Pre-launch validation of ESA's Aeolus mission by airborne wind lidar measurements

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ABSTRACT

ESA's satellite mission Aeolus carrying the direct-detection Doppler wind lidar instrument ALADIN is planned for launch in 2015. DLR operates the ALADIN airborne demonstrator (A2D) from ground and aircraft. The latest results derived from A2D measurements are presented. Several newly developed and A2D specific methods regarding calibration, zero wind correction and quality control allow the retrieval of vertical profiles of line-of-sight wind speeds. An estimation of the statistical error of the A2D Rayleigh wind measurements to about 2.5 m/s is derived by comparisons to wind measurements performed in parallel by a coherent 2-µm Doppler wind lidar. Further investigations show that the main contributor to the instrumental error of the A2D with respect to the Rayleigh channel seems to be the laser beam pointing and the temperature control of the spectrometer.

INTRODUCTION

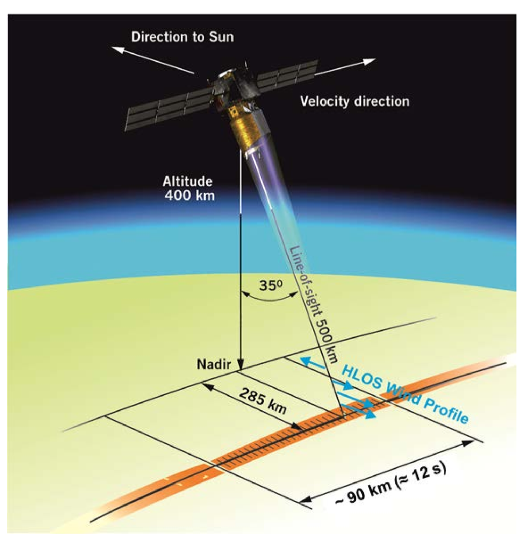


Fig. Viewing geometry and sampling strategy of the Aeolus satellite for horizontal line-of-sight (LOS) wind speed (adapted from [1]).

The A2D is a prototype of the satellite instrument and is operated by DLR from ground and as an airborne demonstrator [2], [3]. Two different types of interferometers analyse Rayleigh- and Mie scattering from molecules and aerosols or clouds.

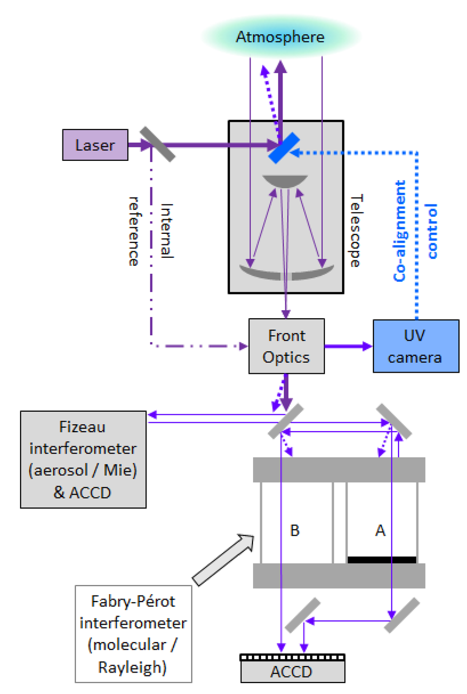


Fig. Overview of the A2D subsystems. The emitted laser light (violett) is partly reflected by the atmosphere, collected by a telescope and analysed by two spectrometers.

The European Space Agency ESA will launch the Aeolus wind lidar satellite by end of 2015 to improve numerical weather prediction and climate studies. By emitting laser pulses at 355 nm and analysing the Doppler shifted light backscattered by the atmosphere, wind speeds between 0-25 km will be provided on a global scale and in near real time.

