Contributions from the DISC to accomplish the Aeolus mission objectives

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The Aeolus Data Innovation and Science Cluster DISC

- DISC established in 2019 from teams co-operating since 2003 on Aeolus algorithms, processors, impact experiments, campaigns
- 14 international partners with about 40 scientists and engineers coordinated by DLR
- Broad range of experts for laser, lidar, retrieval algorithms, software development, calibration, validation, and NWP monitoring and impact assessment cover all aspects of Aeolus
- DISC funded by ESA with strong links to all ESA entities (ESTEC, ESRIN, ESOC) and space industry (Airbus, Leonardo)

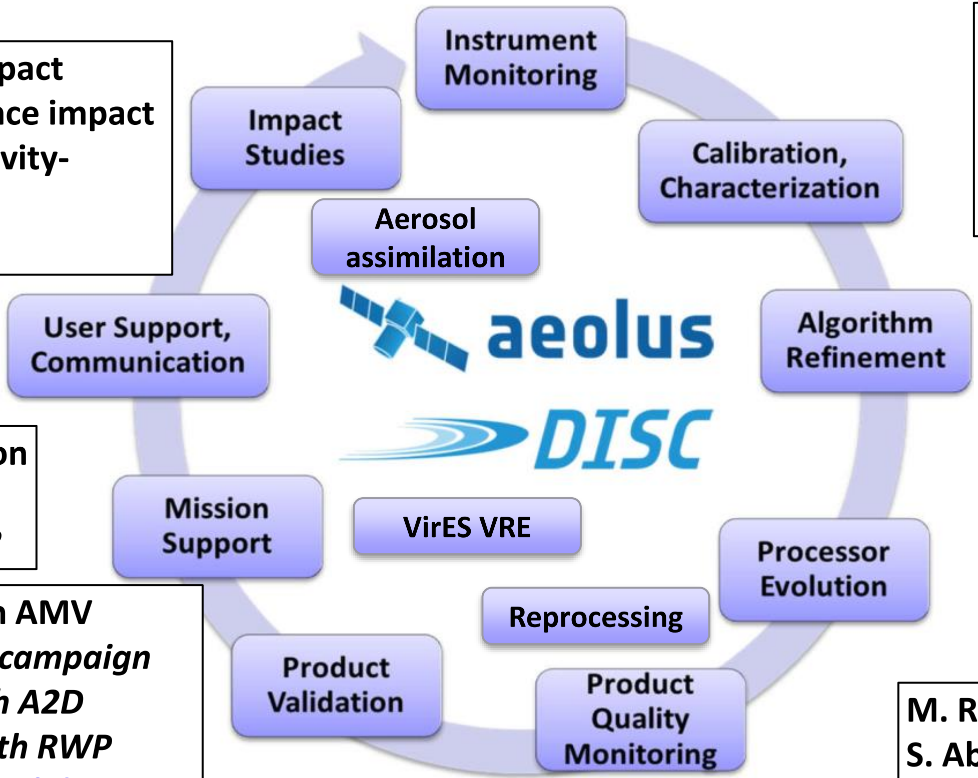
Kick-off Meeting February 2019

Aeolus DISC Tasks and Contributions to this Workshop

M. Rennie: ECMWF impact
V. Pourret: Météo-France impact
V. Cito-Filomarino: Gravity-waves and PSC
I. Krisch: u and v wind

L. Isaksen: Collaboration
O. Reitebuch: DISC
Ch. Lemmerz: Aeolus-2

S. Bley: Validation with AMV
Ch. Lemmerz: Tropical campaign
O. Lux: Validation with A2D
A. Geiss: Validation with RWP
B. Witschas: Airborne validation
O. Lux: QC and estimated errors



K. Schmidt: Solar and atm. signals
N. Masoumzadeh: ACCD noise
I. Nikolaus: Clipping analysis
F. Fabre: Image Synthesis
U. Marksteiner: Mie radiometric

G.-J. Marseille: NWP calibration
F. Weiler: Bias correction using ground returns
F. Weiler: Hot pixel detection

A. Lacour: Aerosol product
D. Donovan: ATLID algorithms
P. Wang: Aerosol product from ATLID algorithms

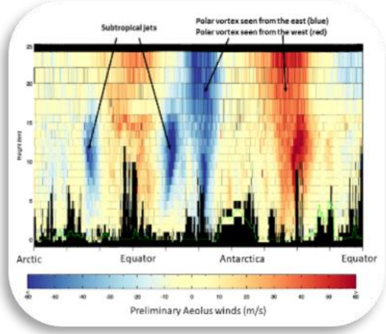
M. Rennie: Wind quality monitoring
S. Abdalla: Re-processed data quality
W. McLean: Aerosol quality monitoring and assimilation

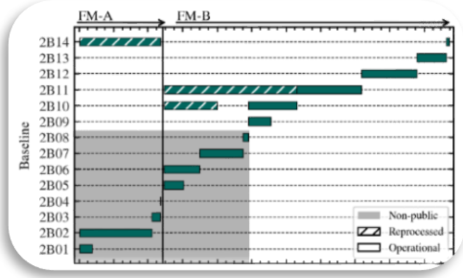
oral presentations
poster presentations
campaign contributions

