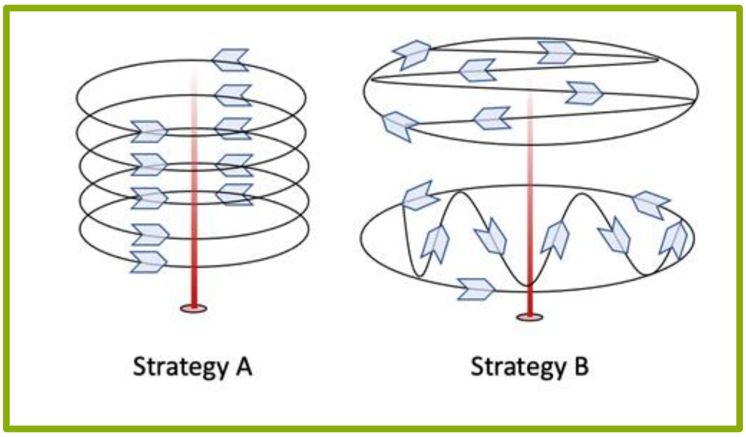
Figure 2: Two different flight strategies. Strategy A (downward spiral), to get vertical profiles that can be matched to lidar retrievals. Strategy B (spatial sampling), to get a representative estimate of water vapor composition at specific altitude level. The red beam represents the lidar line of sight.



The design of specific flight plans to achieve the best data for ground-based lidar validation (points 1 and 2) was discussed among the involved teams. The flight plans designed to probe the vertical and horizontal structure of the water vapor isotopic composition (point 3) were designed by UiB. Moreover, specific flights were performed to study the daily evolution of water vapor isotopic composition within the planetary boundary layer and to study water vapor – clouds water mass exchange in the lower troposphere. A lot of effort has been put to keep the water vapor isotopic analyzer in optimal working conditions during the whole campaign. To this end, daily and sub-daily water isotope and humidity calibrations were performed. The Picarro inlet was characterized several times to define the temporal response of the instrument in-flight configuration. A custom calibration system, named *flash evaporator* and specifically made for the LEMON project, was used to perform all the calibrations and the inlet characterizations.

On the ground, two types of lidar instruments were employed. The Weather and Atmospheric Lidar (WALI) operated by the LSCE is a Raman lidar operating in the ultra-violet and allows for the observation of several atmospheric state parameters along the vertical profile such as aerosols, temperature, and humidity. The WALI instrument was operational for the full campaign period and thus allowed to monitor the vertical evolution of the water vapor field (Figure 3, Figure 4).

