Airborne wind and backscatter measurements during the A-Life campaign in Cyprus

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Abstract: During the A-LIFE campaign 2017 in Cyprus the well-known DLR 2-µm Doppler Lidar has been integrated into the research aircraft Falcon F20 together with an extensive number of in situ sensors from DLR and the University of Vienna. Main objective of the campaign was the investigation of aerosol optical properties, mainly mineral dust and black carbon mixtures. The Doppler lidar was used to gather information about the extension of those dust (aerosol) layers as well as to estimate the mass transport. At each flight one or more altitude profile(s) were performed to gather aerosol information with the in situ sensors. Subsequently in order to calibrate the Doppler Lidar in term of backscatter a calibrated aerosol lidar of the University of Munich was overflown at nearly each flight. This paper will give an overview of all flights and focus on one Saharan dust outbreak for details.

Keywords: Coherent Laser Radar, A-Life, SALTRACE.

1. Introduction

A coherent Doppler lidar is usually not the instrument of choice to provide an estimate for the backscatter coefficient. Due to the heterodyning with a local oscillator it only detects the fundamental transverse mode of the backscattered light. This leads to a much higher speckle noise compared to a direct detection lidar. The comparably long pulse duration of a coherent Doppler lidar which is necessary to obtain an accurate velocity estimate also reduces the geometrical resolution of the backscatter estimate. However the accurate wind estimates, 3 dimensional vector as well as line of sight (LOS) made the airborne DLR 2 micron Doppler lidar to a well-suited instrument for meteorological campaigns for almost 20 years all over the world. Since the SALTRACE campaign in 2013 the question arose if the Doppler lidar can provide additional data like backscatter beside the velocity estimates. One advantage of coherent detection is the much lower dynamic range compared to direct detection. As a result the 8 bit digitizer used in this system is sufficient. The procedure necessary to obtain a calibrated backscatter was described by Chouza in 2015 at the SALTRACE campaign [1,7]. All of those lessons learned were implemented into the software so that at the campaign A-LIFE in CYPRUS uncalibrated but throughout the campaign consistent backscatter profiles were calculated on an operational basis. The next step will be the calibration at overflights of the POLIS Lidar which was also located in Cyprus during the A-Life campaign.

2. Two micron Doppler lidar and signal processing

The 2 µm Doppler lidar has been described in several publications [2-5]. The main parameters of the system are summarized in Table 1. During the years of operation two main operation modes have been established to cover most of the required measurements:

One mode is a fixed nadir with a control loop to compensate for platform (aircraft) movements. This mode is used to acquire vertical wind phenomena like gravity waves and also for high resolution backscatter profiles. The measurement volume is determined vertically by the pulse length and horizontally by aircraft speed (100 - 200 m/s depending on altitude) and the accumulation time (1-2 s).
The accuracy of a LOS estimate was calculated to be in the order of 0.2 m/s typically [6], depending on the SNR.

The other scan pattern is a conical 20° off nadir step and stare scan with 18 positions and one second accumulation time at each stare position. Together with the time needed to move between those positions one scan needs about 40 s. This pattern is used to estimate the 3D horizontal wind. The vertical measurement volume is 100 m as in fixed nadir mode, again determined by the pulse width. The horizontal volume varies with distance from the aircraft. It is roughly 8 km square near the ground with an aircraft altitude of 10 km.

### Table 1: Parameter of the 2 micron lidar

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Wavelength</td>
<td>2,02245 µm</td>
</tr>
<tr>
<td>Energy per pulse</td>
<td>1 – 1.5 mJ</td>
</tr>
<tr>
<td>Pulse duration FWHM</td>
<td>500 ns</td>
</tr>
<tr>
<td>Spectral width FWHM</td>
<td>0.75 MHz</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Average optical power</td>
<td>0.5 – 1 W</td>
</tr>
<tr>
<td>Offset frequency Transmitter - LO</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Telescope diameter</td>
<td>11 cm</td>
</tr>
<tr>
<td>Double wedge scanner max deviation</td>
<td>30° off nadir</td>
</tr>
<tr>
<td>Data acquisition: single shot; resolution:</td>
<td>8 bit</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>500 MS/s</td>
</tr>
</tbody>
</table>