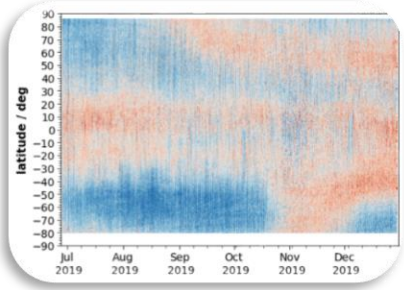
Outline of the talk

- Aeolus/DISC highlights since launch
- Baselines and reprocessing
- ALADIN performance
  - Signal evolution and random errors
  - Sources of bias and corrections
- Summary and Conclusion

First wind on 12 Sept 2018





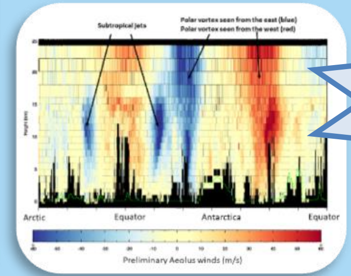


3.5 years of Aeolus in orbit
22 March 2021

Aeolus and DISC highlights during first 3.5 years in orbit

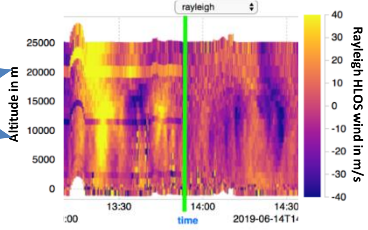
Launch on 22/08/2018

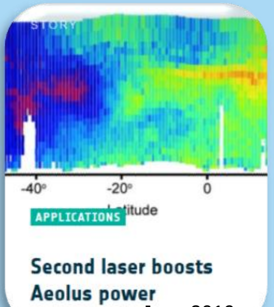
First wind on 12 Sept 2018



Data release to Cal/Val teams on 18/12/2018

Hot-Pixel fix operational on 14/06/19



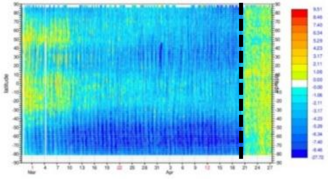


June 2019

9 January 2020

20 April 2020:

M1 temperature correction activated in Aeolus processor



Wind bias before and after implementation of the M1 temperature correction © ECMWF

Planned lifetime of 39 months achieved

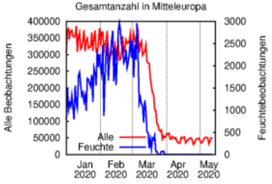
November 2021

2nd repro-cessing released 11 Oct 2021

Public release of L2A aerosol product 12 July 2021

May/June 2020:

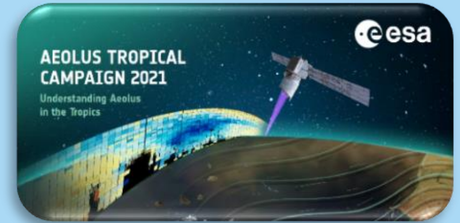
Aeolus winds are used by national weather services (DWD, Météo France) for daily weather forecasts (also caused by the decline in aircraft data)



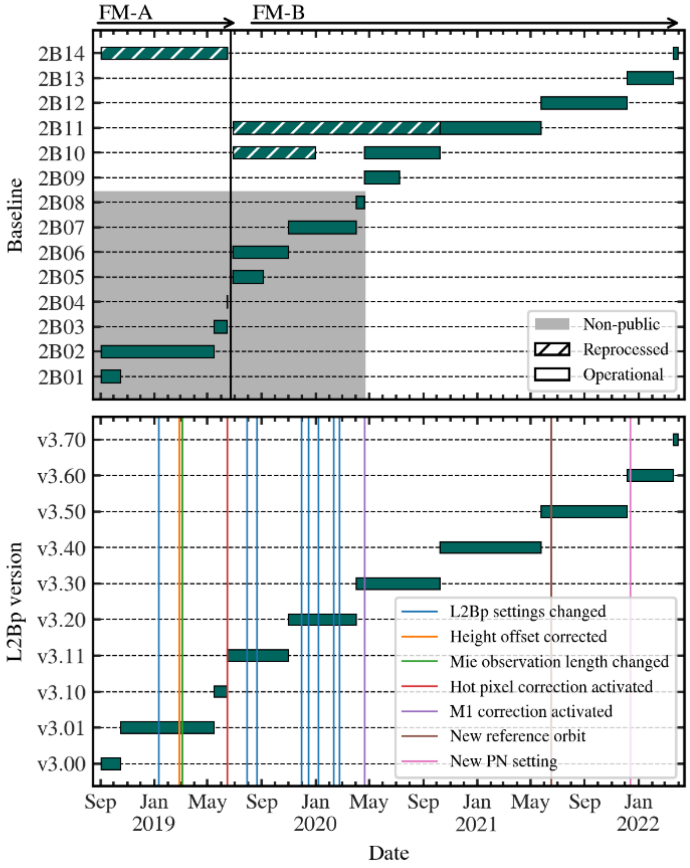
Reduction in meteorological observations from aircraft in Europe © DWD

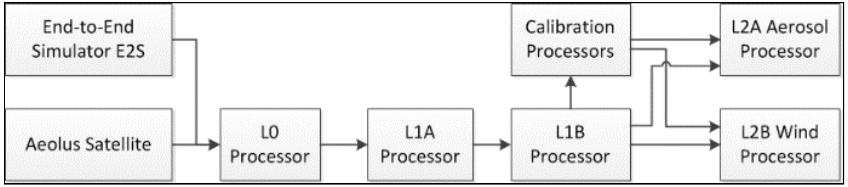
12 May 2020:

Public release of wind products



Frequent update of operational processors by DISC





- success of Aeolus as an Earth Explorer mission is its operational assimilation of wind product by several NWP centers
- near-real time data production by ESA-PDGS and frequent update of full chain of operational processors
- major operational processor deliveries from DISC to ESA-PDGS every 6 months, which results in new product quality and product content - called baselines
- update to baseline B14 planned for March 29, 2022

E2S, L0/L1A/L1B and L2A operational processor by **D. Huber (DoRIT)**
L2B operational processor by **J. de Kloe (KNMI)**
calibration processors at ACMF and codadef by **S&T and ABB**
processor handover and anomaly management by **Serco**

Fig. left by **A. Geiß (LMU)**

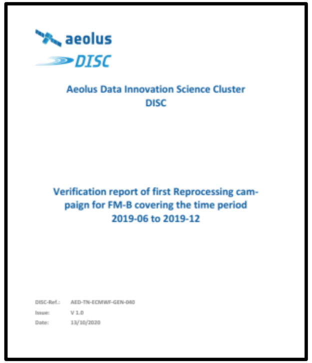
Reprocessing of Aeolus observations

1st reprocessing from June to December 2019 with baseline 10 product quality finished and available in October 2020

2nd re-processing finished using baseline 11 processor versions for period June 2019 to October 2020 and available in October 2021

3rd re-processing campaign on-going using **baseline 14** processor versions for FM-A period September 2018 to June 2019

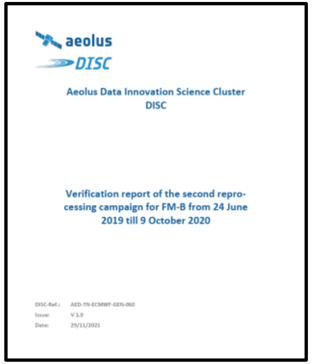
- first time **hot-pixel correction** for FM-A
- first time **M1-bias correction** for FM-A
- first time orbital radiometric calibration for L2A product and **AEL-PRO, -FM, MLE***



aeolus DISC

Aeolus Data Innovation Science Cluster
DISC

Verification report of first Reprocessing campaign for FM-B covering the time period 2019-06 to 2019-12



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DISC

Verification report of the second reprocessing campaign for FM-B from 24 June 2019 till 9 October 2020

Oct 2020 — Re-processed **FM-B data of 2019** including M1 correction (B10) available on 14 October 2020

Oct 2021 — Re-processing **FM-B data from June 2019 to October 2020** (B11) available on 11 October 2021

Oct 2022 — Re-processed **FM-A data** with hot-pixel and M1 **correction** (B13) will become available **in October 2022**

2023-2024 — Re-processing of **complete Aeolus mission** since launch with optimized processor settings and processor version **(B16) will be available end 2023 (FM-B) and mid 2024 (FM-A)**

see presentation from S. Abdalla (ECMWF)

Outline of the talk

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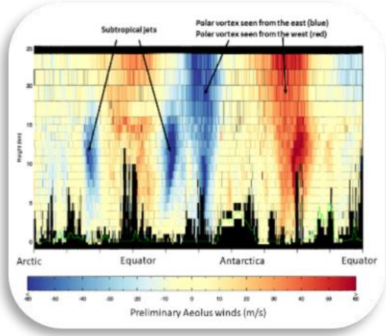
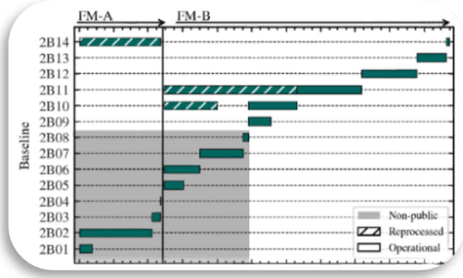
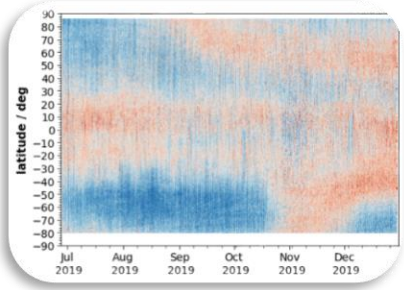
- Baselines and reprocessing
- ALADIN performance
  - Signal evolution and random errors
  - Sources of bias and corrections
- Summary and Conclusion

