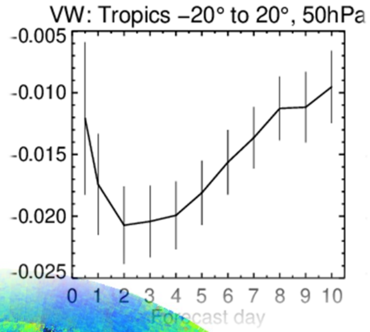
An update on the impact of Aeolus HLOS winds in NWP at ECMWF

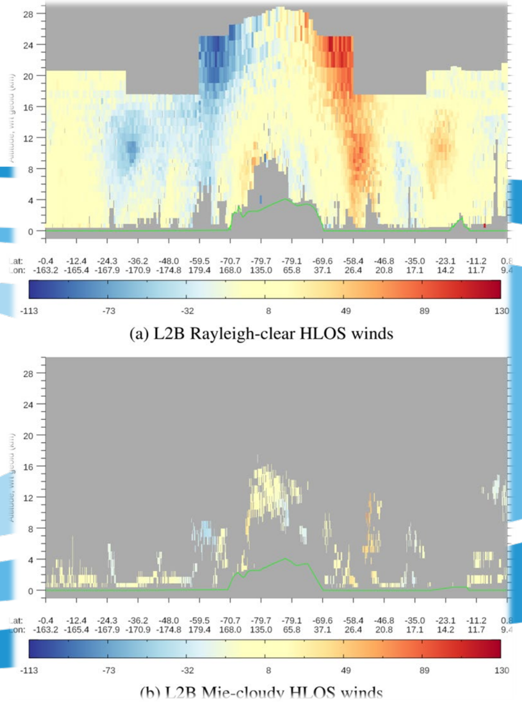
by Michael Rennie (ECMWF)

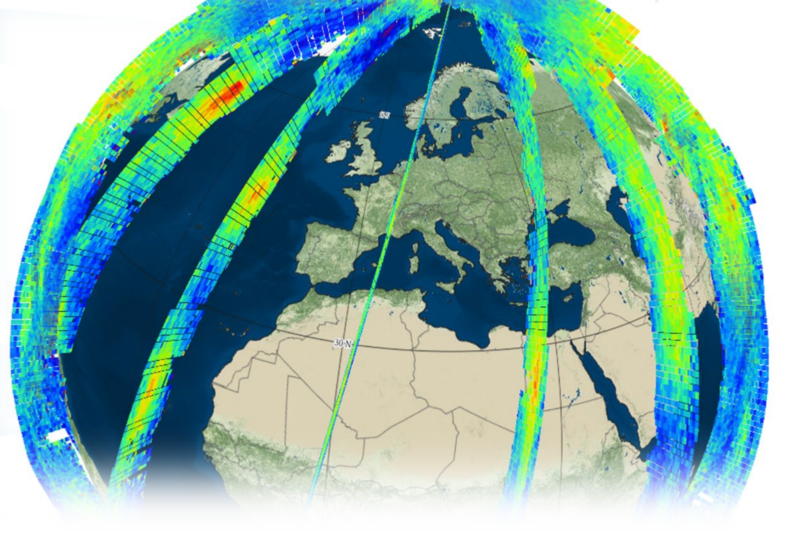
Acknowledgements to colleagues from: DISC, ECMWF, DAMI and ESA

A1.08.1 Aeolus Mission: Scientific Highlights and Data Exploitation – 1

ESA Living Planet Symposium 2022, Bonn, Germany, 25 May 2022







Aeolus L2B horizontal line-of-sight wind NWP impact assessment methods

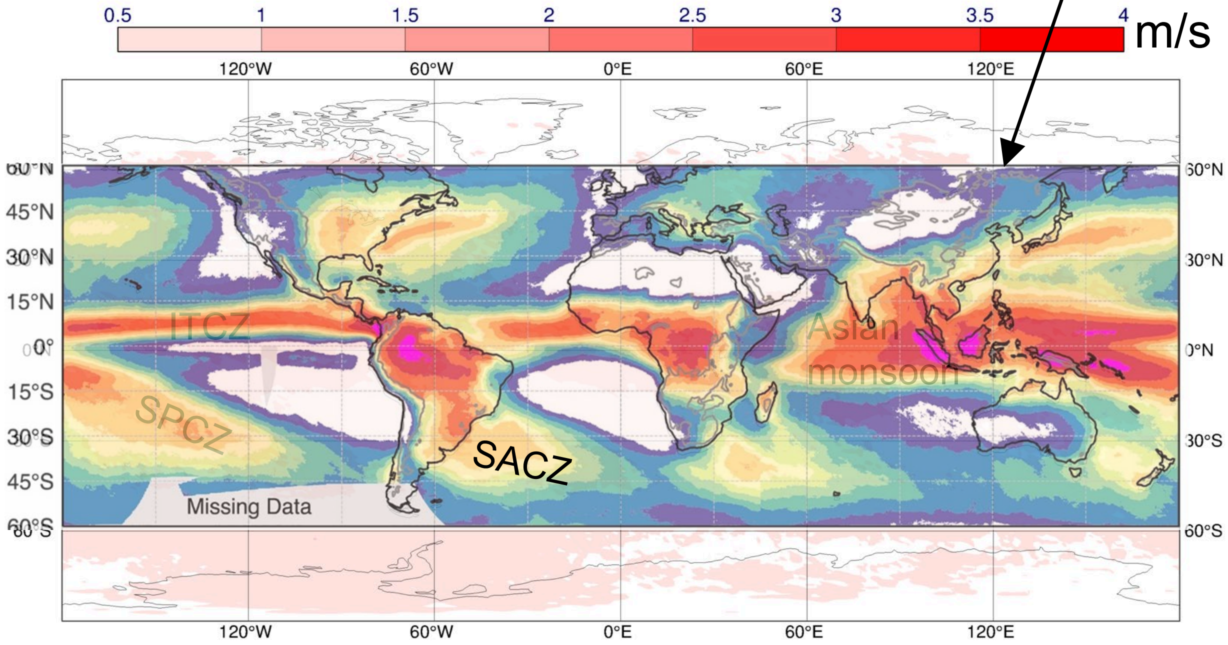
- **O**bserving **S**ystem **E**xperiments (OSEs):
  - For robust assessment of impact into medium-range (to 10 days)
  - Focus on general NWP impact – *for extreme weather/forecast busts see G. De Chiara's talk*
  - **2nd reprocessed FM-B laser period (baseline=2B11)**
    - Rayleigh-clear + Mie-cloudy as current operations; **29 June 2019 to 9 Oct 2020** – *longest OSE for Aeolus (so far)!*
    - $T_{CO}639$ model resolution – higher resolution (~18 km) than previous OSEs (~29 km); operations is ~9 km
  - Compare 2nd to 1st reprocessed dataset (**2B10**) impact
  - Recent NRT dataset OSE (**2B13/14**): 13 December 2021 to 15 May 2022
- **F**orecast **S**ensitivity **O**bservation **I**mpact (FSOI):
  - Assessment of short-range forecast impact (with some limitations)
  - **Operational FSOI** since 9 January 2020 - ***we've been operationally assimilating Aeolus for over 2 years now!***
  - FSOI results from **2nd reprocessed dataset**

OSEs

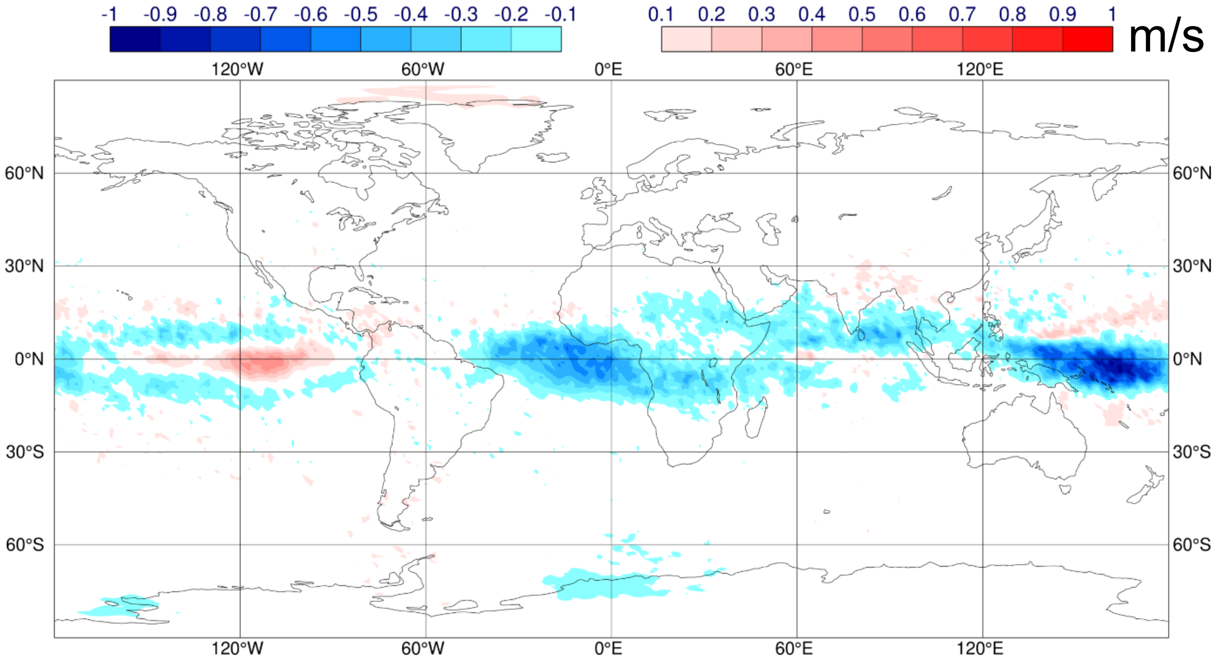
How Aeolus changes the u-wind analysis

- 29 June to 30 December 2019 – 2nd reprocessed dataset
- Largest mean changes in u-wind in tropics
- Largest “random” changes in tropics and extratropical convergence zones – where ECMWF forecast has most uncertainty (background error) at 200 hPa – appears correlated with areas of convection

Annual average number of mesoscale convection systems by [Z. Feng et al. 2021]



Standard deviation of changes in u-wind analysis due to assimilating Aeolus, at 200 hPa (~12 km)

