CoMet: AN AIRBORNE MISSION TO SIMULTANEOUSLY MEASURE CO_2 AND CH_4 USING LIDAR, PASSIVE REMOTE SENSING, AND IN-SITU TECHNIQUES

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ABSTRACT

In order to improve our current knowledge on the budgets of the two most important anthropogenic greenhouse gases, CO_2 and CH_4, an airborne mission on board the German research aircraft HALO in coordination with two smaller Cessna aircraft is going to be conducted in April/May 2017. The goal of CoMet is to combine a suite of the best currently available active (lidar) and passive remote sensors as well as in-situ instruments to provide regional-scale data of greenhouse gases which are urgently required.

1 INTRODUCTION

Confronting Climate Change is one of the paramount societal challenges of our time. The main cause for global warming is the increase of anthropogenic greenhouse gases in the Earth's atmosphere. Together, carbon dioxide and methane, being the two most important greenhouse gases, globally contribute to about 81% of the anthropogenic radiative forcing [1].

However, there are still significant deficits in the knowledge about the budgets of these two major greenhouse gases (GHG) 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, the investigation of sources and sinks of the greenhouse gases and their feedback mechanisms is indispensable.

In the past years, inverse modelling has emerged as a key method for obtaining quantitative information on the sources and sinks of the GHG [2]. However, this technique requires the availability of sufficient amounts of precise and independent data on various spatial scales. Therefore, observing the atmospheric concentrations of the greenhouse gases is of significant importance for this purpose. In contrast to point measurements, airborne instruments are able to provide regional-scale data of greenhouse gases which are urgently required, though currently lacking.

Providing such data from remote sensing instruments (lidar and passive) supported by state-of-the-art in-situ sensors, and additionally comparing the results of the greenhouse gas columns retrieved from aircraft to the network of ground-based stations is the mission goal of the HALO CoMet campaign. The project also aims at preparing the validation activities for upcoming satellite missions such as the German-French Climate mission MERLIN [3], at developing new methodologies for GHG measurements, and promotes technological developments necessary for future Earth-observing satellites.

2 INSTRUMENTATION

The key instrumentation for the CoMet mission consists of a suite of the most sophisticated instruments currently available to measure atmospheric carbon dioxide and methane onboard aircraft. Remote sensing instruments, both active and passive, will be complemented by in-situ sensors to obtain maximum synergy. A list of the instruments is given in Table 1.

Table 1 CoMet airborne instrumentation

Instrument acronym	Description	Aircraft
CHARM-F	CO_2 and CH_4 Lidar (IPDA)	HALO
HALO_JIG	Cavity Ringdown Spectrometer	HALO
HALO_JAS	Flask sampler	HALO
miniDOAS	Differential Optical Absorption Spectroscopy	HALO
BAHAMAS	HALO basic data acquisition system	HALO
Dropsondes	Meteorological sondes	HALO
FOKAL	Frequency comb	HALO
MAMAP	NIR spectrometer	FUB-Cessna
METPOD	Cessna basic data acquisition system	DLR-Cessna
QCLS	Quantum Cascade Laser Spectrometer	DLR-Cessna
CRDS	Cavity Ringdown Spectrometer	DLR-Cessna
Sampler	Flask sampler	DLR-Cessna

2.1 Aircraft

Three aircraft are currently foreseen as part of the campaign to carry this scientific instrumentation. The German Research Aircraft HALO (Figure 1) serves as the flagship for CoMet. HALO is a Gulfstream G-550 aircraft specifically equipped with numerous provisions for in situ and remote sensing instruments. It enables measurements up to an altitude of 15 km within a range of 9000 km. HALO may carry an instrumental payload of up to 3 tons.

