A Consolidated Assessment of the Impact of Aeolus Winds in NWP at ECMWF

By Michael Rennie (ECMWF and ESA Aeolus DISC)

16th International Winds Workshop, 11 May 2023

Thanks to: DISC colleagues, Giovanna De Chiara (ECMWF) for tropical cyclone verification and Sean Healy/Katie Lean (ECMWF) for Aeolus-2 EDA experiments

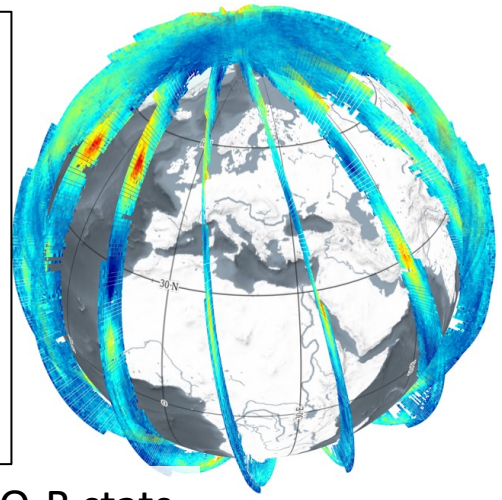
Outline

- Overview of L2B HLOS wind data quality during the mission
- Some recent NWP impact results:
  - **O**bserving **S**ystem **E**xperiments:
    - Reprocessed early FM-A laser period (2018/19)
    - Recent FM-A laser NRT period (2022/2023)
  - **FSOI** since July 2019
- Consolidated assessment of impact during mission and predictions for better data quality

Aeolus Level-2B HLOS (horizontal line-of-sight) wind data quality

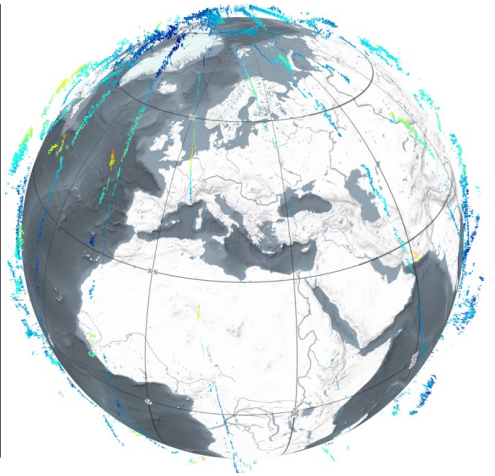
Rayleigh-clear

- Large variability of random errors (variable signal levels)
- Recent ***NRT*** FM-A laser good (best processing, reduced readout noise, reasonable signal)

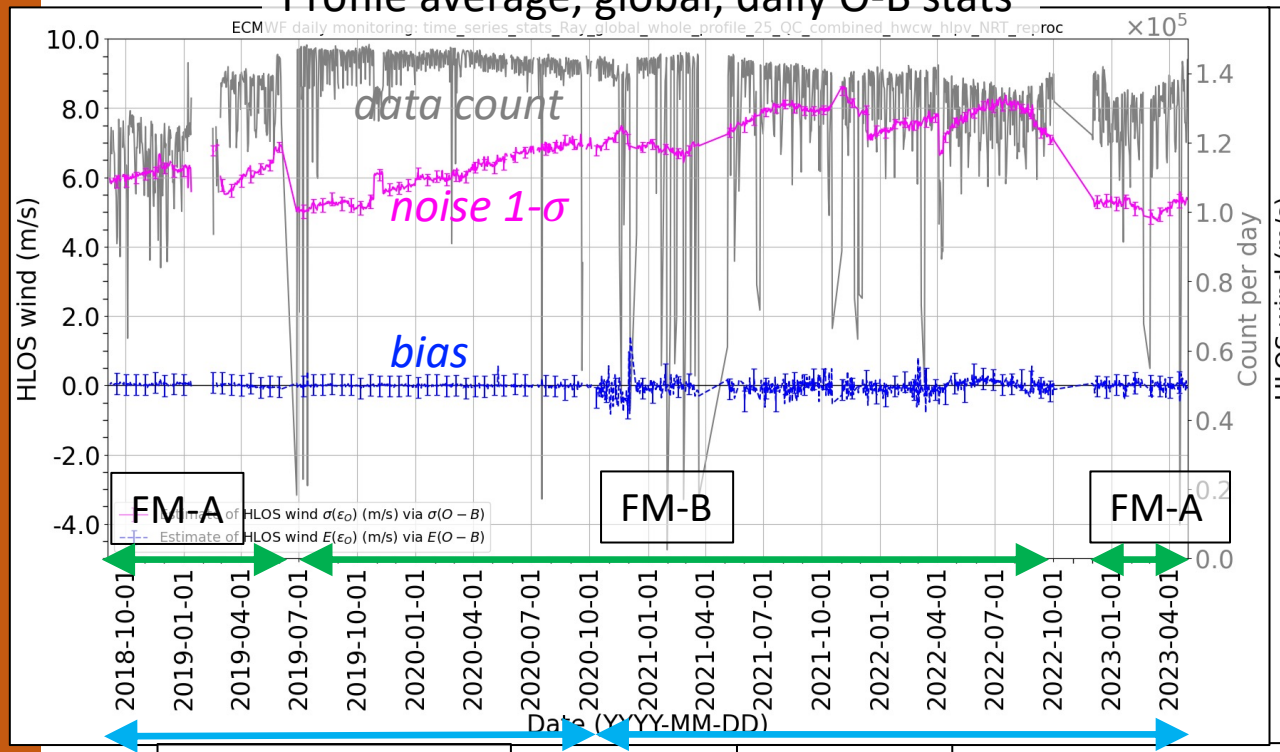


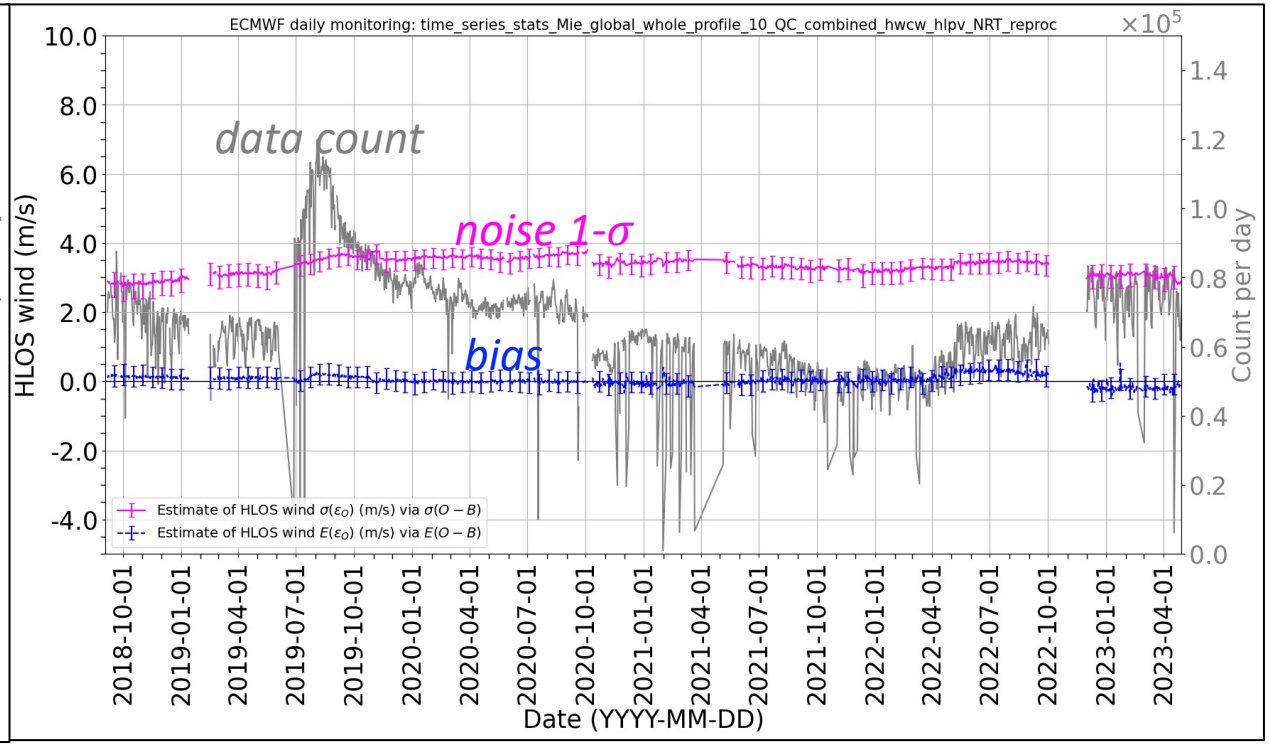
Mie-cloudy

- Noise **quite stable and small** compared to Rayleigh-clear
- But data count variable with signal levels/aerosol load



Profile average, global, daily O-B stats

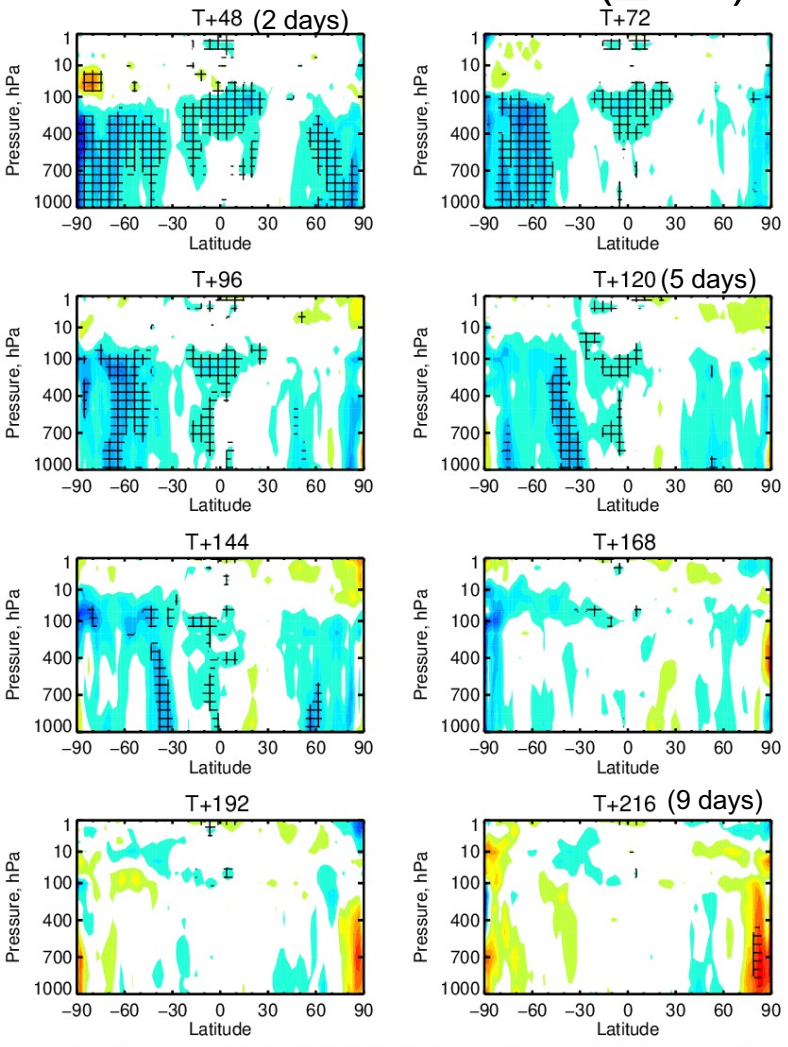




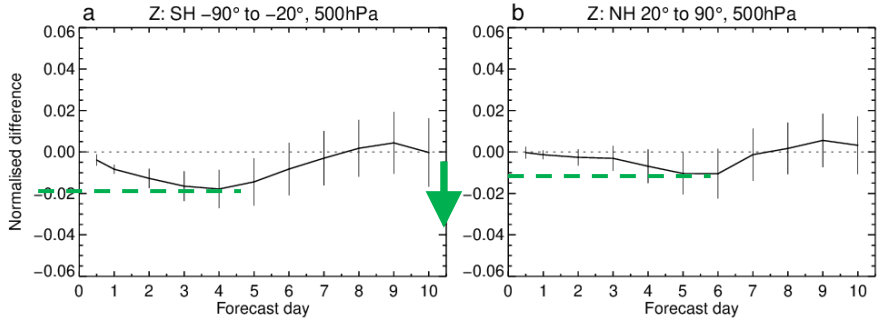
NWP impact

Early FM-A laser OSE (reprocessed): 4/9/18 to 13/1/19 & 14/2/19 to 4/6/19

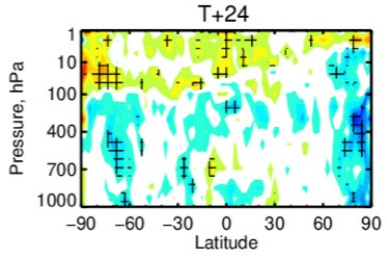
Vector wind RMSE (±5%)



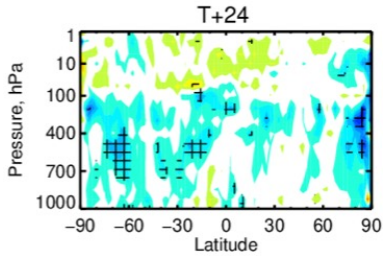
Z500 RMSE improved by 1-2% at day 4-5



- Mie-cloudy winds cause degradation in stratosphere – perhaps overfitting in troposphere (generating gravity waves)
- ***New*** tighter first-guess check QC is helping:

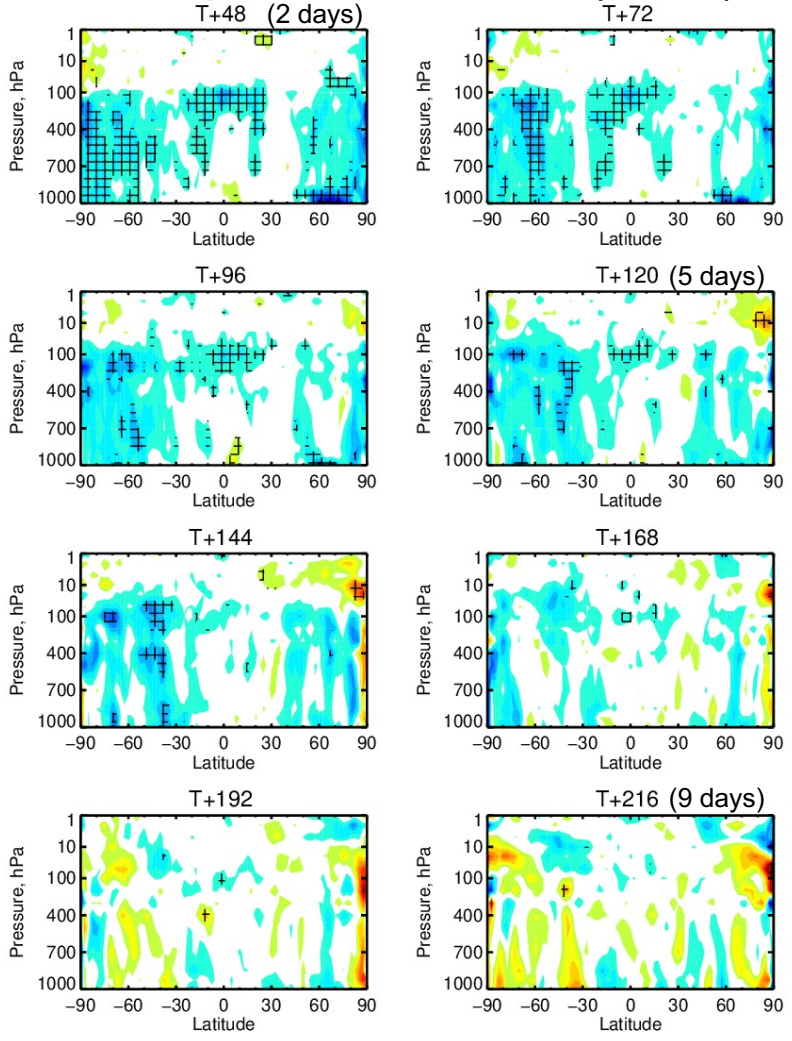


5-σ FG-check



~3.5-σ FG-check

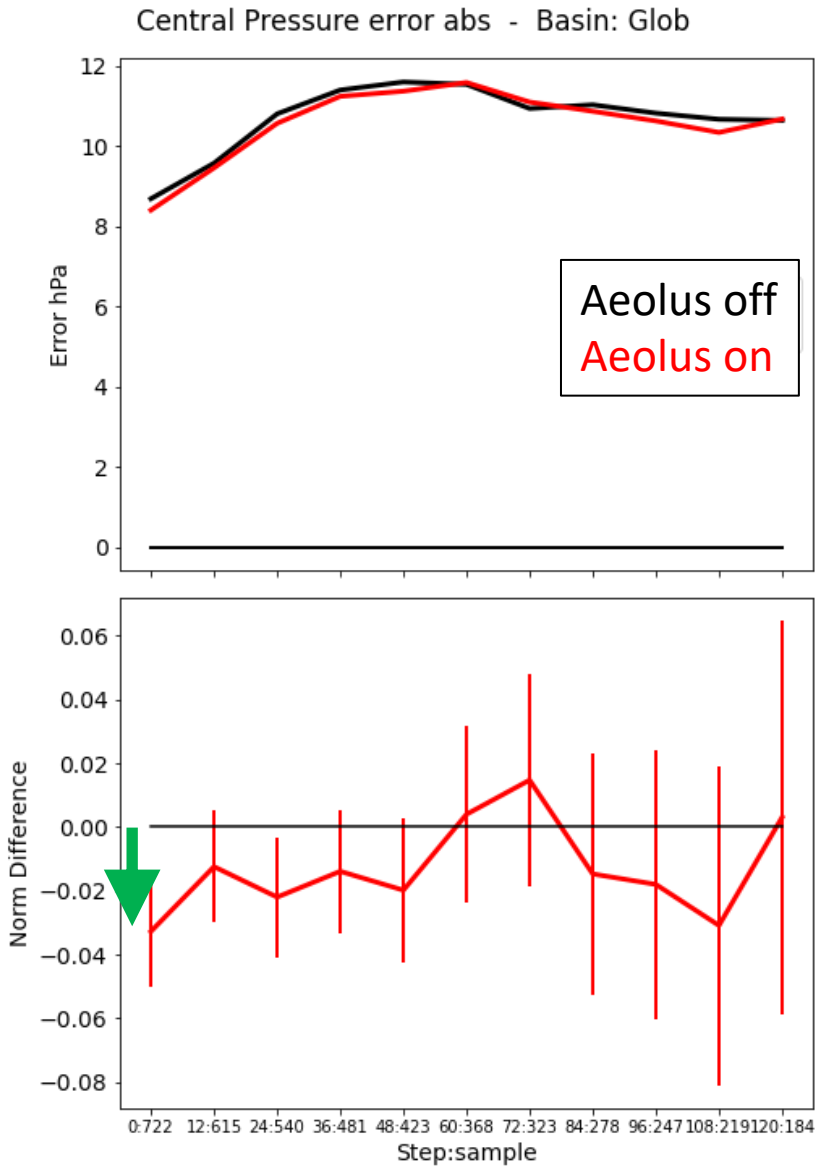
Temperature RMSE (±5%)



Verification against ECMWF oper. analysis

Aeolus improves tropical cyclone **intensity (central pressure)** by a small amount

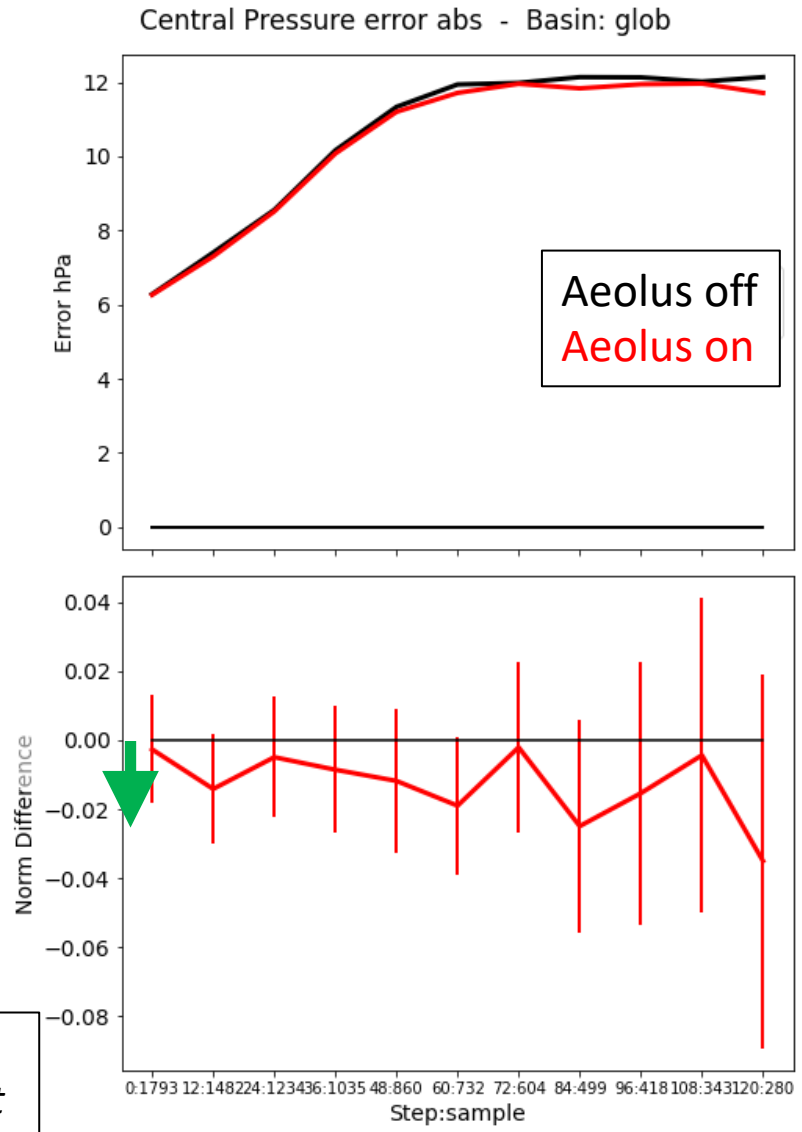
3rd reprocessing OSE – global stats



But impact on position error is mixed (neutral); varies with the period chosen

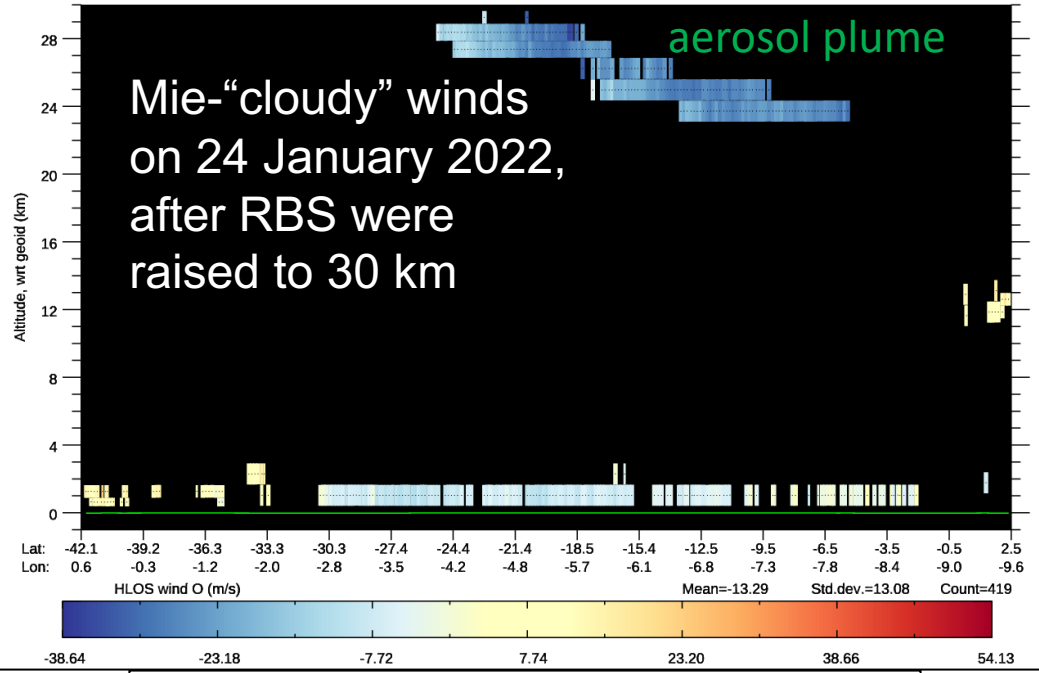
Similar tendency to improve central pressure found with 2nd reprocessing

2nd reprocessing + NRT dataset to Sept 2021 OSE – global stats

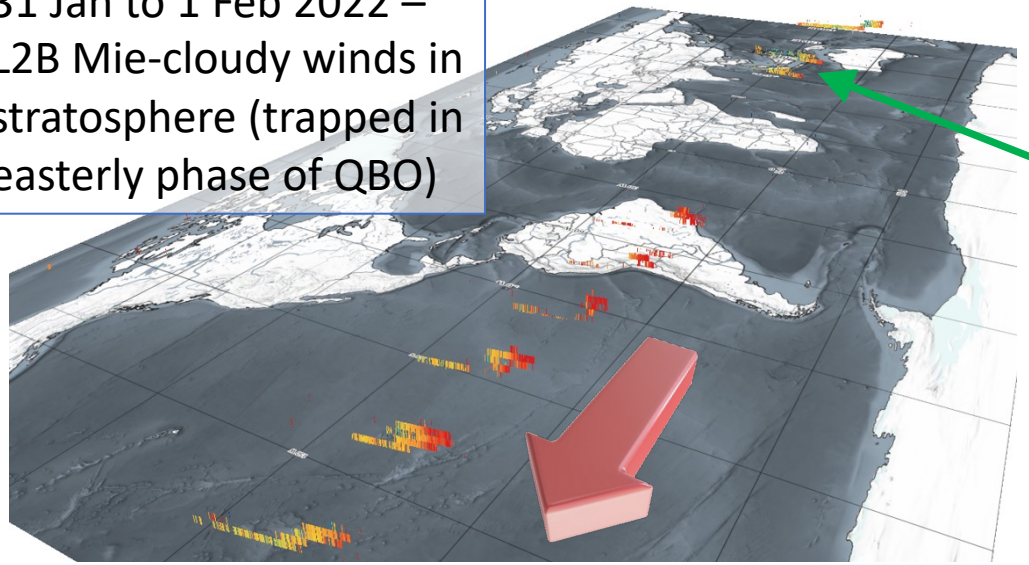


Plots produced by Giovanna De Chiara (ECMWF) – Aeolus extreme weather project with ESA

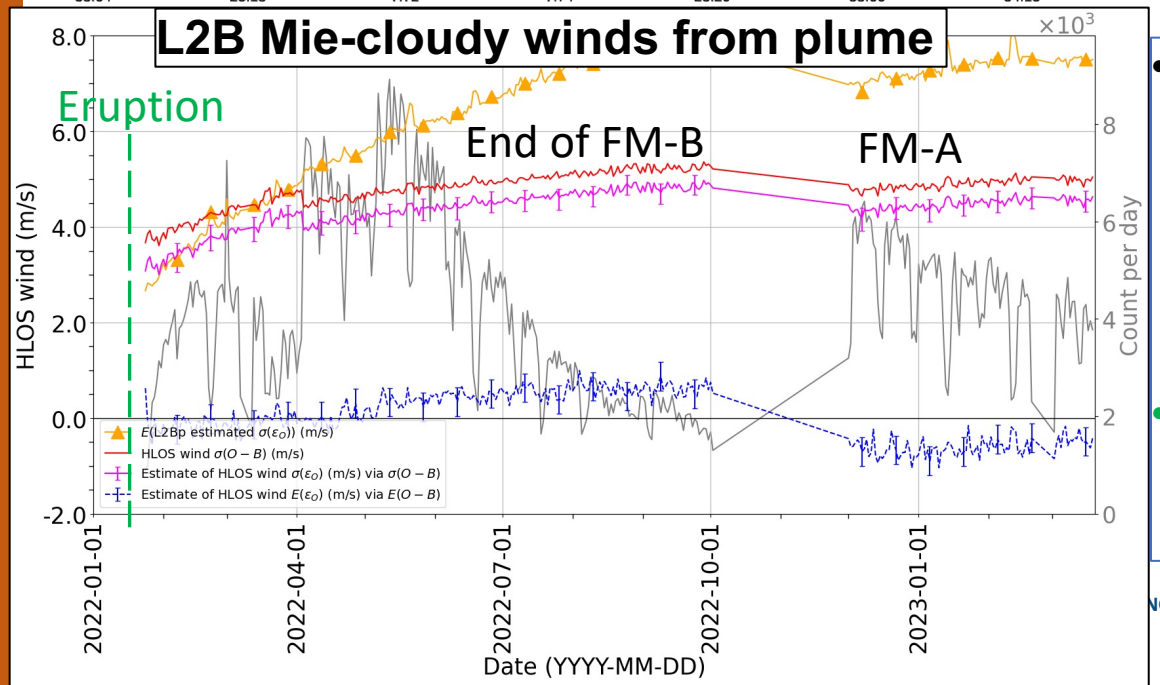
A good sample of Mie winds from Hunga Tonga-Hunga Ha‘apai eruption plume was produced



31 Jan to 1 Feb 2022 – L2B Mie-cloudy winds in stratosphere (trapped in easterly phase of QBO)



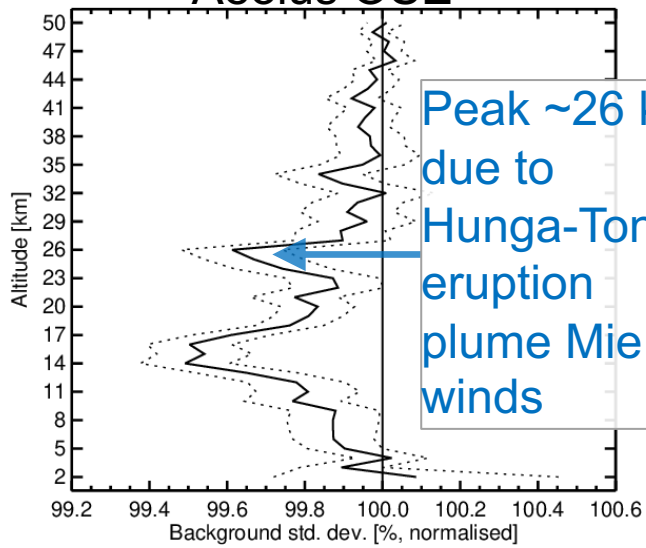
On second trip around world



- By Autumn 2022, aerosol backscatter was weak and winds noisy, low counts due to many rejections by QC
- *Increased signal with FM-A led to a resurgence*