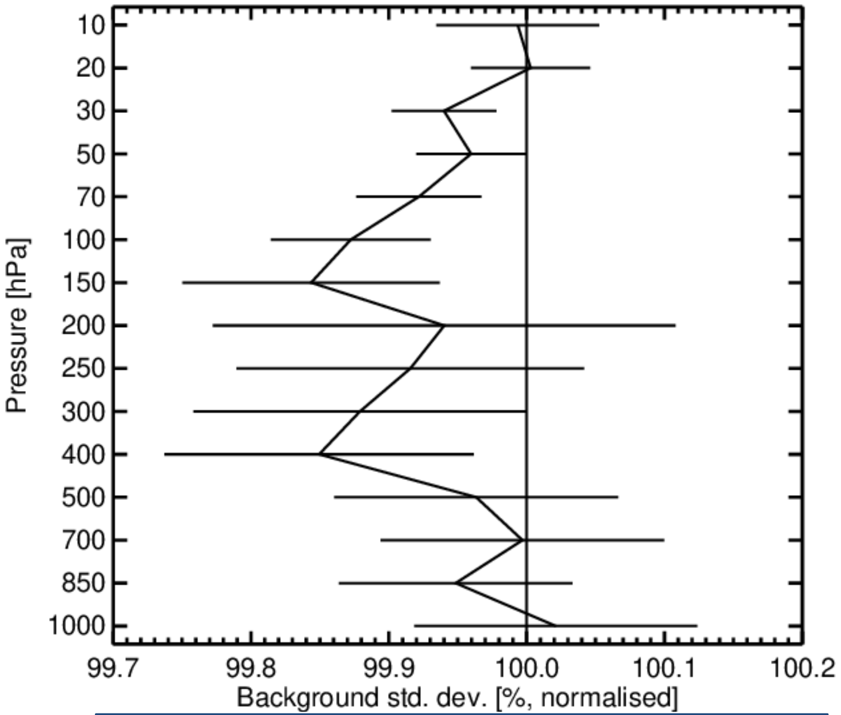


Mean changes in u-wind analysis due to assimilating Aeolus, at 100 hPa (~16 km)

Background (short-range forecast) fit to other observations when assimilating Aeolus – 2nd reprocessed dataset (29 June 2019 – 9 October 2020)

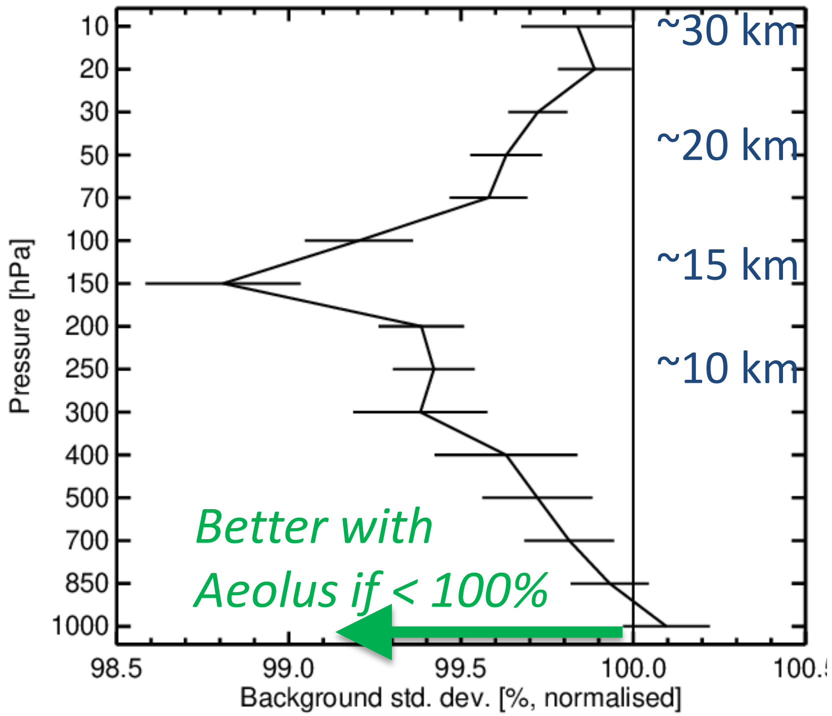
Fit to "conventional" wind observations: aircraft, radiosondes and radar wind profilers

N. Hemi. extratropics



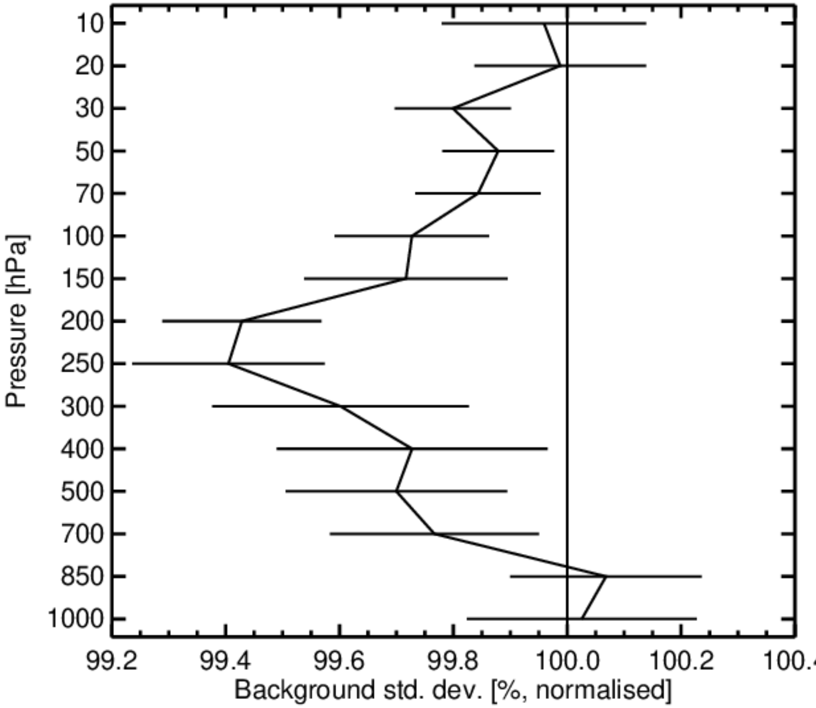
Small positive impact, particularly lower stratosphere

tropics



Strong positive impact in the tropics

S. Hemi. extratropics

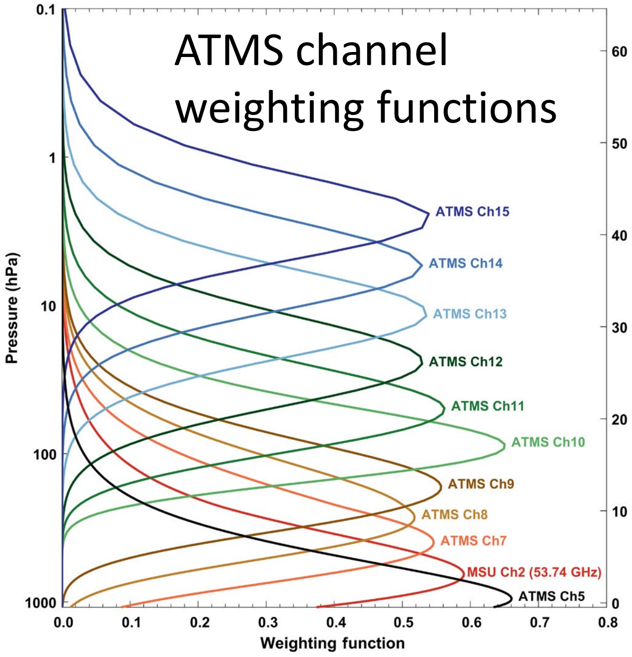


Reasonable positive impact in SH extratropics; *peaking around jet stream*

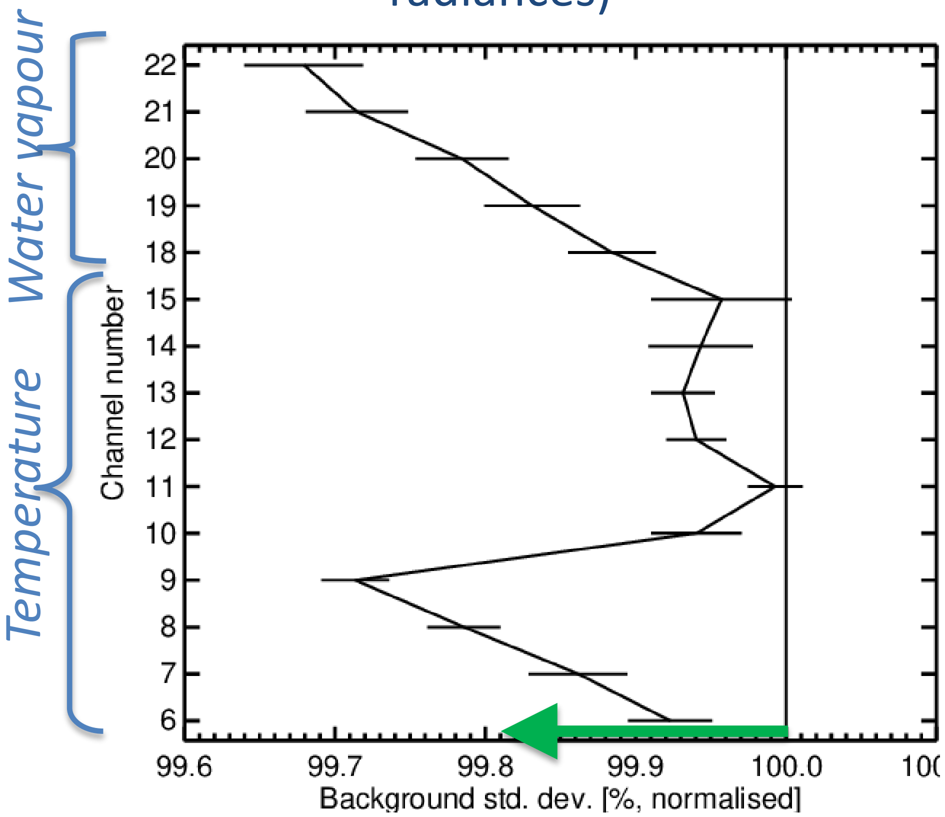
Aeolus' impact largest in tropical upper troposphere – similar to previous OSEs

