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

By Michael Rennie (ECMWF and ESA Aeolus DISC)

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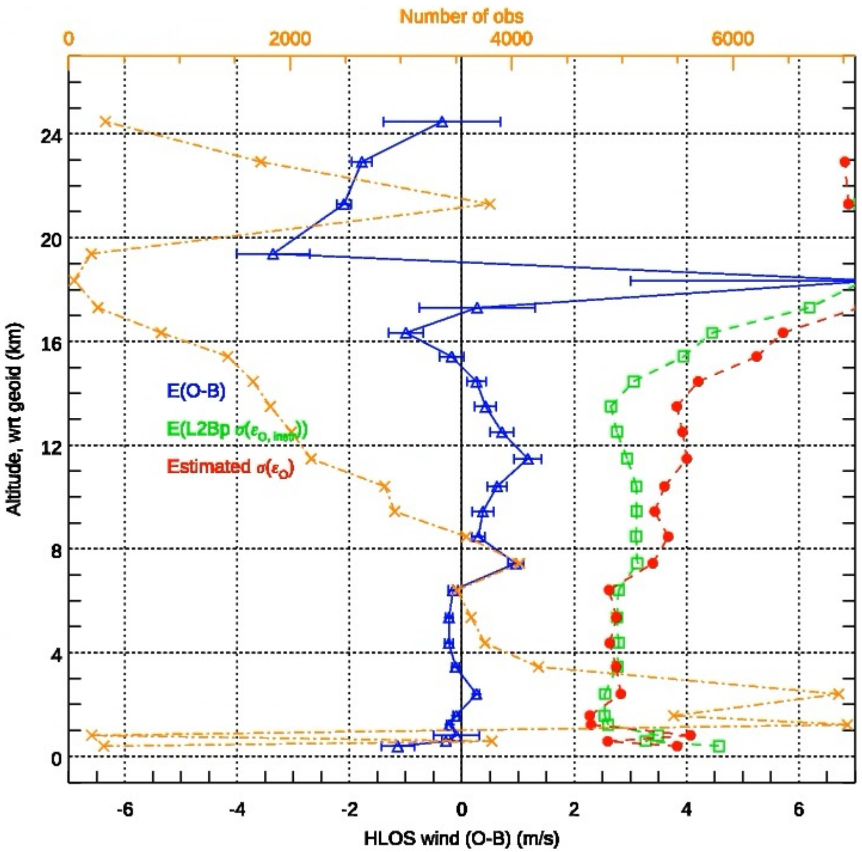
Thanks to: DISC colleagues, Giovanna De Chiara, Sean Healy/Katie Lean (ECMWF)

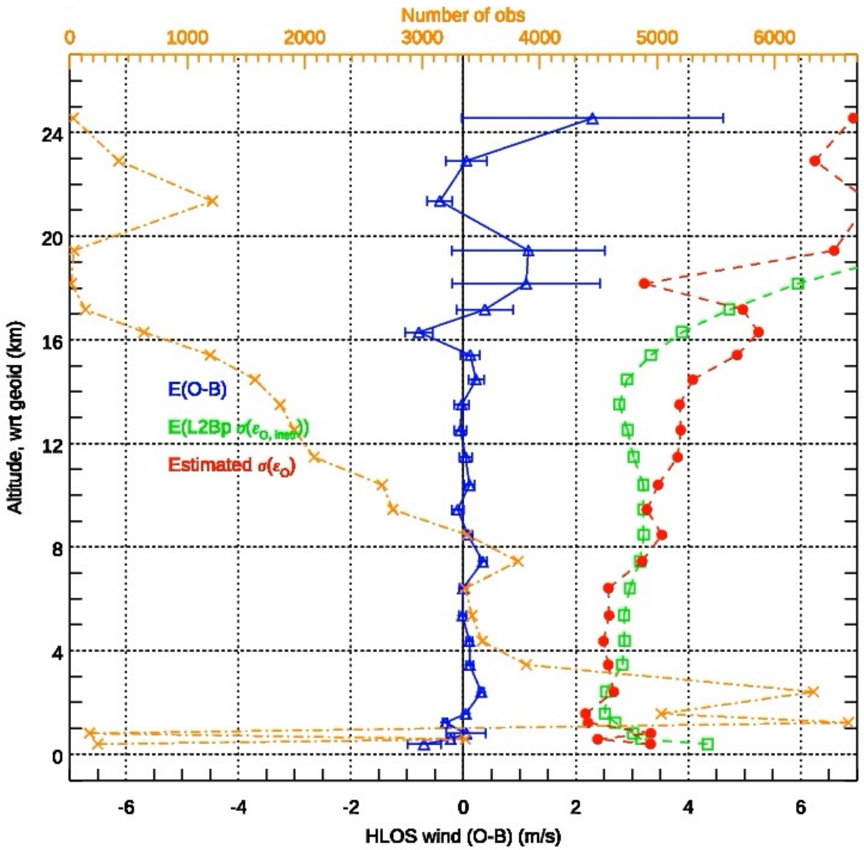
An example of how the L2B wind data quality has continued to improve: recent processing algorithm update to baseline 16

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

Baseline 15



Baseline 16



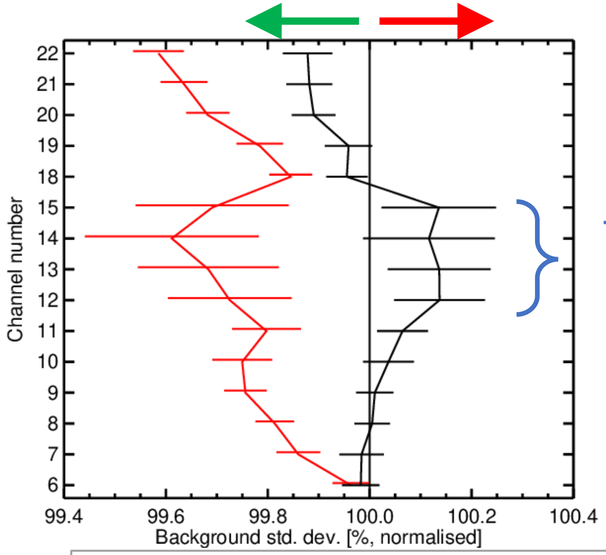
- Tests from 31 Jan 2023
- Baseline 16 went operational on 18 April 2023

- σ_{O-B} improved by ~25% and smaller biases with B16 vs B15 (with relaxed L2Bp estimated error QC)
- Should allow use of weak backscatter (aerosol) Mie winds in future OSEs
- Data counts reduced by 13% due to **improved QC in L2Bp – better detection of gross-errors**
- **Still scope for further improvements in future reprocessing**

A Mie-only OSE for reprocessed 2018/2019 (early FM-A laser) highlighted *some* negative impact

- Mie-cloudy winds caused some *T degradation* in stratosphere
- *Probably* due to **thick range-bins**
  - 2 km thick bins used in Commissioning Phase until 26 Feb 2019 in upper troposphere – negative impact was worse before this date
  - Combined with **point-wind observation operator**
  - **Could explain some large erroneous increments in areas of strong vertical wind-shear**
- *But* Mie-only still provides positive wind impact in polar areas at 2 days

Global O-B fit to ATMS (microwave sounder)

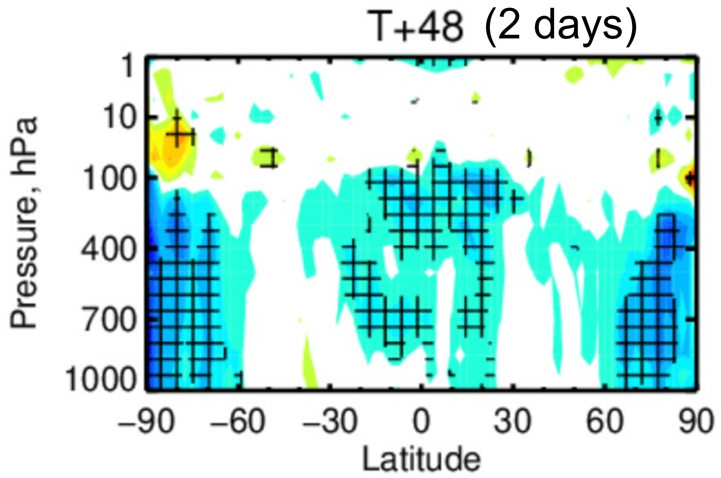


T weighting functions peak ~20-35 km

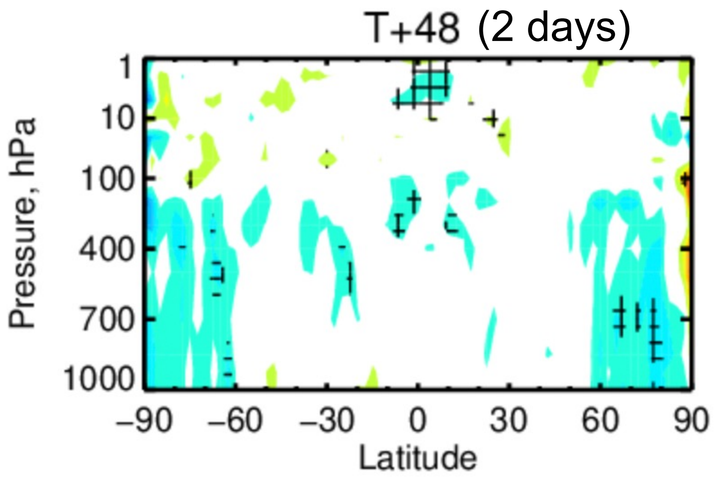
- Mie-cloudy+Rayleigh-clear
- **Mie-cloudy only**

OSE period: 4/9/18 to 8/6/19

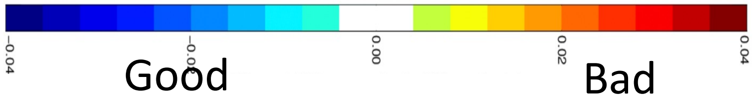
Ray+Mie impact



Mie only impact



Vector wind RMSE (±4%)

