CH_4 AND CO_2 IPDA LIDAR MEASUREMENTS DURING THE COMET 2018 AIRBORNE FIELD CAMPAIGN

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ABSTRACT

Installed onboard the German research aircraft HALO, the integrated-path differential-absorption (IPDA) lidar CHARM-F measures weighted vertical columns of both greenhouse gases (GHG) below the aircraft and along its flight track, aiming at high accuracy and precision. Results will be shown from the deployment during the CoMet field campaign that was carried out in spring 2018, with its main focus on one of the major European hot spots in methane emissions: the Upper Silesian Coal Basin (USCB) in Poland. First analyses reveal a measurement precision of below 0.5% for 20-km averages and also low bias, which was assessed by comparison with in-situ instruments. The measurements flights were designed to capture individual CH_4 and CO_2 plumes from e.g. coal mine venting and coal-fired power plants, respectively, but also to measure large and regional scale GHG gradients and to provide comparisons with the Total Carbon Column Observing Network (TCCON). Many other different instruments, both airborne and ground-based, complemented the lidar measurements to provide a comprehensive dataset for model analyses. CHARM-F also acts as the airborne demonstrator for MERLIN, the "Methane Remote Lidar Mission", conducted by the German and French space agencies, DLR and CNES, with launch foreseen in ~ 2024. In this context, the airborne lidar data are likewise important for mission support such as for e.g. algorithm development and improvement and, moreover, the CoMet mission was also an important step for MERLIN validation preparation.

1. INTRODUCTION

There are still significant deficits in the knowledge about the budgets of two major anthropogenic greenhouse gases, CO_2 and CH_4, which contribute to about 81% of the anthropogenic radiative forcing, such that the ability to accurately predict our future climate remains substantially compromised. Different feedback mechanisms which are insufficiently understood have significant impact on the quality of climate projections. In order to accurately predict future climate of our planet and support observing emission targets in the framework of international agreements (e.g. COP21 Paris Agreement), adequate knowledge of the sources and sinks of these greenhouse gases and their feedbacks is mandatory.

In spite of the recognized importance of this issue, our current understanding about sources and sinks of the gases CO_2 and CH_4 is still inadequate. In order to overcome such shortcomings, the CoMet (CO_2 and Methane) mission has been executed using the most advanced airborne, ground-based and satellite instruments for greenhouse gas monitoring to fill existing gaps and investigate new observation capabilities to support political entities towards raising their ambition to reduce GHG emissions. One of the key instruments of CoMet was the airborne Integrated Path Differential Absorption (IPDA) lidar [1] whose results are the focus of this contribution.

2. METHODOLOGY

2.1 The CoMet 1.0 mission

CoMet is a multi-aircraft mission performed in May-June 2018 deploying a suite of the most sophisticated airborne instruments to measure atmospheric CH_4 and CO_2 and supported by a variety of ground-based in-situ and remote sensing experiments. The German research aircraft HALO acted as the airborne flagship of that campaign. Figure 1 shows all 9 flight tracks of the scientific flights of HALO during CoMet out of Oberpfaffenhofen airport with a total distance of ~44.000 km. Among other instruments, HALO was equipped with the CHARM-F lidar [1] and in-situ instruments for the measurement of greenhouse gases [2]. Parts of the flights were concentrated on a European hot-spot region of methane emissions: the Upper Silesian Coal Basin (USCB).

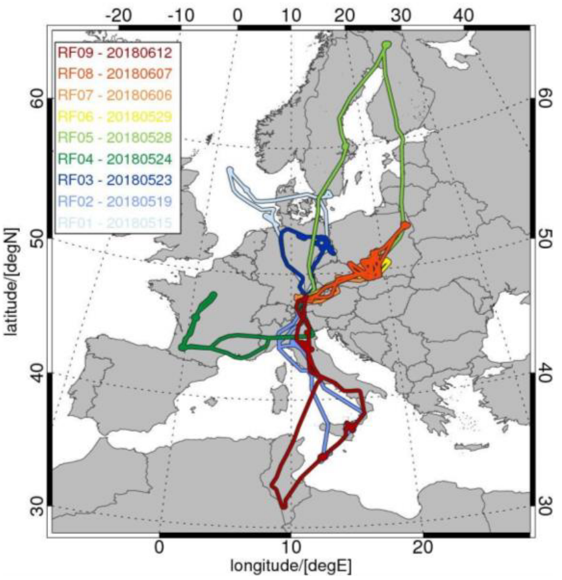

Figure 1: *Flight tracks of HALO during CoMet. On the 28 May, 29 May, 6 June and 7 June the HALO flights concentrated on the Upper Silesian Coal Basin and were coordinated with three propeller aircraft. The flight on 24 May was coordinated with the French Falcon operated by SAFIRE.*

