CONTRIBUTIONS FROM DISC TO THE AEOLUS MISSION IN 2022 AND 2023

Oliver Reitebuch on behalf of the Aeolus DISC Team

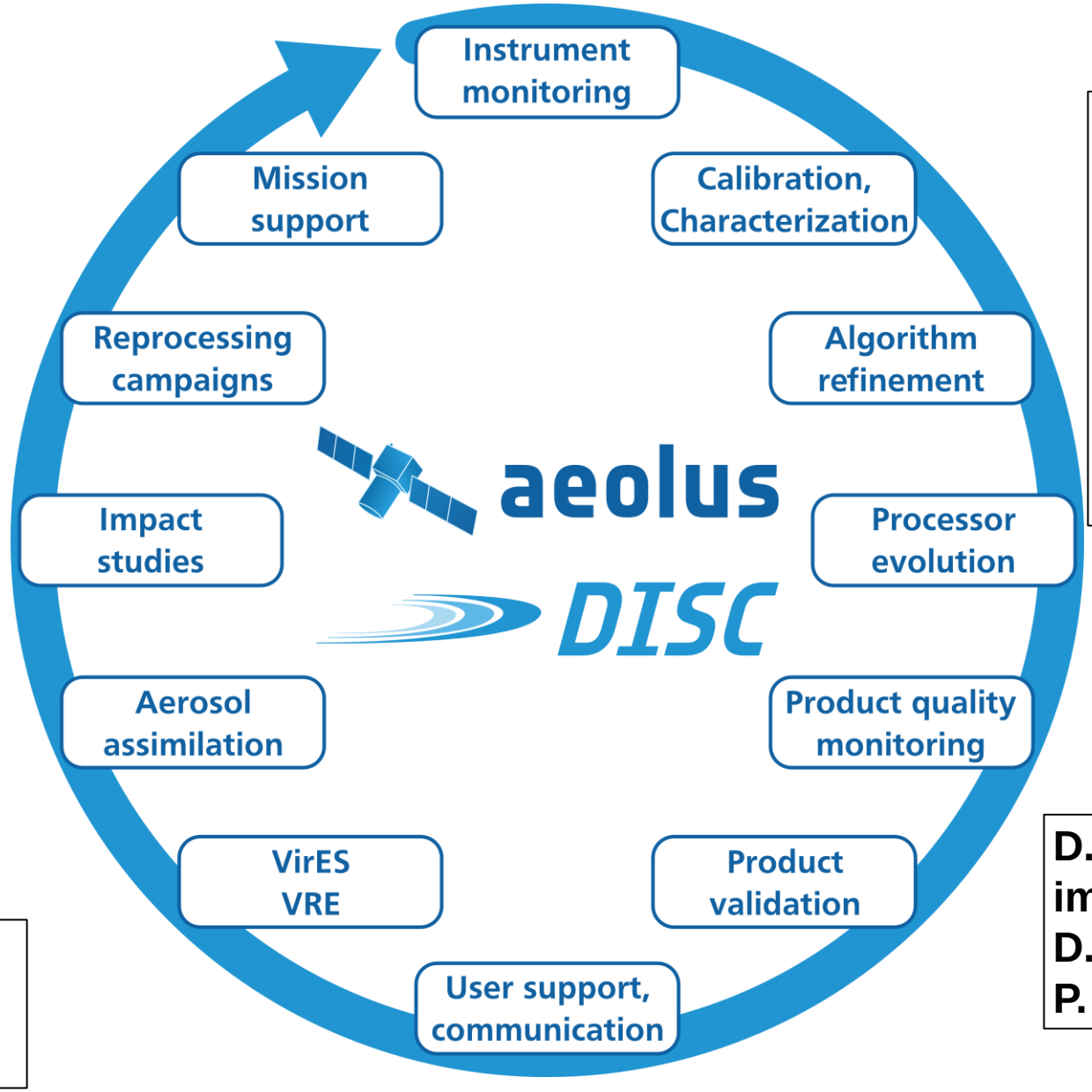
Aeolus Science Conference – 22-26 May 2023 - Rhodes

The Aeolus Data Innovation Science Cluster

Oliver Reitebuch[1] Isabell Krisch[1], Christian Lemmerz[1], Oliver Lux[1], Uwe Marksteiner[1], Nafiseh Masoumzadeh[1], *Fabian Weiler[1]*, Benjamin Witschas[1], Vittoria Cito Filomarino[1], Markus Meringer[2], Karsten Schmidt[2], Dorit Huber[3], Ines Nikolaus[4], Frédéric Fabre[5], Michael Vaughan[6], Katja Reissig[7], *Alain Dabas[8]*, *Thomas Flament[8]*, *Adrien Lacour[8]*, *Jean-Francois Mahfouf[8]*, *Ibrahim Seck[8]*, Saleh Abdalla[9], *Lars Isaksen[9]*, Michael Rennie[9], Angela Benedetti[9], Will McLean[9], Karen Henry[9], Dave Donovan[10], Jos de Kloe[10], Gert-Jan Marseille[10], Ad Stoffelen[10], Ping Wang[10], Gerd-Jan van Zadelhoff[10], Gaetan Perron[11], Sebastian Jupin-Langlois[11], *Bas Pijnacker Hordijk[12]*, Filippo Tagliacarne[12], Marcella Veneziani[12], Simone Bucci[13], Giacomo Gostinicchi[13], Lorenzo Di Ciolo[13], Marco Galli[13], Massimo Cardaci[13], Sebastian Bley[14], Dimitri Trapon[8,14], *Alexander Geiss[15]*, *Thomas Kanitz[16]*, *Anne-Grete Straume[16]*, Denny Wernham[16], Trismono Krisna[16], Jonas von Bismarck[17], Vittorio Trivigno[17], Massimo Romanazzo[17], Stefano Aprile[17], Tommaso Parrinello[17]

- DISC established 2019 from teams cooperating since 2003
- 14 international partners with about 40 scientists and engineers coordinated by DLR
- Funded by ESA with strong links to all ESA entities (ESRIN, ESTEC, ESOC), space industry (Airbus, Leonardo) and Science, Cal/Val community

DISC Tasks and Contributions to Aeolus Science Conference 2023



O. Reitebuch: DISC
N. Masoumzadeh: Reprocessing

M. Rennie: NWP impact
I. Krisch: QBO

W. McLean: Aerosol assimilation
S. Bley: Wind validation
Ch. Lemmerz: Tropical campaign

oral presentations
poster presentations
campaign/science

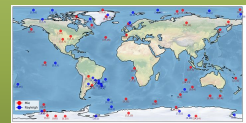
O. Lux: Instrument Performance
K. Schmidt: Solar and atmospheric signals
U. Marksteiner: response calibrations IRC
V. Cito-Filomarino: ground returns

G.-J. Marseille: Rayleigh Cloudy Winds
B. Witschas: New Mie algorithm

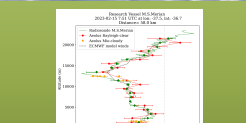
D. Trapon: Aerosol L2A improvements
D. Donovan: ATLID algorithms
P. Wang: Aeolus vs. CALIPSO

OUTLINE

Aeolus highlights in 2022/2023, reprocessing and processor development



Timelines of signal levels, random errors, and hot pixels

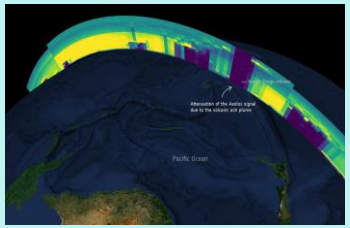


Recent results from wind and aerosol product and Cal/Val

Summary and Conclusion

Aeolus and DISC highlights in 2022 / 2023

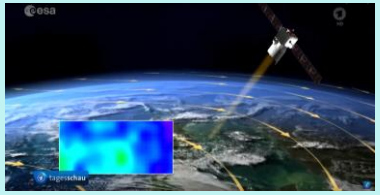
January 2022:
Aeolus data helped to track Hunga Tonga volcanic eruption



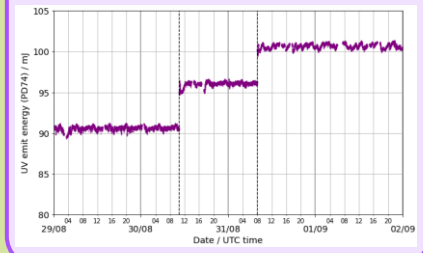
29 March 2022:
Processor baseline update B14

28 March – 01 April 2022:
3rd Anniversary Conference in Taormina

23 – 27 May 2022:
Aeolus prominent at ESA LPS in Bonn and in the reporting media



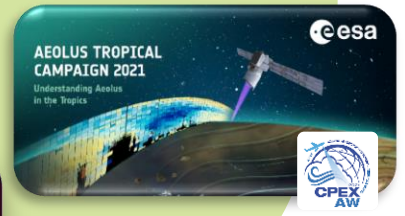
30/31 August 2022:
Laser energy increase to more than 100 mJ



8/9 September 2022:
Doppler wind lidar workshop at EUMETSAT discussing the way forward for EPS-Aeolus

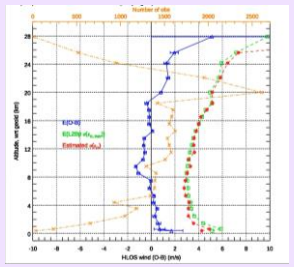
13 September 2022:
Processor baseline update B15