First wind on 12 Sept 2018

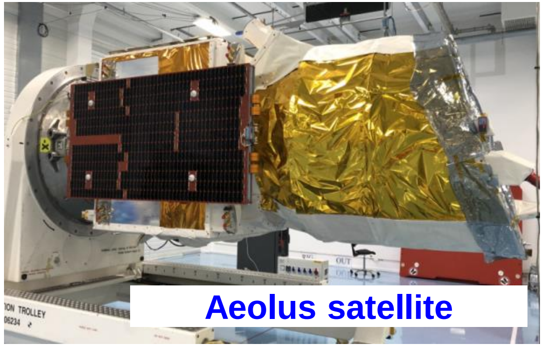


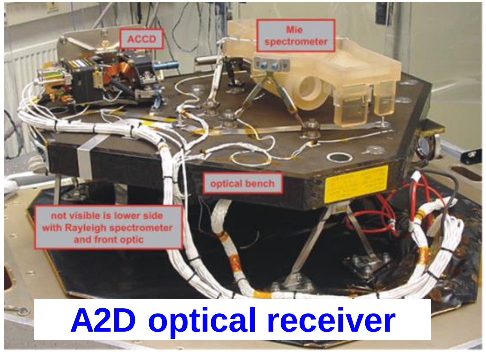


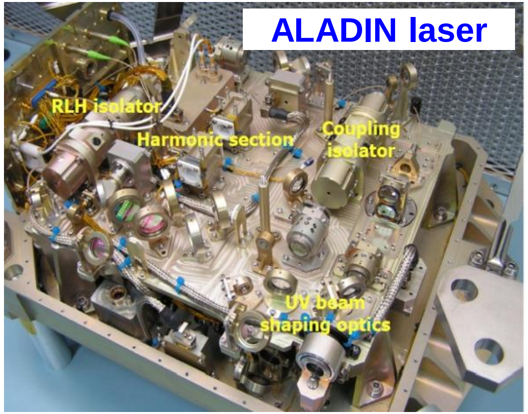


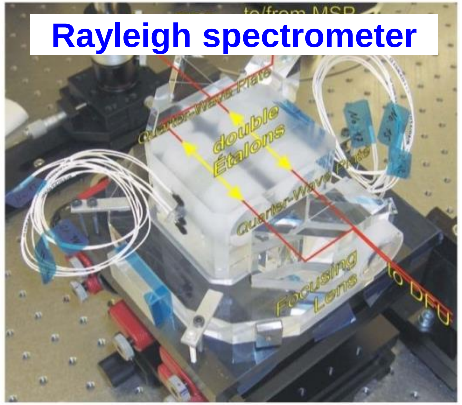
3.5 years of
Aeolus
in orbit
22 March 2021

ALADIN – the first wind lidar in space









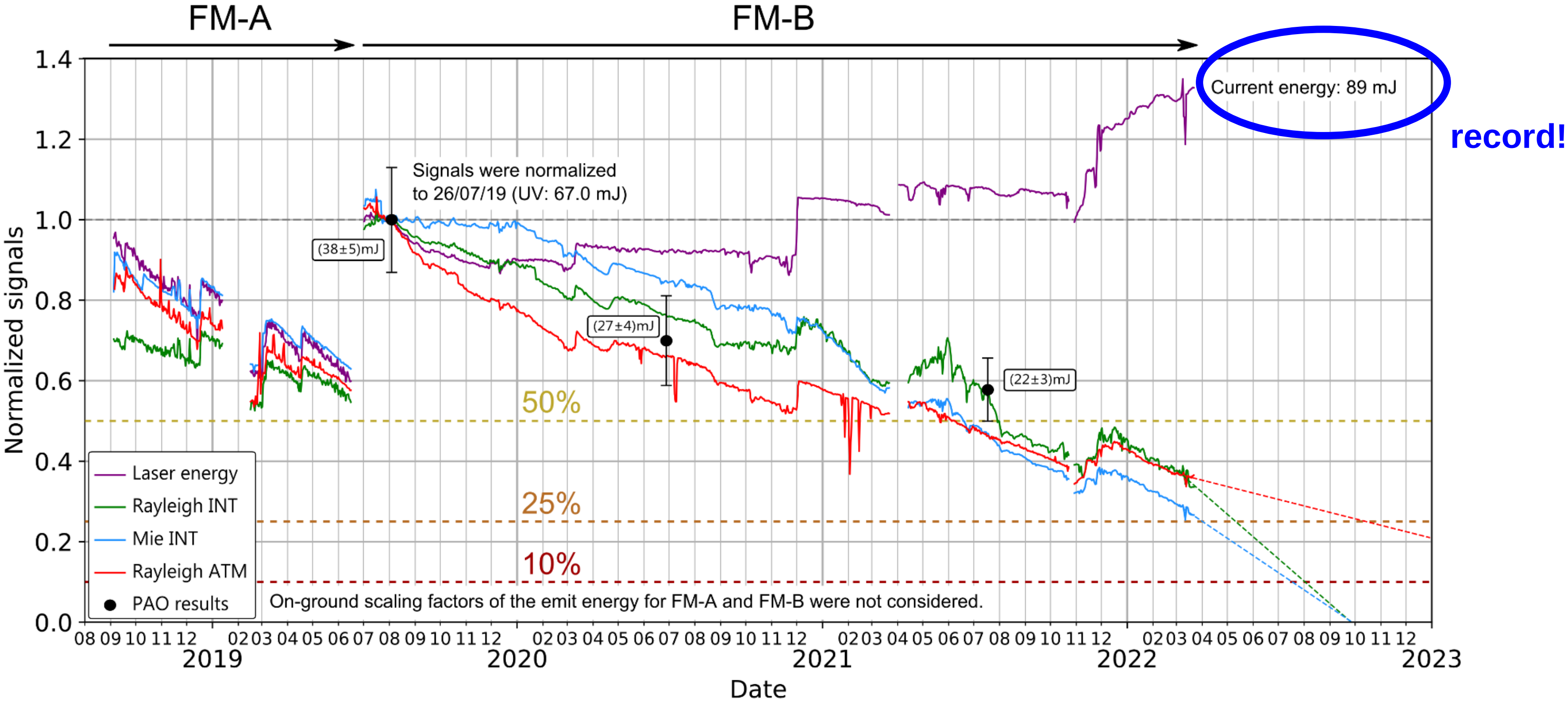
- **First European lidar** in space after 20 years of development challenges
- **First wind lidar and first HSRL in space** – worldwide unique mission
- **Highest power-aperture** product for a lidar in space (40 mJ - 85 mJ / Ø 1.5 m)
- **First high-power, ultraviolet (UV) laser** in space (@ 354.8 nm) with stringent requirements on frequency stability
- **Doppler wind lidar** principle – straightforward but incredibly small effect

