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AIRBORNE DIRECT-DETECTION AND COHERENT WIND LIDAR MEASUREMENTS OVER THE NORTH ATLANTIC IN 2015 SUPPORTING ESA'S AEOLUS MISSION

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ABSTRACT

The launch of the Aeolus mission by the European Space Agency (ESA) is planned for 2018. The satellite will carry the first wind lidar in space, ALADIN (Atmospheric Laser Doppler INstrument). Its prototype instrument, the ALADIN Airborne Demonstrator (A2D), was deployed during several airborne campaigns aiming at the validation of the measurement principle and optimization of algorithms. In 2015, flights of two aircraft from DLR & NASA provided the chance to compare parallel wind measurements from four airborne wind lidars for the first time.

1 INTRODUCTION

In regular intervals expert teams on Numerical Weather Prediction (NWP) of the World Meteorological Organization (WMO) prioritize the need for vertical wind profiles [1]. Wind information available on a global scale would largely contribute to improvements in NWP and forecasts of climate studies. The European Space Agency implemented the Atmospheric Dynamics Mission ADM-Aeolus [2] and is planning to launch the satellite in 2018. With its unique measurement principle, being applied in the environment of space for the first time, Aeolus is considered to be a technology demonstrator [3]. Along its sun-synchronous orbit the mission will provide wind speeds at heights between ground and the lower stratosphere, i.e. up to about 25 km, with vertical resolutions of 250 m – 2 km depending on altitude and scientific objectives. The strict requirements include for example an altitude dependent precision of 1 m/s to 3 m/s by horizontally averaging the signal over 90 km.

Being the single payload on board the satellite, the direct-detection Doppler Wind Lidar (DWL) instrument ALADIN will measure the wind speed along the laser line-of sight (LOS). A viewing angle of 35° off-nadir in across-track direction enables Aeolus to provide one component of the projected horizontal wind velocity vector. The ALADIN laser transmitter operates in the ultraviolet spectral region at 355 nm at a pulse repetition frequency of 50 Hz. Two spectrometers determine the Doppler shift of the signal backscattered from the atmosphere with respect to the frequency of the emitted laser pulse. Whereas the broadband molecular backscatter signal is analyzed by two sequentially arranged Fabry-Pérot interferometers, a Fizeau interferometer is employed for the narrowband Mie signal emanating from aerosol particles and clouds.

For the purpose of assessing the expectable performance of the space-borne instrument, obtaining measurements from real atmospheric conditions as well as optimizing the retrieval algorithms, an airborne prototype was developed: the ALADIN Airborne Demonstrator [4-6]. As the first airborne direct-detection DWL it has been providing airborne wind measurements since 2005 within the framework of several airborne campaigns. Extensive datasets were gathered particularly from a two-week campaign in 2009 and a three-week campaign in May 2015, both conducted in the North Atlantic Region and over Greenland with Keflavik, Iceland serving as a base station [7]. The latest airborne observations were obtained within the context of NAWDEX (North Atlantic Waveguide and Downstream Experiment) in the same region in September-October 2016. The respective wind measurements are currently being evaluated. During all three campaigns the A2D was deployed together with a coherent 2-µm DWL onboard the DLR Falcon aircraft [8]. In 2015, joint scientific flights were performed with the NASA DC-8 aircraft (Figure 1) which carried the coherent DAWN (Doppler Aerosol Wind) and the direct-detection based TWiLiTE (Tropospheric Wind Lidar Technology Experiment) instrument [9,10]. Thus, for the first time four wind lidars were operated simultaneously during an airborne campaign. This campaign comprised a total number of 13 flights with the A2D out of which 7 were coordinated between Falcon and DC-8.

Figure 1 The participants of the airborne campaign in front of the research aircraft DLR Falcon 20 (left) and NASA DC-8 (right) in Keflavik, Iceland in May 2015.

