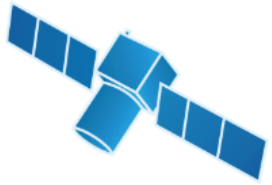
An Update on the Impact of Aeolus HLOS Winds in Numerical Weather Prediction at ECMWF

by Michael Rennie (ECMWF)
Acknowledgements to colleagues from: ECMWF, DAMI, DISC and ESA

Aeolus NWP Impact and L2B Product Quality Working Meeting
Day 2, Aeolus NWP impact, 3 December 2021
On-line meeting



aeolus

DISC

serco

ABB

s[&]t

Methods of assessing Aeolus winds NWP impact at ECMWF

- **O**bserving **S**ystem **E**xperiments:
  - **2nd reprocessed FM-B period (baseline=2B11):** $T_{CO}639$ resolution
    - Nominal set-up; 29 June to 31 Dec 2019 (still running)
  - **1st reprocessed early FM-B period (baseline=2B10):** $T_{CO}399$ resolution
    - Impact with an additional Rayleigh-clear HLOS wind bias correction as function of *atmospheric temperature*; 29 June to 31 Dec 2019
- **F**orecast **S**ensitivity **O**bservation **I**mpact:
  - **ECMWF operational FSOI** since 9 January 2020 and **special offline FSOI** applied to the complete **1st reprocessed period**

References for earlier ECMWF impact results (but similar settings):

- "*The impact of Aeolus wind retrievals on ECMWF global weather forecasts*" by Rennie, Isaksen, Weiler, de Kloe, Kanitz and Reitebuch, QJRMS, https://doi.org/10.1002/qj.4142
- DISC TN on NWP impact at ECMWF v3.1 (can provide upon request)
- ECMWF Tech. Memo. 864 https://www.ecmwf.int/node/19538

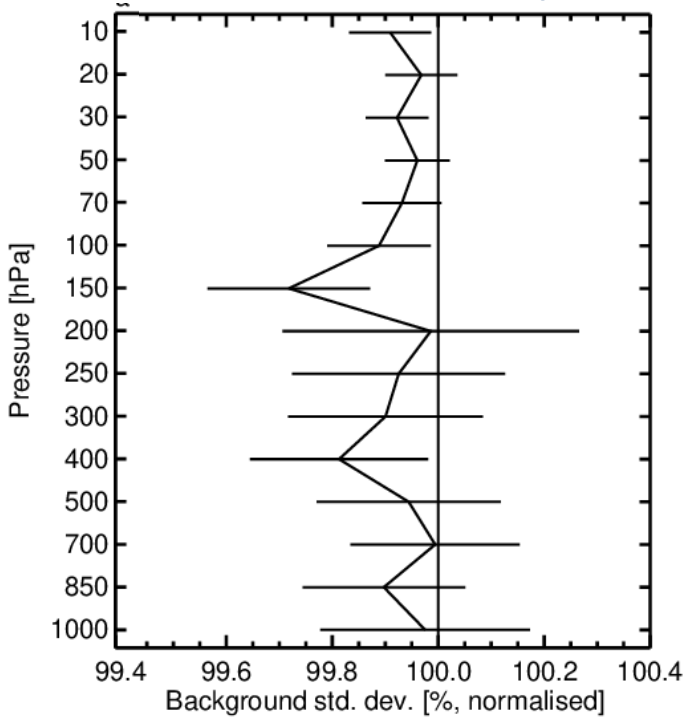
2nd reprocessed dataset

- OSE at higher resolution ($T_{CO}639$) than previous OSEs ($T_{CO}399$)
- Plan to run for whole period of 2nd reprocessing
- Also, archiving metrics for assessing **tropical cyclones** and **extreme weather**
  - Particularly for benefit of parallel ESA contract on *Impact of Aeolus on Extreme Weather* – Giovanna De Chiara (ECMWF)

Background (short-range forecast) fit to other observations when assimilating Aeolus

