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

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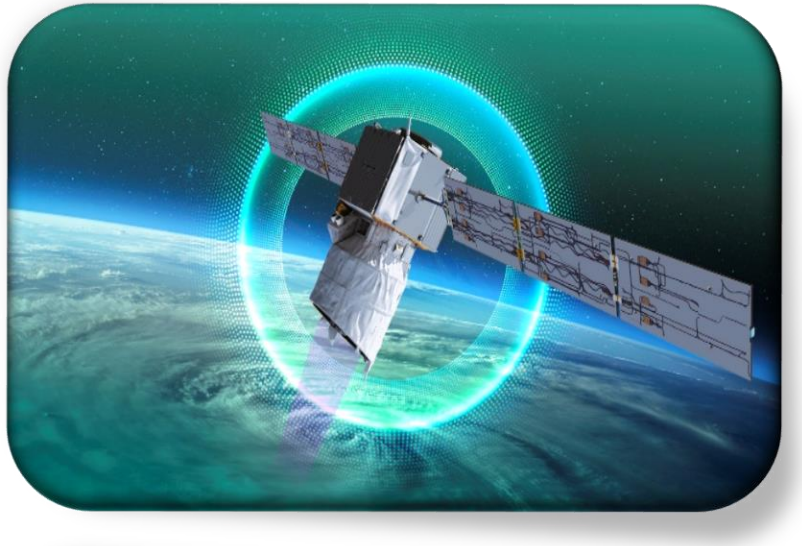
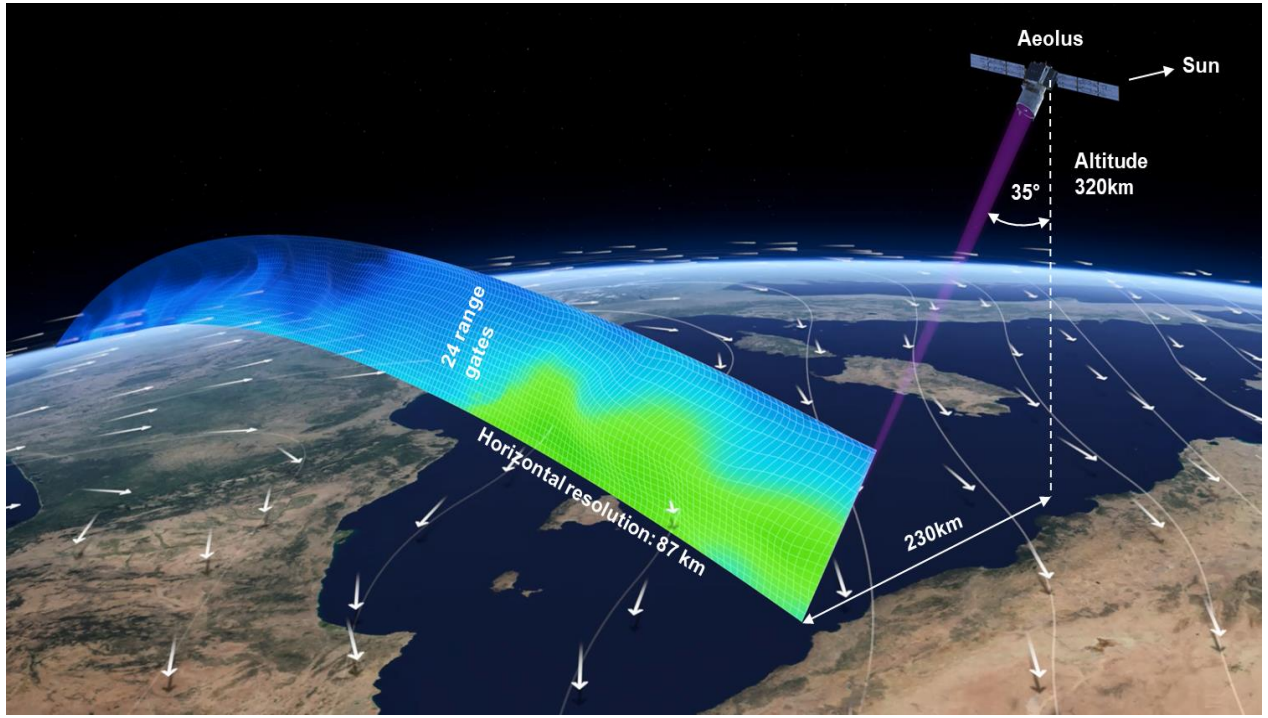
Outline

