# Airborne Wind Lidar Observations for the Validation of ESA's Wind Mission Aeolus

**Oliver Lux[1], Christian Lemmerz[1], Fabian Weiler[1], Uwe Marksteiner[1], Alexander Geiß[2], Benjamin Witschas[1], Stephan Rahm[1], Andreas Schäfler[1], Oliver Reitebuch[1]**

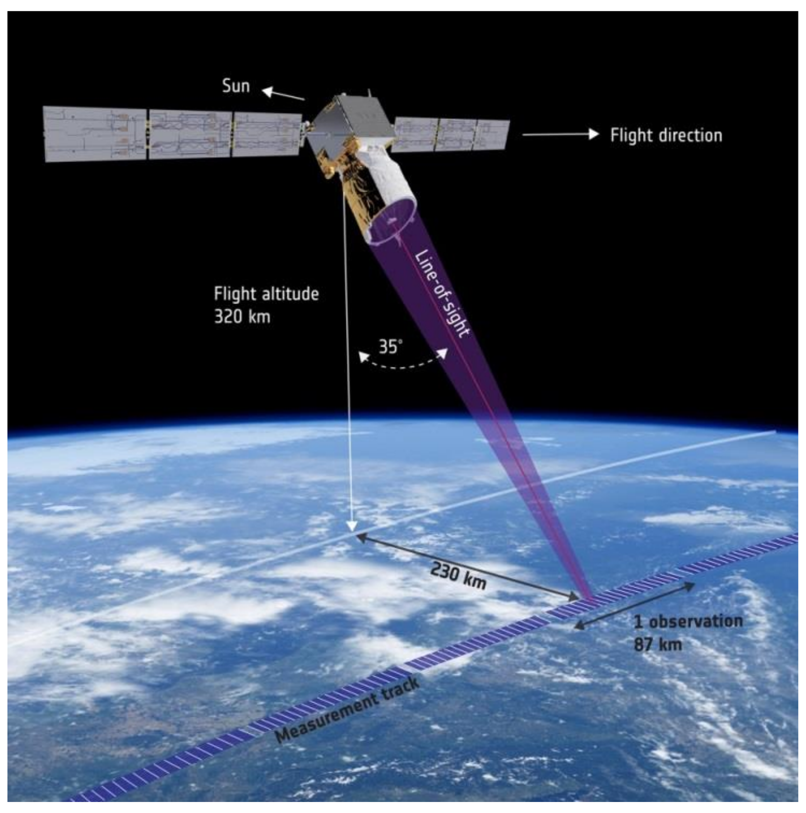
[1] Institute of Atmospheric Physics, German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR), Münchener Str. 20, 82234 Oberpfaffenhofen, Germany

[2] Ludwig-Maximilians-University Munich, Meteorological Institute, 80333 Munich, Germany

*Corresponding author: Dr. Oliver Lux (email: oliver.lux@dlr.de)*


Since the successful launch of ESA's Earth Explorer mission Aeolus on 22 August 2018, atmospheric wind profiles from the ground to the lower stratosphere are being acquired on a global scale deploying the first-ever satellite-borne wind lidar system ALADIN (Atmospheric LAser Doppler INstrument). Already several years before the launch, an airborne prototype of the Aeolus payload, the ALADIN Airborne Demonstrator (A2D), was developed at DLR. Due to its representative design and operating principle, the A2D has been delivering valuable information on the wind measurement strategies of the satellite instrument and helped to optimize the wind retrieval and related quality-control algorithms. Together with DLR's high-accuracy coherent Doppler wind lidar, the A2D was deployed in three airborne campaigns in Europe after launch, providing an extensive dataset under various atmospheric conditions in terms of cloud cover and dynamics for the validation of the Aeolus mission.

