Compact Doppler lidar platform for multi-parameter atmospheric monitoring via lidar networks

Jan Froh[(a)], Gerd Baumgarten[(a)], Ronald Eixmann[(a)], Josef Höffner[(a)], Alsu Mauer[(a)], Thorben Mense[(a)], Alexander Munk[(b)], Sarah Scheuer[(b)], Michael Strotkamp[(b)]
[(a)] *Leibniz Institute of Atmospheric Physics IAP,*
Schlosssstraße 6, 18225 Kühlungsborn, Germany,
[(b)] *Fraunhofer Institute for Laser Technology ILT,*
Steinbachstraße 15, 52074 Aachen, Germany
froh@iap-kborn.de

Abstract: We present a brief overview of our current developments of compact multi-field-of-view lidars for studying the 3-dimensional structure of the atmosphere and its processes over a wide range of scales with a network of lidars. Each lidar unit is based on a narrowband laser and receiver to measure the spectra of the Doppler-shifted and –broadened backscatter. We demonstrate that matched narrowband components enable precise daylight aerosol measurements with high aerosol visibility and high Doppler wind sensitivity in the troposphere and stratosphere 24/7. We present recent results with a focus on aerosol measurements and our next steps to demonstrate a lidar array with extended measurement capabilities.

1. Introduction

Lidar networks, such as EARLINET (European Aerosol Research Lidar Network) or NDACC (Network for the Detection of Atmospheric Composition Change), and satellite instruments, such as Aeolus, provide important datasets to enhance our understanding of atmospheric processes. They are used to validate and improve climate models and short- to mid-term weather forecasts [1, 2]. In particular, it has been found that continuous wind and temperature measurements above 5 km are increasingly important for detailed atmospheric models [3, 4], but are not really available at present.

Therefore, we have developed VAHCOLI (Vertical And Horizontal COverage by LIdar) to investigate the 3-dimensional structure of the middle atmosphere [5-7]. Distributed compact lidars with multiple fields of view (multi-FOV) will allow studying small- to large-scale atmospheric processes (Figure 1). Each single lidar is designed for measuring Doppler Mie, Doppler Rayleigh, and Doppler resonance signals to enable multiple observations (wind, temperature, aerosols, metal density) from the troposphere to the thermosphere.

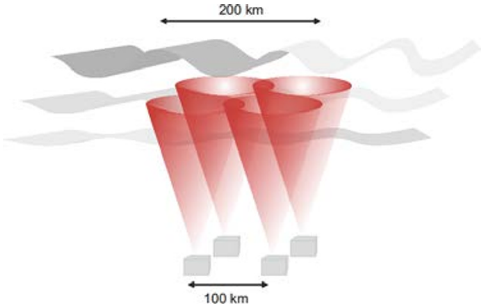

Figure 1. Sketch of measurement geometry with four lidar units to achieve Vertical and Horizontal coverage by lidar.

This paper focuses on the unique narrow-band emitter and receiver, resulting in high aerosol visibility and high wind sensitivity. We also present our current activities in developing compact lidar units with network capability. As an example, we demonstrate a novel solar blind Doppler Mie wind and aerosol method. Compared to established methods, such as Aeolus, fewer photons for wind and aerosol observations are required, allowing Doppler Mie wind observations under all circumstances from the troposphere to ~25 km altitude 24/7 without gaps in time or altitude.

2. General purpose lidar platform

Within the Project VAHCOLI (Vertical And Horizontal COverage by Lidar) we developed a compact and transportable lidar platform with multi-FOVs for various applications as standalone or network lidar, as shown in Figure 2. Each daylight-capable unit is observing into five directions and contains all technologies required for automatic and maintenance-free operation. The housing and optical system are largely based on 3D printing to reduce costs and speed up assembly.

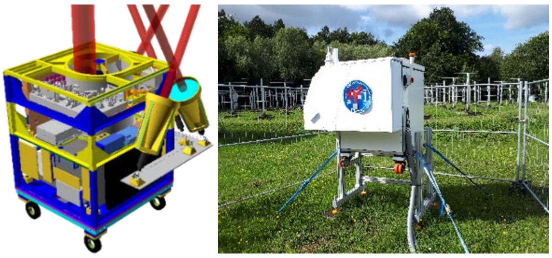

Figure 2. (a) 3D CAD model of a lidar platform, (b) first prototype of a lidar unit at IAP's atmospheric test ground.

We designed the optical system for the combined study of Mie scattering (aerosols), Rayleigh scattering (air molecules) and resonance fluorescence on free potassium atoms in the middle atmosphere. A unique frequency-scanning laser and combination of different filters allow the spectral characterization of the Doppler-shifted and broadened signals with sub-MHz spectral resolution. The spectral information of the different Doppler signals allows precise wind, temperature, aerosol and metal density observations. In particular, the combination of a narrowband emitter (~3.3 MHz @ 770 nm, alexandrite laser, developed in cooperation with the ILT [8-10]) and a matched narrowband receiver (~7.5 MHz, tunable confocal etalon), as shown in Figure 3, results in high Doppler wind sensitivity and aerosol visibility.

