Assessment of the Aeolus performance and bias correction – results from the Aeolus DISC

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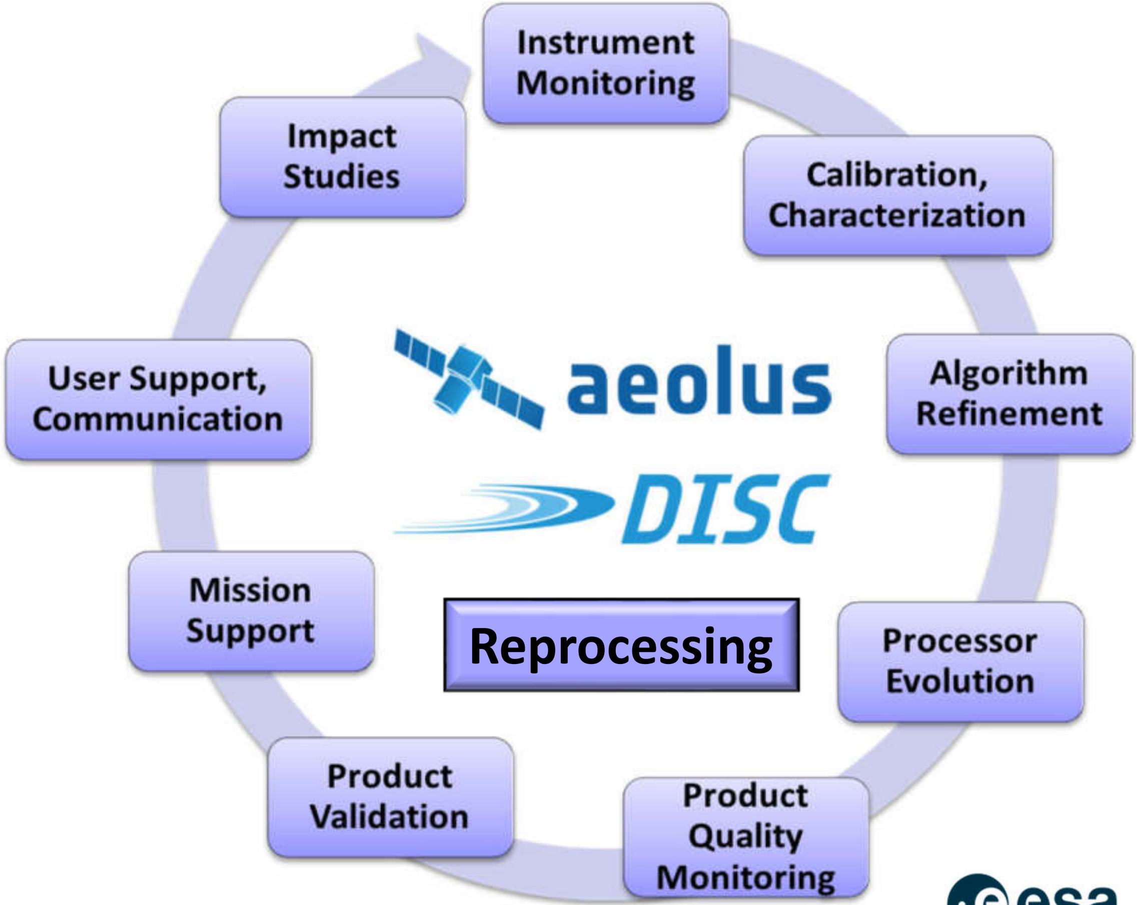
[10]KNMI, The Netherlands
[11]ABB, Canada
[12]S&T, The Netherlands
[13]serco, Italy
[14]ESA-ESTEC, The Netherlands
[15]ESA-ESRIN, Italy

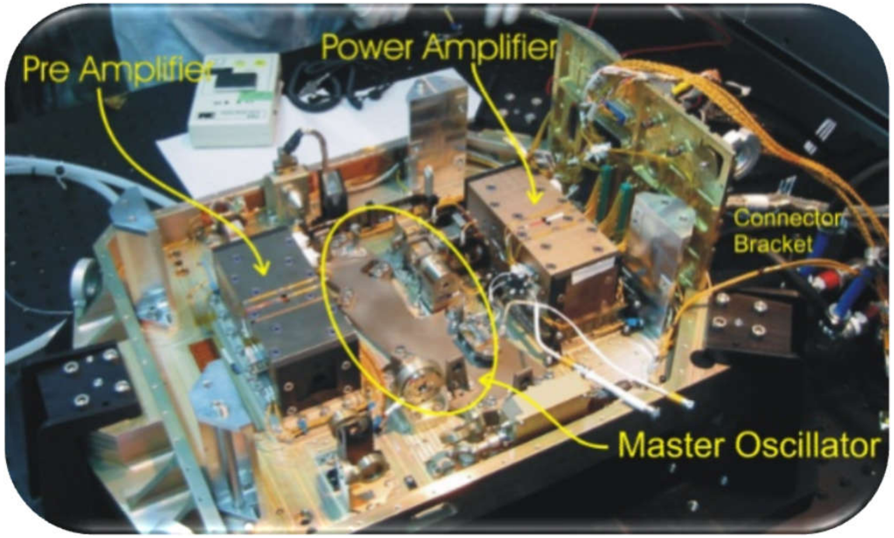
Aeolus Data Innovation and Science Cluster (DISC)



DISC KO February 2019 @ DLR

Outline of the talk

- evolution of random and systematic errors
  - main causes and correction for systematic errors
  - main causes for random error and evolution of signal levels
- reprocessing of Aeolus data products and their quality

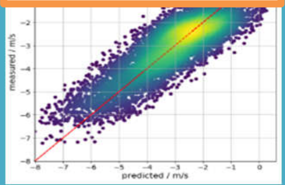


Major events for Aeolus and DISC in 2020

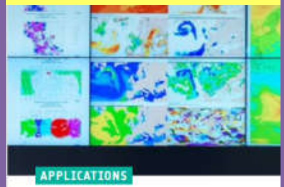
Illustrations from Gilles Labruyère:
***aeolus differently*, 2018**

Development of AUX-TEL generator for bias correction at DLR / ECMWF

Dec 2019 / Jan 2020



★ Highlight ★

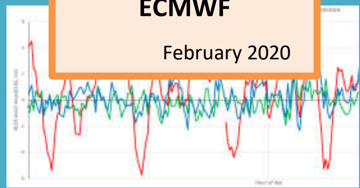


Aeolus winds now in daily weather forecasts

10 January 2020

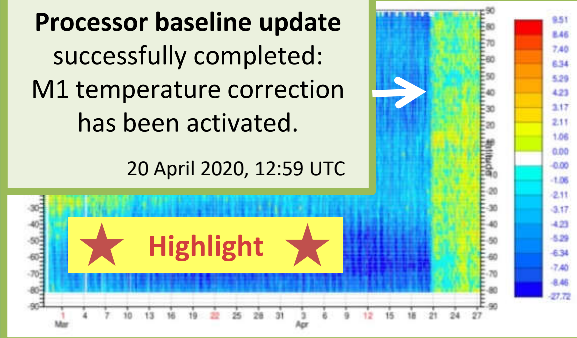
Integration of AUX-TEL generator for bias correction at ECMWF

February 2020



Processor baseline update successfully completed: M1 temperature correction has been activated.