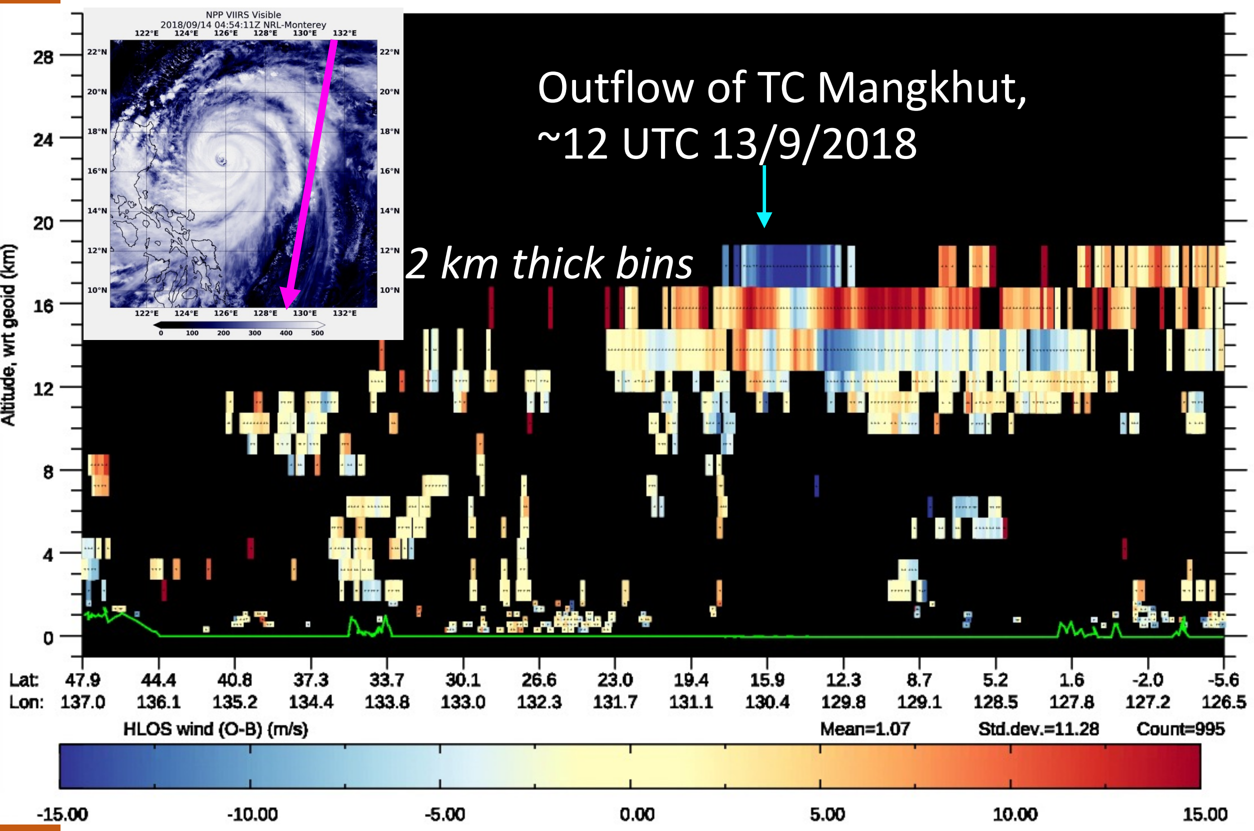


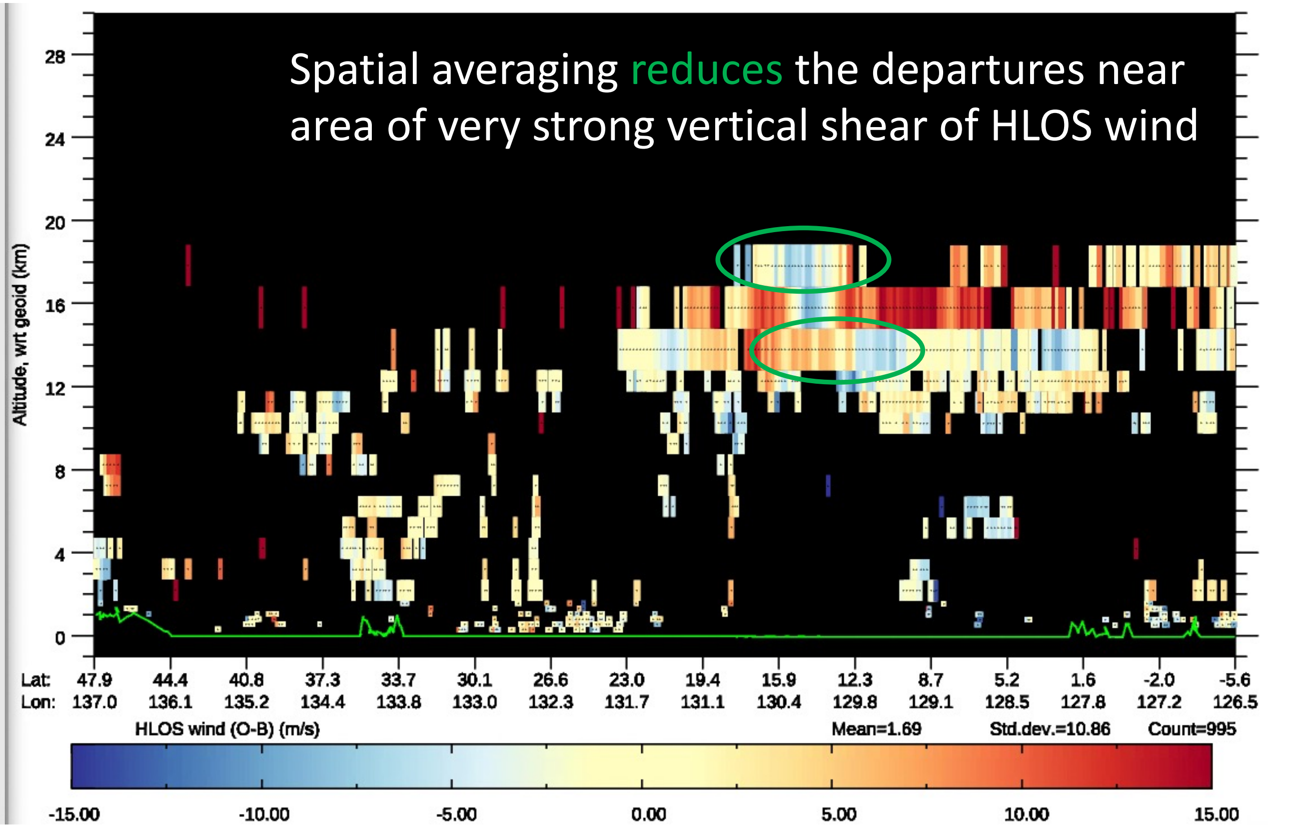
An example of where thick range-bins matters e.g. tropical cyclone outflow, Sept 2018

Nominal **“point-wind”** observation operator *H*(x) – centre of bin

Mie-cloudy O-B values

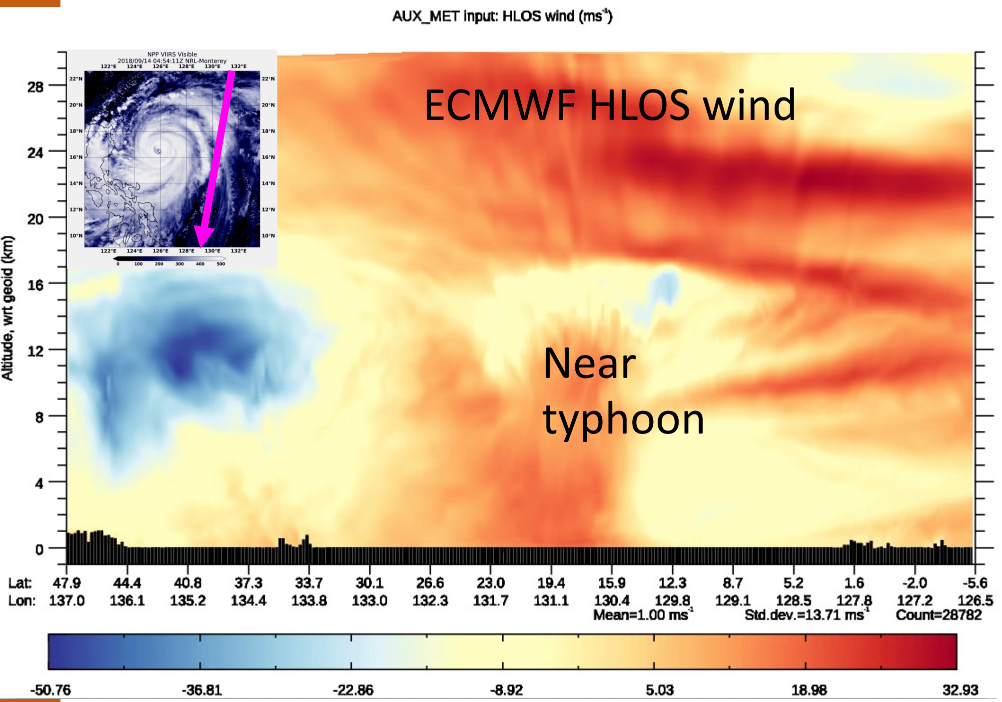
Attenuated backscatter **weighting of model HLOS wind** over range-bin “box” *H*(x)

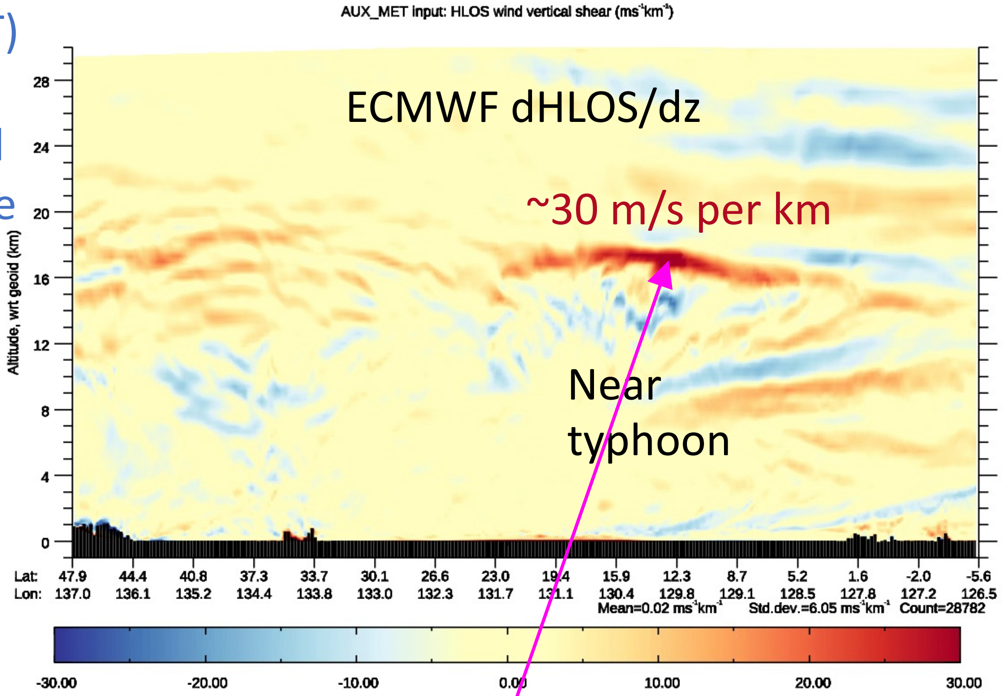


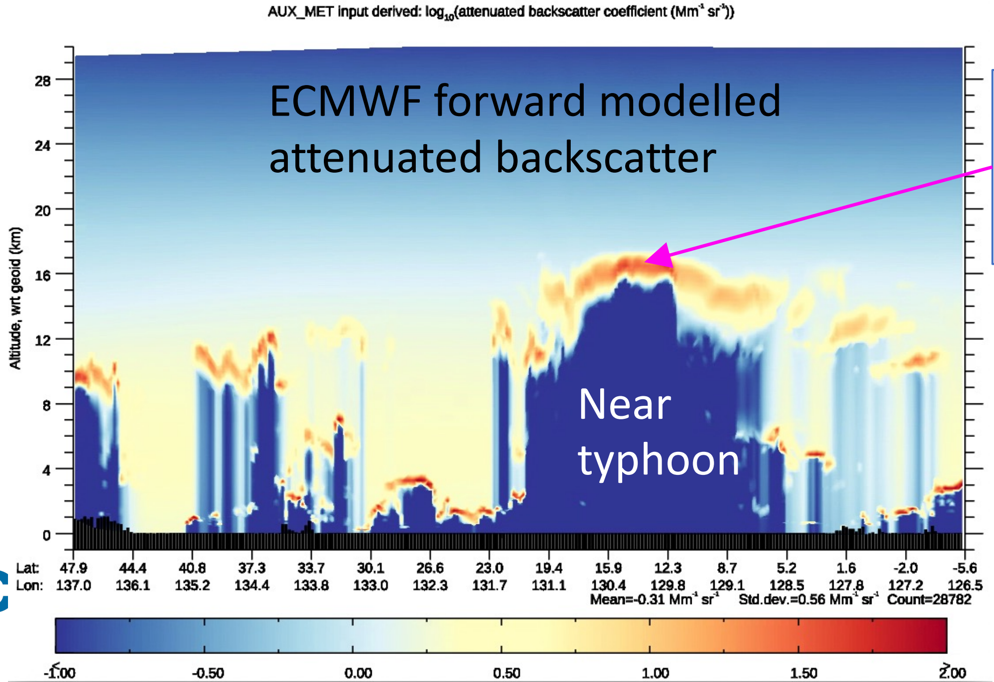


Over whole orbit: Mie-cloudy σ_{O-B} reduces from 3.82 m/s to 3.64 m/s, with the spatial averaging *H*(x); 5% improvement

ECMWF model (AUX_MET) shows strong wind shear (probably underestimated compared to reality) in the same area



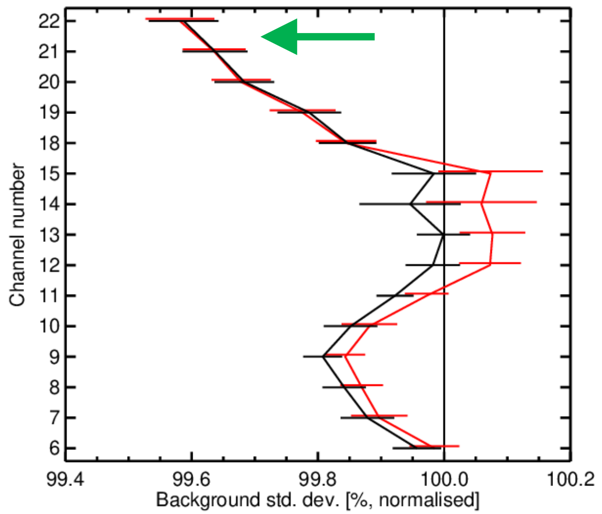




Model vertical shear of HLOS wind was **very strong** in this area (clouds at top of TC outflow)

Test of **stricter quality control in IFS** (O-B check) for 2018/2019 FM-A reprocessed dataset

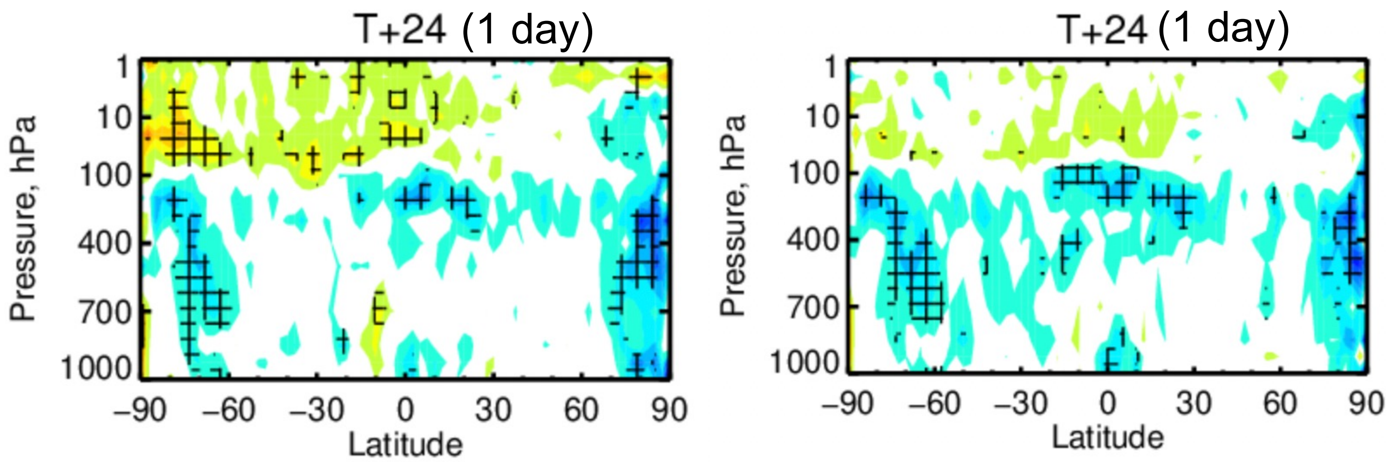
Global O-B fit to ATMS



- Normal (5-σ) QC
- Stricter (~3.5-σ) QC

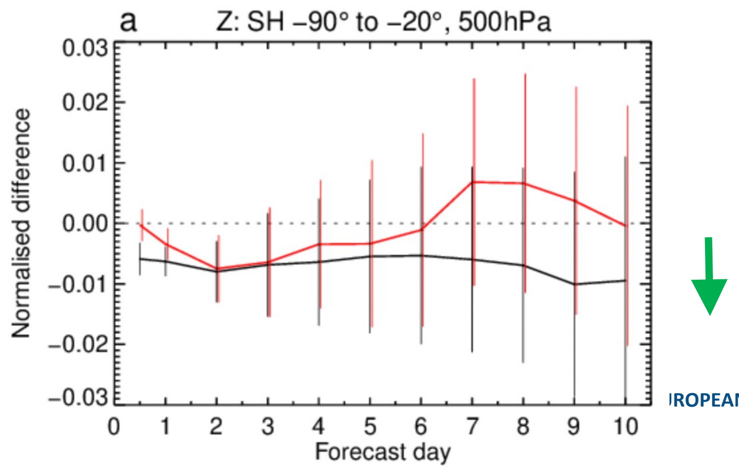
5-σ O-B check (nominal setting)