## Aeolus – The First Wind Lidar in Space

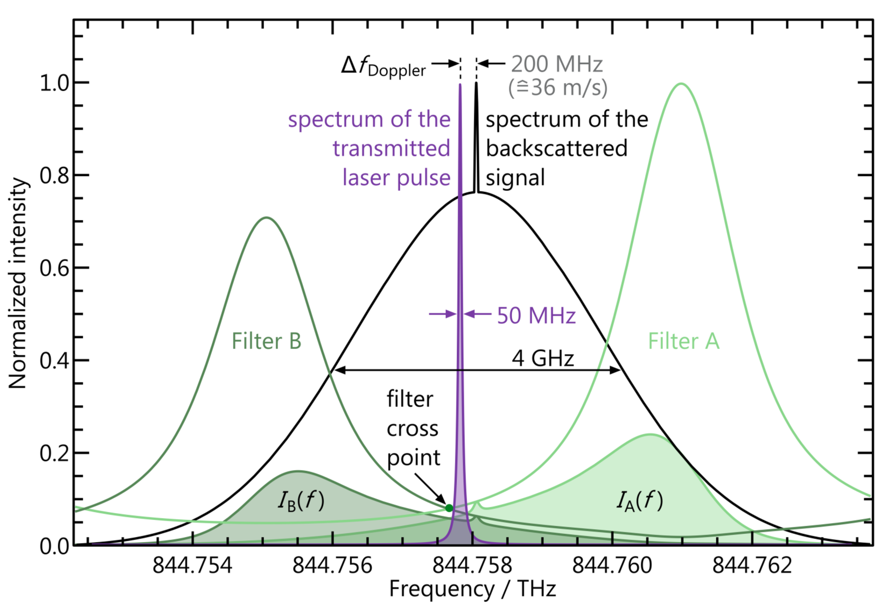



Schematic of the measurement geometry of the polar-orbiting Aeolus satellite.

- Doppler wind lidar called ALADIN (Atmospheric LAser Doppler INstrument) is accommodated on Aeolus flying in a polar, sun-synchronous orbit at an altitude of about 320 km
- Wind profiles in line-of-sight (LOS) direction under a slant angle of 35° from ground up to 30 km with horizontal resolution of 90 km and vertical resolution of 0.25 to 2 km depending on altitude
- Accuracy for the horizontal LOS wind component: <1 m/s
- Precision: 3 m/s to 6 m/s depending on altitude (in-orbit performance)

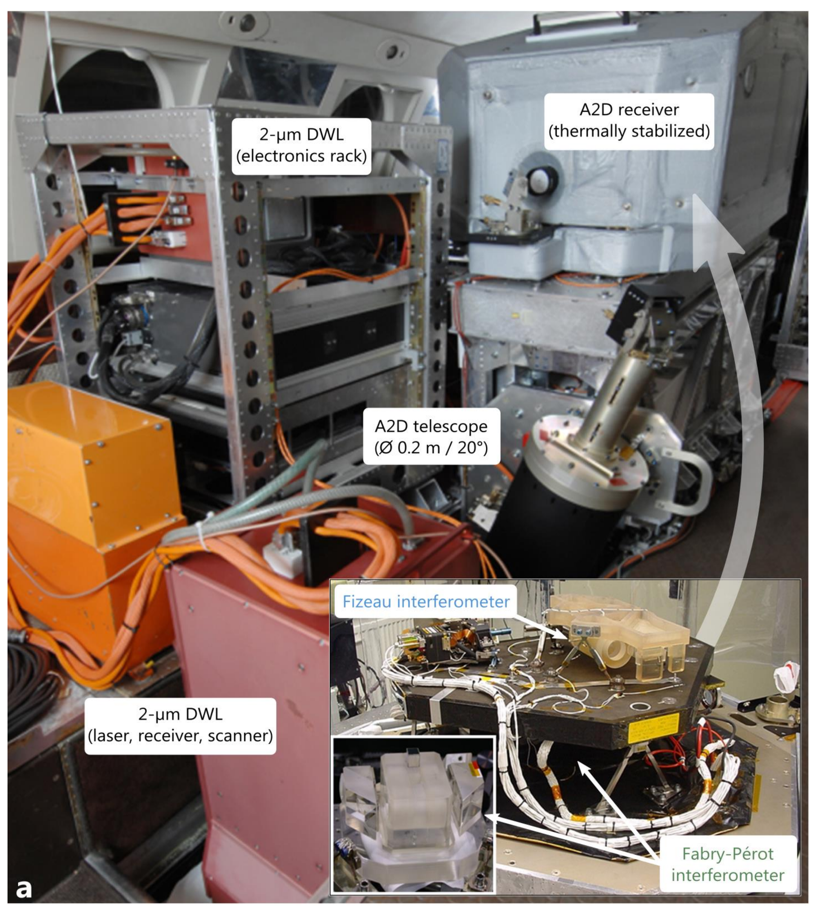
## Principle of the Direct-Detection Wind Lidar