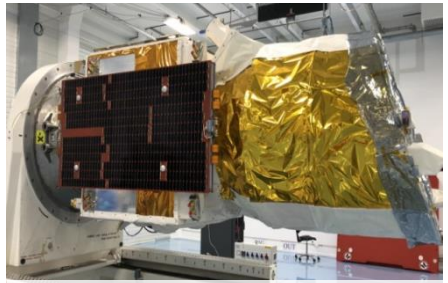


1. ESA‘s Aeolus mission

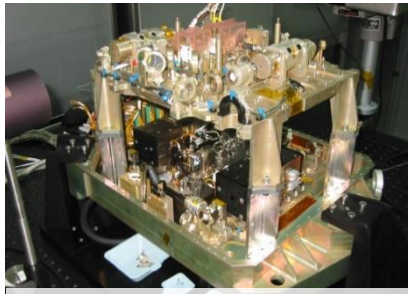
2. DLR‘s CalVal activities

ESA‘s Aeolus mission and ALADIN – the first wind lidar in space

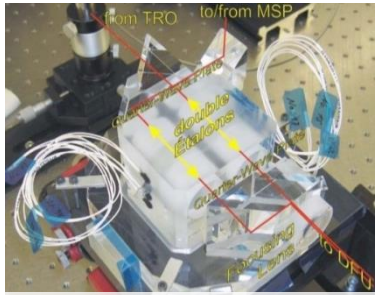




Aeolus satellite



ALADIN laser transmitter



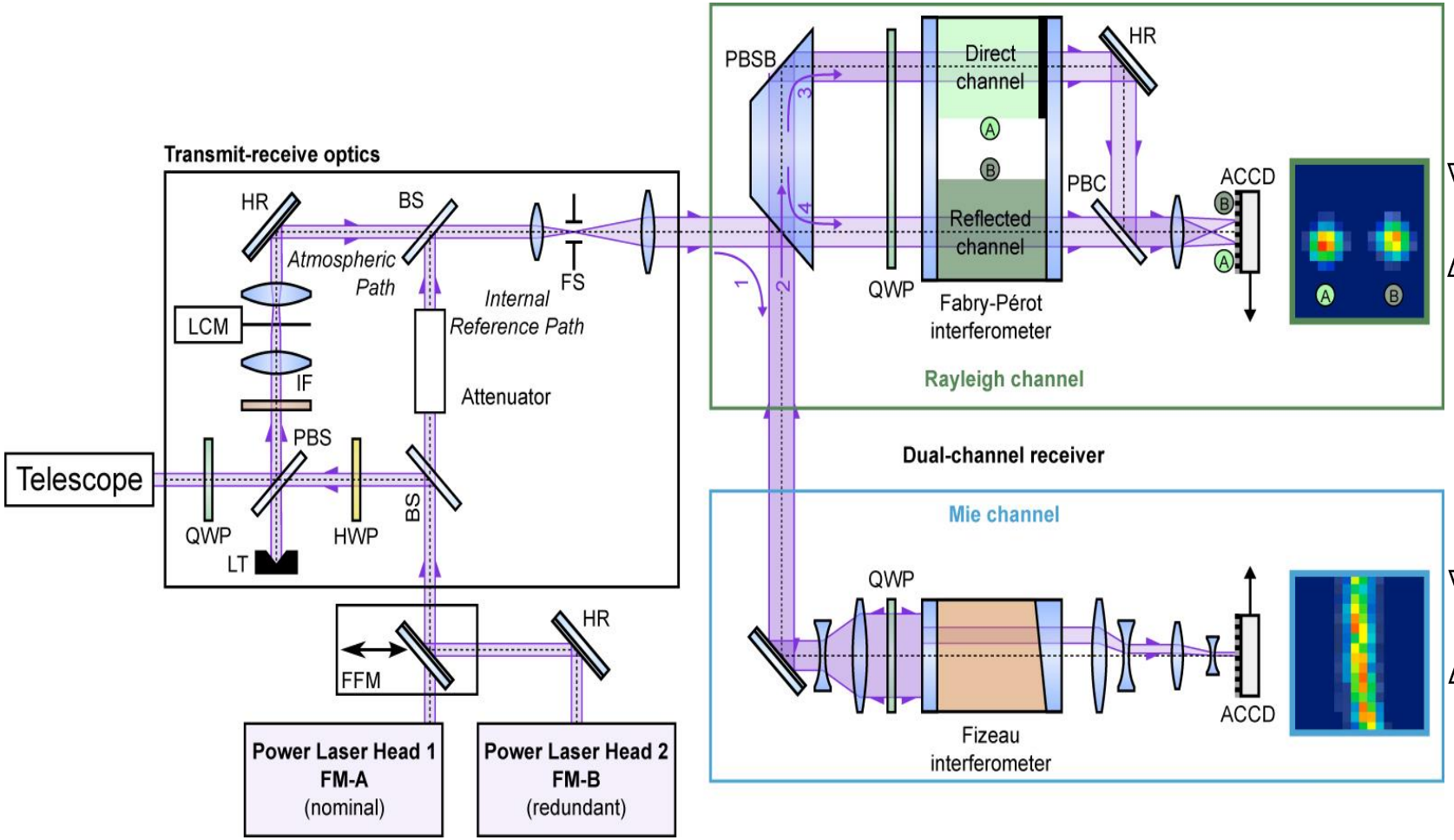
Rayleigh spectrometer

Fig. credits Airbus DS

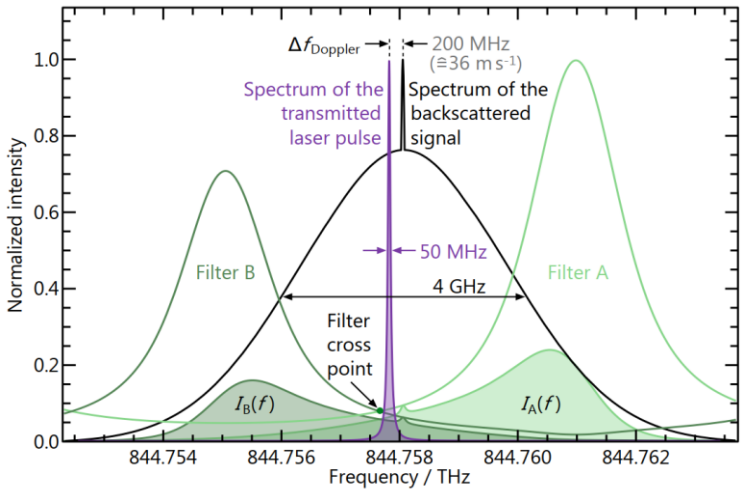
- **Polar orbit**, 7 days repeat cycle (111 orbits)
- **Global wind profiles** (0 to 30 km)
- Wind accuracy **better than 0.5 m/s**
- Random error of **4 to 7 m/s**
- Vertical resolution of **250 m to 2000 m**

- **First European lidar** in space after 20 years of development challenges
- **First wind lidar in space** – worldwide unique mission
- **Highest power-aperture** product for a lidar in space (60 mJ to 80 mJ / Ø 1.5 m)
- **First high-power, ultraviolet (UV) laser** in space (@ 354.8 nm) with stringent requirements on frequency stability