2 OBJECTIVES AND DEDICATED FLIGHT TRACKS

The objectives of the airborne campaign in 2015 mainly relate to the pre-launch validation of the ADM-Aeolus mission. The primary goals were to:

- confirm and document the technical performance of the A2D and its suitability for the foreseen calibration and validation (Cal/Val) of ADM-Aeolus.
- extend existing datasets on response calibrations over favorable areas for Aeolus calibrations, e.g. regions with high surface albedo.
- extend existing datasets on Rayleigh and Mie wind observations, particularly in highly variable atmospheric conditions.
- rehearse airborne Cal/Val activities after launch of the satellite with focus on airborne flight planning and on coordination with other aircraft and ground validation sites.
- perform co-located measurements with other satellite instruments, e.g. TDS-1 or ASCAT.

From May 11th until May 28th, the DLR Falcon and the NASA DC-8 were operated from Keflavik achieving 35 and 50 flight hours, respectively. Figure 2 shows the flight tracks of the DC-8 and the Falcon (excluding four transfer flights) as well as the dates and corresponding objectives.

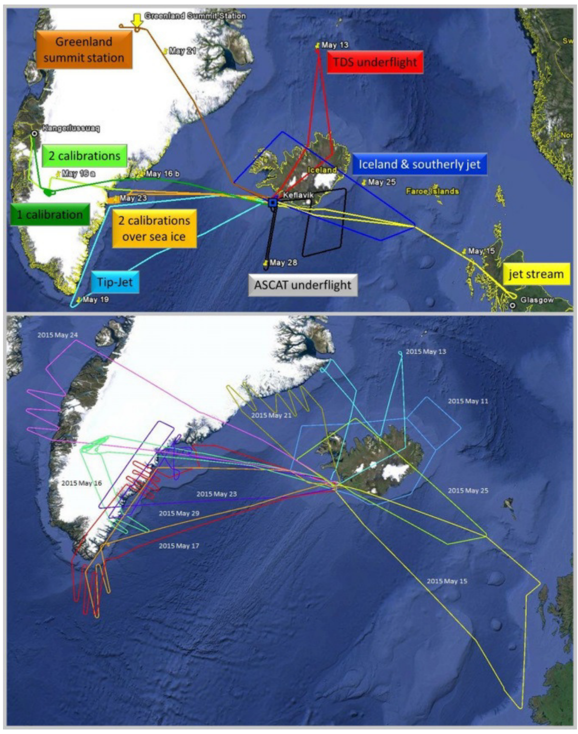

Figure 2 Flight tracks of the DLR Falcon (top) and the NASA DC-8 (bottom) from May 2015. For the Falcon the scientific objectives are given according to the color of the flight track.

Coordinated wind lidar measurements were performed from both aircraft during seven of these flights. At an altitude of about 10 km the Falcon exhibits a maximum endurance of slightly less than 5 hours and a maximum range of about 3500 km. In contrast, an endurance of about 8 hours enables the DC-8 to fly more extended tracks. In addition to the two DWLs the DC-8 deployed a large number of dropsondes [11]. A total number of 101 of these were released during the campaign measuring profiles not only of the horizontal wind vector but also of pressure, temperature and humidity. Therefore, the DC-8 was able to provide valuable information for the A2D calibration mode. One of the flights of the Falcon was dedicated to overpasses of a ground based wind lidar set up at the Greenland summit station [12].

3 AIRBORNE AND GROUND-BASED WIND LIDAR MEASUREMENTS

Due to its high precision of better than 1 m/s, the 2-µm DWL [8] serves as a reference instrument for the A2D. Table 1 lists the main specifications of both lidars.

Table 1 Operating parameters of the 2 DWLs on-board the DLR Falcon aircraft

parameter	**A2D**	**2-µm**
detection principle	direct	coherent
wavelength / nm	354.9	2022.5
pulse repetition rate / Hz	50	500
pulse energy / mJ	50 - 60	1 – 2
pulse length / ns	30	400
telescope diameter / m	0.2	0.11
resolution vertical / m	300 - 2400	100
resolution temporal / s	18	40
Line-of-sight	20° off-nadir (fixed)	vertical (fixed) or 20° off-nadir (scanning)

Theoretically, all noise sources for ALADIN are small enough to render shot noise the dominating contributor to the total noise. However, for the A2D we experience higher noise levels, which are primarily related to fluctuations of the co-alignment of transmission and reception paths as well as the internal reference measurements. Figure 3 shows an example of typical wind measurements of the A2D and the 2-µm DWL. This 30-minutes section measured around 2 p.m. on May 19th was obtained during a straight flight leg heading south along the south-eastern coast of Greenland. Only wind measurements outside the telescope overlap region of the A2D (range-gates 8-21 in Figure 3 bottom) are considered for the statistical comparison presented in Figure 4.