Doppler Equation: $\Delta f = 2 f_0 \frac{V_{LOS}}{c}$

relative Doppler shift $\Delta f/f_0 \approx 10^{-8}$
1 m/s (LOS)⬄ 5.64 MHz ⬄ 2.37 fm
size H-atom 50 pm, H-nucleus 1.2 fm

Reitebuch et al. (2009), JAOT; Reitebuch (2012), Springer; Reitebuch/Hardesty (2022), Springer

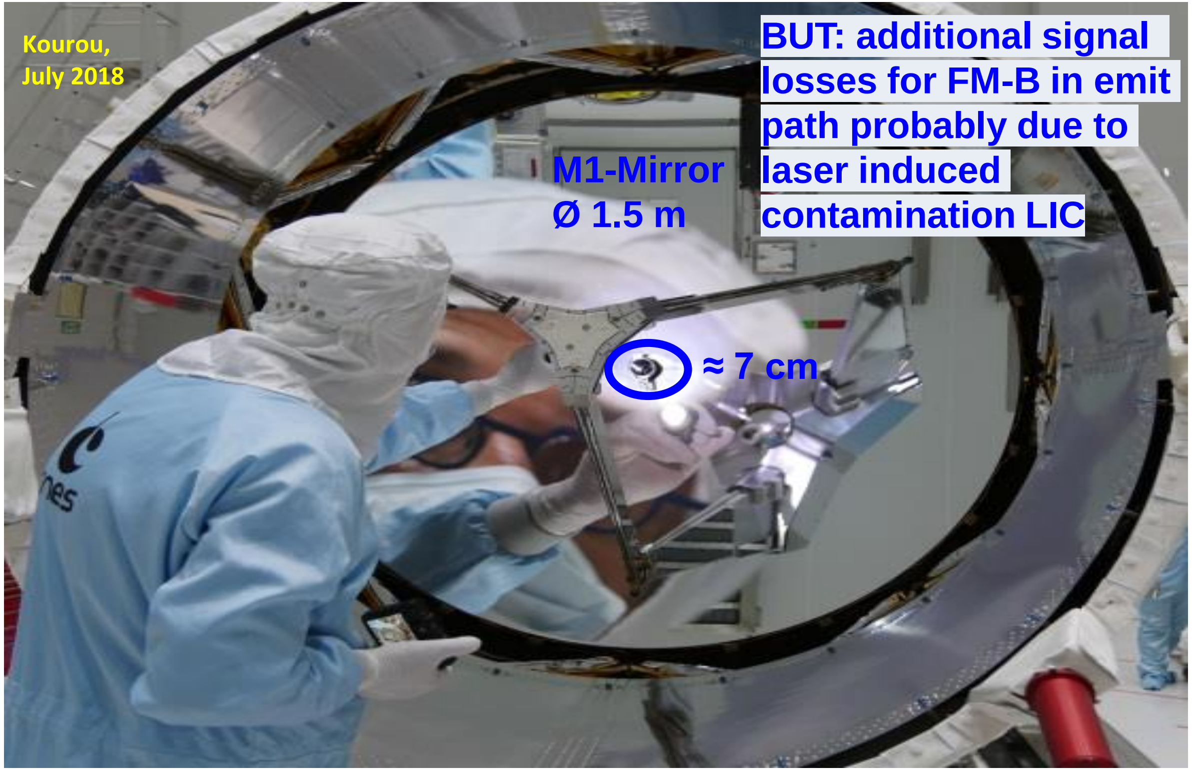
Evolution of the signal levels during the complete mission timeline



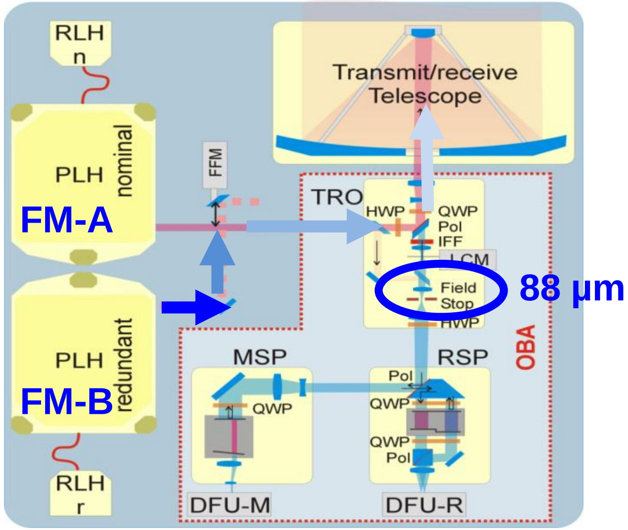
ATM signal levels are around 35% of initial FM-B and about 40% lower than at the end of FM-A (0.6)
=> extrapolation to 25% (ATM) by October 2022 and to 10% (INT, ATM) by August 2022

What causes the signal loss for ALADIN?