20 April 2020, 12:59 UTC



★ Highlight ★

COVID-19: Aeolus and weather forecasts

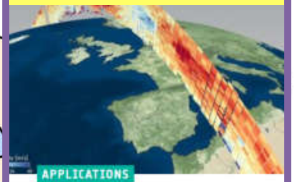
21 April 2020

1st Aeolus session at EGU 2020:

21 presentations, more than 100 participants

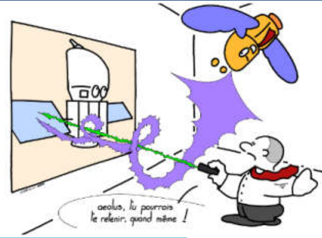
5 May 2020

★ Highlight ★



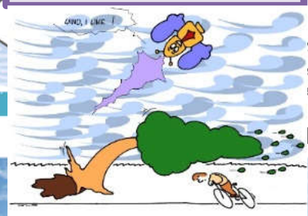
Aeolus goes public

12 May 2020



Aeolus winds are used by national weather services (DWD, Météo France) for daily weather forecasts

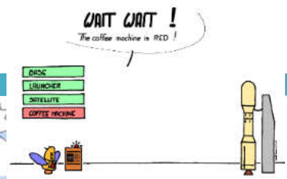
DWD: 19 May 2020
Météo France: 30 June 2020



Aeolus NWP impact assessment working meeting #2

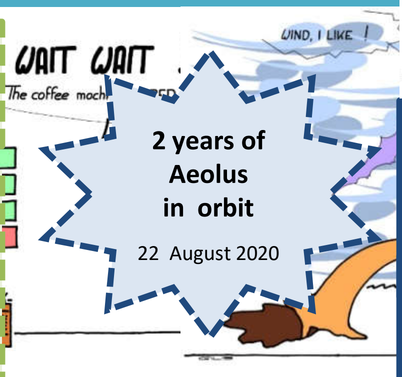
Aeolus L2A working meeting #2

30 June 2020



2 years of Aeolus in orbit

22 August 2020



Processor baseline update B11

8 October 2020

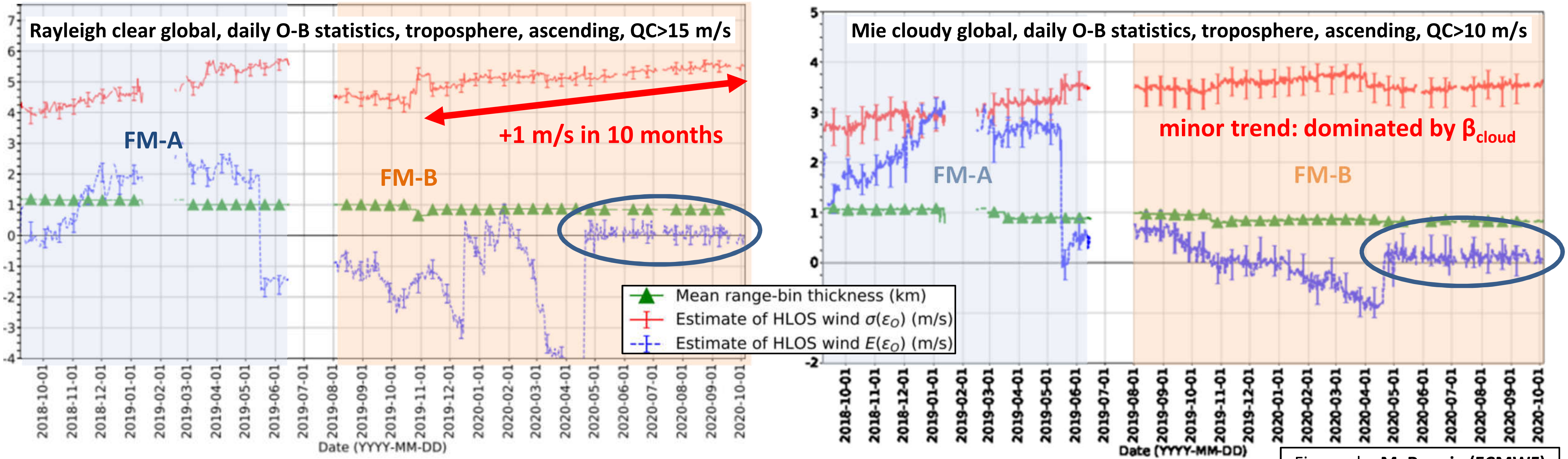
Public release of reprocessed dataset FM-B period Jun to Dec 2019

14 October 2020

Sketch by **I. Krisch (DLR)**

Evolution of Aeolus random and systematic errors

ECMWF operational monitoring of Aeolus Rayleigh and Mie winds from 7 Sept 2018 to 5 Oct 2020



Figures by **M. Rennie (ECMWF)**

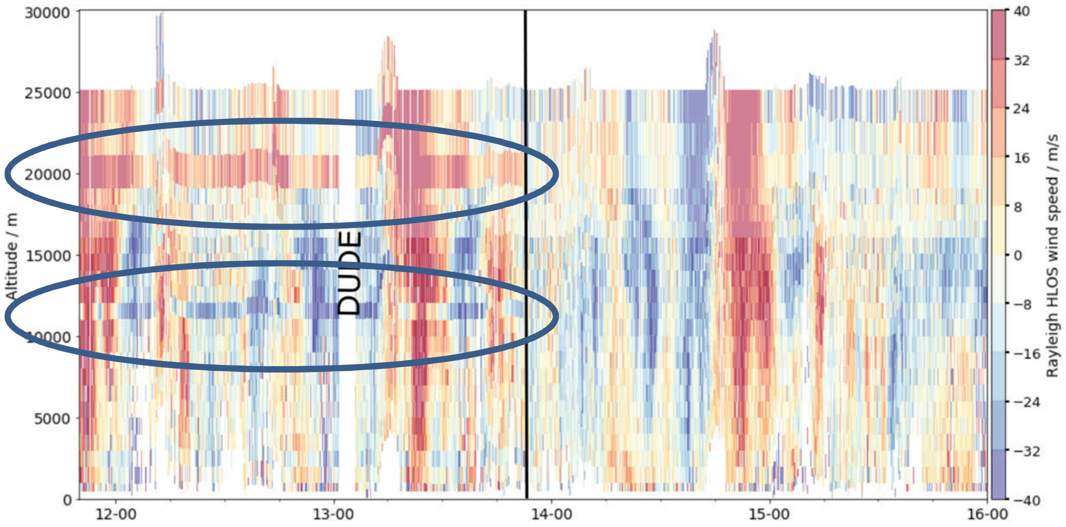
- **random error** is currently in the order of **5.5-6.5 m/s for Rayleigh winds and 3-3.5 m/s for Mie winds** (mostly clouds): random errors in both channels increased since launch and show some decrease due to L2B processor improvements
- **systematic errors (bias) for both Mie and Rayleigh winds (several m/s)** show **strong slow drifts, orbital variations**, **differences for ascending and descending orbits**, and **occurrence in some range-gates**