September 2022:
Tropical campaign in Cap Verde with NASA participation



Nov /2022
ESA CMIN for Aeolus 2

01 December 2022:
FM-A NRT data becomes available to the public



16 February 2023:
Calibrated Rayleigh cloudy winds available

1 March 2023
NRT products back

Aeolus laser shut-down

21 Feb 2023

18 April 2023:
Processor baseline update B16

30 April 2023
End of nominal operations and start of EOL activities

08 March 2023:
Public release of B11 L2A NRT dataset from 2020-2021

3 October 2022:
Switch off FM-B

22 November 2022:
Public release of 3rd reprocessed dataset → 4 years of high-quality Aeolus data

Summer 2023 assisted reentry

Reprocessing of Aeolus observations

poster by N. Masoumzadeh

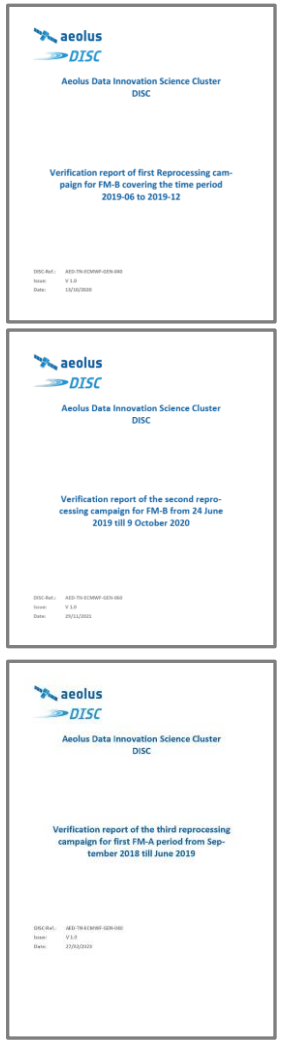
DLR

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 data products published on 22 Nov 2023; final verification report available (27 Feb 2023) **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***



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

Nov 2022

Re-processed **FM-A data** with hot-pixel and M1 **correction** (B14) available on 22 November 2022

2023-2024

Re-processing of **complete Aeolus mission** since launch with optimized processor settings and processor version **(B16) will be available early 2024 (FM-B) and early 2025 (FM-A**)

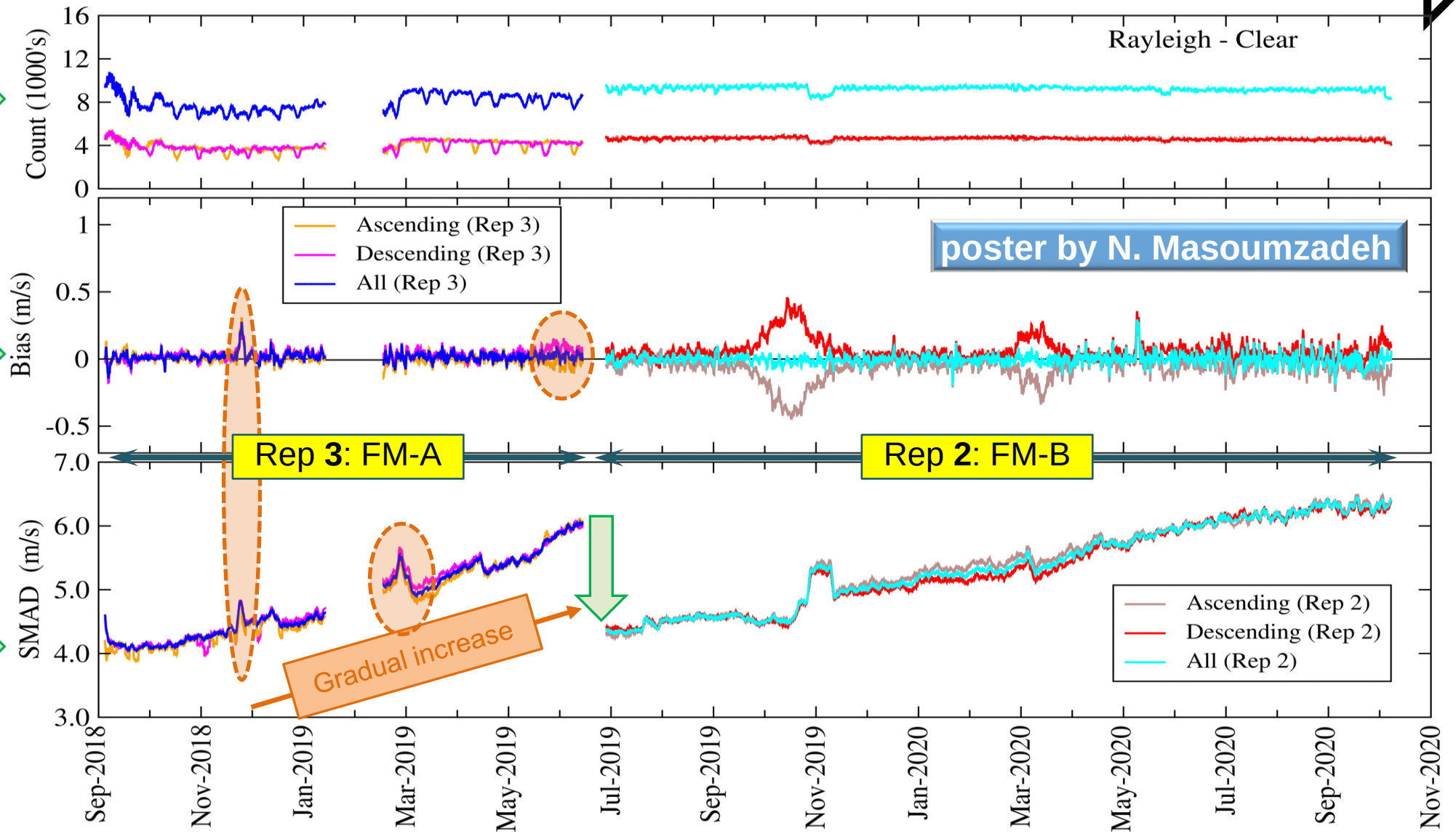
* AEL-PRO, AEL-FM and MLE are flagged invalid in B14

2nd and 3rd reprocessing of Aeolus for FM-B / FM-A period: Rayleigh

Num. of obs. ~ constant

V. small bias

Small SMAD



SMAD = scaled median absolute difference = 1.48 MAD

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

Major updates for baseline 16 data products since 18 April 2023

L1B processor V7.14.1:

- **Update of Rayleigh signal-to-noise-ratio (SNR) calculation**: The dark current offset and read-out noise are added to the Rayleigh SNR calculation; this effects **Rayleigh estimated errors** in the L2B product.
- **New dark current offset (DCO) correction using orbital means:** This slightly improves the random errors of the wind products (~1-2%).
- Due to a new **hot pixel issue in range gate 16** appearing in December 2022, a **new flag** has been introduced **to turn off the hot pixel correction for single pixels**.

L2A processor V3.16:

- **New QC in MLE subBRC:** A quality flag has been added to the higher horizontal resolution (subBRC) MLE PCD
- The **Aeolus Feature Mask (AEL-FM) and the Aeolus Profile (AEL-PRO) product is flagged valid**
- **Improved Cloud/aerosol discrimination in AEL-FM / AEL-PRO processing**

L2B processor V3.90:

- A **new residual threshold option** has been added as QC for the **Mie Core output**. This removes a lot of gross errors in the low signal Mie winds (e.g. in aerosols).
- A new **Rayleigh channel wind bias correction based on the Mie channel emitted frequency** has been added.

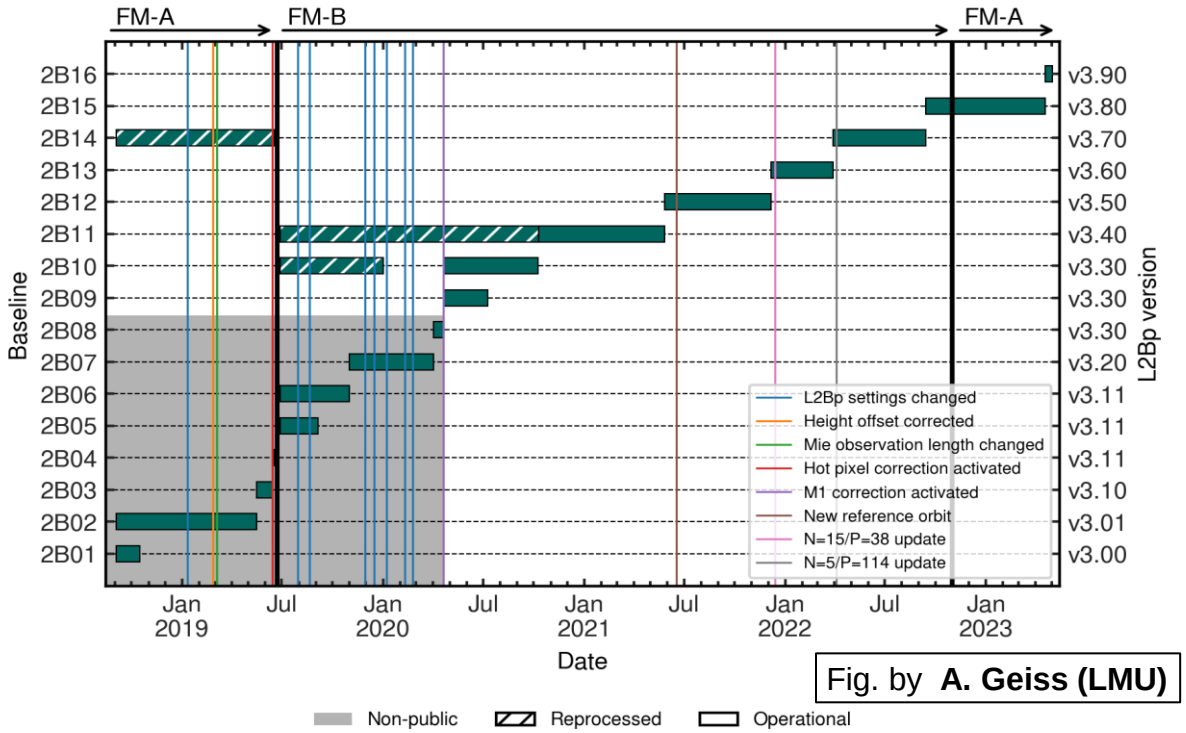
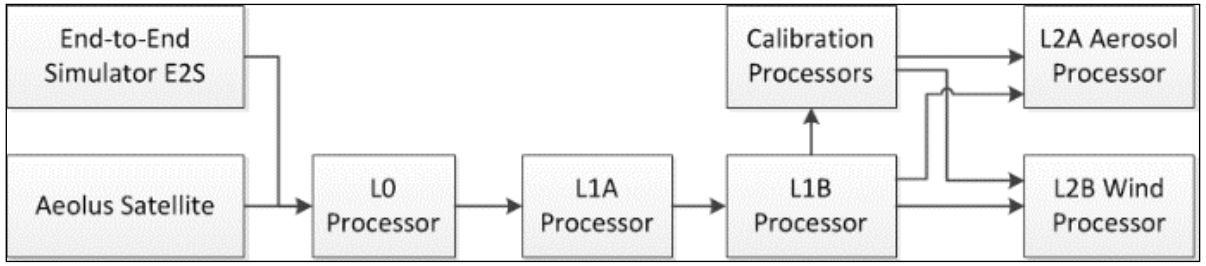


