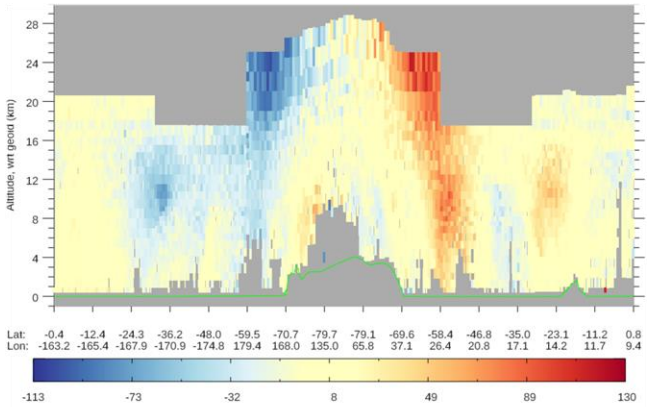
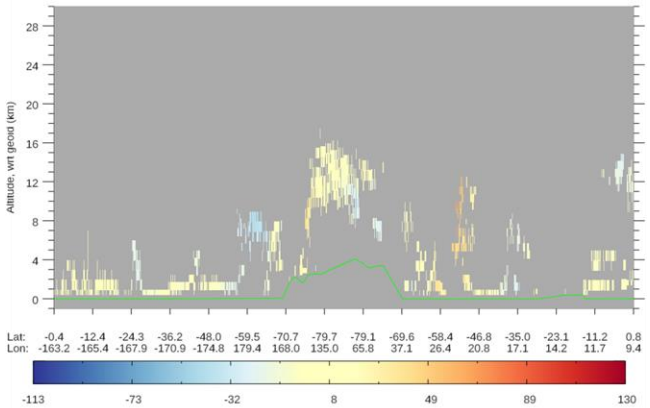
The impact of Aeolus winds in global NWP at ECMWF

15th IWWG workshop (virtual meeting)

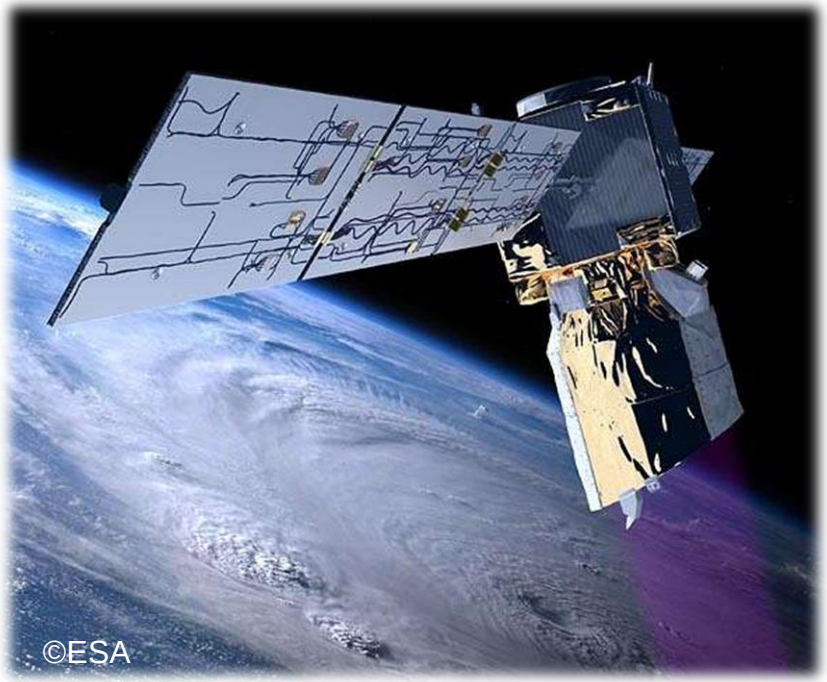
by **Michael Rennie,** Lars Isaksen (ECMWF)
Acknowledgments: Aeolus DISC team and ESA