Instrumental setup and measurement principle

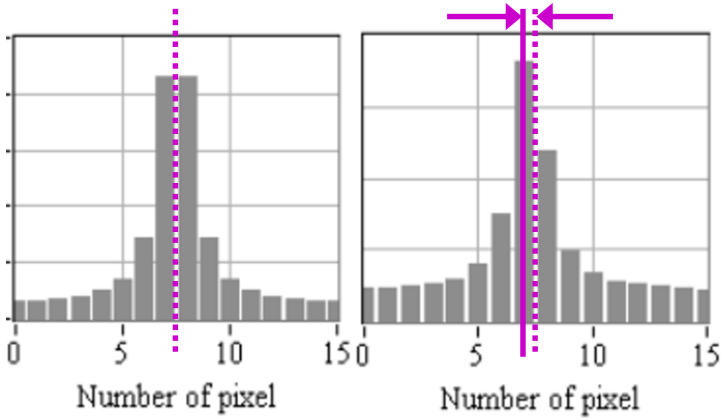


Double-edge technique



Fringe imaging technique

$\Delta f_{Doppler}$ = 0.25 px = 5 m/s



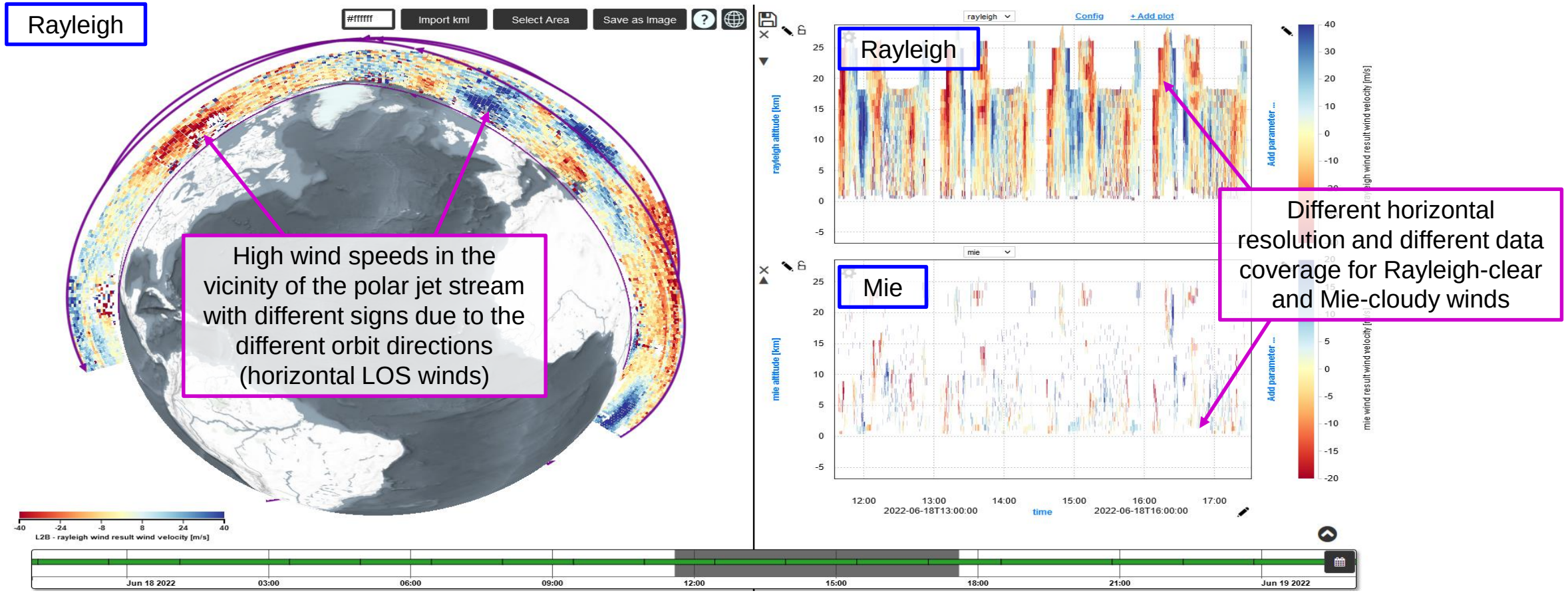
Lux et al., AMT (2018); Lux et al., AMT (2020)

22. August 2018 – The launch of Aeolus

Overview of Aeolus Rayleigh-clear and Mie-cloudy winds

Example from 18 June 2022 visualized by the VirES (Virtual Research Environment)

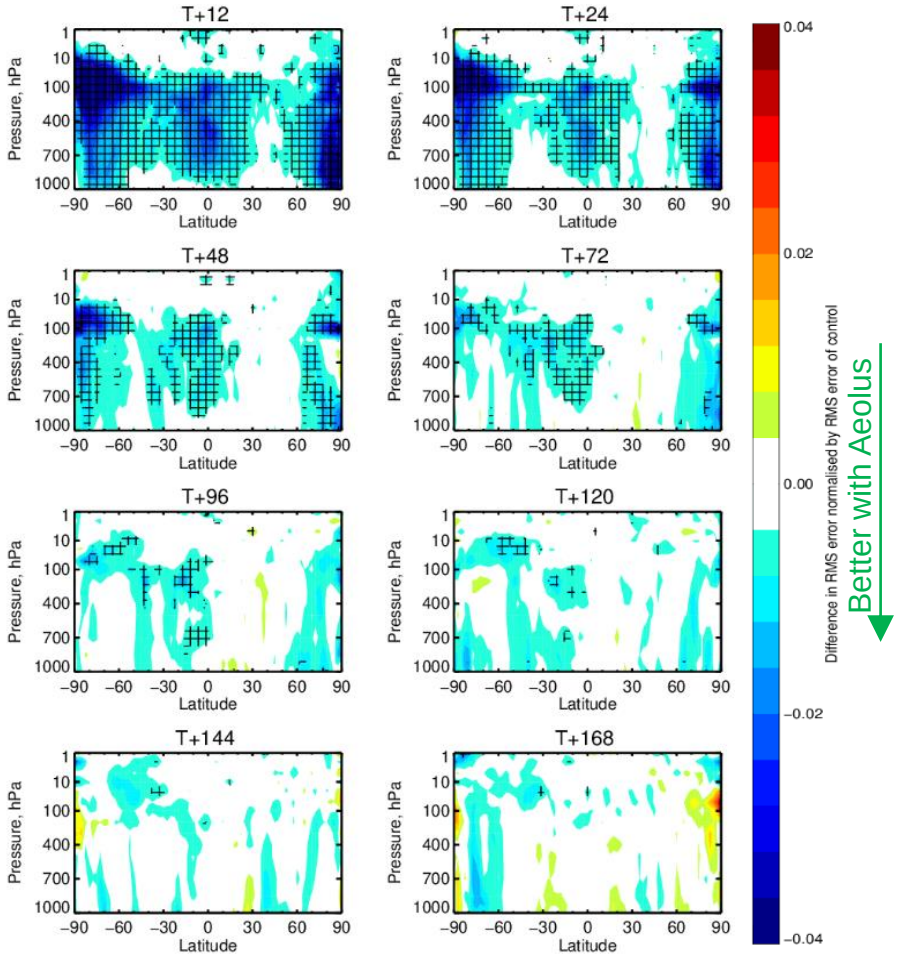
Due to the extended pre-launch activities and the connected gained knowledge about the instrument and the algorithms, the first signal was already available after two weeks, and the **first wind measurements after 3 weeks**