… background fit to other observations when assimilating Aeolus

Fit to important temperature/humidity sensitive data

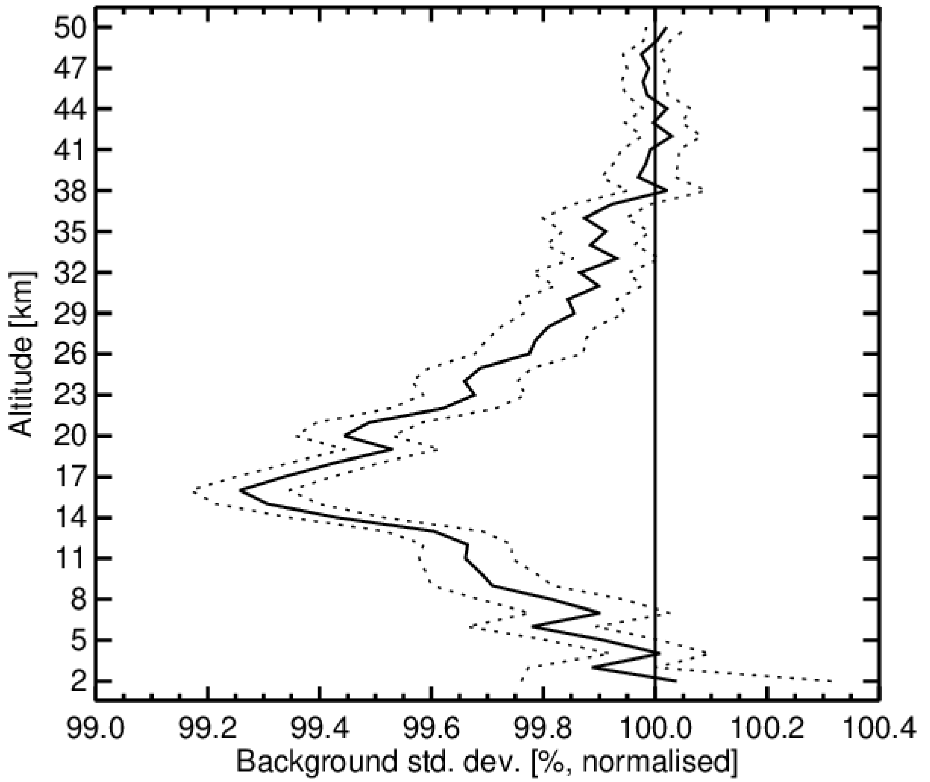


Global, ATMS (microwave radiances)



Better with Aeolus if < 100%

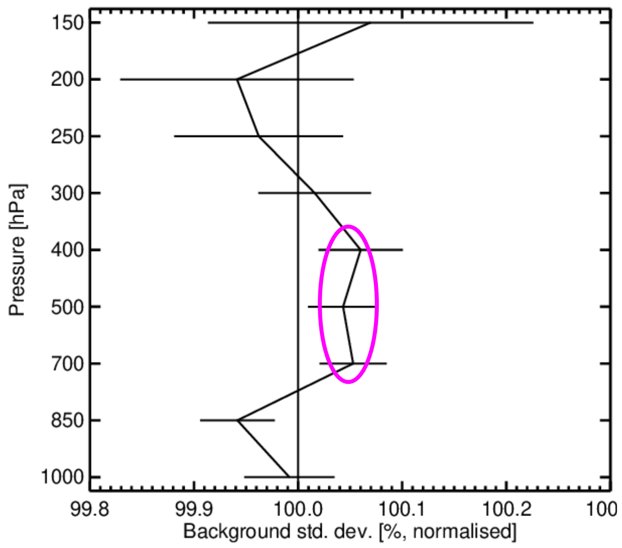
Global, GNSS radio occultation (bending angles)



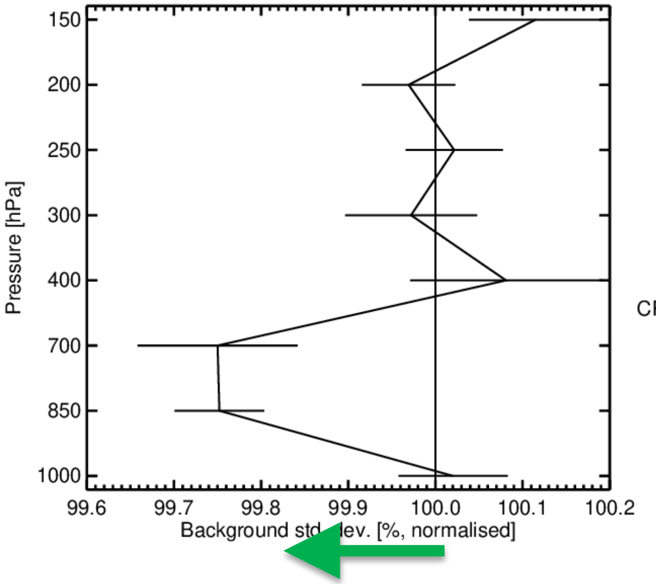
Good positive impact: **Aeolus improves wind**, **temperature** and **humidity** background fits, most strongly in **upper troposphere**

Some further interesting short-range forecast impact signals

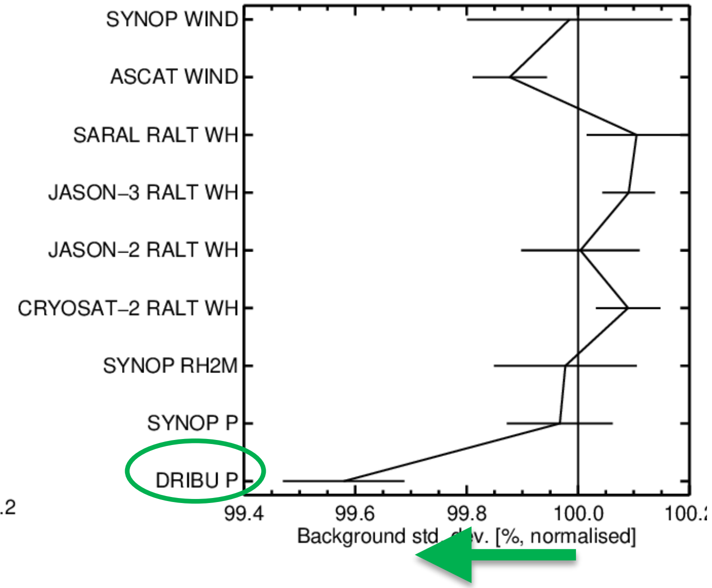
AMVs, SH extratropics



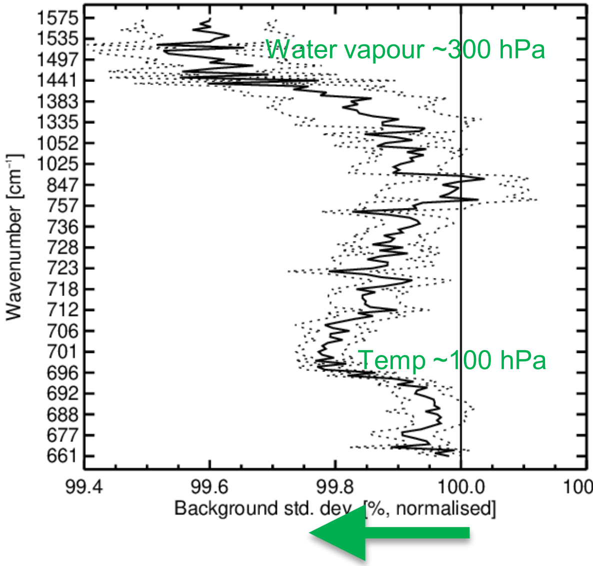
AMVs, Tropics



Surface based obs in SH extratropics



Cross-track Infrared Sounder (CrIS), global



Better with Aeolus if < 100%

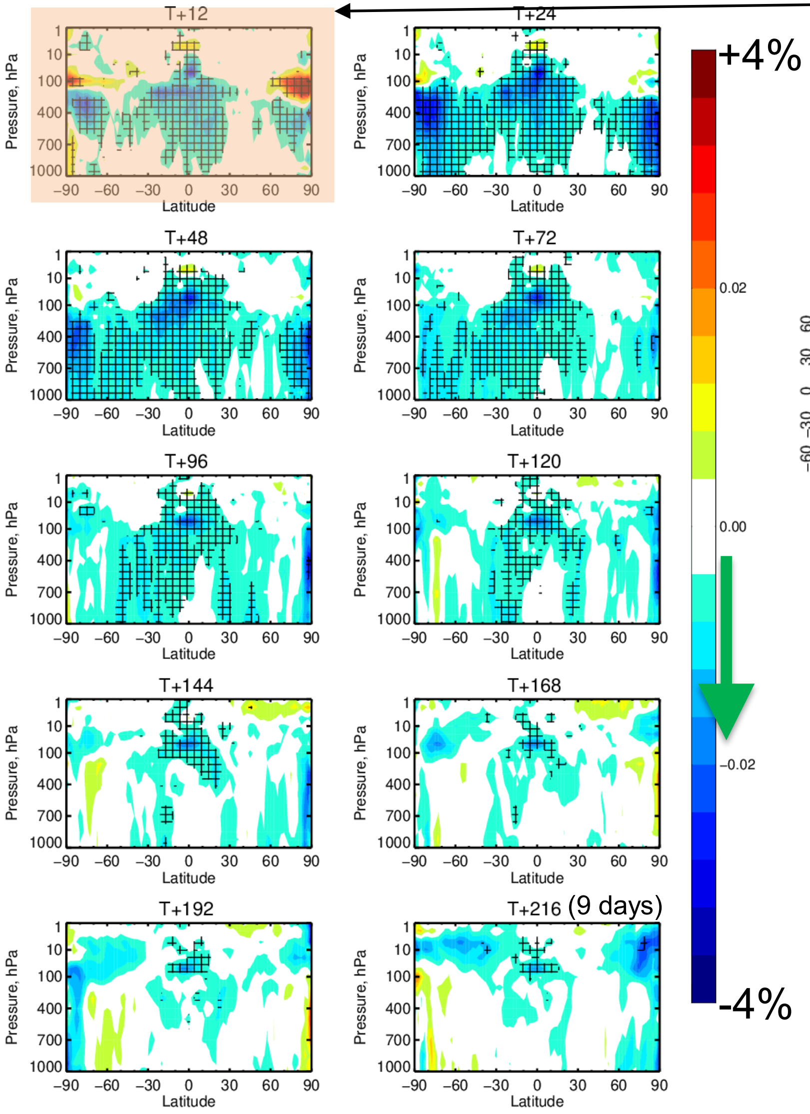
Fit to AMVs is made slightly worse at ~400-700 hPa from assimilating Aeolus in S. Hemi. extratropics; OK in tropics