Therefore, two other aircraft were performing extensive flight operations in that region with their base at Katowice Pyrzowice airport: a Cessna 208 Grand Caravan operated by DLR with a comprehensive in-situ payload [3] and a Cessna 207 operated by FU Berlin with the MAMAP passive spectrometer [4] as the main instrument. Additionally, two flights dedicated to survey exhaust plumes of coal mine ventilation shafts were performed with a Do228 aircraft equipped with a hyperspectral imager. In order to support the validation preparation activities of MERLIN [5], a coordinated flight of the French Falcon 20 operated by SAFIRE and HALO was performed in France. That flight was designed to provide comparison with airborne in-situ instruments, ground based remote sensing measurements (e.g. TCCON instruments), and balloons equipped with aircore samplers. On the ground, a variety of instruments supported the airborne measurements. In the USCB, an array of four ground-based and a mobile FTIR instruments were deployed. Three wind lidars accurately measured the local wind conditions to help inferring fluxes by means of e.g. mass balance approaches. A mobile backscatter lidar provide information about the planetary boundary layer evolution. In addition, in-situ measurements from mobile vans and small drones were made available through an in-kind contribution of the MEMO^2 network to provide near-surface information of GHGs and to quantify CH_4 and CO_2 emissions from individual coal mining shafts. All measurements were planned to provide best possible synergy with satellite measurements from GOSAT, Sentinel-5P and OCO-2. Further measurements activities such as in Sodankylä, Finland, supported CoMet. Finally, a model infrastructure (regional inverse modelling, chemistry-climate modelling with regional refinement) is employed in order to use the data streams of the individual instruments for modelling the greenhouse gas fluxes. Those models were also used in forecast mode to optimize flight strategies.

2.2 The CHARM-F lidar

In the past years, an airborne IPDA system (CHARM-F) has been developed and successfully tested at DLR [1]. To our knowledge, CHARM-F currently is the only airborne IPDA capable to measure both greenhouse gases, CH_4 (at 1645 nm) and CO_2 (at 1572 nm) at the same time [1].

The lidar transmitter (Fig. 2) is based on two optical parametric oscillators which are pumped by means of diode-pumped, injection seeded, and

Q-switched Nd:YAG lasers in a master-oscillator power-amplifier configuration. At both wavelengths, 1571 nm and 1645 nm, an energy of ~ 10 mJ is generated within a pulse length of ~ 20 ns.

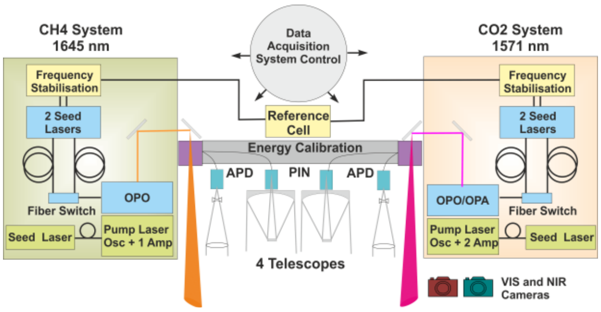

Figure 2: *Schematic set-up of the airborne CO_2 and CH_4 integrated path differential absorption lidar.*

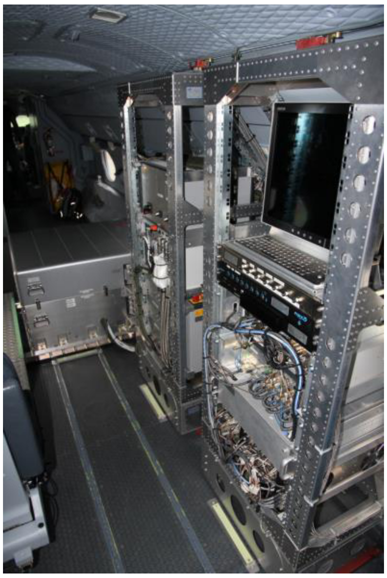

Figure 3: *Photograph of the CO_2 and CH_4 IPDA lidar as installed into the cabin of HALO.*

The IPDA technique requires the generation of two wavelengths that act as the on-line and off-line. This is achieved by injection seeding cw radiation from two stabilized DFB lasers. In order to fulfil the stringent requirements on frequency stability for the on-line and off-line wavelengths, a sophisticated locking scheme has been developed that is based on DFB lasers referenced to a multipass absorption cell and offset locking techniques. In order to monitor the frequency stability of the seed system (at 1572 nm) with highest possible accuracy under in-flight conditions, a compact optical frequency comb (Menlo Systems) has been employed, to the best of our knowledge, for the first time onboard an aircraft. Previously, such measurements were only possible in the laboratory.