~3.5-σ O-B check (test setting)



Temperature RMSE (±4%)

500 hPa geopotential RMSE, SH

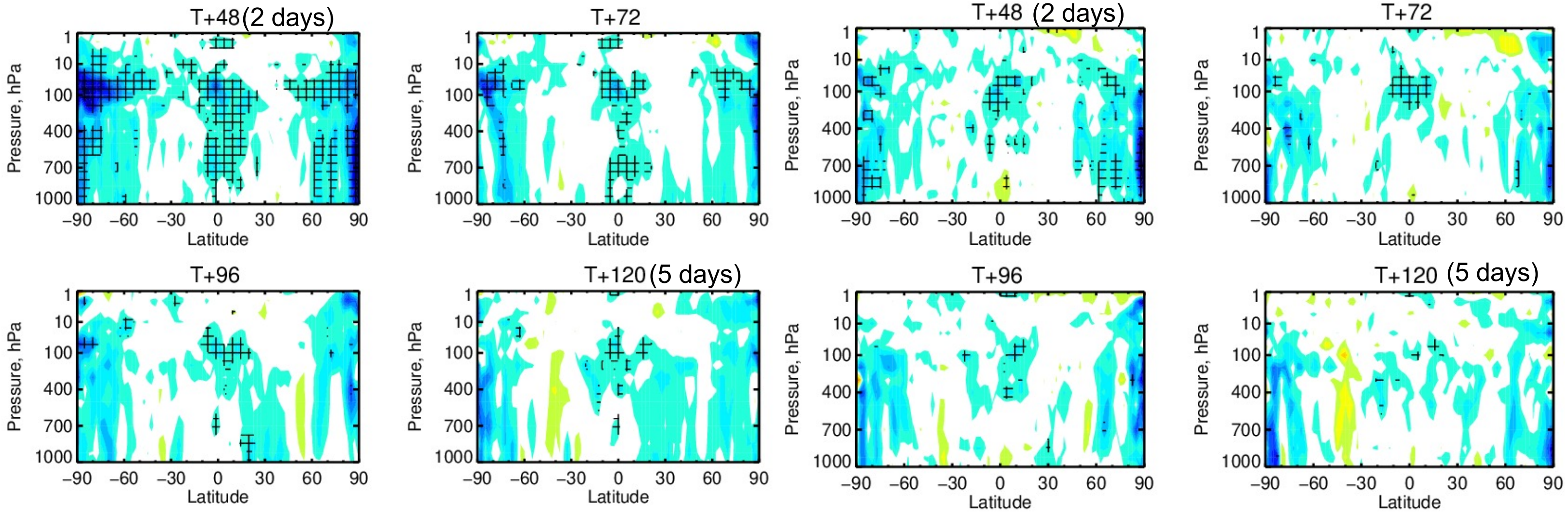


- ***Stricter*** first-guess (O-B) check QC improves impact (period: 4/9/18 to 24/3/19 (*still running*))
    - Stricter QC applies to both Rayleigh-clear and Mie-cloudy
- Removes short-range negative impact on stratospheric temperature verified with ATMS and operational analysis
- Improves medium range impact in S. Hemisphere and tropics
- Should test this on other periods

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

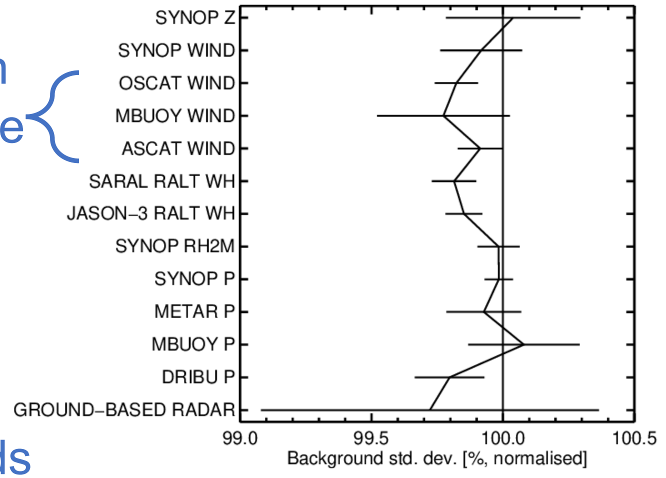
Vector wind RMSE (±5%)

Temperature RMSE (±5%)

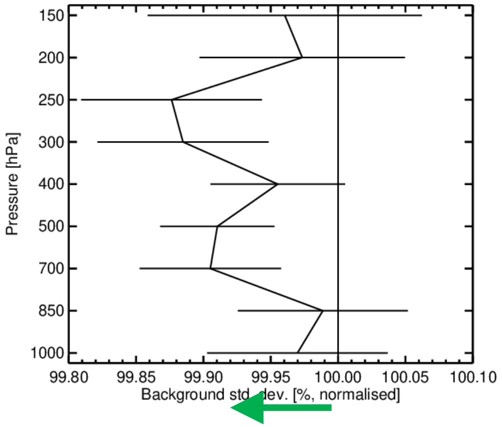


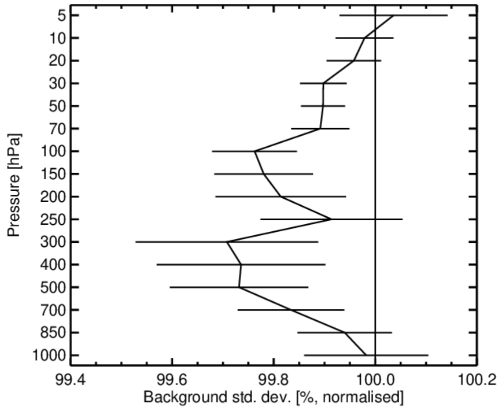
Improvements in global O-B fit to other wind observations

Ocean surface winds



AMV winds

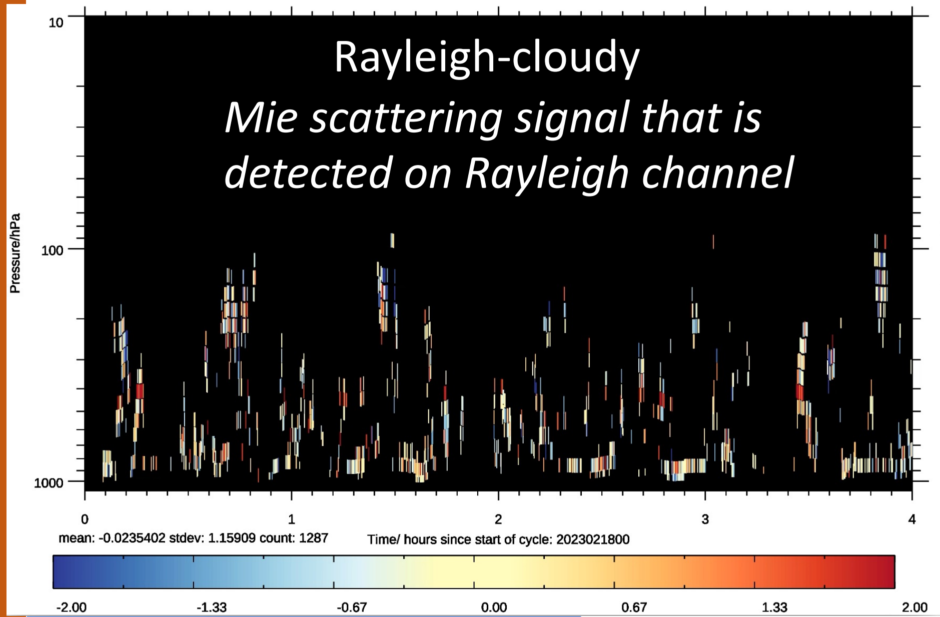


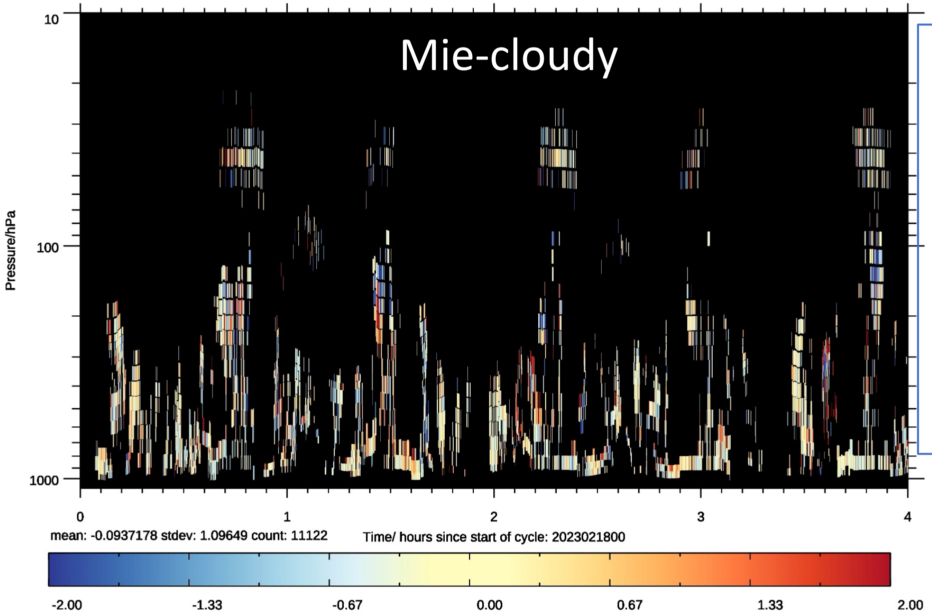


Radiosonde, aircraft, profiler winds

- 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?
    - Missing a range-bin for a long period?
  - Or improved global observing system?

Improved Rayleigh-**cloudy** winds (see Gert-Jan's talk) improve short-range humidity





Normalized departures of assimilated data:

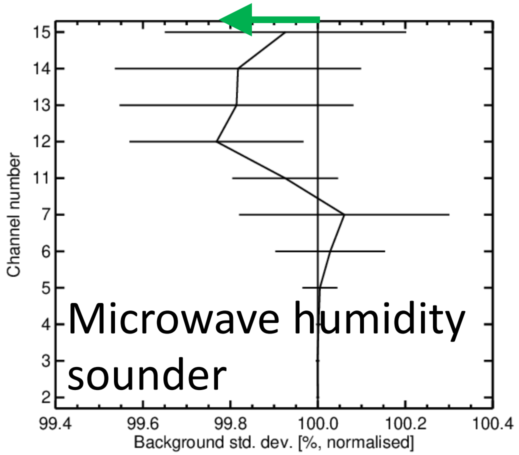
$$\frac{O-B}{\sigma_{obs\_err}}$$

Ray-cloudy derived via different photons on Rayleigh channel. But requires L1B scattering ratio from Mie channel

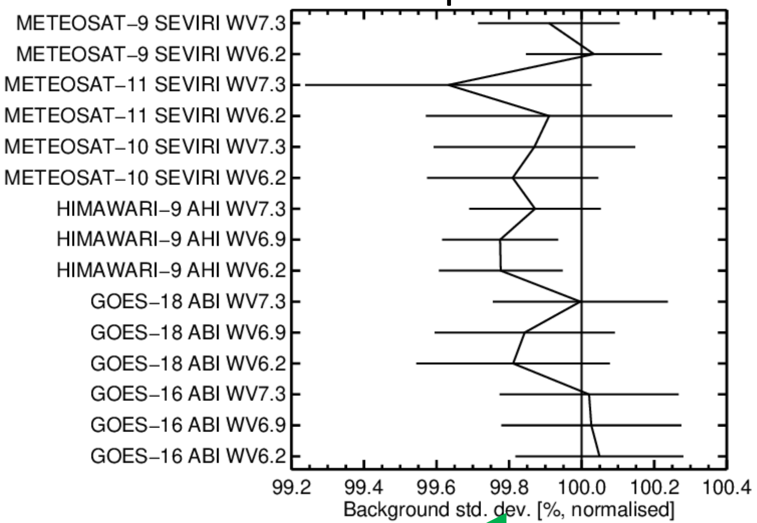
% assimilated:

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

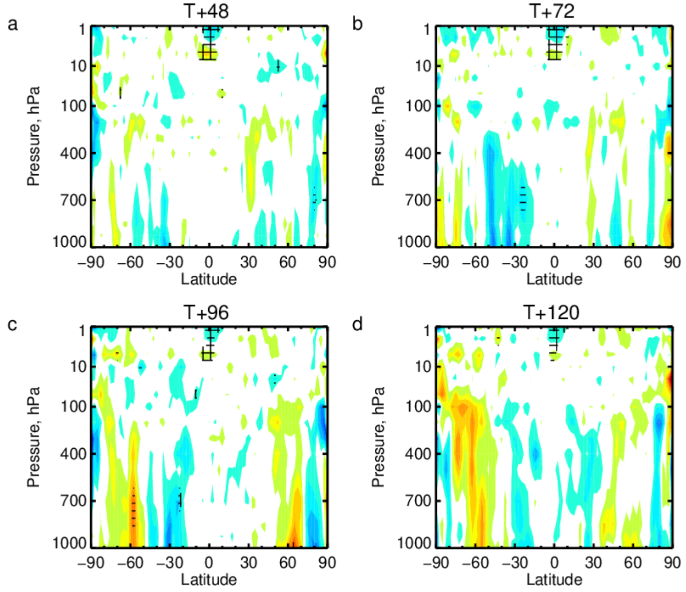
Rayleigh-cloudy in addition to Rayleigh-clear + Mie-cloudy OSE (3 March to 30 April 2023)



O-B fit to geostationary water vapour channels

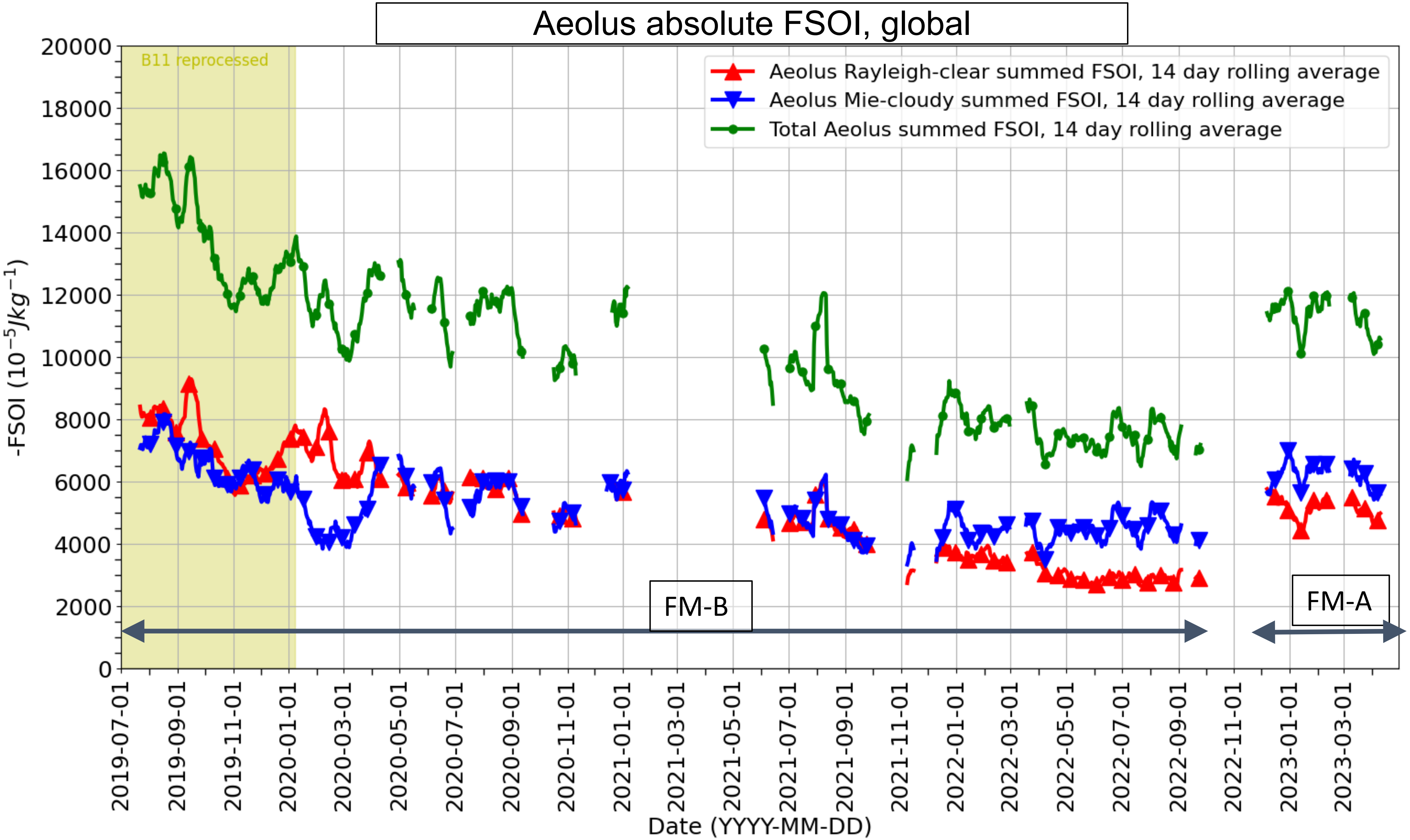


Vector wind RMSE (±5%)



Fairly neutral – hints of positive impact in SH

Short-range forecast impact by Forecast Sensitivity to Observation Impact (FSOI) time-series

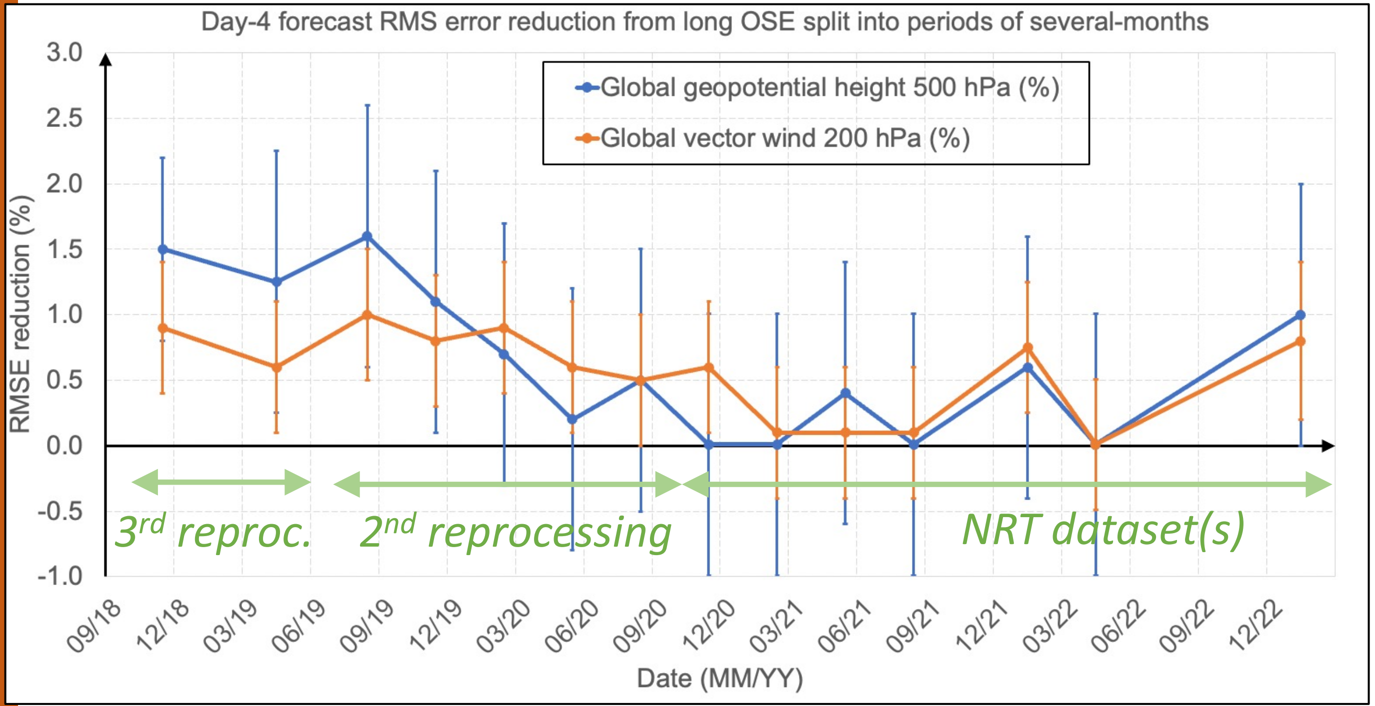


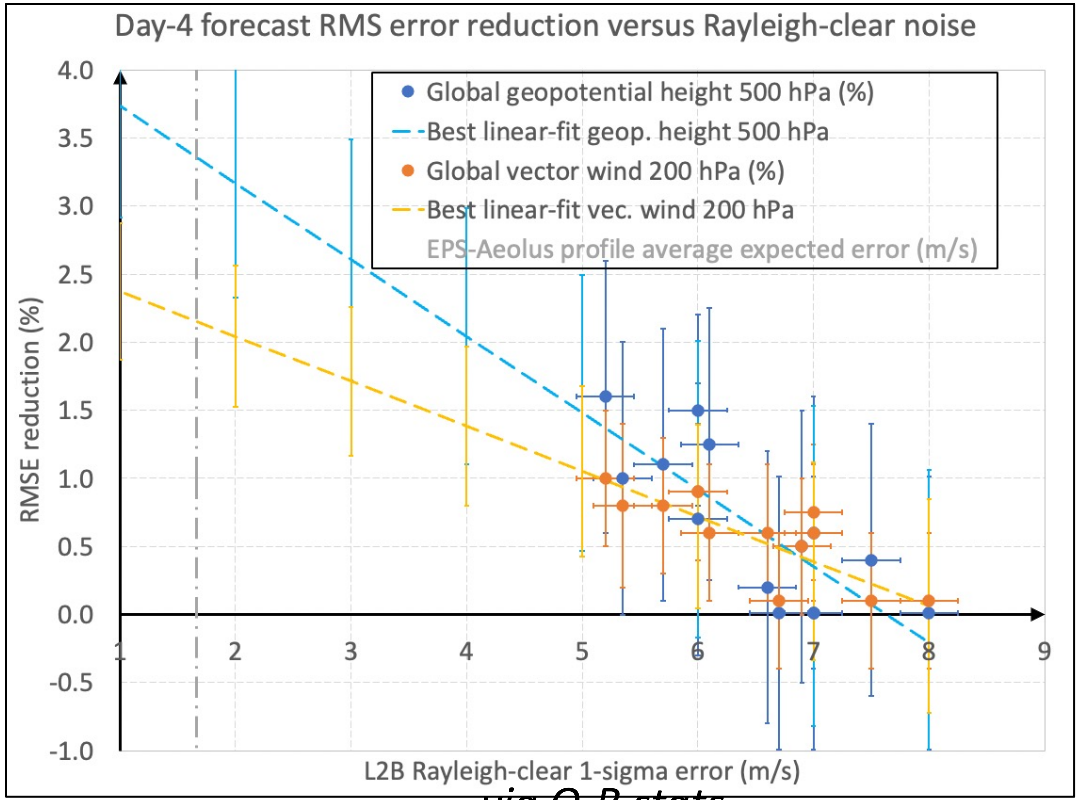
Impact with recent FM-A laser increased by ~60% compared to ***end*** *of FM-B – thanks to better signal*

Consolidating Aeolus impact over many OSEs

Smaller (better) Rayleigh-clear random **errors increases OSE day-4 impact**

Global NWP impact metrics: 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***