Positive impact with respect to **surface pressure observations from buoys** – Aeolus has impact in remote areas of S. Hemisphere

Consistent positive impact with respect to this accurate infrared sounder

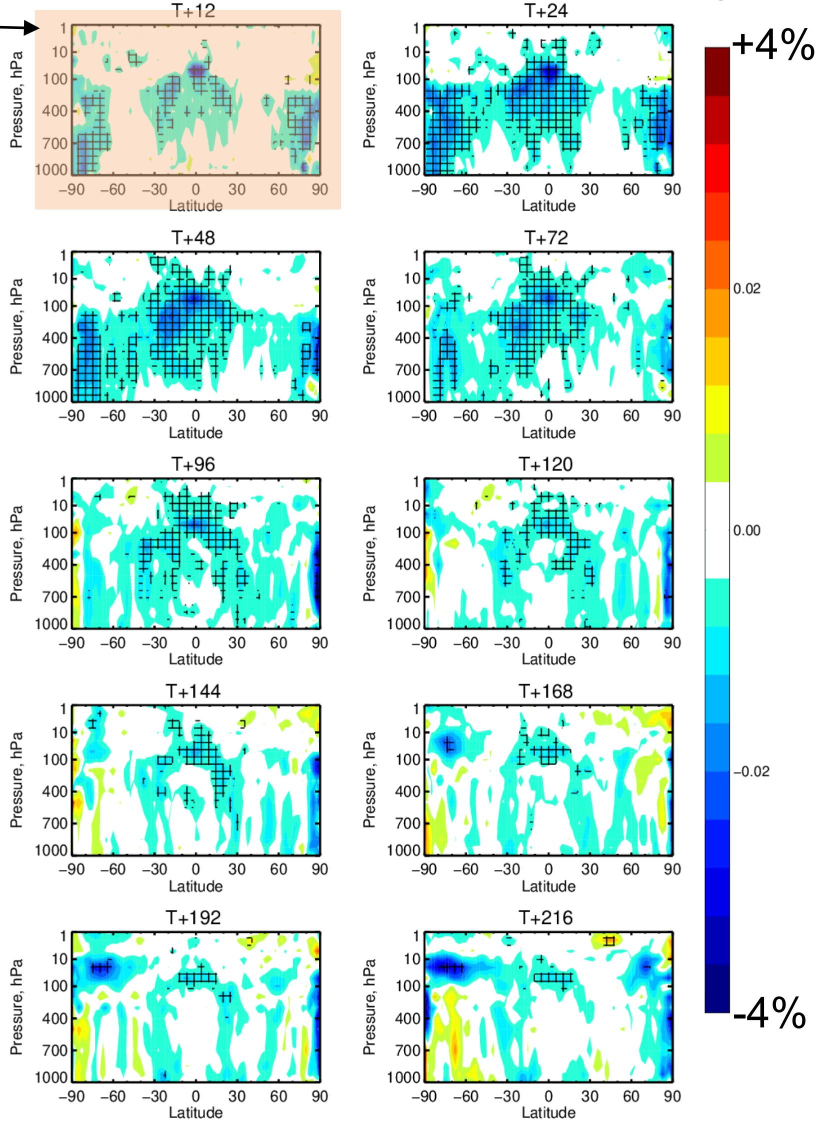
Impact of Aeolus; forecast root mean square error

Vector wind RMSE zonal average



Short-range analysis-based verification is not trustworthy

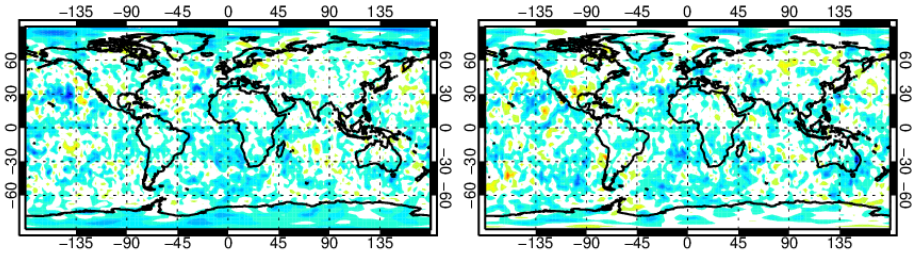
Temperature RMSE zonal average



Vector wind RMSE 500 hPa (±10%)

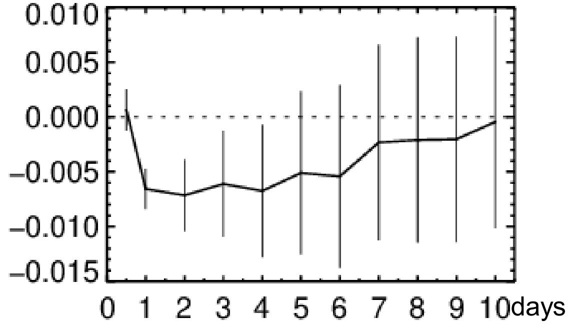
2 days

3 days



Better with Aeolus if blue

Reasonable positive impact even on N. Hemi extratropics 500 hPa geopotential height to 4 days



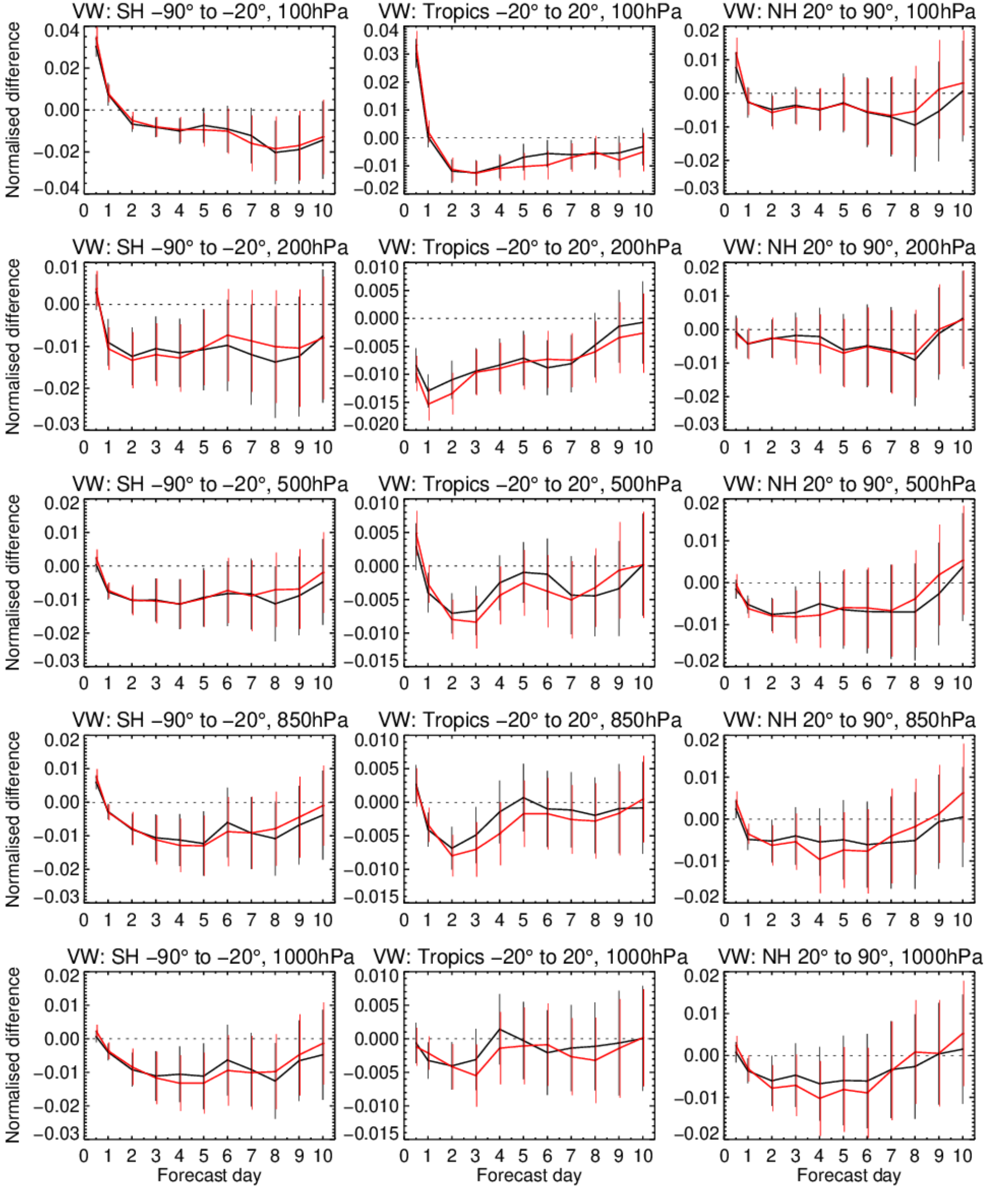
A lot of positive impact – of a **good magnitude for one satellite instrument**. Impact tends to reduce in 2020 as the Rayleigh-clear HLOS wind noise increased

Comparison of 1st reprocessing and 2nd reprocessing via OSE; both at $T_{CO}639$ for same period (limited by 1st reprocessing)

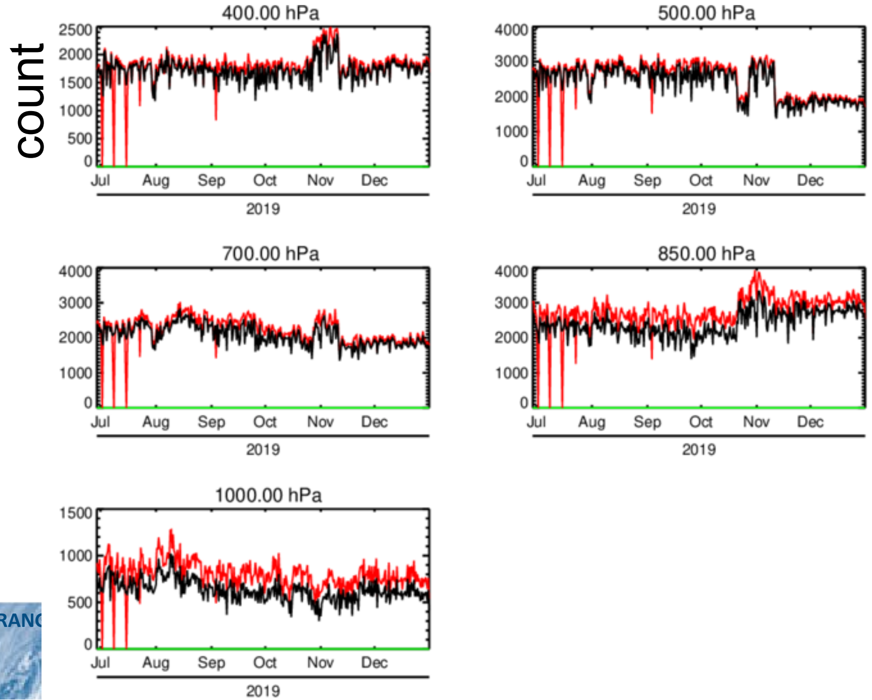
Vector wind RMSE (29 June – 31 Dec 2019)

