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

Oliver Reitebuch[1]

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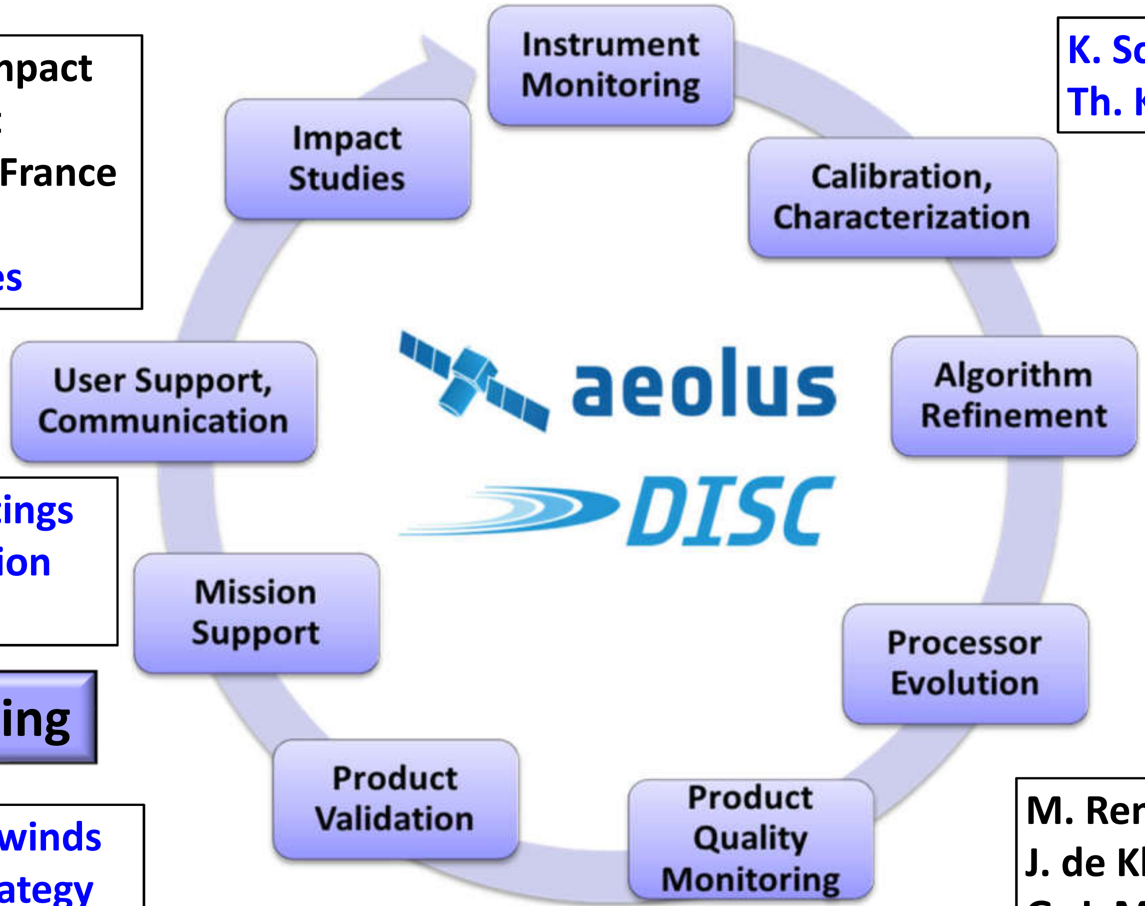
[8]Météo-France, France
[9]ECMWF, UK
[10]KNMI, The Netherlands
[11]ABB, Canada
[12]S&T, The Netherlands
[13]serco, Italy
[14]ESA-ESTEC, The Netherlands
[15]ESA-ESRIN, Italy

Aeolus Data Innovation and Science Cluster (DISC)

M. Rennie: ECMWF impact
M. Savli: NWP impact
J.-F. Mahfouf: Météo-France impact
I. Krisch: gravity-waves

K. Schmidt: radiometric performance
Th. Kanitz: instrument performance

U. Marksteiner: HBE vs. M1



A. Dabas: calibration and L2A
F. Ehlers: L2A noise suppression
D. Donovan: ATLID approach

S. Bley: range-bin settings
M. de Laurentis: mission planning

Reprocessing

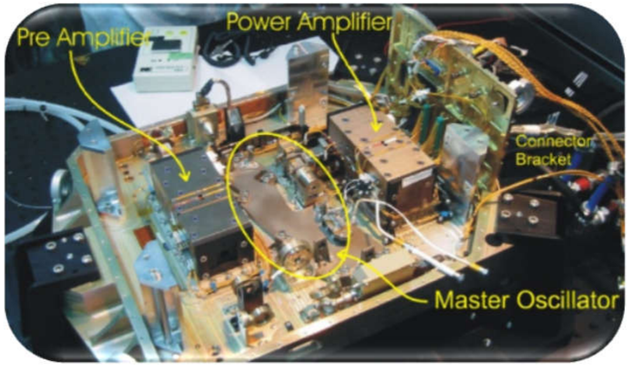
S. Abdalla: quality of winds
N. Masoumzadeh: strategy

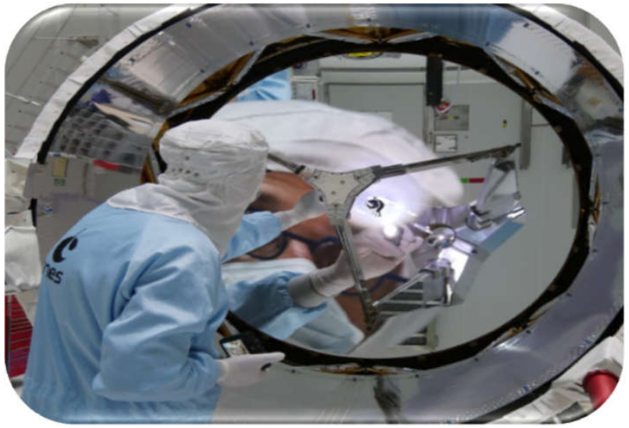
M. Rennie: L2B bias correction
J. de Kloe: L2B processor
G.-J. Marseille: L2B scene classification

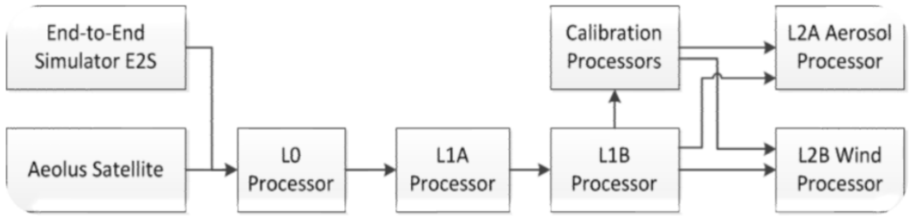
oral presentations
flash presentations

Outline of the talk

- evolution of random and systematic errors
  - main causes and correction for systematic errors
  - main causes for random error and signal levels
- recent investigations on performance related issues
- processor and data product evolution





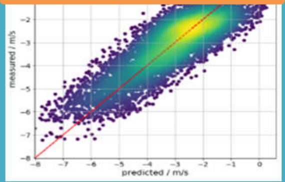


Major events for Aeolus and DISC in 2020

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

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

Dec 2019 / Jan 2020

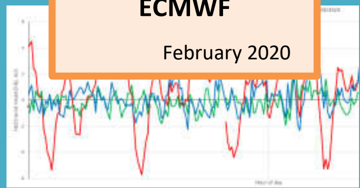


★ Highlight ★

10 January 2020

Integration of AUX-TEL generator for bias correction at ECMWF

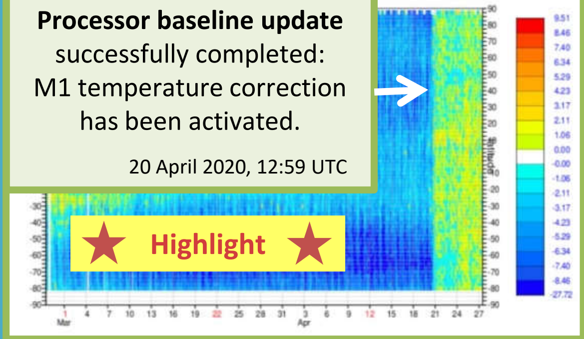
February 2020



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

20 April 2020, 12:59 UTC

★ Highlight ★

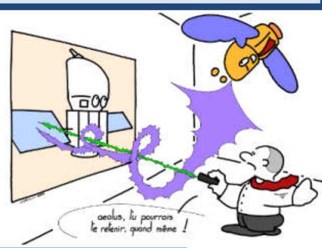


21 April 2020

1st Aeolus session at EGU 2020:

21 presentations, more than 100 participants

5 May 2020

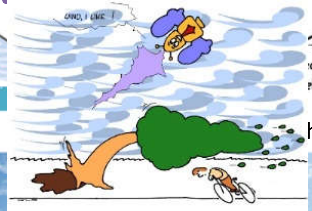


★ Highlight ★

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

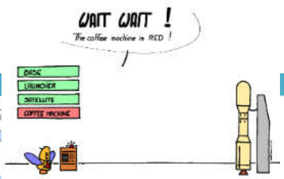


hold yourself back, anyway!

Aeolus NWP impact assessment working meeting #2

Aeolus L2A working meeting #2

30 June 2020



2 years of Aeolus in orbit

22 Aug. 2020

SAG and DISC Exploitation Readiness Review

22-25 Sep. 2020

Processor baseline update B11

8 October 2020

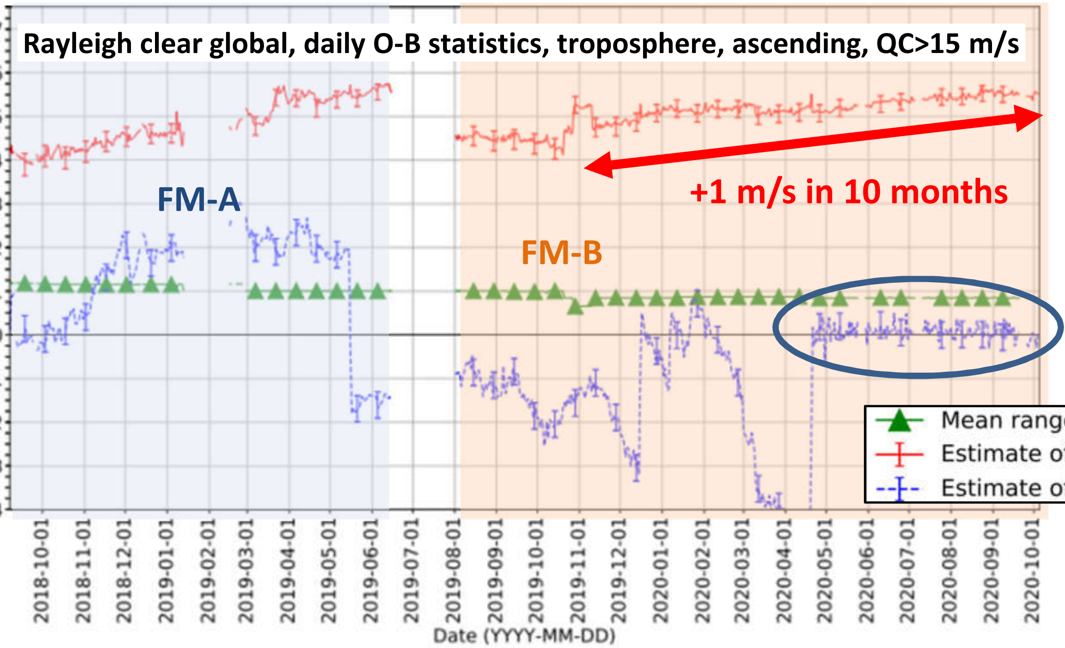
Public release of reprocessed dataset FM-B period Jun to Dec 2019

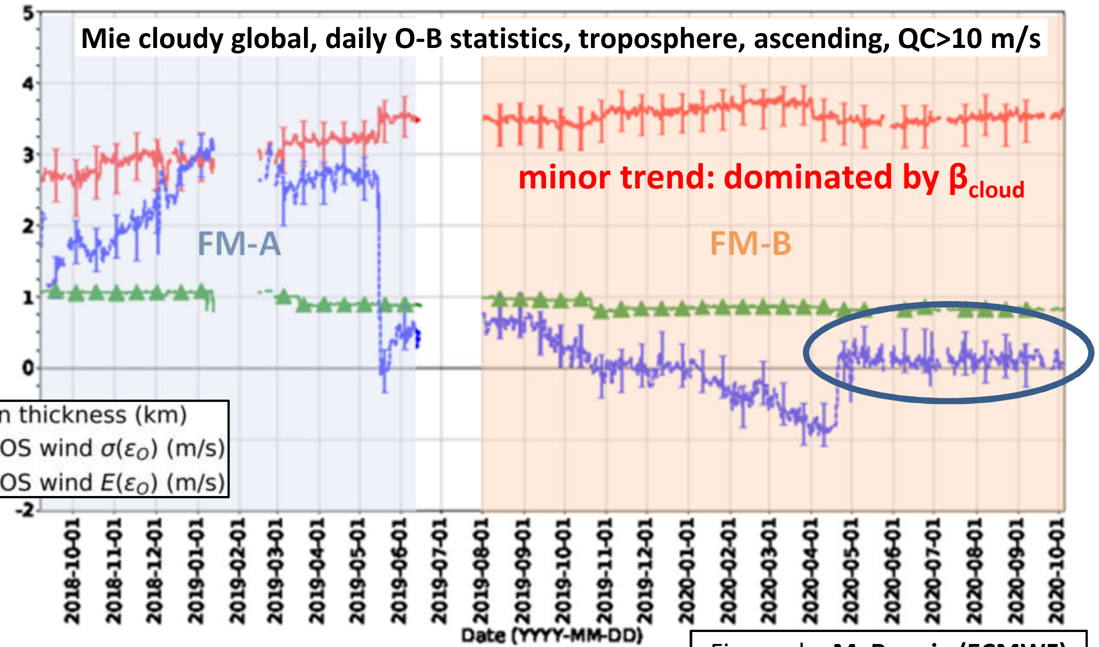
14 October 2020

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)**

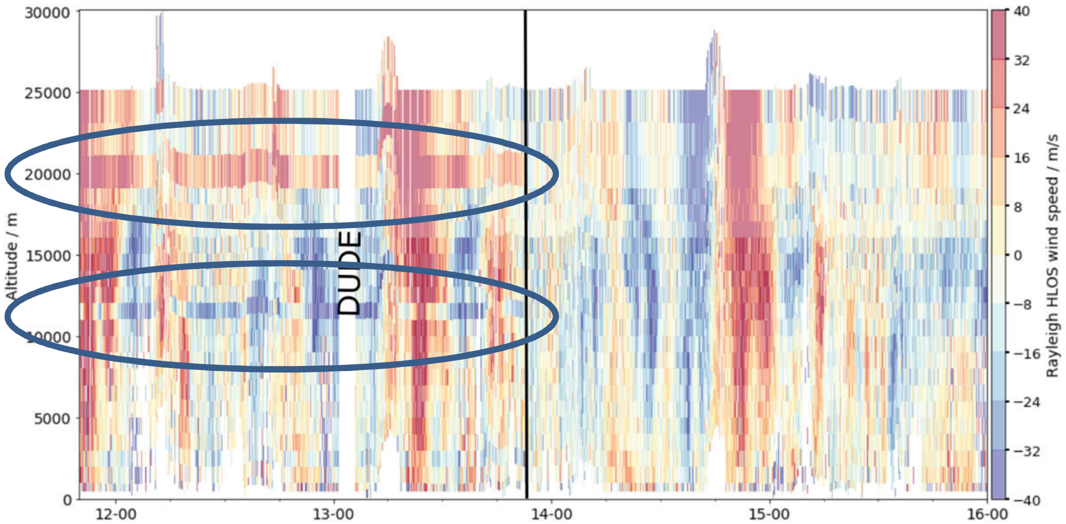
- **random error** is currently in the order of **5.5-6.5 m/s for Rayleigh winds and 3-3.5 m/s for Mie winds** (mostly clouds): random errors in both channels increased since launch and show some decrease due to L2B processor improvements
- **systematic errors (bias)** **for both Mie and Rayleigh winds (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