➢ combination of **4 unexpected sources** for the bias investigated and corrected for L1B/L2B product

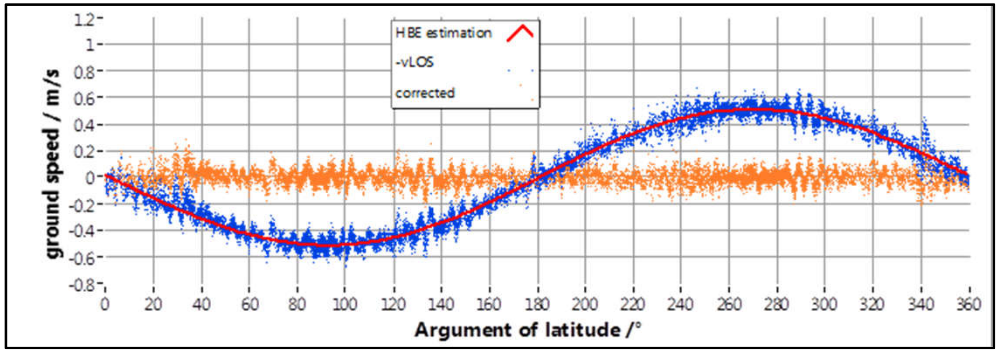
What caused the wind systematic error in the past?

combination of 4 unexpected (before launch) 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-times / day) and on-ground correction in L1B processing since 14 June 2019



2. error in the on-board software in calculation of residual projection of the **satellite ground speed on the line-of-sight =>** workaround implemented in 2019 by de-activating correction and corrected on-ground with new L1b processor version 7.09.1 (baseline B11 from 8 October 2020)



v_{SAT} during June 29 – Jul 05, 2019

L1B processor implementation by **D. Huber (DoRIT)**
L2B processor implementation by **J. de Kloe (KNMI)**

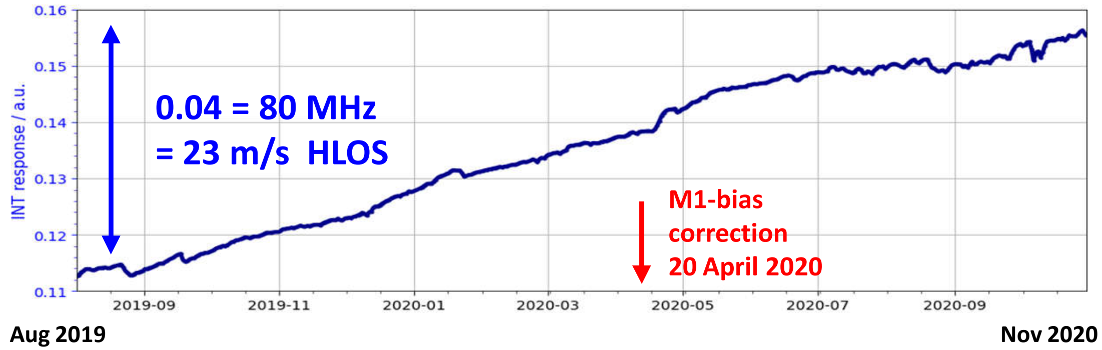
Figures by **F. Weiler (DLR), I. Nikolaus (PSol)**

What caused the wind systematic error in the past?

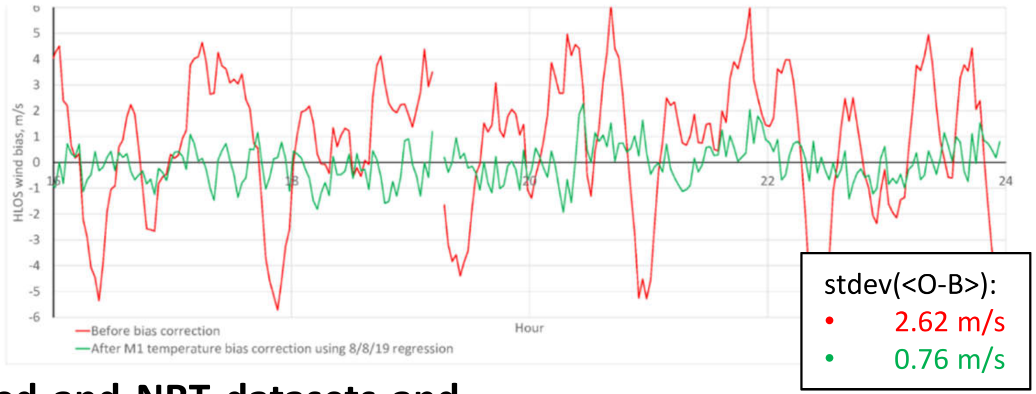
3. **slow drifts in the illumination of the Rayleigh/Mie spectrometers** causing a **slowly, linear drifting constant bias =>** implemented as constant factor correction for Rayleigh/Mie winds within M1-bias correction since April 20 (baseline B09 data from 20 April 2020)

4. variation of the **M1 telescope mirror temperatures (mean and gradients)** which results **in Rayleigh and Mie bias with orbital phase (argument of latitude) and longitude** => corrected for L2B winds with use of correlation between M1 temperatures and mean model departures from ECMWF with daily to half-daily update rates using a processor at ECMWF (AUX-TEL) since baseline B09/20 April 2020

temporal evolution of internal Rayleigh Response R_{Int}



Rayleigh bias versus time on 09/08/2019

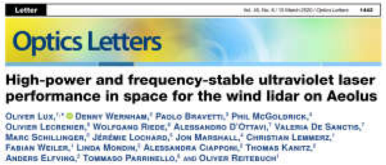


=> on-going investigations on remaining bias in re-processed and NRT datasets and M1-correction without use of ECMWF model by use of ALADIN ground-returns: reduces biases significantly to almost the same level: confirms correctness of bias correction using ECMWF model

Figure by **F. Weiler (DLR), M. Rennie (ECMWF)**

What influences the wind random error and signal loss ?

