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NEWSLETTER °1

OCTOBER 2019

Welcome to the first newsletter from the LEMON project

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.

Word from the Coordinator

DIAL can be an efficient tool to detect, localize and quantify gaseous species.
However, the performances achieved with such technology, either for range-resolved or for integrated path measurements, are highly dependant on the performances of the DIAL subsystems.
Key elements are the detector, the emitter source, the wavelength reference and measurement system.
Over the last decades, a real effort has been pursued by the DIAL community to propose new detectors, innovative laser and/or parametric architectures for the emitter, high precision frequency references.
In Europe, the scientific community is eager for new tools for green-house gases and water vapour remote sensing measurements from space: this enthousiasm lead the European and national Space Agencies to fund studies at different technical readiness levels.
In such frame, LEMON consortium ambition is to bring to the community a new, versatile, instrument, able to target several species (CO_2, CH_4, water vapour), in a challenging wavelength range (2µm), and to assess its potential for space operation, targetting more specially the emiter part. Our main force is a complementary consortium of experts in their field, dedicated to achieve this goal !

Dr. Myriam Raybaut
Research engineer
ONERA – France

NEWS & EVENTS

LEMON presentation leaflet is now downloadable:
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This project has received funding from European Union’s Horizon 2020 research and innovation programme under grant agreement No 821868

Word from the Project Officer

Figure 1 : LEMON EC Project Officer, Sabri Mekaoui

The challenge for the European Union is to mature application-oriented technologies particularly in space atmospheric measurements. These technologies are expected to be the building blocks of a European greenhouse gas monitoring architecture and potentially part of the payload of the next generation of sentinels. Together with passive measurements, Differential Absorption Lidar (DIAL) sensor concepts for greenhouse gases and water vapour measurements are part of the solution. Yet, lidar remote sensing of the Earth's atmosphere is challenging and therefore DIAL system concepts and particularly LEMON is expected to mature the technology in order to improve the performance of future Earth Observation systems and to become part of the global solution.

Several activities targeting atmospheric measurements, either at technology or data retrieval levels, have been funded through the European Commission Space Programme. Already through FP7, the project Britespace designed an Integrated Path Differential Absorption (IPDA) lidar and particularly validated the concept of a semiconductor laser transmitter to be used for the detection of carbon dioxide. In Horizon 2020 and complementary to LEMON, the HOLDON project is designing and building a cutting-edge photon noise limited Lidar detection chain based on HgCdTe avalanche photodiodes that will be hybridized to a CMOS Readout Circuit. Overall, LEMON is designing the emitter while HOLDON is designing the receiver. Alternatively, SWIRup is developing an IR image sensors that do not require cryogenic cooling. They will complement visible light image sensors in high-resolution earth observation missions (e.g. vegetation / greenhouse gas monitoring). As previously stated, passive measurements will complement LIDAR concepts. This is the case of the SCARBO project which will address both CO_2 and CH_4 species by implementing a novel miniaturised static spectrometer concept on a constellation of Small Satellites (< 500 kg), coupled with aerosol sensors and high-end reference instruments. SCARBO aims at improving the temporal revisit over the various sites of interest while meeting the accuracy and spatial resolution requirements. Finally, the CHE project is studying the carbon cycle by investigating a possible synergetic solution through the combination of top-down and bottom-up approaches, by merging the available knowledge from emission inventories and process models with the increasing amount of observational data for the atmosphere and the Earth's surface. The CHE initiative aims to bring together relevant expertise to develop the science and to scope out the necessary architecture for a European CO_2 monitoring capacity.

Sabri Mekaoui
Project Officer – Research Executive Agency

PROJECT HISTORY

It is a long history of national and European collaborations among the consortium partners which has led to the LEMON project. First, LEMON started from a scientific need for local, airborne, satellite greenhouse gases and water vapour observations requested by the Intergovernmental Panel on Climate Change (IPCC) members. Over the last decades, several airbornes lidars such as Leandre (by Latmos) and Charm-F (by DLR) had been developed, allowing to perform high quality measurements, but needing a single emitter par targetted species.

In parallel, both LEMON partners CNRS/Latmos and UiB had a strong scientific need and history in studying the atmospheric hydrological cycle process.

Despite the technological difficulties to mature spaceborne lidars, the Aeolus mission and the Aladin 1µm laser could be realised successfully.

