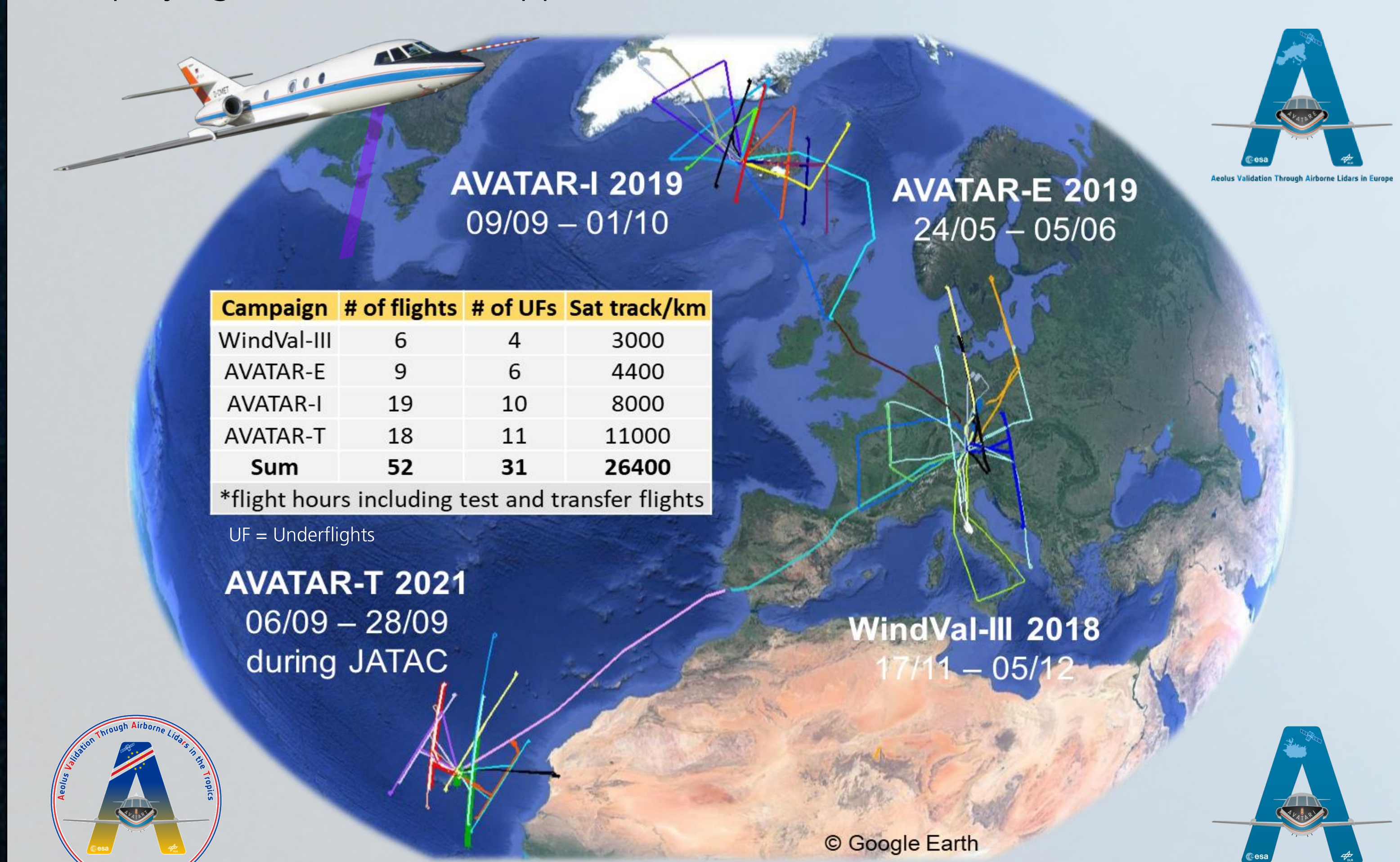
Validation of the Aeolus L2B wind product by means of airborne wind lidar measurements performed in the North Atlantic region and in the Tropics*