1. **laser emit energy**


Letter
Optics Letters
High-power and frequency-stable ultraviolet laser performance in space for the wind lidar on Aeolus
Oliver Lux, Denny Wernham, Paolo Bravetti, Phil McGoldrick, Olivier Lecrenier, Wolfgang Riede, Alessandro D'Ottavi, Valeria De Sanctis, Marc Schillinger, Jérémie Lochard, Jon Marshall, Christian Lemmerz, Fabian Weiler, Linda Mondin, Alessandra Ciapponi, Thomas Kanitz, Anders Elfving, Tommaso Parrinello, and Oliver Reitebuch

   ⇨ lower than expected: 65 mJ instead of 80 mJ (specified)

   ⇨ decrease for FM-A period from launch until June 2019 by 25 mJ

   ⇨ small decrease during FM-B period from July 2019 until stabilization in Dec 2019 and recovery in March 2020 to > 60 mJ

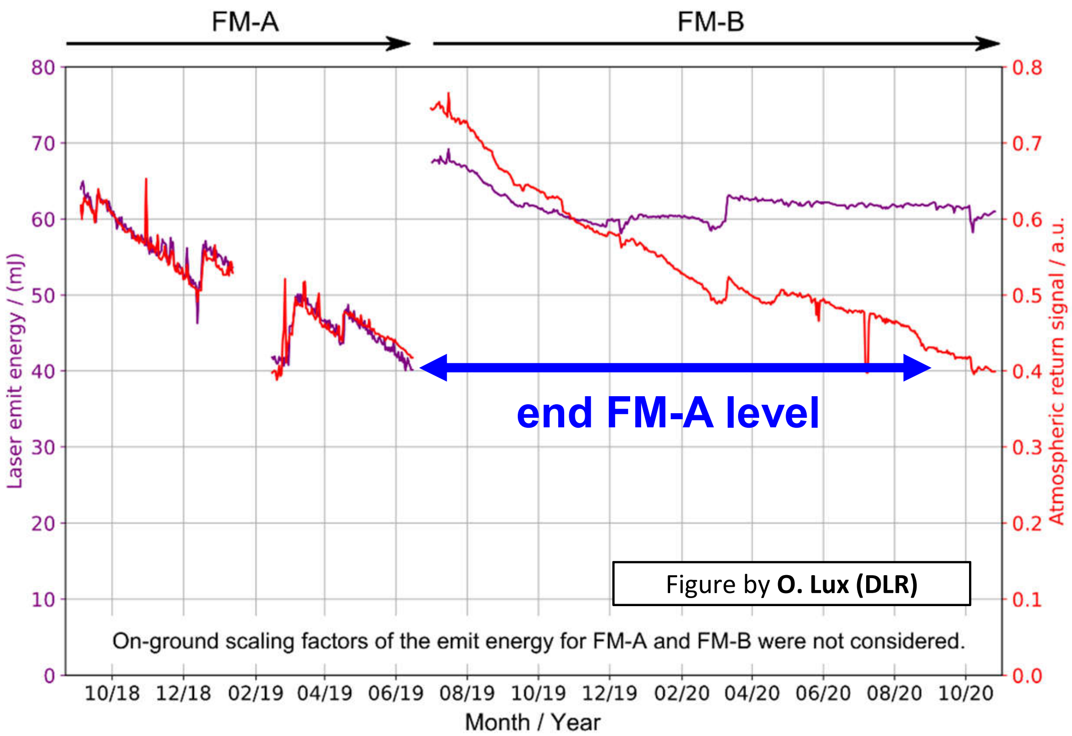
2. **optical signal throughput** in receive path for atmospheric signal

   ⇨ lower than expected (factor 2-3) since launch

   ⇨ significant decrease since July 2019 until end October 2020 by 47% to 50% for FM-B

   ⇨ signal levels currently below end FM-A levels

laser energy and Rayleigh atmospheric path signal



Discrepancy between these lines for FM-B period indicates that laser energy is not representative for instrument performance. This hints to a signal loss in optical emit and receive path.

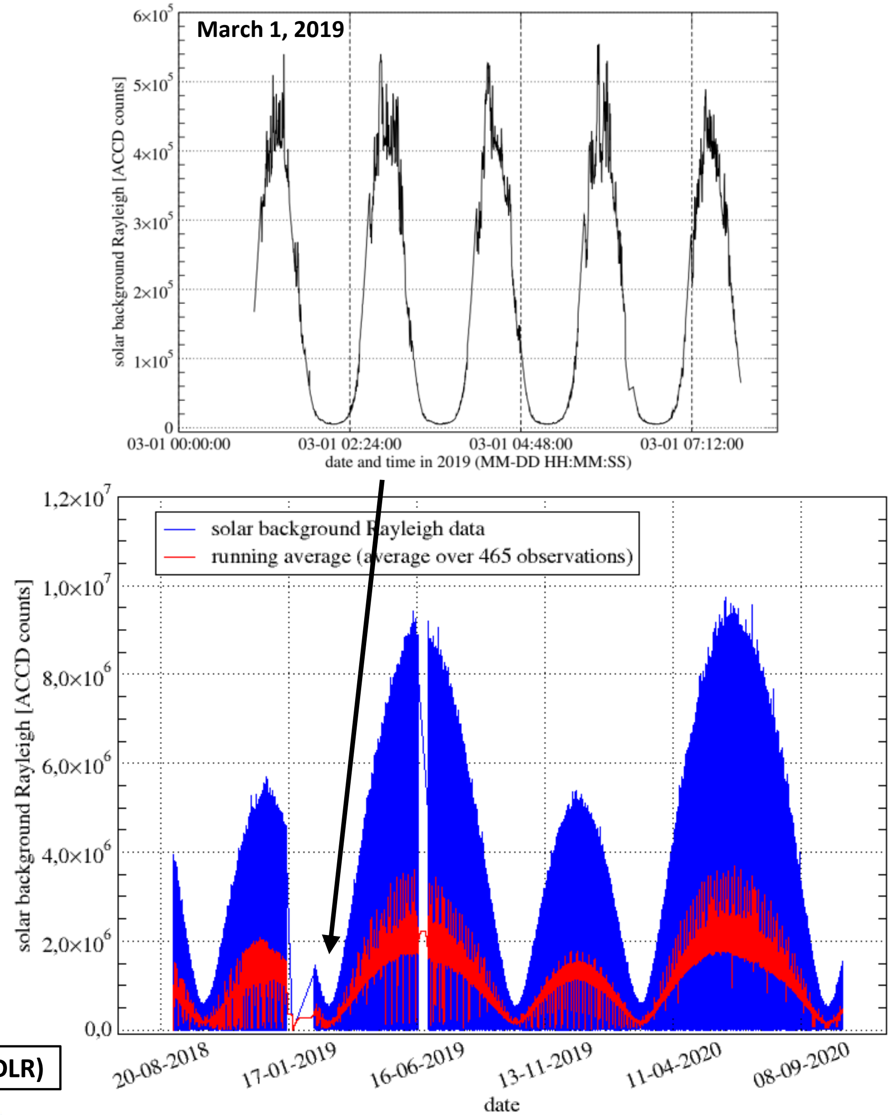
Analysis of root cause of signal loss and specific instrument tests with highest priority during last year by DISC/ESA/industry.