Fig. by **A. Geiss (LMU)**



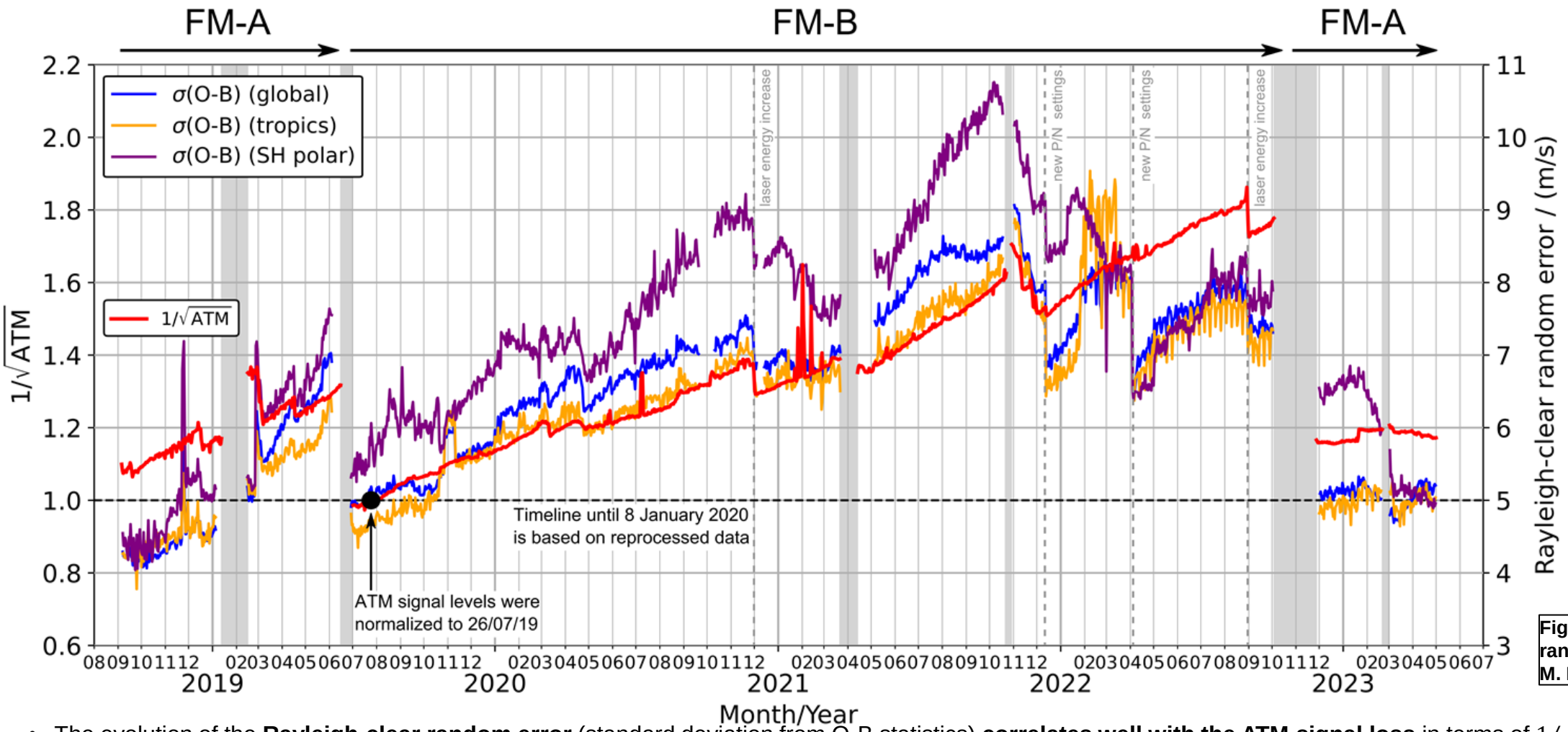
E2S, L0/L1A/L1B and L2A operational processor by **D. Huber (DoRIT)**
L2B operational processor by **J. de Kloe (KNMI)**
calibration processors at ACMF and codadef by **S&T and ABB**
processor handover and anomaly management by **Serco**

Timelines of signal levels, random errors, and hot pixels

Evolution of the Rayleigh random error

talk by O. Lux / M. Rennie

DLR



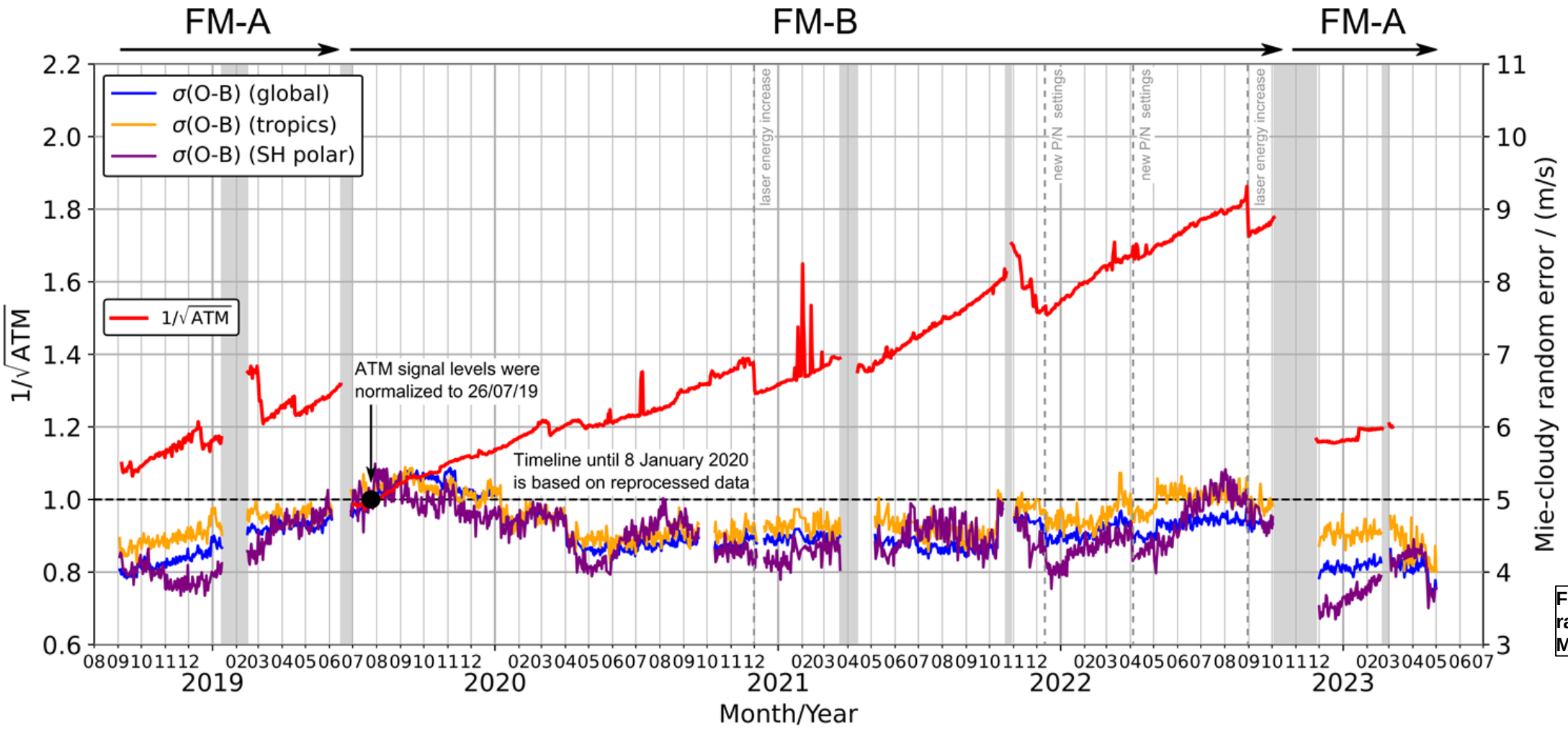
Figures by O. Lux (DLR)
random error by
M. Rennie (ECMWF)