Positive Impact of Aeolus observations on numerical weather prediction

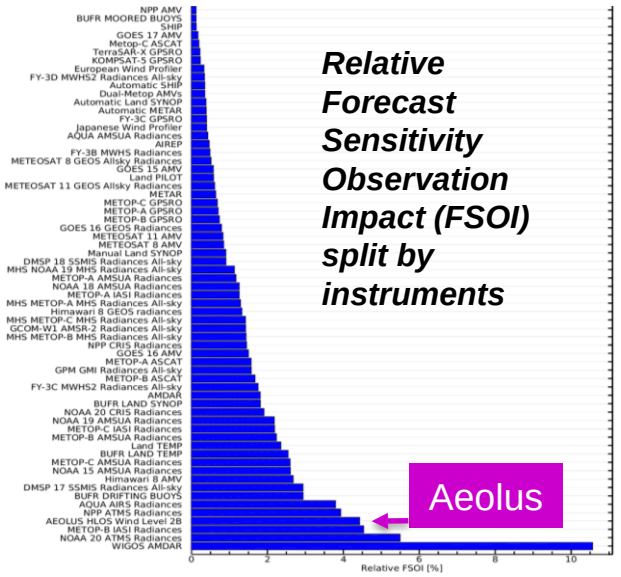
Main mission goal accomplished

April to September 2020 NRT data
Observing System Experiment



- **Good positive impact** in tropical troposphere and lower stratosphere throughout the forecast range
- **Good positive impact** in polar troposphere up to day 3-4
- Similar impact patterns **for temperature and humidity forecasts**

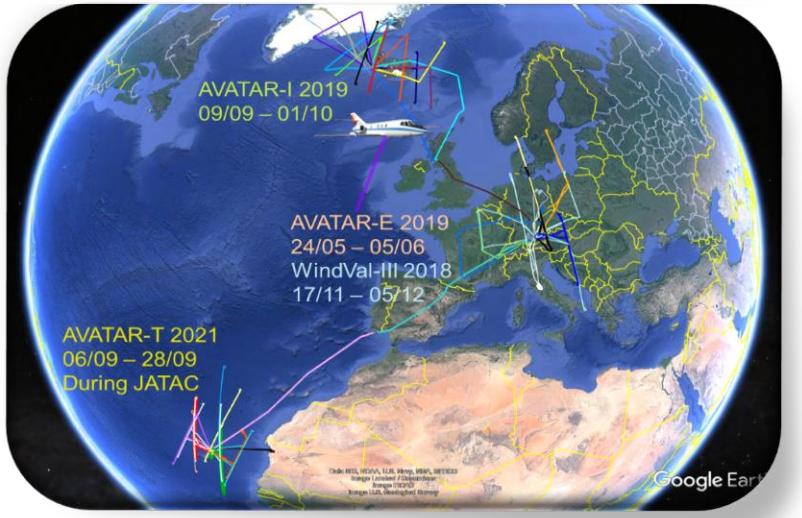
- **Aeolus performs very well** in FSOI for one satellite instrument
- **Relative impact** was **comparable to** Metop-B **IASI** in 2019



Figs. by M. Rennie (ECMWF)

Outline

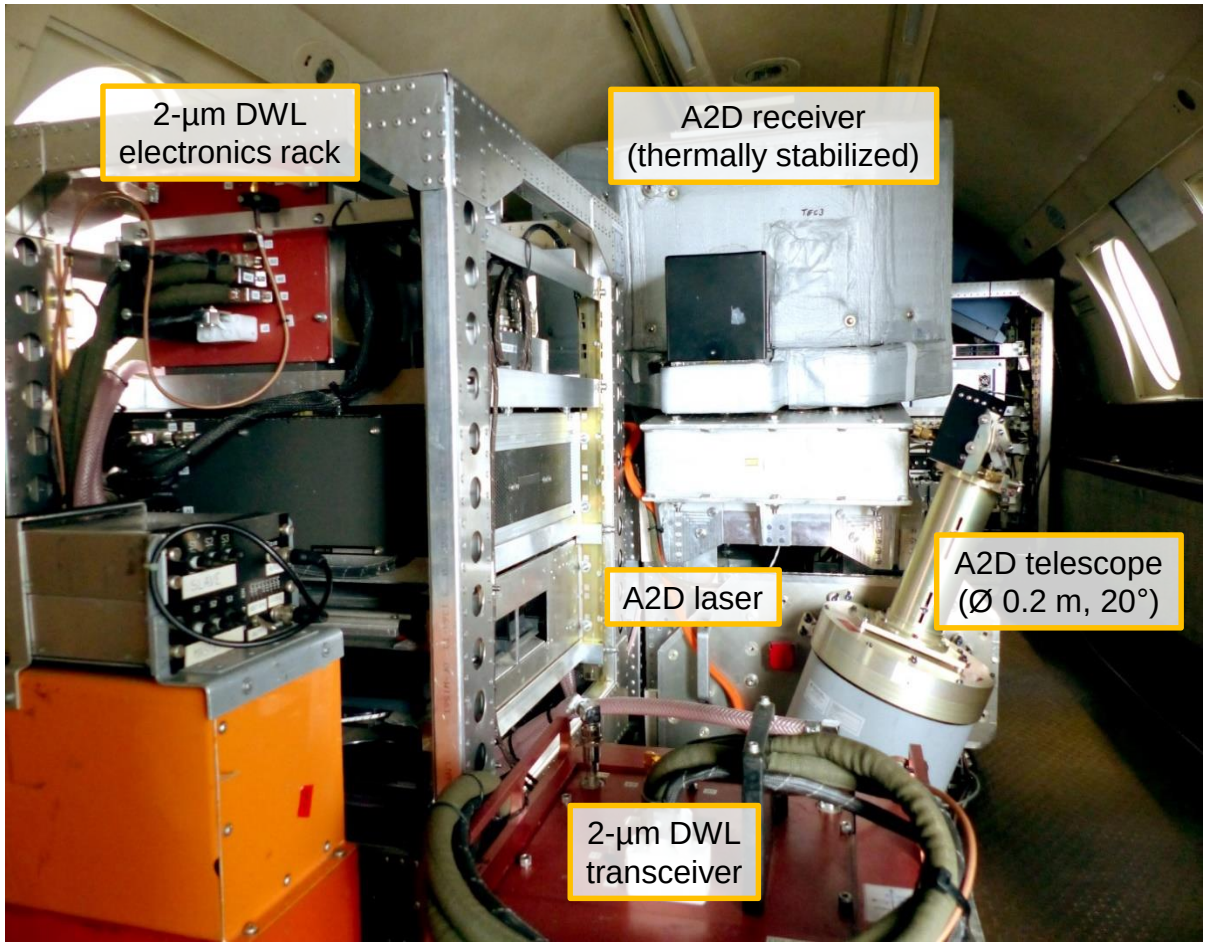
1. ESA‘s Aeolus mission



2. DLR‘s CalVal activities

DLR‘s airborne Aeolus-CalVal payload

The A2D and the 2-µm reference wind lidar mounted within the Falcon aircraft as deployed since 2007 already for several pre-launch campaigns