What influences the wind random error and signal loss ?

1. **laser emit energy**
2. **optical signal throughput** in receive path for atmospheric signal
3. **solar background noise (mainly on Rayleigh winds)**
   - ⇨ impact higher than expected due to lower atmospheric signal
   - ⇨ seasonal variation of solar background by factor 18: Rayleigh random errors of 7-8 m/s were obtained in summer months for polar regions

Random error could be only reduced by further averaging in vertical (>1 km => range-bin settings, on-ground processing) or horizontal (>90 km) or improving signal throughput at instrument level

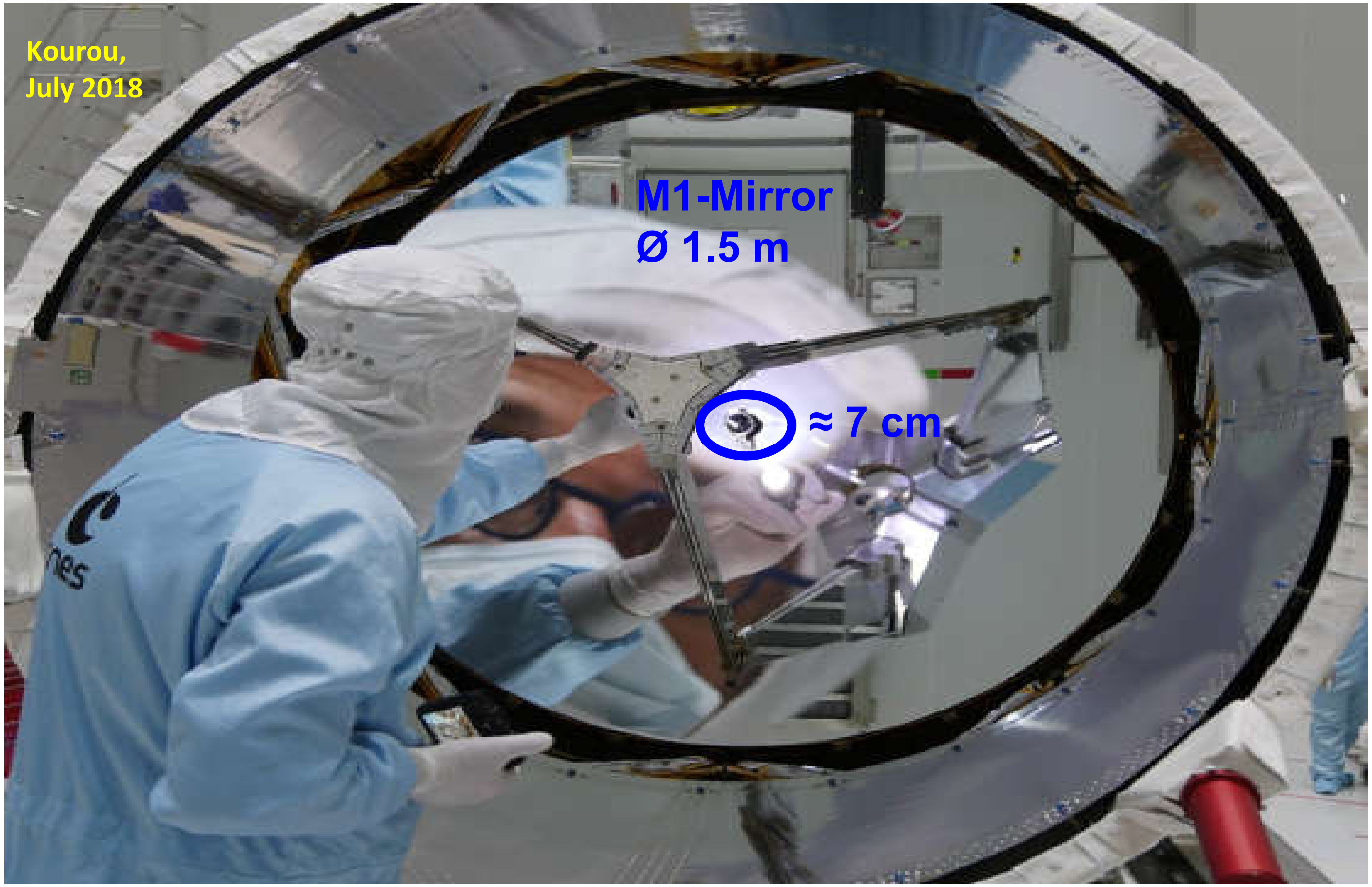
Orbital variation of Rayleigh solar background noise