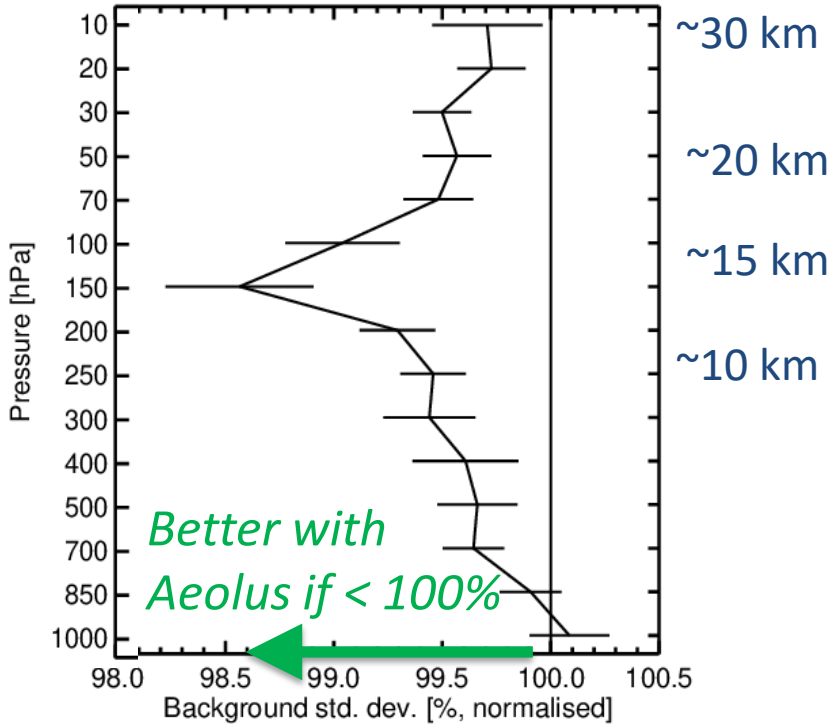
Fit to “conventional” wind observations: from aircraft, radiosondes and radar wind profilers