- The evolution of the **Rayleigh-clear random error** (standard deviation from O-B statistics) **correlates well with the ATM signal loss** in terms of $1/\sqrt{\mathrm{ATM}}$, as it is **dominated by shot noise** from the detection process
- The **changes in the P/N settings in December 2021 and April 2022 have reduced the random error**, but the ATM signal loss leads to an increasing impact of the solar background, particularly in the extra-tropics
- Tonga plume in February/March 2022 increased random error in the tropics, new RBS in extratropics (1 km thick) end-August 2022 reduced random error
- **Switchback to FM-A in November 2022 resulted in large improvement of the random error** to about 5.0 m/s (global)

Evolution of the Mie random error

talk by O. Lux / M. Rennie

DLR

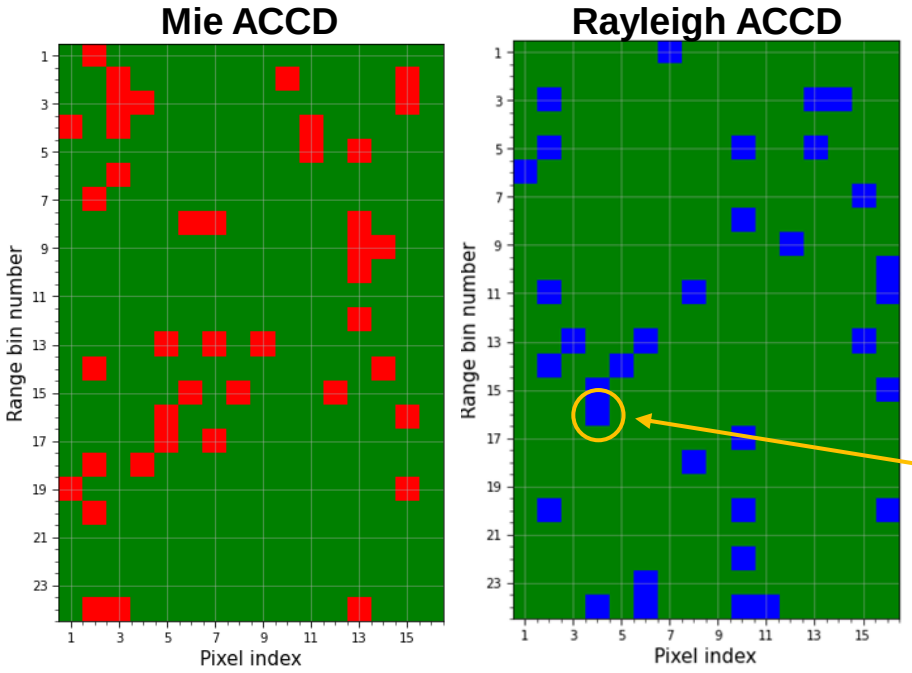


Figures by O. Lux (DLR)
random error by
M. Rennie (ECMWF)

- **Mie-cloudy winds have higher precision (4…5 m/s)** than Rayleigh-clear due to much stronger backscatter from clouds
- Hence, **Mie random error is much less driven by laser energy and atmospheric receive path transmission and solar background levels, due to significantly lower spectral bandwidth of Mie spectrometer**
- It is rather **influenced by changes in the data processing algorithms** during the mission
- **Switchback to FM-A in November 2022 improved the random error from about 4.5 m/s to 4 m/s (global)**

talk by O. Lux

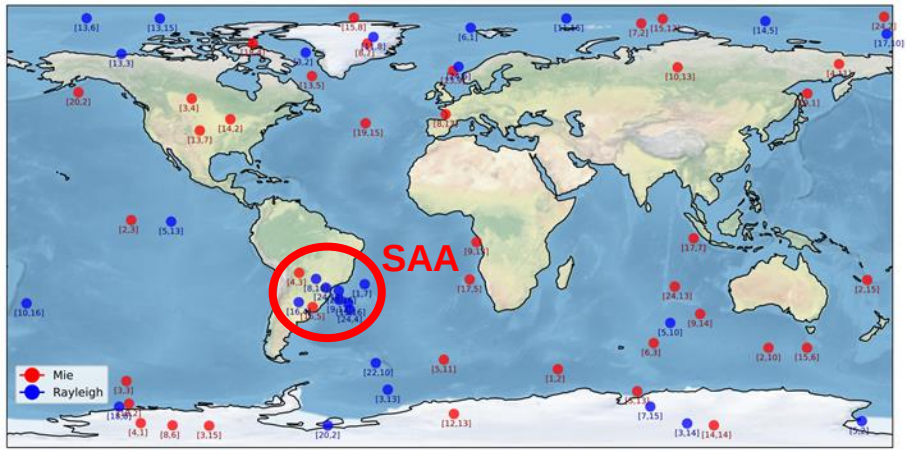
Evolution of the hot pixels



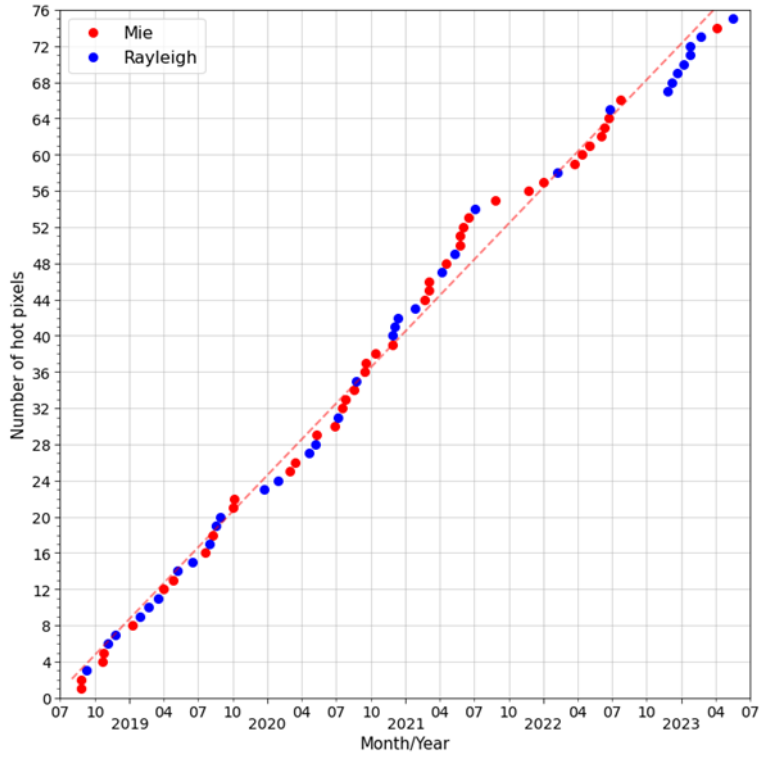
- **75 hot pixels (Mie: 41, Rayleigh: 34) on the two ACCDs appeared during the mission corresponding to about 10% of all pixels in the memory zone.**
- **Nearly linear increase over the mission** (1 new hot pixel every 2…3 weeks)
- However, increasing departures from linearity, e.g. gap between July and Nov 2022
- **Rayleigh pixel [15,3]** became hot on 22/12/2022 and has **caused wind bias of ≈8 m/s** in corresponding range bin 15 despite DCMZ correction (analysis on-going).

Red/blue squares indicate hot pixels

Rayleigh hot pixel [15,3] where DCMZ correction does not work!



Preponderance of hot pixel activations around the poles and the South Atlantic Anomaly (SAA) region: enhanced influence of cosmic rays