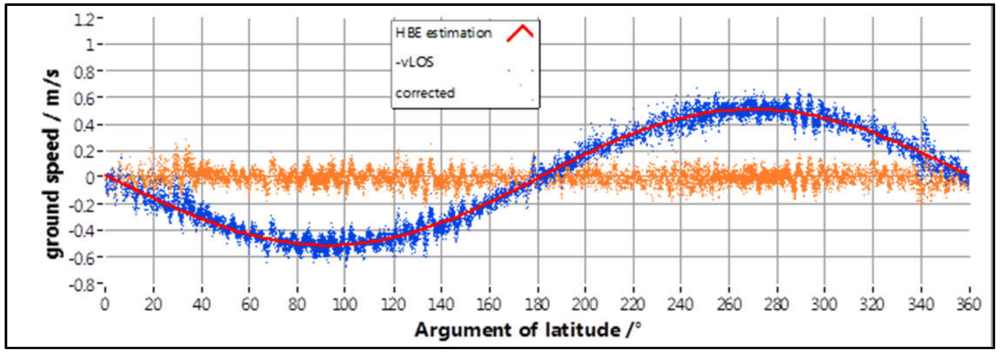
What caused the wind systematic error in the past?

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

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

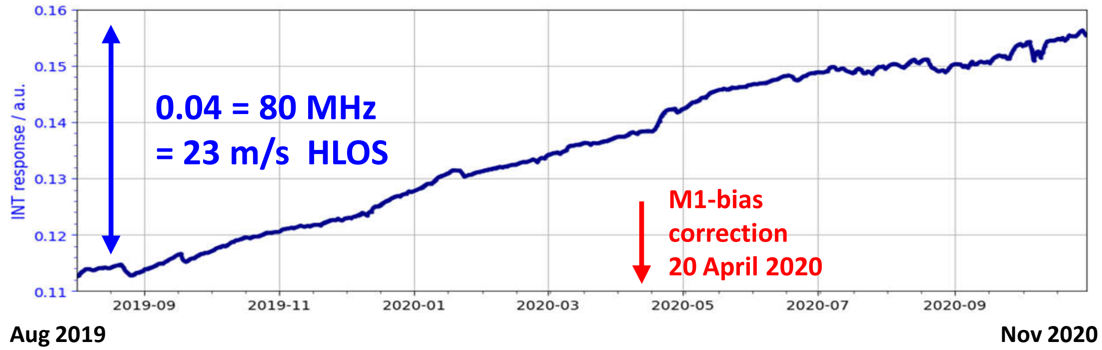
L1B processor implementation by **D. Huber (DoRIT)**
L2B processor implementation by **J. de Kloe (KNMI)**

What caused the wind systematic error in the past?

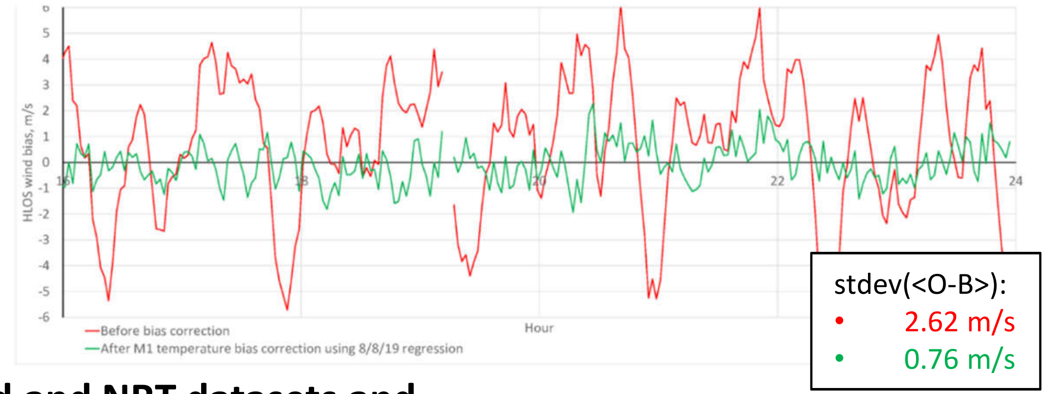
3. **slow drifts in the illumination of the Rayleigh/Mie spectrometers** causing a **slowly, linear drifting constant bias =>** implemented as constant factor correction for Rayleigh/Mie winds within M1-bias correction since April 20 (baseline B09 data from 20 April 2020)

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

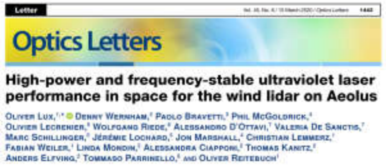


=> on-going investigations on remaining bias in re-processed and NRT datasets and M1-correction without use of ECMWF model by use of ALADIN ground-returns: reduces biases significantly, but currently not as good as using NWP model

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

What influences the wind random error and signal loss ?

1. **laser emit energy**
   - ⇨ 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

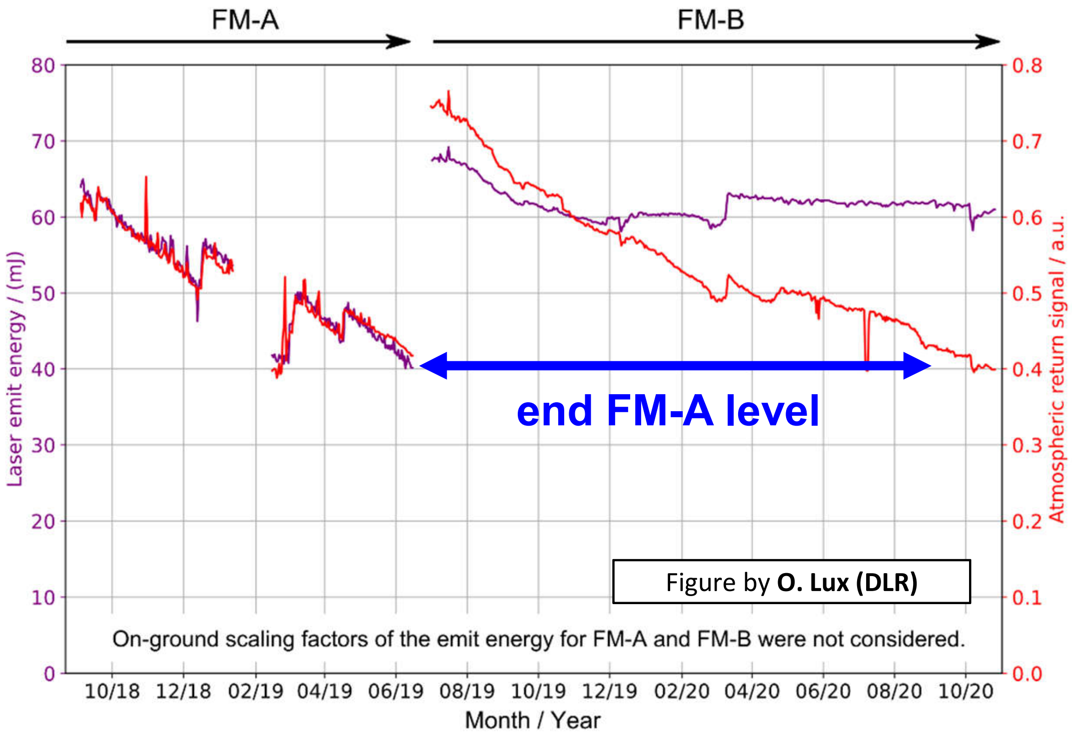

Optics Letters

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

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.