(a) L2B Rayleigh-clear HLOS winds



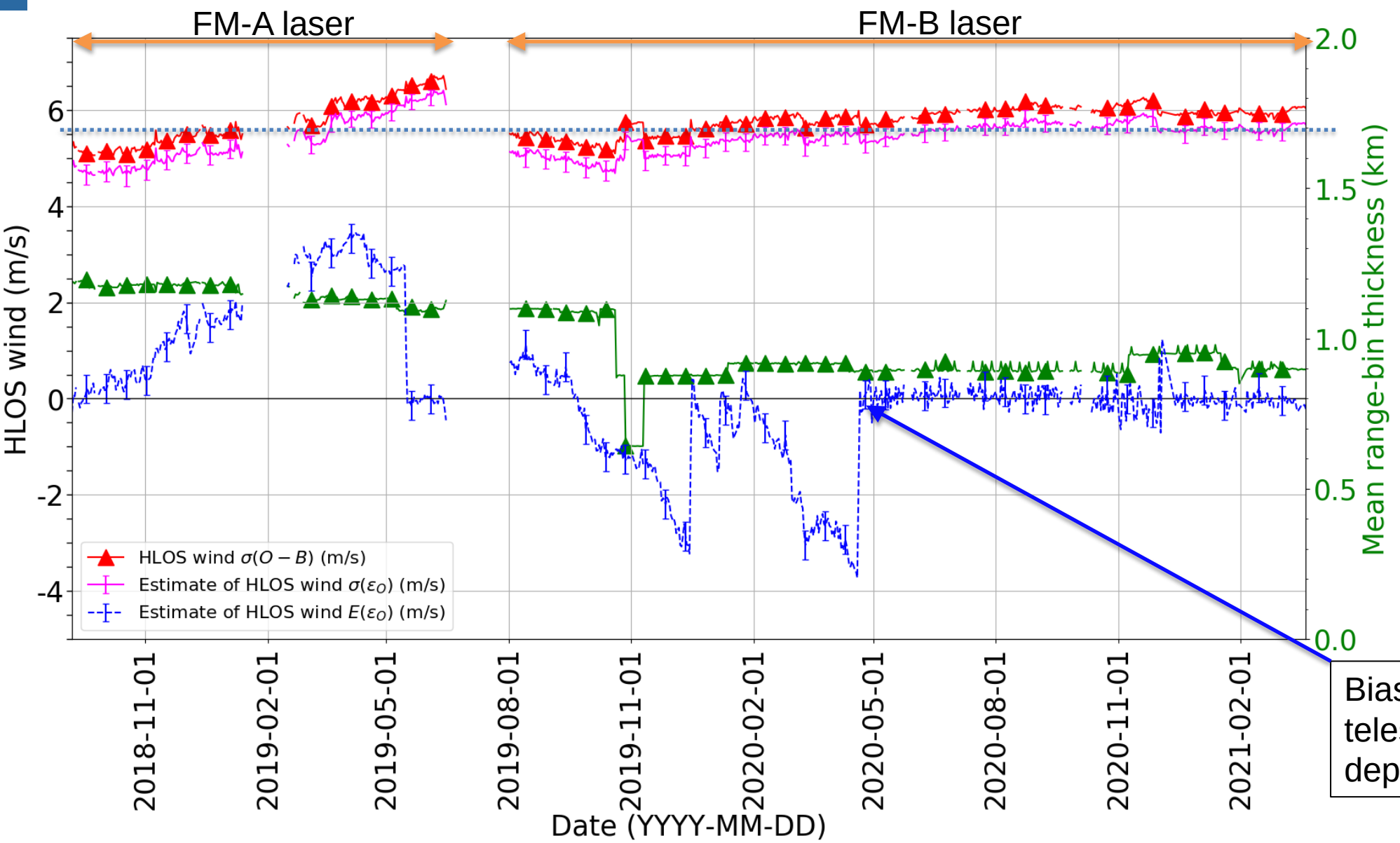
(b) L2B Mie-cloudy HLOS winds



Long-term L2B HLOS wind quality monitoring

Relaxed QC: $|O - B| > 15\ m/s$ rejected

L2B Rayleigh-clear winds; **daily**, **global** data, **whole** profile



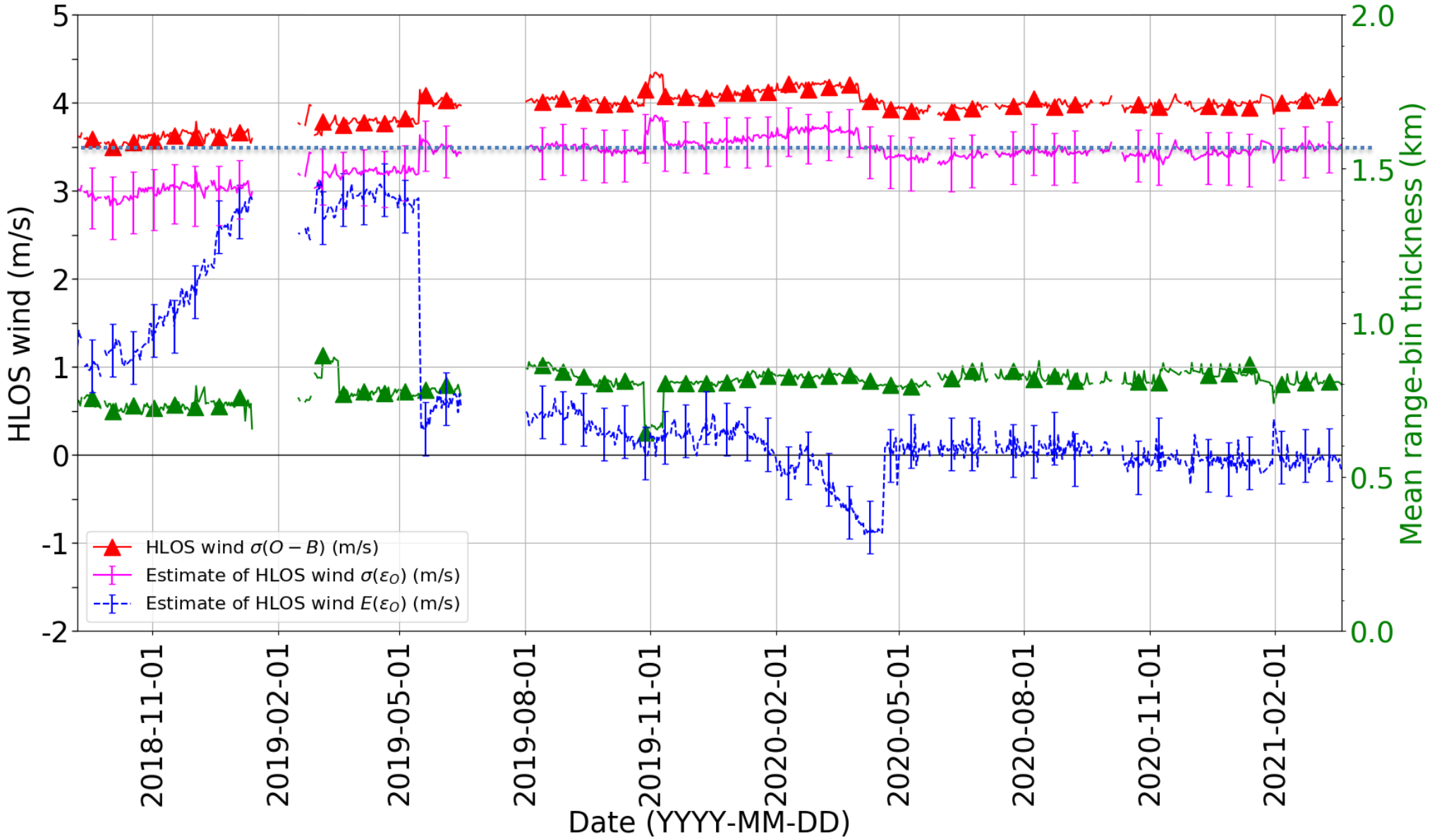
- Random error looks fairly flat recently
- Improvements in ground processing algorithms and settings helped mitigate **signal losses**

Due to radiometric performance issues the Rayleigh winds as ~twice as noisy as expected pre-launch