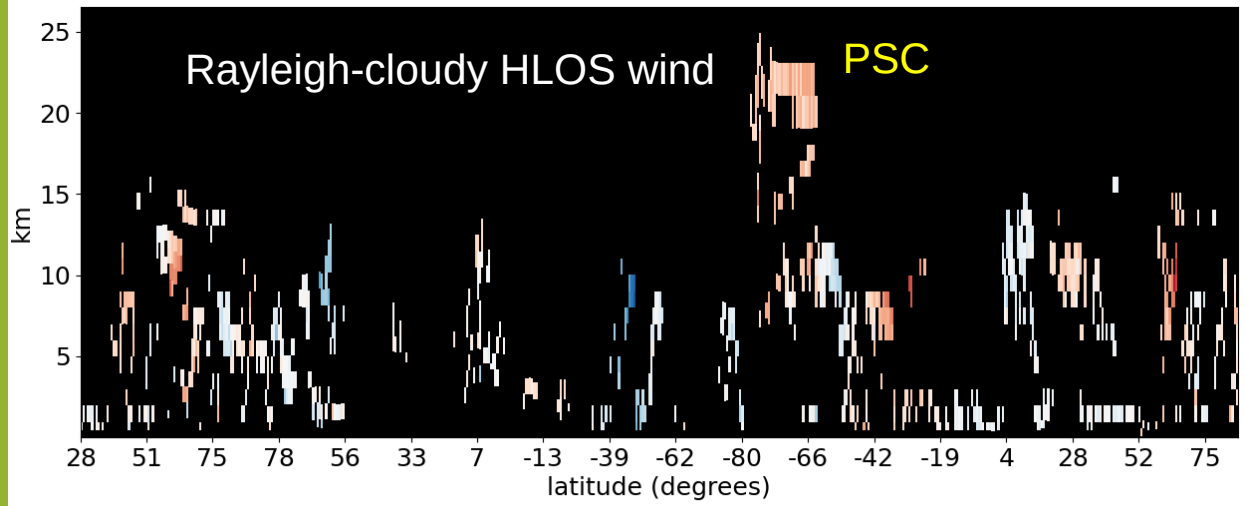


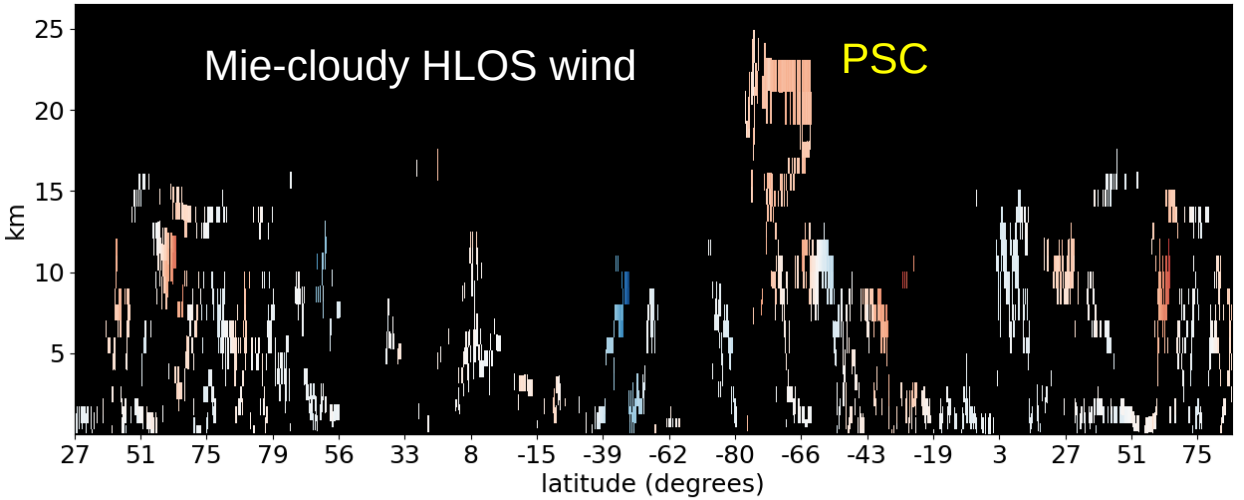
Figures: O. Lux (DLR)

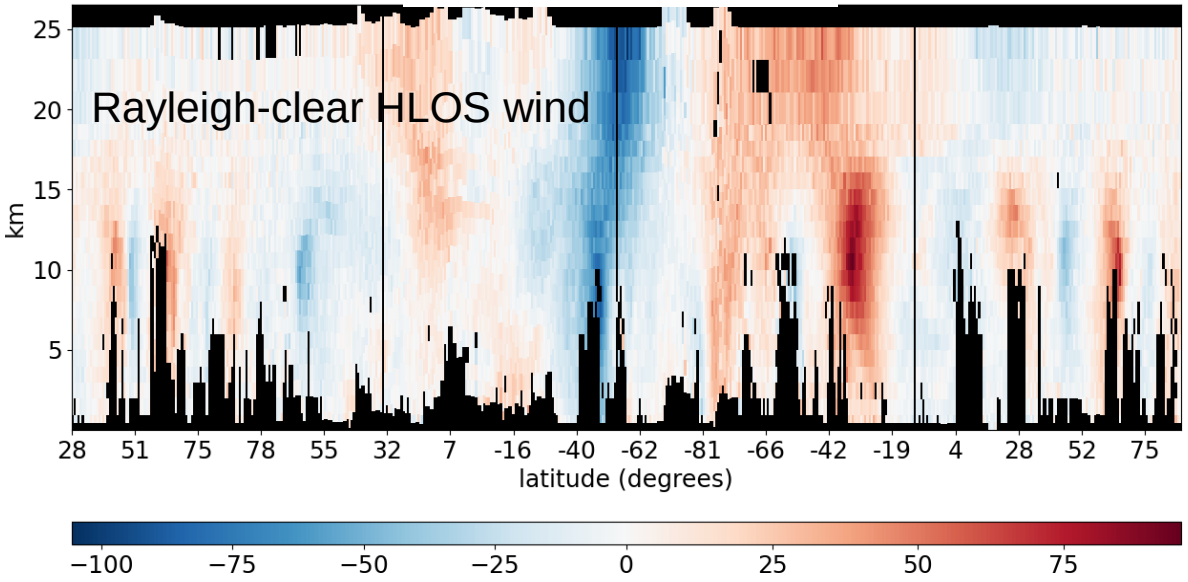
L2B wind and L2A aerosol product updates

Rayleigh cloudy winds with improved errors since Feb 2023

talk by G. J. Marseille







- Rayleigh-cloudy winds are similar to Mie-cloudy winds (visually) and are derived with NWP calibration
- Rayleigh-cloudy winds have lower resolution, but are more representative to model winds (resolution)

Aeolus Rayleigh-channel winds in cloudy conditions

Gert-Jan Marseille[1] | Jos de Kloe[1] | Alain Dabas[2] | Thomas Flament[2,3] | Michael Rennie[4]

submitted to QJRMS

Figures by **G.-J Marseille (KNMI)**

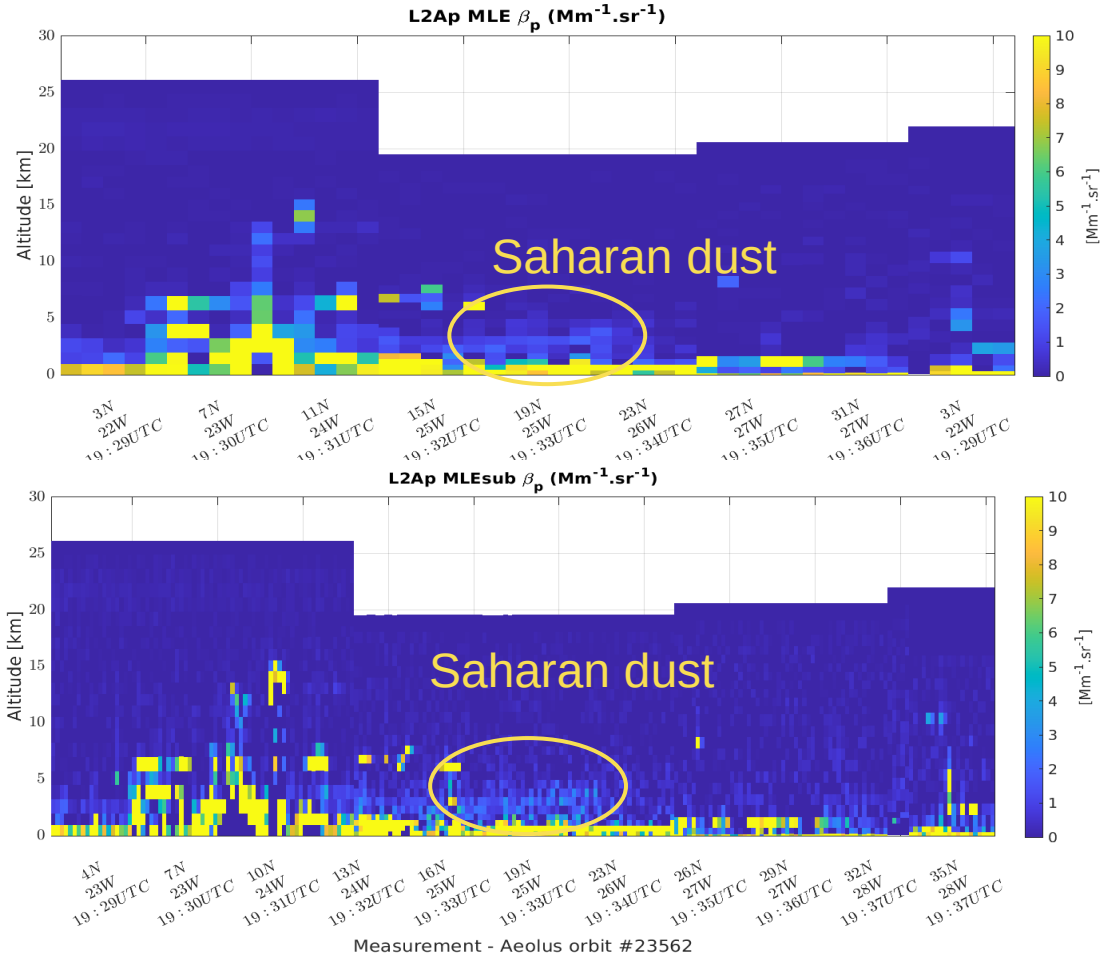
Latest L2A developments for aerosol optical properties

talk by D. Trapon

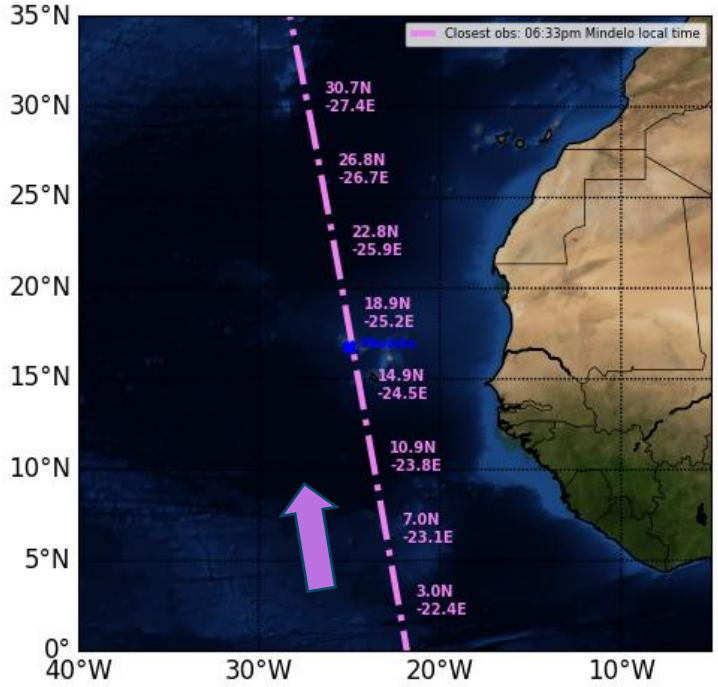
Main evolutions for Baseline 15/16 for L2A processor