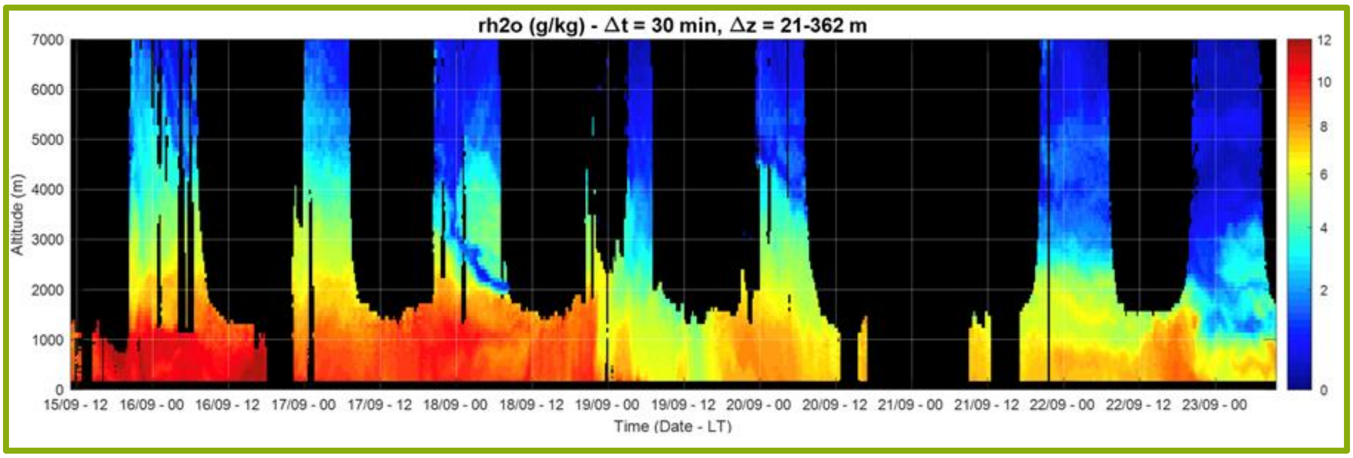


Figure 3: Temporal evolution of the water vapor profile during the campaign as sampled by the ground-based WALI instrument.

The Water Vapor and Isotope Lidar (WAVIL) operated by ONERA was the second ground-based lidar. It is a differential absorption lidar with the capability of measuring water vapor isotopes in the atmosphere. The measurement principle of this kind of lidar is based on the attenuation of laser light passing through the atmosphere by absorption of the gas of interest. The WAVIL lidar is a preliminary test-bed experiment for LEMON Lidar. The WAVIL system uses a laser source in the near infrared developed at ONERA and it was the first-ever demonstration of WAVIL in the frame of a field campaign. Due to the long installation process of more than one week, the WAVIL system was not operational until the last few days of the field campaign. However, all the hard work paid off resulting in the acquisition of several vertical profiles of two different water isotopes, which are a first demonstration of the capability to perform range resolved measurement of these two istopes, and are thus very promising preliminary results (Figure 5). The comparison with data obtained by balloon radio-soundings the WALI instrument and flights with the isotope-analyzer-equipped ULA, will provide valuable insights into the accuracy of the WAVIL instrument. Preliminary comparisons showed a bias in the DIAL measurements. The bias sources will be investigated in the coming weeks and, if necessary, will thus serve as a feedback for the optimization of the LEMON instrument.

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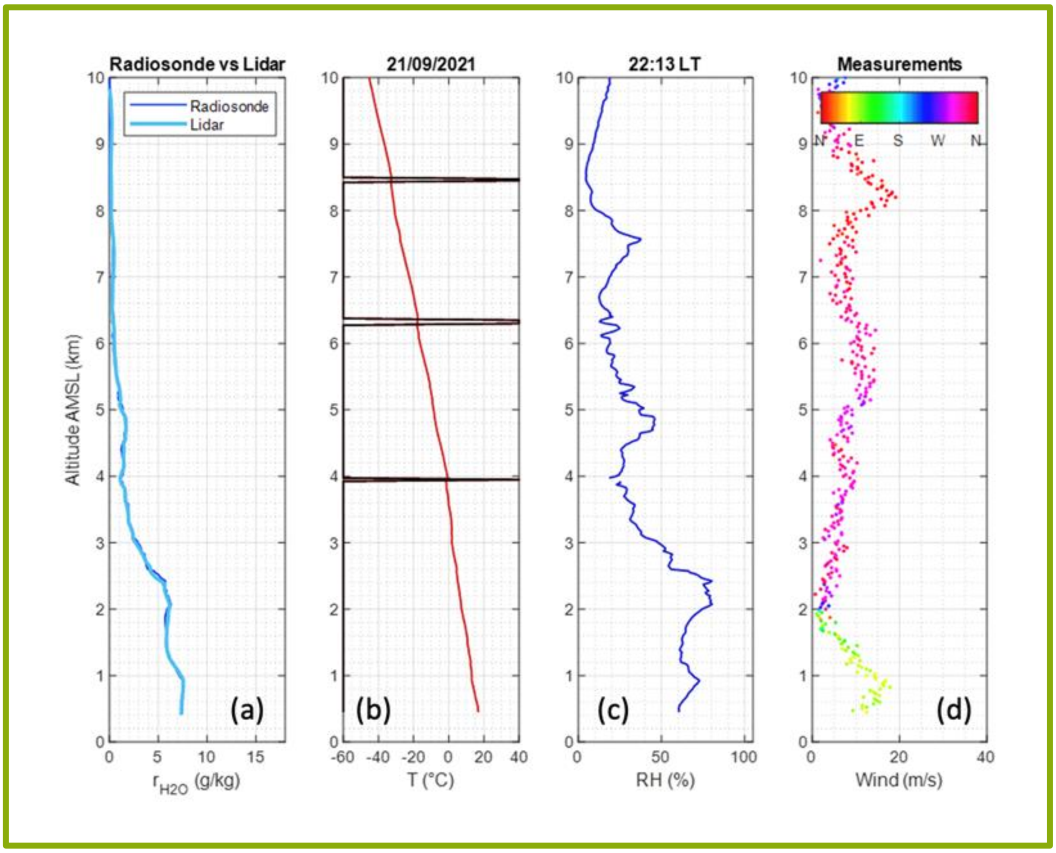