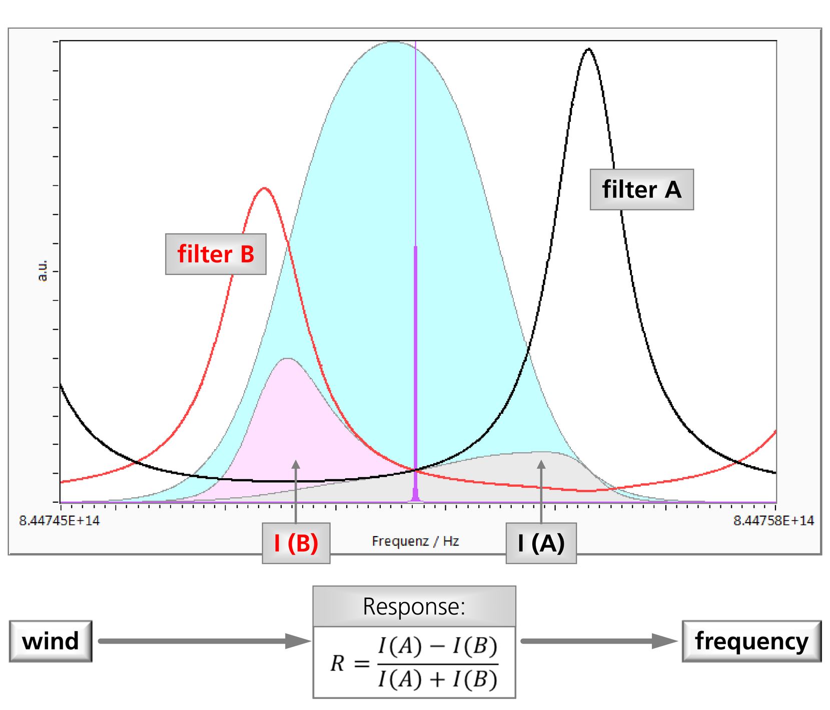
OBJECTIVES

Compared to the satellite environment and geometry, A2D airborne measurements are the most similar ones available and their analysis requires the:

- Development, validation and optimization of retrieval algorithms
- Validation of measurement principle and particularly the calibration strategy
- Characterization of the instrument performance
- Validation of wind measurement results & first estimation of errors

METHODS

The Rayleigh spectrometer contains two Fabry-Pérot interferometers each consisting of two parallel plates. Different spacings between these plates result in different positions of the peak transmission.
The Fizeau interferometer consists of two plates with a small wedge angle. The position of the fringe that is imaged onto the CCD is related to the wind speed.



$$R = \frac{I(A) - I(B)}{I(A) + I(B)}$$

Fig. Principle of the Rayleigh spectrometer: A laser pulse (violet) is emitted towards the atmosphere. The spectrally broadened backscatter from molecules (blue) is sequentially directed onto 2 Fabry-Pérot interferometers (filters A and B). The contrast ratio of the transmission I(A) and I(B) is the link between the Doppler frequency shift and the wind speed.

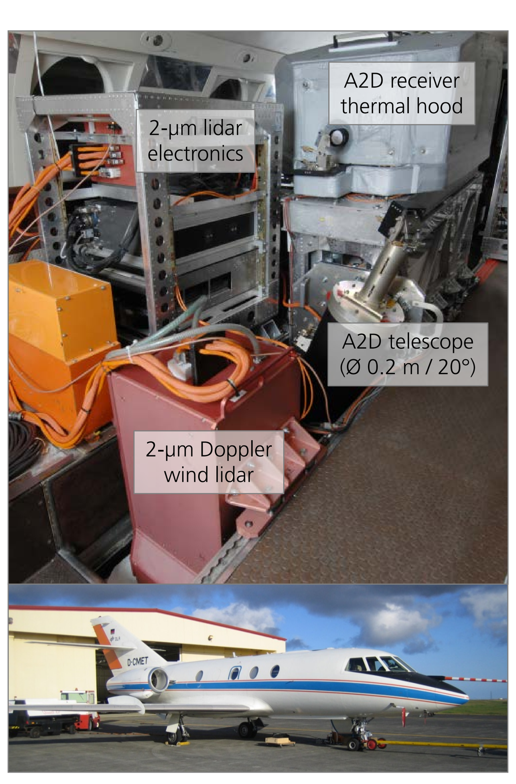


Fig. Top: payload of the DLR Falcon aircraft during the airborne campaign in September 2009. Bottom: DLR Falcon aircraft in front of the hangar in Keflavik, Iceland.

