Results from recent airborne campaigns aiming at the preparation of ESA's Aeolus Wind Lidar Mission

Benjamin Witschas, Christian Lemmerz, Oliver Lux, Uwe Marksteiner, Stephan Rahm, Oliver Reitebuch, Andreas Schäfler, Fabian Weiler

Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institute of Atmospheric Physics, 82234 Oberpfaffenhofen, Germany

Benjamin.Witschas@dlr.de

Abstract: Almost 20 years after its selection as an Earth Explorer Core Mission of ESA's Living Planet Program, Aeolus is ready to be launched in August 2018. Aeolus will carry the first wind lidar instrument in space, ALADIN (Atmospheric Laser Doppler Instrument), aiming at the measurement of wind profiles globally from ground up to 25 km.
To validate ALADIN's measurement principle and calibration routines, DLR has developed an airborne Calibration and Validation (Cal/Val) payload based on a direct detection wind lidar (355 nm), and a coherent detection wind lidar (2 µm) which was deployed in several field campaigns over the last years.
From September to October 2016, as part of the international campaign NAWDEX (North Atlantic Waveguide and Downstream Impact Experiment), 14 flights were performed from the airport of Keflavik, Iceland. In this paper, an overview of results obtained during NAWDEX and their conclusion on the Aeolus mission will be discussed.

Keywords: Aeolus, Wind Lidar, Coherent Wind Lidar, Direct Detection Wind Lidar, Airborne Wind Lidar Measurements

1. Introduction

Accurate knowledge of wind profiles on a global scale is of highest priority in order to improve the quality of numerical weather prediction [1]. For that reason, the European Space Agency ESA initiated the Aeolus mission in 1999 as an Earth Explorer Core Mission of ESA's Living Planet Program. Aeolus will carry the direct-detection Doppler Wind Lidar (DWL) ALADIN which will deliver global wind profiles from ground up to 25 km after being launched in August 2018.

As the ALADIN instrument combines various techniques that were not implemented in wind lidars before, such as the sequential combination of a molecular and an aerosol channel as well as the usage of accumulation charge coupled devices as detectors, it was decided to develop the ALADIN Airborne demonstrator (A2D) in 2003 [2], which has since then been deployed in several field campaigns aiming at the validation of the satellite instrument as well as the optimization of its retrieval algorithms and calibration schemes.

To complete the airborne Cal/Val payload for ALADIN, DLR additionally implemented a coherent DWL onboard the DLR-Falcon aircraft which serves as a reference system for the A2D and ALADIN and which has been operated at DLR already since 1999. The 2-µm DWL has contributed to a variety of atmospheric-science related airborne campaigns e.g. [3,4] as well as to Aeolus pre-launch Cal/Val campaigns [5-7].

As a rehearsal for the upcoming Cal/Val activities foreseen to be performed after the satellite launch, the Aeolus Cal/Val payload was recently deployed in several field campaigns. In May 2015, the joint ESA-DLR-NASA airborne campaign WindVal I was conducted based in Keflavík, Iceland. For the first time, four DWLs were operated together onboard the NASA DC-8 and the DLR-Falcon aircraft.

One and a half years later, in autumn of 2016, the Aeolus Cal/Val payload was employed in the framework of the NAWDEX campaign, again based in Keflavík. This international field campaign focused on investigating the influence of diabatic processes on the evolution of disturbances of the North Atlantic jet stream. For this purpose, four research aircraft equipped with diverse payloads were employed which allowed for the observation of a large set of atmospheric parameters using a multitude of state-of-the art remote sensing instruments [5,6].

With a view to the forthcoming Aeolus mission, the NAWDEX campaign was an ideal platform for extending the wind dataset obtained with the Aeolus Cal/Val payload, as it offered the opportunity to perform wind measurements in dynamically complex scenes, including strong wind shear, varying cloud conditions and high wind speeds in the vicinity of the jet stream. In addition, the unique setting in Iceland with its large-scale cooperation of atmospheric research groups from around the world was beneficial for the preparation of the upcoming launch of Aeolus.

In this paper, an overview of the wind measurements of the A2D and the 2-µm DWL performed during NAWDEX is given. A statistical comparison of the A2D and 2-µm DWL winds is done based on a wind scene measured on 4 October 2016 illustrating the good agreement of the wind data acquired with both DWLs.

2. DLR's Aeolus Cal/Val payload

DLR's Aeolus Cal/Val payload consists of the direct detection DWL A2D and the coherent detection 2-µm DWL, both integrated onboard the DLR-Falcon research aircraft. A picture of the Falcon itself and of both wind lidars integrated within the aircraft is shown in Figure 1.

Details about the A2D instrumental setup and wind retrieval procedures are given in [2,6,7], and more specifically, the laser frequency stability is discussed in [8]. Details about the 2-µm DWL instrumental setup and wind retrieval routines can be found in [3,9].