- **Implementation of Aerosol Algorithm MLE (Maximum Likelihood Estimation) at finer horizontal resolution ~17.4km** (→ activated in L2A operational product B16)
- **Add Quality Checks (QC) flag for MLE given at coarser horizontal resolution ~87km** (→ activated in L2A B16)
- **Add Quality Checks (QC) flag for MLE given at finer horizontal resolution ~17.4km** (→ activated in L2A B16)

Horizontal resolution X5



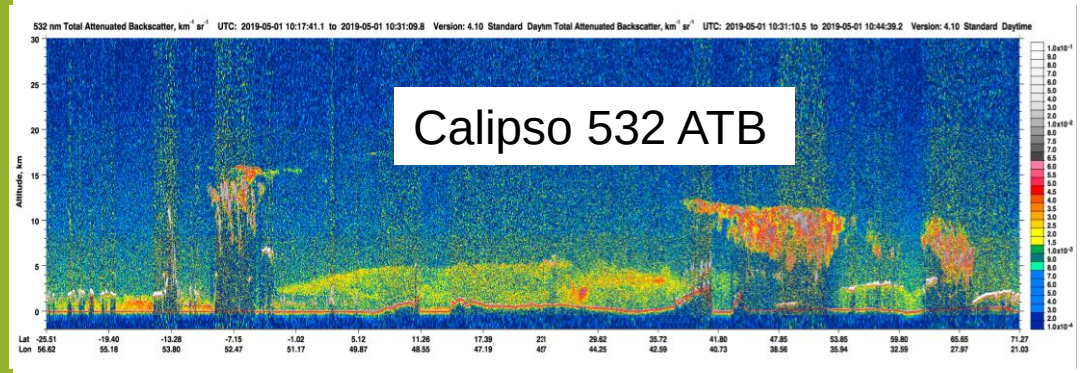
backscatter coefficient [Mm^{-1} sr^{-1}]



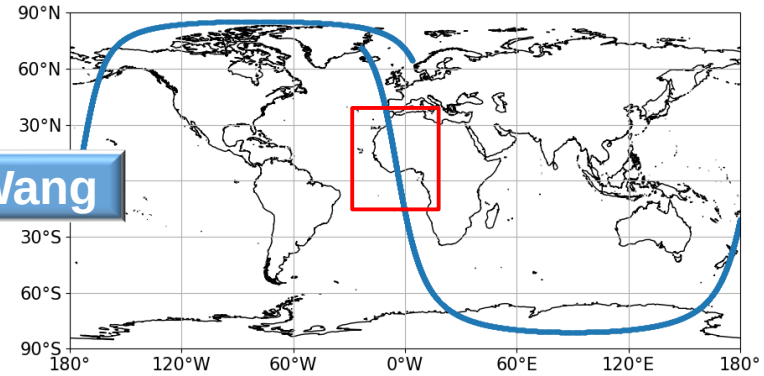
backscatter coefficient [Mm^{-1} sr^{-1}]

Figures by **D. Trapon (TROPOS)**

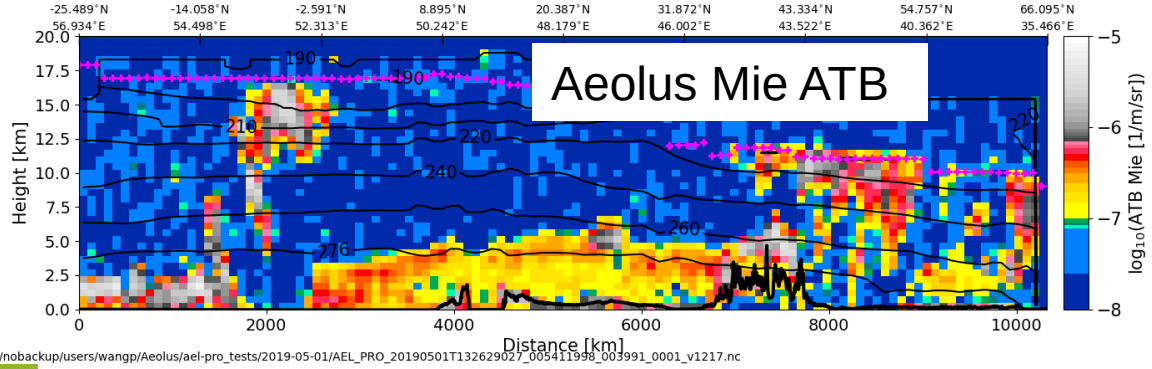
Calipso and Aeolus optical product

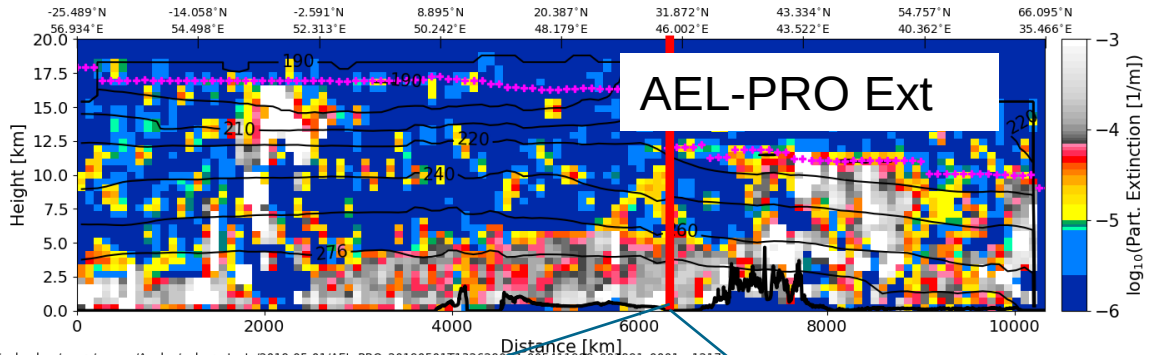


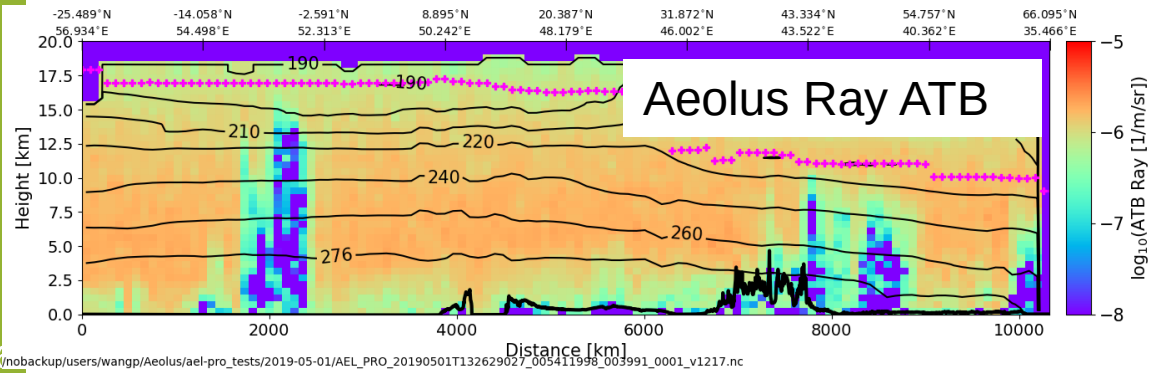
talk by D. Donovan / P. Wang

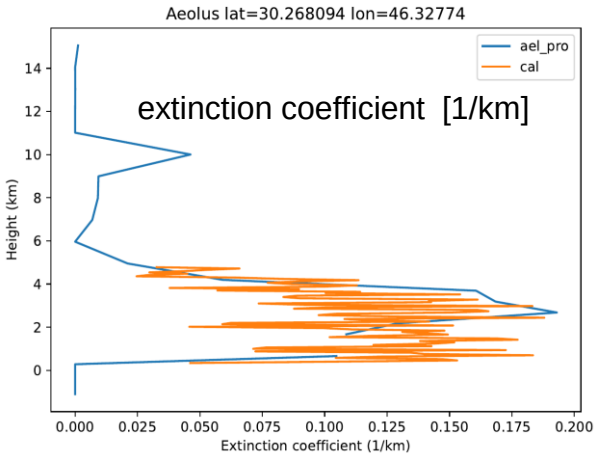


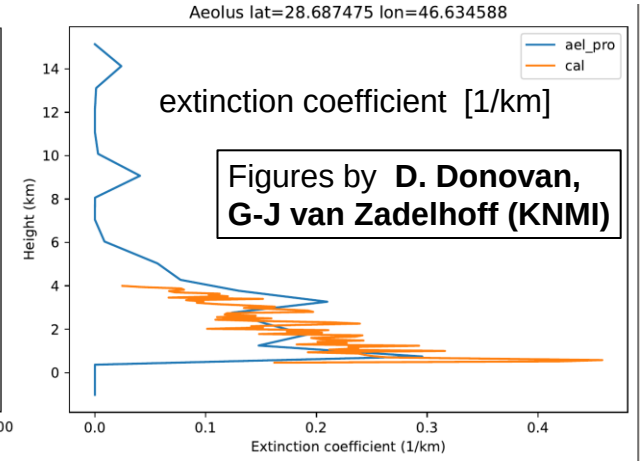
May 01, 2019
Co-location within 20 km and 3.5 hrs.