NGE WEATHER FORECASTS

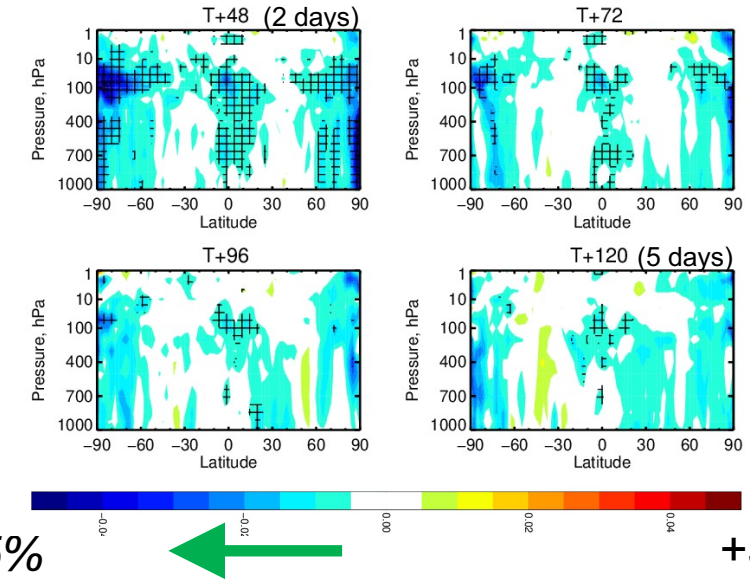
O-B GNSS radio occultation (tropics); Aeolus OSE



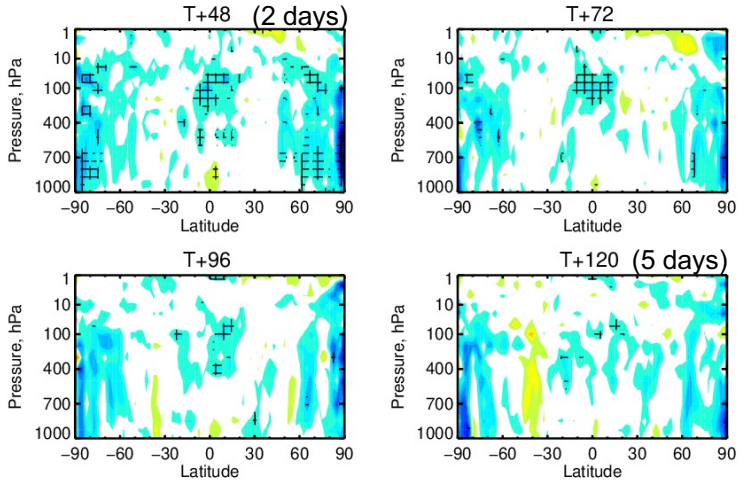
Peak ~26 km due to Hunga-Tonga eruption plume Mie winds

Recent FM-A period OSE (1 Dec 2022 to 30 Apr 2023). Better impact than **end of FM-B** period due to improved signal levels

Vector wind RMSE

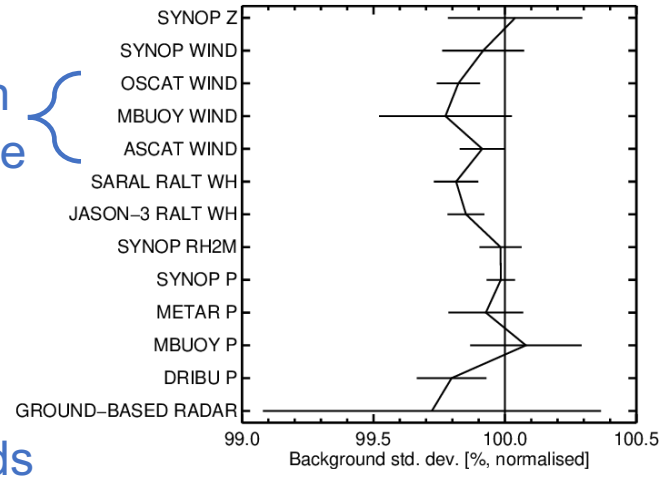


Temperature RMSE (±5%)

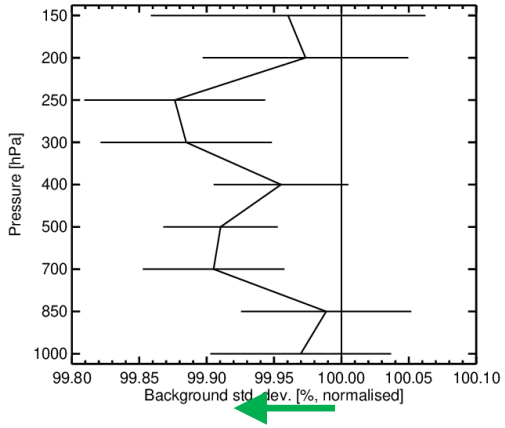


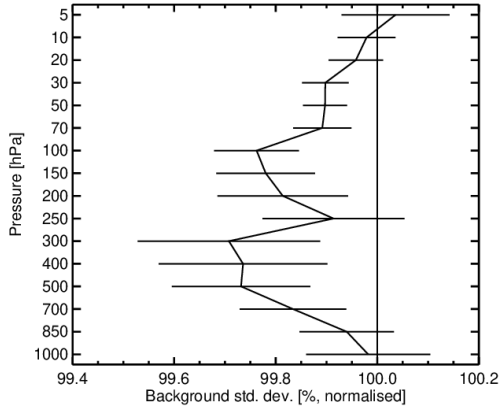
Improvements in global O-B fit to other wind observations

Ocean surface winds



AMV winds

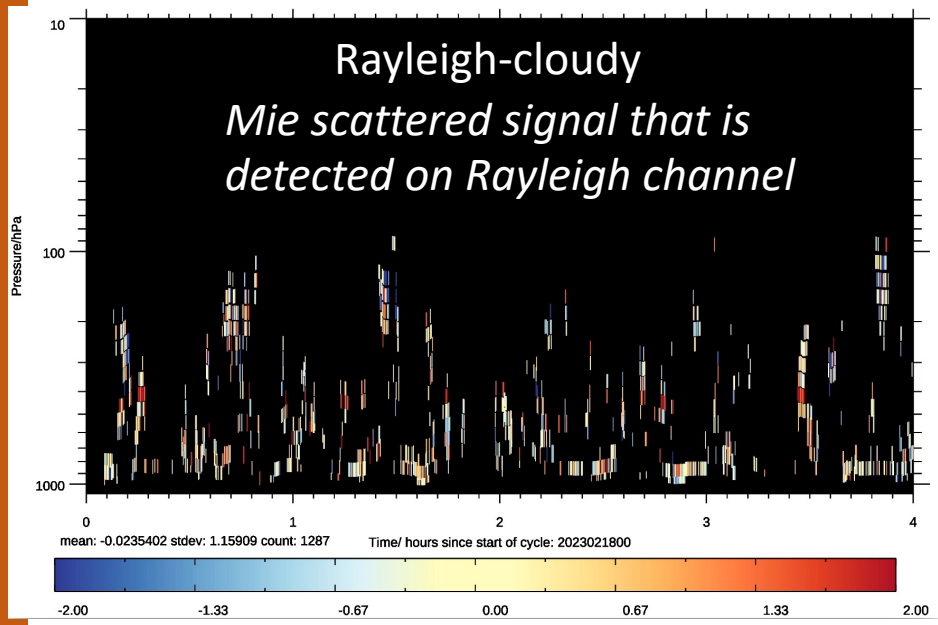


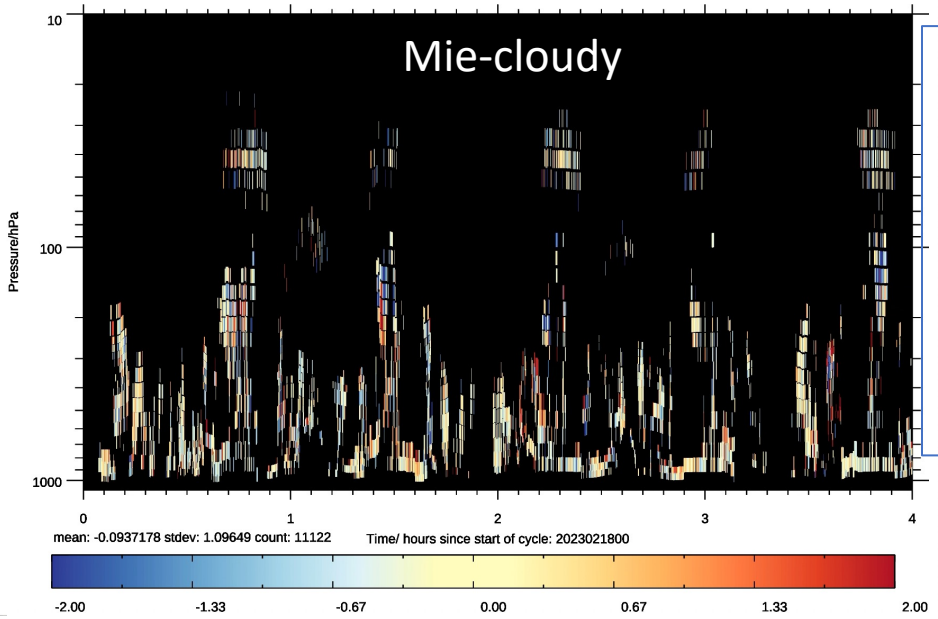


Radiosonde, aircraft, profiler winds

- Greater positive impact than ***end of FM-B,*** **but smaller than 2019 FM-B period**
  - Perhaps increased frequency of *hot-pixel* induced biases affecting impact?
  - Or improved global observing system?

Rayleigh-**cloudy** winds (recently improved with low bias) improve short-range humidity





Normalized departures of assimilated data:

$$\frac{O-B}{\sigma_{obs\_err}}$$

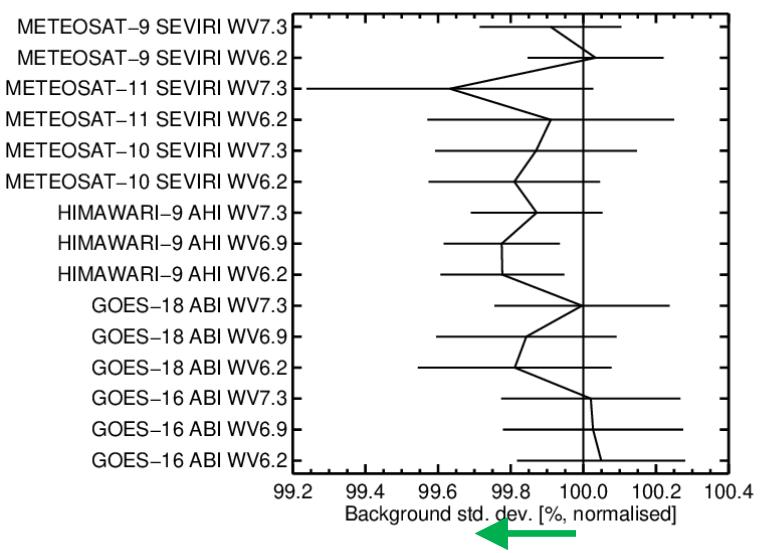
Rayleigh-cloudy are poorer horizontal resolution than Mie-cloudy, but independent wind results

Fraction of assimilated by count:

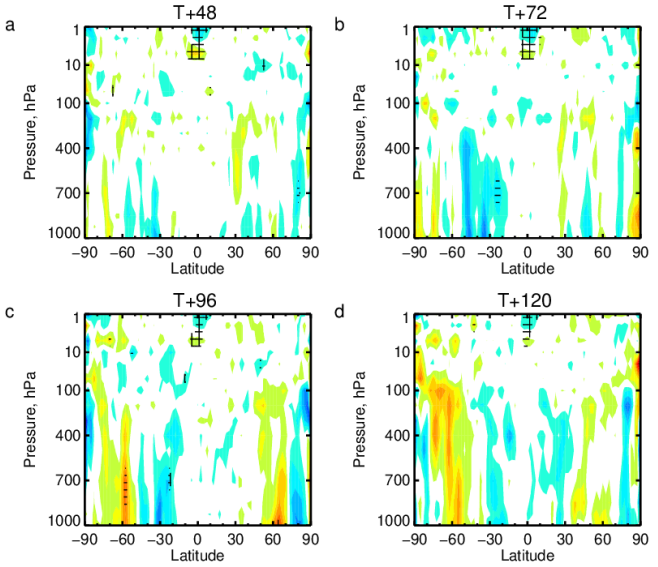
- Rayleigh-clear = 59.0%
- Mie-cloudy = 36.6%
- Rayleigh-cloudy = 4.4%

Rayleigh-cloudy in addition to Rayleigh-clear + Mie-cloudy OSE (3 March to 30 April 2023)