B. Witschas[1], A. Geiß[2], O. Lux[1], C. Lemmerz[1], U. Marksteiner[1], A. Schäfler[1], S. Rahm[1], O. Reitebuch[1], F. Weiler[1]

[1] German Aerospace Center (DLR), Institute of Atmospheric Physics, Oberpfaffenhofen 82234, Germany
[2] Ludwig-Maximilians-University (LMU) Munich, Meteorological Institute, 80333 Munich, Germany
* Co-funded by DLR & ESA – ESTEC (T. Fehr, Head of Atmospheric Section)

Aeolus Validation Through Airborne Lidars – AVATAR–X

To validate the quality of Aeolus wind observations, **DLR** performed **four airborne campaigns** over **central Europe**, **Iceland** and the **Tropics**, deploying two different Doppler wind lidars on board the DLR Falcon aircraft.



Campaign	# of flights	# of UFs	Sat track/km
WindVal-III	6	4	3000
AVATAR-E	9	6	4400
AVATAR-I	19	10	8000
AVATAR-T	18	11	11000
Sum	**52**	**31**	**26400**
*flight hours including test and transfer flights			

Flight tracks of the Falcon aircraft during the previous Aeolus CalVal campaigns performed by DLR.

The Aeolus CalVal payload at DLR

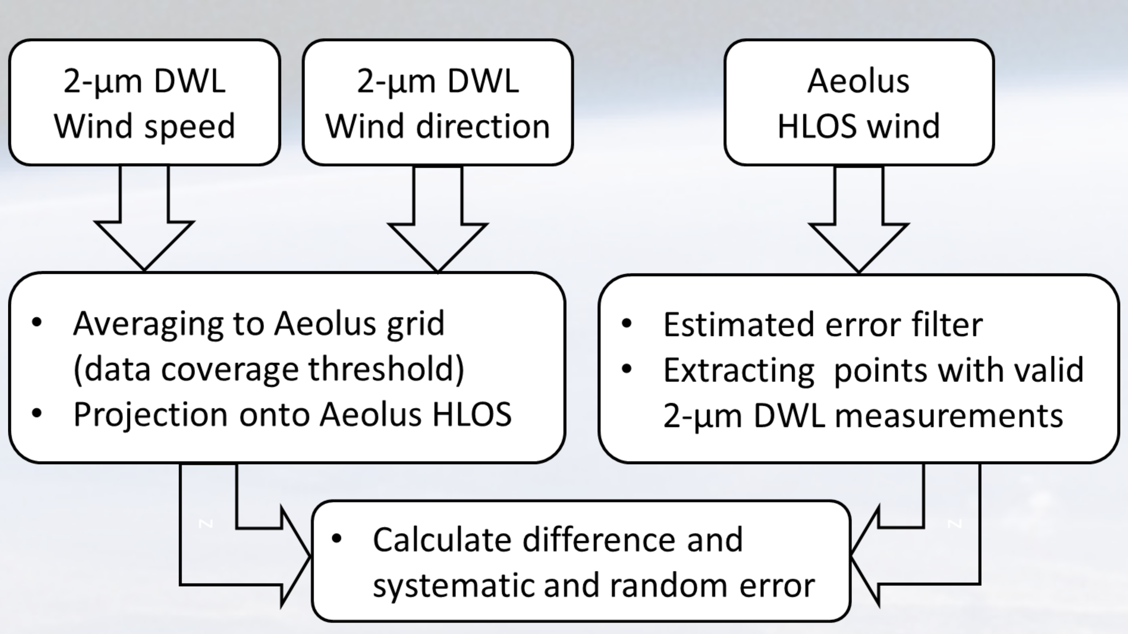
- DLR's Aeolus CalVal payload is composed of a **direct detection wind lidar** (ALADIN airborne demonstrator, **A2D**) **[1]** and a highly accurate **scanning coherent 2-µm wind lidar [2,3]** used as a reference system.
- With this payload, both the **Aeolus wind products** as well as **specific calibration** and **retrieval algorithms can be validated**.
- DLR has been using this payload for **15 years** already for **pre-launch activities since 2007**.