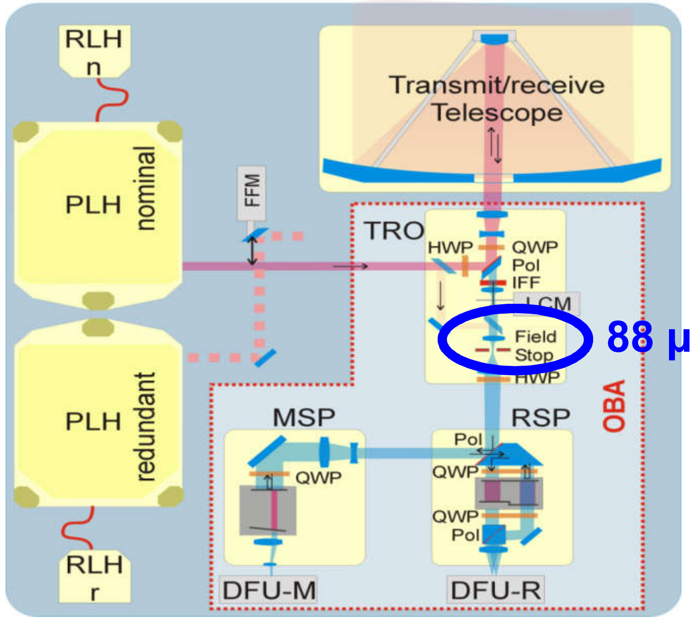
Figures by **K. Schmidt (DLR)**

View into the ALADIN Ø1.5 m telescope

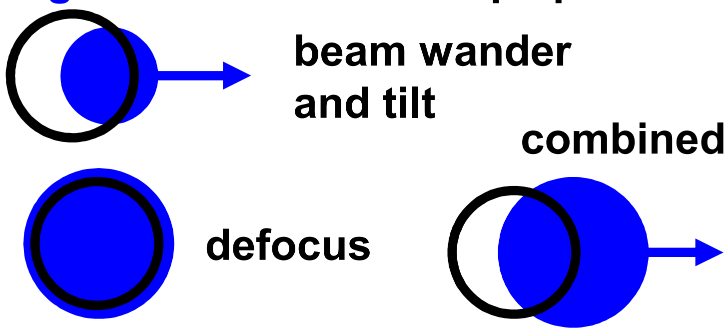
FOV 18 µrad
7 m @ 400 km



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



signal Loss at field stop aperture



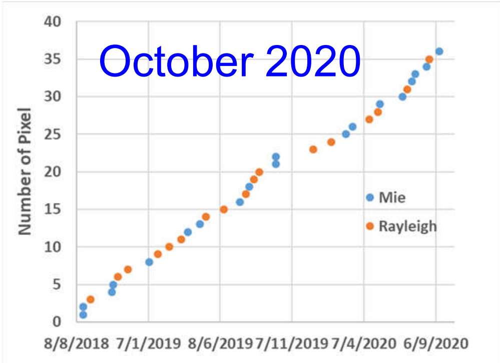
Recent results from assessment of ACCD detector

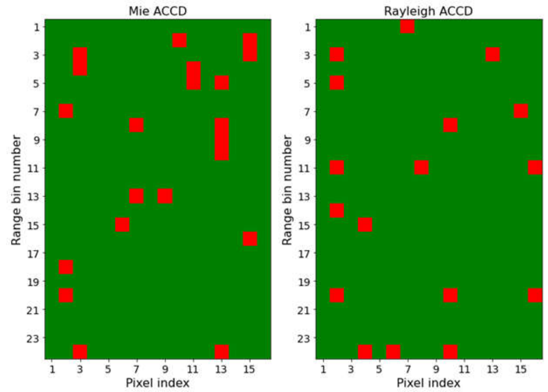
ACCD detector: currently 17 Rayleigh and 21 Mie **hot pixel**, a new hot pixel every ≈15 days => 10% hot pixel predicted for EOL (not critical), different characteristics RTS, Clock-Induced and causes (radiation, Clock-induced) => dark current levels could be reduced by changing operating temperature from -30°C to -35°C (tested with A2D), on-ground correction limited to time periods between 2 DUDE´s (every 6 hours) => potential mitigation is to increase number of DUDE´s per day

submitted to AMTD

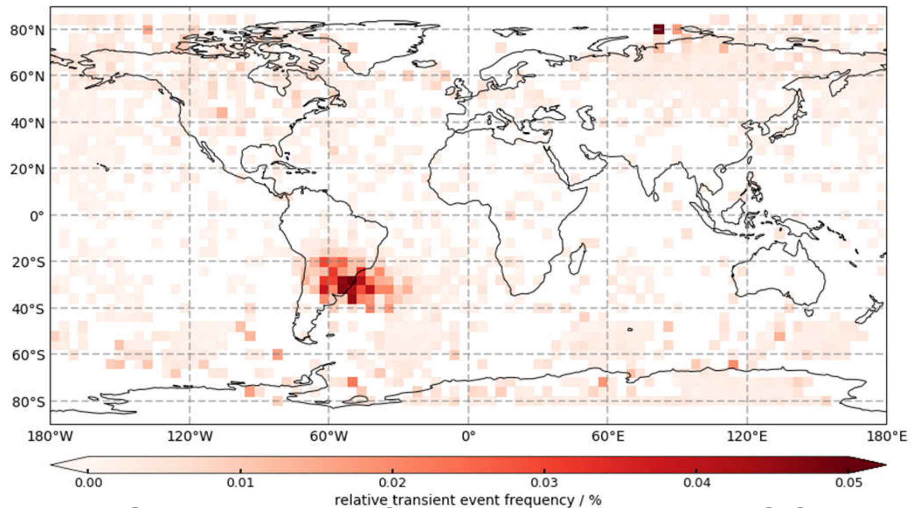
Characterization of dark current measurements of the ACCDs used on-board the Aeolus satellite

Fabian Weiler[1], Thomas Kanitz[2], Denny Wernham[2], Michael Rennie[3], Dorit Huber[4], Marc Schillinger[5], Olivier Saint-Pe[5], Ray Bell[6], Tommaso Parrinello[7], Oliver Reitebuch[1]