Figure 1. The left picture shows the three aircraft operated during the NAWDEX campaign from the airport in Keflavik, Iceland, namely DLR's Falcon (left), the HALO aircraft (middle) and the French SAFIRE Falcon (right). The right picture illustrates the Aeolus Cal/Val payload integrated in DLR's Falcon aircraft with the 2-µm and A2D DWL including data acquisition unit (DAQ).

3. Wind measurements during the NAWDEX campaign

On 4 October 2016 a flight was performed in order to measure the high wind speeds and wind speed gradients in the vicinity of the jet stream which was located south-east of Iceland. For this purpose, the Falcon crossed the jet stream twice, as it flew two legs back and forth between the way points located at 66.0°N, 17.5°W and 64.0°N, 7.0°W (see Figure 2, left). The corresponding wind speed measured with the 2-µm DWL during the entire flight is shown in Figure 2, right. It can be seen that the 2-µm

DWL could already measure during ascent from about 8 km altitude on. Furthermore, the pronounced jet-stream structure with wind speeds up to 72 m/s becomes obvious from the wind measurements (~800 km to 1600 km). The white areas indicate regions with low aerosol content and thus, no valid wind data that could be retrieved with the coherent detection system here. Furthermore, the vertical data gaps at around 600 km and 1900 km are caused by a failure of the GPS module that led to a stop of the data acquisition and thus to missing data in this region.

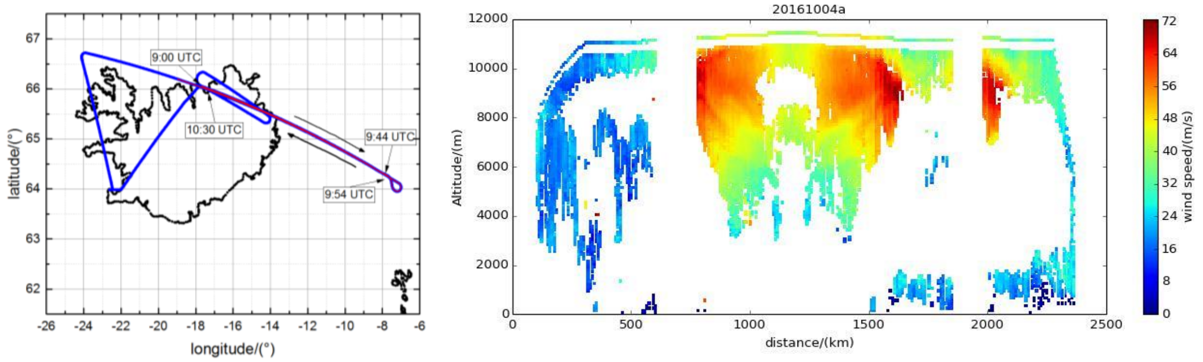

Figure 2. The flight track flown on 4 October 2016 (left) and the corresponding horizontal wind speed measured with the 2-µm DWL (right).

At the same flight, the A2D measured wind profiles during the periods from 09:00 to 09:44 UTC (~750 km to 1100 km) and from 09:54 to 10:30 UTC (~1300 km to 1650 km) that can be used for comparison with 2-µm DWL data. However, as the A2D only measures the line-of-sight (LOS) wind speed at an off-nadir angle of 20°, the 2-µm data first has to be projected on the A2D viewing direction. Furthermore, as both systems have a different temporal resolution (A2D ~ 14 s for one LOS, 2-µm ~ 42 s for the wind vector), a weighted interpolation has to be performed before the data can be compared. Details about the projection and weighted interpolation can be found in [6,7].

The A2D wind speed obtained from the Mie and Rayleigh channel (combined), as well as the 2-µm DWL winds projected onto the A2D LOS are shown in Figure 3 top and bottom, respectively.