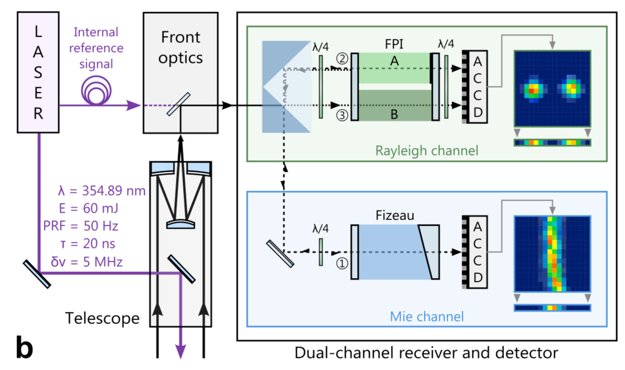
- Determination of the LOS wind speed from the Doppler frequency shift $\Delta f = 2 f_0 \cdot \frac{v}{c}$ imposed on ultra-violet laser pulses that are transmitted into the atmosphere from a high-power and frequency-stabilized laser operating at 355 nm wavelength
- Analysis of backscatter signals using a complementary dual-channel receiver
- Rayleigh and Mie channel for sensing the Doppler shift from molecules as well as particles (aerosols, clouds)
- Measurement of the Doppler frequency shift with accuracy of $10^{-8}$ in order to achieve wind speed accuracy of 1 m/s




Measurement principle of the Rayleigh channel based on the double-edge technique.

## ALADIN Airborne Demonstrator (A2D) Wind Lidar



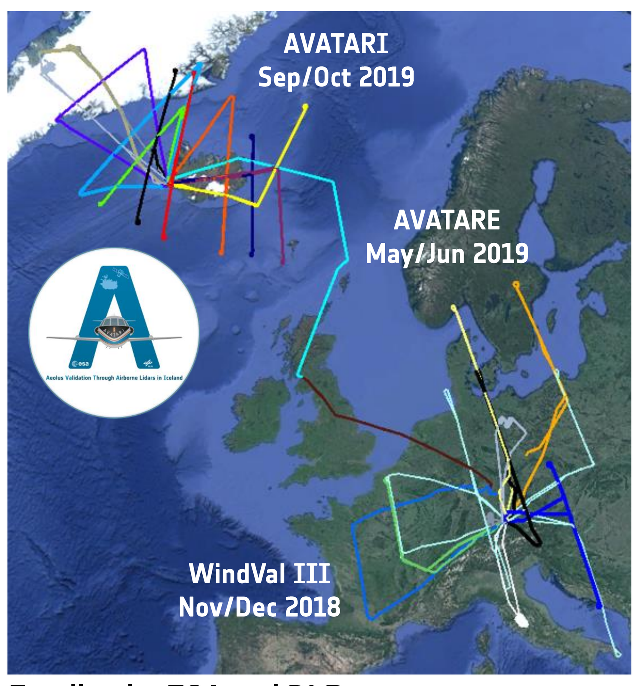




- Direct-detection airborne Doppler wind lidar which serves as a prototype for the satellite instrument
- Single-frequency Nd:YAG laser at 355 nm wavelength
- Rayleigh: Fabry-Pérot interferometer with double-edge technique
- Mie: Fizeau interferometer with fringe-imaging technique
- Telescope: 100 µrad FOV, Ø 0.2 m

**a** Instrumentation of the Falcon aircraft comprising the A2D and the 2-µm DWL as a reference. **b** Schematic of the A2D Doppler wind lidar.