Figures by **F. Weiler (DLR)**

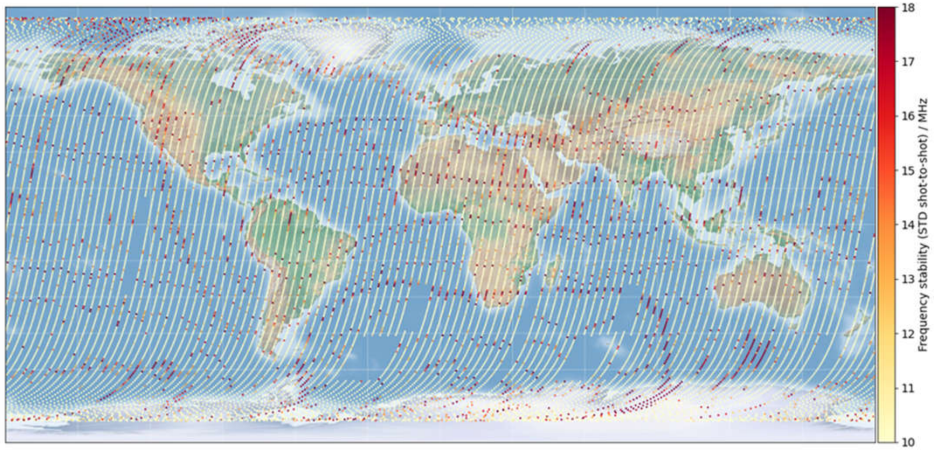


Occurrence of signal spikes on ACCD

Recent results from assessment of laser frequency stability

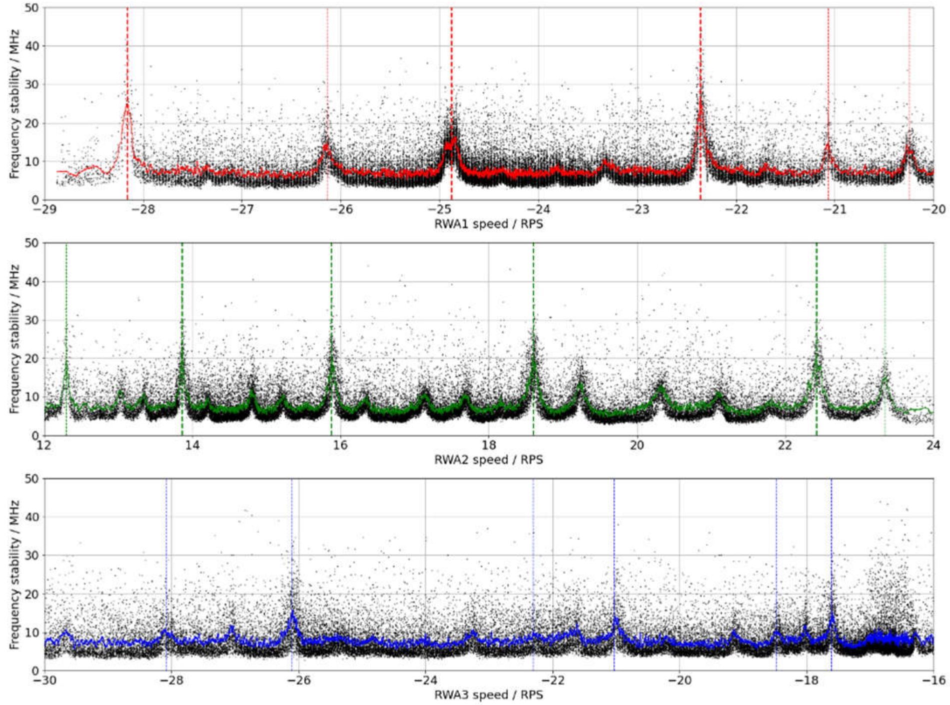
laser frequency stability is good (8-10 MHz (UV) rms shot-to-shot, relative 10^{-8}) but **periods with enhanced frequency jitter** (up to 30 MHz rms) are correlated to critical rotation speeds of the reaction wheels (micro-vibrations) => results in specific patterns of geolocations around the globe (indirect link to magnetorquers and earth magnetic field gradient) => these periods show enhanced Mie wind and ground-returns errors

Descending orbits



Data from 11/09/2019 to 18/09/2019
(50k observations / 27 million laser pulses)

frequency stability in MHz, 14/10/2019 to 21/10/2019

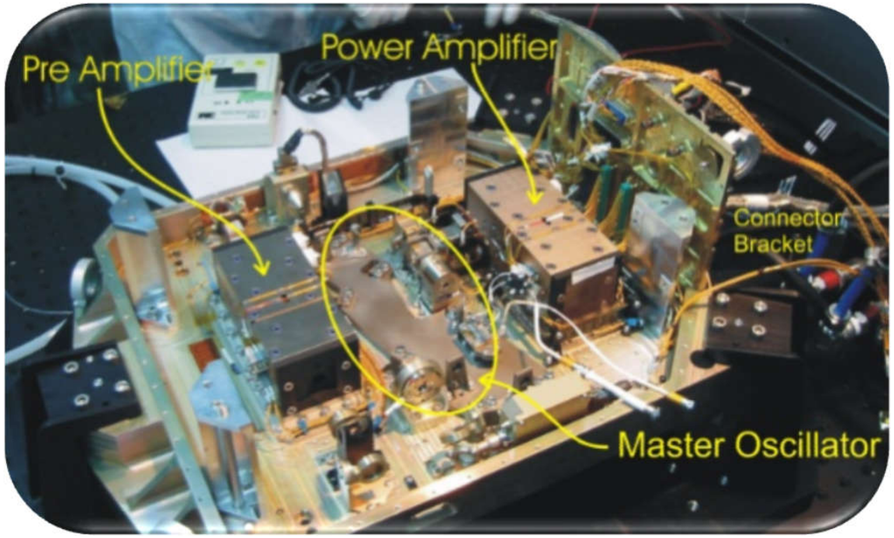


satellite reaction wheel speeds in RPS

Figures by **O. Lux (DLR)**

Outline of the talk

- evolution of random and systematic errors
  - main causes and correction for systematic errors
  - main causes for random error and evolution of signal levels
- **reprocessing of Aeolus data products and their quality**



Re-processing of Aeolus data

- Re-processing activities started begin 2020 for early FM-B period June to December 2019
- Use of L1B 7.08.2, L2A 3.10.1 , L2B 3.30.1 processor versions of early 2020 (comparable in quality to baseline 09 and 10)
- Main improvements wrt. NRT data products
  - Correction of hot pixels also in time periods between dark signal measurements (DUDE) for L1B
  - M1-bias and drift correction of L2B winds with daily updates using ECMWF O-B correlation to M1 temperatures
  - Use of orbital means for radiometric calibration (K_{ray}, K_{mie}) of L2A products and improved QC
- Next re-processing campaign will cover full period for FM-B (June 2019 to October 2020) and use October 2020 processor versions of baseline 11: available in April 2021