A2D measurements will be discussed by C. Lemmerz (Thursday, 11:40)

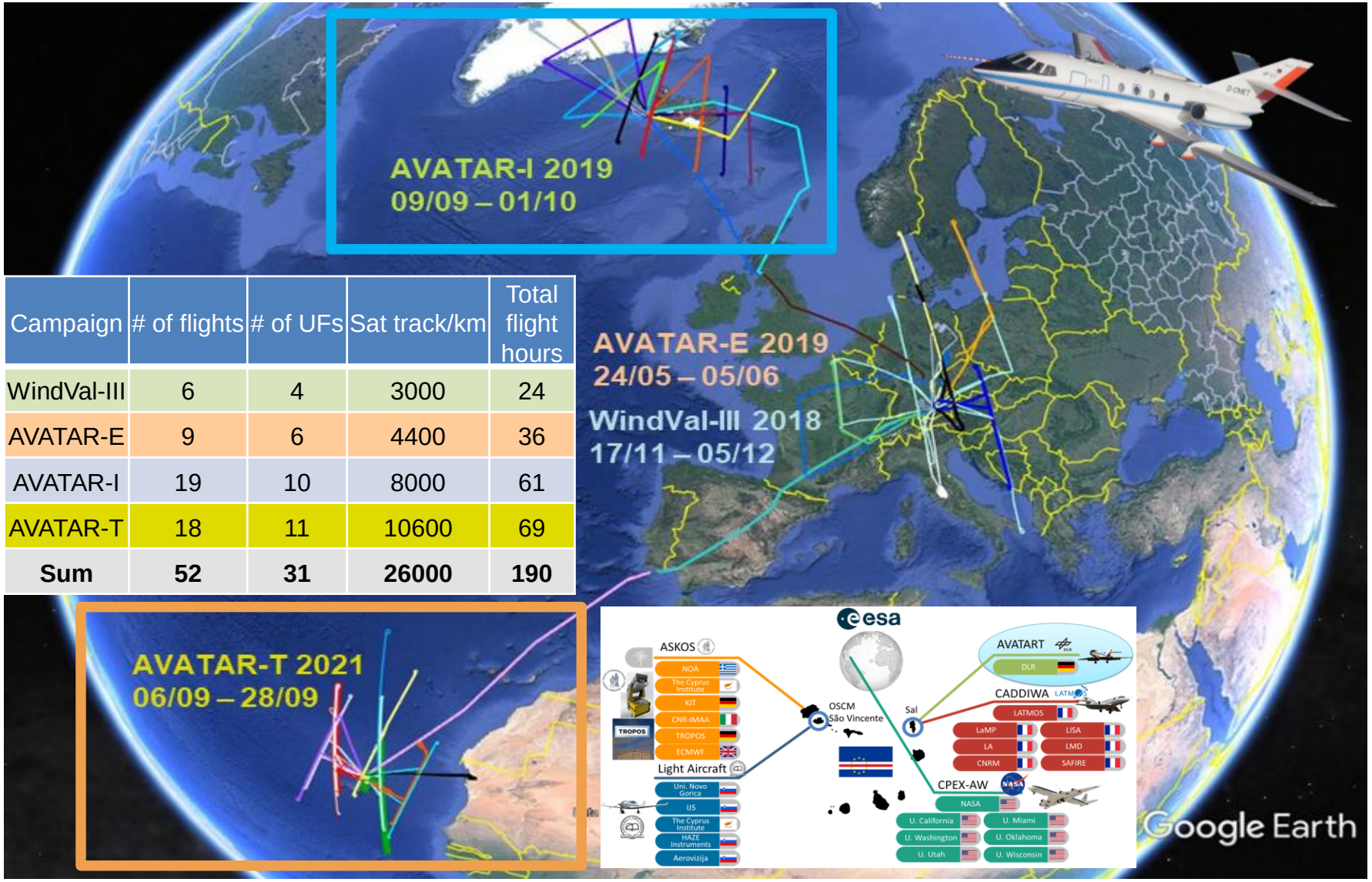
2-µm DWL measurements are discussed here

Basic specification

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 $m \cdot s^{-1}$

Lux et al., AMT (2020); Witschas et al., AMT (2020); Lux et al., AMT (2022)

DLR‘s airborne validation campaigns



Campaign	# of flights	# of UFs	Sat track/km	Total flight hours
WindVal-III	6	4	3000	24
AVATAR-E	9	6	4400	36
AVATAR-I	19	10	8000	61
AVATAR-T	18	11	10600	69
Sum	**52**	**31**	**26000**	**190**

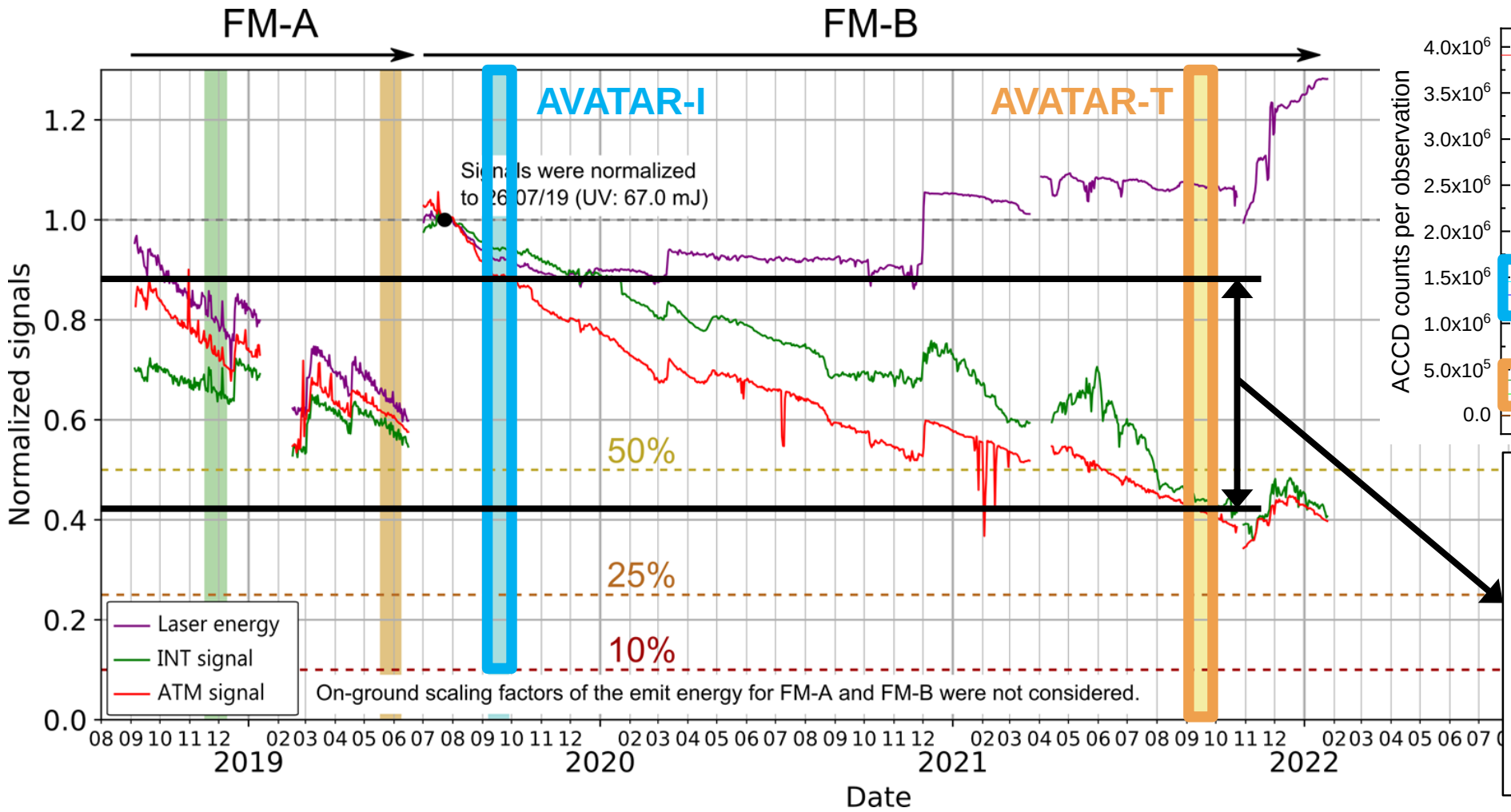
4 airborne campaigns were performed (2018-2021) with a **total of 52 flights**, **26400 km along track**