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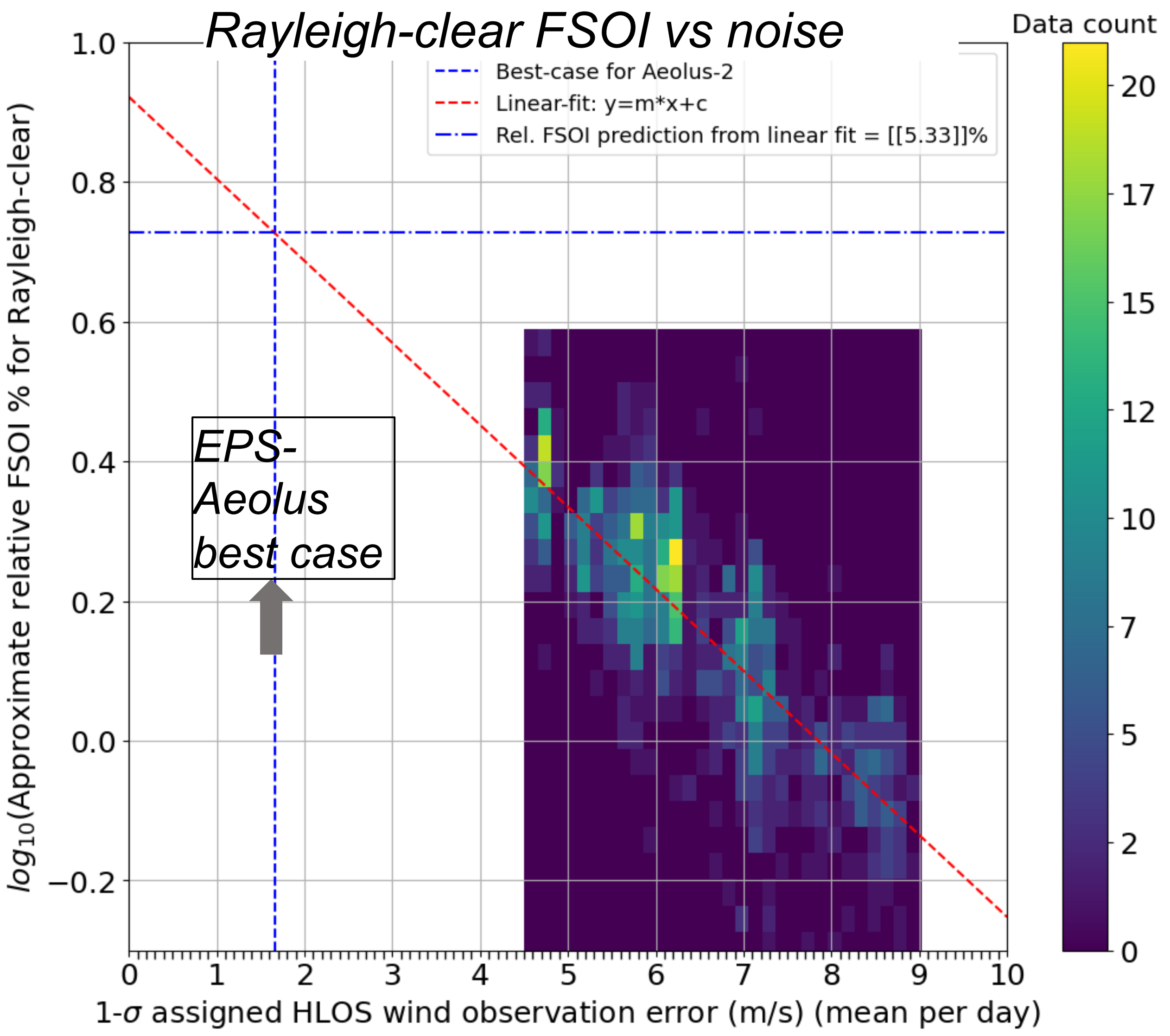
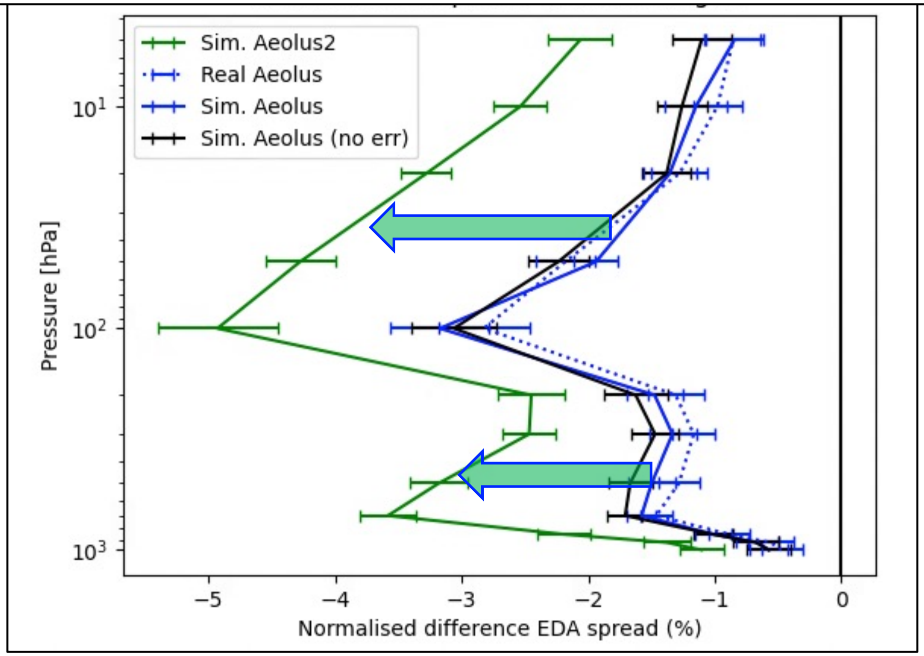
Smaller (better) Rayleigh-clear random errors improve the short-range impact

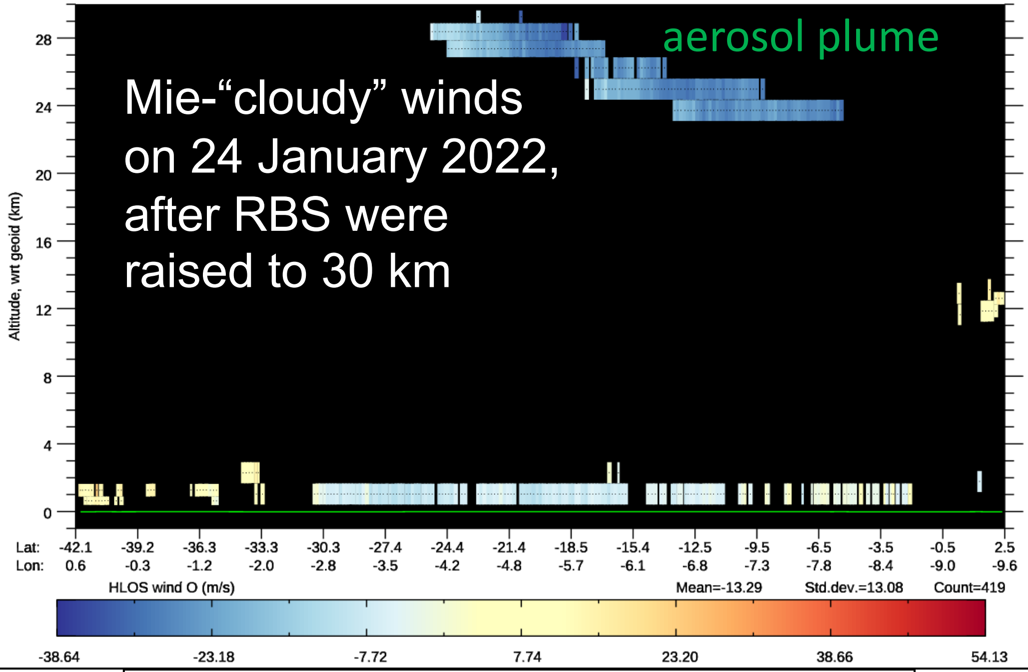


- **FSOI improves with smaller Rayleigh-clear noise**
- Extrapolation suggests **FSOI can more than double** with **<2 m/s random errors**
  - **Result supported by: Ensemble Data Assimilation *spread reduction* for simulated EPS-Aeolus**

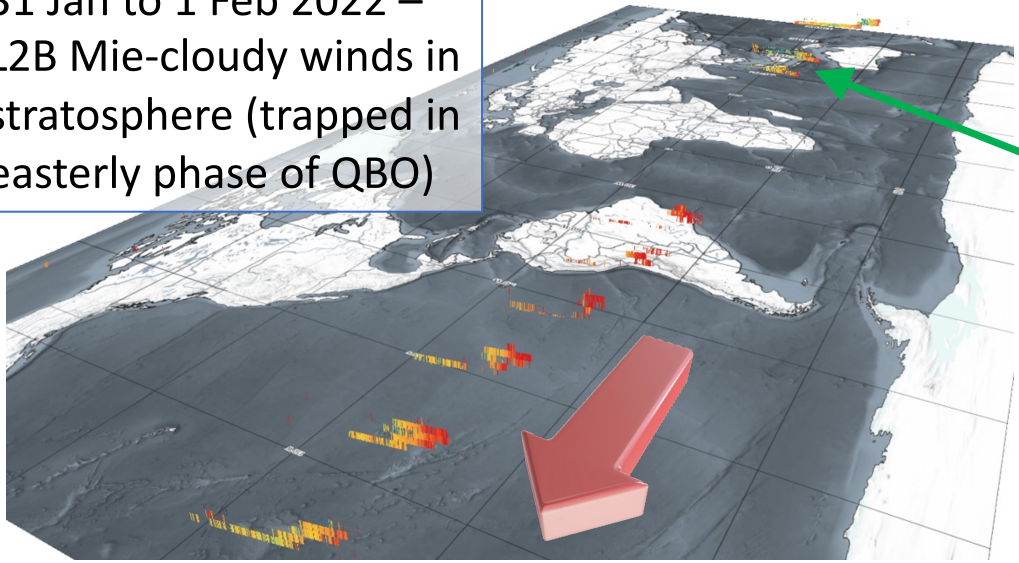
Global u-wind component EDA spread difference



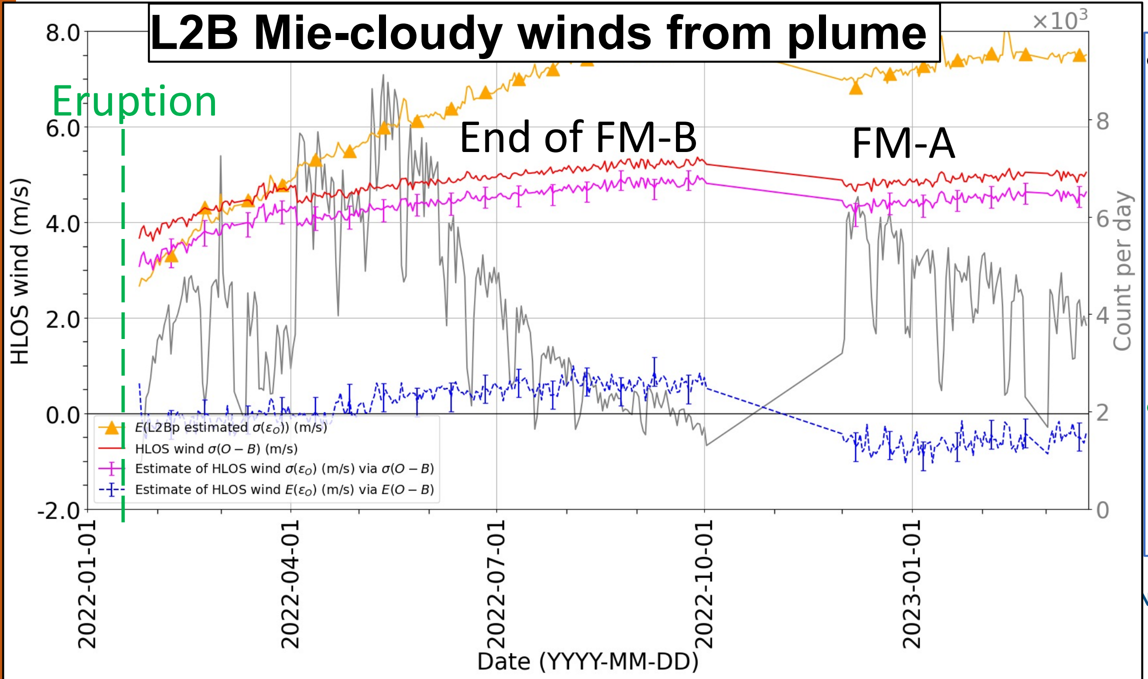
A good sample of Mie winds from Hunga Tonga-Hunga Ha‘apai eruption plume in 2022/2023



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

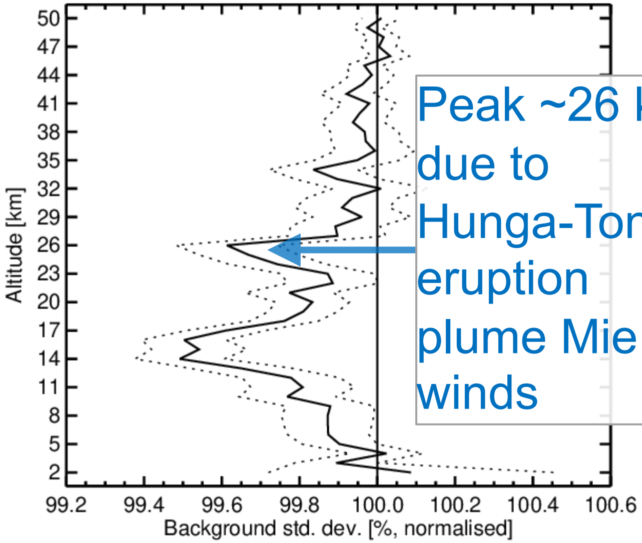


On second trip around world



- 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*

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



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

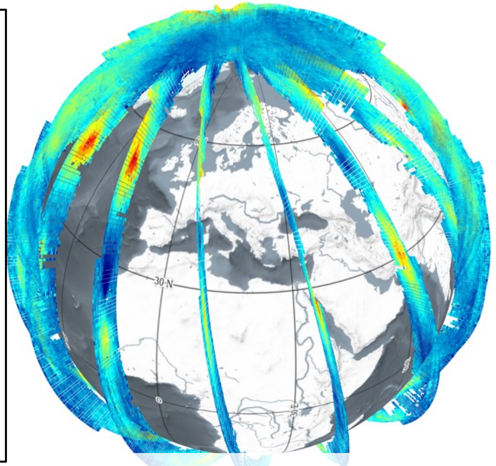
Summary

- Third reprocessing (early FM-A laser data) also shows a **good NWP impact** for one satellite instrument, some similarities with early FM-B period impact:
  - Ray+Mie shows positive impact on wind, temperature and humidity
    - Largest impact in tropics and polar regions; into medium range
  - Mie-*only* caused some degradation in lower stratosphere, apparently due to: thick range-bins *and* strong vertical wind shear *and* point-wind observation operator
    - Stricter O-B QC in IFS removes the negative impact and **improves scores** generally
- Impact improved significantly using 2022/2023 FM-A data vs end of FM-B 2022
- Some benefit for short-range humidity from additional assimilation of *Rayleigh-cloudy winds*
- Several methods agree that ~2 m/s profile-average 1-σ random error for Rayleigh-clear HLOS winds (rather than more typical 5-6 m/s for Aeolus) should *at least* double impact
  - EPS-Aeolus aims for such levels of random error

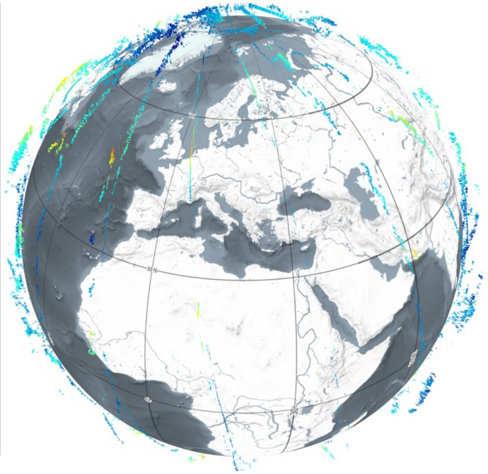
Thanks for listening, any questions?