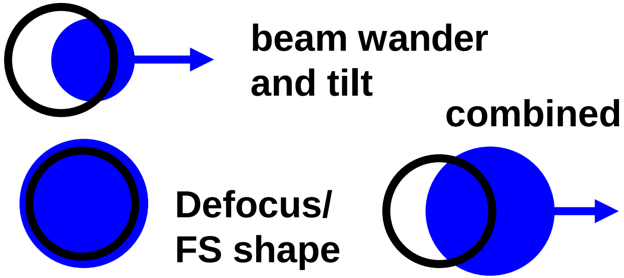
FOV 18 µrad
7 m @ 400 km



from Aeolus blog https://aeolusweb.wordpress.com/



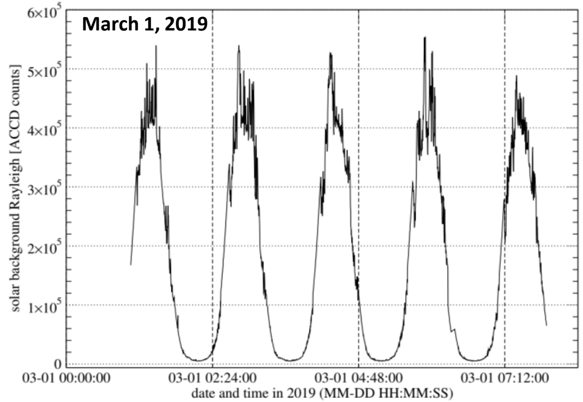
signal loss at field stop FS aperture



What influences the wind random error?

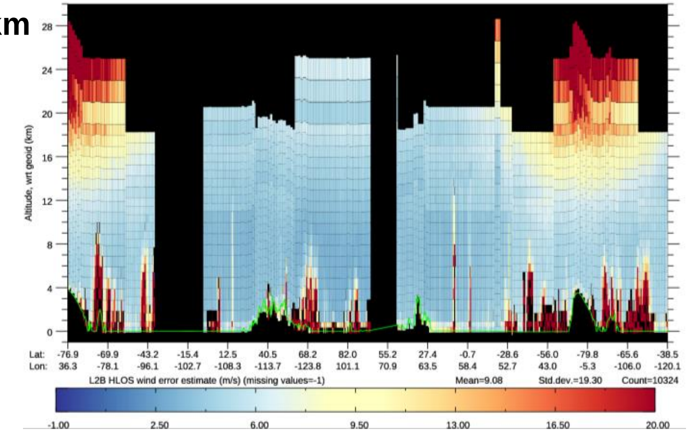
1. **Laser emit energy and optical signal transmission** in laser emission and receive path for atmospheric signal
2. **Solar background noise mainly for Rayleigh winds**
   - ⇨ Impact higher than expected due to lower atmospheric signal
   - ⇨ Seasonal variation of solar background by factor 18: Rayleigh random errors increased from 7-8 m/s to >15 m/s in summer months for polar regions and stratosphere