1st reprocessing

2nd reprocessing



- Two reprocessed datasets have reasonably similar impact, but 2nd reprocessing is more positive in the tropics
- The 2nd reprocessed improved L2B data quality/data counts relative to the 1st

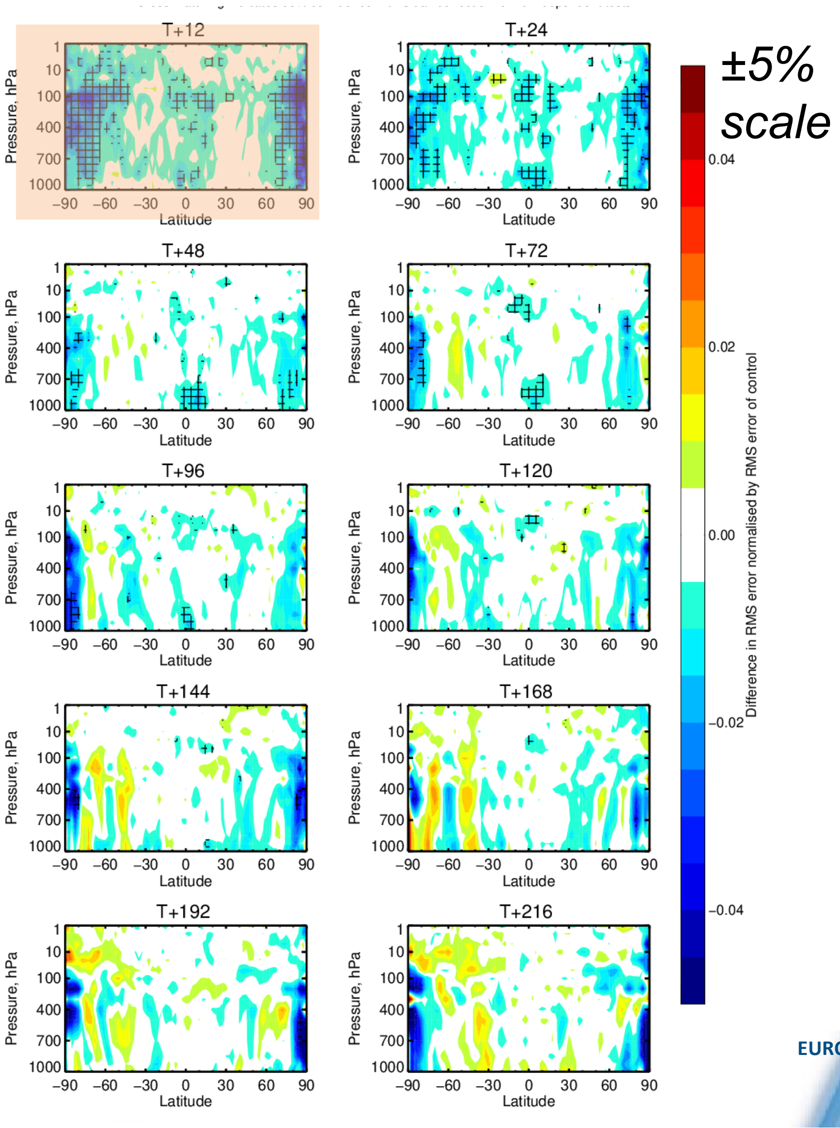


More HLOS winds were assimilated in tropics from 2nd versus **1st** reprocessed datasets

NRT data OSE (late 2021/early 2022) – does Aeolus still provide positive impact via OSE?

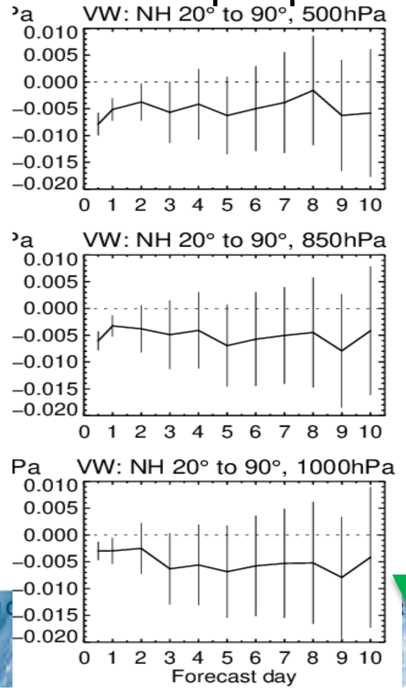
13 Dec 2021 to 15 May 2022

Temperature RMSE zonal average

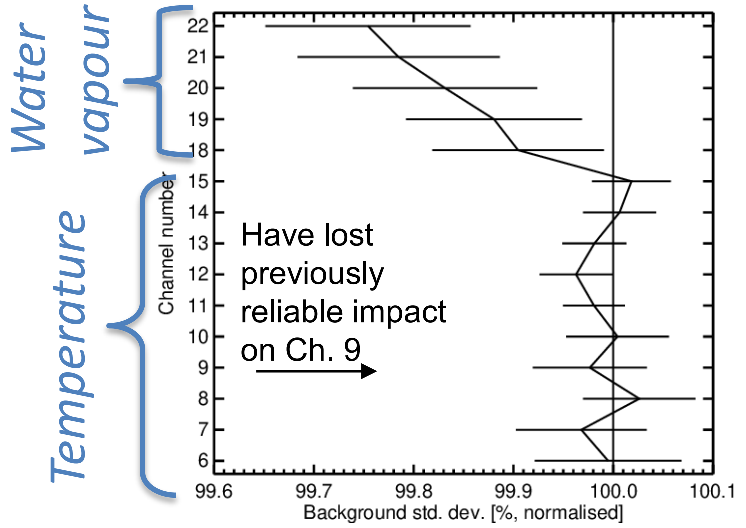


- Still some positive impact in tropics and polar areas
- Tropical impact smaller than seen previously
  - Rayleigh-clear noise?
- Mie-cloudy probably providing most of polar impact

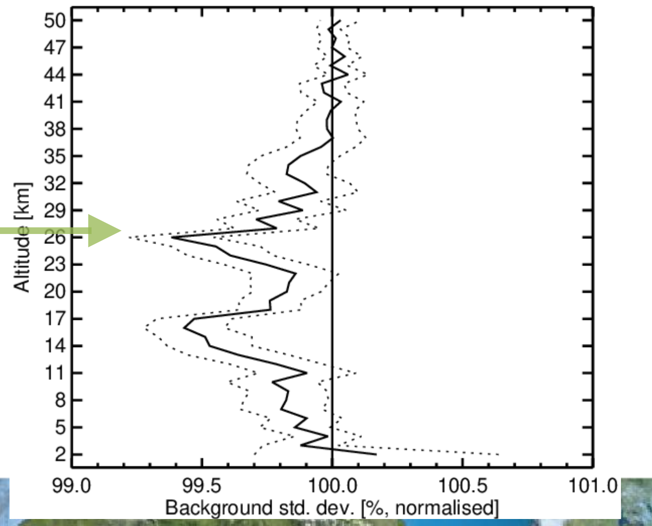
NH lower troposphere winds



ATMS, SH extratropics



GNSS radio occultation, tropics

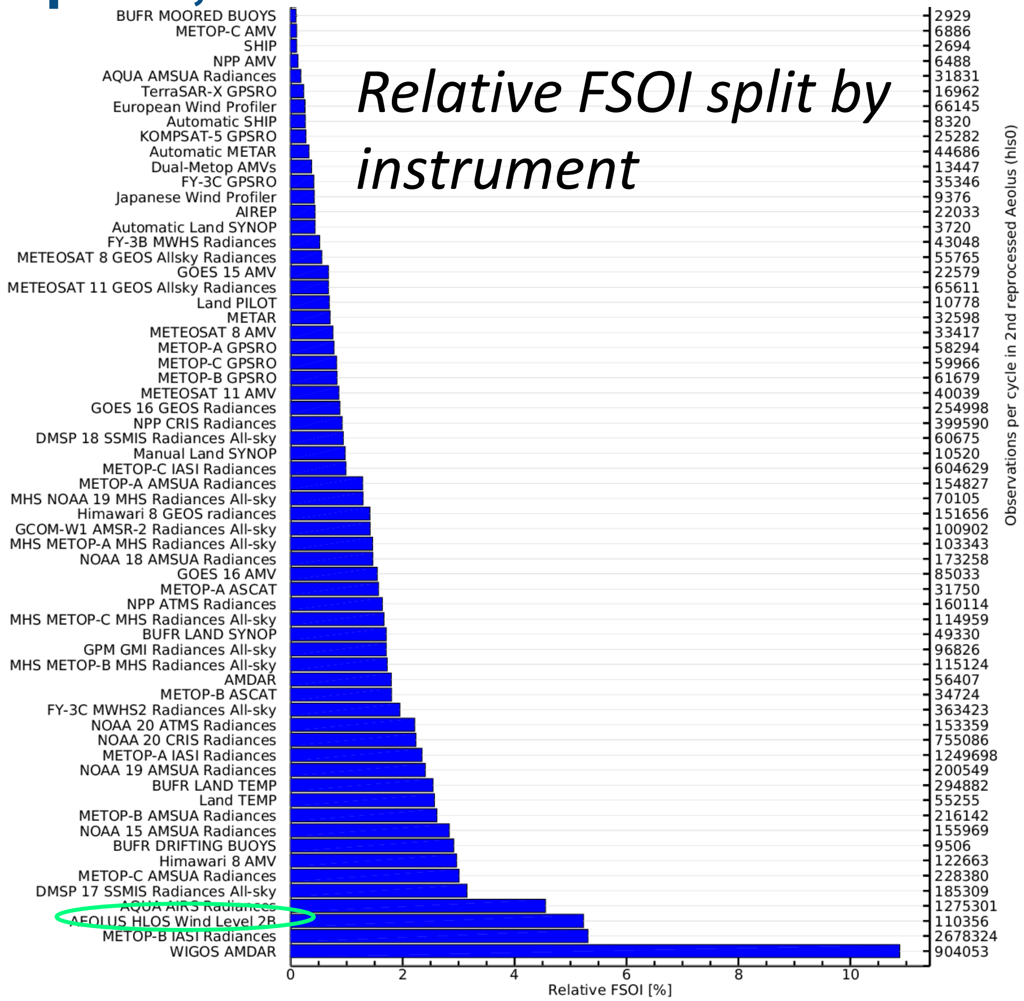


26 km peak due to Hunga-Tonga eruption plume Mie winds!