Figure 4: (a) Example of water vapor mixing ratio vertical profile measured with the ground-based WALI instrument (light blue) and calibrated using nighttime radiosonde profile (blue). (b-d): temperature, relative humidity and wind profiles acquired with the radiosonde.

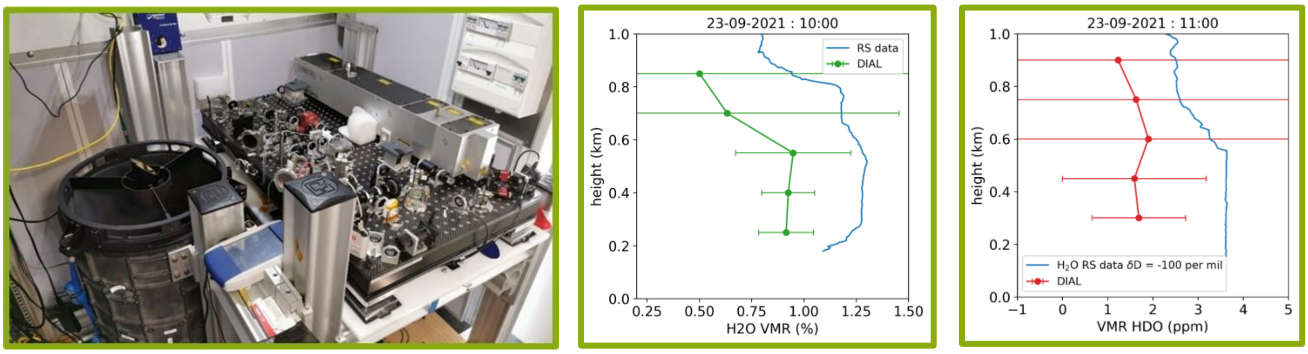

Figure 5: WAVIL DIAL laboratory system consisting of laser bench (right) and reception telescope (left) a). Preliminary WAVIL water vapour volume mixing ratio (VMR in %) and comparison with weather balloon radio-sounding (RS) b). Preliminary HDO volume mixing ratio (VMR in %) and comparison with HDO content calculated as the water vapour weather balloon radio-sounding (RS) and a supposed isotopic ratio δD of -100 per mil c). Error and biases sources are to be investigated in the coming weeks.

Daily and sub-daily weather balloon launches were performed during the campaign. Atmospheric soundings were extremely helpful for planning the flights. For example, it was possible to infer the altitude of the inversion layer and at which altitude it was needed to focus the water vapor ULA's sampling effort.

The late summer weather and the orographic conformation of the study area allowed to have very different atmospheric conditions on a day-by-day basis. Such conditions included stable clear sky as well as the fast development of convective clouds and unstable atmospheric conditions. There were some weak precipitation events during the first few days of the campaign and the wind condition prevented flight operations only on one occasion. All in all, the weather conditions did not significantly affect the planned flight operations. The two-week campaign was very intense, and each team worked really hard. The whole campaign was like a continuous Formula 1 race, where flights and data acquisition were punctuated only by instrument calibrations, ULAs refueling and short briefing-debriefing with the pilots.