Bias improved due to telescope temperature dependent bias correction

L2B Mie-cloudy; daily, global, whole profile

QC: $|O - B| > 10\ m/s$ rejected



- Random error increased slightly since May 2020

Assessment of Aeolus winds NWP impact at ECMWF

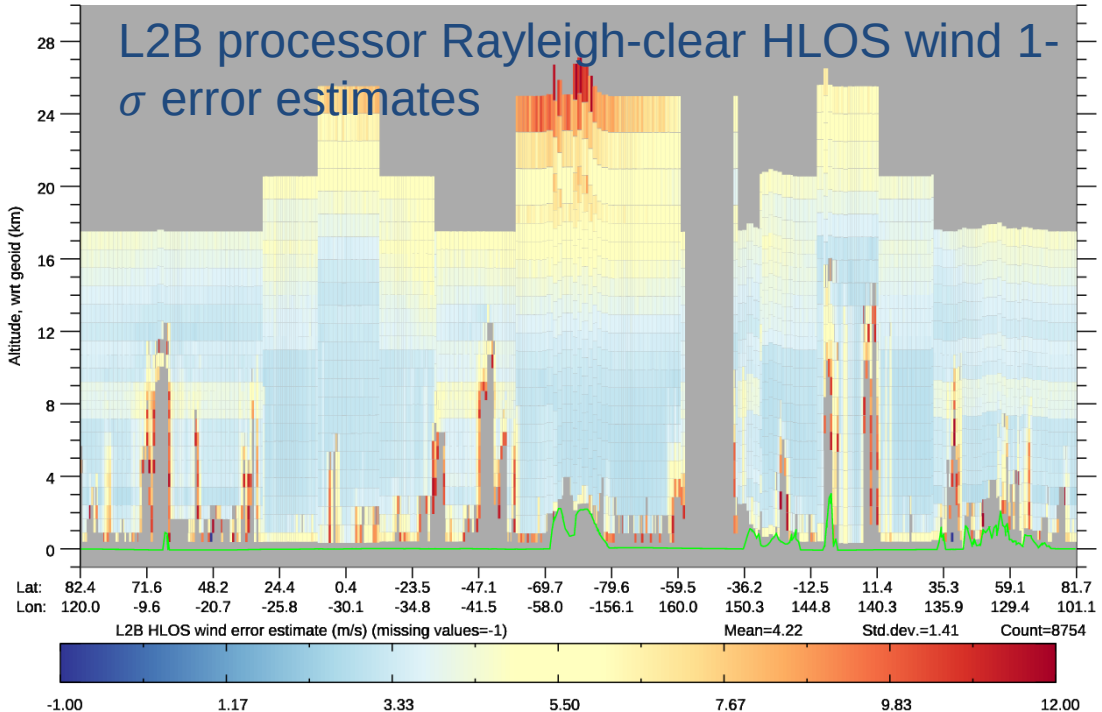
- **O**bserving **S**ystem **E**xperiments (5 periods tested)
  - Earlier OSEs (not shown today):
    1. **Early FM-A (first laser) with NRT data:** 12 September to 16 October 2018
    2. **Late FM-A:** April to June 2019
    3. **Early FM-B (second laser) with NRT data:** August to December 2019
  - Will use results today from:
    4. **Mid-2020 FM-B (second laser) with NRT data:** 4 April 2020 to early September 2020
    5. ***Reprocessed* early FM-B period:** July to December 2019 (***still running: up to end-Oct 2019***)
       - *Lowest noise of the mission for this period*
- **F**orecast **S**ensitivity **O**bservation **I**mpact
  - From ECMWF operations (since 9 Jan 2020) and the reprocessed early FM-B period experiment
- *Great achievement by the Aeolus DISC, ESA, Industry and CAL/VAL teams to get the L2B winds to a state were they are suitable for operational assimilation in a short time, given Aeolus is the world's first Doppler wind lidar in space!*

References:

- "*The impact of Aeolus wind retrievals in ECMWF global weather forecasts*" by Rennie, Isaksen, Weiler, de Kloe, Kanitz and Reitebuch, revised manuscript (minor revisions) submitted to QJRMS (29/3/2021)
- Rennie, M., and L. Isaksen. (2020). "The NWP Impact of Aeolus Level-2B Winds at ECMWF".
- 1007 ECMWF Technical Memoranda 864. https://dx.doi.org/10.21957/alift7mhr
- DISC TN on NWP impact at ECMWF v2.0 (delivered 25 Feb 2021) - available on request

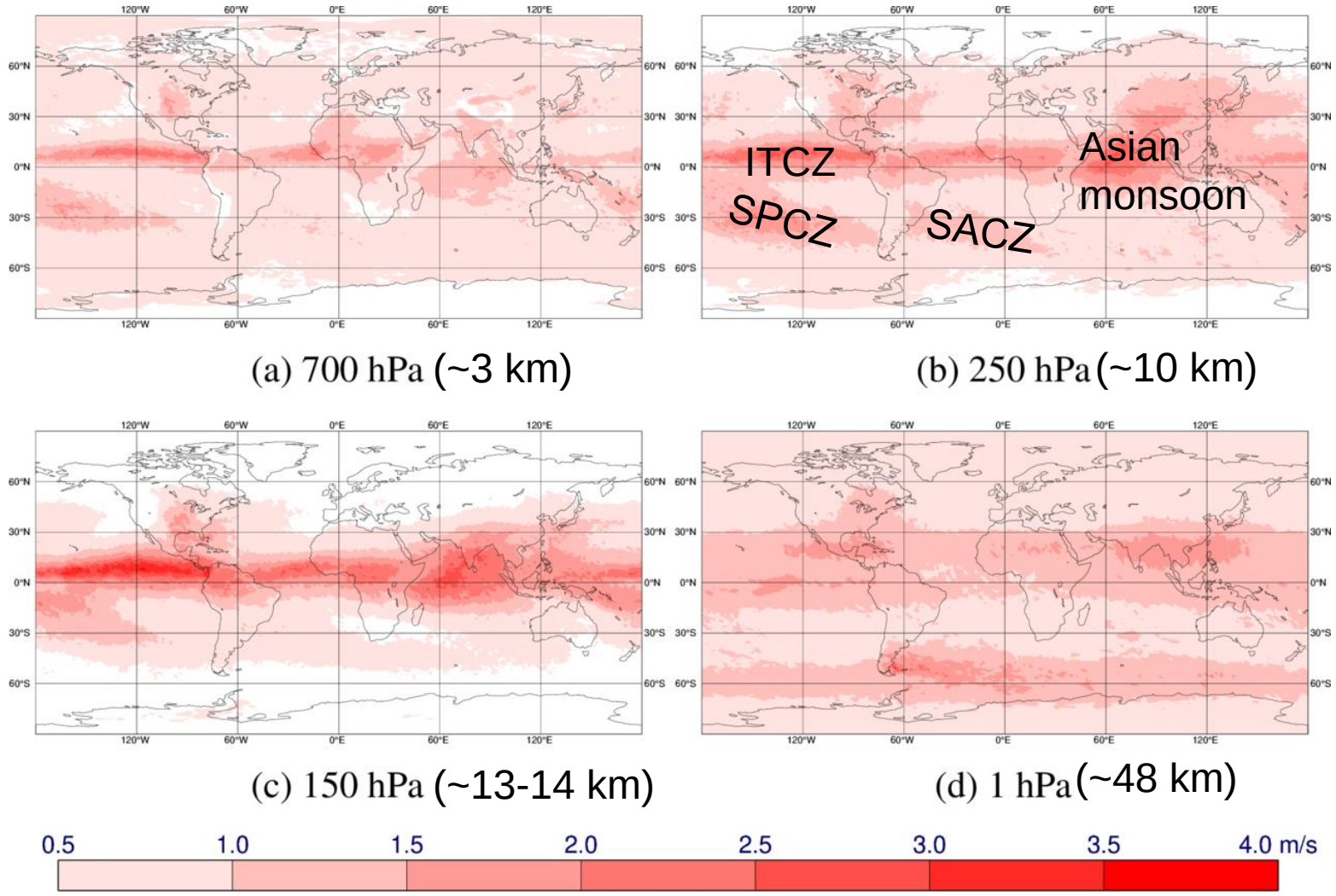
OSE for assessing NWP impact of Aeolus

- Experiment assimilated **first available reprocessed** L2B wind retrievals, and use full observing system applied by ECMWF operations at the time
  - Both **Rayleigh-clear and Mie-cloudy winds** used
- Model horizontal resolution $T_{CO}399$ (~29 km model grid) for 4D-Var outer loop and forecast
- Assigned observation error in data assimilation is a function of L2B product **instrument error estimate** ($\sigma(\varepsilon_{O,instr})$)
  - Multiplicative factor and representativeness error to better agree with Desroziers' diagnostics
    - $\sigma(\varepsilon_{O,assign}) = \sqrt{\alpha^2\sigma^2(\varepsilon_{O,instr}) + \sigma^2(\varepsilon_{O,rep})}$
    - **Rayleigh-clear:** $\alpha = 1.40$; $\sigma(\varepsilon_{O,rep}) = 0\ m/s$
    - **Mie-cloudy:** $\alpha = 1.25$; $\sigma(\varepsilon_{O,rep}) = 2\ m/s$