At signal processing stage the digitized heterodyne signal is divided into 100 m altitude range gates. As the number of samples in the range gate is usually not a power of two zero padding is applied in order to be able to use an efficient FFT algorithm. This zero padding has to be corrected to obtain comparable power estimates for different range gates in pointing directions. The power spectrum obtained by the FFT has to be corrected also by the frequency response of the system: detector, amplifier, digitizer. For this the assumption is used that the system is dominated by shot noise from the local oscillator that is spectrally white noise. After passing detector, preamplifier, amplifier and A/D converter the resultant noise spectrum carries all of the information needed about the frequency response and local oscillator power. At an airborne lidar the part of the signal below the ground return contains definitely only noise. Thus the spectrum of this noise is used to correct for the frequency response by dividing the FFT from the signal by the noise spectrum and subtracting 1 for all frequency channels. The resultant signal power has then only to be corrected by the transmitted energy which can easily be accessed by measuring the pulse built up time (BUT) of the laser pulse. With an R² correction the resulting power represents the optical back scattered power multiplied by all of the instrument parameters like transmission of the optics and heterodyne efficiency which are assumed to be constant.

### 3. A-LIFE campaign

A-LIFE (Absorbing aerosol layers in a changing climate: aging, lifetime and dynamics) is a project that investigates the optical properties of aerosols. Details about the project can be found at https://www.a-life.at/. Central part of the project was the field campaign conducted from Cyprus in April 2017. The DLR research aircraft Falcon F20 was equipped with the 2 micron Doppler Lidar and an extensive range of in-situ instruments collecting the aerosol data. Ground-based in-situ and remote sensing instruments were deployed at Cyprus as well. The interesting instrument for the synergy with the coherent Doppler lidar is the POLIS backscatter lidar that can be used to “calibrate” the coherent lidar in term of backscatter [1].
One idea of the combination of remote sensing and in-situ instruments is that atmospheric layers with aerosol / dust are investigated in detail with the in-situ particle counter by performing an altitude profile with the in-situ instruments collecting data on aerosols at different altitudes. With the Doppler lidar it may be possible to extend the point measurements over a wider area passing at a higher altitude over the volume investigated by in situ. As Saharan dust and other aerosols were investigated over the Mediterranean Sea at stable cloud free weather condition it can be assumed that those air masses are stable at least over the observation time which ranges from one to four hours. A nice example of this strategy can be found on the research flight to Malta on April 19. The received optical power (range corrected) can be seen in Figure 2. Figure 1 shows all of the A-Life flight tracks including the transfer flight from Oberpfaffenhofen. The main region of investigation was located close to Cyprus, but three cross sections of Saharan dust were investigated on two flights to Crete and one to Malta and back.

Figure 1: Overview of all A-Life flights.

The obvious idea to search with the lidar for an interesting dust laden air mass and to investigate this area with the in-situ sensors was not possible due to flight planning constraints. Fortunately the forecast for Saharan dust was accurate enough to identify the regions for an altitude profile and to consider this already at the flight planning stage.

Figure 2: Range corrected backscatter power at flight from Cyprus (right edge) to Malta (left) on April 19.

Figure 2 shows a rare example of nearly full coverage from aircraft level down to the ground. Two layers of dust can easily be seen. The high backscatter region close to the sea surface (below 500 m
altitude) may be caused by the ship traffic to and from the Suez Canal. This volume did show a rather high black carbon concentration according to the in situ sensors. Further were some optically thin clouds present at this flight lag. Those can be identified as white areas with a virtually reduced backscatter below. At a further processing step it is planned to compensate for this loss in transmission through the clouds.

4. Conclusion and further outlook
The lidar worked well during the whole A-Life campaign. The processing software was modified in order to be able to have a quantitative estimate of the backscatter coefficient. The comparison, calibration and synergy with the in-situ instruments are pending. During the local flights close to Cyprus the same pattern was performed at different flight levels. Here the volume of Doppler lidar measurements was investigated by the in-situ sensors.

5. Acknowledgements
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6. References