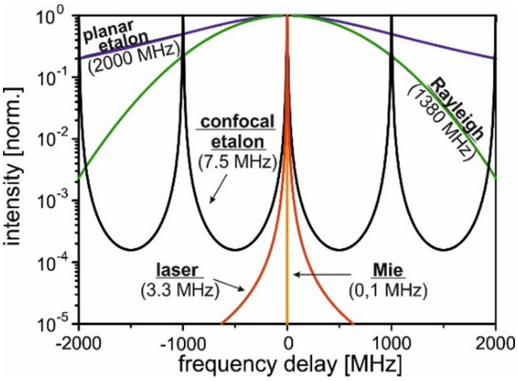

Figure 3. Expected spectral shapes of the narrowband filter combination, laser and Doppler-broadened Mie and Rayleigh signals.

The atmospheric Doppler spectra and the spectra of various optical components are acquired about ten times per second by fast laser frequency scanning at laser repetition rates of up to 750 Hz. We determine various spectral information from the laser and filters in real-time for the stabilisation of the pulsed and cw-laser and all filters. Moreover, the system determinates all relevant instrumental properties, such as spectral shape of the laser line and filters for each single atmospheric measurement, considering residual deviations not compensated by the lock-technology during data analysis.

Figure 4 (a) shows an example of a daytime aerosol measurement at the IAP in Kühlungsborn. The spectra of the backscattered signals at each altitude are derived by obtaining the transmitted signal of the narrowband confocal etalon at different laser frequencies. The narrowband filtering with the confocal etalon strongly reduces the Rayleigh signal (~100 times) and increases the visibility for aerosols largely. The Mie and Rayleigh signals are extracted by selecting frequency intervals near and away from the Mie peak, as shown in Figure 4 (b) and 4 (c). Figure 4 (c) shows a spectrally resolved signal sampled at 500 kHz channels at altitudes around 20 km, with a narrowband Mie peak and a small portion of the Rayleigh spectrum.

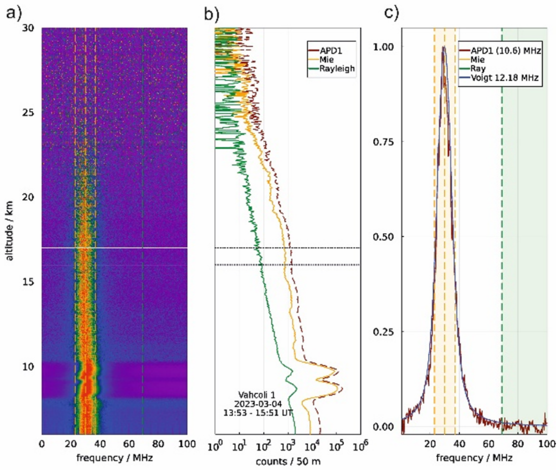

Figure 4: (a) Daytime measurement of Doppler-shifted Mie spectra (aerosols) over altitude. (b) Separation of Mie and Rayleigh scattering by selecting different frequency intervals (yellow line: frequencies close to the Mie peak [yellow shading in (c)] and green line: frequencies in the wings [green shading in (c)]). (c) Example of a narrowband Mie spectrum at around 20 km altitude with significantly reduced Rayleigh component.

In this example, the frequency range of the scanning laser is 100 MHz and the observed spectra is a Voigt function. The three main contributions to the observed spectra are the laser line shape, the spectral shape of filters and Doppler broadening occurring due to turbulence or wind gradients. Because the filter spectral shape and laser line shape are obtained in real time for each single measurement, spectral resolution below the laser line width can be achieved with more advanced data analysis.

3. Outlook

We are currently assembling several multi-FOV lidar units to monitor the atmosphere (wind, temperature, aerosols, metal density) from the troposphere to the thermosphere. In addition, we have several follow-on projects focusing on the development and demonstration of new lidar technologies together with scientific and industrial partners. For example, in the project LidarCUBE (funded by BMBF - Federal Ministry of Education and Research), we are developing new compact IR lidar systems with reduced complexity and higher TRL level together with mostly local industrial partners, with the aim of future commercially available systems. Furthermore, in the EU project EULIAA (European Lidar Array for Atmospheric Climate Monitoring), we are extending the technology to UV wavelengths for improved daylight capability and enhanced observation capabilities [11]. The aim is to demonstrate a lidar array in hard-to-reach environments with autonomous measurement and real-time data processing for databases such as Copernicus. The unique IR and UV lidar units will enable distributed lidar measurements to understand large and small-scale phenomena at altitudes not covered by other techniques.

In addition, theoretical calculations show that aerosols should be observable above altitudes of 30 km, which is the subject of our project O-MSP-Li (Observations of Meteor Smoke Particles in the Middle Atmosphere with a Novel Lidar Method).

4. References

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