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Figure 6: (a) Hans Christian Steen-Larsen (UiB) and Loïc Toussaint (ULA pilot) discuss the best flight strategy to capture cloud-atmospheric water vapor exchange processes. (b) Towards the Mont Blanc. A picture from a high altitude flight which allowed to capture regional water vapor transport (courtesy of Loïc Toussaint). (c) Pascal Genau (LATMOS) launched a radiosonde during strong atmospheric instability to obtain data in extreme conditions for calibrating the water vapor lidar.

To summarize, the main results of the campaign are:

- Several hours of data from three ULAs that include: air temperature, humidity, water vapor isotopic composition, cloud droplets size distribution, cloud water organic/inorganic chemistry, atmospheric vertical structures, and aerosol optical and chemical properties.
- Several hours of ground based lidar observations for water vapor H_2O, HDO, temperature and aerosols.
- A complete characterization of the horizontal and vertical structure of the water vapor isotopic composition within the lower troposphere of the study area. The data collected by several water vapor ULA flights can be used for direct comparison and validation of the WALI water vapor retrievals. Data from at least two flights can be used to validate the WAVIL instrument.
- Successful test for the UiB custom calibration system that was designed specifically for the LEMON campaigns. This calibration system will be used on board the ATR42.

It is expected to share the campaign data on a public repository that will be linked to a specific data descriptor publication. The data will be available via the AERIS database (https://metclim-lidars.aeris-data.fr/) for the entire scientific community.

For the time being, each group is now working on the data post-processing and want to focus on specific scientific questions. For ONERA and CNRS, the first task is to compare the obtained WAVIL data with radio soundings, and be able to point out biases and measurement errors on water vapour profiles. These inputs will then be used as feedback for the LEMON instrument. For ONERA, UiB and CNRS this also means to coordinate the effort on the data post processing to find the right way to compare lidar H_2O/HDO retrievals and CRDS observations.

Written by Daniele Zannoni (UiB), Patrick Chazette (CNRS), Jonas Hamperl (ONERA), Julien Totems (CNRS) and Myriam Raybaut (ONERA)

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Focus on calculations performed to estimate the LEMON instrument performances for ground-based range resolved DIAL, HDO and water vapour.

Given different atmospheric parameters and different instrument parameters, additional calculations were performed to estimate the ultimate LEMON instrument performances for the demanding scenario of ground-based range resolved DIAL, for HDO and water vapour retrieval. However, HDO is one of the key species, since the corresponding isotopic ratio δD has never been range resolved measured by any lidars before. Main calculations results were published in open access in [J. Hamperl et al, https://doi.org/10.5194/amt-14-6675-2021]. Some of these results are reported here.

The following lidar simulator was used at ONERA. It takes into account different parameters to build a simple atmosphere model, and also different emitter, receiver, and detector parameters to perform a calculation of the received DIAL signals and their signal to noise ratio, allowing to estimate a volume mixing ratio precision.

