A New Airborne Lidar for the Measurement of Methane and Carbon Dioxide – a Demonstrator for MERLIN

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CHARM-F is a newly developed airborne integrated path differential absorption (IPDA) lidar that will be operated on board HALO to quantify concentration gradients and surface fluxes of CH_4 and CO_2 both over anthropogenic point sources and larger-scale natural sources. IPDA uses hard target reflection from the Earth's surface to measure the column concentrations of CO_2 and CH_4 with high accuracy and low bias. 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. Due to similar measurement geometry and weighting function, HALO validation campaigns with CHARM-F will be essential to MERLIN's success (the French-German methane IPDA lidar satellite mission).

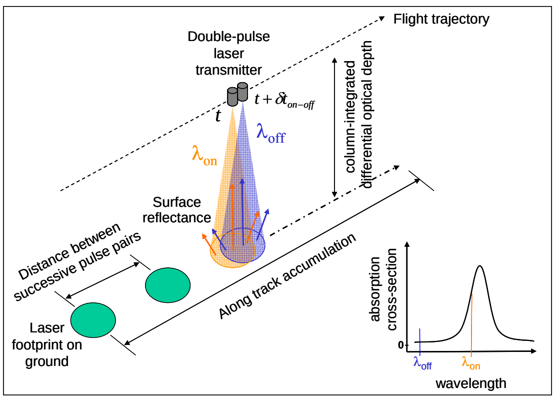

Figure 1: IPDA measurement principle

An IPDA Lidar analyses the laser light scattered and reflected from the Earth's surface and cloud tops which are illuminated by narrowband laser pulses having slightly different wavelengths (see Figure 1). The online wavelength is accurately positioned in the absorbing region of either a CO_2 or CH_4 line in the near-infrared (NIR) spectral region. Another measurement denoted offline serves as the reference measurement with negligible absorption by the greenhouse gas molecules in the light path. The on- and offline wavelengths are spectrally close enough to consider the atmospheric and surface properties to be identical with the exception of the greenhouse gas absorption. Since the return signals are very weak, it is necessary to accumulate several single measurements of the return signals along the flight track in order to achieve the required measurement sensitivity for the greenhouse gas column. The latter can be directly calculated from the ratio of the surface lidar echoes.

The main equations for the retrieval of the column averaged gas mixing ratio *Xgas* are:

$$Xgas = \frac{DAOD}{\int_{p\_aircr}^{p\_target} WF(p,T)\cdot dp} \quad \text{(Eq. 1)}$$

with *DOAD* as the differential absorption optical depth, calculated from the measured signals:

$$DAOD = \frac{1}{2}\cdot \ln \frac{S_{off}^{target} / E_{off}^{ref}}{S_{on}^{target} / E_{on}^{ref}} \quad \text{(Eq. 2)}$$

S^{target} is the backscatter signal from the ground (or clouds) and E^{ref} the system-internal laser pulse energy reference measurement. Both are determined for online and offline laser pulses. In Eq. 1 the *DAOD* is divided by the integrated weighting function (integrated from the aircraft to the scattering target). The weighting function *WF* is defined as follows:

$$WF(p,T) = \frac{\sigma_{on}(p,T) - \sigma_{off}(p,T)}{gM_{air}} \quad \text{(Eq. 3)}$$

with the gas absorption cross sections $\sigma\,(p,T)$ for the online and offline wavelengths, g as the standard gravity and M_{air} as the average mass of an air molecule.

Figure 2: CHARM-F system, integrated in the HALO research aircraft

The CHARM-F system on HALO consists of an optical head and two standard racks (see Figure 2). The optical head houses the receiving system and two custom-built, ruggedized laser systems (one for each trace gas) emitting pulse-pairs with short duration (20 ns) which allow for a precise ranging and a clean separation of atmospheric influences from the ground return leading to an unambiguously defined column. The close temporal separation of 500 µs for on- and offline pulses ensures that nearly the same spot on ground is illuminated. Further main properties are listed in Table 1.

Table 1: CHARM-F system properties

System parameter	Value
Wavelengths	1,57 µm (CO_2) 1,64 µm (CH_4)
Laser pulse energy	10 mJ (both lasers)
Pulse repetition	50 Hz double pulses
Receiver FOV	3.3 mrad
Detectors	InGaAs PINs and APDs
Gas reference	36-m multipass cell

The wavelengths have been carefully selected within sensitivity studies to minimise thermal and pressure effects as well as the interference with other constituents such as water vapour.

The required wavelengths are generated by optical parametric oscillators (OPOs) pumped by Nd:YAG lasers. To achieve single mode operation both the pump and the OPO are injection seeded. The seed lasers are locked to a gas cell filled with a mixture of CO_2 and CH_4 which ensures an absolute wavelength calibration.

In spring 2015, a first test measurement campaign took place on HALO (5 flights, about 22 flight hours). The primary goals were: the completion of the airworthiness certification, instrument test as well as the collection of first data. Data from various backscatter conditions could be obtained: different orography types, sea surfaces, clouds as well as broken clouds.

All campaign goals were achieved successfully and the results are very promising. Table 2 and Table 3 summarize first analysis results obtained from the test flights.

Table 2: Measurement precision for CO_2

Averaging time	Standard deviation
single shots	38 ppm (8.6 %)
1 s (≈ 200 m)	2.9 ppm (0.7 %)
10 s (≈ 2 km)	1.2 ppm (0.3 %)

Table 3: Measurement precision for CH_4

Averaging time	Standard deviation
single shots	166 ppb (8.6 %)
1 s (≈ 200 m)	24 ppb (1.2 %)
10 s (≈ 2 km)	9 ppb (0.5%)

For spring 2017, the scientific flight campaign CoMet is planned on HALO, together with several active, passive as well as in-situ instruments.

References

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