ECMWF

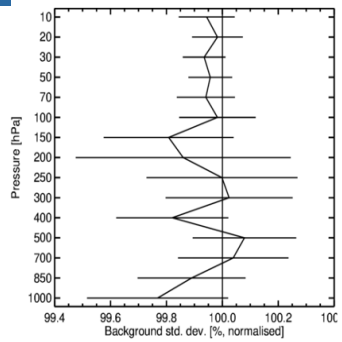
Standard deviation of zonal wind analysis differences due to assimilating Aeolus



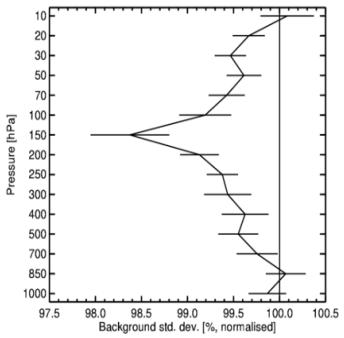
Mid-2020 OSE:
Period 4 April to 19 August 2020

Largest changes made to tropical upper troposphere and SH extratropics – in climatological **convergence zones**; larger model wind errors in convective outflow?

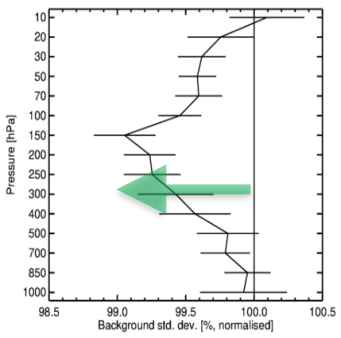
Short-range forecast fit (O-B) to other observations when assimilating Aeolus (both Rayleigh-clear and Mie-cloudy) – **results of early FM-B reprocessed OSE**



(a) In situ vector wind; NH

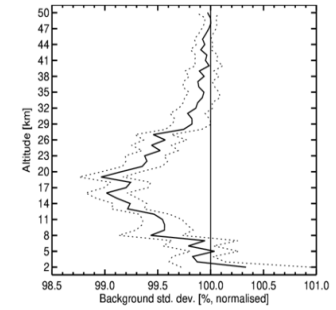


(b) In situ vector wind; TR

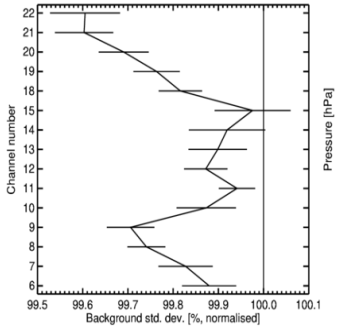


(c) In situ vector wind; SH

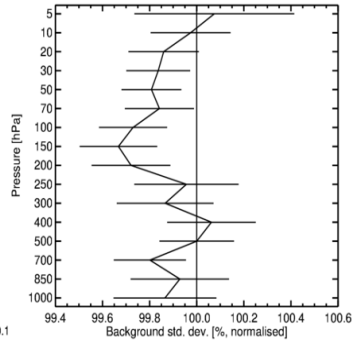
<100 % means Aeolus improves the forecast