FSOI

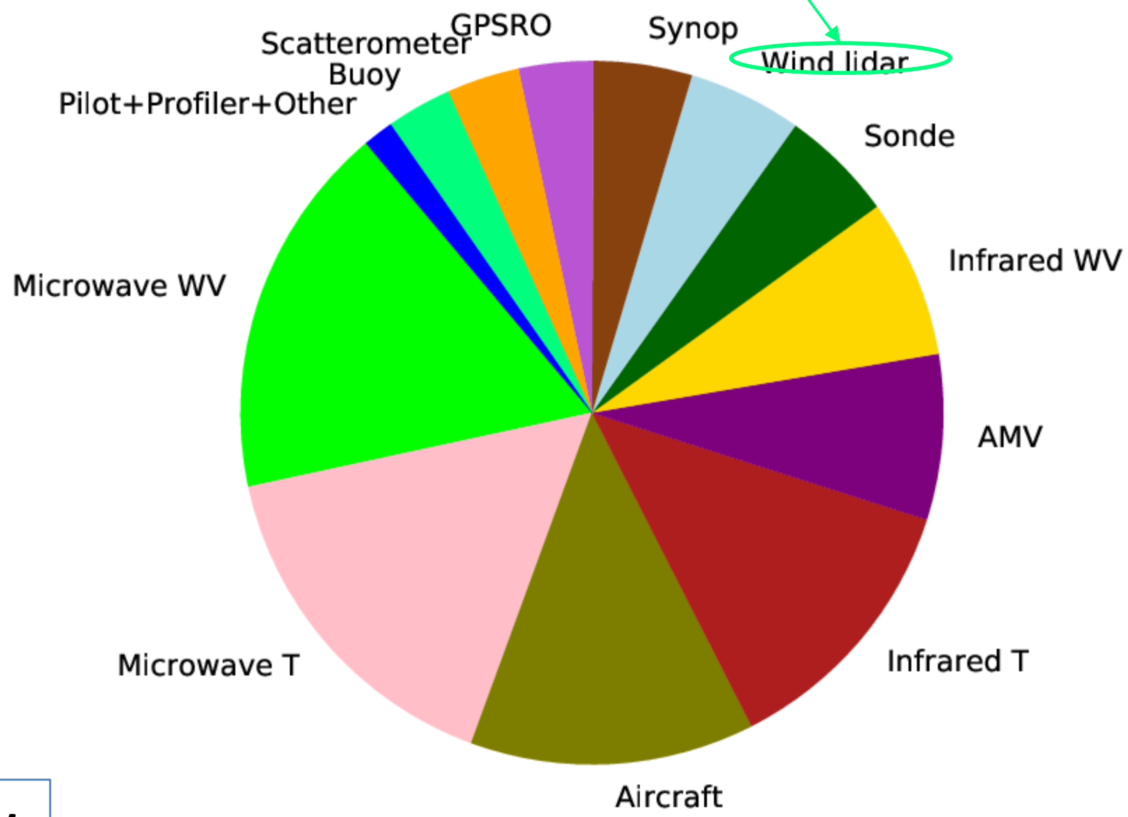
Relative FSOI with 2nd *reprocessed dataset*; 3 July to 18 October 2019; impact at its peak, due to lowest noise of mission

Relative FSOI split by instrument



Relative FSOI by observation group

Wind lidar = Aeolus = 5.22%



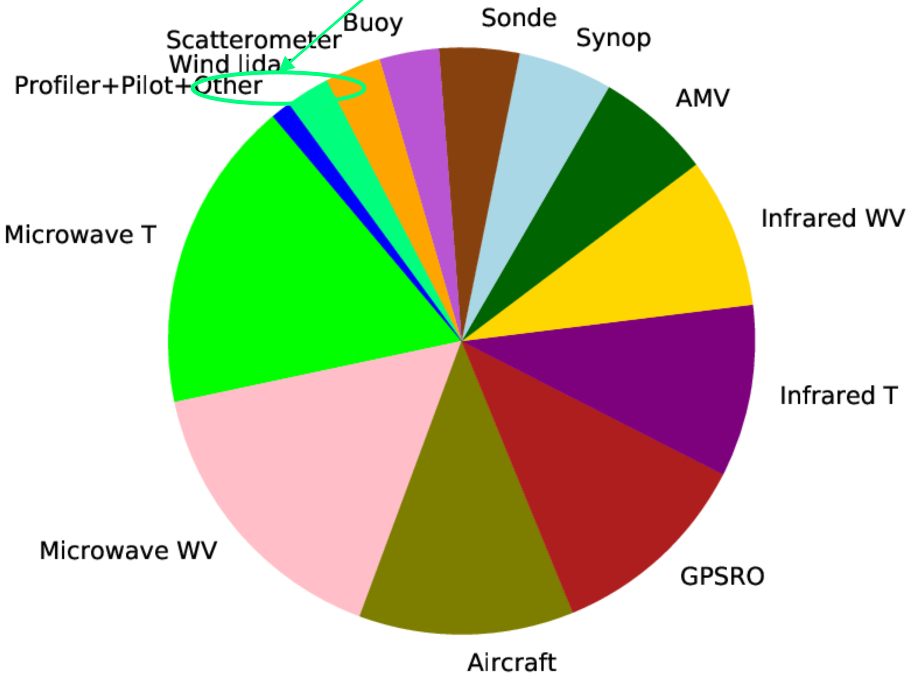
Aeolus FSOI ≈ radiosondes FSOI

- Aeolus **performs strongly** for **one satellite instrument; only exceeded MetOp-B IASI (very similar)**
- This is possible when we have *reasonable* Rayleigh-clear random errors

Relative FSOI from operations (NRT dataset); 1 Jan to 28 Feb 2022

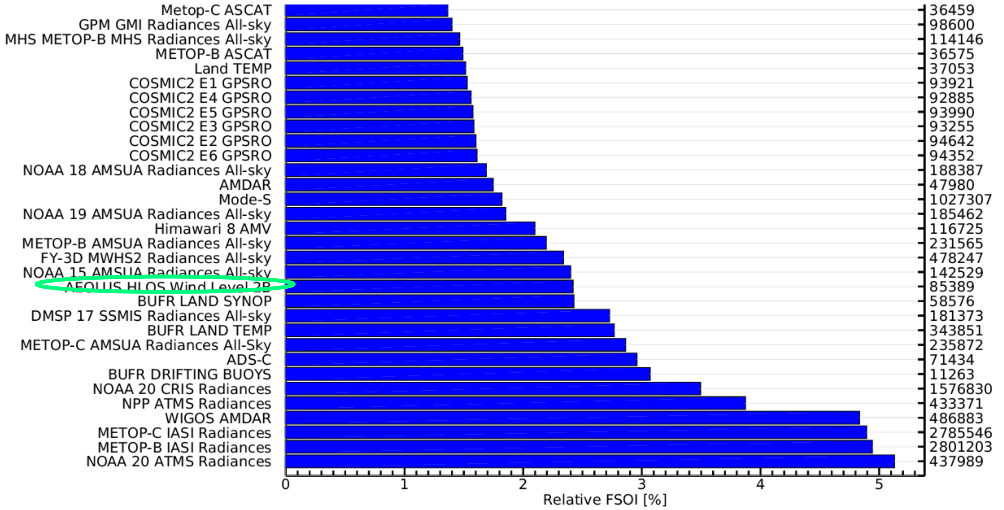
Relative FSOI by observation group

Wind lidar = Aeolus = 2.42%

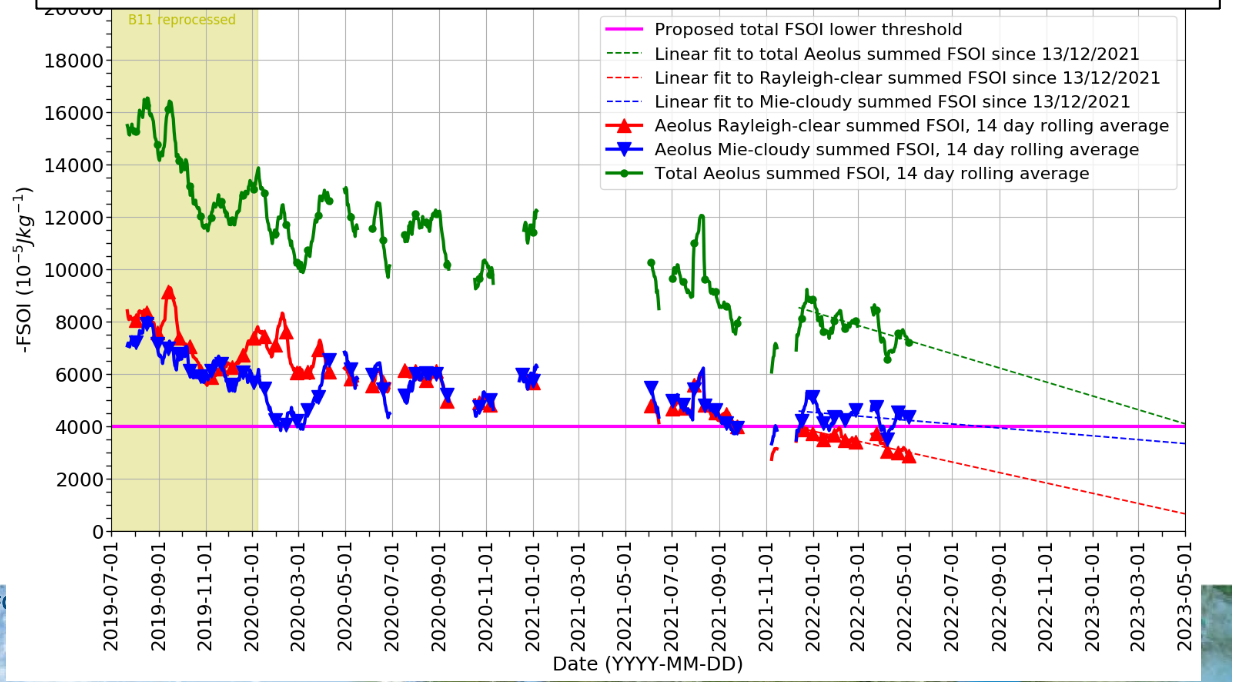


- More recently Aeolus *still* providing useful positive impact
- *But less than half of at its peak (early FM-B)*

