Retrieval of aerosol backscatter and vertical wind from airborne coherent Doppler wind lidar measurements

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Abstract: This study presents methods for the retrieval of calibrated backscatter and vertical wind speed from an airborne Doppler wind lidar (DWL). The backscatter retrieval relies on sun photometer measurements and the simultaneous retrievals of an airborne DWL at 2 µm and a ground-based aerosol lidar at 532 nm for the retrieval of the calibration constants. A refinement of the vertical wind retrieval algorithms based on speed and distance of ground returns will also be discussed.

The derived methods were applied to a set of case studies from the SALTRACE campaign (http://www.pa.op.dlr.de/saltrace), which aimed to characterize the Saharan dust long range transport between Africa and the Caribbean. The calibrated backscatter measurements, first validated with a set of ground based lidar and CALIPSO measurements, were then used in combination with horizontal and vertical wind retrievals for the characterization of island induced gravity waves and the evaluation of an aerosol transport model.

Keywords: baskcatter retrieval, vertical wind retrieval, airborne Doppler wind lidar, SALTRACE

1. Introduction

Mineral dust is a key component of the climate system and the most mass abundant type of aerosol, accounting for about half of the total aerosol mass emissions [1], acting as cloud and ice nuclei and playing an important role in the radiation budget of the earth.

The Saharan desert has been identified as the world largest source of mineral dust [2]. Each year, large amounts of Saharan dust are transported across the Atlantic into the Caribbean region [3]. Despite the progress made during the last decades, the transport mechanisms of the Saharan dust over the Atlantic and their relative importance remain under discussion [4,5].

The Saharan Aerosol Long-range Transport and Aerosol-Cloud-Interaction Experiment (SALTRACE: http://www.pa.op.dlr.de/saltrace) conducted during June/July 2013 provided a whole new set of measurements, including in-situ, airborne and ground based observations. For the first time, an airborne coherent DWL was deployed onboard the DLR Falcon 20 research aircraft to study the Saharan dust transport over the Atlantic in combination with an extensive set of in-situ instruments to measure aerosol properties.

Usually, airborne coherent DWLs provide horizontal wind vector and qualitative aerosol backscatter measurements. In this work, quantitative aerosol backscatter and extinction profiles retrieved from the SALTRACE data set by means of a new calibration method (Sec. 3) are presented [6]. In addition the retrieval of the vertical wind from airborne wind lidar was largely refined (Sec. 4), providing new insights in the generation of island-induced gravity waves and their interaction with the Saharan dust [7]. The simultaneous retrieval of aerosol properties and, horizontal and vertical winds (Sec. 5), enhance the capabilities of the DWL for aerosol transport studies.

2. Instrumental description

The coherent DWL deployed on the DLR Falcon 20 research aircraft during SALTRACE is based on a CLR Photonics instrument [8] combined with a two wedge scanner and acquisition system developed at DLR [9]. The system operates at a wavelength of 2.02254 µm, with a pulse full width at half maximum (FWHM) of 400 ns, a pulse energy of 1-2 mJ, and a repetition frequency of 500 Hz.

3. Backscatter calibration

The DWL calibration method relies on sun-photometer measurements of the extinction coefficient wavelength dependency and the concurrent measurements of the DWL and a ground based aerosol lidar (Fig 1a). Based on these simultaneous measurements, calibration constants corresponding to different aerosol types were calculated (Fig 1b). These constants are then applied to retrieve calibrated backscatter and extinction coefficient profiles at a wavelength of 532 nm from the coherent DWL measurements during other sections of the flight. Further details of the calibration method are available in [6].

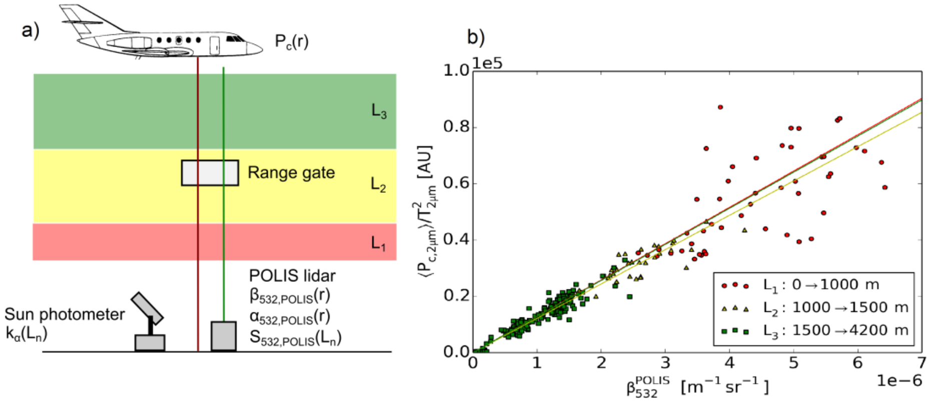

Figure 1. Scheme of the instruments and atmospheric parameters involved in the calibration and retrieval process (left). Correlation between the extinction corrected backscattered power of the DWL and the POLIS measured backscatter coefficient for 3 different aerosol layers: boundary layer (red dots), mixed layer (yellow triangles) and Saharan Air Layer (green squares) (right).