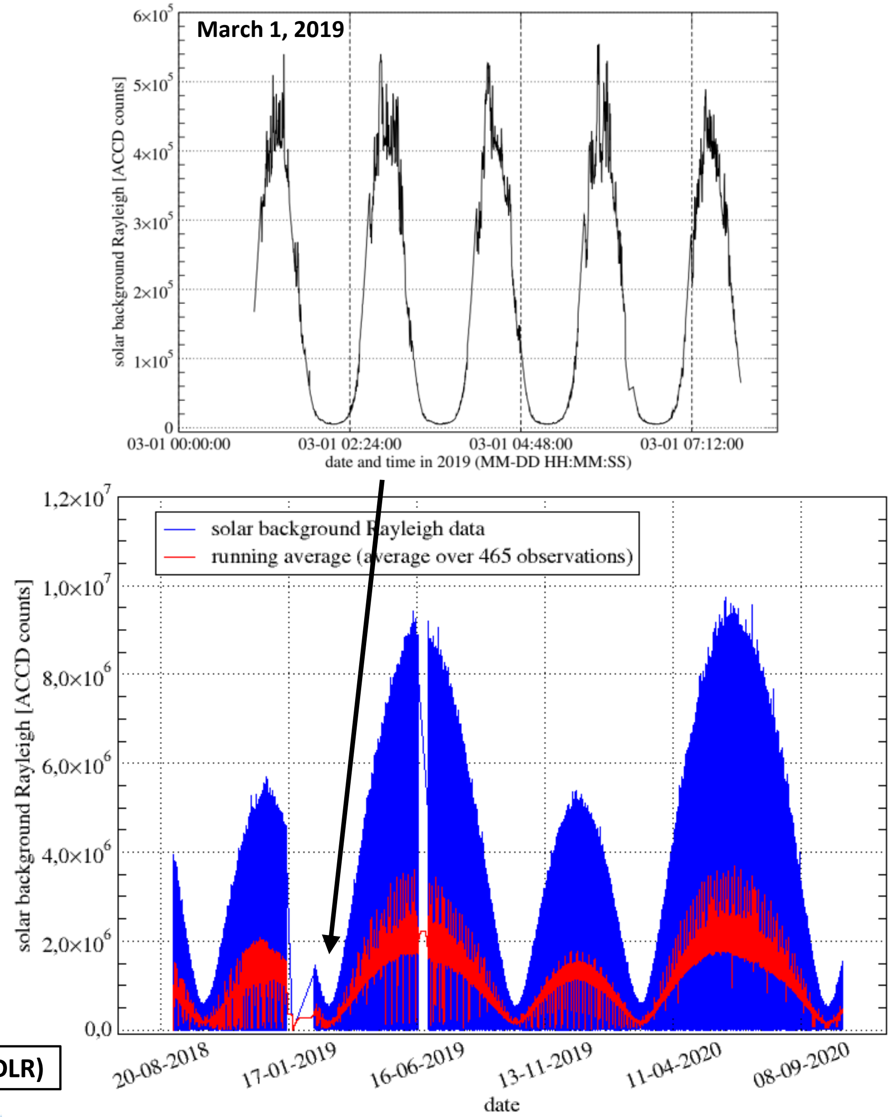
Analysis of root cause of signal loss and specific instrument tests with highest priority during last year by DISC/ESA/industry.

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

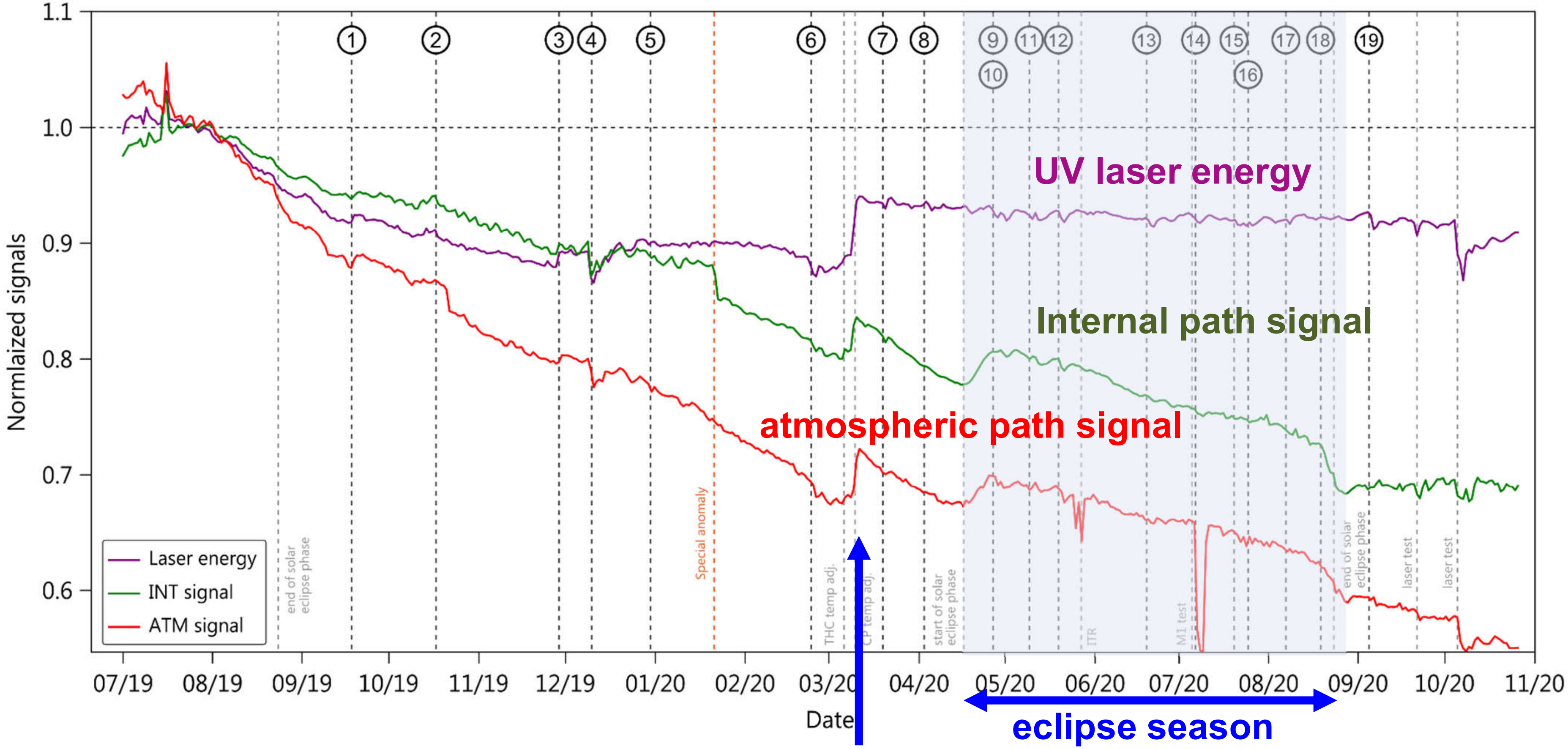
Random error could be only reduced by further averaging in vertical (>1 km => range-bin settings, on-ground processing) or horizontal (>90 km) or improving signal throughput at instrument level