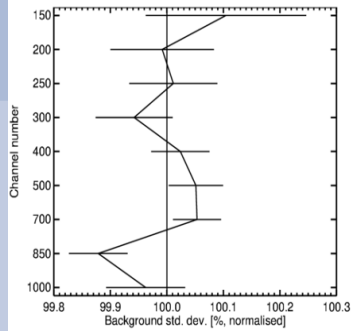
(d) GNSS radio occultation; global



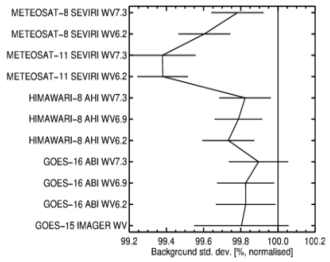
(e) ATMS; global



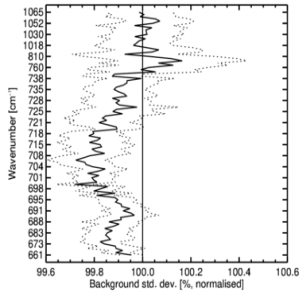
(f) Radiosonde temperature; global



(g) AMVs; global



(h) Geostationary water vapour; global



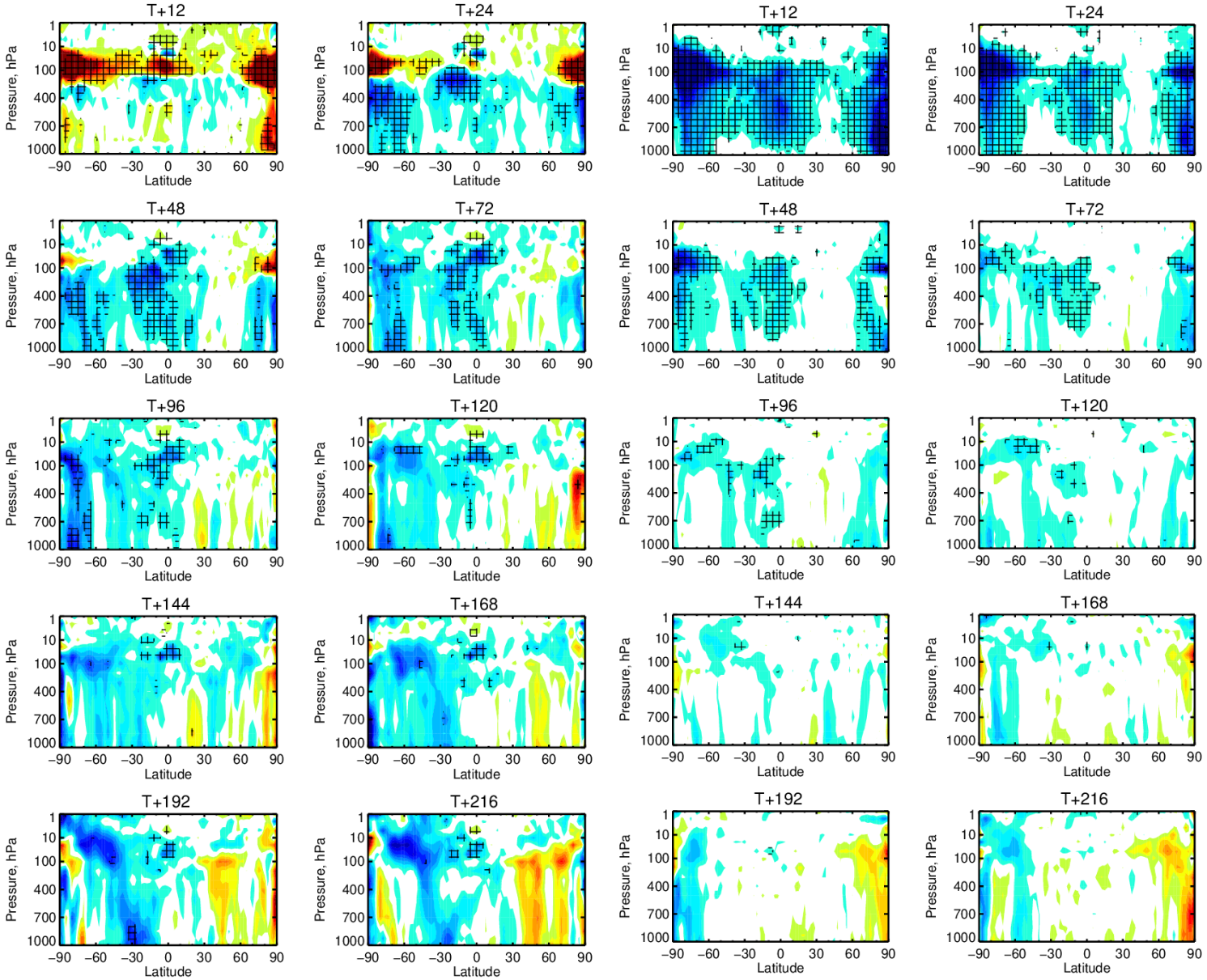
(i) CrIS; global

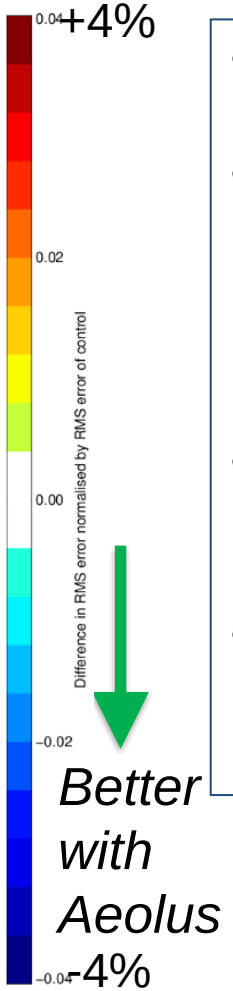
- Aeolus **improves wind, temperature and humidity**, most strongly in upper troposphere and lower stratosphere
- Largest impact globally in tropical upper troposphere
- Similar results found for mid-2020 OSE

Vector wind root mean square error change due to Aeolus (Rayleigh-clear + Mie-cloudy)

Early FM-B reprocessed OSE

Mid-2020 NRT data OSE





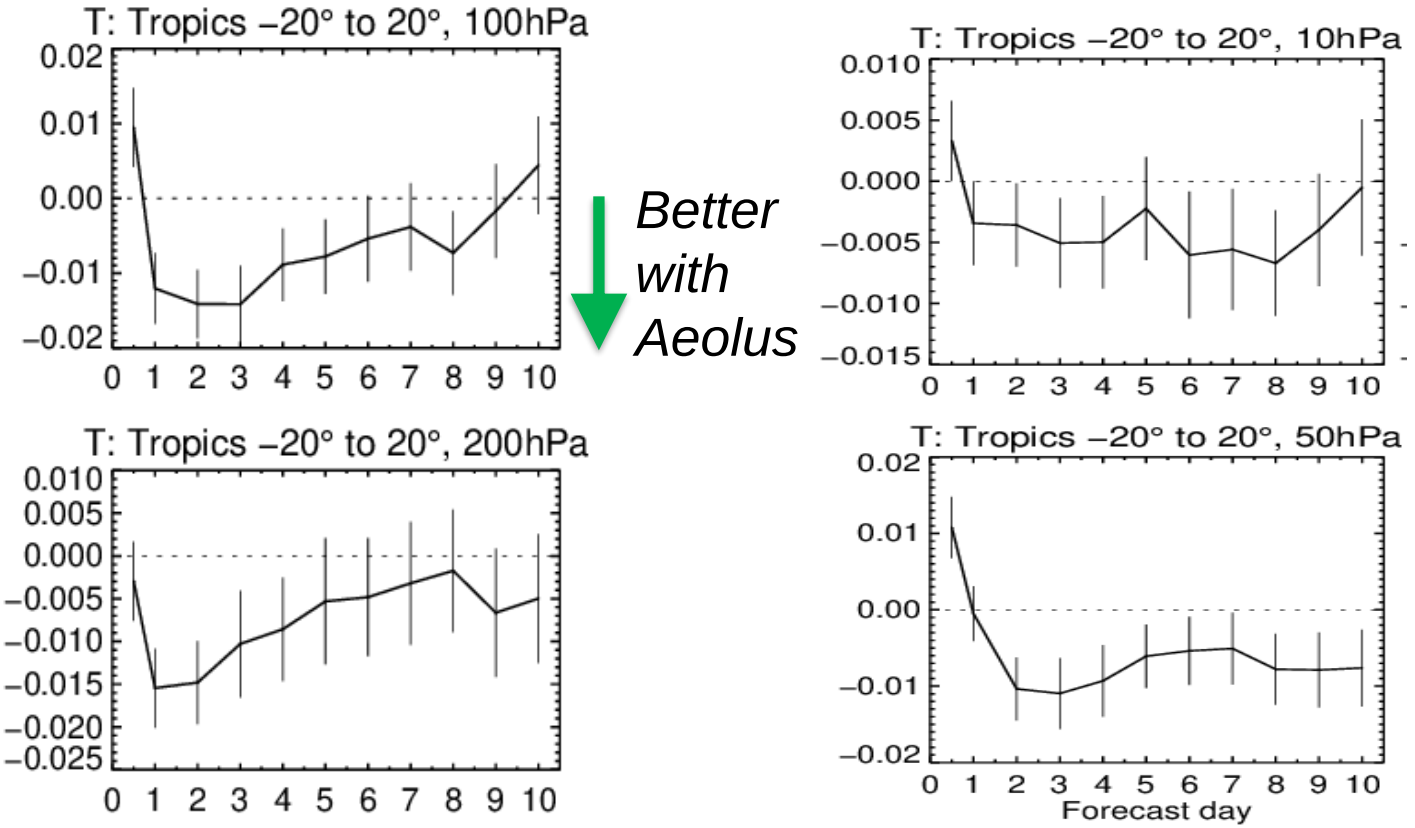
- Verification against ECMWF operational analysis
- **Good positive impact** in tropical troposphere and lower stratosphere
  - Throughout forecast range in LS
- **Good positive impact** in polar troposphere
  - Up to 3-4 day range
- Similar patterns of impact for temperature and humidity forecasts (not shown)

Largest impact from Aeolus found in **tropical UTLS**

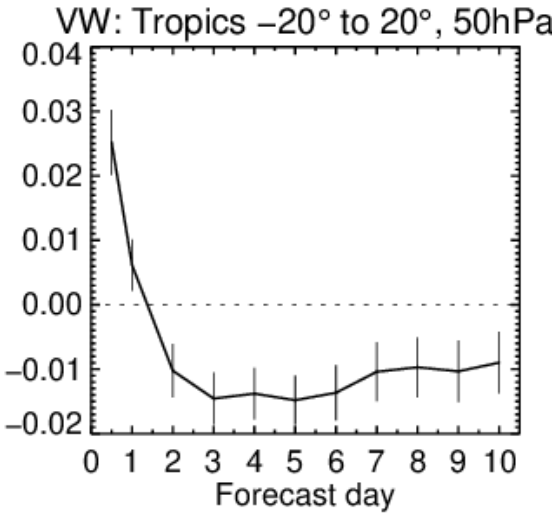
Reprocessed early FM-B OSE shows positive impact in tropical tropopause and lower stratosphere