Thereupon, the CNES/DLR MERLIN (CH_4) mission was selected as first Differential Absorption Lidar in space in the next years. At that point, the following scientific issue was raised: what if a generic lidar transmitter architecture was possible? That would mean having a single transmitter maturation process towards space, for different missions, and benefitting form an instrument which could be used for airborne campaigns, as well as for the ground calibration and validation processes of other missions.

This is the concept underpinning the LEMON DIAL Lidar principle: a laser transmitter emits different successive laser wavelengths "on" and "off" the absorption lines of a given species; then, a receiver collects the backscattered light (same particles) from the atmosphere and/or the ground.

From the technical point of view, several stages led to the LEMON project. As a first technological brick there are Onera's patents for a widely tuneable

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source, initially developed for Onera own applications (local sensing, multi-species) and based on a "NesCOPO" (Nested Cavity Optical Parametric Oscillator) architecture. Furthermore, between 2006 and 2010, the European Space Agency technical research program PULSNIR provided a proof of concept of the adaptability of this source for CO2 lidar remote sensing specifications. This made it possible to benefit from the latest develepoments in terms of 1µm laser for space applications.

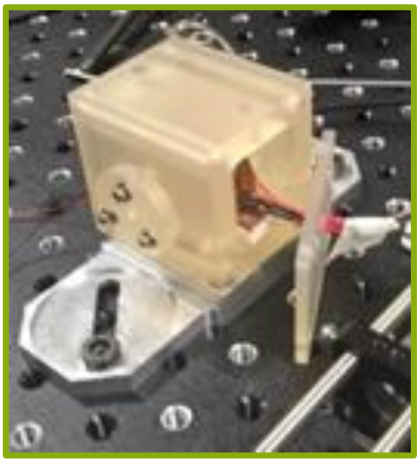

Figure 2 : ONERA patent NesCOPO

Between 2010 and 2016, CO2 Lidar remote detection tests were performed with CNES support and CNRS-Latmos collaboration, leading to a multi-species proof of concept (CO_2, H_2O, CH_4…) in the 2µm range: 1µm pump laser combined with a Generic Frequency Conversion Unit (GFCU) architecture provides a multispecies DIAL lidar emitter.

Moreover, between 2015 and 2018, Onera also worked on a 1.5-1.6µm multispecies DIAL instrument,which could be depoyed for field campaigns, working with Innolas for the 1µm pump source.

Then, between 2012 and 2018, first TRL improvements towards space operation were performed with ESA's support and thanks to KTH's innovative crystals: NesCOPO's mechanical design was improved, preliminary vibration and radiation testing were performed.

Meanwhile, Fraunhofer ILT and SpaceTech were implied in MERLIN instrument development. This allowed them to increase their knowhow on, respectively, i) lasers and parametric sources for space applications, for which Fraunhofer ILt had already a strong experience through ESA FULAS project,and ii) ultra-fine frequency references and measurements schemes for SpaceTech.

In 2016, WAVIL, the French ANR proposal, coordinated by Latmos, was launched to develop a ground-based H_2O/HDO Lidar prototype. This lidar prototype is currently under realisation, and whose retex will be used in the LEMON project.

Finally, in 2016, discussions with the best partners available at the ICSO conference led to the decision to propose the LEMON project.

EXPECTED INNOVATION

Based on innovative photonics components, LEMON will develop a cutting-edge Differential Absorption Lidar (DIAL) sensor concept that can either measure CO_2, CH_4 or water vapour stable isotopes (H_2O and HDO) in a rugged and compact architecture.

The LEMON concept is based on a generic tuneable frequency conversion unit (GFCU) which converts a 1µm pump laser radiation into two wavelength tuneable radiations to match the targeted species absorption lines. This single emitter concept differs from classical approaches that rely either on direct laser emission or classical parametric converters design, which limits their use to detect a single species.

Based on a specific optical parametric approach (NesCOPO), amplified to the 50 mJ energy level, LEMON GFCU will therefore provide a versatile and increased function instrument to support climate models and meteorological studies.

At the end of the project, the objective will be to demonstrate the TRL6 validation of the LEMON GFCU through airborne campaigns.

LEMON's specific objectives are the following:

- Demonstrate unprecedented versatility and reactivity in addressing the main greenhouse gases with a single instrument.
- Perform the first range resolved water vapour and isotopes DIAL measurements, leading to a better understanding in meteorology.
- Provide technical breakthroughs in terms of laser emitter output energy and wavelength tunability (1.98-2.3µm tunability).
- Elaborate a roadmap to integrate LEMON GFCU in a future EU space mission.