Relative FSOI by instrument type



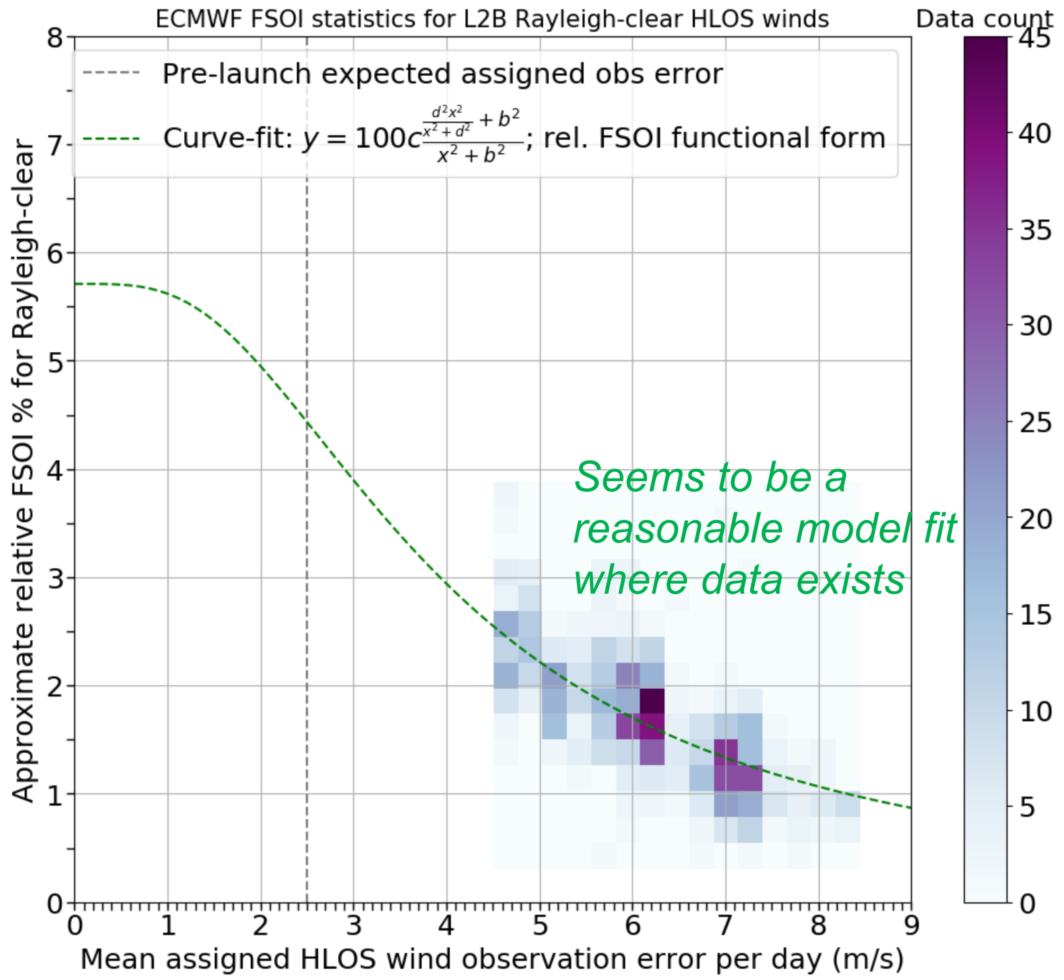
Time-series of Aeolus absolute FSOI for whole of FM-B



DLR

ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER F

Relative FSOI (%) vs. assigned data assimilation observation error for Rayleigh-clear – based on mean values per day using FSOI stats for whole FM-B period



- Curve-fit via simple DA equivalent of relative FSOI at analysis:

$$\frac{\sigma^2_{a,subset}-\sigma^2_b}{\sigma^2_{a,all}-\sigma^2_b} = \frac{\sigma^2_{o,all}+\sigma^2_b}{\sigma^2_{o,subset}+\sigma^2_b} = \frac{\frac{\sigma^2_{o,rest}\sigma^2_{sub}}{\sigma^2_{o,rest}+\sigma^2_{o,sub}}+\sigma^2_b}{\sigma^2_{o,sub}+\sigma^2_b}$$

- Gives an impression of impact possible with *mission requirements* random error (~2.5 m/s for Rayleigh-clear):
  - Suggests Rayleigh-clear impact could go from ~1.8%@6 m/s for real mission to ~4.4%@2.5 m/s
  - If 4.4% for Rayleigh-clear was combined with ~2% typical of Mie-cloudy then this would give a total of ~6.4% relative FSOI (compare to peak of 5.2% early FM-B)
    - *May be an underestimate because more signal would also lead to more Mie-cloudy winds – hard to predict impact of this via this method*

Summary

- **Short-to-medium range Aeolus forecast impact via OSEs:**
  - Longest OSE (2nd reprocessing) shows **best impact** seen (so far) – partly due to: large sample (statistical significance); higher resolution OSE; improved data quality with 2nd reprocessing
  - **Summary of OSE based verification:**
    - **Statistically significant and good magnitude** positive impact on **wind, temperature, geopotential and humidity** forecasts in **tropics and polar regions:**
      - Up to **9-10 days** in tropics and S. Hemi. extratropics at 100 and 50 hPa (15-20 km); by 0.5-2%
      - Even **N. Hemi. extratropics geopotential at 500 hPa (~5 km) is improved** to day 4 by ~0.5-1%
  - Impact starts to wane as 2nd reprocessing OSE length increased, due to noisier data
  - Recent NRT data OSE shows Aeolus still provides positive impact – but noticeably smaller than 2nd reprocessed OSE; particularly in the tropics
- **Short forecast range Aeolus impact via FSOI:**
  - July-Oct 2019 for 2nd reprocessing FSOI shows **Aeolus has 2nd largest impact of individual satellite** instruments (similar to MetOp-B IASI) and has **similar impact to radiosonde network**
  - Operational **FSOI** shows **positive impact recently (~2.4%)**
    - **But less than half of July-Oct 2019 (~5.2%)**; due to ongoing atmospheric path signal decrease (wind noise increase)
    - Extrapolation of Rayleigh-clear FSOI to reduced noise (~2.5 m/s); *suggests* 6-7% total relative FSOI is achievable for a Doppler wind lidar (*we'll hopefully see this level of impact for an Aeolus follow-on!)*

Thanks for listening, any questions?

We look forward to seeing you on our booth in the centre of the exhibition area, attached to the central ESA booth...

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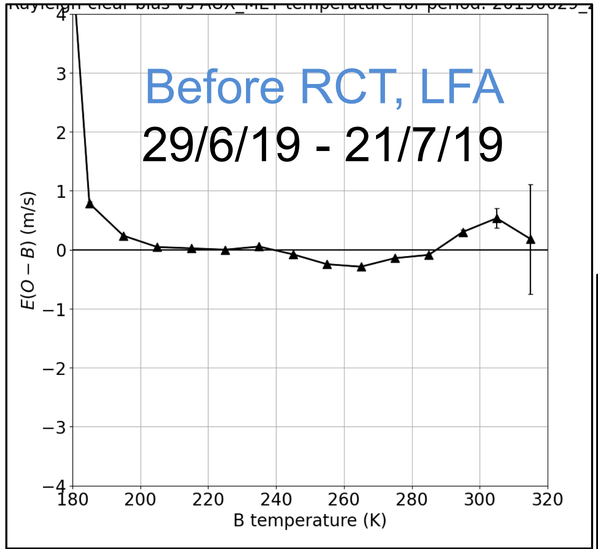
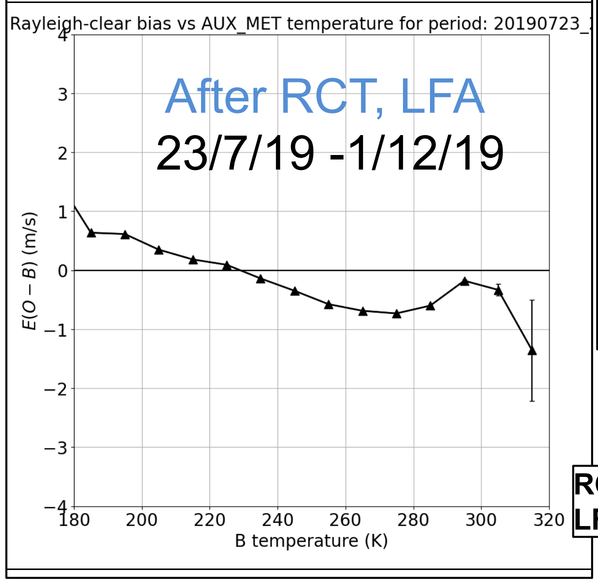
L2B Rayleigh-clear wind *bias correction* as function of *atmospheric* temperature