Orbital variation of Rayleigh solar background noise



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

ALADIN atmospheric and internal path signal evolution for FM-B

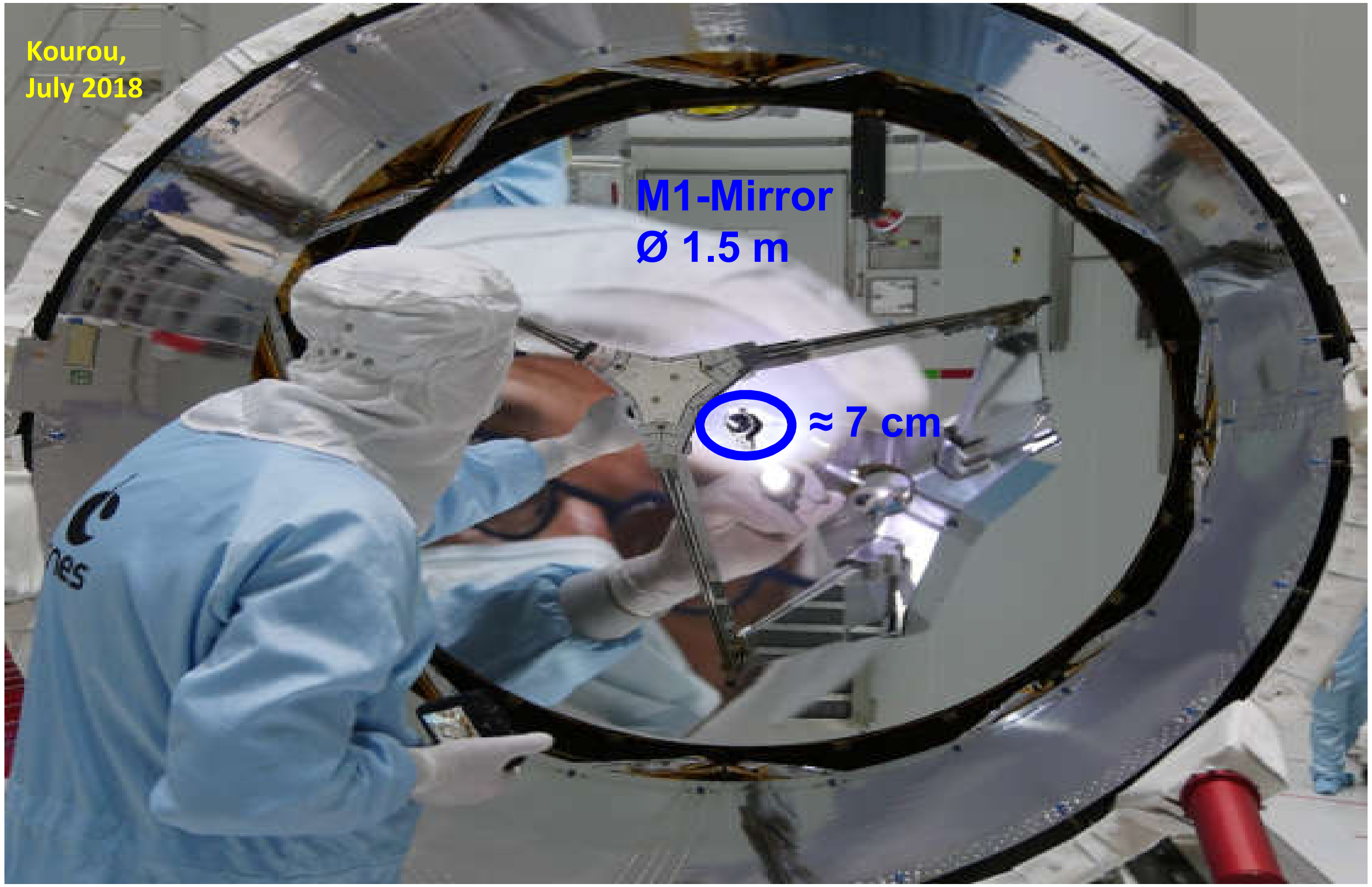


laser energy increase in March 2020

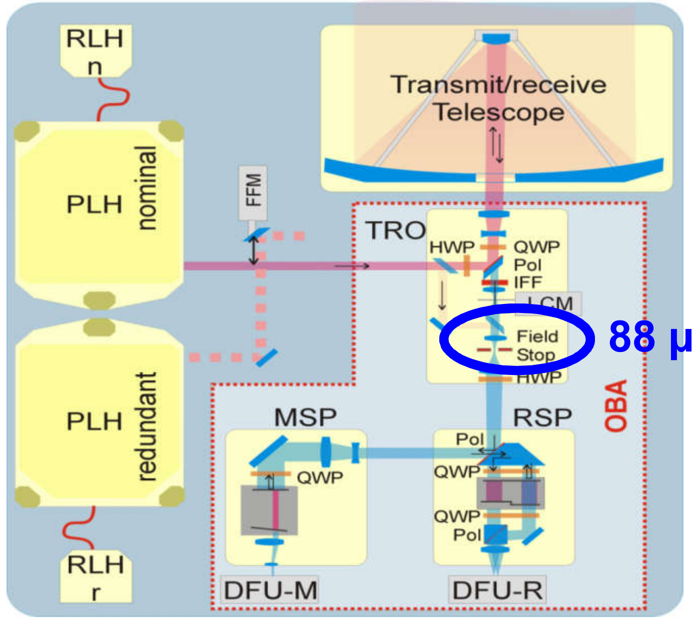
Figure by **O. Lux (DLR)**

View into the ALADIN Ø1.5 m telescope

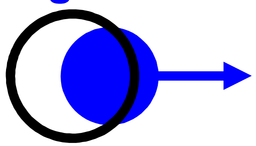
FOV 18 µrad
7 m @ 400 km



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

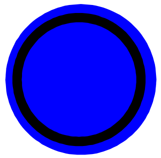


signal Loss at field stop aperture

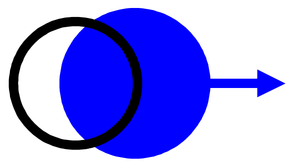


beam wander and tilt

combined

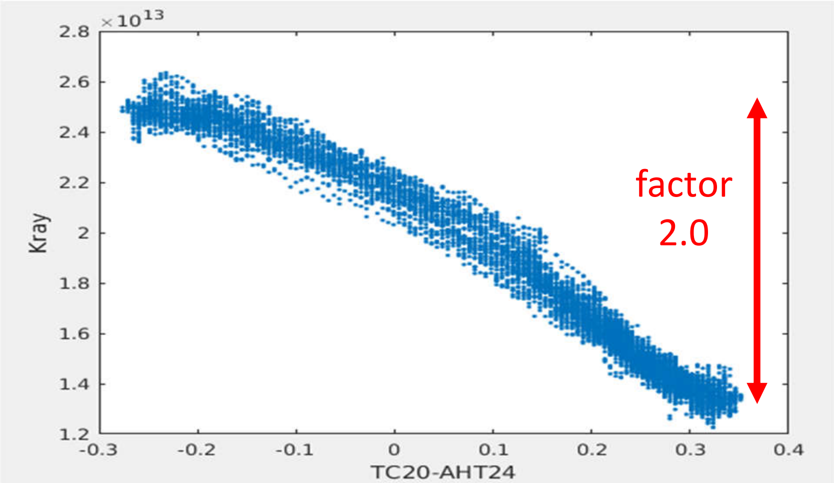


defocus



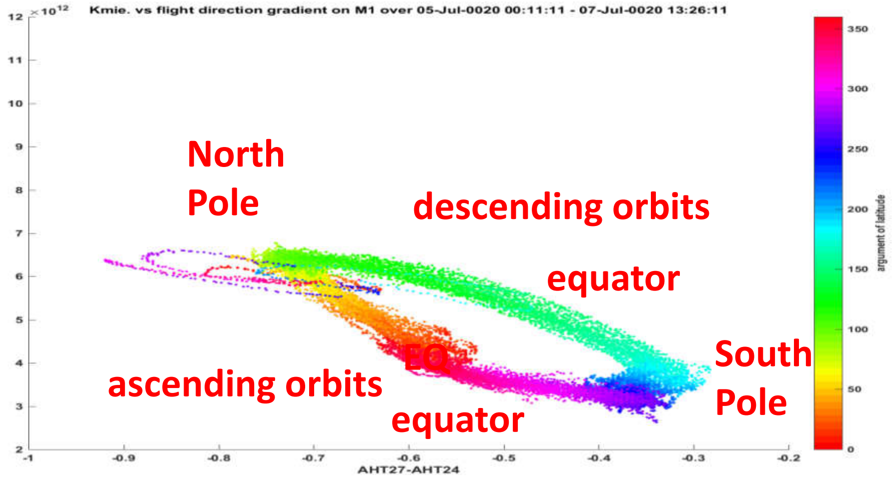
Temperature gradients along M1 influence signal levels – July 2020

