On the prospects of using the cloud slicing technique in integrated path differential absorption lidars

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Integrated Path Differential Absorption Lidar (IPDA)

- IPDA lidar is a very attractive approach to measure greenhouse gases (GHGs) such as methane (CH$_4$) and carbon dioxide (CO$_2$) from space (or aircraft).
- IPDA shows much promise to provide column-averaged dry air mixing ratios with unprecedented accuracy.
- IPDA is independent of sunlight due to the active laser technology and much less prone to interferences with aerosol or clouds than passive sensors.
- MERLIN, the upcoming German-French climate mission, is based on this active remote sensing technique.
The IPDA Principle

IPDA uses the laser light scattered back from a surface ("hard target") to obtain measurements of the column content of a specific atmospheric trace gas between lidar and target which typically constitutes the Earth's surface or clouds. The figure shows the measurement geometry of a nadir-viewing lidar with the measurements aligned along the sub-satellite or aircraft track.

Differential absorption uses the difference in atmospheric transmission between a wavelength tuned onto or near the center of an absorption line, denoted on-line, and a reference off-line wavelength with significantly less absorption.

The quantity of scientific interest is the **weighted average** of the greenhouse gas’ dry-air volume mixing ratio along the probed column, XGHG (e.g. XCO$_2$ or XCH$_4$), which is given by:

$$XGHG = \frac{1}{2} \cdot \ln \left[ \frac{P_{off} \cdot E_{on}}{P_{on} \cdot E_{off}} \right] = \frac{DAOD}{IWF}$$

- **$P_{on,off}$**: Measured power
- **$E_{on,off}$**: Transmitted laser energy
- **DAOD**: Differential Absorption Optical Depth
- **IWF**: Integrated weighting function

needs input: $T$, $p$, humidity, spectroscopic data
The use of clouds in a IPDA-Lidar measurement offers the opportunity to derive partial column mixing ratios (pseudo-profile) in broken cloud situations.

It also can be used – the other way around – to verify the vertical dependency of the used spectroscopic data, that are input to the weighting function.
CHARM-F – DLR’s airborne IPDA lidar for CH$_4$ and CO$_2$

- For the preparation of MERLIN, future validation activities, and scientific deployments, an airborne IPDA demonstrator (dubbed CHARM-F) has been developed at German Aerospace Center (DLR) for operation onboard the German Research Aircraft HALO.
Data overview

- The data presented in the following were recorded during the Carbon dioxide and methane mission, CoMet in 2018.
- HALO@CoMet: May-June 2018, 65 Flight hours, 44.000 km
  Base: Oberpfaffenhofen (Germany)

The scientific payload of HALO consisted of several remote sensing and in-situ instruments (see Table). Here, we only use CHARM-F data and in-situ data from the Cavity Ringdown Spectrometer operated by Max-Planck-Institute for Biogeochemistry.

<table>
<thead>
<tr>
<th>HALO Instrument acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>CHARM-F</td>
<td>DLR  Lidar (IPDA) XCO₂ and XCH₄</td>
</tr>
<tr>
<td>HALO_JIG</td>
<td>MPI  Cavity Ringdown Spectrometer</td>
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<tr>
<td>HALO_JAS</td>
<td>MPI  Flask sampler</td>
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<tr>
<td>miniDOAS</td>
<td>IUP-UH Differential Optical Absorption Spectroscopy</td>
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<tr>
<td>BAHAMAS</td>
<td>DLR  HALO basic data acquisition system</td>
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<tr>
<td>Dropsondes</td>
<td>DLR  Meteorological sondes</td>
</tr>
<tr>
<td>FOKAL</td>
<td>Menlo/DLR Miniaturized Frequency comb</td>
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Vertical distribution of the Scattering Surface Elevation (SSE)

- This exemplary case shows an almost continuous vertical distribution of available SSEs (which is the elevation of the laser signals received by the system),
- It is composed by ground elevation changes as well as cloud signals over a wide range
- It is thus ideal for the Cloud Slicing Analysis

View from the aircraft
Auxiliary Data needed for the calculation of the expected DAOD

- Data from vertical in-situ measurements (spirals) in the vicinity of the cloud slicing area give the absolute gas mixing ratio information.
- Meteorological data from ECMWF are used to calculate the weighting function.

Due to the spatial spread of the lidar measurements used for cloud slicing, it has to be ensured that there is a constant horizontal as well as vertical methane distribution, which can be checked by using model data (e.g. CAMS)
Preliminary Results

This exemplary case shows very good agreement for the measured vs calculated CO$_2$ DAODs, which is valid for all performed analyses during the CoMet 1.0 aircraft campaign in 2018.

For CH$_4$, there are deviations in the lower and upper part of the column. This deviation shows up in all analyses of the campaign!
A closer look

Same graph as on the previous slide, but zoomed into the lower part for better visualisation. For CH$_4$, a bias is clearly seen (circle).
Main findings

The **methane** spectroscopic data calculations using three different data sets
- HITRAN 2012
- Hartmann-Tran (Delahaye et al. 2016)
- Hartmann-Tran incl. temperature dependency (Delahaye et al. 2019)

seem not to result in an appropriate match between calculated DAODs and CHARM-F DAODs applying the cloud slicing method (further investigations ongoing).

The **carbon dioxide** spectroscopic data calculations using
- HITRAN 2016

show a good agreement between calculated DAODs and CHARM-F DAODs.
Take-Home Messages

1. Cloud slicing of IPDA data is an attractive means to infer some vertical information about greenhouse gas distributions.

   Thus, there is prospect to get such information (pseudo-profiles) also from MERLIN as important input to models.

2. At the same time, this analysis is a sensitive tool helping to verify the spectroscopy used for the IPDA data retrieval.

   The preliminary data shows good agreement for CO₂ spectroscopy. In contrast, discrepancies were detected for CH₄.

   Studies to improve the spectroscopic data for the MERLIN absorption lines are ongoing.
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