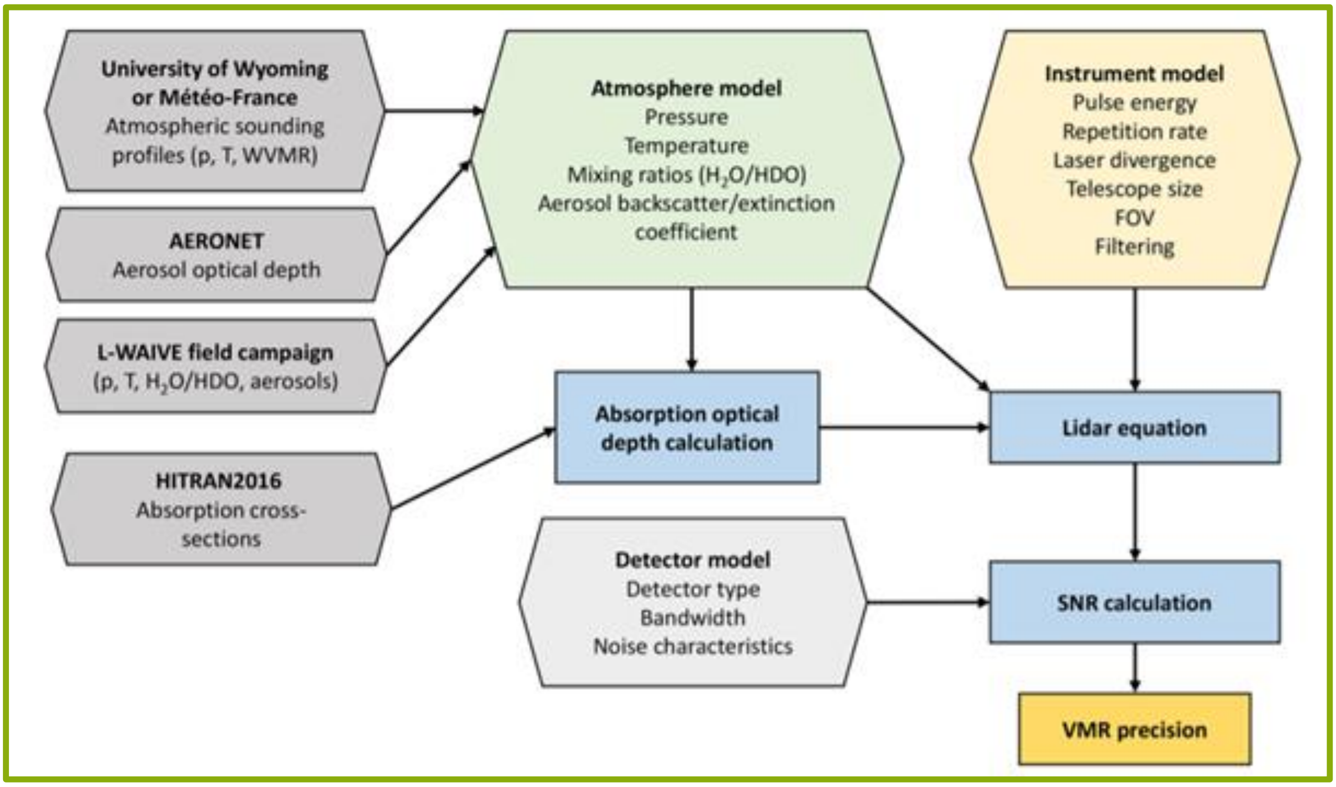

Figure 7: Block diagram of the DIAL simulator. Input models and databases are in hexagons, and principal calculations are indicated by rectangles. p: pressure; T: temperature; WVMR: water vapor mixing ratio; FOV: telescope field of view. The signal-to-noise ratio (SNR) is used to calculate the statistical random error (precision) of the volume mixing ratio (VMR) of H_2O/HDO.

In LEMON, it is expected to use a commercial detector. However, more sensitive detectors are developed in the frame of other projects, and the precision was calculated for two sets of photodiodes, a commercial one and a top state-of-the-art one.

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Transmitter		Receiver		
Energy	10–20 mJ		i)	ii)
Pulse duration	10 ns	Telescope aperture	40 cm	40 cm
Repetition rate	150 Hz	Detector type	InGaAs PIN	HgCdTe APD
λ_{on} $H_2{}^{16}O$ (1)	1982.93 nm	Detector diameter	300 µm	180 µm
λ_{on} $H_2{}^{16}O$ (2)	1982.97 nm	Field of view (FOV)	630 µrad	630 µrad
λ_{on} $HD^{16}O$ (1)	1982.47 nm	NEP	600 fW $Hz^{-1/2}$	75 fW $Hz^{-1/2}$
λ_{on} $HD^{16}O$ (2)	1983.93 nm	Bandwidth	1 MHz	1 MHz
Divergence	270 µrad		Responsivity: 1.2 AW^{-1}	Quantum efficiency: 0.8
				Excess noise factor: 1.2

Table 1: DIAL parameters.