Using 1st reprocessed dataset

Bias correction: Rayleigh-clear HLOS wind mean(O-B) vs. AUX_MET temperature

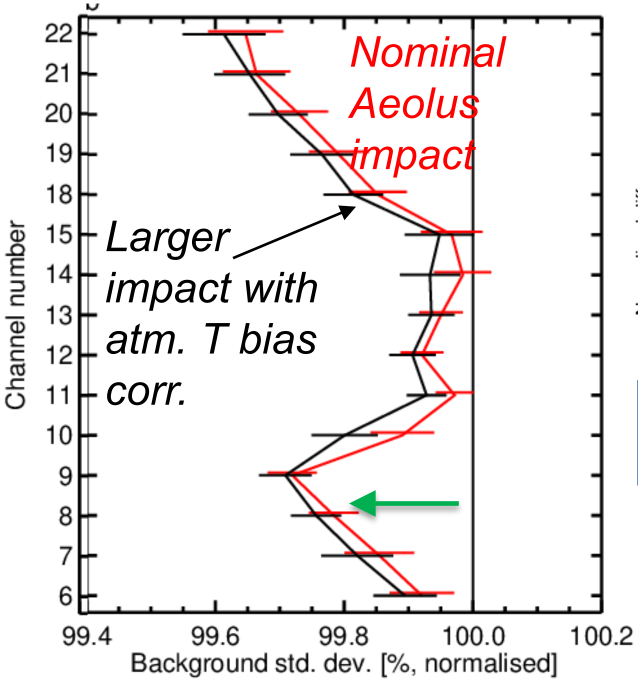




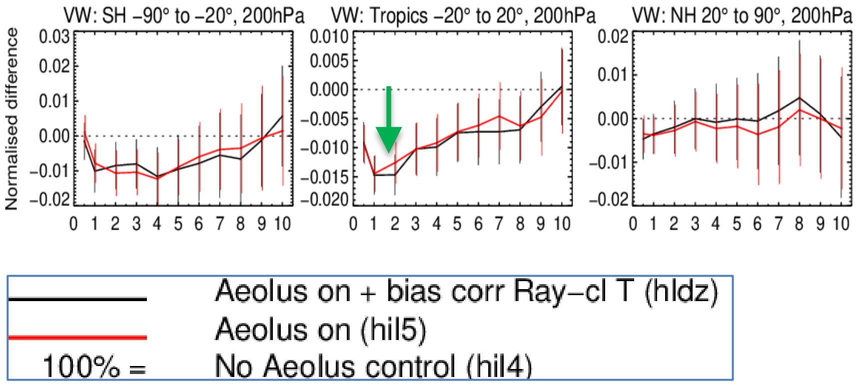
- Bias structure changed after RCT and LFA (on 22 July 2019)
- Further evidence of sensitivity to applied Rayleigh-Brillouin calibration
- Bias probably more correctly fixed in the RBC directly

RCT= Rayleigh Cover Temperature
LFA = Laser Frequency Adjustment

Short-range forecast fit to ATMS microwave radiances

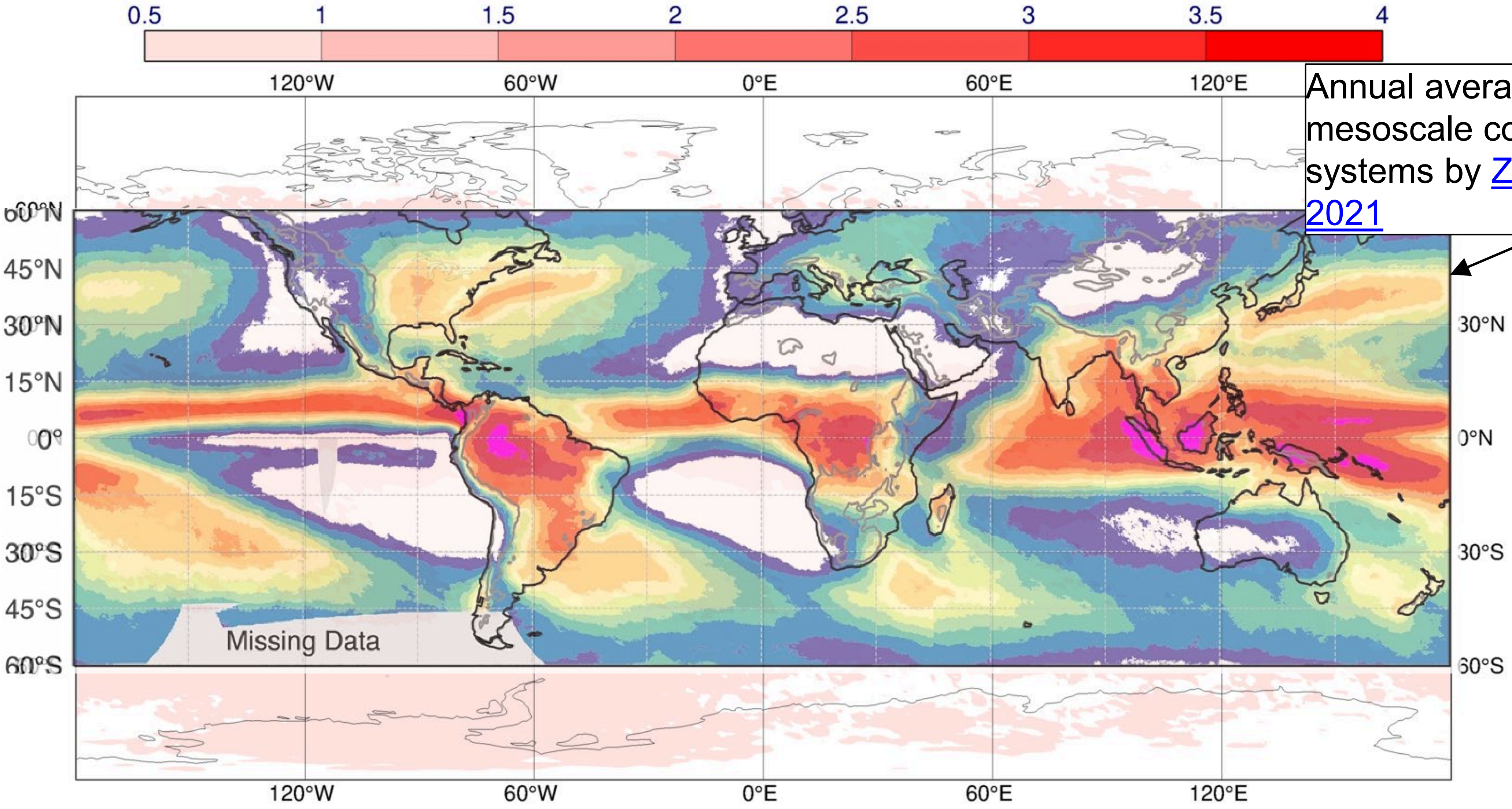


Medium-range vector wind RMSE



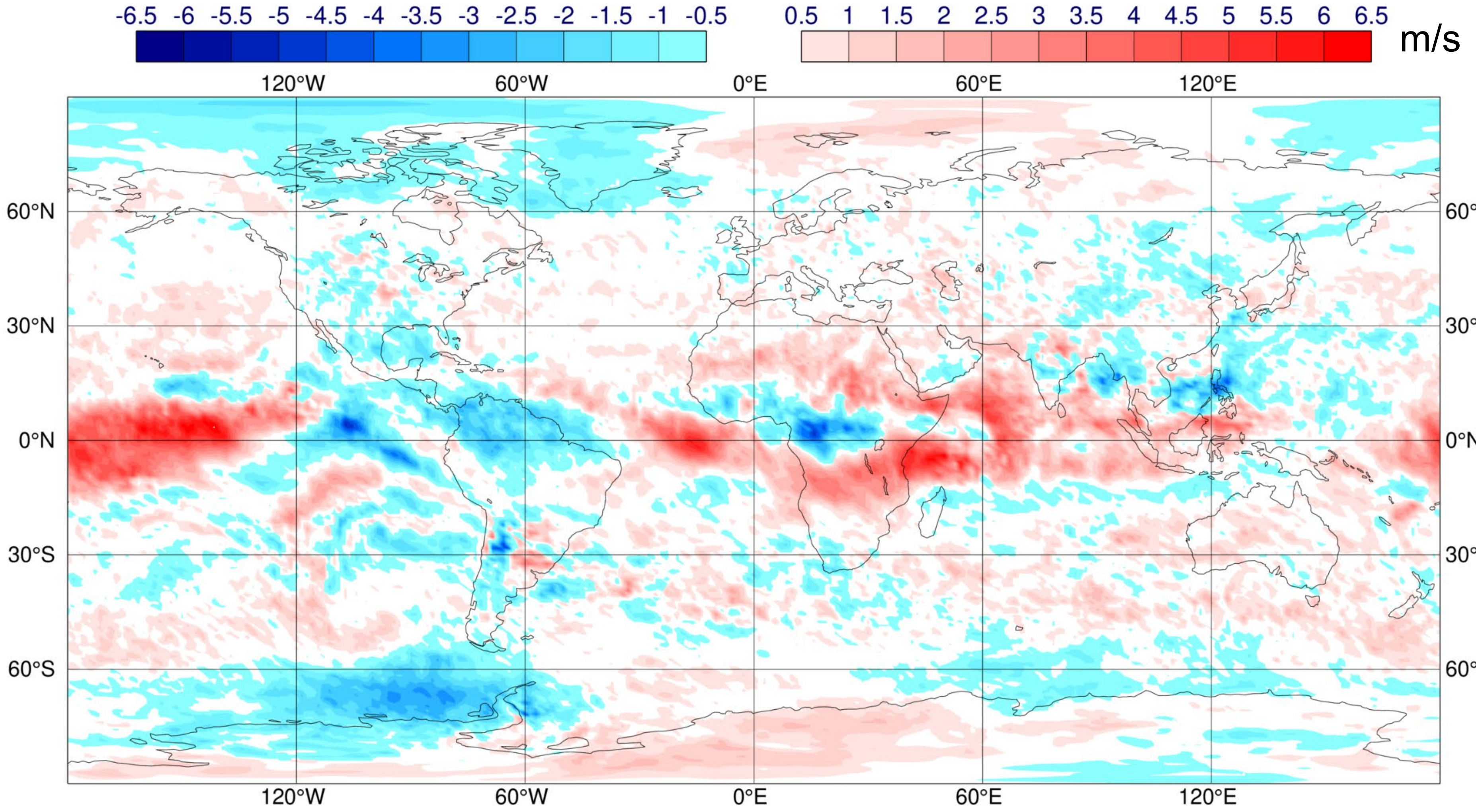
- Impact from bias correction is positive for **short-range forecast** fit to other observation types
    - e.g. ATMS, NH conventional winds
- But impact on longer range forecasts **is *mixed***
- *Suggests further bias correction is important, but need to correct it properly via improved Rayleigh-Brillouin Correction look-up tables (in L2B processing)*

Mean stdev of analysis differences due to Aeolus in u-wind for 29 June to 30 Dec 2019 at ~200 hPa



Annual average number of mesoscale convection systems by [Z. Feng et al. 2021]

Example of mean difference between ECMWF and Met Office analysis u-wind component for 29 June – 3 July 2019



Systematic differences between different NWP centres at 100 hPa in winds can be large