Figure 1 The German Research aircraft HALO (D-ADLR) operated by DLR

Co-ordinated HALO flights are planned with two smaller, low-flying aircraft (Figure 2). The first one is a Cessna T207A operated by Freie Universität Berlin (FUB) and providing a maximum scientific payload of up to 400 kg. Its typical speed during measurement flights is ~60 m/s at standard cruising altitudes of up to 3.5 km. During CoMet, this aircraft will be equipped with the passive spectrometer MAMAP [4] (see Section 2.3). The second one is a Cessna 208B Grand Caravan operated by DLR. This aircraft carries up to 500 kg of payload, can reach up to 7.6 km, and provides a maximum endurance of 1600 km. During CoMet, it will be equipped with in-situ instrumentation for greenhouse gases and an underwing meteorological sensor package that measures temperature, pressure and humidity as well as wind speed and direction (see Section 2.4).

Figure 2 Cessna C107 (D-EAFU, left) operated by FU Berlin and Cessna Grand Caravan (D-FDLR, right) operated by FU Berlin and DLR, respectively

Both Cessna aircraft play an important role in the EUFAR (EUropean Fleet for Airborne Research) initiative.

2.2 Lidar

Concerning active remote sensing, the Integrated Path Differential Absorption (IPDA) lidar technique using hard target reflection from the Earth's surface in the near IR has been identified in the last few years to measure the column averaged dry air mixing ratio of CO_2 and CH_4 with high accuracy and low bias [5]. The advantages of a lidar are that it does not require the sun as a light source, and can therefore provide both day and night, all-seasons and all latitude measurements. But more important, such an active instrument concept provides a direct measurement of the atmospheric path by means of runtime measurement and, thus, is comparatively weakly influenced by aerosol and thin clouds.

In the past years, an airborne IPDA system (CHARM-F) has been developed and successfully tested at DLR [6]. In contrast to other development in either the US or Japan, it uses a pulsed direct detection scheme at 1.6 µm. 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 [6].

The lidar system is based on two optical parametric oscillators which are diode-pumped by means of injection seeded, Q-switched Nd:YAG lasers in a master-oscillator power-amplifier configuration. 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. During CoMet, an airborne optical frequency comb (FOKAL) will be employed for the first time in order to monitor the frequency stability under in-flight conditions to highest accuracy. Previously, this was only possible in the laboratory.

2.3 Passive Remote Sensing

As a passive remote sensing instrument, the MAMAP airborne spectrometer system capable of direct and quantitative remote column-averaged measurements of atmospheric CH_4 and CO_2 complements the payload. This instrument measures reflected and scattered solar radiation in the short wave infrared (SWIR) and near-infrared (NIR) parts of the electro-magnetic spectrum and will be installed on the FUB Cessna. In recent campaigns in Europe [7] and the US, MAMAP data demonstrated that small gradients in total column CO_2 and CH_4 can be detected with sufficient precision to derive emissions from local sources (coal mine ventilation shafts, power plants, landfills, etc.).

The combination of CHARM-F and MAMAP offers the unique opportunity to further improve their individual data quality, for example, by minimizing large scale biases of MAMAP using co-located measurements with CHARM-F. On the other hand MAMAP data with its smaller ground scene measurements in comparison to CHARM-F can potentially help identifying emissions of smaller area sources below the detection limit of CHARM-F.

A second remote sensing instrument, mini-DOAS operated by Universität Heidelberg, will be installed on HALO to complement the passive remote sensing payload. Mini-DOAS is a 6-channel optical spectrometer for the detection of atmospheric stray-light in nadir and limb direction capable to detect various trace gases related to combustion in the UV/VIS/NIR spectral range and will contribute through characterization of the respective air masses.

2.4 In-Situ Instrumentation

In order to validate the remote sensing instruments and provide greenhouse gas profile information traceable to WMO scales, highly accurate in-situ instruments to measure CO_2 and CH_4 based on cavity-ringdown spectrometry (HALO_JIG) will complement the core payload on HALO. Also part of the HALO payload is a flask sampler (HALO_JAS) which will collect air samples for subsequent laboratory analysis, providing supplemental information on isotopic composition and other tracers correlated with the emission of GHGs. Along with the measurement of GHGs, the basic HALO measurement system (BAHAMAS) is going to provide important meteorological and aircraft attitude data indispensable for the retrieval of the remote sensors.