Rayleigh calibration K_{ray}



temperature gradient y (outer – inner T)

Mie calibration K_{Mie}



temperature gradient x (outer – inner T)

major findings from M1 test of July 2020

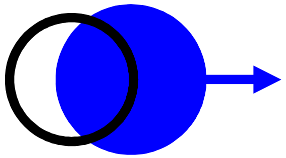
⇒ **we need y-axis temperature gradients of -0.3 K and lower over larger part of the orbit**

⇒ **we need x-axis temperature gradients of -0.8 K or lower over larger part of the orbit**

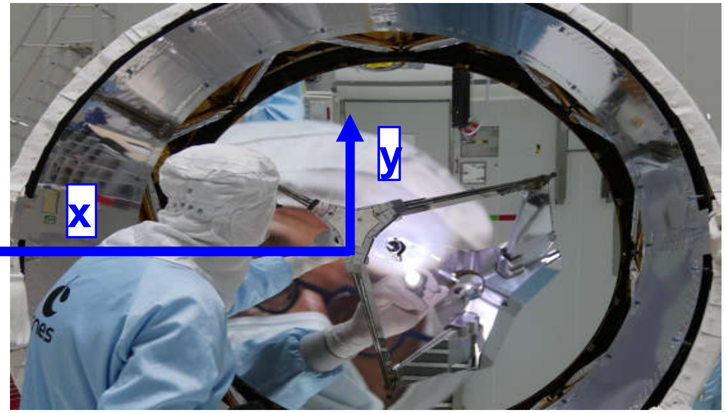
⇒ **North Pole conditions, inner part M1 warmer**

⇒ **next M1 tests planned for December-February**

defocus + beam tilt and wander



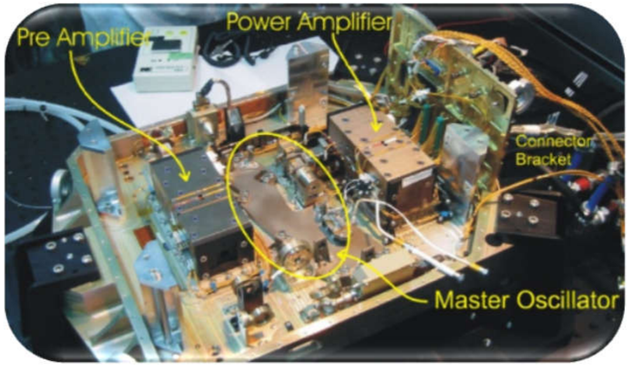
satellite flight direction

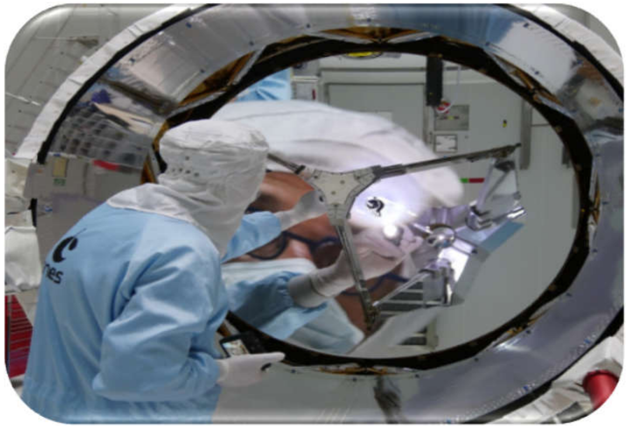


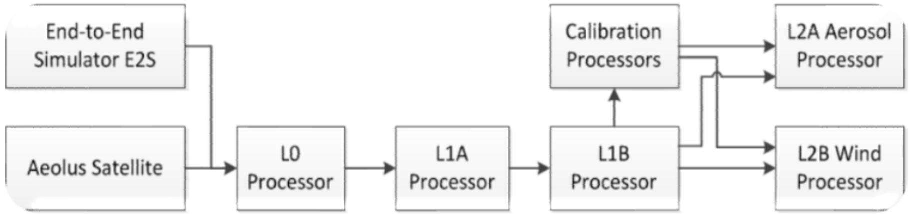
Figures by **Th. Flament (Météo-France)**

Outline of the talk

- evolution of random and systematic errors
  - main causes and correction for systematic errors
  - main causes for random error and signal levels
- **recent investigations on performance related issues**
- processor and data product evolution







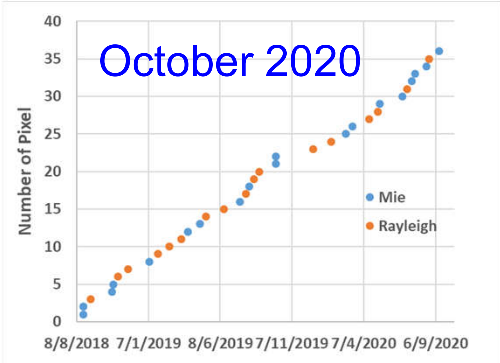
Recent results from assessment of ACCD detector

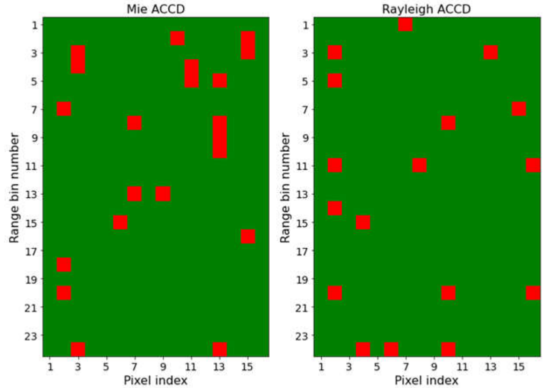
ACCD detector: currently 17 Rayleigh and 21 Mie **hot pixel**, a new hot pixel every ≈15 days => 10% hot pixel predicted for EOL (not critical), different characteristics RTS, Clock-Induced and causes (radiation, Clock-induced) => dark current levels could be reduced by changing operating temperature 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

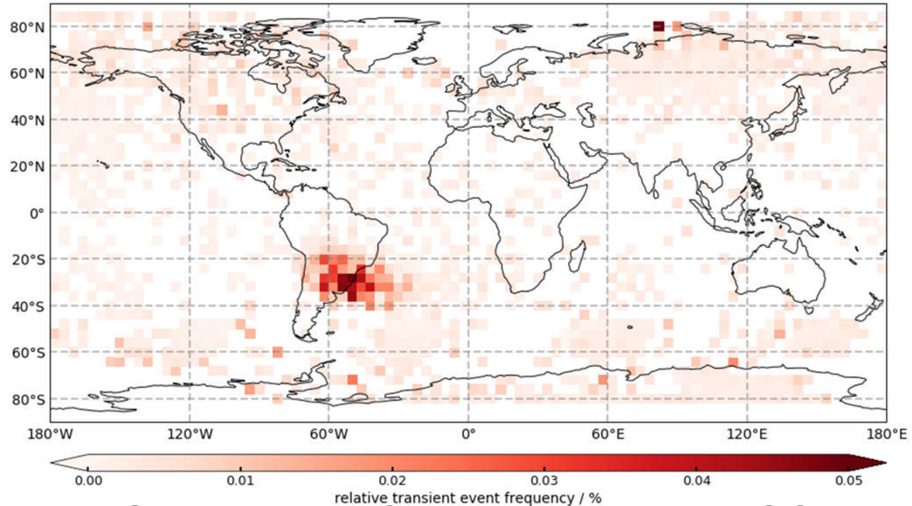
a manuscript will be submitted soon to AMT