The A2D and the 2-µm DWL mounted in DLR's Falcon aircraft

Parameter	DLR A2D	DLR 2-µm DWL
Wavelength	354.89 nm	2022.54 nm
Laser energy	50-60 mJ	1-2 mJ
Pulse repetition rate	50 Hz	500 Hz
Pulse length	20 ns (FWHM)	400-500 ns (FWHM)
Telescope diameter	20 cm	10.8 cm
Vertical resolution	300 m to 2.4 km	100 m
Temporal averaging raw data (horizontal)	20 shots = 400 ms	single shot = 2 ms
Temporal averaging product (horizontal)	14 s (+4 s data gap)	1 s per LOS (500 shots), 44 s scan (21 LOS)
Horizontal resolution @ 200 $m \cdot s^{-1}$ = 720 km/h = 12 km/min.	3.6 km (18 s)	0.2 km LOS, 8.4 km scan
Precision (random error)	1.5 $m \cdot s^{-1}$ (Mie) 2.5 $m \cdot s^{-1}$ (Rayleigh)	< 1 $m \cdot s^{-1}$

Specifications of the A2D and the 2-µm DWL

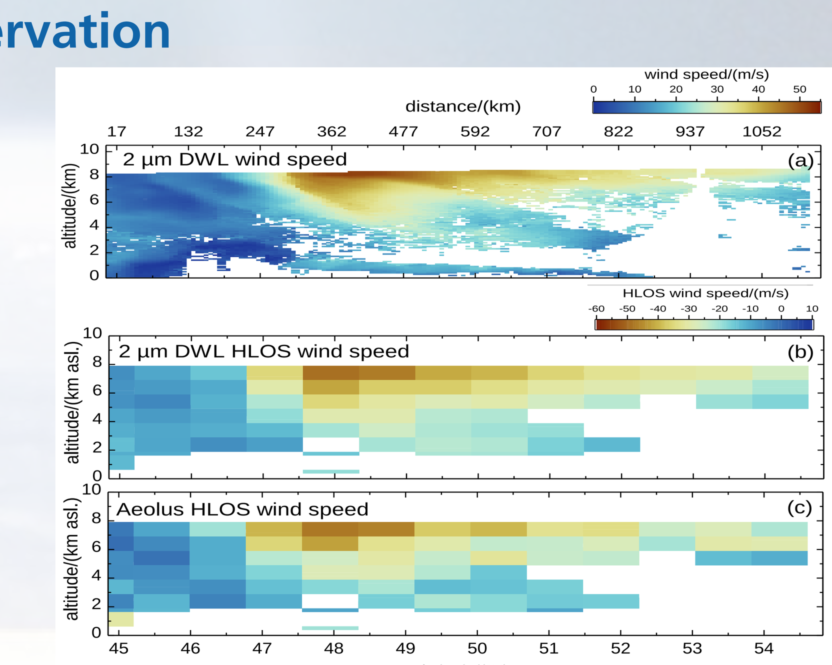
Comparison procedure of 2-µm DWL measurements and Aeolus observation



Sketch of the processing steps used to compare 2-µm DWL measurements with Aeolus observations [3].