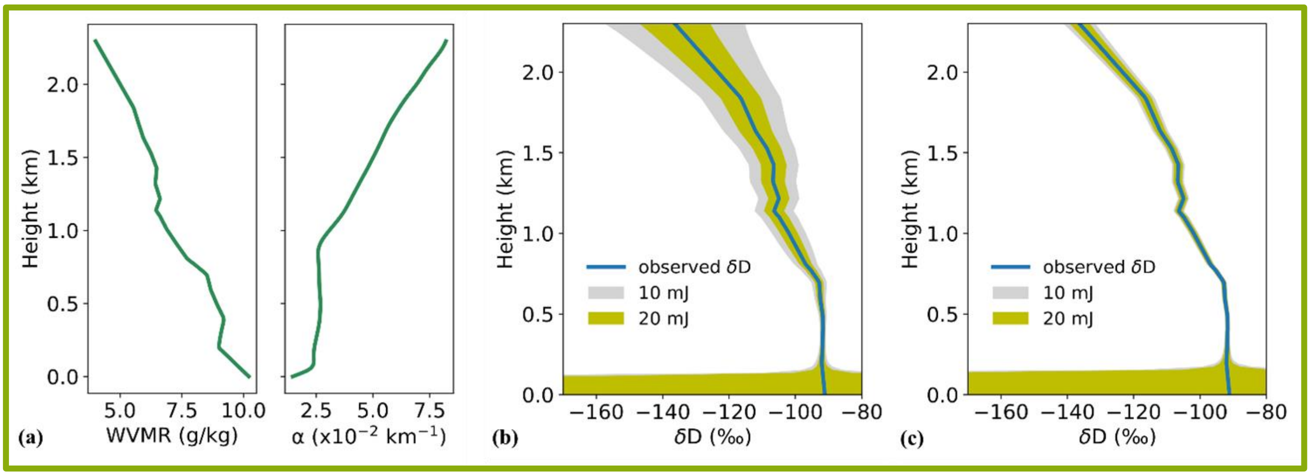

Figure 8: (a) Experimental profiles of the water vapor mixing ratio (WVMR) and aerosol extinction coefficient (α) obtained from the LWAIVE field campaign. Expected precision in the isotopic ratio in terms of δD for the InGaAs PIN photodetector (b) and the low-noise HgCdTe avalanche photodiode detector (c). Shaded areas indicate the absolute uncertainty based on random noise in terms of standard deviation for laser energies of 10 and 20 mJ. High uncertainty in the first 200 m is due to low signal caused by the overlap function increasing from zero to unity. Calculations are based on a measurement bandwidth of 1 MHz (150 m spatial resolution) and an integration time of 10 min.

A precision estimate was performed (see Figure 8), applied to a specific field campaign carried out in 2020 and involving both **CNRS** and **University of Bergen** teams [P.Chazette et al. https://doi.org/10.5194/acp-21-10911-2021, 2021.]. The calculated precisions are compatible with the observed variations in the isotopic ratio δD, which is very encouraging for the LEMON project.

Written by Jonas Hamperl and Myriam Raybaut (ONERA)

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GET TOGETHER

In this chapter you will find a selection major conferences, exhibitions and other events which are of interest for the LEMON community.

SPIE PHOTONICS WEST, "SOLID STATE LASERS XXXI: TECHNOLOGY AND DEVICES" CONFERENCE, SAN FRANCISCO, CALIFORNIA, US, 25-26 JANUARY 2022

The primary purpose of the SPIE PHOTONICS WEST "Solid State Lasers XXXI: Technology and Devices" conference is to highlight the development of new laser sources, advanced technologies, components, and laser system designs that can benefit the development, commercialization, and fielding of new laser platforms based on solid state media and associated frequency-conversion techniques. Key topics include diode-pumped lasers, hybrid fiber/solid state lasers, seed lasers for solid state/fiber amplifiers, and recent developments in tuning, Q-switching, ultrafast pulse generation, and frequency-conversion technologies.

LEMON partner **Fraunhofer ILT** will attend the conference and give a presentation of the paper "**Versatile laser transmitter for an airborne CO2 and water vapor DIAL based on a parametric laser setup**".

Source: https://spie.org/conferences-and-exhibitions/photonics-west/

LASER WORLD OF PHOTONICS 2022, MÜNCHEN, GERMANY, 26-29 APRIL 2022

LASER World of PHOTONICS 2022 is the 25th World's leading trade fair for components, systems and applications of photonics. This event features the combination of research, innovative technology and industrial application sectors, as well as the entire range of solutions, from components to systems.