CHARM-F's receiving system consists of two telescopes for each wavelength range, one adapted for optimum operation onboard the aircraft and attached to an InGaAs pin diode, and another smaller telescope for mimicking the viewing geometry of a satellite system and equipped with an InGaAs avalanche photodiode (APD). This redundant measurement capacity proved to be very valuable for an independent quality assessment of the data. The received signals are sampled using fast digitizers and processed by means of a home-built data acquisition system. Housekeeping data monitoring as well as laser control is maintained by separate computer systems. Figures 2 and 3 show the schematic set-up and a photograph of the system installed on-board, respectively.

The prime quantities to be measured by CHARM-F are the column-integrated dry-air mixing ratio of corresponding GHG (denoted as XGHG) [6].

3. RESULTS

During previous test flights the precision of CHARM-F measurements of XCO_2 and XCH_4 have already been quantified to be below 0.5% for 20-km averages [1]. During CoMet, the accuracy of the lidar measurements has been carefully assessed by comparing the lidar data to measured profile data from a cavity ring-down spectrometer (CRDS). For this purpose, the in-situ profiles were integrated according to CHARM-F's weighting function and compared to the CHARM-F XGHG values from fly-bys in the vicinity of the respective descent. Figure 4 shows the comparison for the case of XCO_2 independently measured with the two different receivers. Given the fact that the CHARM-F data result from a simple cross section calculation by just using the HITRAN16 data base (www.hitran.org), the agreement is considered very good. The mean absolute bias is of the order of 0.6%. For XCH_4 the results are comparable.

These results lend confidence in quality of the CHARM-F data acquired during the research flights on all relevant spatial scales. Small sub-continental and regional greenhouse gas gradients

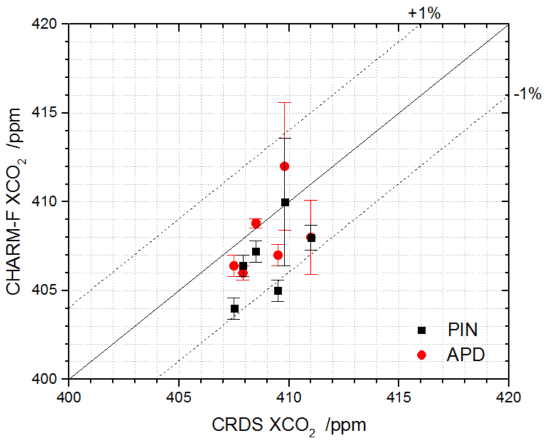

Figure 4: *CHARM-F column-integrated dry air mixing ratio of CO_2 compared to the same quantity derived from profiles of a cavity ring-down spectrometer (CRDS).*

were detected as well as plumes from individual sources such as coal-fired power plants or coal mine ventilation shafts. For the first time, emissions from such GHG hot spots were measured simultaneously by active and passive remote sensing techniques on aircraft and also in-situ instruments. The data will be exploited in conjunction with the models that are now going to be used to hindcast the campaign period to evaluate GHG fluxes and transport.

4. SUMMARY AND OUTLOOK

The CHARM-F lidar operated by DLR was successfully employed onboard HALO during the CoMet mission in May-June 2018. CoMet is a multi-aircraft mission comprising of a fleet of five aircraft that provided a comprehensive data set of active and passive remote sensing data as well as in-situ measurements. This innovative airborne payload together with the data from supporting ground-based instruments and modeling activities shows much prospect to determine greenhouse gas fluxes more precisely than previously possible and support activities to reduce GHG emissions.

While this first CoMet mission in 2018 focused on anthropogenic sources of the major greenhouse gases, successor missions are already in planning that will extend the CoMet study from Central Europe to the highly relevant natural fluxes of Arctic and Tropical wetlands. Beyond the scientific goals, those activities will continue the preparation of the validation activities of the German-French climate mission MERLIN [5] that is scheduled for launch in ~2024.

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