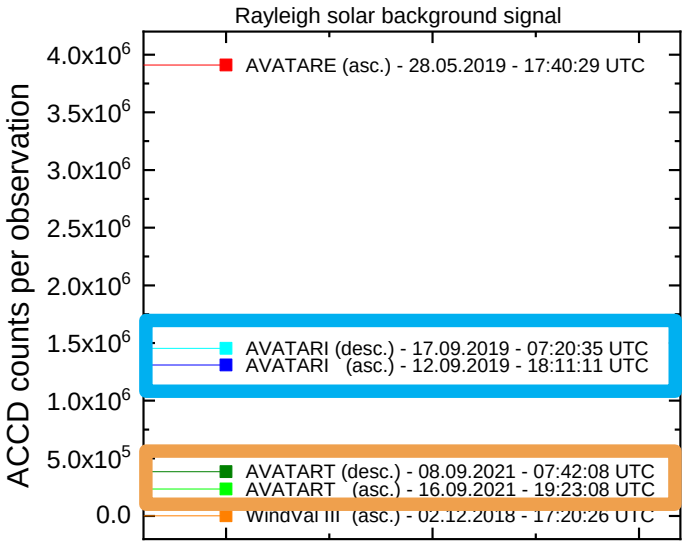
- Aeolus performance characterization under different conditions (time, geo. regions, atmos. cond.)
- Topics for processor evolution processor (repro. Data)

Results from the later two campaigns (**AVATAR-I** and **AVATAR-T**) are discussed on the following slides

Lux et al., AMT (2020); Witschas et al., AMT (2020); Lux et al., AMT (2022)

Aeolus performance history and DLR campaign time lines





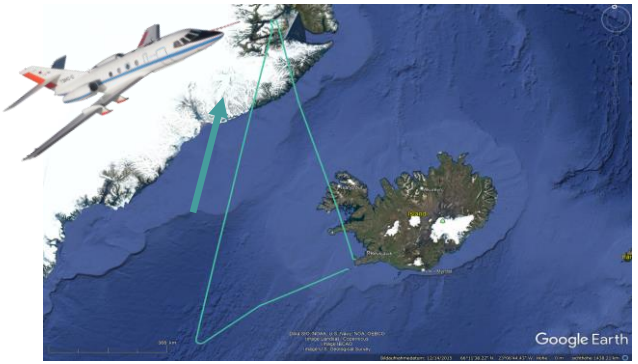
~ 50% less signal during AVATAR-T (compared to AVATAR-I), partly compensated by a lower solar background (factor 3) and longer range gates (750 m instead of 500 m)

Different meteorological conditions during the campaigns as high wind speeds in the vicinity of the polar jet stream, low aerosol loads and low level broken clouds during **AVATAR-I** and on the other hand moderate wind speeds and larger aerosol loads in the Saharan Air Layer (SAL) during **AVATAR-T**.