In order to validate the presented method, the calibrated backscatter coefficient corresponding to a flight carried out during SALTRACE on the west coast of Africa was retrieved. The results, compared with the measurements from a CALIPSO overpass, are presented in Fig. 2.

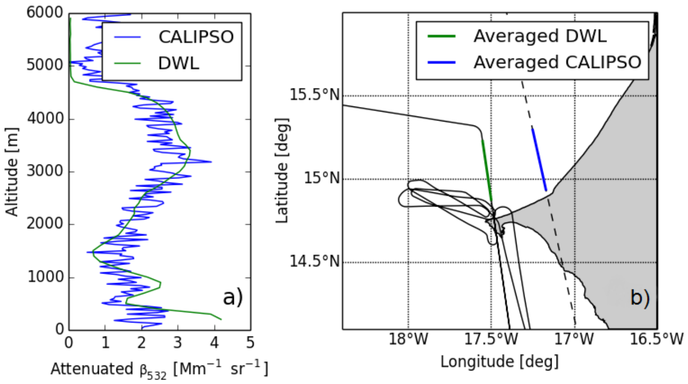

Figure 2. a) Averaged attenuated backscatter profile retrieved from the DWL (green) compared to the averaged CALIPSO measurements (blue) on the 12 June 2013. b) DLR Falcon flight track (black, solid), CALIOP overpass (black, dashed) together with the averaged flight sections.

4. Vertical wind retrieval

Due to the relatively low magnitude of the vertical winds $\vec{w}$ compared to the horizontal winds $\vec{V}$ and the Falcon flight speed $\vec{v}_{ac}$, the retrieval of the vertical wind speed require a set of instrumental corrections to be applied in order to reduce the systematic errors introduced by the uncertainties in the DWL pointing direction $\vec{L}$ and the projection of the horizontal winds (Fig. 3).

The proposed retrieval method is based on a 3-steps approach. First, an estimation of the DWL mounting angles and pointing offsets is calculated based on ground return speed $v_{DWL}(R_g)$ and distance $d_{DWL}(R_g)$ from all measurement flights. Then, the residual ground speed error, when available, is subtracted from the line-of-sight (LOS) speed $v_{DWL}(R)$ for each flight leg. Finally, if horizontal wind speed profiles are available, its projection is calculated and subtracted from the LOS speed. A detailed description of the retrieval method, the associated uncertainties and measurements performed during SALTRACE are presented in [7].

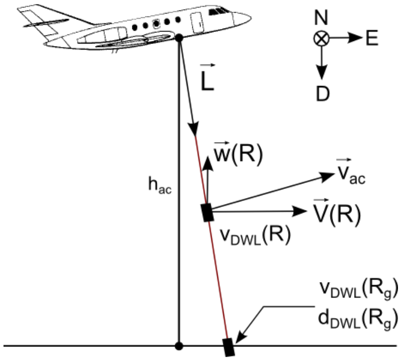

Figure 3. Sketch of the vertical wind measurements and its various contributors for correction.

Figure 4 presents a first validation of the presented vertical wind retrieval method. The DWL vertical wind measurements carried out on 20 June 2013 on the lee side of Barbados are compared with the vertical wind measurements retrieved by the Falcon in-situ sensors. Although a difference of 600 m exists between the first lidar range gate and the in-situ sensors of the aircraft, a good agreement can be observed between both measurements. The lidar retrievals show an enhanced convection over Barbados as well as the presence of island induced gravity waves on the lee side.

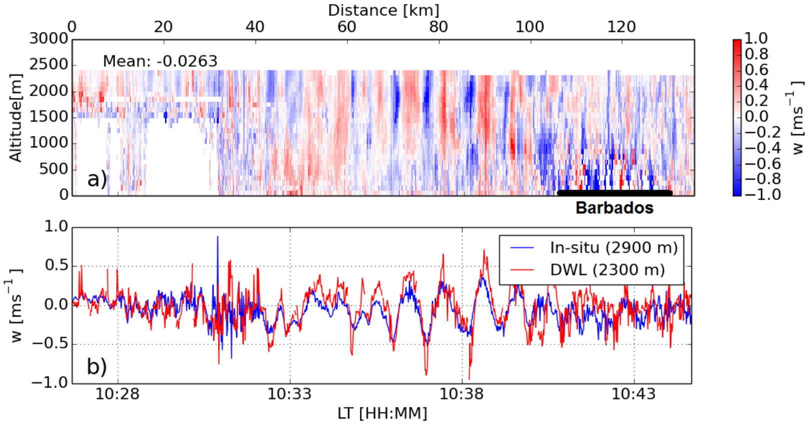

Figure 4. a) Vertical wind speed retrieved from the DWL on the lee side of Barbados. b) Vertical wind speed corresponding to the first range gate of the DWL retrieval (red) and the corresponding measurements from the Falcon in-situ sensors (blue).

5. Conclusions

Based on the methods presented in this work, the DWL capabilities were extended. The simultaneous retrievals of extinction coefficient, vertical and horizontal wind form the DWL provide a unique opportunity to evaluate different aspects of the Saharan dust transport as well as the ability of different models to reproduce them. Based on the measurements carried out during SALTRACE and the methods presented in this abstract, the capabilities of the MACC model are being evaluated [10]. The results will provide the opportunity to identify the models strengths and weaknesses.

6. References

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