Orbital variation of Rayleigh solar background noise



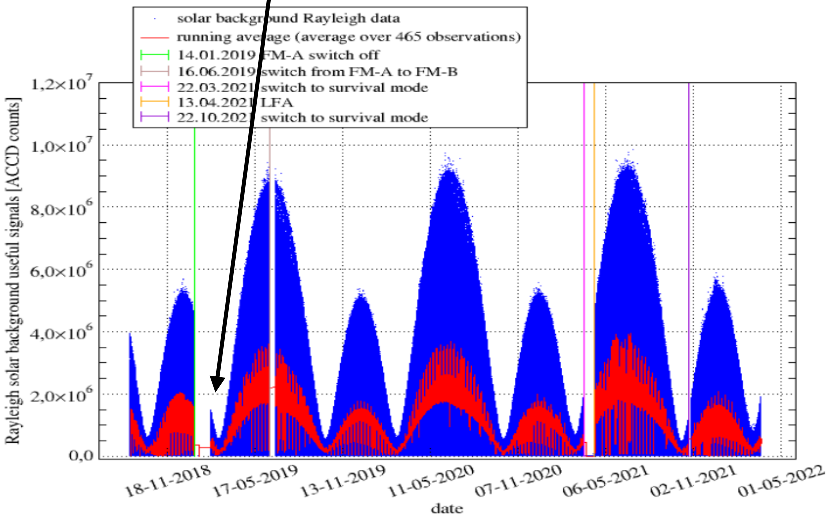
28 km

L2B wind random error for 1 orbit on Nov 11, 2021



6 m/s

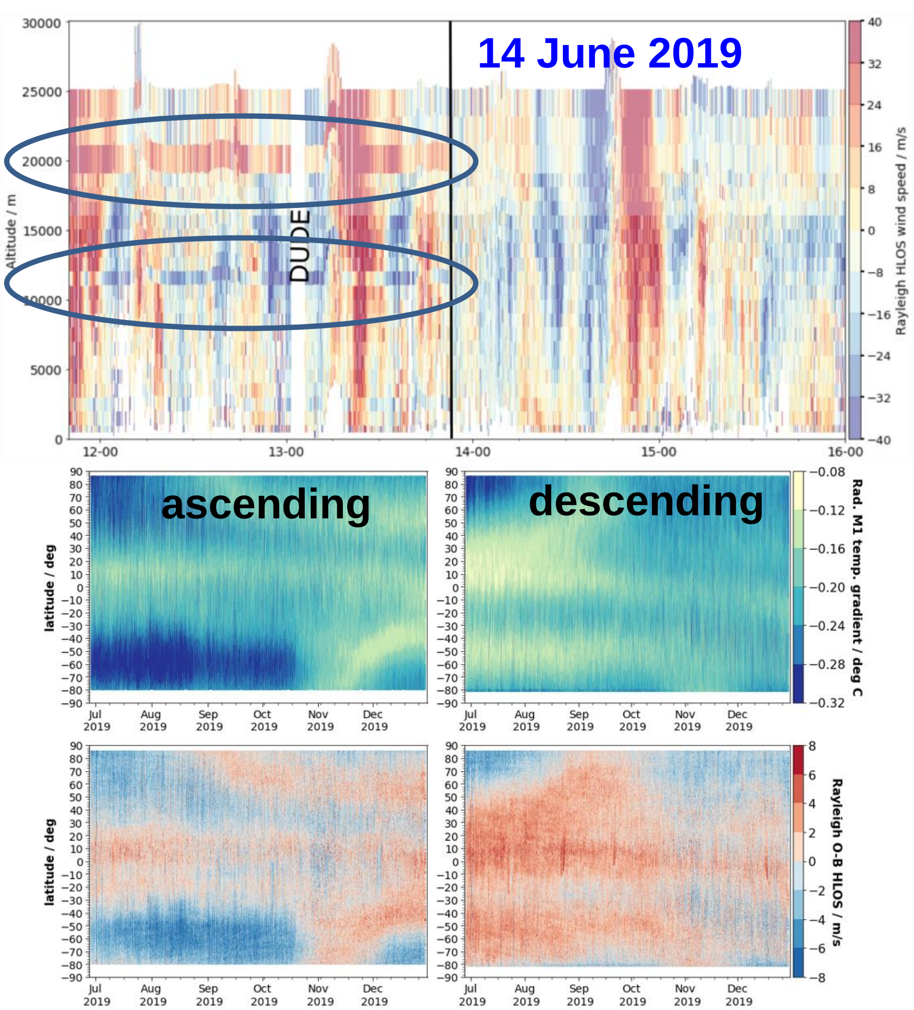
20 m/s



Aeolus bias and corrections 1/2

combination of several unexpected error sources with different temporal characteristics:

1. higher dark current rates for **"hot pixels"=>** corrected with special instrument operation DUDE (Down Under Dark Experiment, 4 per day, today 8 per day) and on-ground correction in L1B since 14 June 2019
2. variations of the **M1 telescope mirror temperatures** (mean and gradient along mirror)
   - ⇨ Rayleigh and Mie bias as a function of orbital phase (argument of latitude) and longitude
   - ⇨ use correlation between M1 temperatures and ECMWF model bias (O-B) for correction every 12/24 h; **implemented since 20 April 2020**
   - ⇨ on-going study to **use ground-returns** (**see poster F. Weiler)**: NWP model independent, slightly lower performance of 10%

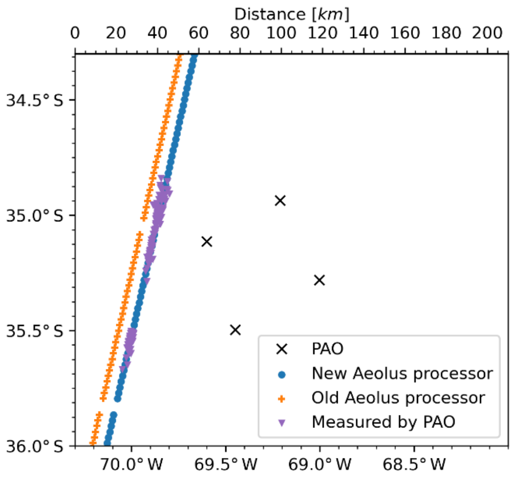


Figures Weiler et al. (2021a), AMT; Weiler et al. (2021b), AMT; Rennie et al. (2021), QJRMS
details on ACCD noise (poster N. Masoumzadeh) and HP detection (F. Weiler)

Aeolus bias and corrections 2/2

Other unexpected error sources

3. Error in the on-board software in calculation of residual projection of the **satellite ground speed on the line-of-sight** **=>** corrected with L1b V7.09.1 (baseline B11 from 8 October 2020)
4. **Slow drifts** in the illumination of the Rayleigh/Mie spectrometers causing a **slowly drifting constant bias => corrected with M1-bias correction**
5. **Geolocation error for longitude by 0.075°** (≈ 8 km at equator) discovered with help of Auger observatory; is corrected in L1B V7.12 (baseline 14)
6. **Enhanced bias of up to 0.4 m/s in October and March** due to Aeolus orbit on terminator with permanent twilight => harmonic orbital variation of bias; is corrected as part of M1-bias correction for B14



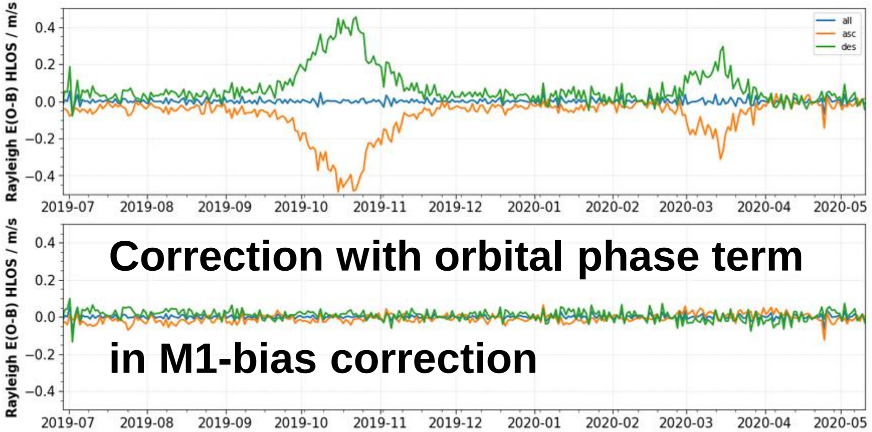
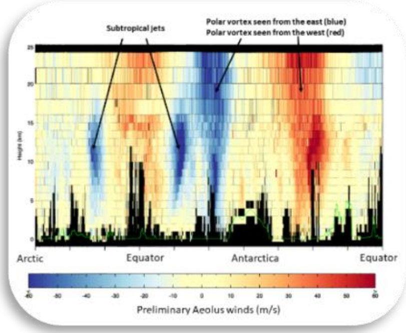