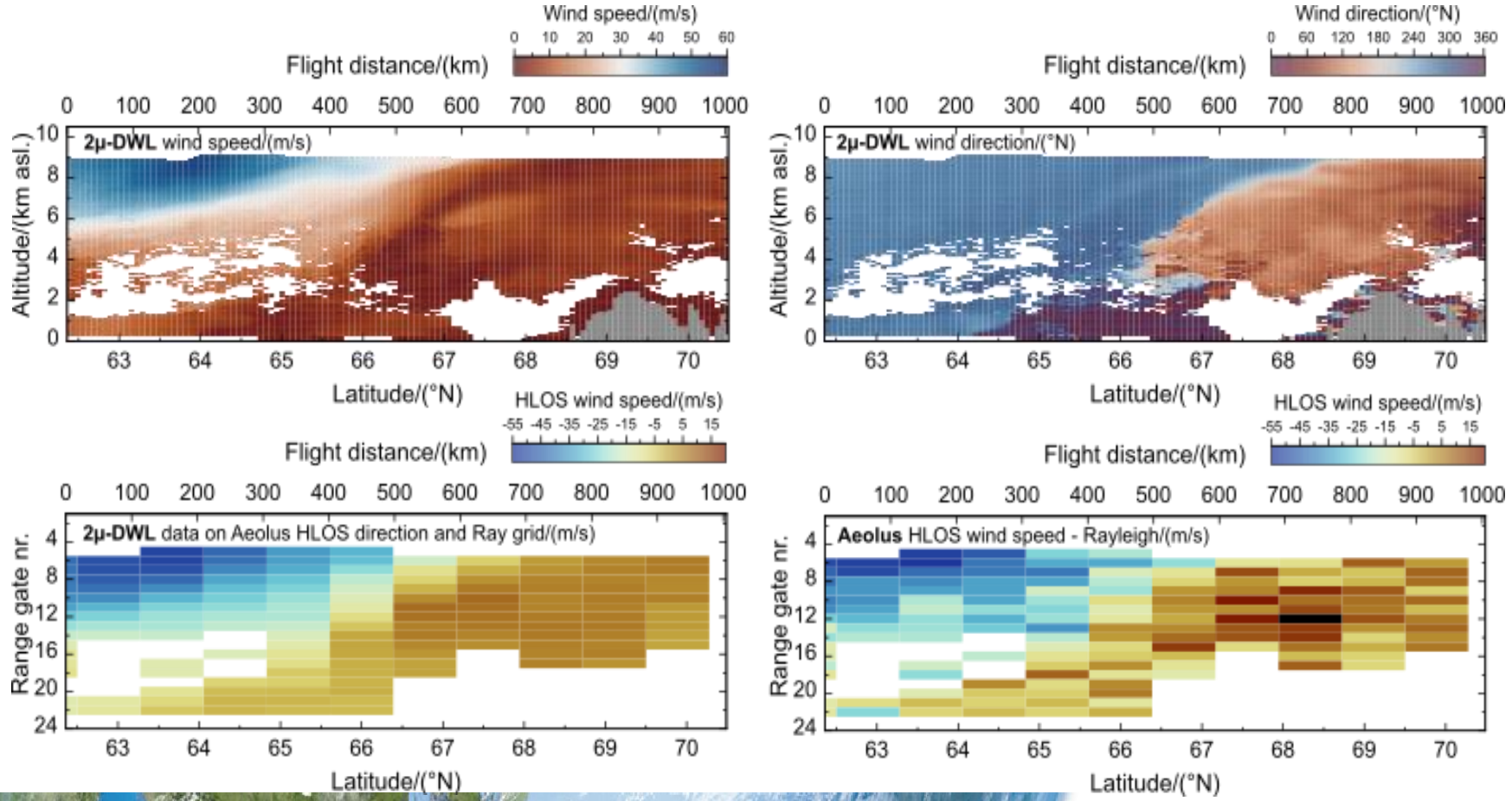
Rayleigh solar background observations provided by K. Schmidt, DLR, DISC

Comparison of 2-µm DWL and Aeolus data

AVATAR-I underflight performed on 16 Sept 2019



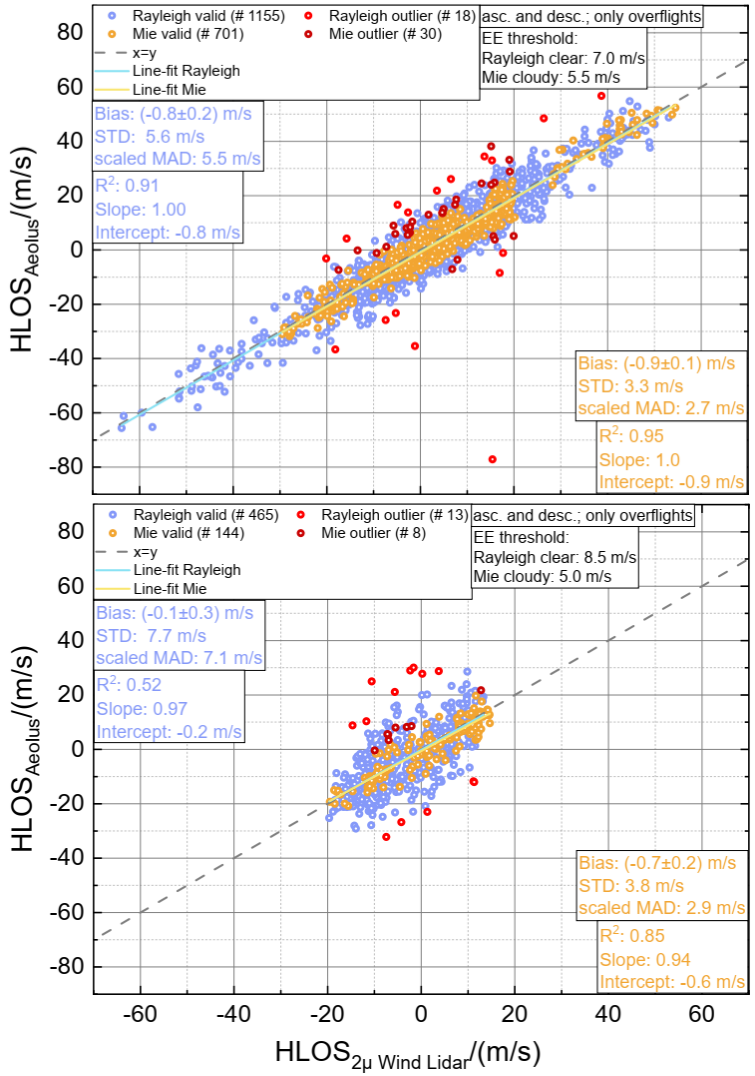
Due to the different horizontal/vertical resolutions of 2-µm DWL measurements (≈ 8,4 km, 100 m) and Aeolus meas. (**≈ 90 km (Rayleigh)** and down to **≈ 10 km (Mie)**, 0,25 km to 2 km), averaging procedures are needed:



- 2-µm DWL measured wind speed/direction are **averaged to the Aeolus grid** (2-µm data coverage threshold = 50%) and afterwards **projected onto the Aeolus horiz. LOS**.
- Next, the Aeolus HLOS winds (**valid** Rayleigh-clear and Mie-cloudy winds) are extracted for areas of valid 2-µm DWL measurements. Beforehand, the Aeolus data is filtered by means of an **estimated error** for the wind speeds given in the L2B data product.