For the first time worldwide two wind lidar instruments were operated simultaneously on the same aircraft in 2009: The A2D and a well-established coherent reference lidar at 2 µm, the latter being characterized by low random and systematic errors of about 0.1 m/s.

RESULTS

In total 10 flights with more than 20 hours of measurements were conducted over the North Atlantic region during this airborne campaign. Two response calibrations were performed over the Greenland iceshield. Wind measurements were performed during the occurrence of catabatic winds, high altitude jet-streams and in in cloud free as well as in cloudy conditions.

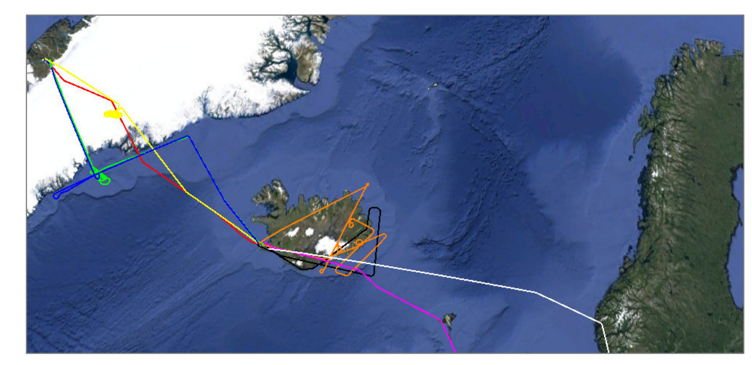


Fig. Flight tracks of the DLR Falcon aircraft during the airborne campaign in September 2009. Google Earth was used to display this information.

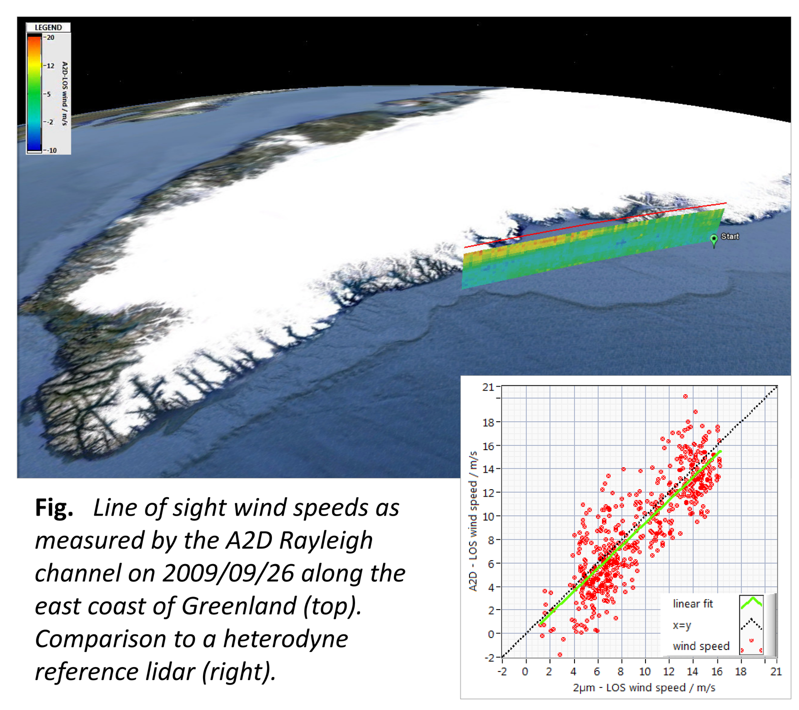


Fig. Line of sight wind speeds as measured by the A2D Rayleigh channel on 2009/09/26 along the east coast of Greenland (top). Comparison to a heterodyne reference lidar (right).