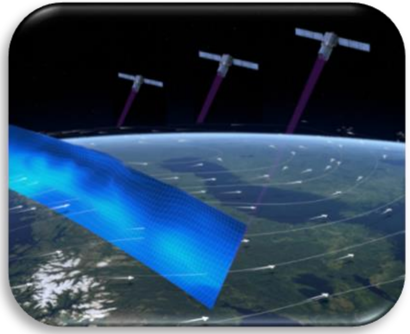
Figure I. Krisch (DLR) with data from F. Knapp (KIT) and F. Weiler (DLR)
more details in presentation of F. Knapp (KIT) on Auger and M. Rennie (ECMWF) on L2B

Summary and Conclusion

- First European lidar and first wind lidar in space in operation for 3.5 years: lifetime objective was achieved.
- Mission objective to demonstrate wind lidar technology including operation of a laser in the ultraviolet spectral region was achieved.

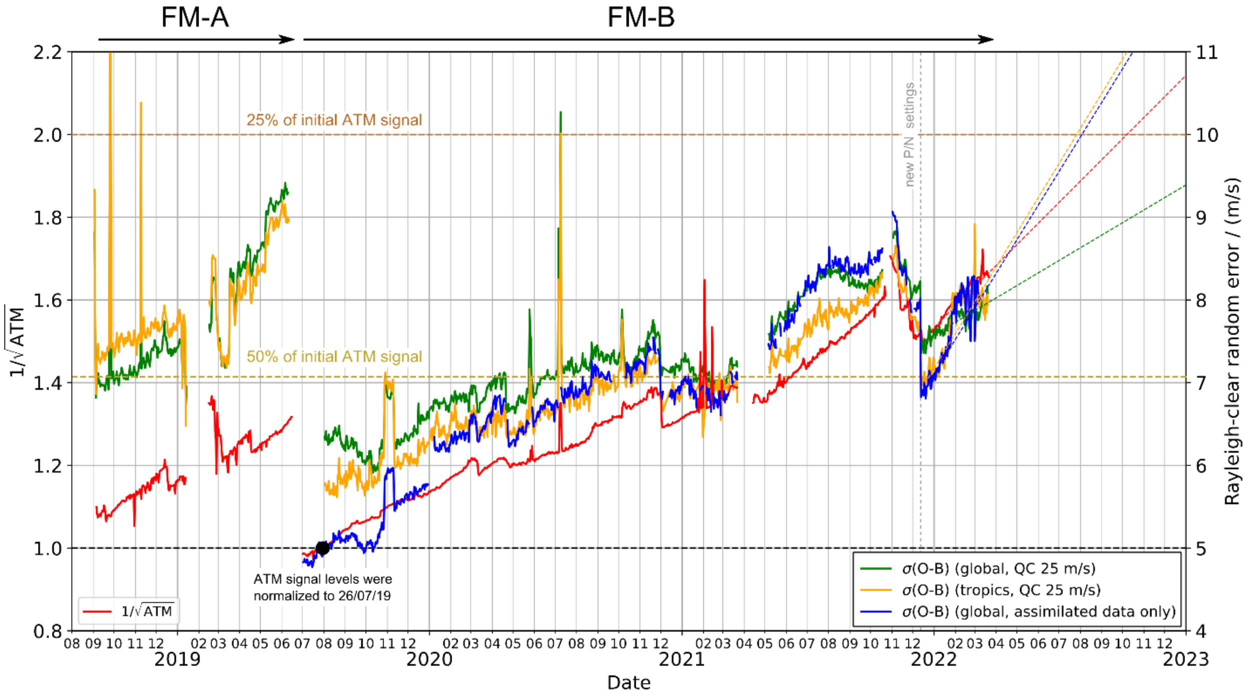


- Mission objective to demonstrate positive impact for numerical weather prediction was achieved: ECMWF, DWD, Météo-France, UK Met Office and NCMRWF are using Aeolus wind products in operation and show positive impact; positive impact is demonstrated in various other global models, e.g. ECCC, NOAA.
- Aeolus demonstrates the high-spectral resolution lidar approach for retrieval of aerosol optical properties for the first time in orbit



- Aeolus DISC contributions were key to achieve mission objectives.
- Aeolus paves the way for the future lidars from Europe (EarthCARE and Merlin) and a European operational follow-on wind lidar mission in 2030+.

Rayleigh random error and signal evolution during the mission timeline



σ(O-B), global, assimilated data (blue): passed first-guess check of O-B and other QC using estimated. err.

σ(O-B), global (green), with outliers QC (<25 m/s) (plots M. Rennie <15 m/s)

σ(O-B), Tropics (orange): low influence of solar background, with outliers QC (<25 m/s)

Figure by **O. Lux (DLR),** with data from **M. Rennie (ECMWF), more details during talk of M. Rennie**