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ENVIRONMENTAL CHALLENGE ADDRESSED BY LEMON

The LEMON project is expected to have significant impacts on climate change, notably both on climate modelling and meteorological studies. With LEMON, the aim is to provide a breakthrough in terms of emitter for space applications to monitor greenhouse gases and water vapour and improve the accuracy of climate change analysis as recommended by the Copernicus report [1].

LEMON will enable to perform airborne measurements of CO_2 and CH_4. This is particularly interesting, because these greenhouse gas fluxes at the Earth's surface exhibit a complex pattern, and through the airborne measurement the concentration measurements of the vertical total column may be used to infer surface sources and sinks by means of inverse models that describe atmospheric transport and mixing.

The added value of measuring vertically resolved profiles of H_2O, CO_2 (compared to column integrated retrievals) lies in the ability to separate boundary layer processes from free tropospheric ones.

Moreover, high resolution observations of water vapour in the lower troposphere, such as those provided by ground-based and airborne lidars, have proved to be invaluable in recent years for advancing science on planetary boundary layer processes, convective initiation and moisture transport into convective systems [2]-[3].

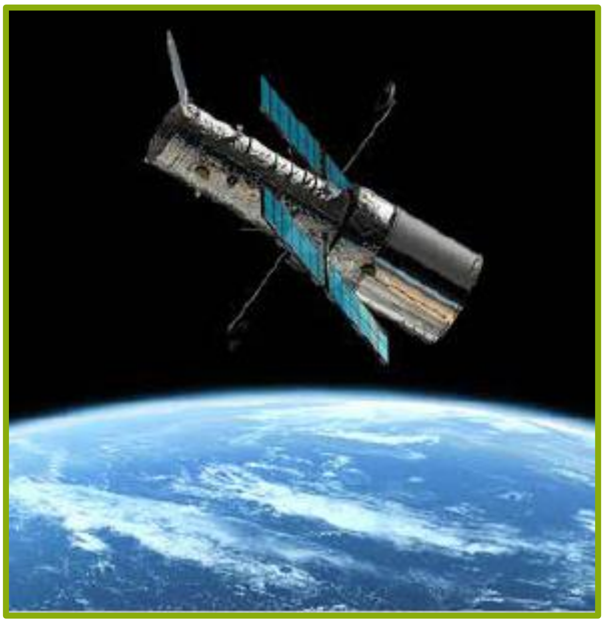

Figure 4: Space applications to monitor greenhouse gases and water vapour

Figure 3: Measurements of water vapour, CO_2 and CH_4 to improve the accuracy of climate change analysis

Nevertheless, humidity observations alone are not sufficient for identifying the variety of processes accounting for the properties of tropical, subtropical and polar tropospheric air masses.

Since the stable isotopic composition of water vapour is affected by fractionation during phase changes, measurements of the isotopes of water vapour can thus provide complementary information on the water budget when combined with humidity because they record the integrated history of phase changes within a given air mass and provide a unique signature of multiple processes involved in the water vapour cycle. As a consequence, adding an "isotopic" dimension to such an active remote sensing will further enhance LEMON's capability to analyse and comprehend the water vapour cycle in the lower troposphere, in interaction with the Earth surface.

[1] http://www.copernicus.eu/main/towards-european-operational-observing-system-monitor-fossil-co2-emissions

[2] K.-O. Lee, C. Flamant, V. Ducrocq, F. Duffourg, N. Fourrié and S. Davolio, 2016: Convective initiation and maintenance processes of two back-building mesoscale convective systems leading to heavy precipitation events in Southern Italy during HyMeX IOP 13, Q. J. Roy. Meteorol. Soc., 142, 2623-2635, doi: 10.1002/qj.2851.

[3] D. Bruneau, P. Quaglia, C. Flamant, M. Meissonnier and J. Pelon, 2001: The Airborne LIDAR LEANDRE 2 for Water Vapour Profiling in the Troposphere. Appl. Opt., 40, 3450-3475.

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FIRST RESULTS

LEMON project started early january 2019.

A first phase of instrument specification definition, to answer the requirements of our end-users, CNRS/LATMOS, LSCE and University of Bergen, was of course necessary in the early months.

This phase also included

- Early discussions with CNRS/Safire partner, with a visit of the ATR 42 aircraft in Toulouse.
- Preliminary identification of a potential campaign site.

Given these specifications, it was then possible to define the transmitter, frequency reference and receiver units specifications. This work was done in close collaboration between the partners involved in the technical developments (Fraunhofer ILT, Innolas, KTH, ONERA, Spacetech). This included specific calculations for DIAL, performed at the ONERA.