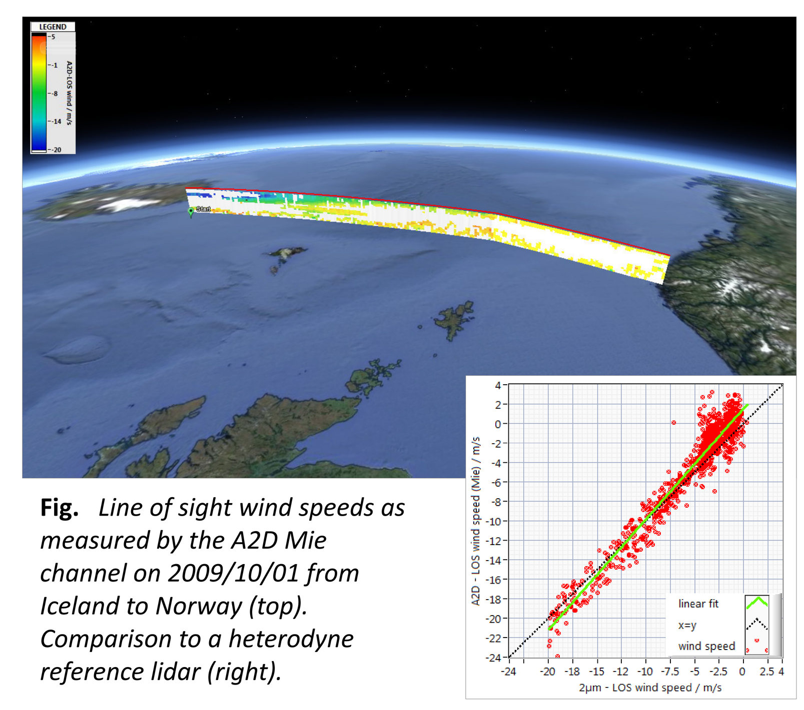


Fig. Line of sight wind speeds as measured by the A2D Mie channel on 2009/10/01 from Iceland to Norway (top). Comparison to a heterodyne reference lidar (right).

The wind speeds derived from the A2D Rayleigh and Mie channel were compared to the winds measured by the 2-µm lidar. Random errors of ≈2.5 m/s and 1.5 m/s were found for the Rayleigh and Mie channel, respectively. The systematic errors are about -0.5 m/s and 1 m/s. The enhanced noise on the A2D wind speed measurements is higher than what could be expected from Poisson distributed signal noise,

DISCUSSION

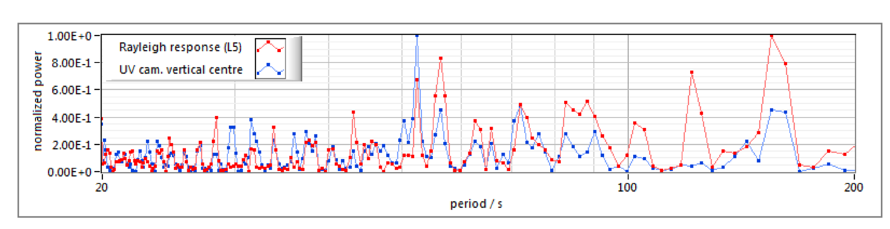


Fig. Excerpt from the power spectra (normalized to maximum value) of the Rayleigh response and the vertical reference position on the UV camera (correlation coefficient ≈0.5) for the flight on 2009/10/01 from Iceland to Norway.

The noise on the Rayleigh response seems to depend strongly on the performance of the co-alignment loop. Also, the temperature control loop for the Rayleigh spectrometer contributes significantly to the present magnitude of the noise.

CONCLUSION

A main goal is the characterization and reduction of the systematic and random errors in the wind speeds derived from the Mie and especially the Rayleigh channel. New dedicated airborne, ground based and laboratory measurements are needed to identify the contributing noise sources, to determine their behaviour and to design appropriate countermeasures. In the future, particular notice must be spent on the performance of the reponse calibration.

MAJOR REFERENCES

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[2] **Reitebuch et al.,** "The Airborne Demonstrator for the Direct-Detection Doppler Wind Lidar ALADIN on ADM-Aeolus. Part I: Instrument Design and Comparison to satellite Instrument," JAOT, 26 (2009).

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[4] **Marksteiner, U.,** "Airborne wind lidar observations for the validation of the ADM-Aeolus instrument," PhD thesis, Technische Universität München, (2013).

Funding for the development of the ALADIN Airborne Demonstrator A2D and performance of campaigns was provided by ESA and DLR. Special thanks go to Engelbert Nagel for his permanently available technical assistance and to the pilots of the DLR flight facility.

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