- To **day 10 (!)** forecast-range at 50 hPa (~20 km)

Tropical temperature



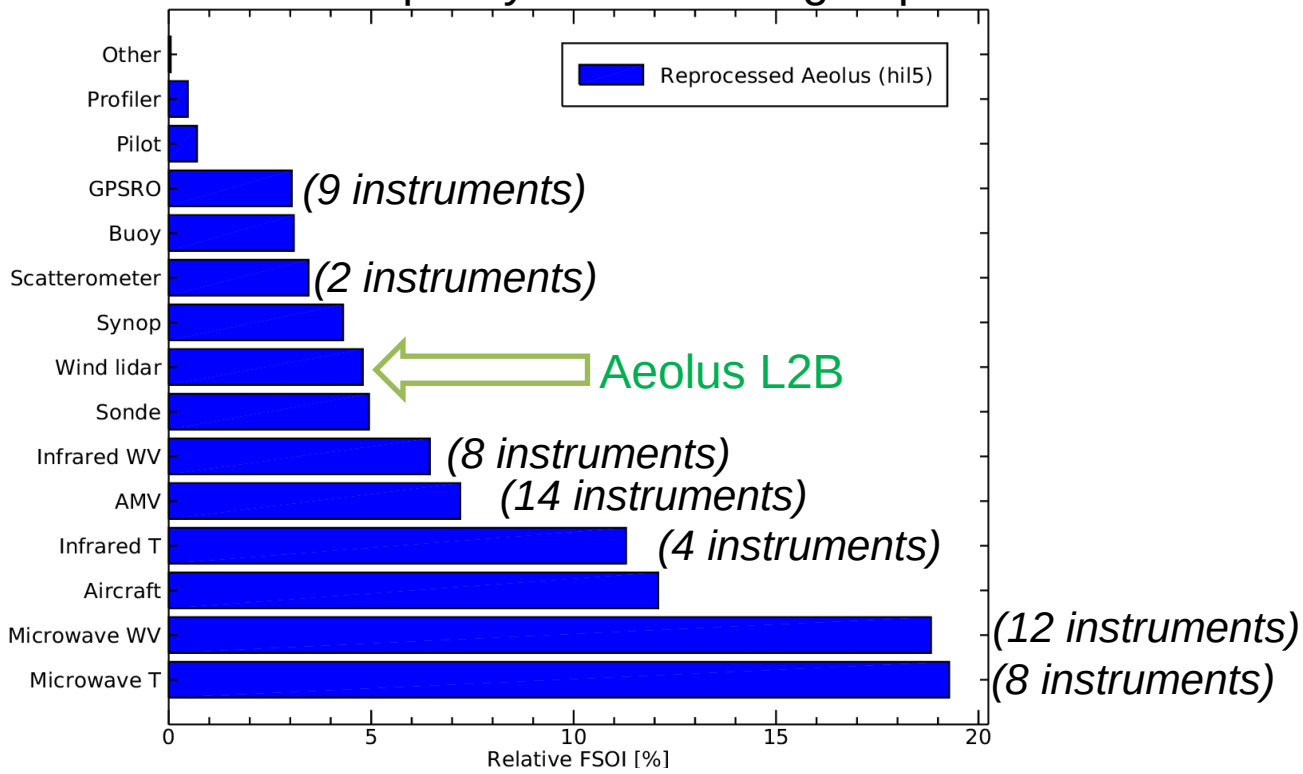
Tropical vector wind



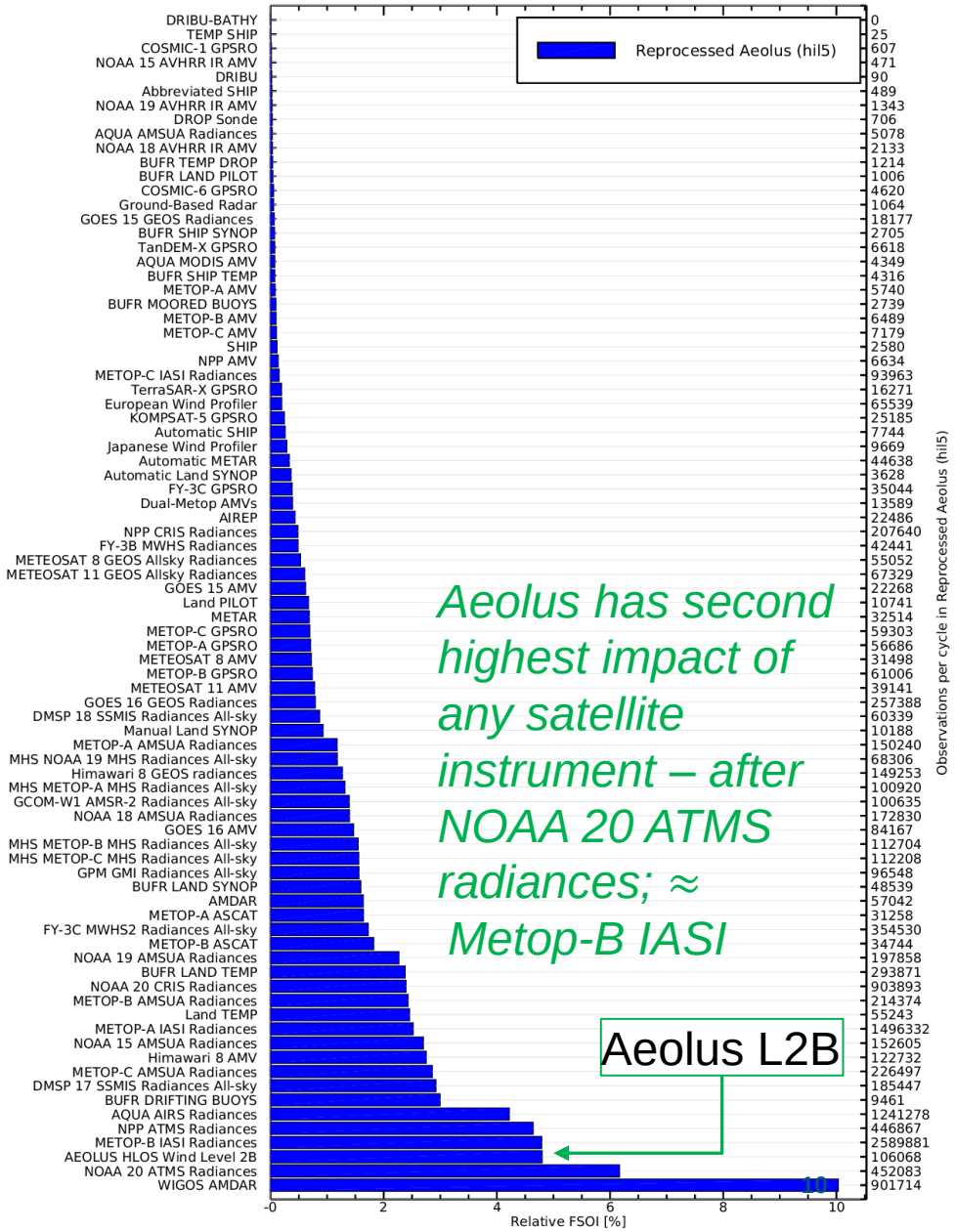
ECMWF

FSOI for reprocessed L2B data period (3 July to 27 Sept 2019)