## Validation Campaigns in Europe in 2018 and 2019

- Three airborne campaigns after launch of Aeolus between Nov 2018 and Oct 2019
- 20 Aeolus underflights covering more than 15,000 km of the Aeolus measurement swaths
- Comprehensive evaluation of the satellite's wind product quality at different phases of the mission (laser performance, seasonal effects)
- Deployment of A2D in combination with coherent Doppler wind lidar (2-µm DWL) that offers high accuracy and precision

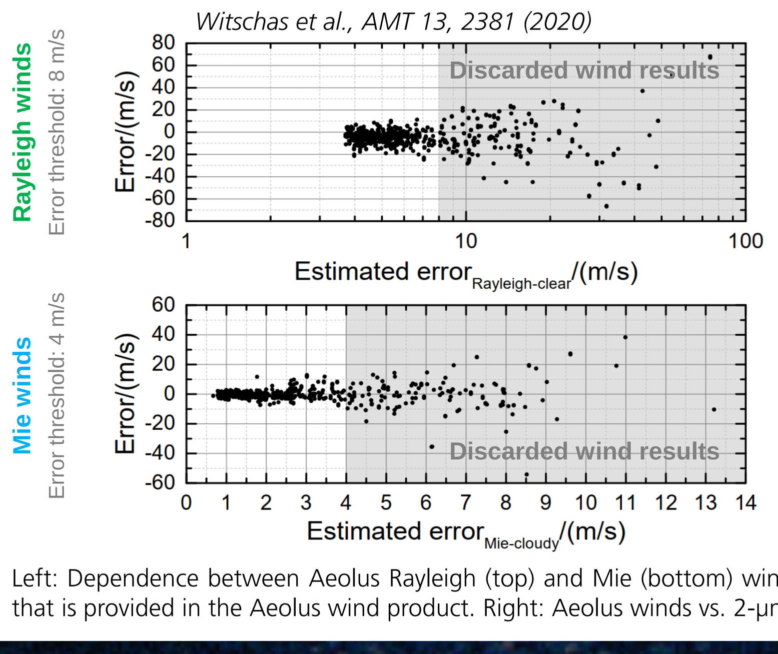


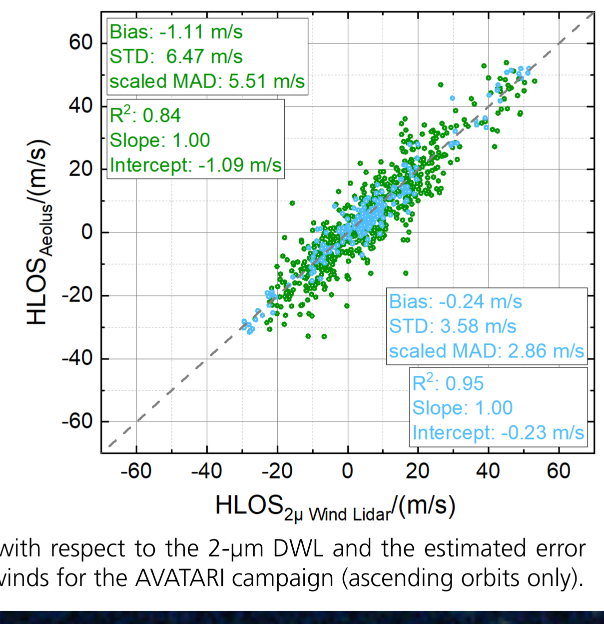

Funding by ESA and DLR

Photo of DLR Falcon aircraft in Keflavik, Iceland and flight tracks of the DLR Falcon aircraft during the Cal/Val campaigns in 2018 and 2019.