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

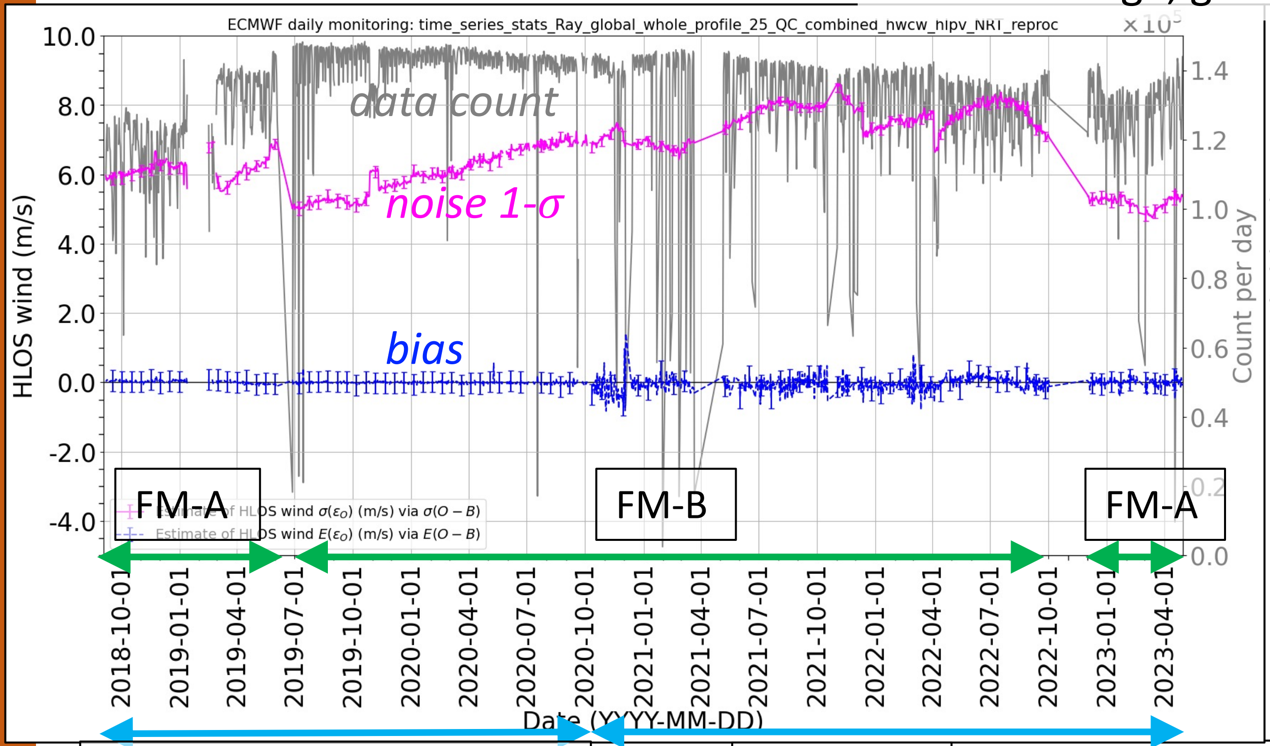
Rayleigh-clear
- Large variability of random errors (variable signal levels)
- Recent ***NRT*** FM-A laser was good (best processing, reduced readout noise, reasonable signal)