Source: https://world-of-photonics.com/en/

CLEO 2022 - CONFERENCE ON LASERS AND ELECTRO-OPTICS, SAN JOSE, CALIFORNIA, US, 15-20 MAY 2022

CLEO is the world's premier international forum about innovative advances, research and new technologies from the laser science industry. CLEO 2022 highlights the latest research, applications and market-ready technologies in all areas of lasers, optics and photonics.

Source: https://www.cleoconference.org

The LEMON consortium partners look forward to meeting you!

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Interview

The University of Bergen (UiB) team members involved in the LEMON project are Harald Sodemann, Hans Christian Steen-Larsen, and Daniele Zannoni. In this LEMON Newsletter issue, you will read an interview with Daniele Zannoni, Postdoc at UiB's Geophysical Institute.

Daniele Zannoni is a Post-doc at the Geophysical Institute of the University of Bergen. Previously, Daniele worked in Italy, at the *Consiglio Nazionale delle Ricerche* (CNR), first at the Institute of Condensed Matter Chemistry and Technologies for Energy (ICMATE) in Padua, and after at the Institute of Polar Sciences (ISP) in Venice. His core research is centred on the following fields: isotope geochemistry, water cycle, and particulate matter. Daniele has co-authored 16 papers in several journals. Within LEMON, Daniele is highly involved in the work package "Instrument Ground validation and airborne demonstration".

DANIELE ZANNONI, POSTDOC AT THE GEOPHYSICAL INSTITUTE OF THE UNIVERSITY OF BERGEN

Question (Q) 1: Within the LEMON project, University of Bergen is a key partner in the work package "Instrument Ground validation and airborne demonstration", led by CNRS. What are the objectives of this work package? To what extent does this work package play a key role in view of the LEMON project outcomes?

Answer (A) 1: The main objective of this work package is to demonstrate that the LEMON instrument can serve to monitor H_2O/HDO, CO_2 and CH_4 in the atmosphere, from the ground and from an aircraft. The goals of this work package are to use the LEMON instrument in these two different contexts and, at the same time, to collect data from reference instrumentation. Indeed, only with field measurements and with the use of reference instrumentation we will be able to prove the robustness of LEMON retrievals.

Q2: What are the main activities performed by the University of Bergen within the work package "Instrument Ground validation and airborne demonstration"?

A2: Since validation is a fundamental step in remote sensing, the main activity of UiB is to provide the expertise and the instrumental capabilities to validate the LEMON's H_2O/HDO retrievals. Operationally, this is translated into measuring the water vapor concentration and isotopic composition in the line of sight of the LEMON instrument using state-of-the-art Cavity Ring-Down Spectroscopy (CRDS). Our main activities are then to collect the data with the validation instrument and to provide strong quality assessment on the data that will be used as a reference.

Q3: Which are the University of Bergen's key assets to perform these activities?

A3: Before applying to this Post-doc, I have always thought of the UiB group as "the water vapor isotopes dream team". In fact, the UiB group is equipped with many instruments for measuring water vapor isotopic composition and is made of top-level scientists with a lot of expertise in doing such type of measurements in very diverse environments. These environmental contexts include aircrafts, ships, and even remote places like the top of the Greenland Ice Sheet and Antarctica. In addition to measurement capabilities, the UiB group has also isotope-enabled climate model resources. Those modelling resources can be used in the LEMON project to simulate the atmospheric water cycle during the validation campaigns.

Figure 9: Daniele Zannoni, Postdoc at the Geophysical Institute of the University of Bergen, next to an Ultralight aircraft during the DIAL instrument ground-based validation campaign, September 2021.

Q4: Within the task "Instrument ground validation", you have just conducted a two-week field campaign in Southern France in

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collaboration with ONERA and CNRS, with the aim to measure humidity and water vapor isotopic composition using different strategies. What were the challenges of this campaign and how did you tackle them? Was the work achieved in line with the expectations?