## Aeolus Error Assessment using 2-µm DWL Winds

- Statistical analysis based on 2-µm DWL data showed different biases of Aeolus Mie and Rayleigh winds for ascending and descending orbits even after correction for temperature variations across the satellite's primary telescope mirror (M1 correction)
- Systematic error (ascending/descending): Rayleigh: -1.1 / -0.4 m/s, Mie: -0.2 / -0.5 m/s
- Random error (1 km range bins): Rayleigh: 3.8 to 4.4 m/s, Mie: 2.0 to 2.8 m/s

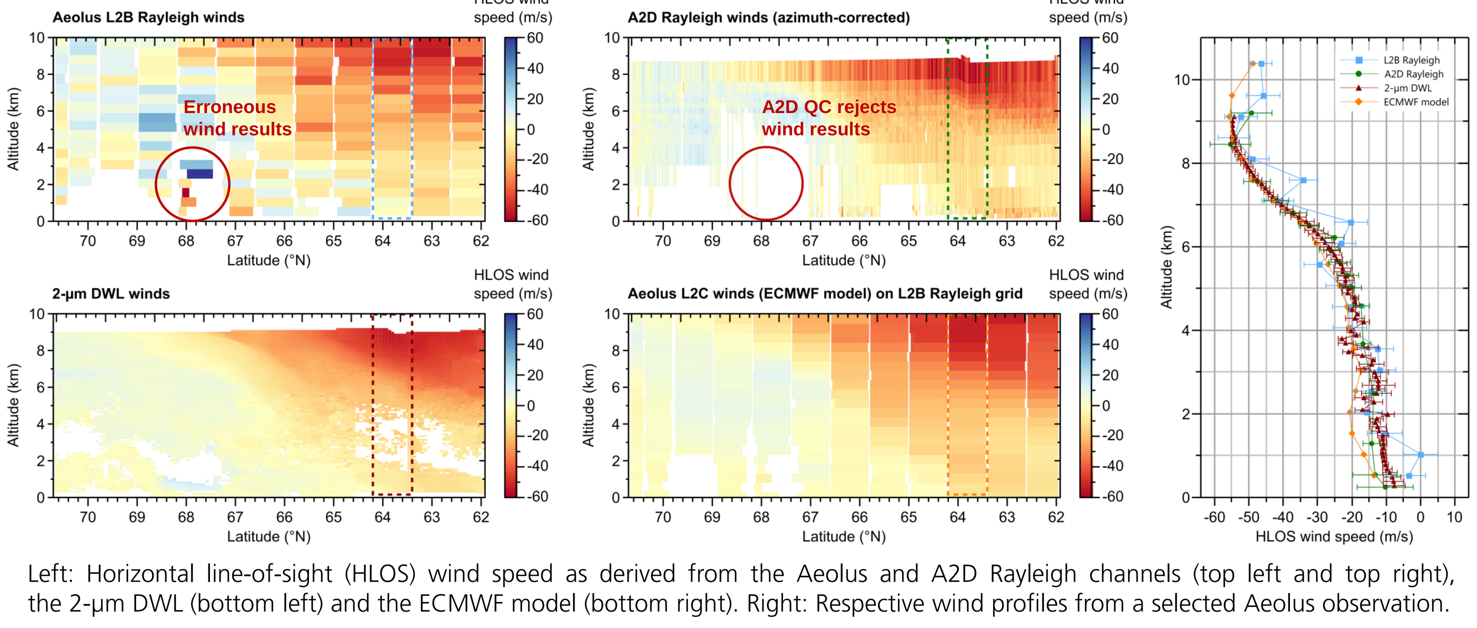



Left: Dependence between Aeolus Rayleigh (top) and Mie (bottom) wind error with respect to the 2-µm DWL and the estimated error that is provided in the Aeolus wind product. Right: Aeolus winds vs. 2-µm DWL winds for the AVATARI campaign (ascending orbits only).

## Case Studies for Aeolus Processor Improvements

- Collocated wind observations of Aeolus and the two DLR airborne wind lidars along descending Aeolus orbit over Greenland and North Atlantic on 16 September 2019
- Analysis of Aeolus Rayleigh wind errors in complex atmospheric scenes allows to draw recommendations for processor evolution (improved QC based on A2D scheme)
- A2D as a testbed to explore new measurement strategies and algorithm modifications




Left: Horizontal line-of-sight (HLOS) wind speed as derived from the Aeolus and A2D Rayleigh channels (top left and top right), the 2-µm DWL (bottom left) and the ECMWF model (bottom right). Right: Respective wind profiles from a selected Aeolus observation.