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

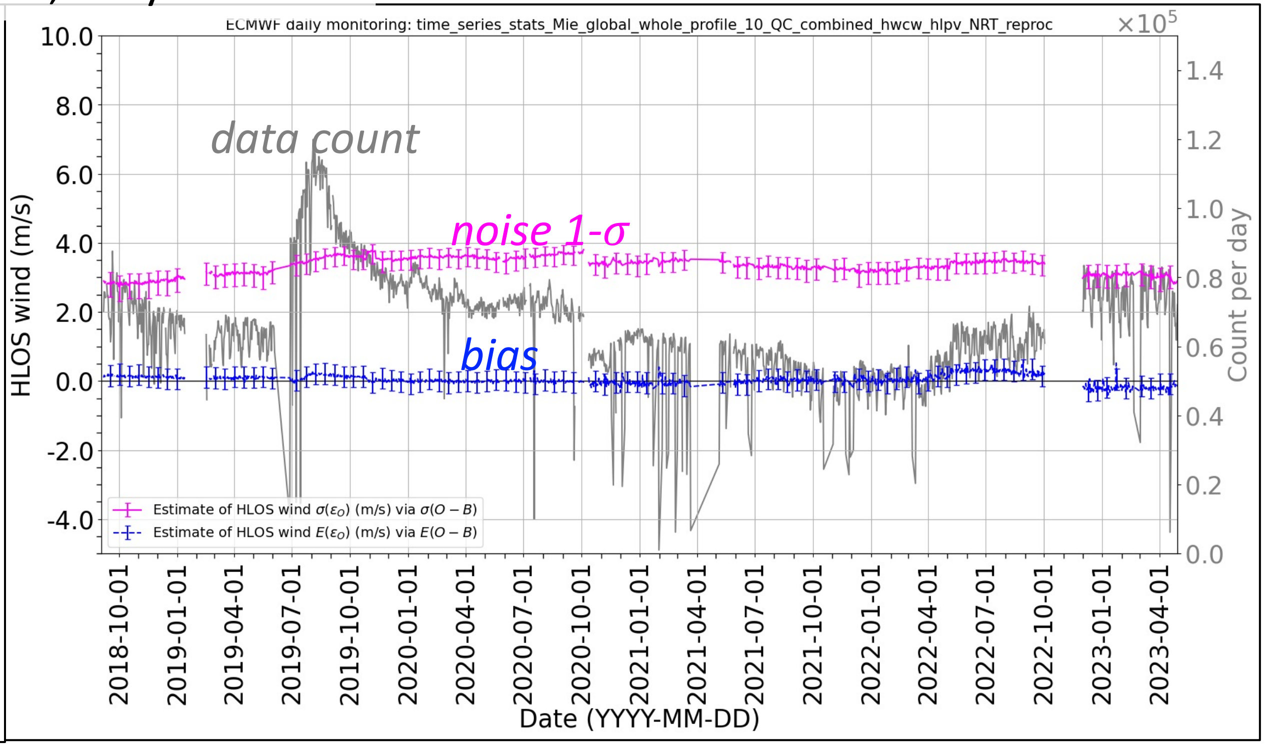


Profile average, global, daily O-B stats



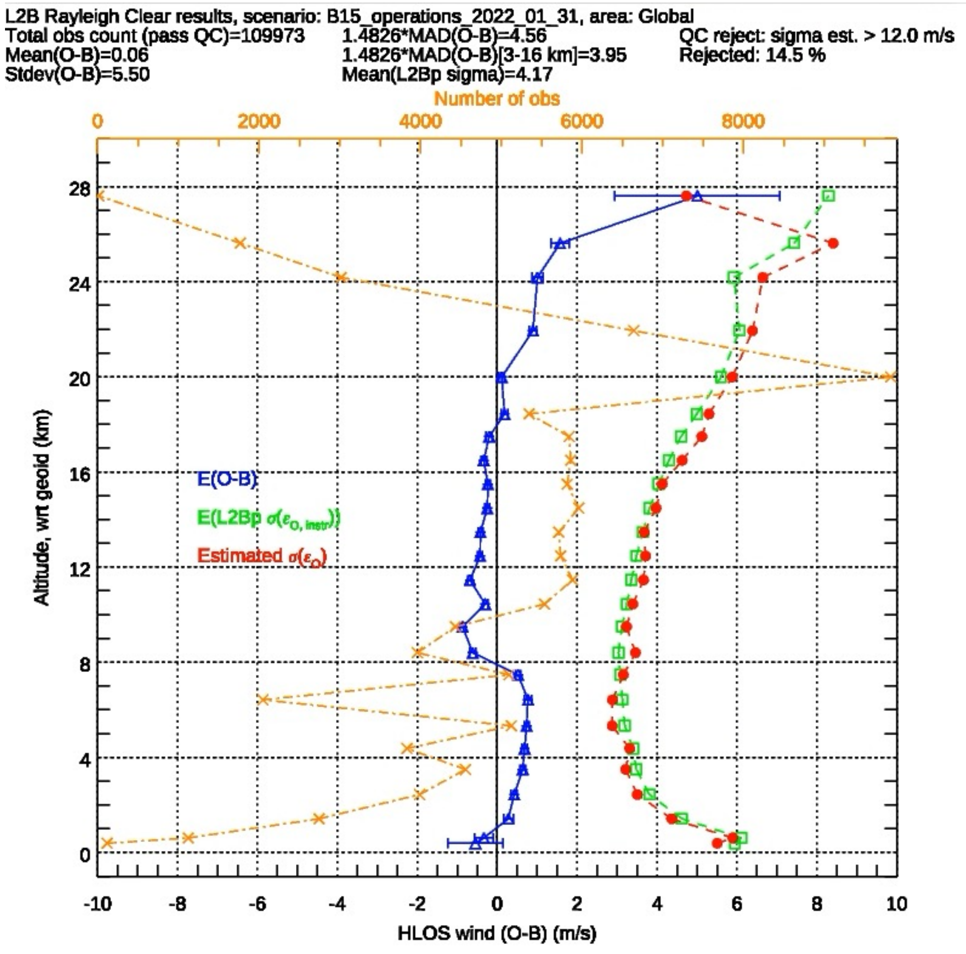
Reprocessed, B14 and B11

NRT data

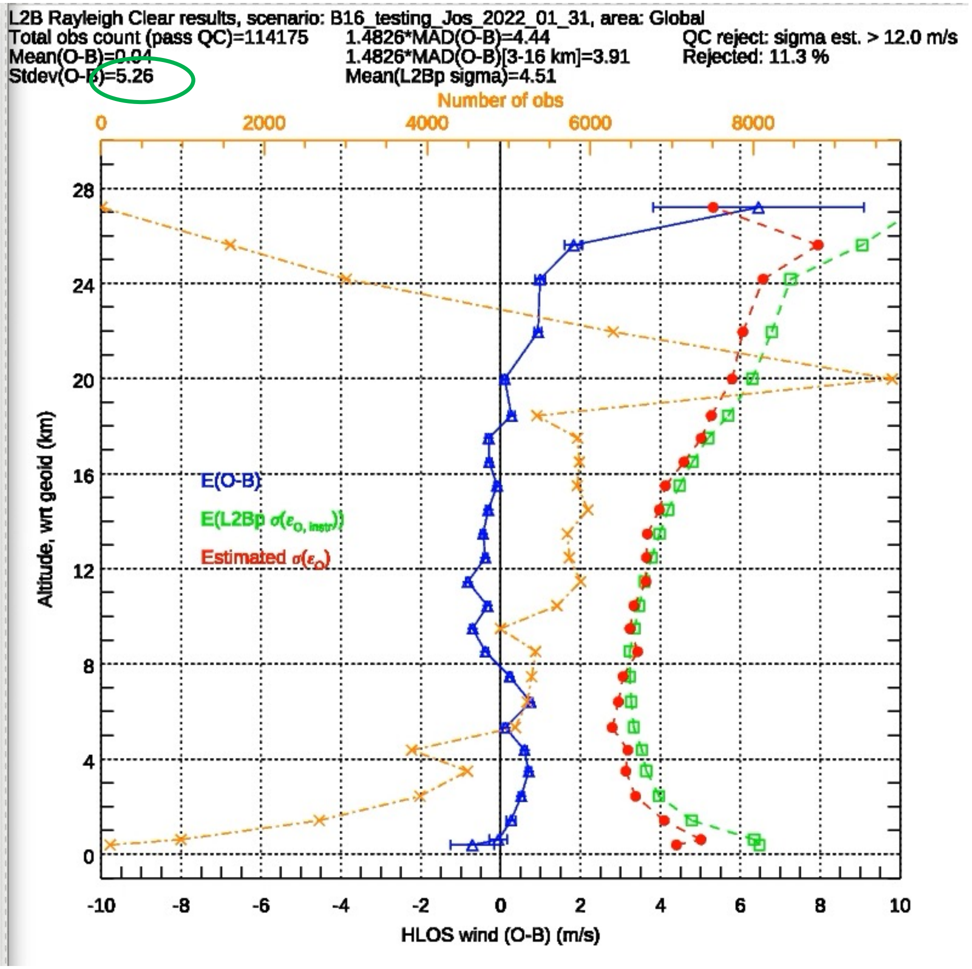


L2B Rayleigh-clear O-B statistics, global, versus altitude

B15



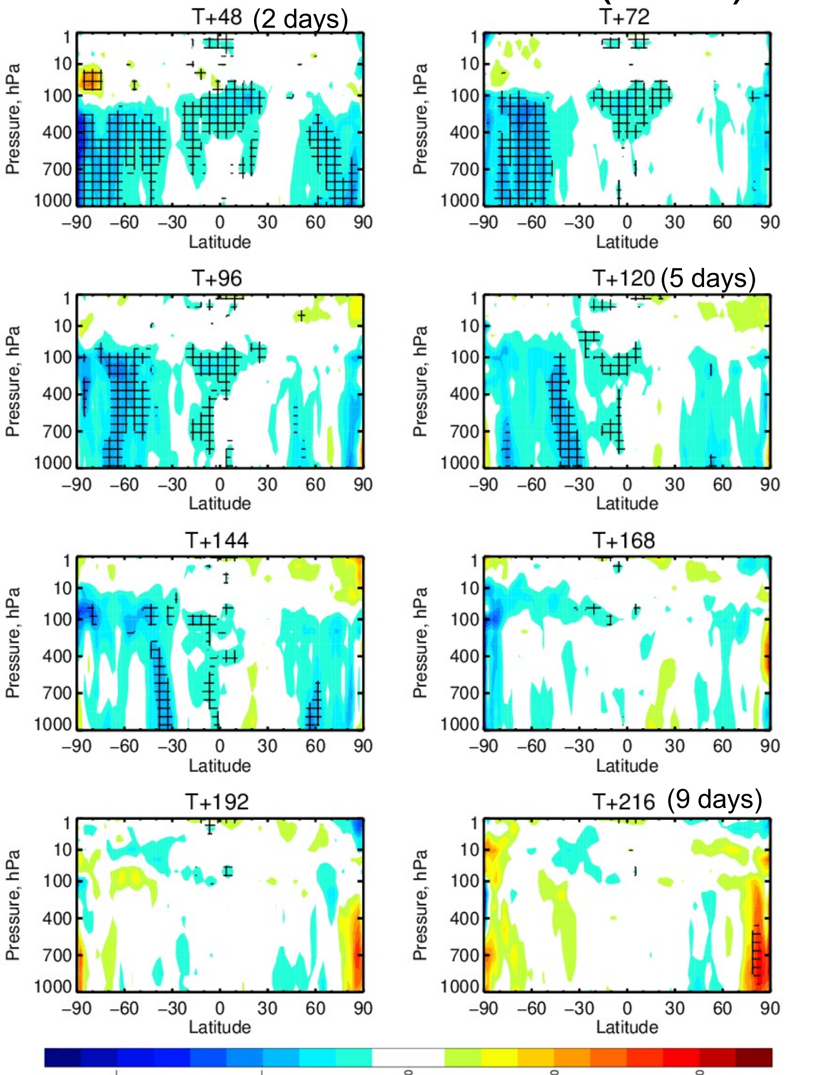
B16



- σ_{O-B} improved by 4% with B16 vs B15
- L2B product estimated error increased by ~8% , more realistic error estimate
- More data (+4.5%) due to L1B **fix for range-bin 15** (fake hot-pixel issue)
- 4th reprocessing will use B16

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

Vector wind RMSE (±5%)

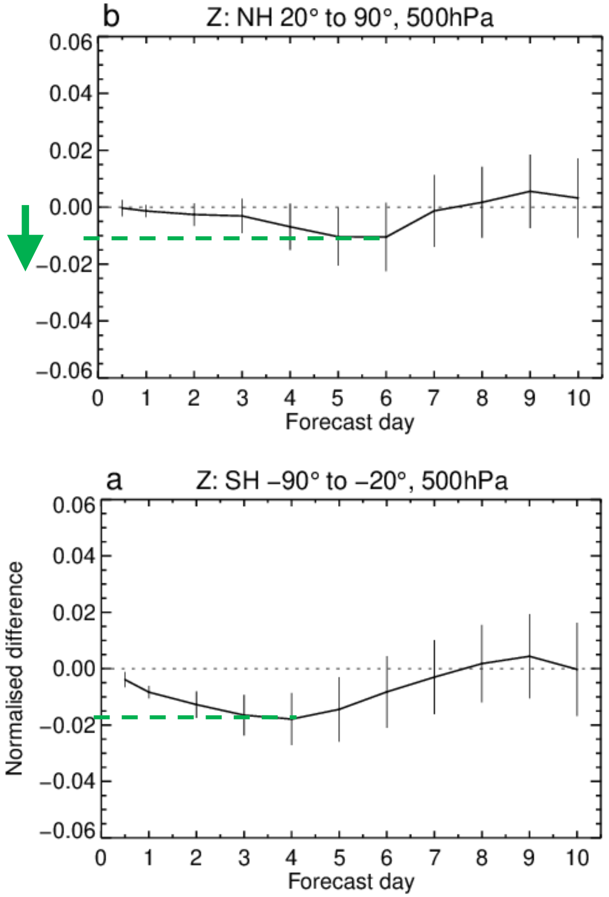


-5%

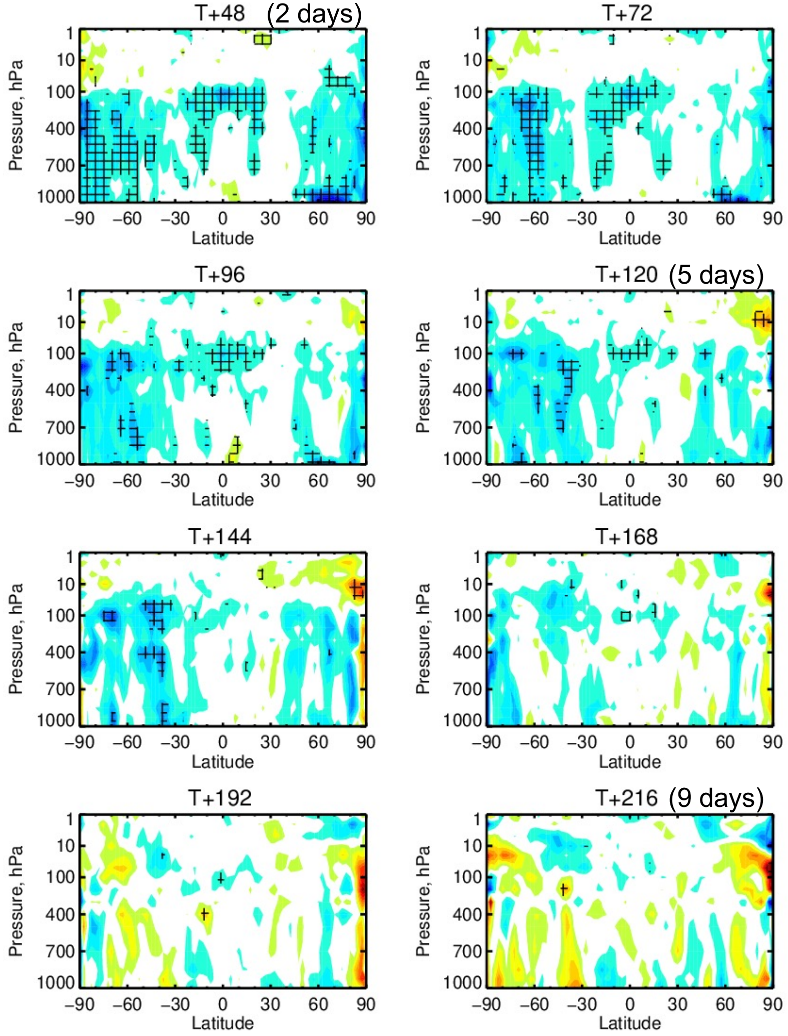
+5%

Blue is good

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



Temperature RMSE (±5%)



Verification against ECMWF oper. analysis

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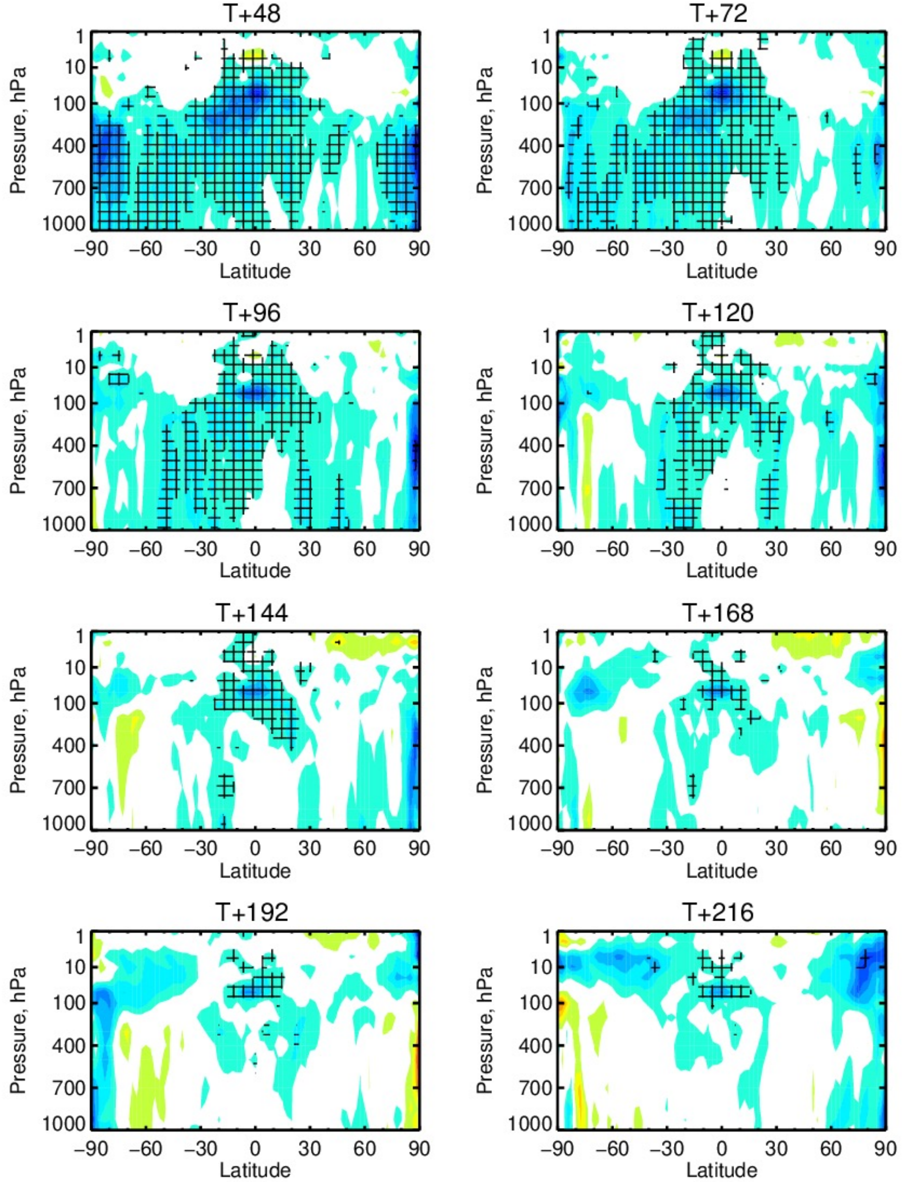
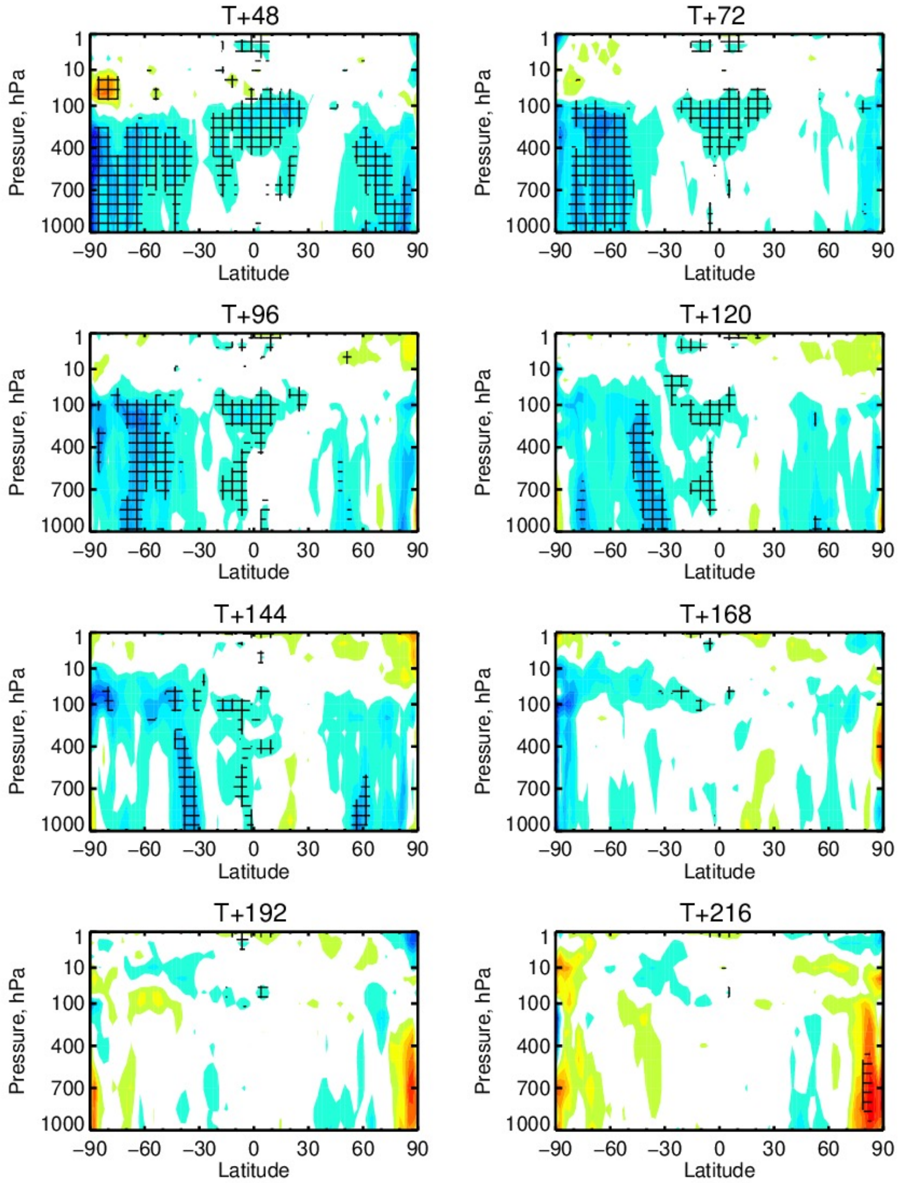
Comparison reprocessed data OSEs for different periods