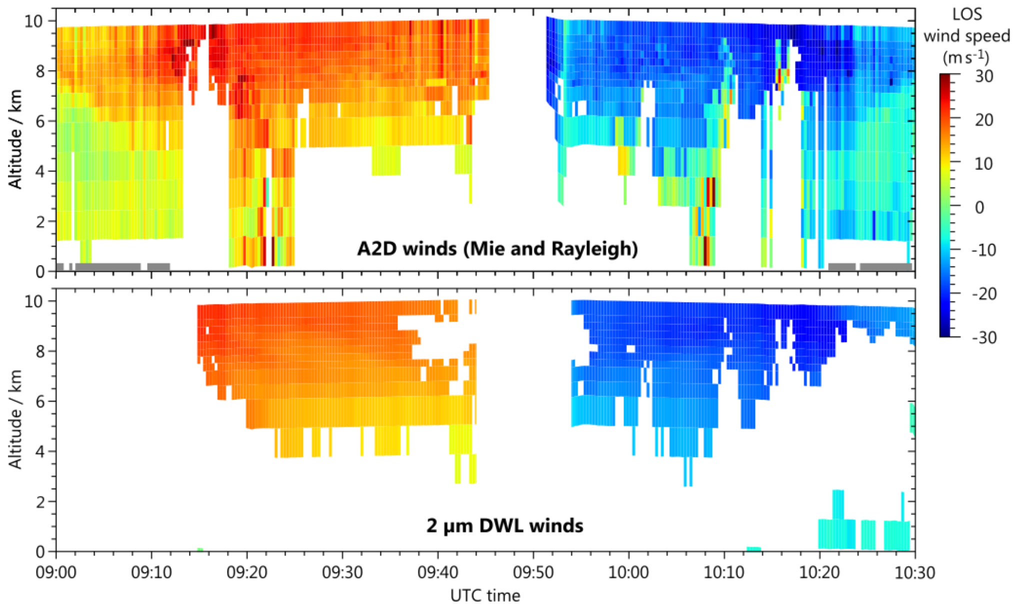

Figure 3. LOS wind profiles during the flight on 4 October 2016 between 09:00 UTC and 10:30 UTC from A2D (top panel – combined Mie and Rayleigh winds) and the 2-µm DWL (bottom).

Since the wind was blowing towards the A2D LOS on the first leg, positive LOS wind speeds of up to 25 m/s (projection to horizontal LOS: 73 m/s) were measured, whereas negative winds of the same magnitude were detected on the flight leg back to Iceland. Furthermore, it can be seen that the coverage for A2D and 2-µm DWL winds is different. 2-µm DWL winds are available in the vicinity of the jet stream where cirrus clouds are prominent and lead to particulate backscatter. Thus, this is also the region where winds from the A2D Mie channel are available. In addition to that, the A2D also provides wind measurements in the aerosol-poor regions before and after the jet stream from the Rayleigh channel based on molecular scattering. Hence, this nicely demonstrates the complementarity of the Mie and the Rayleigh channel and at the same time shows the limits of a coherent detection DWL system.

The wind measurements shown in Figure 3 are now used for a statistical comparison as indicated by Figure 4. Here, the A2D winds are plotted versus the corresponding interpolated 2-µm DWL winds, resulting in a cloud of data points that ideally lie on the dashed line representing $v_{A2D} = v_{2\mu m}$. The non-weighted linear fit $v_{A2D} = A \cdot v_{2\mu m} + B$ through the real data provides values for the slope A and intercept B. Before comparison, eleven gross outlier with $v_{A2D} - v_{2\mu m} > \pm 10$ m/s were excluded from the Rayleigh wind data.

As the 2-µm relies on particulate backscatter, a more sophisticated comparison can be performed for Mie winds (Figure 4, blue points). In particular, 1246 bins are available for comparison. Still, due to the very high sensitivity of the coherent detection of the 2-µm DWL, even 168 valid bins are available for comparing wind from the A2D Rayleigh channel (Figure 4, green points).

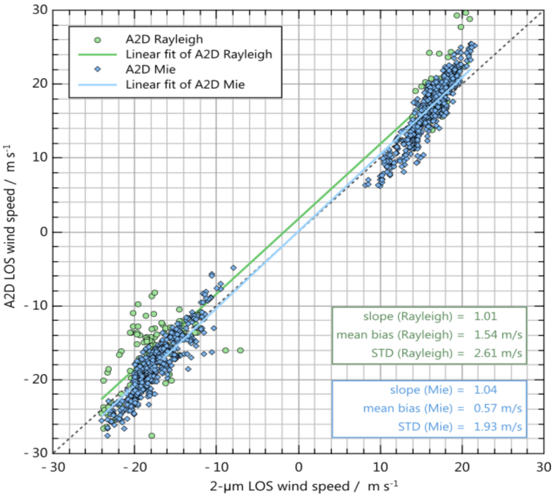

Figure 4. Statistical comparison between LOS winds measured by A2D and the 2-µm DWL during the flight on 4 October 2016.

It can be seen that the comparison of A2D and 2-µm data shows good agreement. For the Mie winds, the mean bias is 0.57 m/s and for the Rayleigh winds it is 1.54 m/s. The corresponding standard deviations are 1.93 m/s and 2.61 m/s. As already mentioned, the comparison to Rayleigh winds is more difficult as only few 2-µm DWL data is available in the clear atmosphere. Hence, the overlap of valid data from both systems is restricted to regions where weak particulate backscattering occurs which is still sufficient to be analyzed by the sensitive 2.µm DWL, while significant Mie contamination of the A2D Rayleigh signal is negligible according to the current wind retrieval settings.

The shown result demonstrates that DLR has a well-established Aeolus Cal/Val payload based on two different DWLs that is perfectly suited for the upcoming Cal/Val activities after the satellite has been launched in August 2018. In addition to the comparison shown here, further comprehensive comparisons to measurements from dropsondes launched form the HALO aircraft and to wind measurements from radar and lidar flown onboard the French SAFIRE Falcon were performed and confirmed the good performance of the 2-µm DWL and the A2D based on the NAWDEX data set.

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