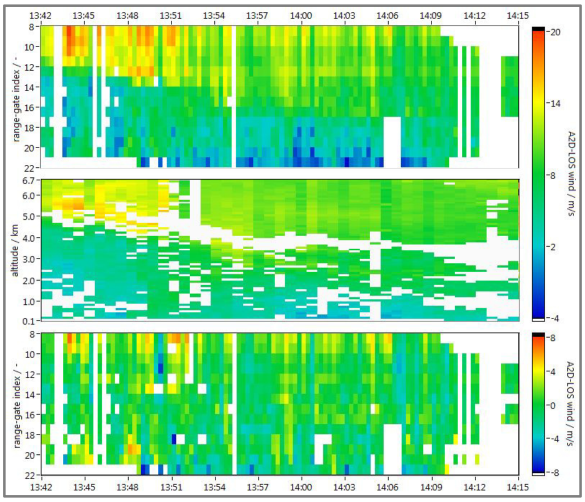

Figure 3 Wind measurements from the A2D Rayleigh channel (top) and the 2-µm DWL (middle) from May 19th in 2015. The wind speed differences after interpolation of 2-µm wind onto the A2D grid (min. coverage 50%) are shown at the bottom.

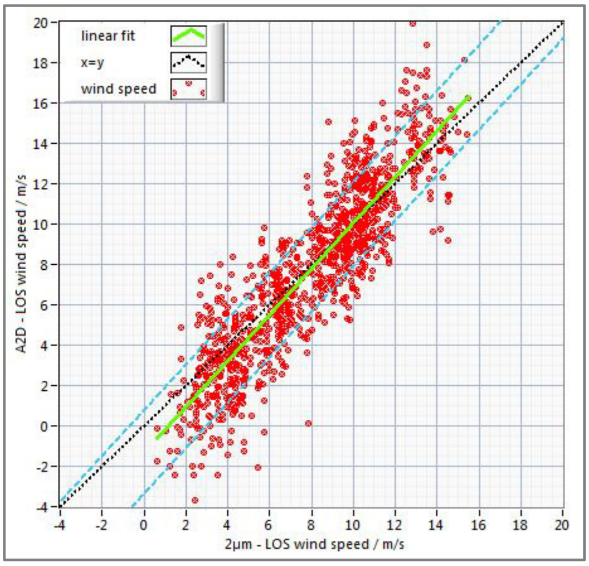

Figure 4 Statistical comparison of A2D Rayleigh winds and winds from the 2-µm DWL (benchmark) for the flight section from 2015/05/19 around 2 p.m. (UTC). Blue dashed lines mark a standard deviation of ±2m/s around the linear fit.

The coarse structure of the A2D and 2-µm wind fields show a remarkable agreement with highest LOS wind speeds on the top left. An edge between high and low winds speeds descending from 5 km to about 3 km seems to come along with a thin layer free of aerosol visible as a horizontal white band in the 2-µm wind field. Generally, white areas represent invalid or quality controlled measurements. As shown in Figure 4 a mean bias of -0.9 m/s, a slope error of 14% and a standard deviation of 2.0 m/s were found from a number of 1021 A2D and 2-µm LOS wind observations.

4 CONCLUSIONS

In 2015, a joint airborne campaign under participation of DLR and NASA was performed over the North Atlantic region, operating four DWLs during coordinated flights of two aircraft for the first time. The current analysis encompasses extensive data sets from the lidar instruments, dropsondes, a ground-based wind lidar on the Greenland Summit Station as well as numerical weather prediction models. Most of the objectives of the airborne campaign could be met and the basis for future coordinated airborne validation campaigns after the launch of ADM-Aeolus has been established.

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