FSOI split by observation group



FSOI split by instrument



- ***For this period*** with ***good atmospheric signal*** and **reprocessing**, Aeolus provides **4.8% relative FSOI** – compare this to ~3.2% for first half 2020 operations
  - Aeolus ≈ radiosondes, > scatterometer & GPSRO
- **Shows the importance of DWL in NWP**
  … even with less useful signal than expected pre-launch

ECMWF

Summary of Aeolus NWP impact assessment at ECMWF

- **OSEs** show Aeolus winds provide **statistically significant and good magnitude** positive impact in the **tropics and polar regions**
  - Well into medium range in tropical LS (10 days), which is a strong performance compared to other satellite wind data shown in ECMWF OSEs
- Aeolus <1% by number of data assimilated; ***good OSE impact demonstrates the benefit of satellite winds with good vertical resolution***
- **FSOI** confirms the OSE positive impact
- Other NWP centres corroborate the positive impact e.g. DWD, Météo-France, Met Office, NOAA, Indian NCMRWF, HARMONIE consortium
- Aeolus is still very new and the winds have been considerably noisier than pre-launch expectations
  - ***Still potential to boost impact:*** *by mitigating radiometric performance issues, continuing ground processing improvements and data assimilation method improvements*
  - The potential **EUMETSAT** Aeolus follow-on operational mission should resolve the radiometric issues (misalignment) and hence increase Rayleigh-clear wind impact

Thanks for listening. Any questions?

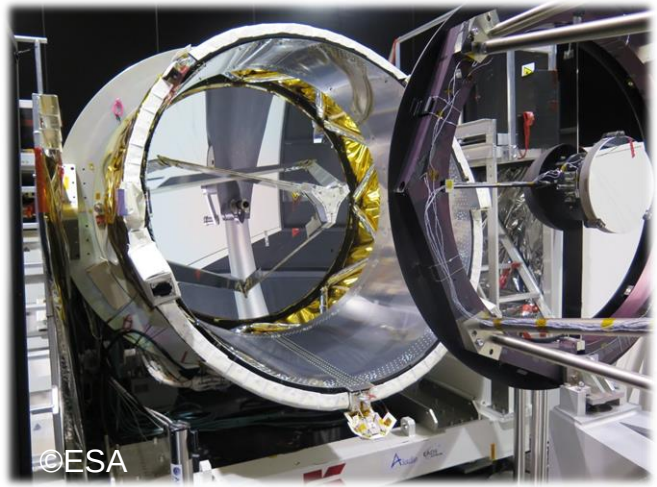
What is Aeolus?

- Earth observation satellite. 5th satellite launched (22 Aug 2018) in ESA's Earth Explorer programme – a technology demonstration

- **Scientific payload:** UV Doppler wind lidar measuring profiles of line-of-sight wind information (06/18 hour local solar time)
  - Also provides profiles of aerosol and cloud backscatter and extinction

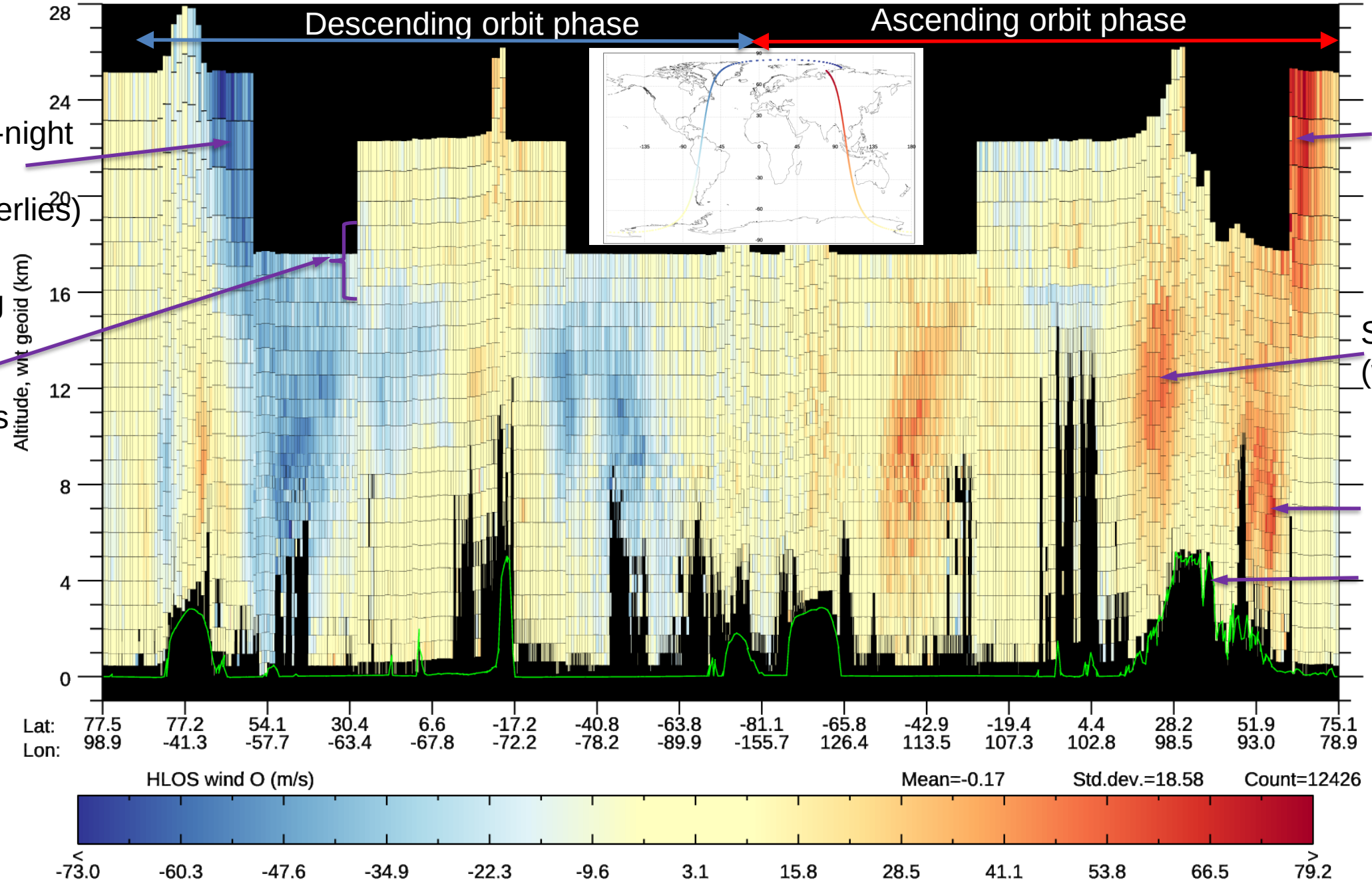
- Main goal is to improve weather forecasts by **partially filling the gap in wind profiles (as stated by WMO RRR 2018)** and improve understanding of the atmospheric dynamics