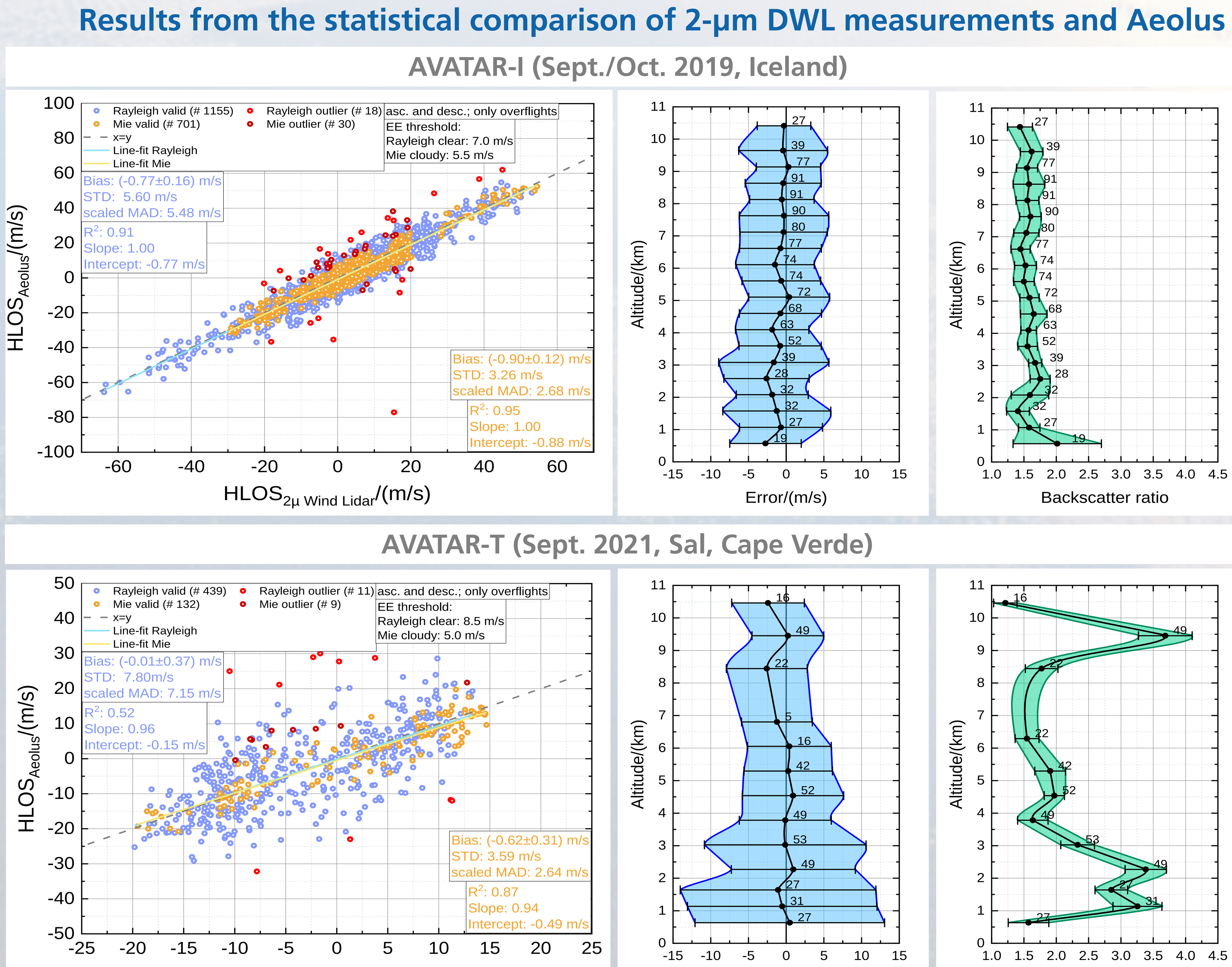
Due to the **different horizontal/vertical resolutions** of 2-µm DWL measurements (e.g. 8.4 km/100 m) and Aeolus observations (e.g. 90 km (Rayleigh) and down to ≈ 10 km (Mie), 0.25 to 2 km), **averaging and projection procedures have to be applied before comparison:**

1. 2-µm DWL wind speed/direction are averaged to the Aeolus grid by using the **top/bottom altitudes** and **start/stop latitudes** (L2B data). A 2-µm DWL data coverage threshold of **50%** is used to consider the averaged data point as valid.
2. The averaged **wind speeds/directions are projected onto the horizontal LOS** of Aeolus.
3. Aeolus **HLOS winds** (Rayleigh-clear and Mie-cloudy) **are extracted for areas of valid 2 µm DWL measurements**.
4. Beforehand, the **Aeolus data is quality controlled** by means of an **estimated error** threshold. Additionally, outliers are sorted out by applying a modified **Z-score threshold of 3** (for further details see poster by Lux/Witschas et al. about the Aeolus QC).