A phase of optical conception thus began, up to september, to define the critical designs of these TREE (transmitter), FRUIT (frequency reference unit), ARM (acquisition and receiver module) modules.

This included specific calculations for:

- Non linear optics crystals definition by KTH;
- Pump laser design by Fraunhofer and Innolas;
- Optical parametric oscillator by ONERA and Fraunhofer;
- Optical parametric amplifier by KTH and ONERA;
- Frequency measurement sensitivity using different measurement schemes by Spacetech.

These calculations were supported by Retex from past experiments as well as experiments using available tests beds.

Close collaboration between the teams allowed the optical set-up definition by september 2019.

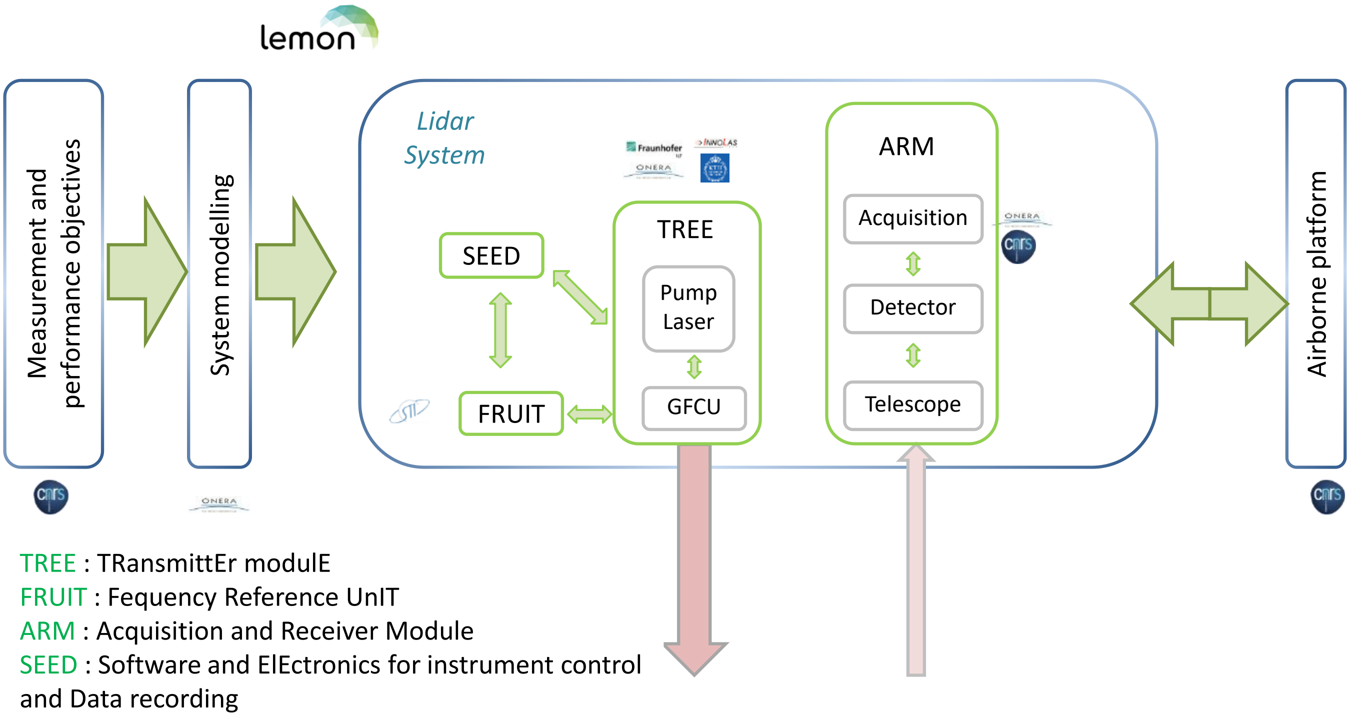

Figure 5 : LEMON sub-systems interconnection

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GET TOGETHER LIST

ICLO 2020, 19TH INTERNATIONAL CONFERENCE LASER OPTICS, ST.PETERSBURG, RUSSIA, 8-12 JUNE, 2020

The International Conference on Laser optics is This is a traditional scientific event in the field of laser physics, optics, and photonics. The LEMON coordinator, Myriam Raybaut, as well as Valdas Pasiskevicius from KTH, have been invited to talk at this event about LEMON.