A4: The main challenge was to make our water vapor observations reliable for being used as a validation data, especially for the HDO isotope. Putting a CRDS analyser on an ultralight aircraft entails many aspects to consider. First, the aircraft is a flying object which moves rather fast in the atmosphere and the on-board instrumentation has its own time response. So, during the data post-processing we need to synchronize the instrumentation to correctly convert the timeseries of water vapor HDO into spatial data. We tackled this challenge by doing precise measurements of the instrumentation response time with the "in-flight configuration" and by using a GPS and several atmospheric pressure sensors. Second, vibrations, fast temperature and humidity variations during the flight contribute to stress the instrumentation and could affect the precision and accuracy of our instrument. To minimize those effects, we thermally-insulated the instrumentation, we performed regular calibrations and we monitored the instrumental status during each flight. Finally, to reduce the uncertainty in the spatial data even further, we planned different flight strategies such as continuously sampling water vapor at the same altitude level or by repeating several times a specific vertical profile in the same geographical location. At the end, I'm happy to say that we were able to do all the planned work and we collected a lot of valuable data for the LEMON project.

Q5: What are the main next steps towards the achievement of the activities under the University of Bergen's responsibility in the work package "Instrument Ground validation and airborne demonstration"?

A5: The next big step is to prepare our reference instrumentation and calibration system for the airborne demonstration. For the airborne demonstration, the LEMON instrument and the reference instrumentation will be mounted inside an ATR42 aircraft. The time response and the spatial representativeness of our instrument will be pushed to the limit because the aircraft moves really fast and can climb to much higher altitude compared to the ultralight. Therefore, we need to characterize our reference instrument for sudden variations of humidity and isotopic composition. This characterization is fundamental especially for low humidity - high altitude conditions. In addition, all the instrumentation needs to be flight compliant. Therefore, we need to certify that our systems, commercial ones and custom made, are safe on-board during flight operation.

Q6: Daniele, you were hired by the University of Bergen as a Post-doc in June 2020 to work full-time on the LEMON project. How interesting is this opportunity for your career?

A6: I believe this Post-doc to be a great opportunity for my career for two main reasons. The first reason is that I'm working with both state-of-the-art technologies and with experimental technologies that can redesign our understanding of the atmospheric water cycle. The second reason that can boost my career is that I'm building my network of collaborators. The combination of these two points allows me to prepare and submit interesting articles on scientific journals, which is fundamental to proceed in academia. I would also mention that this Post-doc gives me the opportunity to train some practical skills from the logistic-managing point of view, because of the campaign organization from the UiB side.

Q7: What is the impact of LEMON project on your field of research?

A7: LEMON and water isotopes lidars will really improve our understanding of the atmospheric water cycle because, for the first time, we will be able to have high frequency, spatially resolved, water vapor isotopes measurements in the atmospheric column. This was unimaginable even just 10 years ago, despite the advancements made with passive H_2O/HDO satellite retrievals. I think that the LEMON instrument will be revolutionary in the hydrology-climate-isotope communities, as was the CRDS approximately a decade ago.

Q8: During your professional career, apart from this experience at the University of Bergen in Norway, you worked in Italy in two different research institutes at the *Consiglio Nazionale delle Ricerche*. Would you say that these experiences made you acquire specific intercultural skills? In what extent do they benefit the LEMON project?

A8: The experience at CNR in Italy was fundamental for me to get involved in this Post-doc. At the CNR-ISP, I worked with isotopic continuous flow analysis of ice-cores (CFA). This gave me the opportunity to work with the same instrument that we use to validate the LEMON instrument and to build custom systems to generate precise water vapor streams. We use a water vapor generator similar to the CFA-type for calibrating our reference instrument. At the CNR-ICMATE, I had the opportunity to gain experience in nuclear electronics and in general, in fast signal acquisition and signal processing. So, the answer to the first question is yes, I have acquired specific intercultural skills in isotope geochemistry, physics, digital-analog electronics and signal processing. Regarding the second question, the skills gained in my previous works benefit the LEMON project because I can successfully set up custom measuring and calibration systems for water vapor isotopes that the LEMON instrument can use as validation source.

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