Wind observations obtained during the WindVal III campaign (17 Nov. 2018). (a) 2-µm DWL wind speed. (b) 2-µm DWL observations averaged to the Aeolus grid and projected onto its viewing direction. (c) Aeolus Rayleigh-clear winds in regions where 2-µm DWL data are available for comparison [3].

Results from the statistical comparison of 2-µm DWL measurements and Aeolus observation during AVATAR-I and AVATAR-T



Aeolus HLOS Rayleigh-clear winds (light-blue) and Mie-cloudy winds (yellow) plotted against the 2-µm DWL data projected onto the horizontal viewing direction of Aeolus for the data sets of AVATARI (top) and AVATART (bottom). Line fits are indicated by the light-blue and yellow lines, and the x=y-line is indicated in gray. Outliers with a modified Z-score > 3 are indicated in red and dark red. 11 underflights performed during AVATART. Data points are color coded with respect to the Aeolus estimated error. The x=y line is indicated by the dashed line.

Systematic and random error (left) and backscattering ratio taken from the L1B data product (right) depending on altitude retrieved from the AVATARI data set (top) and the AVATART data set (bottom), respectively. The uncertainty bands (colored areas) represent the scaled MAD that is calculated for the respective altitudes. The given numbers at each altitude denote the number of available data points.

- During the **AVATAR-I campaign, 10 coordinated flights** along the Aeolus track were conducted (**~8000 km** of the Aeolus swath)
- During **AVATAR-T 11 flights** could be performed (**~11000 km**)
- The acquired data set from both campaigns enables the **validation of the Aeolus** wind product **during different time periods** of the mission, **in different geographical locations** and **under different meteorological conditions** (clear air and high wind speeds in Iceland, or in aerosol-loaded air around Cape Verde).
- Accurate wind measurements were performed with the 2-µm DWL, leading the **1155 / 439 data points for Rayleigh-clear** wind comparison and **701 / 132 data points for Mie-cloudy** winds.
- A statistical comparison yields a systematic/random error of **-0.8 m/s / 5.5 m/s** (**Ray.-clear**, AVATAR-I) and **0.0 m/s / 7.2 m/s** (**Ray.-clear**, AVATAR-T)
  - The **increase of the random error** between both campaigns can be assigned to the **decreased signal levels** as well as the **enhanced aerosol-load** observed **during AVATAR-T**. This is also verified by the shown backscatter ratio profiles (right).
  - The systematic error of **0.0 m/s** obtained for the AVATAR-T data is remarkable. The **-0.8 m/s** obtained for AVATAR-I might be a result of **regional discrepancies** that are not fully covered by the M1 bias correction.
- The systematic/random error of for **Mie winds (only from high-SNR cloud returns)** is determined to be **-0.9 m/s / 2.7 m/s** (AVATAR-I) and **-0.6 m/s / 2.6 m/s** (AVATAR-T)
  - The random error (**2.7 m/s** (AVATAR-I) and **2.6 m/s** (AVATAR-T)) is less affected as the Rayleigh-clear winds, as the signal levels are still sufficient during AVATAR-T (larger aerosol-load)
  - The obtained systematic error (**-0.9 m/s** (AVATAR-I) and **-0.6 m/s** (AVATAR-T)) is comparable.
- The **altitude-dependent analysis** of the systematic/random error demonstrates, that the **random error is negatively affected by larger aerosol-loads → cross talk is not corrected sufficiently.**

References:
[1] Lux et al., 2020, AMT, Intercomparison of wind observations from the ESA's Aeolus satellite mission and the ALADIN Airborne Demonstrator.
[2] Witschas et al., 2017, JTEC, Airborne Wind Lidar Measurements of Vertical and Horizontal Winds for the Investigation of Orographically Induced Gravity Waves.
[3] Witschas et al., 2020, AMT, First validation of Aeolus wind observations by airborne Doppler wind lidar measurements.