Statistical comparison of Aeolus and 2-µm DWL observations

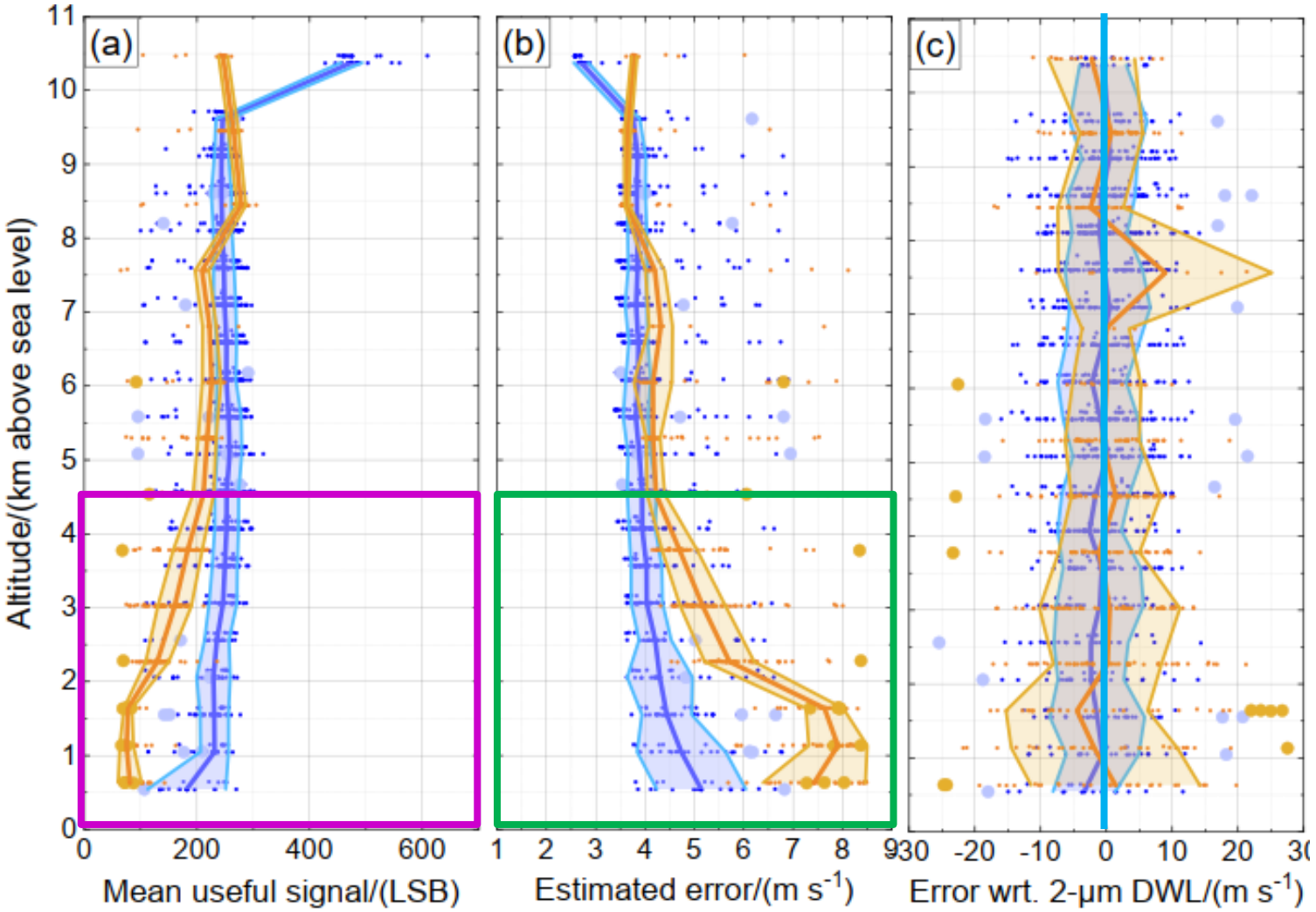
From the AVATAR-I (North Atlantic) and the AVATAR-T (Tropics) campaign



- During the AVATAR-I campaign, a much larger wind speed range was sampled (-65 m/s to 55 m/s) compared to AVATAR-T (-20 m/s to 15 m/s)
- Much more data points are available from AVATAR-I (1155 Ray., 701 Mie) compared to AVATAR-T (465 Ray., 144 Mie), which is due to the different range bin settings and the better 2-µm DWL performance during AVATAR-I.
- The systematic error is close to the specified value of **< 0.7 m/s** for both campaign data sets (AVATAR-I and AVATAR-T) and both wind products (Ray. and Mie).
- The random error for Rayleigh-clear winds (**5.5 m/s AVATAR-T** and **7.1 m/s for AVATAR-T**) is significantly larger than the specified value of **2.5 m/s**, which is **due to the lower signal levels** probably caused by misalignment and laser induced contamination.
- The increase of the random error for the AVATAR-T campaign data set is due to the even lower signal levels compared to AVATAR-I especially in the lower altitudes caused by the additional extinction of aerosols in the SAL (see next slide).
- The random error of the Mie-cloudy winds is less depending on the receiver alignment as it depends on the stronger backscatter of clouds and on a different retrieval method (fringe imaging technique), compared to Rayleigh-cloudy winds (double-edge technique).

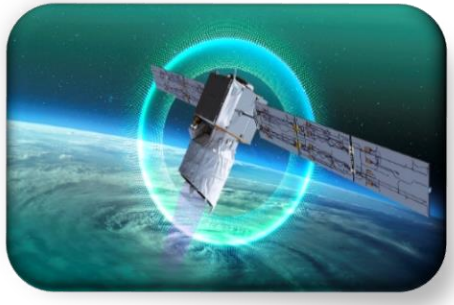
Height dependency of L2B Rayleigh-clear products

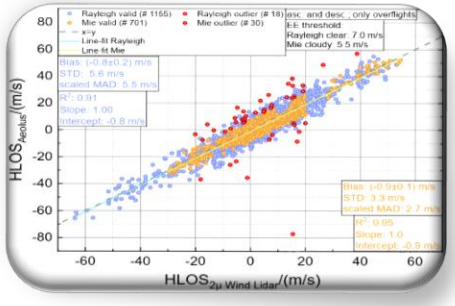
For the **AVATAR-I** and the **AVATAR-T** data set



- Despite the larger Aeolus range gates applied during AVATAR-T (750 m instead of 500 m), the overall signal levels were lower than during AVATAR-I.
- This is especially true for lower altitudes due to the extinction of aerosols present in the SAL.
- The estimated error shows larger values in regions of lower signal levels (as expected)
- This is verified by the comparison to 2-µm DWL observations.
- The systematic error (wrt. to the 2-µm DWL) shows no altitude dependency → proper calibration is used

Summary





- The **first spaceborne wind lidar** Aeolus was **successfully launched** on 22 August 2018 and is still operational
- **Aeolus met it's primary goal** of improving numerical weather forecast
- To validate the Aeolus L2B wind product, **DLR performed four CalVal campaigns** deploying two wind lidar systems on the Falcon research aircraft
- After calibration improvements (correction of hot pixels and temperature fluctuations on the telescope mirror), **the systematic error is shown to fulfil the specifications of < 0.7 m/s** for both wind products (Rayleigh-clear and Mie-cloudy)
- **The random error of Rayleigh-clear winds is shown to be larger than specified (< 2.5 m/s)** due to the lower signal levels caused by misalignment and laser induced contamination
- The random error of Mie-cloudy winds is close to the specifications