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]







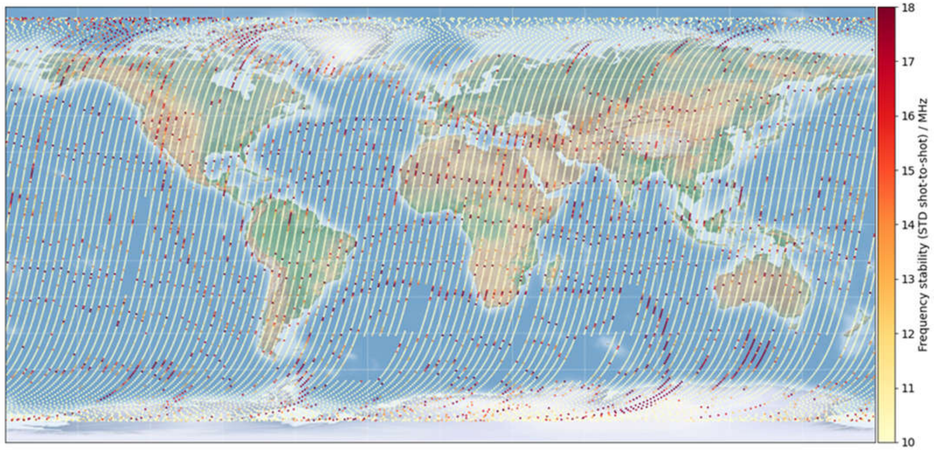
Occurrence of signal spikes on ACCD

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

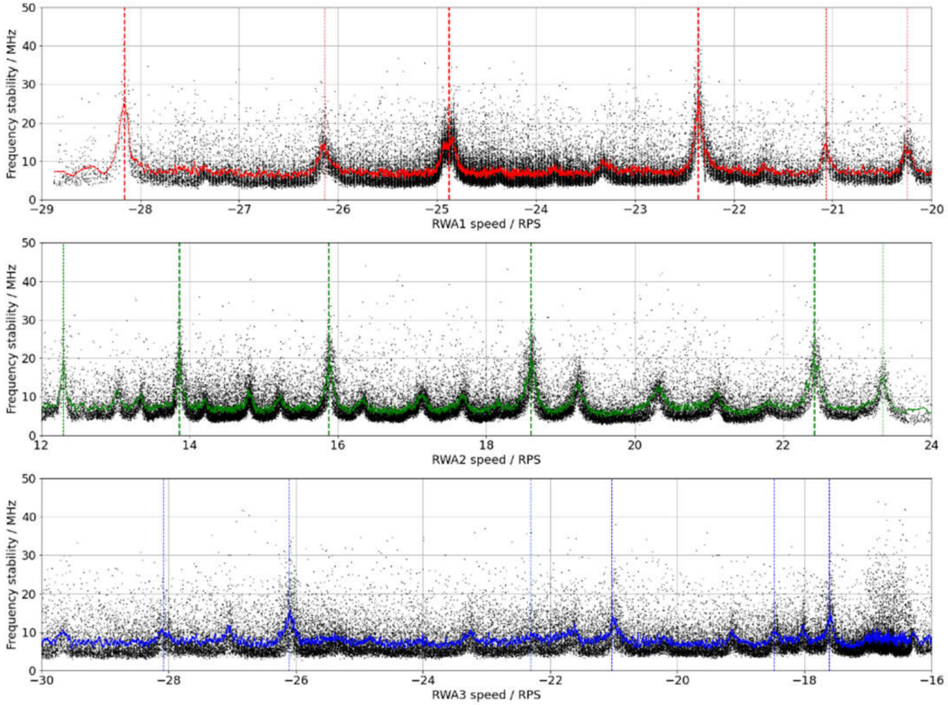
Recent results from assessment of laser frequency stability

laser frequency stability is good (8-10 MHz 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



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



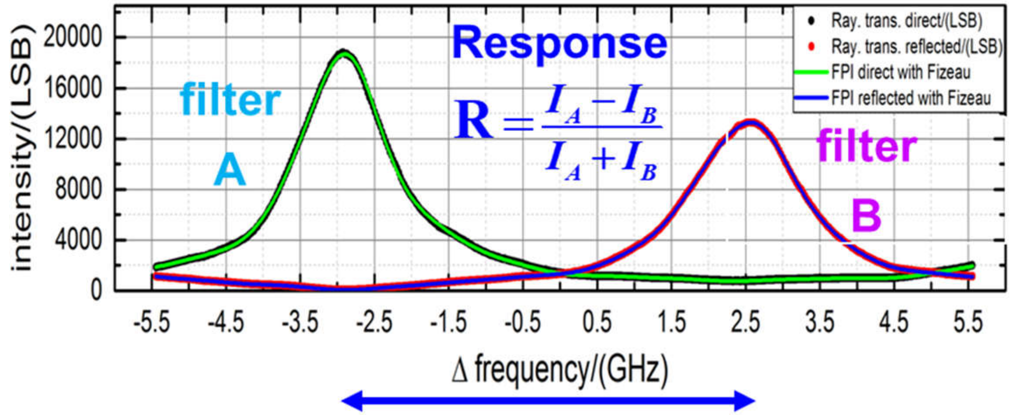
satellite reaction wheel speeds in RPS

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

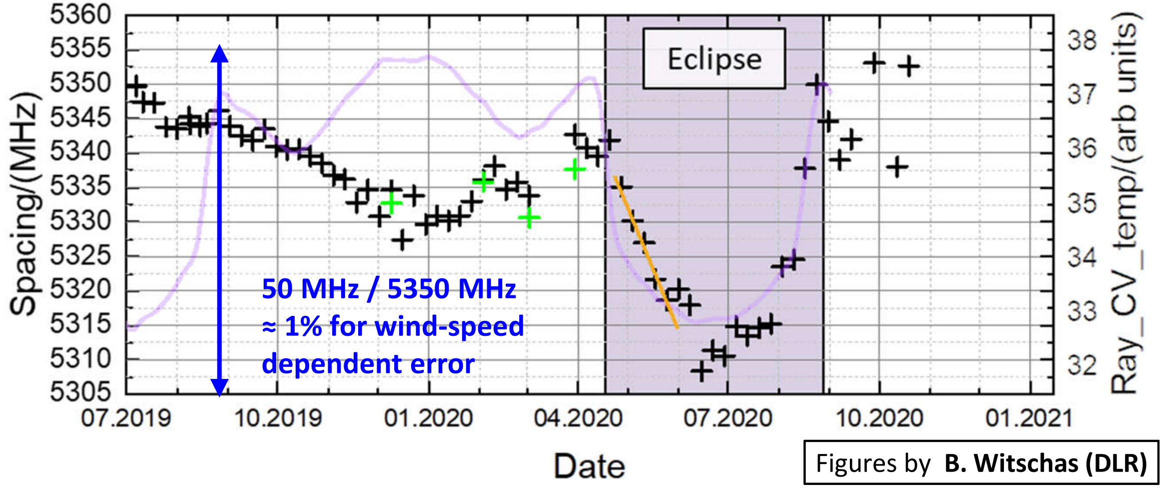
Figures by **O. Lux (DLR)**

Recent results from assessment of spectrometer drifts

spectrometers angle of incidence (AoI) drifts: strong drifts of the AoI present on both MSP and RSP on the internal and atmospheric paths as observed by different instrument modes (ISR, LBM, IDC), mainly due to large non-perpendicular AoI on internal path of ≈500 µrad (RSP); drift of AoI is related to laser LOS drift **and/or** drift between laser output and spectrometer input with strong influence of satellite temperature (eclipse season)