O-B fit to geostationary water vapour channels

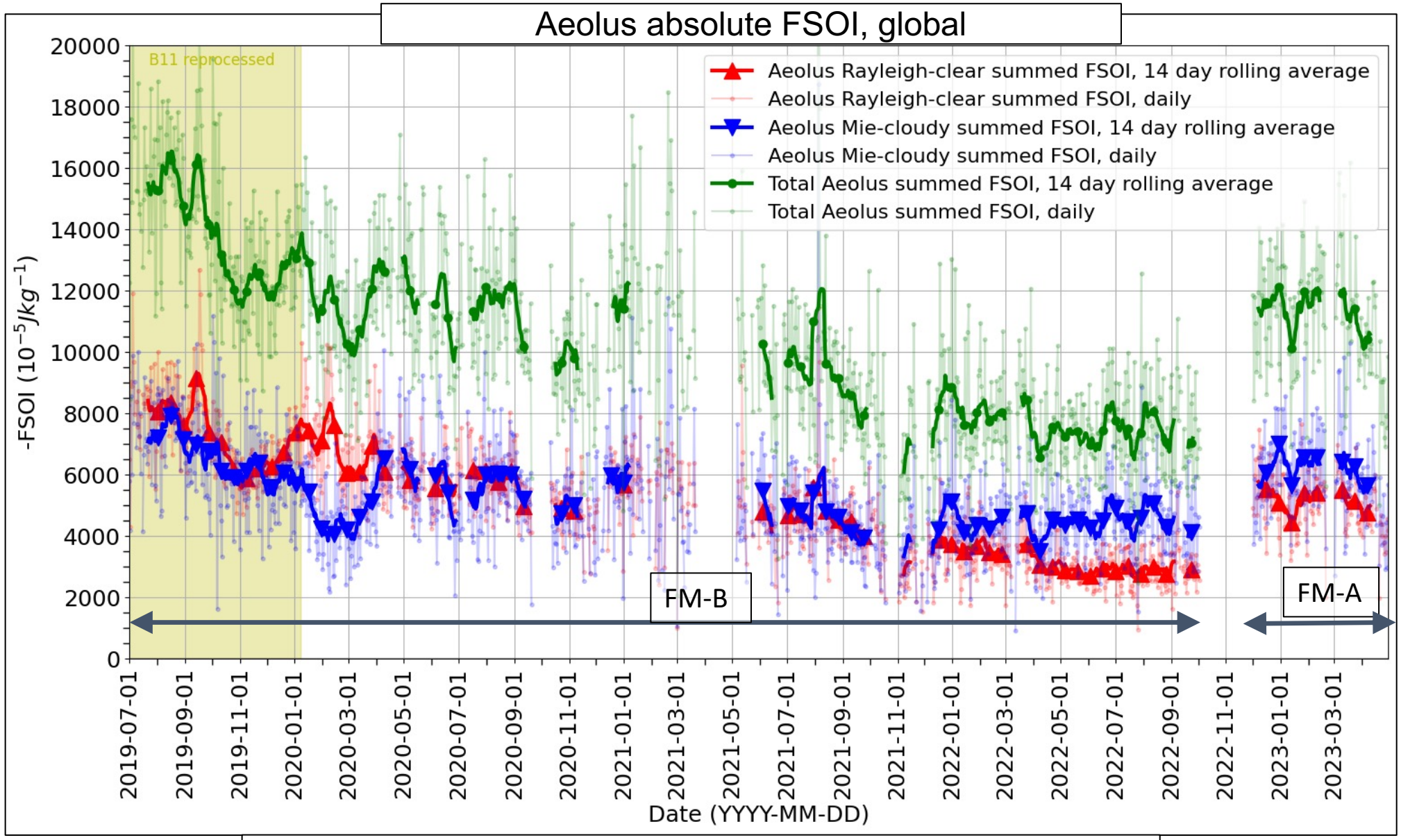


Vector wind RMSE (±5%)



Fairly neutral – hints of positive impact SH

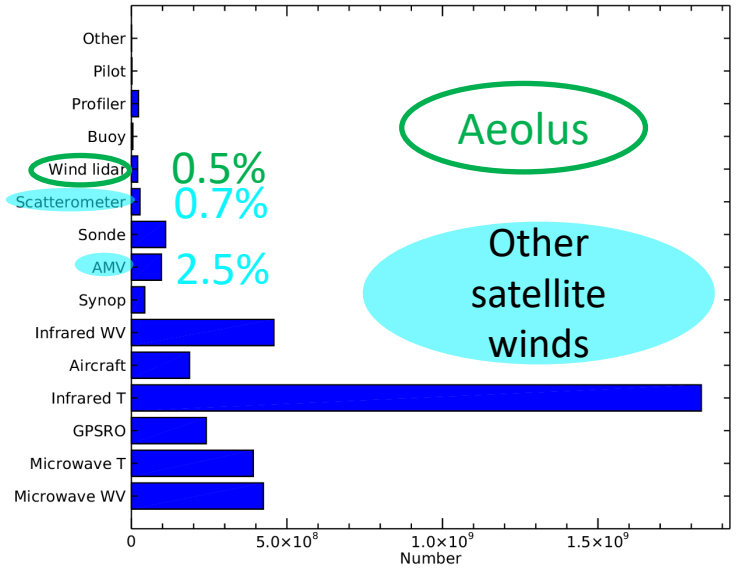
Short-range forecast impact by **F**orecast **S**ensitivity to **O**bservation (FSO) time-series



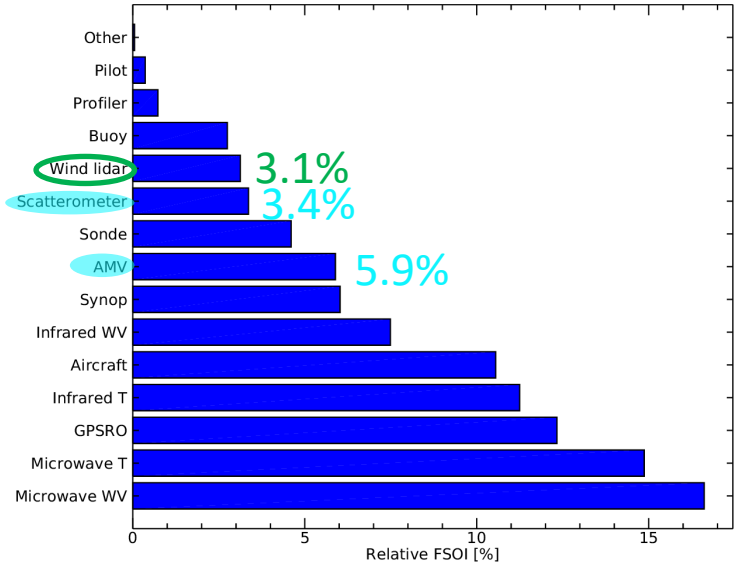
Impact with recent FM-A laser increased by ~60%
compared to ***end*** *of FM-B – thanks to better signal*

ECMWF recent operational relative FSOI (1 Jan to 30 April 2023)

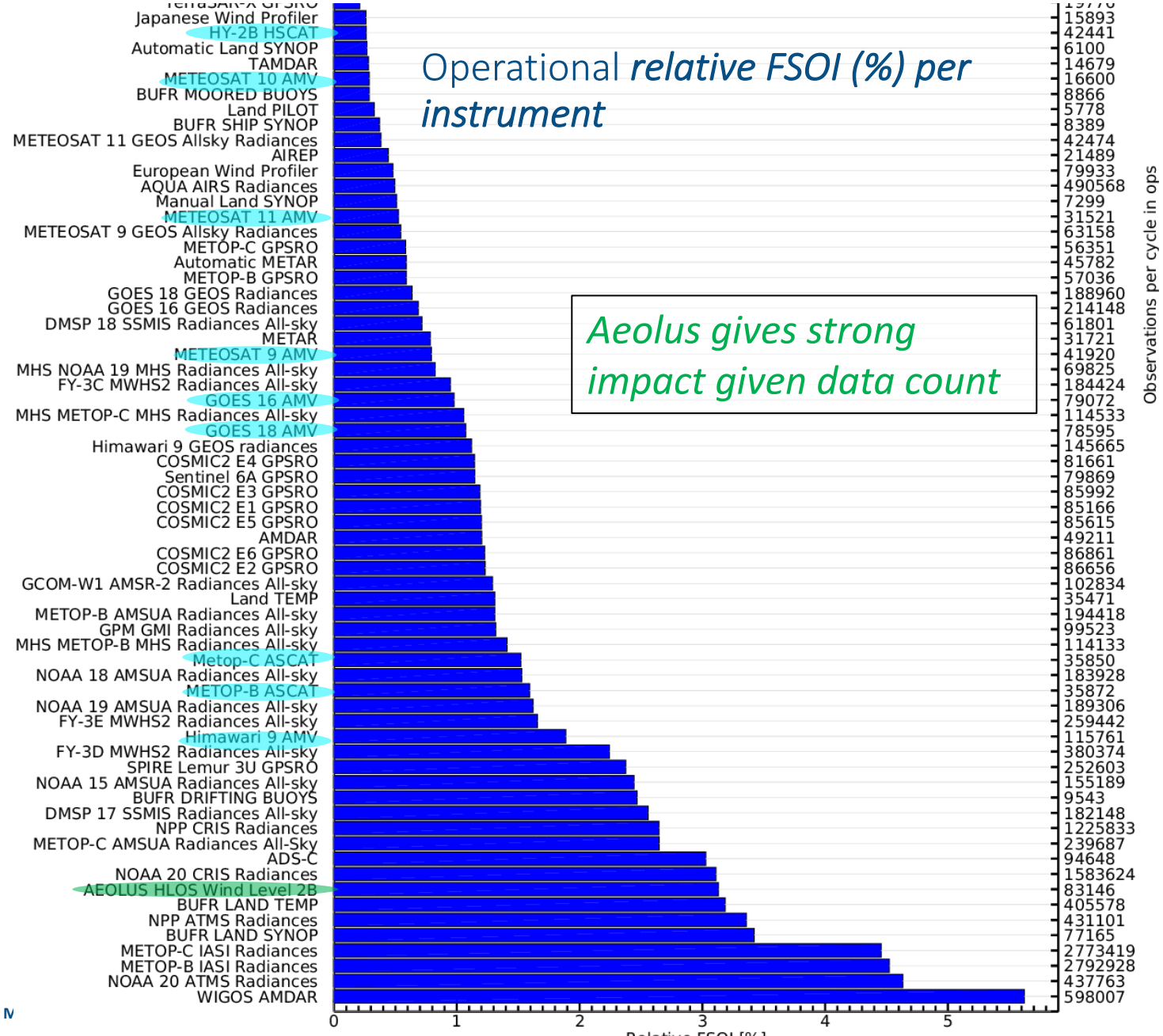
Data counts by group



Relative FSOI (%) by group



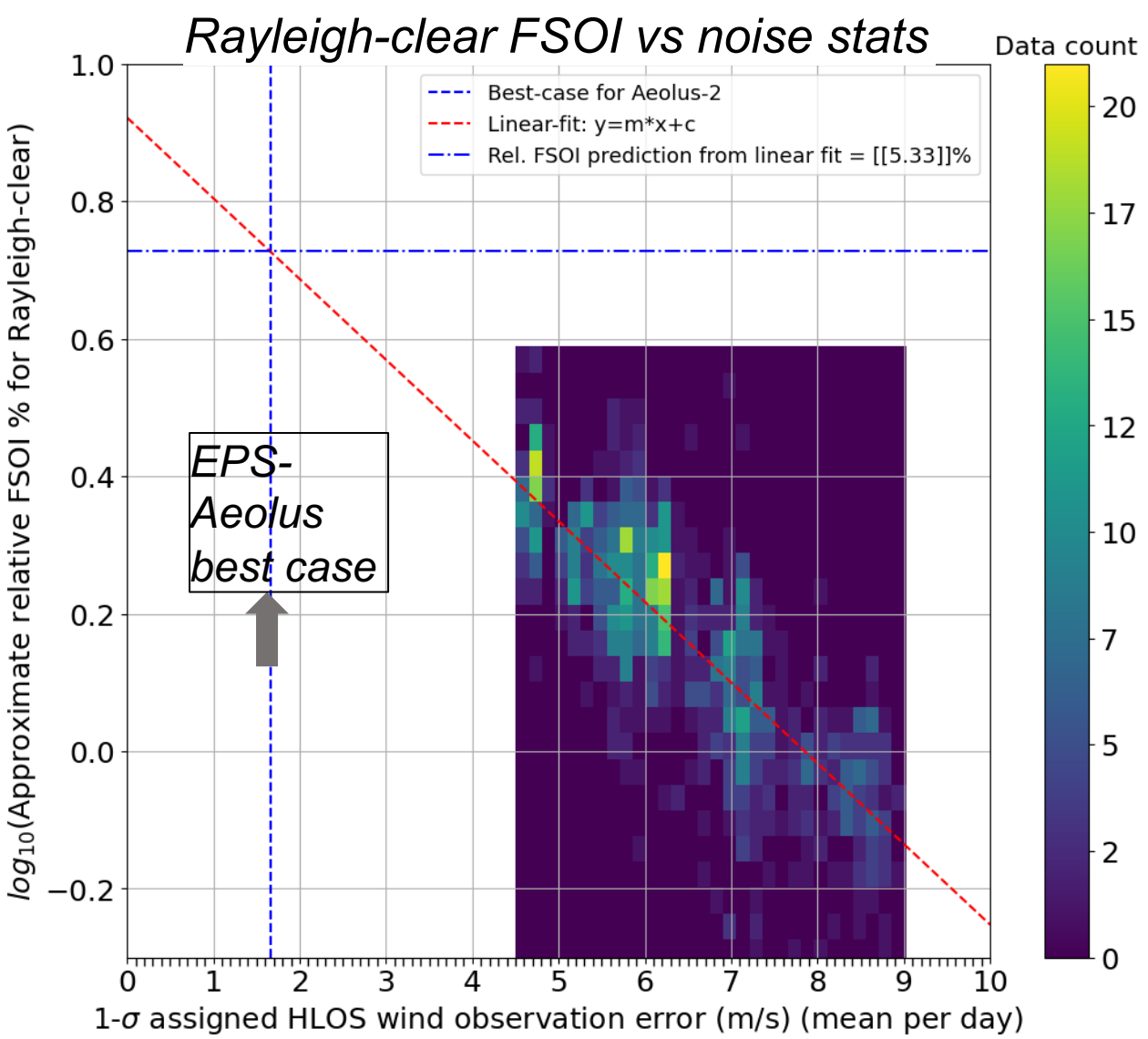
Operational *relative FSOI (%) per instrument*



Aeolus gives strong impact given data count

Plots courtesy of A. Geer (ECMWF)

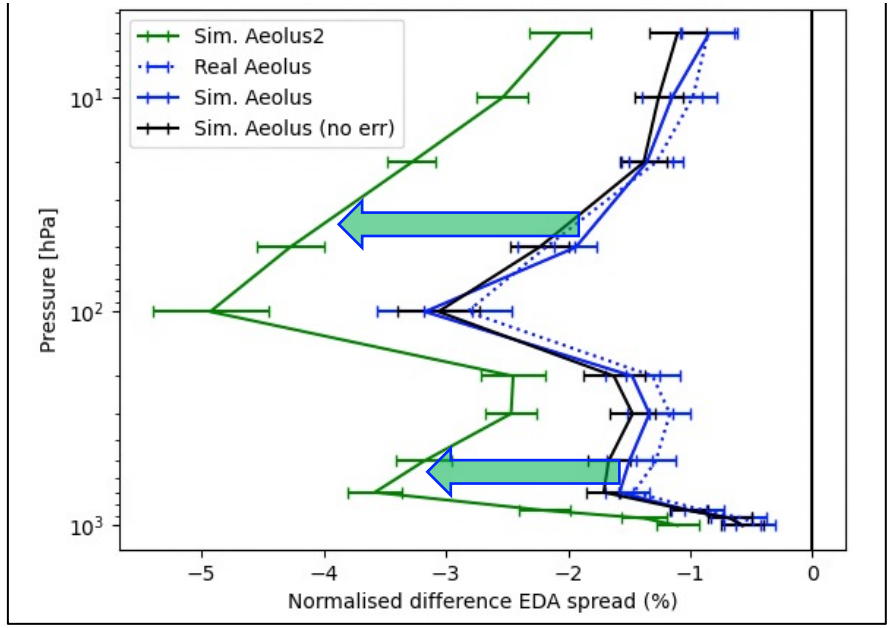
Smaller (better) Rayleigh-clear random **errors increases the FSOI impact**



- **FSOI improves with smaller Rayleigh-clear noise**
- Extrapolation suggests **FSOI can more than double** with **<2 m/s random errors**

  - **Result supported by: Ensemble Data Assimilation *spread reduction* for simulated EPS-Aeolus**