It will be the occasion to present the last project advancements to experts in lasers, optics and photonics from all over the world. The last year event attracted more than 1000 attendees, and nearly 800 presentations from 35 countries.

Source: https://www.laseroptics.ru/

PHOTONICS AND ELECTROMAGNETICS RESEARCH SYMPOSIUM 2019 XIAMEN, CHINA , 17-20 DECEMBER 2019

The PhotonIcs and Electromagnetics Research Symposium (PIERS) provides an international forum for reporting progress and recent advances in the modern development of electromagnetics, photonics and applications, and includes topics like remote sensing and radars.

The LEMON project was already present at this symposium last June in Roma, where J. B. Dherbecourt (ONERA), The WP2 leader, gave a presentation on the LEMON project principles and goals.

Source: http://piers.org/piers/

LASER WORLD OF PHOTONICS MUNICH, 21-24 JUNE 2021

LASER World of PHOTONICS, the world's leading Trade Fair with Congress for Photonics Components, Systems and Applications. Together with the World of Photonics Congress, the fair unites research and industry and promotes the use and ongoing development in the Photonics industry.

Fraunhofer, as partner of the LEMON project, presented its activities and experience on the last session, from 24th - 27th of June 2019 and will attend this major event again on its next happening.

Source: https://world-of-photonics.com/index-2.html

PAST EVENTS

OSA LASER CONGRESS 2019 VIENNA, 29 SEPTEMBER - 3 OCTOBER 2019

LEMON coordinator, Dr. Myriam Raybaut (ONERA), has been invited to speak at the OSA Laser Congress, which took place in Vienna from the 29th of September to the 3rd of October 2019. On this international stage, offering a view of the latest technological advances in solid-state lasers as well as the applications of laser technologies for industrial products and markets, Dr. Myriam Raybaut gave a presentation of the LEMON project, its main challenges, principles and goals.

Source: https://www.osa.org/en-us/meetings/osa_meetings/laser_congress/

H2020 SPACE INFODAYS AT CNES PARIS, 5 SEPTEMBER 2019

Dr. Myriam Raybaut (ONERA) participated as a speaker to the Horizon 2020 Space national Information Day on the 5th of September 2019, organized by the H2020 Space NCP Network at the French National Centre for Space Studies (CNES) premises in Paris. On this occasion, Dr. Raybaut held a presentation of the LEMON project as an example for a project selected by the European Commission (EC) for funding.

Source: http://www.horizon2020.gouv.fr/cid144328/journee-nationale-d-information-espace-horizon-2020-a-paris.html

INTERNATIONAL LIDAR RADAR CONFERENCE 2019 HEFEI, CHINA, 24-28 JUNE 2019

LEMON WP2 Leader, J. B. Dherbecourt (ONERA), was invited to speak about the LEMON project principles and goals at the International Lidar Radar Conference (ILRC) 2019, held in Hefei, China, from the 24th to the 28th of June 2019. The biannual ILRC conferences highlight application results and recent technological advances in the field of laser remote sensing as applied to the atmosphere, earth and oceans.

Source: https://www.ilrc29.cn

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Interview

In this edition of the LEMON Newsletter # 1, we propose you an interview with LEMON's co-coordinator, Cyrille Flamant, who is Directeur de recherche CNRS at LATMOS.

These tags will lead you into the interview: **water vapour - hydrological cycle - climatic studies - evapotranspiration - greenhouse gas - methane - carbon dioxide - climate warming - airborne lidar.**

CYRILLE FLAMANT, RESEARCHER CNRS-LATMOS

Q1 : Why is it important to measure water vapor and its isotopes, as well as carbon dioxyde and methane?

Water vapour plays a significant role in the physical and chemical processes occurring in the troposphere. It is a key component of the hydrological cycle and the climate system. Measuring water vapour is challenging, especially because in the troposhere it may fluctuate very rapidely on both spatial and temporal scale. This is due to the fact that water experiences multiple phase changes in troposheric air masses on the scale of few hours, with water vapour varying on the vertical by up to 5 orders of magnitude between the Atmospheric Boundary Layer (ABL) and the lower stratosphere.

The two most abundant stable water vapour isotopes, H_2O and HDO, differ by their mass and molecular symmetry. As a result, during water phase transitions, they have slightly different behaviors. The heavier molecules prefer to stay in the liquid or solid phase while the lighter ones tend to evaporate more easily. This unique characteristic makes water isotopes the ideal tracers for processes in the global hydrological cycle. Water isotopes are independent quantities depending on many climate factors, such as vapour source conditions, circulation, local precipitation, and ambient temperature. The isotopic compositions of water vapour can therefore provide an integrated perspective on the hydrological history of air masses and can be used for tracing physical processes in hydrological and climatic studies.