Rayleigh spectrometer filter spacing



Figures by **B. Witschas (DLR)**

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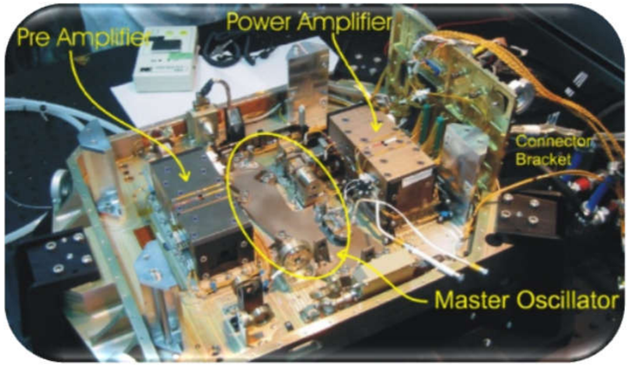
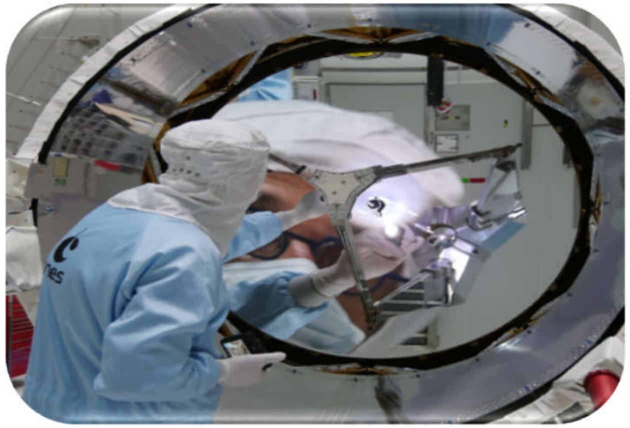
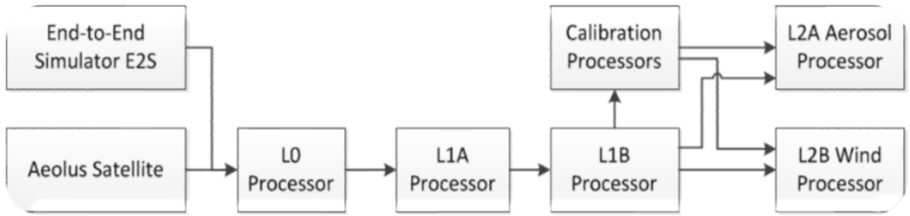
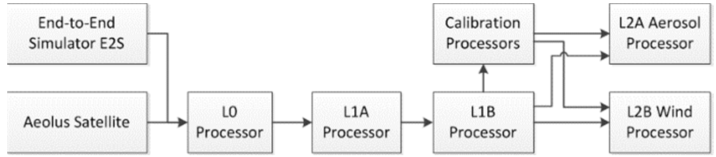
- **processor and data product evolution**







Aeolus processor evolution in 2020-2021



Third major processor release L0/L1A/L1B/ L2A/L2B and ACMF was delivered to ESA **end July 2020**

L1B updates:
- **Sat-LOS velocity correction**
- Improved DCO & DCMZ corrections
- Sun elevation and gyro angles in L1B product
- SR and SNR refinement for Mie

L2B updates:
- Improved scattering ratio calculation
- **Different SNR thres-holds for** classification of **Mie and Rayleigh**
- Option to flag winds invalid for specific periods **(blocklist)**

L2A updates:
- **New radiometric correction including orbital variation**
- New quality checks
- New user-friendly Python script for reading/plotting of L2A

Processor baseline update on **8 October 2020**: L1B V7.09.1, L2A V3.11 and L2B V3.40.2 were deployed

Reprocessing
14 Oct 20
FM-B 2019 data
Including M1 bias correction

Fourth major processor release L0/L1A/L1B/ L2A/L2B + ACMF will be submitted to ESA **end January 2021**

New processor versions from DISC and baseline update for NRT and reprocessing every 6 months with improvements in data quality for all products

Public data release of L2A data in 2021

Reprocessing
early 2021
FM-B June 19 – Oct 20

Processor baseline update is planned for **March 2021**: L1B V7.10, L2A V3.12 and L2B V3.50 will be deployed

Potential L2A updates:
- Further tuning of radiometric correction
- Improvement of relative error estimates
- Additional feature classification using ATLID approach

Potential L2B updates:
- Use of averaged Mie non-linearity for wind correction
- Study of scattering ratio for RBC calibration and potential of NWP calibration

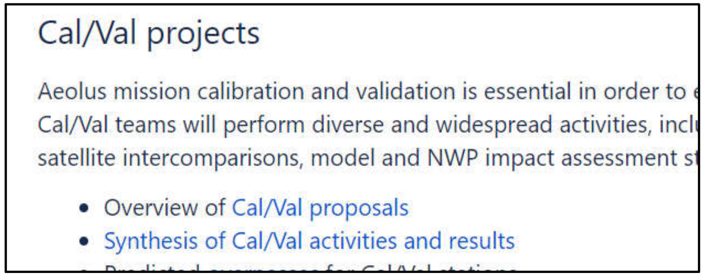
Potential L1B updates:
- energy correction for Mie channel ISR
- Ground bin & DEM info in L1B M/RRC product
- add more AOCS flags to product for QC
- Improve LBM mode processing

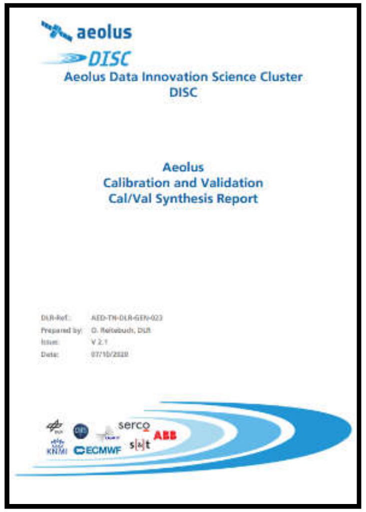
L1B+L2A processor by **D. Huber (DoRIT)**
L2B processor by **J. de Kloe (KNMI)**
ACMF calibration processors by **ABB+S&T**

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

Contribution of Cal/Val teams

- **Cal/Val Team reports** provide significant input for DISC/ESA on data quality assessment, algorithms and processor evolution in addition **to Cal/Val Wiki discussion items and workshop presentations**
- 14 Cal/Val team reports were delivered to ESA in time period May-July 2020 and are summarized in a report provided on the Cal/Val WIKI on 8 October 2020





error	L2B Mie cloudy	L2B Rayleigh clear	Team
random from instru-ment compa-rison	FM-A: 2-4 m/s, FM-B: 3-5 m/s (short hor. int. length) March 2020: 4-5 m/s	FM-A: 4-6 m/s, FM-B: 4-6 m/s, March 2020: 6 m/s	EVAA-LMU-RWP (up to B06), Germany
	4-5.7 m/s	5-7.7 m/s	EVAA-Tropos Raso Leipzig (B06-09)
	no comparison	5.2 m/s (rmse)	USA-DAWN April 2019, Pacific
	no comparison	asc./desc. RMSE 6.4 / 5.7 m/s FM-A 5.8 m/s, 5.5 m/s FM-A 4.9 m/s / 6.0 m/s FM-B	SMHI-IRF Kiruna radar 2018/2019 FM-A SMHI-IRF Antarctica radar 2019 FM-A/B
random from NWP	4-5 m/s	4-6 m/s	ECCC Canada (FM-B)
	2-3 m/s (>800 hPa)	4-5 m/s	SMHI (Sept/Oct 2018)

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 early FM-B dataset
- 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