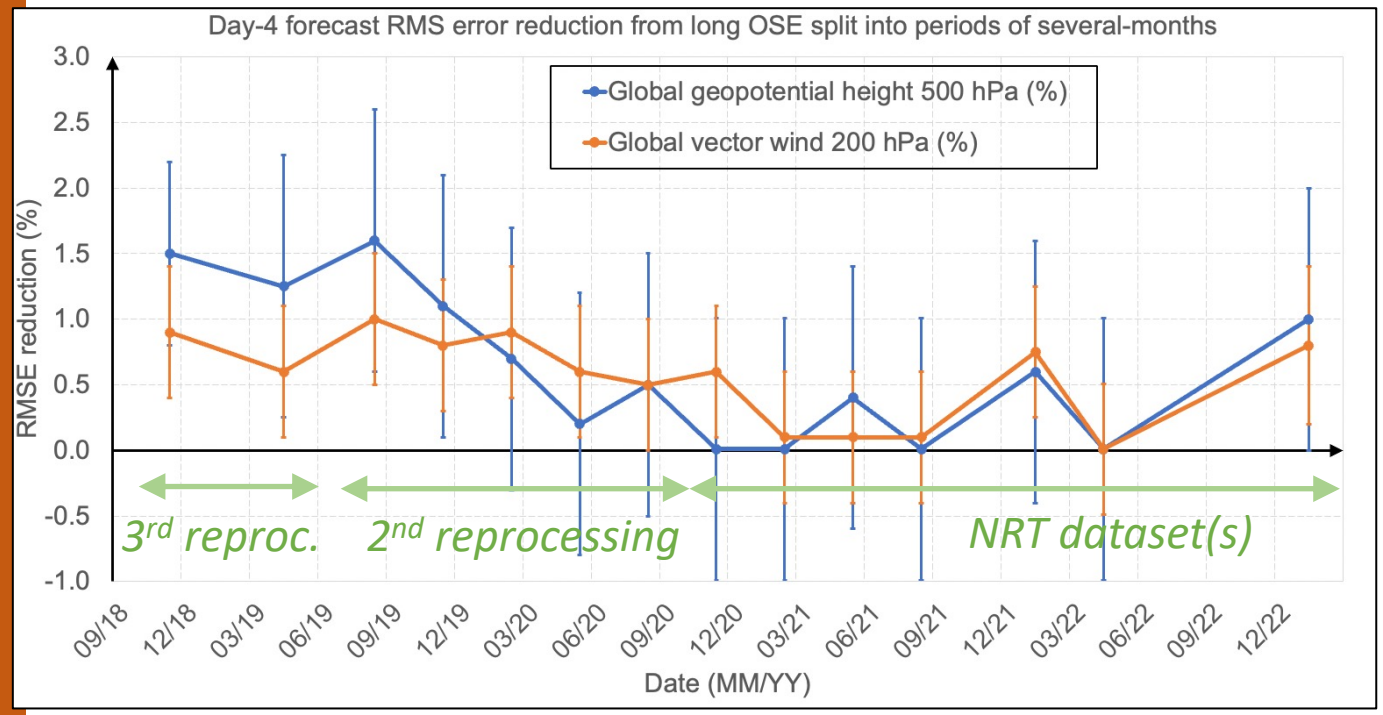
Global u-wind component EDA spread difference

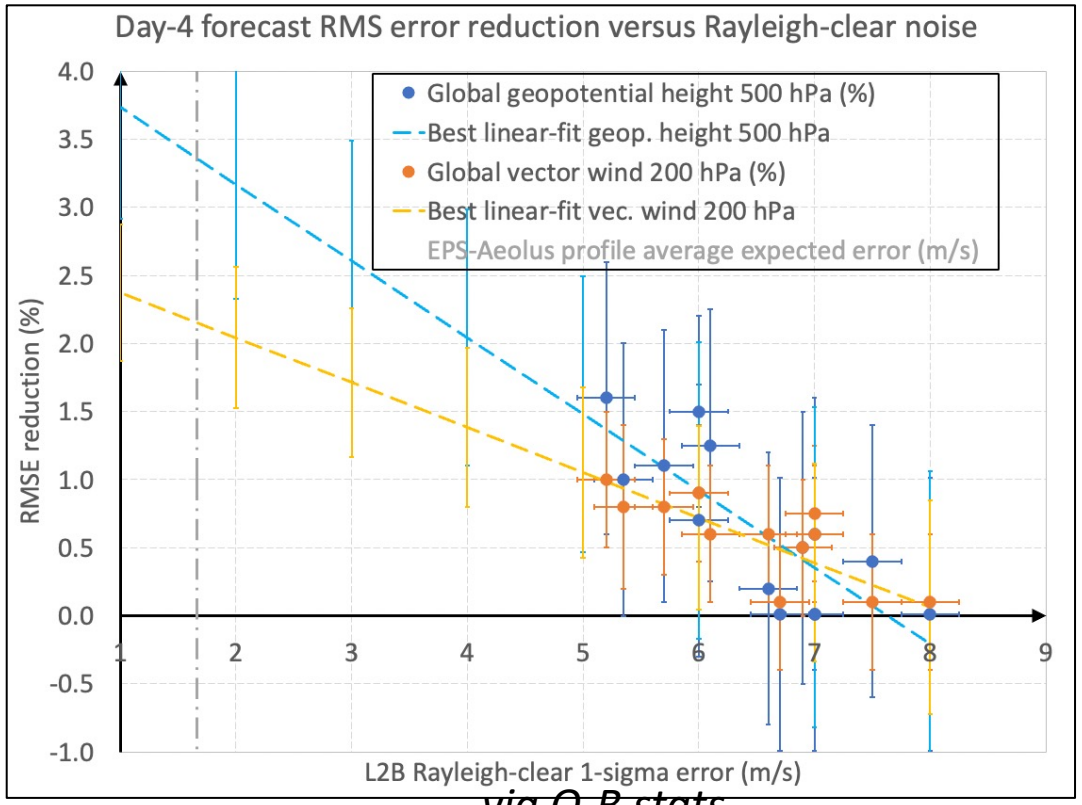


Consolidating Aeolus impact over many OSEs

Smaller (better) Rayleigh-clear random **errors increases the OSE impact**

Global NWP impact metrics at day 4: 3rd (FM-A); 2nd reprocessing (FM-B); and NRT-processing until Feb 2023 (FM-B and FM-A)





via O-B stats

Linear-fit extrapolation to show tendency, suggests ***impact could more than double with random errors ~2 m/s***

Summary

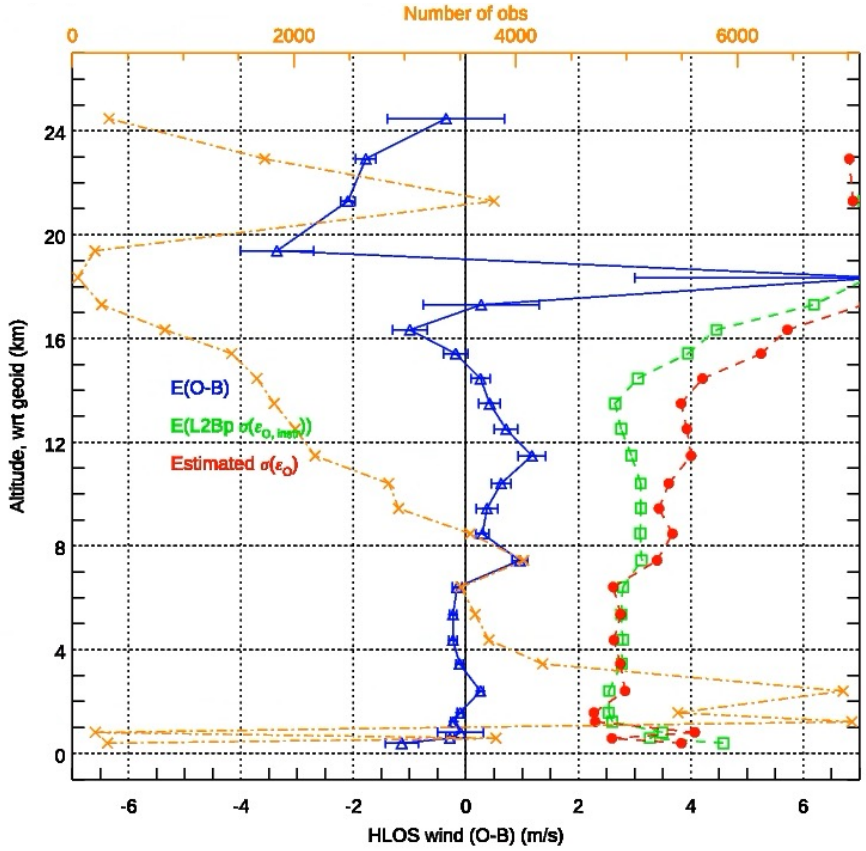
- Data quality varied during the mission due to varying signal levels and ground processor versions
- Reprocessed early FM-A laser data (2018/2019) also shows a **good NWP impact** for one satellite instrument:
  - Positive impact on wind, temperature and humidity
    - Largest impact in tropics and polar regions; into medium range
  - FM-A showed 1-2% improvement in 500 hPa Z at day 4-5
    - Highlights continuing need for more wind profiles
- Provided useful NWP impact until last available operational data
  - A small additional benefit for humidity with *Rayleigh-cloudy winds*
- Several methods agree that ~2 m/s 1-σ random error for Rayleigh-clear HLOS winds (rather than more typical 6 m/s for Aeolus) should at least double impact
  - This level of noise is aimed at with the ESA/EUMETSAT operational follow-on mission (Aeolus-2/EPS-Aeolus)

Thanks for listening, any questions?

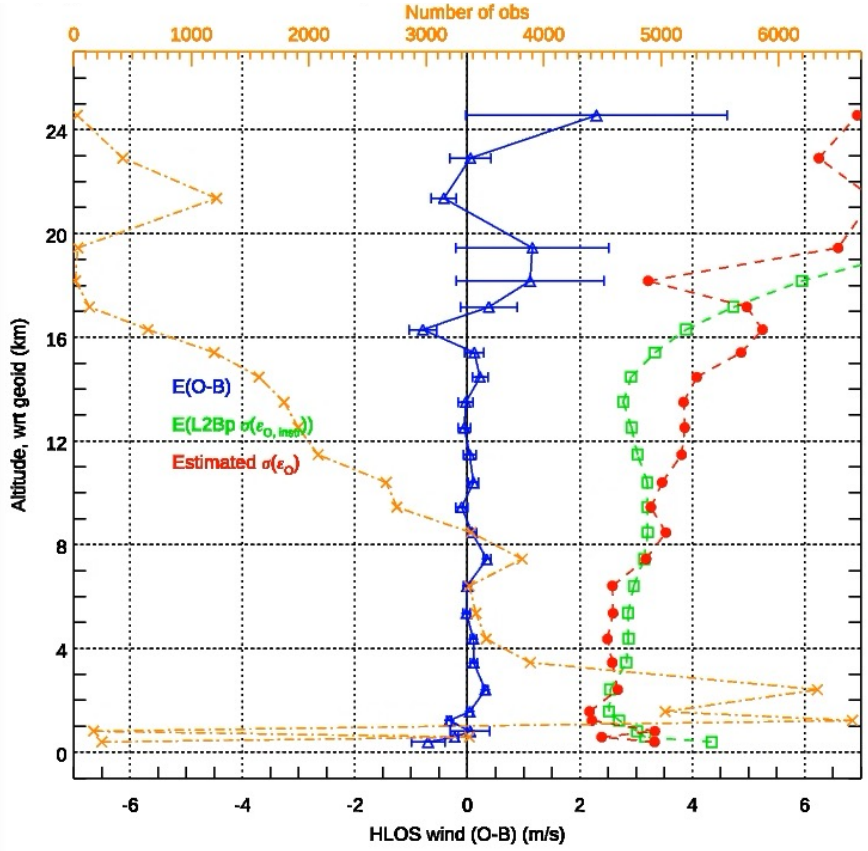
NRT HLOS wind quality gradually improved, e.g. recent processing algorithm update ….