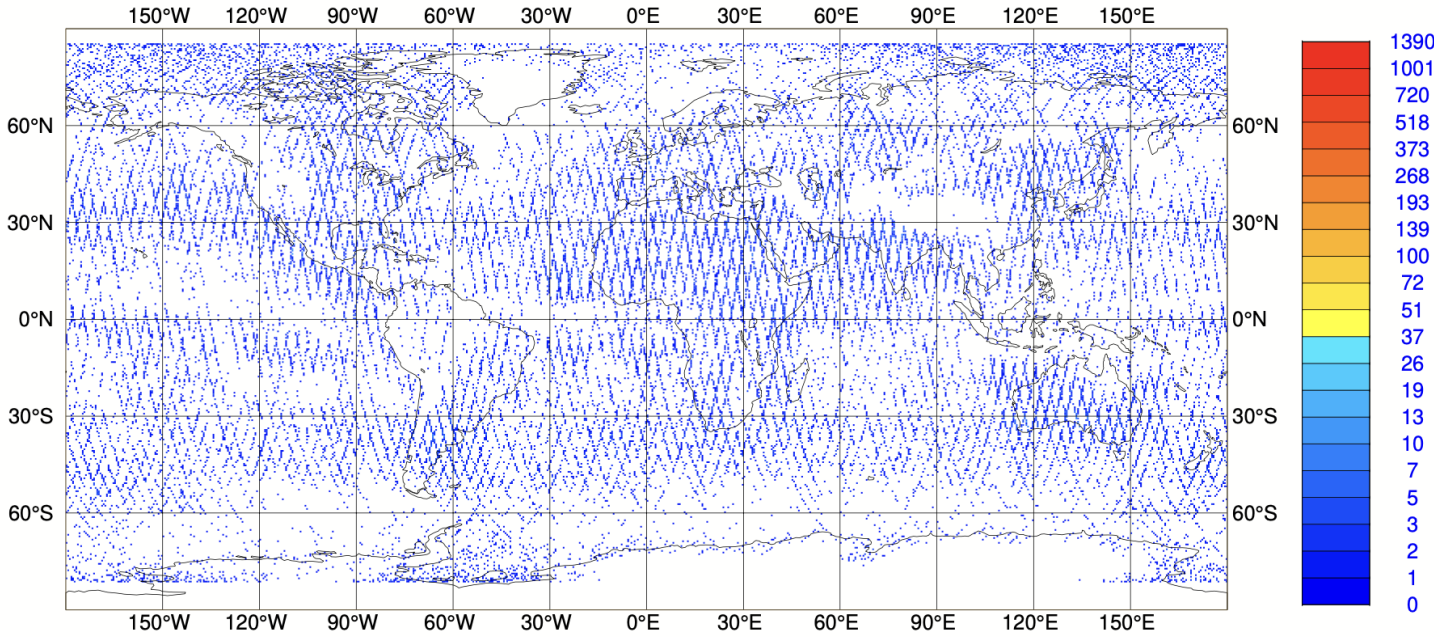
Figures by **D. Donovan, G-J van Zadelhoff (KNMI)**

Monitoring of aerosol product at ECMWF

NRT monitoring in CY48R1: observation coverage and temporal statistics for Feb 2023

talk by W. McLean

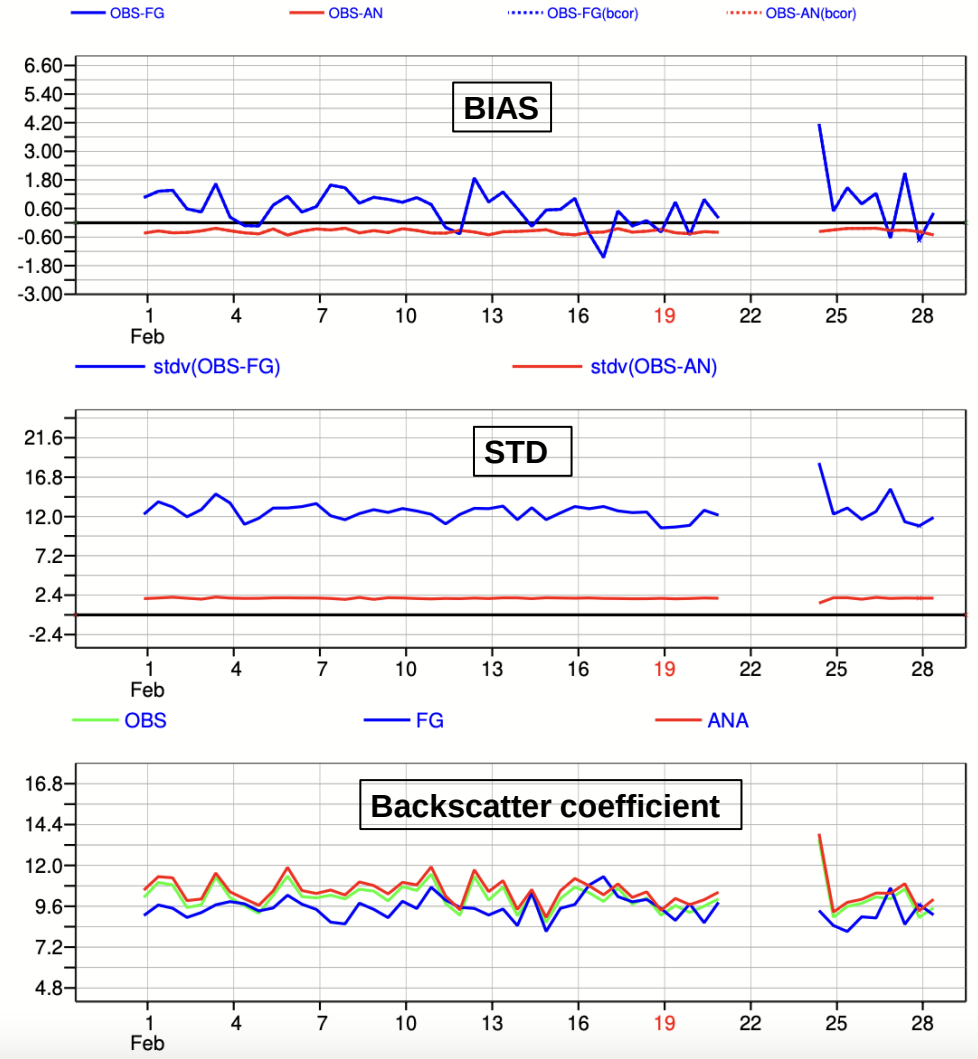
AEOLUS LIDAR ASSIMILATION WITH CLOUD SCREENING
NUMBER OF OBSERVATIONS (USED)
DATA PERIOD = 2023-01-31 21 - 2023-02-28 09
EXP = HXVI, LEVEL = 700.00 - 1013.25 HPA
Min: 0 Max: 12 Mean: 2.1 Total: 39263.0
GRID: 0.50x 0.50



All units are in $10^{-7}\,\mathrm{m}^{-1}\mathrm{sr}^{-1}$.

AEOLUS LIDAR ASSIMILATION WITH CLOUD SCREENING
LEVEL =700.00 - 1013.25 HPA, USED DATA [TIME STEP = 12 HOURS]
Area: lon_w= 180.0, lon_e= 180.0, lat_s= -90.0, lat_n= 90.0 (over All_surfaces)
EXP = HXVI

Backscatter coefficient in 10^{-7} m^{-1} sr^{-1}



Slide by **W. McLean (ECMWF)**

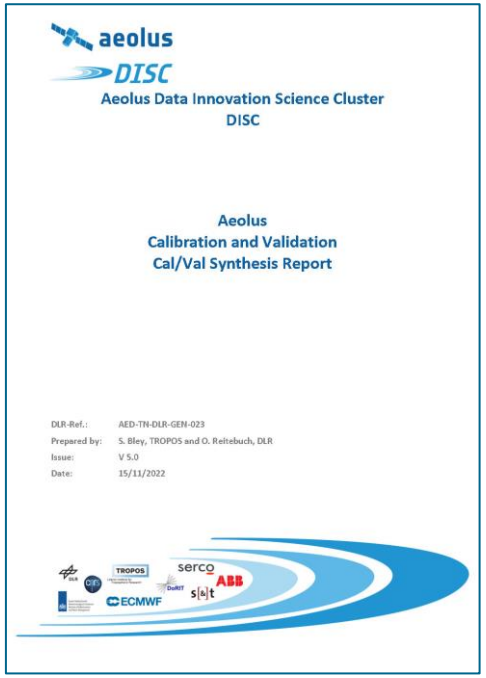
Synthesis of Cal/Val Activities

DLR

Cal/Val synthesis and Scientific Outreach

talk by S. Bley

- 9 Cal/Val teams (NOA, TROPOS, LATMOS, KIT, NICT, DWD, LMU, UK MetOffice, Uni Bath, DTU Denmark, EARLINET-ACTRIS community) provided Cal/Val status reports in Sep-Nov 2022
- Synthesis in **5th DISC Cal/Val Synthesis Report** (V5.0, 15 Nov 2022)
- Active scientific outreach and publication record for Aeolus
  - Special Issue **QJRMS: 9**
  - Special Issue **AMT/ACP/WCD: 50**
  - Other journals, e.g. GRL, Opt. Lett.