- Operationally assimilated at ECMWF since 9 January 2020 – also at DWD and Météo-France since summer 2020



ECMWF

Aeolus L2B Rayleigh-clear **and** Mie-cloudy HLOS wind retrievals (1 orbit)



Polar-night jet (westerlies)

Varying range-bin settings

Polar-night jet (westerlies)

Subtropical jet (westerlies)

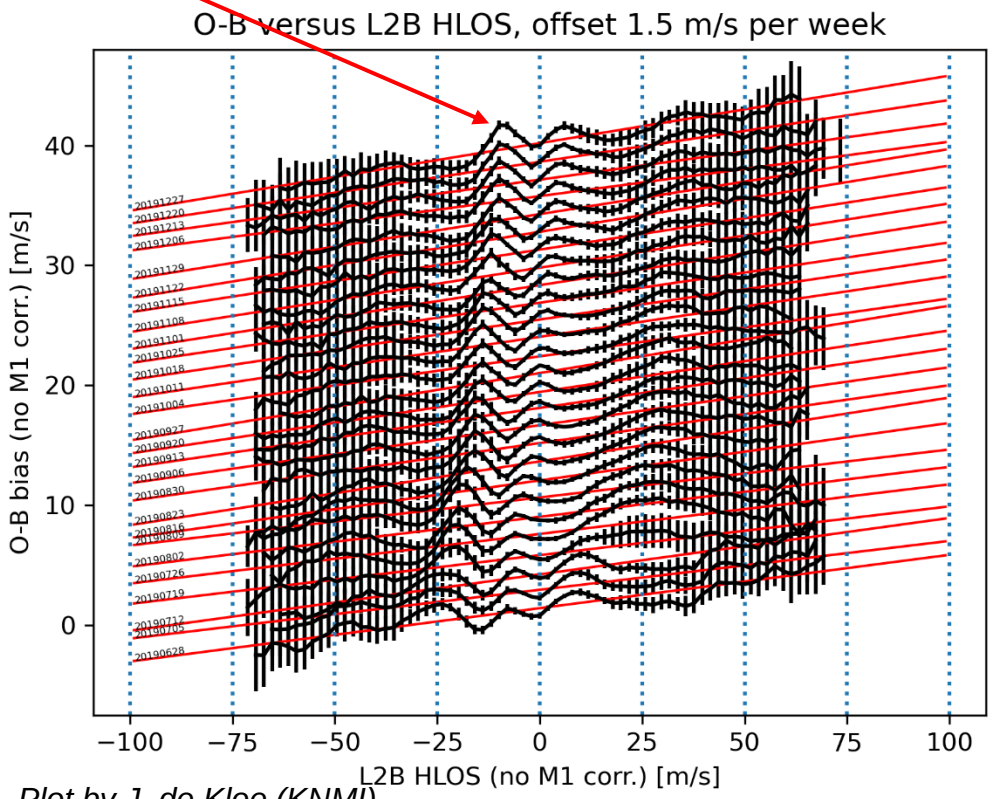
Polar front jet (westerlies)

Mountains

Aeolus HLOS winds are positive if wind blowing away from satellite

Two bias issues, which may improve NWP impact when resolved

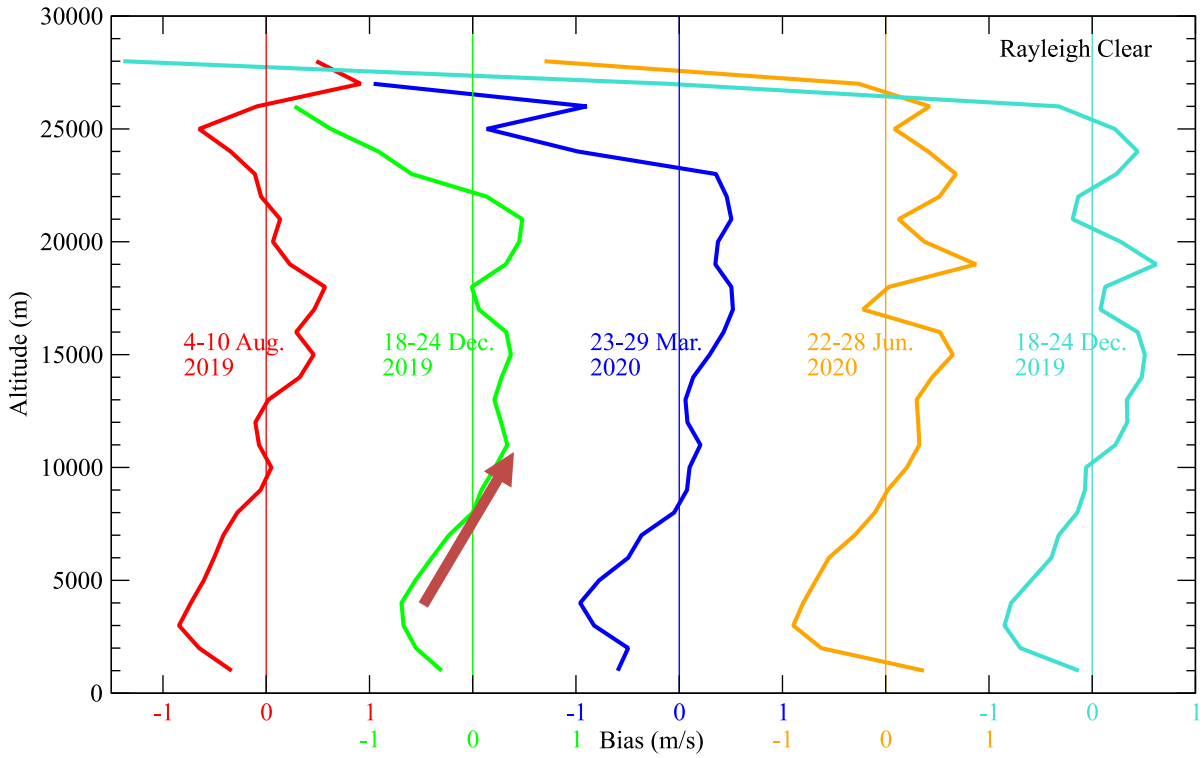
“Wiggles” in Mie-cloudy bias, shifting with time



Plot by J. de Kloe (KNMI)

Likely due to errors in applied **M**ie **R**esponse **C**alibration

L2B Rayleigh-clear “altitude dependent” bias



Plot by S. Abdalla (ECMWF)

Likely a temperature dependent bias due to imperfect Rayleigh-Brillouin calibration file

ECMWF