L2B Mie-cloudy O-B (ECMWF) statistics, global, versus altitude

Baseline 15



Baseline 16

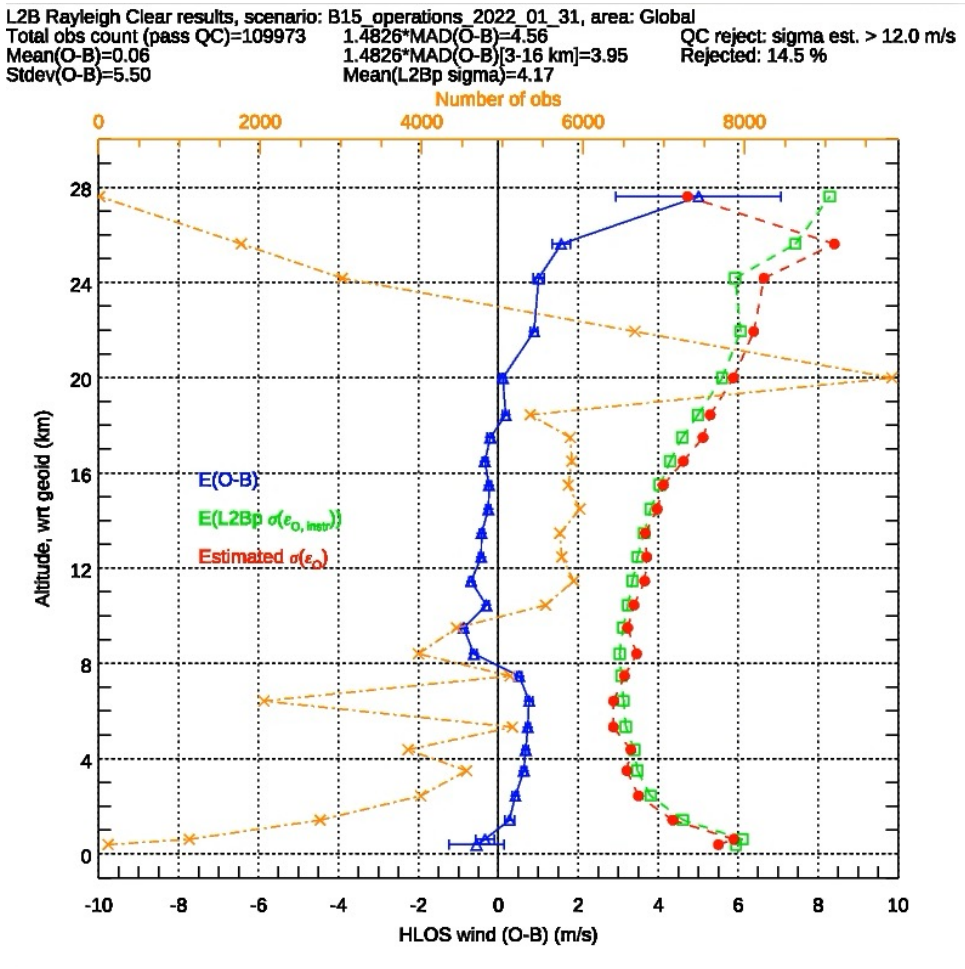


- Tests from 31 Jan 2023
- Baseline 16 went operational on 18 April 2023

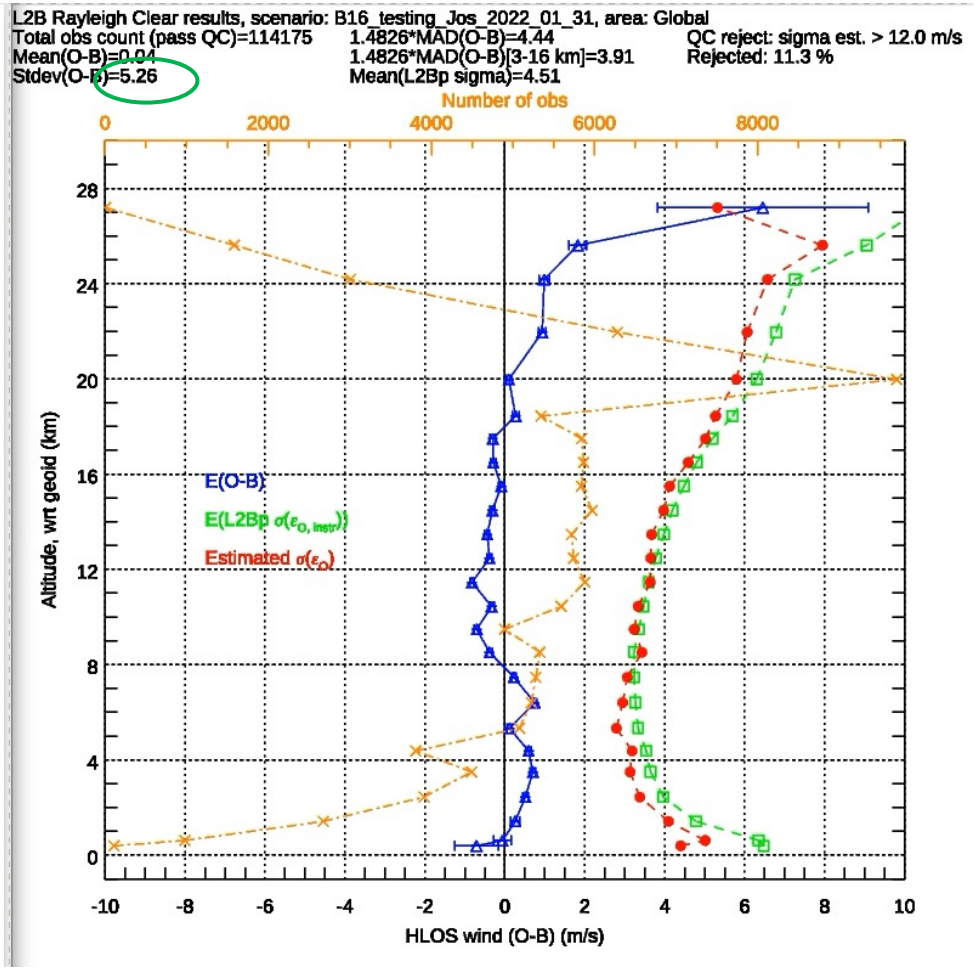
- σ_{O-B} was improved by ~25% and smaller biases with B16 vs B15
- Data counts reduced by 13% due to **improved QC in L2Bp – better detection of gross-errors**
- **Expect more improvements in future reprocessing (despite end of operational data)**

L2B Rayleigh-clear O-B statistics, global, versus altitude

B15



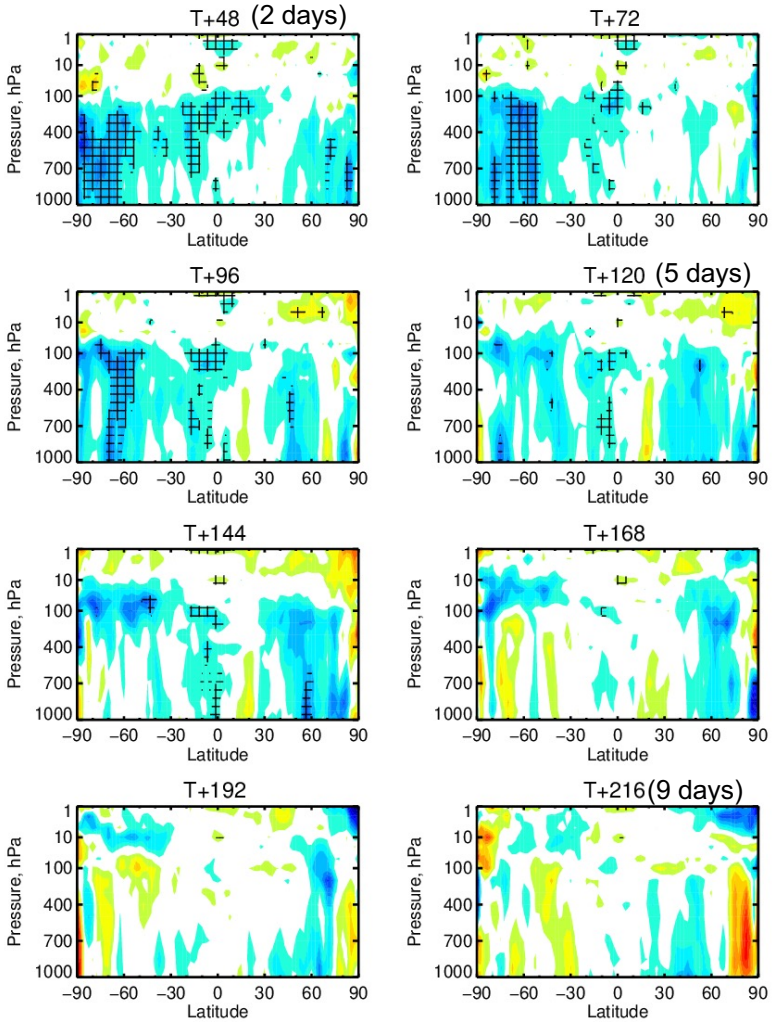
B16



- Stdev(O-B) is improved by 4% with B16 vs B15
- L2B product estimated error (used in assimilation) increased by ~8% which is a more realistic error estimate
- More data (+4.5%) due to L1B **fix for range-bin 15** (fake hot-pixel issue)
- B16 will be used in fourth reprocessing campaign (in preparation), covering the whole mission

First part of 3rd reprocessing (FM-A laser): 4 Sept 2018 to 13 Jan 2019

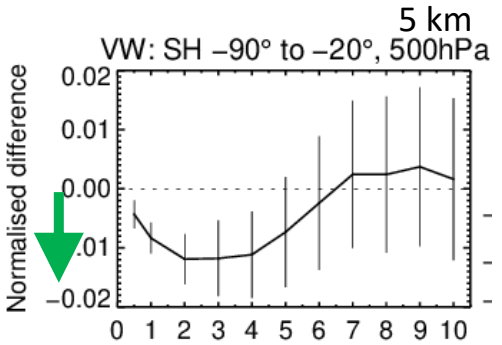
Vector wind RMSE



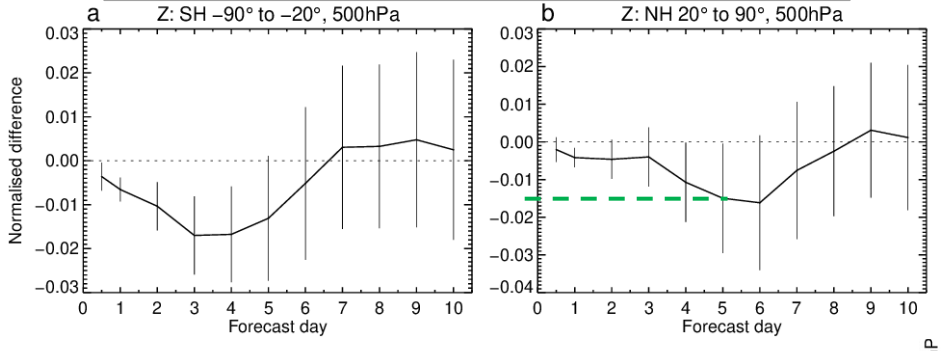
-5% +5%

Blue is good

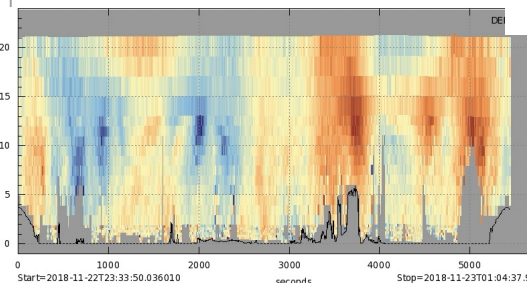
Impact good in SH troposphere to day 4



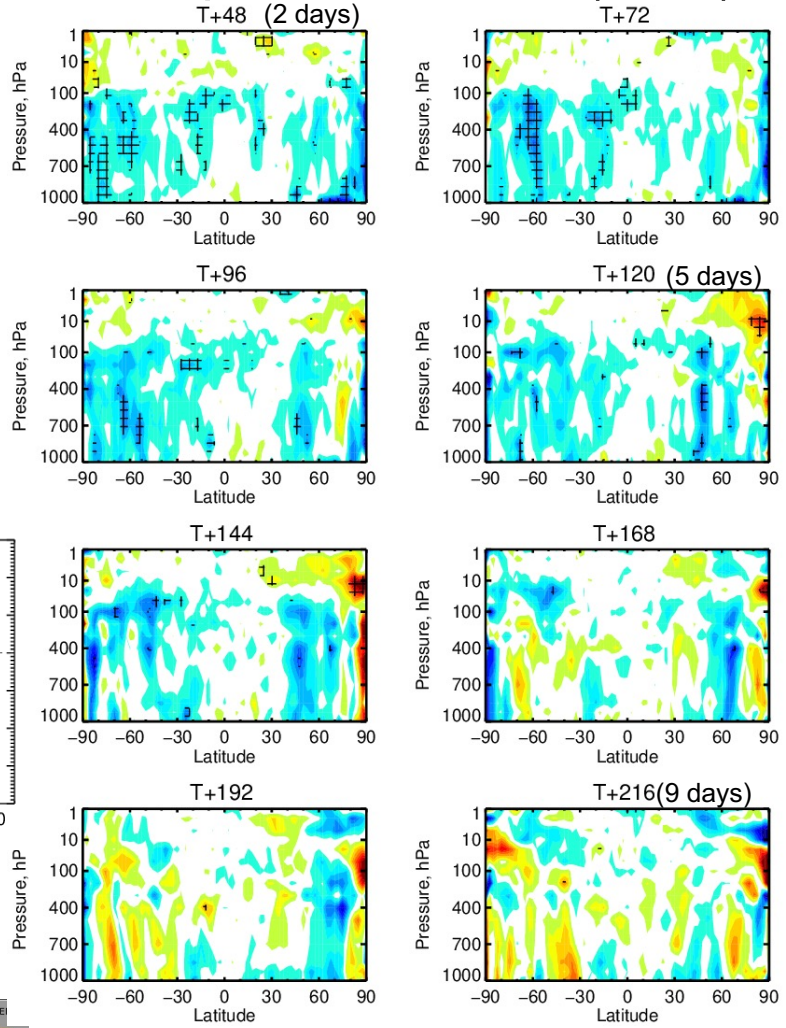
N Hemi. Z500 RMSE improved by 1.5% to day 5



Smaller/mixed impact in LS – 2 km thick range-bins > 14 km caused issues



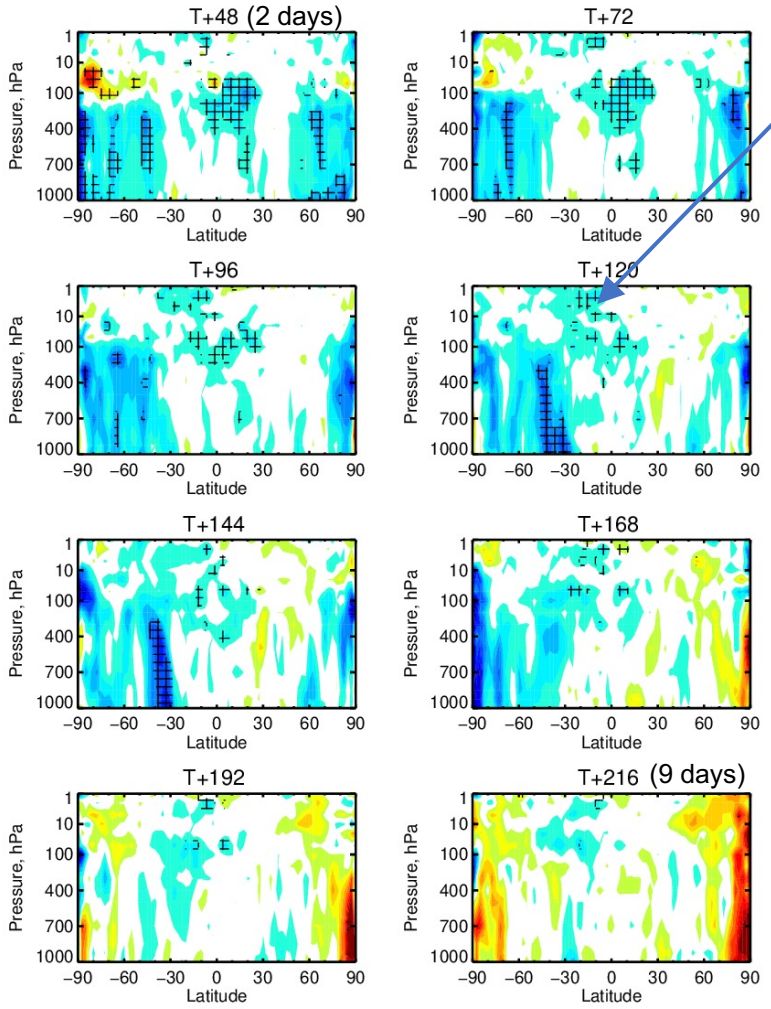
Temperature RMSE (±5%)



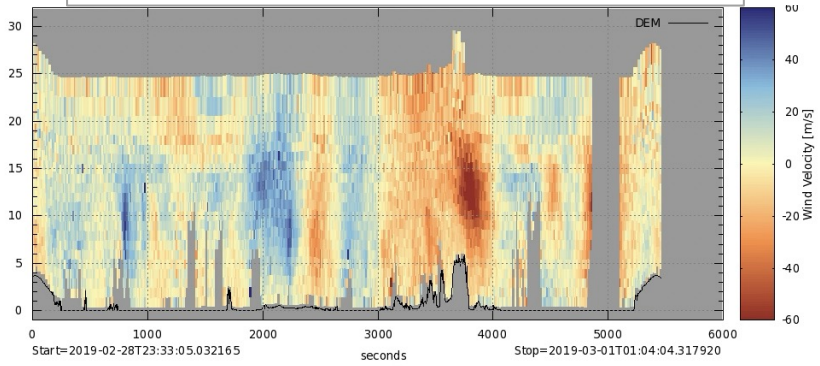
Verification against ECMWF oper. analysis