- Upcoming years will result in **further exploration** of Aeolus and synthesis of results based on almost 5 years of unique observations

- Active participation of community in **Aeolus Range-Bin Setting Working Group** led to important and significant adaptations of range-bins during the mission, e.g. QBO setting, various campaign settings, Hunga-Tonga setting

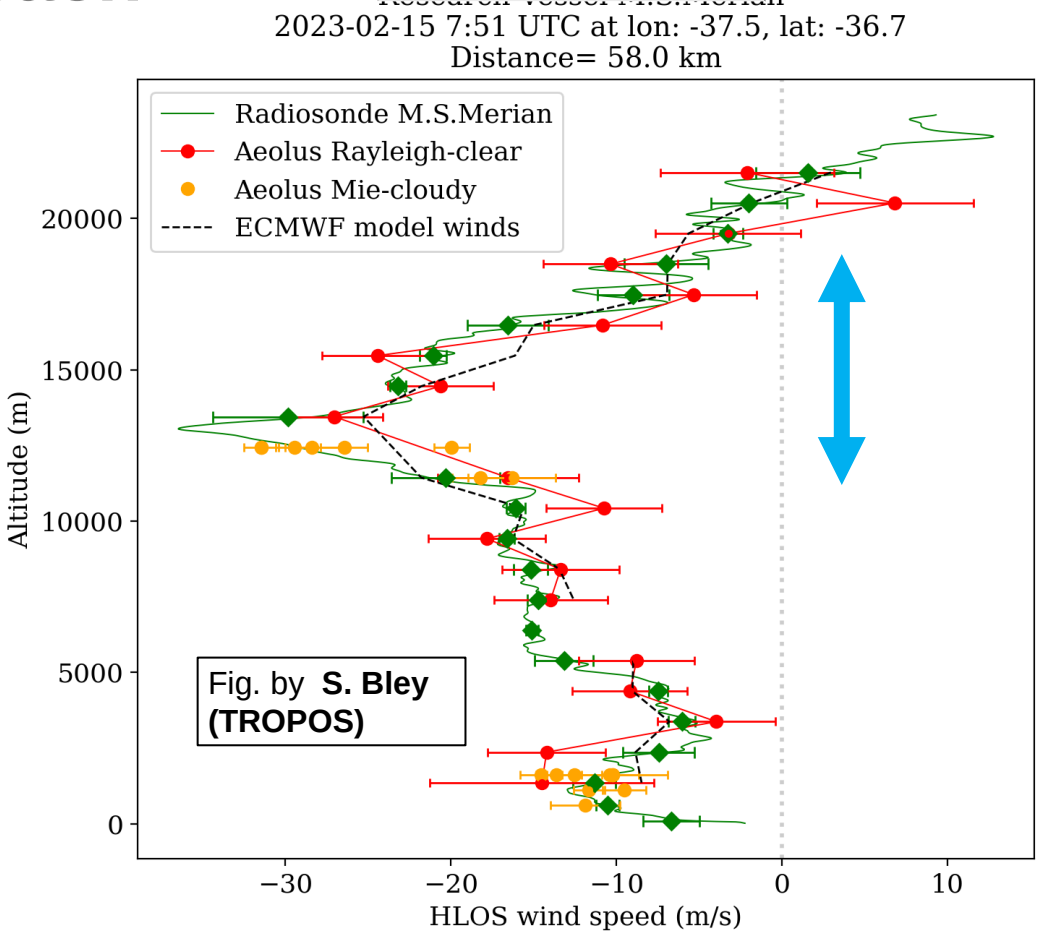
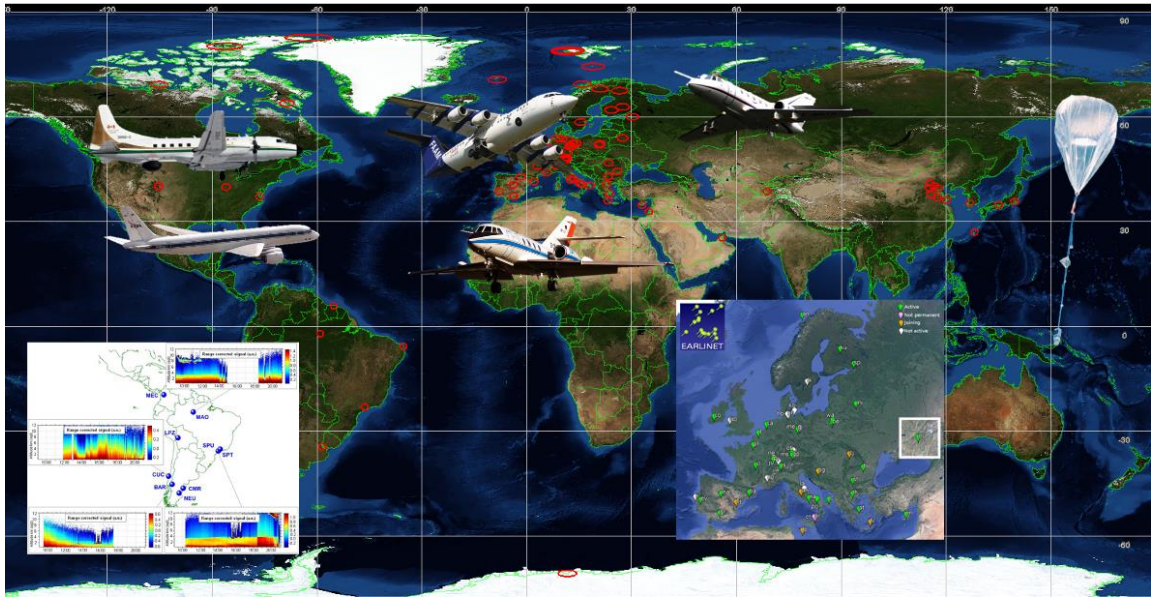


Fig.: Aeolus Rayleigh clear (red) and Mie cloudy (yellow) winds versus radiosonde winds (green) and ECMWF HLOS reference winds at Aeolus observation scale (dashed).

→ A new Range Bin Setting was activated to measure high quality winds with 500 m bins in the Tropical Tropopause Layer starting on 20 March

Upcoming topics for future analysis by Cal/Val Teams



Aerosol and Wind Product Validation

- Validation of wind and aerosol products from **4th reprocessing (B16)** for FM-B (available early 2024) and FM-A (available early 2025)
- Assessment of **error estimates** for wind and aerosol products
- Focus on wind/aerosol validation during **special range-bin settings campaigns** (AMV, MARS, higher resolutions in Tropics) using the reprocessed dataset

Specific Topics for Wind Product (L2B) Validation

- Validation of **Rayleigh cloudy winds** since January 2023 and in B16 reprocessed datasets
- Impact of range bin thickness and on N/P setting on L2B **Mie cloudy winds**
- Improvements of **L2B Mie cloudy winds** (less gross outliers) in B16

Specific topics for scattering ratio (L1B) and aerosol product (L2A) validation

- Validation of L1B scattering ratio (total/molecular backscatter coefficient) with new approach in B16
- Assessment of lowest sensitivity for L2A products, e.g. lowest backscatter coefficients or attenuated backscatter
- Comparison of MLE, SCA and AEL-PRO products and their error estimates
- Assessment of higher resolution MLE product
- Please use operational L2A products for your future analysis, and prototype products only for few examples

Summary and Conclusion

The 6 major challenges => achievements / “firsts” of Aeolus

- **First** European lidar and **first** wind lidar in space in operation for 4 years and 8 months: lifetime objective (3.5 years) was achieved and demonstration of wind lidar technology in space

- **First** successful demonstration of operation of a ultraviolet laser in space with stable performance of FM-A after switch in November 2023
  => end of life of Aeolus is not determined by the instrument, laser or oxygen supply for cleaning, but by the satellite fuel and solar activity

- **First** demonstration of positive impact of wind profiles (HLOS) for numerical weather prediction with even operational use: ECMWF, DWD, Météo-France, UK Met Office and NCMRWF; in addition impact studies for various other global and regional models, e.g. ECCC, NOAA, SMHI, JMA, WRF

- **First** demonstration of high-spectral resolution lidar for retrieval of aerosol extinction in orbit => demonstrated potential also for enhanced aerosol capabilities for EarthCARE and EPS-Aeolus with depolarization channel

- **First** Earth Explorer Mission, which succeeded in becoming an operational follow-on programme with the positive decision on ESA´s Ministerial Meeting in November 2022

- Aeolus paved the way for the future European lidar missions (EarthCARE and Merlin) and EPS-Aeolus in 2030+ wrt. **technology, framework and spirit of cooperation** of ESA, Industry, DISC, NWP, Cal/Val and Science community

Thank you for your attention!