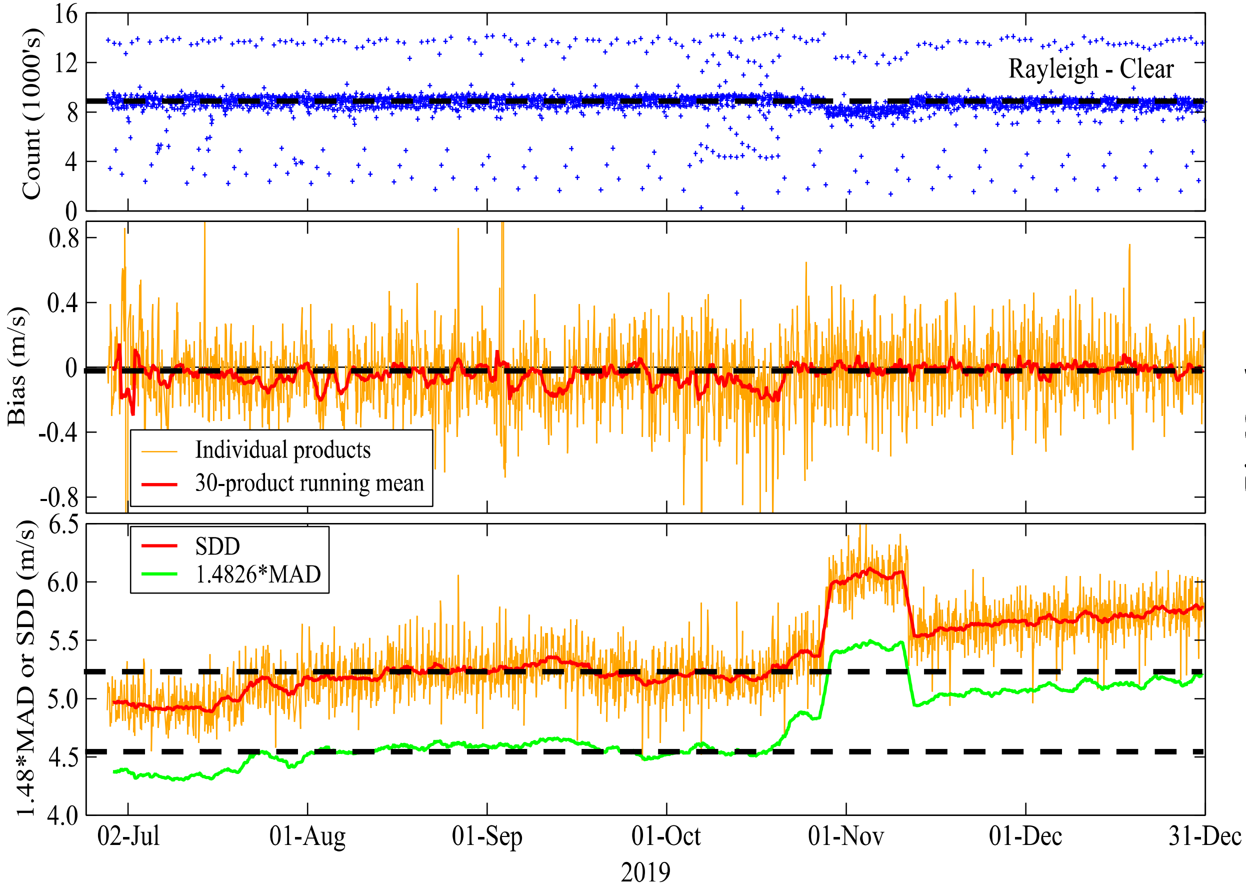
fall 2020: Re-processed **FM-B data of 2019** including M1 correction was released on 14 October 2020

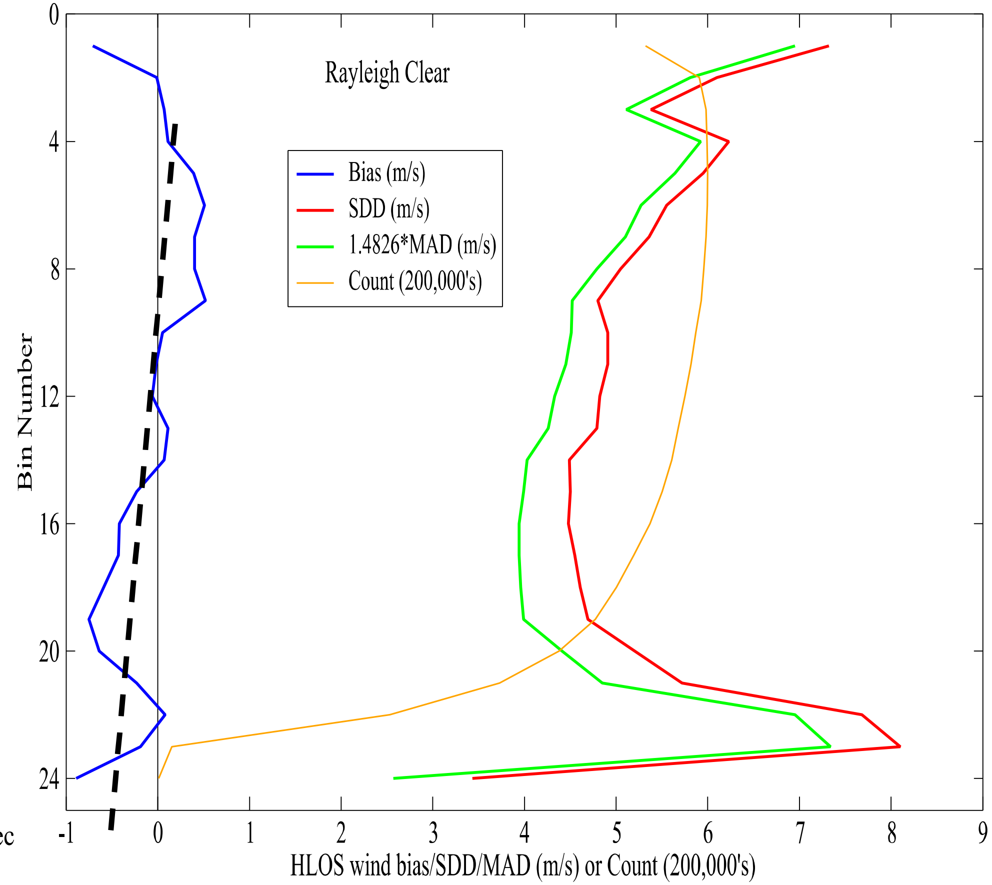
early 2021: Next: Re-processing of **FM-B data from June 2019 to October 2020** will become available in April 2021

end 2021: Re-processed **FM-A data** with hot-pixel and M1 correction will be available end 2021

2022: Re-processing of **complete Aeolus mission** since launch with optimized processor settings and all available corrections.

Quality of re-processed L2B Rayleigh winds for June-Dec 2019





significant improved Rayleigh bias (several m/s, lat/lon=> M1 dependency) to around 0 m/s (pp<0.9 m/s)

Rayleigh random error 4-6 m/s except lowest 2-3 range gates (PBL)

Figures by **S. Abdalla (ECMWF)**

Summary and conclusion

- 4 causes of wind bias (hot pixel, satellite speed, linear drifts and M1 temperature) are corrected since April 20, 2020 (baseline 09) and in re-processed dataset (2019)
- major performance issue is the on-going loss in signal on the atmospheric and internal optical path, which results in an increase of the Rayleigh wind random errors
- influence of laser beam pointing, thermal environment (eclipse) and M1 temperatures on atmospheric path signal loss were shown => potential for mitigation actions on recovery of signal loss
- new processor versions for baseline 11 was deployed for NRT products on 8 October 2020; re-processed products for early FM-B period have been available since 14 October 2020 => next updates in March-April 2021
- results from next laser parameter optimizations and next M1 tests will be available in early 2021