Second part of 3rd reprocessing (FM-A): *14 Feb to 4 Jun 2019*

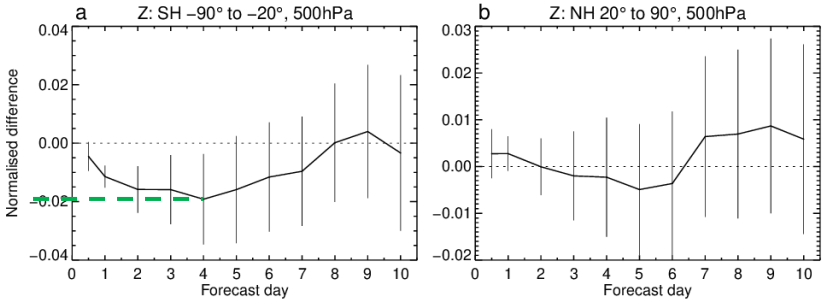
Vector wind RMSE



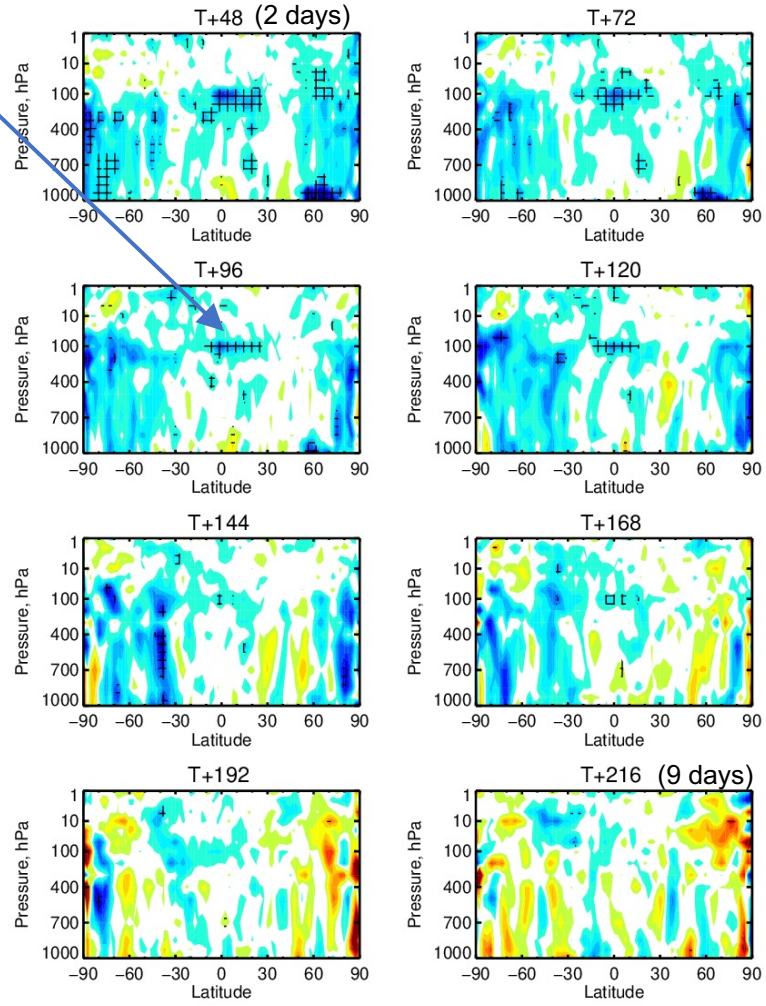
Lower stratosphere better – range-bins more suited to NWP after 26 Feb 2019



S. Hemi Z500 improved by 2% at day 4 – more neutral in N. Hemi.

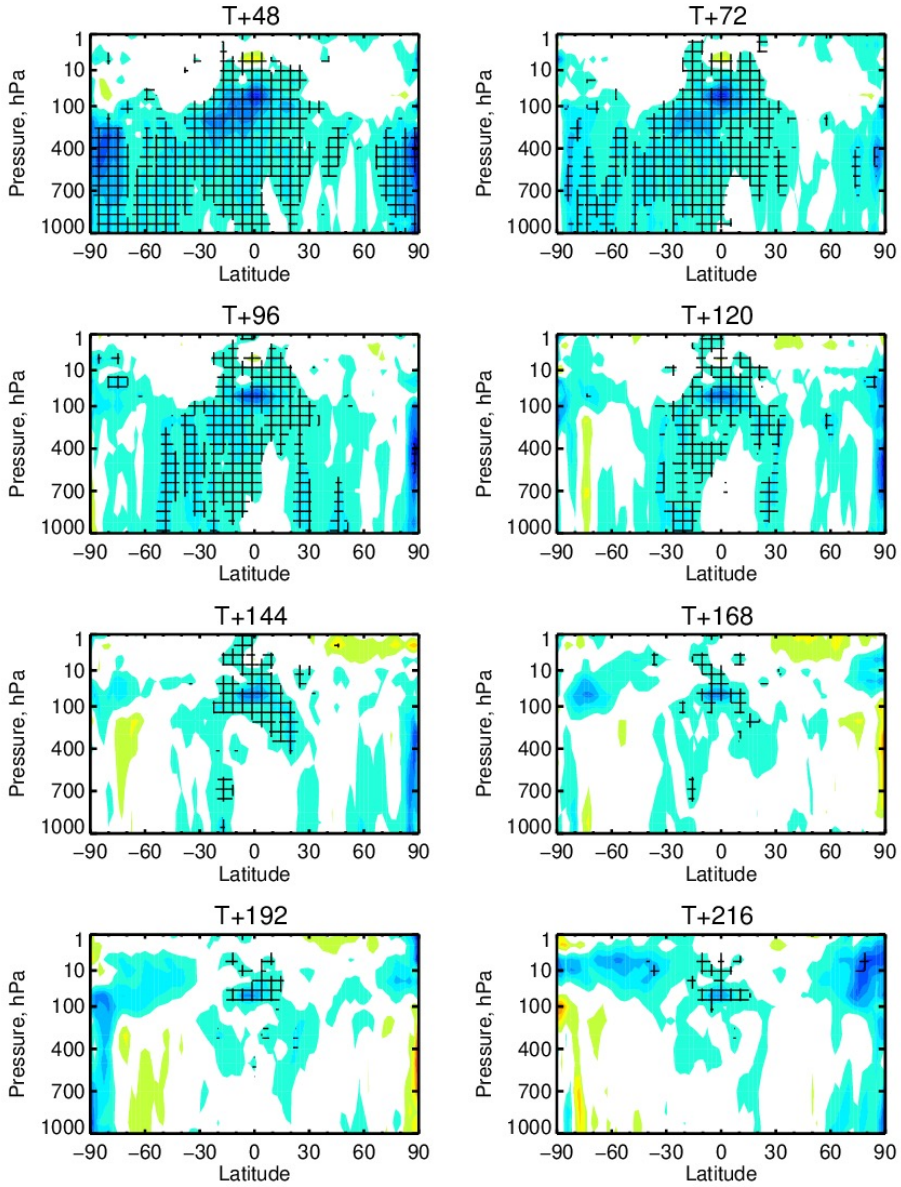


Temperature RMSE (±5%)



Comparison reprocessed data OSEs for different periods

2nd reprocessing, FM-B, B11, 29/6/19 - 9/10/20 (±4% scale)

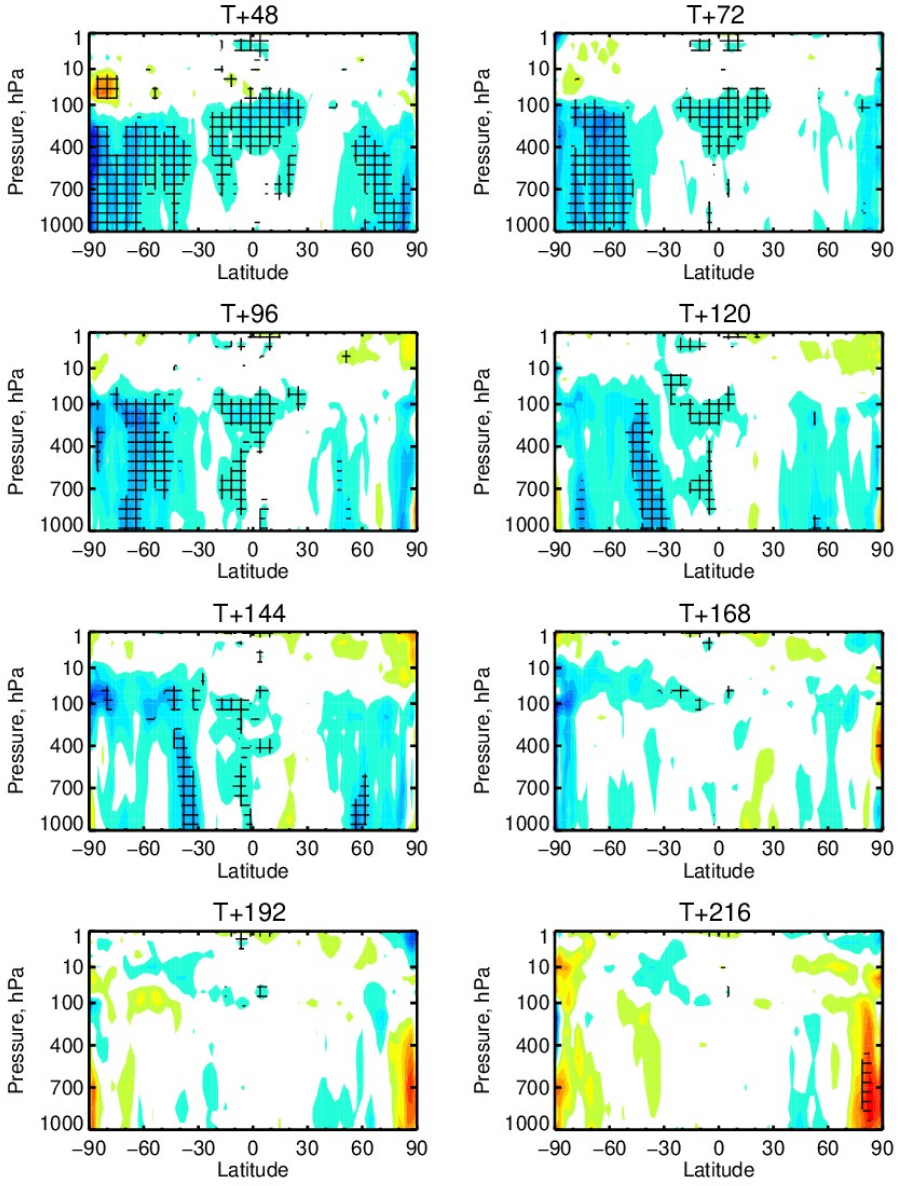


Vector wind RMSE

Similar geographical patterns of positive impact (to day 6) – but not as strong in tropics UTLS for 3rd *vs* 2nd reprocessing

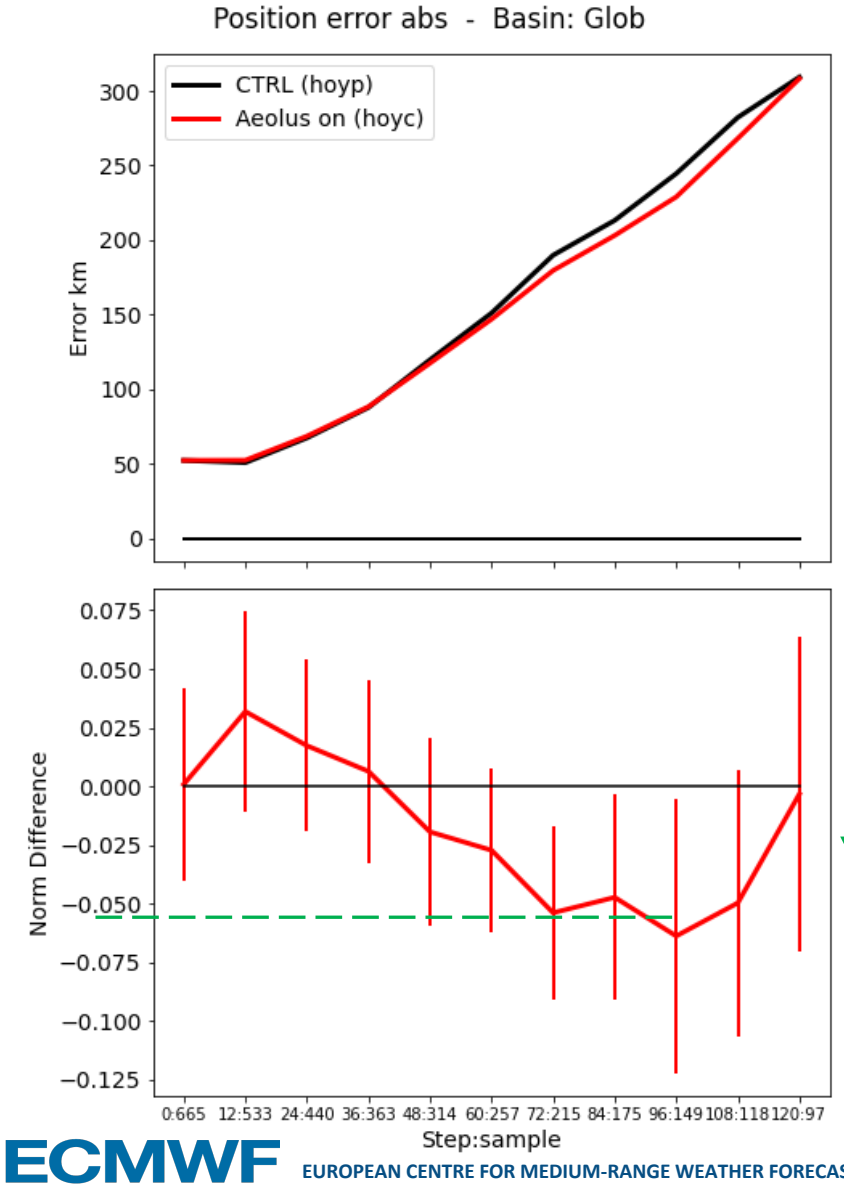
- Better vertical resolution range-bins in strong wind-shear?