Concommittant observations of H_2O and HDO at high spatio-temporal resolution, as obtained by lidar over a significant depth of the troposphere, will contribute to advance knowledge on processes such as evaporation at the surface, evapotranspiration by ecosystems, vertical and lateral mixing in the atmosphere, condensation during cloud formation and water phase changes, processes that are currently very difficult to observe in the troposphere by means of in-situ instruments. Furthermore, because a large fraction of the water vapour available over the continents in the ABL is associated with evapotranspiration from ecosystems, adding CO_2 measurements to H_2O and HDO observations will help enhance understanding the vegetation respiration processes.

Figure 6 : Cyrille Flamant, LEMON's co-coordinator

Water vapour also plays a major role in the Earth's radiative balance at the global scale. It is, in terms of concentration, the primary greenhouse gas in the Earth's atmosphere (responsible for about 60% of the clear sky greenhouse effect). Methane (CH_4) and carbon dioxide (CO_2) are also potent greenhouse gases, with CH_4 having a higher global warming potential and radiative forcing than CO_2. Furthermore, water vapour is responsible for doubling the amount of warming associated with the primary greenhouse gases that are CO_2 and CH_4.

Globally, large parts of the Earth's natural surface (wetlands, rivers and streams, peats) are important sources of CO_2 and CH_4, with emission fluxes being controled by temperature and other meteorological variables. Water vapour being expected to rise in the future warmer climate, this will lead to more extreme weather events and likely enhanced CO_2 and CH_4 emissions with potentially further warming.

Hence, the quantification and the elucidation of processes underlying the variations in atmospheric water vapour, methane and carbon dioxide, remain one of the grand challenges in the interwinded water and carbon cycles science, pertaining to climate change. Therefore, not only is it crucial to measure H_2O, CO_2 and CH_4, is is also of paramount importance to measure them comcomittantly.

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Q2: What is the interest of measuring these constituants from a plane? What is the interest to measure them from space?

Using an airborne lidar system operating from an aircraft will enable us to target specific objectives and to access regions of the globe that cannot necessarly be reached with a ground-based system. For instance, conducting airborne measurements allows making meaningful observations of water vapour in the vicinity of significant weather phenomena such as organized deep convection that leads to heavy precipitation over populated areas, in order to understand how moisture is fed in such sytems. It also enables targetting specific regions known to hold some of the most important carbone dioxyde and methane sources in the tropics such as natural wetlands, rivers estuaries and irrigated surfaces such as rice paddies. Measurements from such a platform will also permit targetting high latitude areas where permafrost thawing is a paramount issue with massive amounts of methane being relased to the atmosphere as a result of climate warming. Finally, the anthropogenic contribution to the H_2O, CO_2 and CH_4 of megacities throughout the world to the regional atmospheric composition can only be apprehended using aircraft measurements, whereas surface-based measurements from specific sites cannot be considered representative at the scale of such large cities.

Carefully designed airborne strategies will help enhance knowledge of mesoscale to regional scale processes responsible for the large and rapid variations in atmospheric consituants in regions affected by climate change. With an airborne-based approach we can understand processes controling emissions associated with each type of natural and anthropogenized surfaces, and assess their respective contribution to atmospheric composition.

"The quantification and the elucidation of processes underlying the variations in atmospheric water vapour, methane and carbon dioxide, remain one of the grand challenges in the interwinded water and carbon cycles science, pertaining to climate change."

Measuring water vapour, carbon dioxyde and methane from space will contribute to unravel the distribution of sources and sinks at the global scale that cannot currently be addressed by ground based in-situ observations because the existing measurement network is too coarse.

Q3: What is the impact of LEMON project for your field of reseach?

LEMON will boost my research on processes leading to heavy precipitation events in the Mediterranean and in West Africa. Such events are multiscale atmospheric phenomena that result from a complex and multiscale interaction between ambient flow, topography and deep convection that govern the amount, timing and location of precipitation. The synoptic moisture transport feeding the deep convection together with the local sources are important to understand the life cycle of precipitating systems. LEMON measurements of H_2O and HDO will provide priceless information for that matter.

Figure 7: LEMON partners visit of the aircraft that will integrate the lidar

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