In parallel, onboard the DLR Cessna, an instrument package consisting of a quantum cascade laser spectrometer (QCLS), CRDS, and a flask sampler - similar to the one installed on HALO - will be deployed. The basic meteorological sensor package that measures temperature, pressure and humidity as well as wind speed and direction will provide ancillary data to enable budgeting of localized sources such as coal mine ventilation shafts, landfills, or urban agglomerations using the mass balance approach.

3 CAMPAIGN OBJECTIVES

For CoMet, an intensive measurement period of 4 weeks is planned at the beginning of the growing season in April-May 2017 in Central Europe. During this period, optimized HALO research flights will comprise extended latitudinal transects to capture the GHG gradients, flights over known regions of strong emissions as well as comparison overflights over the ground-based remote sensing sites of the Total Carbon Column Observing Network (TCCON). While HALO will provide a larger scale picture, the two Cessna aircraft will concentrate on two regions of prime interest, the Upper Silesian coal belt in Poland and the greater Berlin area. In these areas, additional ground-based remote sensing capabilities as well satellite products (i.e. GOSAT) will support the CoMet mission. These targets, characterized by significant anthropogenic CH_4 and CO_2 emissions, have been selected in order to demonstrate that the innovative airborne instrumentation can distinguish between anthropogenic and natural sources of GHGs.

For this purpose, modelling is an equally important component of the CoMet mission. The goal is to use the measurement results to determine regional scale fluxes of the GHGs more precisely than possible today. To do so, results from chemistry-climate models on various scales are required and need to be linked to regional transport models. It will also be possible to validate the transport models using such independent, non-surface, atmospheric CO_2 and CH_4 measurements. By selectively using different data streams in a regional inversion, we will be able to assess the benefit from high-resolution measurement of the dry-air columns.

Finally, the project also aims at preparing the validation activities for upcoming greenhouse gas satellites such as Sentinel 5-P, GOSAT-2, and MERLIN as well as at developing new, combined methodologies for greenhouse gas measurements from space using lidar and passive remote sensing.

OUTLOOK

Currently, a successor mission is already being planned that will extend the CoMet study from Central Europe to the highly relevant Arctic and Tropical wetlands and that also aims at validation of the German-French climate mission MERLIN that is scheduled for launch in ~2021.

At that time, MAMAP will have been upgraded into a 2-dimensional imaging spectrometer system providing improved detection sensitivity with certification for HALO in order to measure from the same platform as CHARM-F.

ACKNOWLEDGEMENTS

CoMet is partly supported by DFG within its Priority Program HALO-SPP 1294. We would like to thank the following individuals and institutions for scientific, technological, or logistical support: J. Marshall, MPI; P. Jöckel, and A. Butz, DLR; J. Swolkień and J. Nęcki, AGH University, Krakow; A. Kuze, JAXA; DLR Flight Experiments; Institute for Space Sciences, FU Berlin; and Menlo Systems GmbH.

References

[1] Stocker, T.F. et al.: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC, Cambridge University Press.

[2] Gurney, K.R., et al., 2002: Towards robust regional estimates of CO2 sources and sinks using atmospheric transport models," Nature 415, 626-630.

[3] Pierangelo, C. et al., 2015: MERLIN (Methane Remote Sensing Lidar Mission): An Overview, in Proc. 27th International Laser Radar Conference, ILRC, New York, USA, (2015).

[4] Gerilowski, K. et al., 2011: MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: instrument description and performance analysis, Atmos. Meas. Tech., 4, 215-243.

[5] Ehret, G. et al., 2008: Space-borne remote sensing of the greenhouse gases CO2, CH4, N2O by integrated path differential absorption lidar: a sensitivity analysis, Appl. Phys. B90, 593–608.

[6] Amediek, A. et al., 2017: CHARM-F – a new airborne integrated-path differential-absorption lidar for carbon dioxide and methane observations: measurement performance and methodology to quantify strong point source emission, Appl. Opt., submitted.

[7] Krings, T., et al., 2013: Quantification of methane emission rates from coal mine ventilation shafts using airborne remote sensing data, Atmos. Meas. Tech., 6, 151–166.