3rd reprocessing, FM-A, B14, (±5% scale)



Strangely, best tropical cyclone position error result from low signal period

OSE for Dec 2021 to Sept 2022



Other reprocessed periods show neutral impact

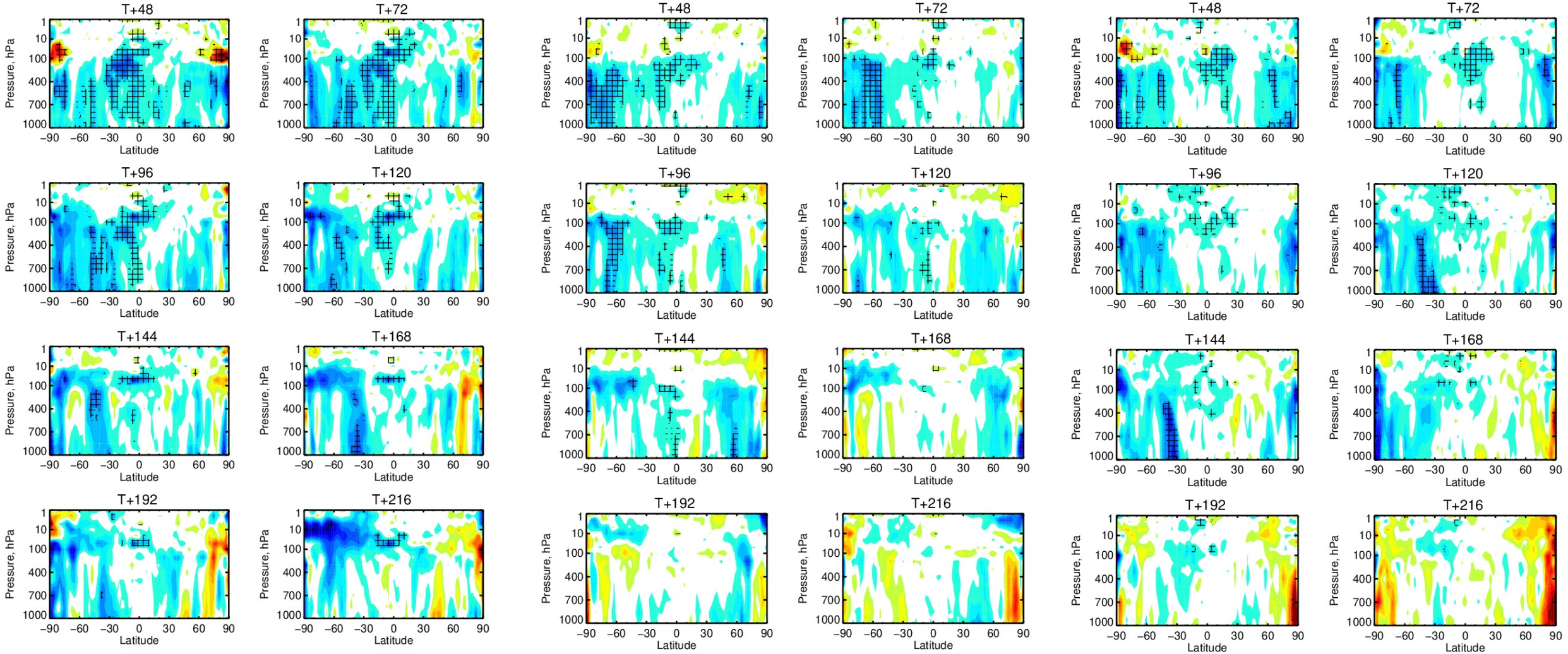
- ~5% improvement at day 3-4
- Seems robust due to large sample of tropical cyclones (149 to 215)

Comparison of vector wind RMSE different periods (±5% scale)

2nd reprocessing, FM-B, B11, 29 June – 29 Sept **2019**)

3rd reprocessing, FM-A, B14, 4 Sept **2018** – 13 Jan **2019**

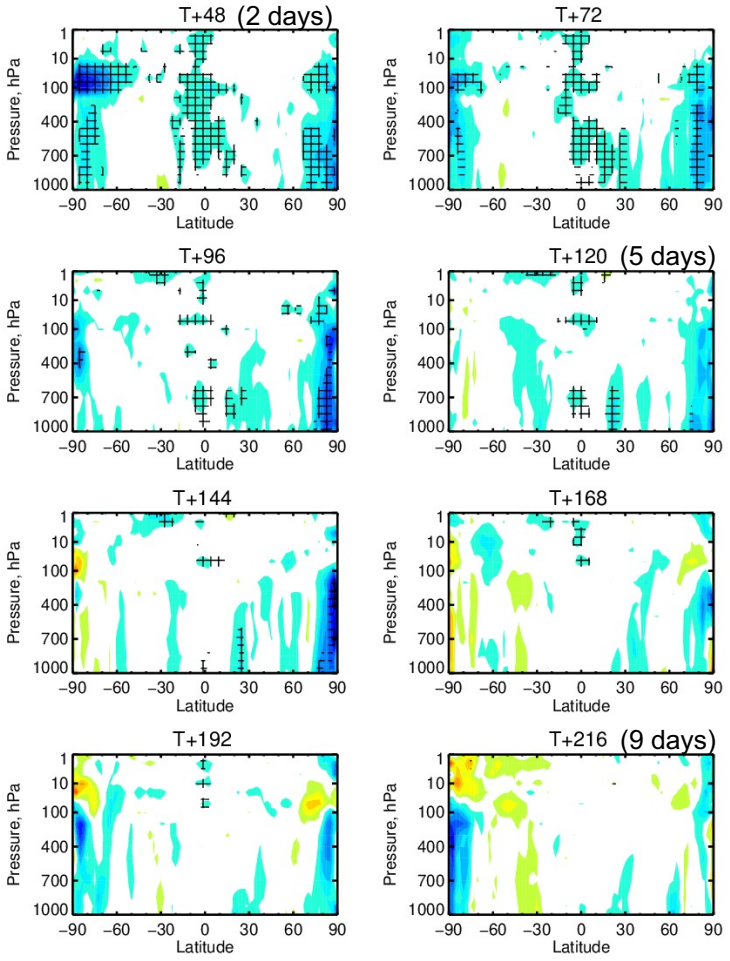
3rd reprocessing, FM-A, B14, 14 Feb – 4 Jun **2019**

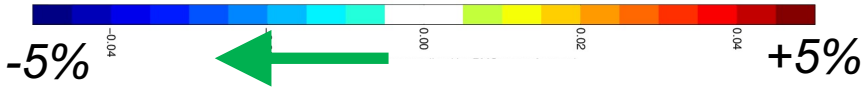


Similar patterns of positive impact (to day 6) – but stronger for 2019 FM-B (best SNR)

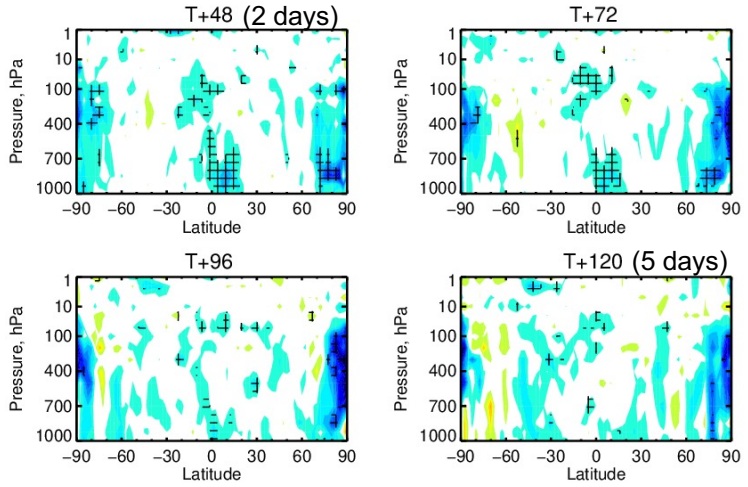
Even some positive impact with **large Rayleigh noise** at **end of FM-B period OSE** (Dec 2021-Sep 2022)

Vector wind RMSE



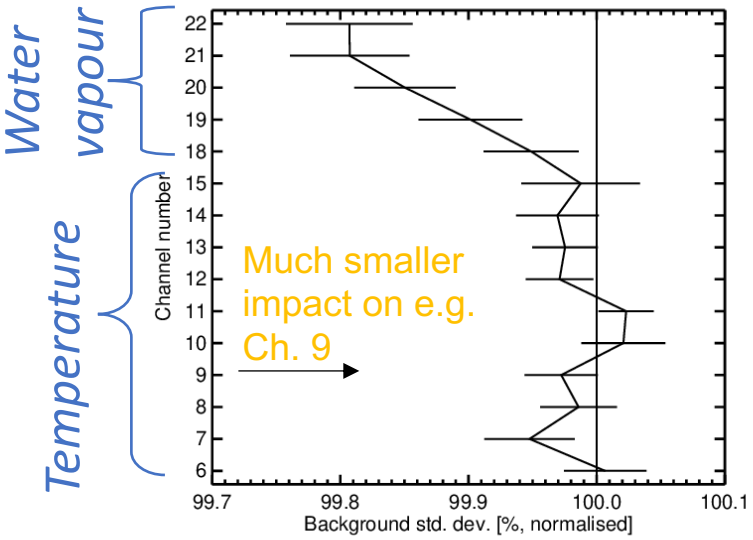


Temperature RMSE (±4%)

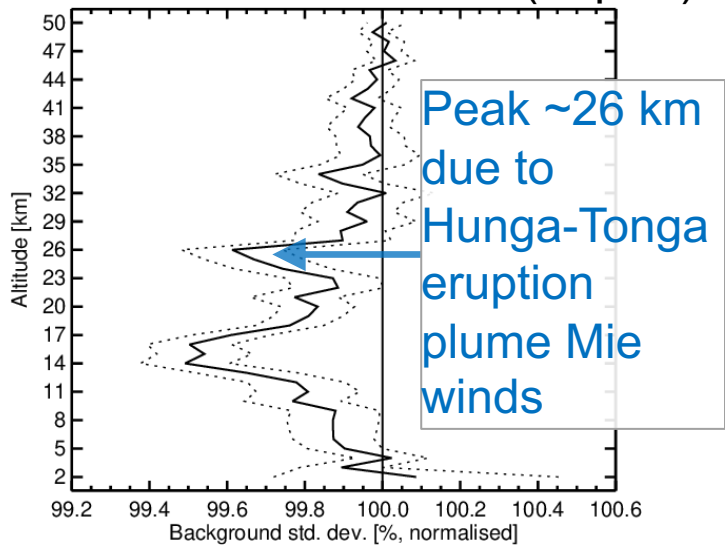


- Positive impact in tropics and polar areas up to day 4
- But tropical impact small compared to 2018-2020
- Mie-cloudy probably providing most of polar impact

O-B ATMS (global)

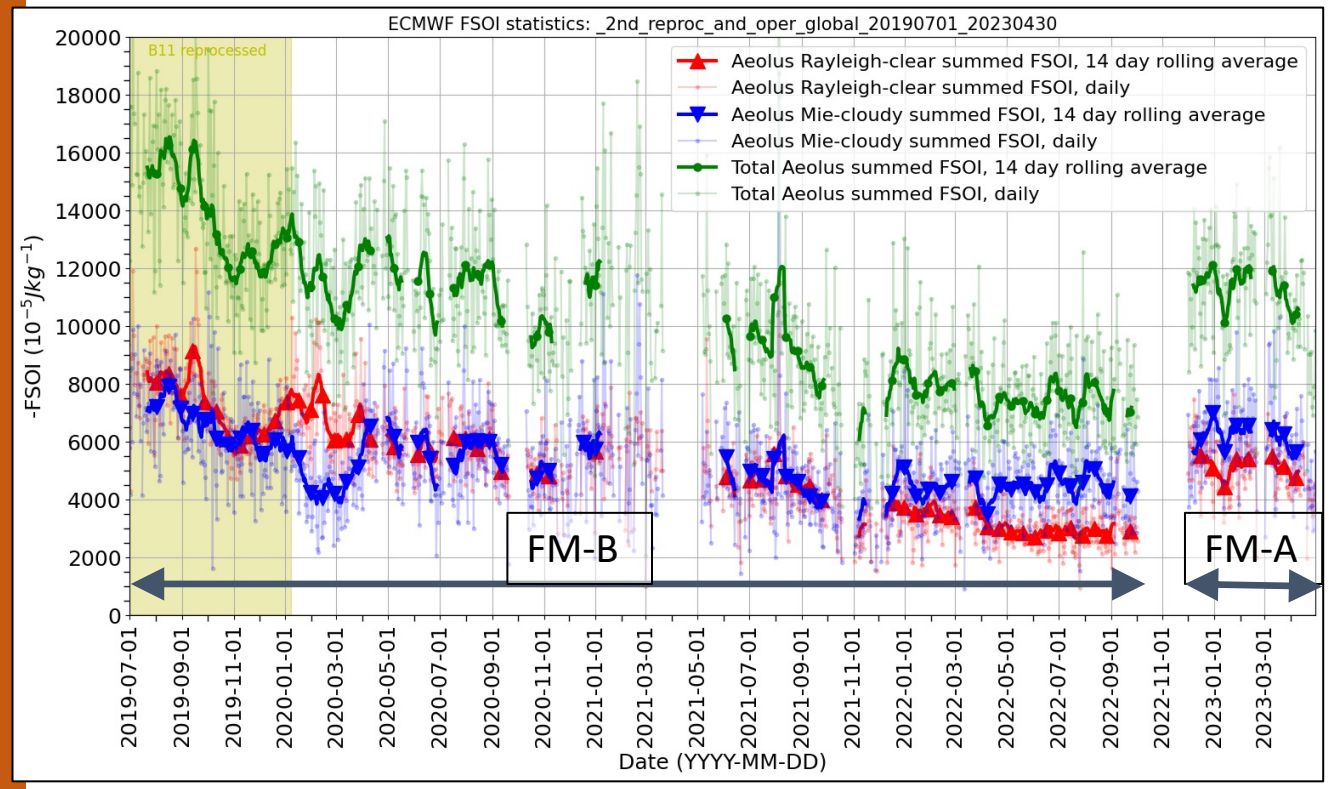


O-B GNSS radio occultation (tropics)



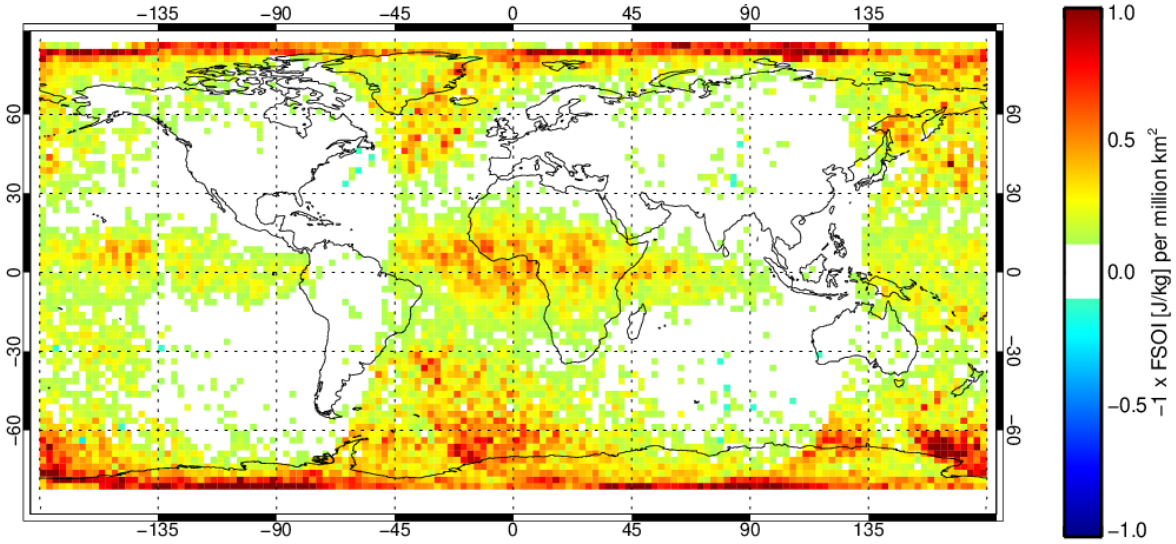
Short-range forecast impact by **F**orecast **S**ensitivity to **O**bservation (FSO) over mission

Time-series of Aeolus absolute FSOI, global



Impact with recent FM-A laser increased by ~60% compared to ***end*** *of FM-B – thanks to better signal*

Aeolus FSOI per area (Jan 2020 to June 2022)



Largest impact over the **oceans**, **tropics** and **polar** regions

- Regions of lower impact are due to Aeolus' orbit occurring at start of ECMWF 12-hour 4D-Var window (9-21 UTC, 21-09 UTC)