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



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



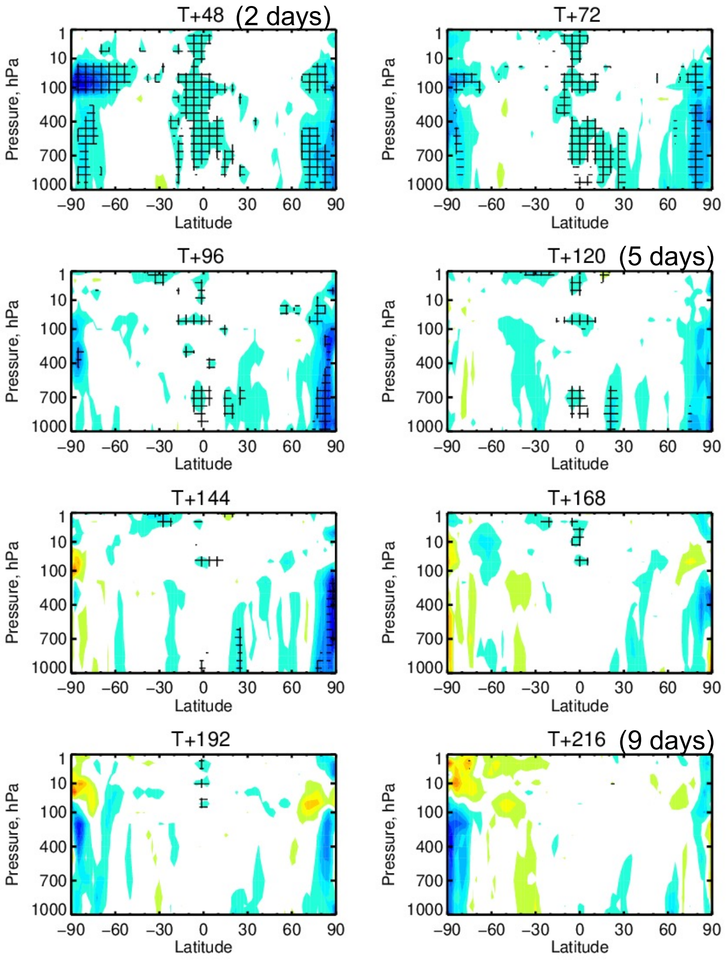
Vector wind RMSE

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

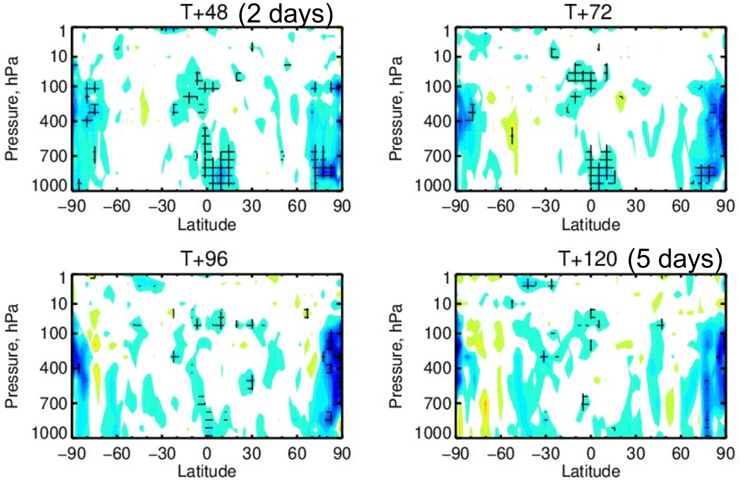
- Better vertical resolution range-bins in strong wind-shear?

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

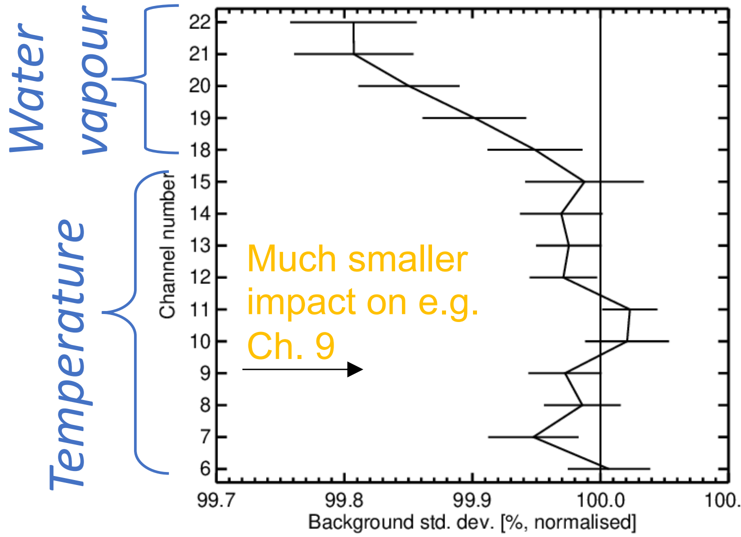
Vector wind RMSE



Temperature RMSE (±4%)

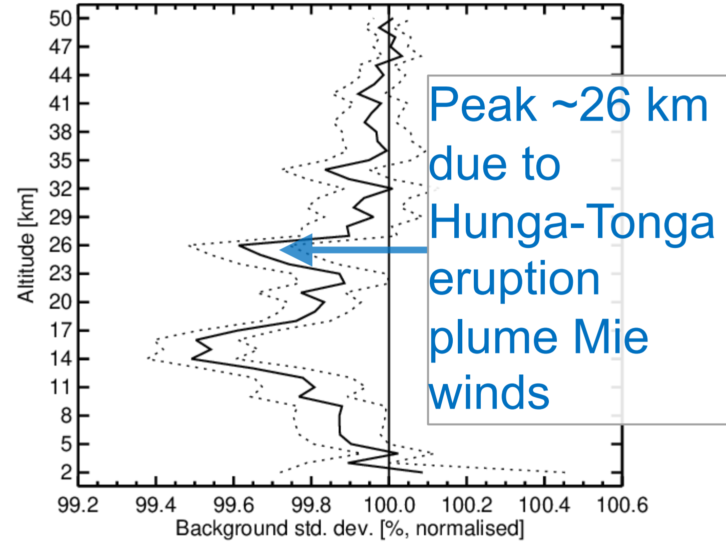


O-B ATMS (global)



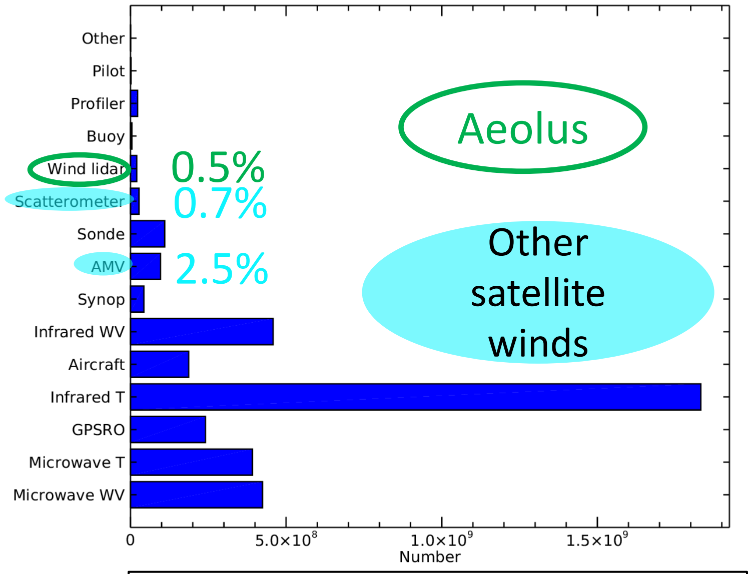
- Positive impact in tropics and polar areas up to day 4
- But tropical impact small compared to 2018-2020
- Mie-cloudy probably providing most of polar impact

O-B GNSS radio occultation (tropics)

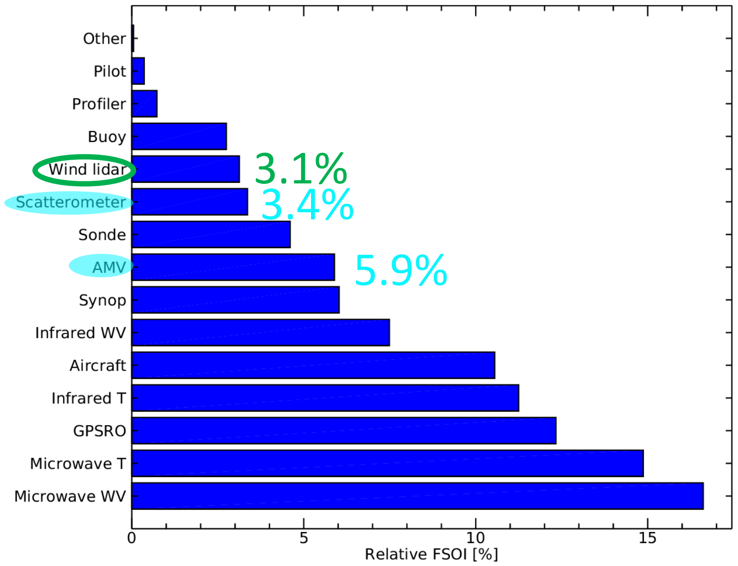


ECMWF recent operational relative FSOI (1 Jan to 30 April 2023)

Data counts by group



Relative FSOI (%) by group



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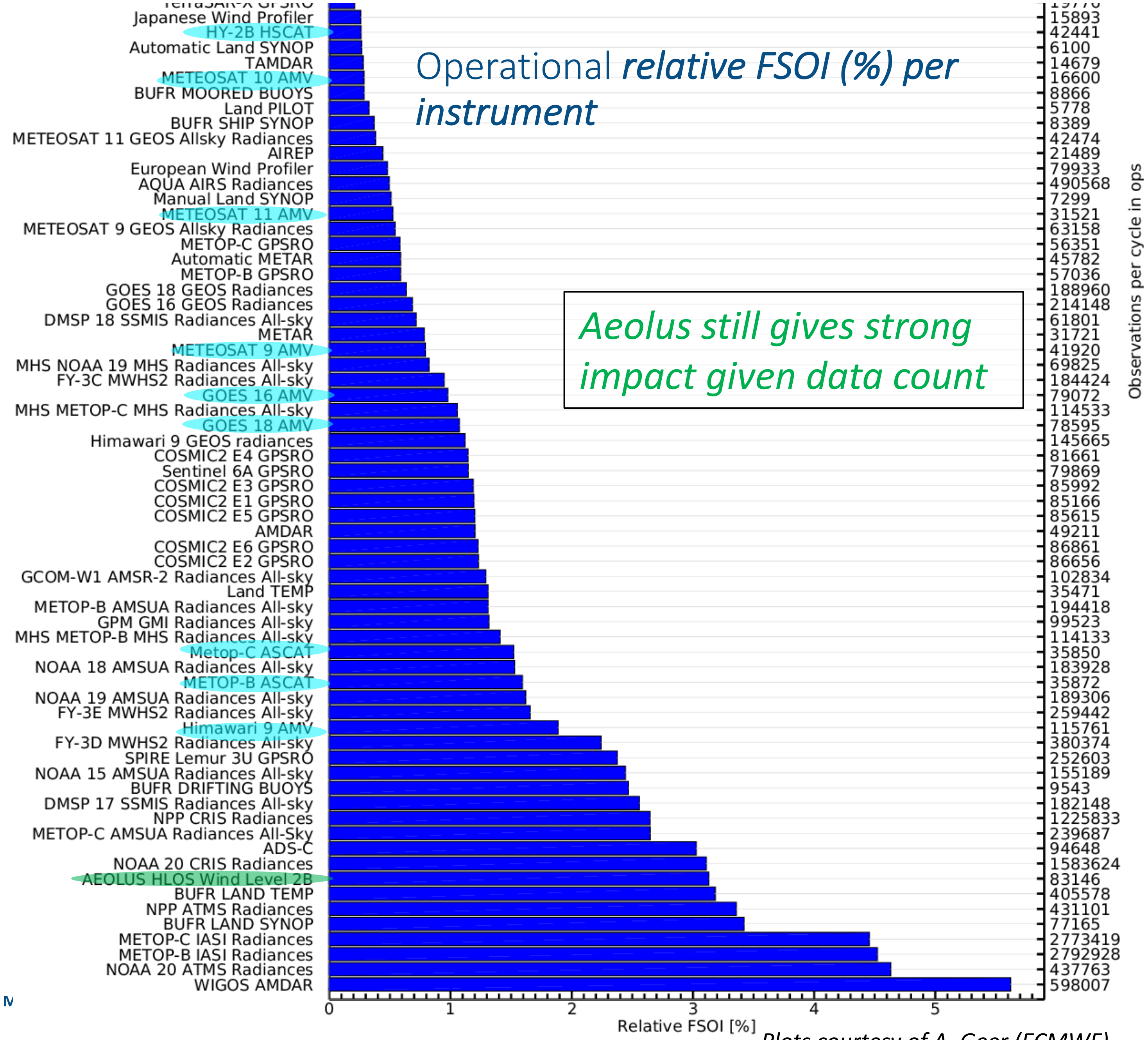
Operational ***relative FSOI (%) per instrument***

Aeolus still gives strong impact given data count



Plots courtesy of A. Geer (ECMWF)