N. Hemi. extratropics



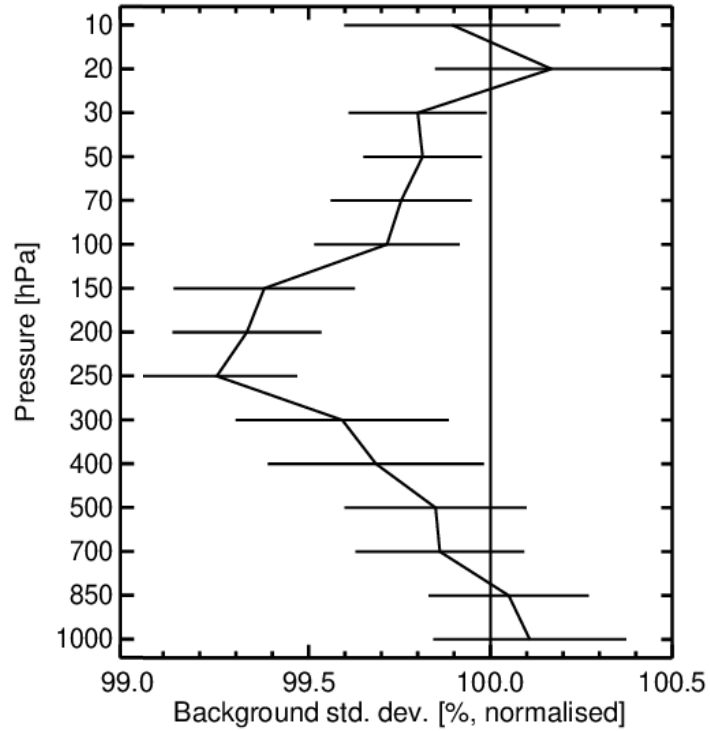
Slightly positive in NH extratropics

tropics



Good impact in the tropics; apart from > 850 hPa

S. Hemi. extratropics

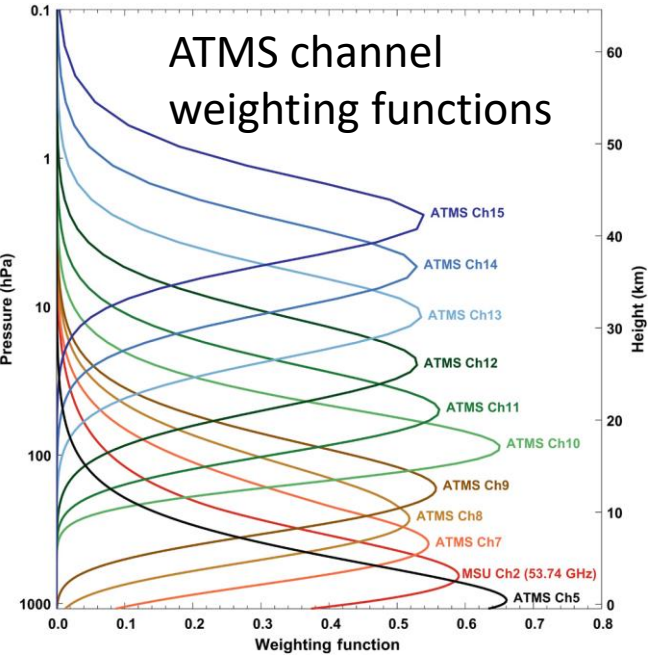


Good impact in SH extratropics; apart from > 850 hPa

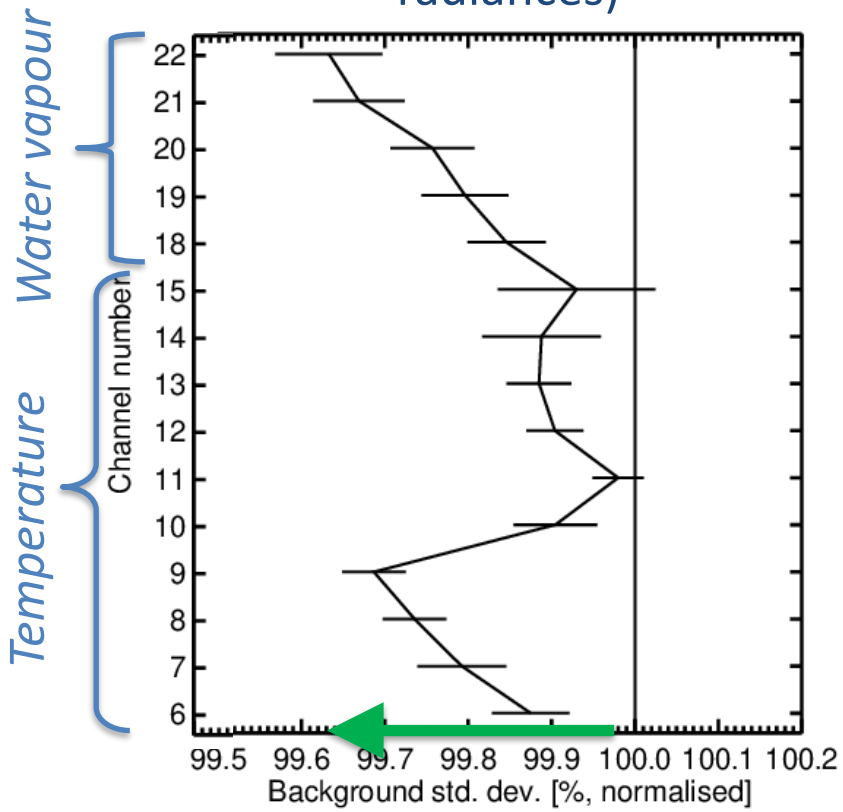
Aeolus’ impact largest in tropical upper troposphere – similar to 1st reprocessed dataset

… background fit to other observations when assimilating Aeolus

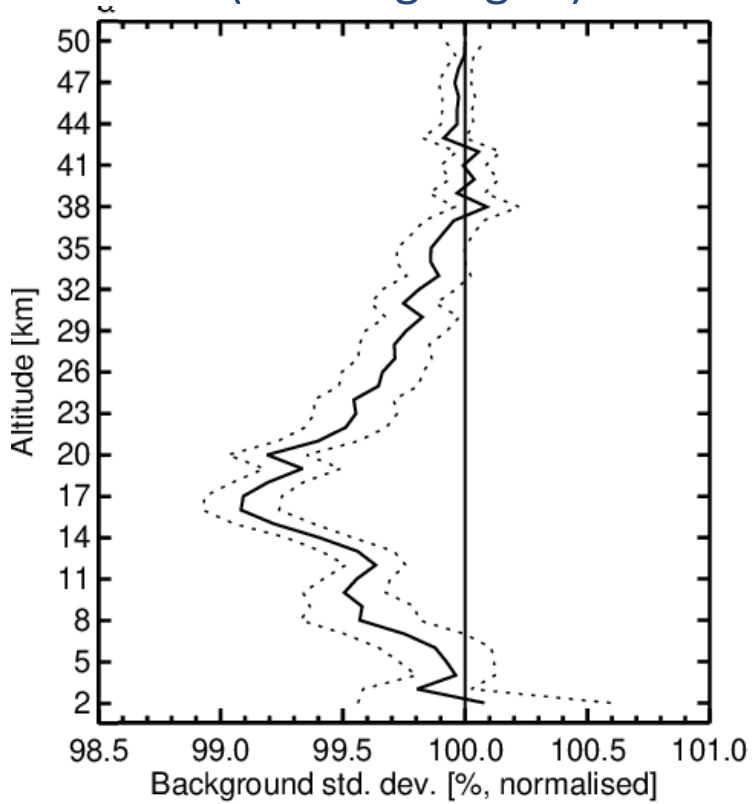
Fit to important temperature/humidity sensitive data



Global, ATMS (microwave radiances)



Global, GNSS radio occultation (bending angles)



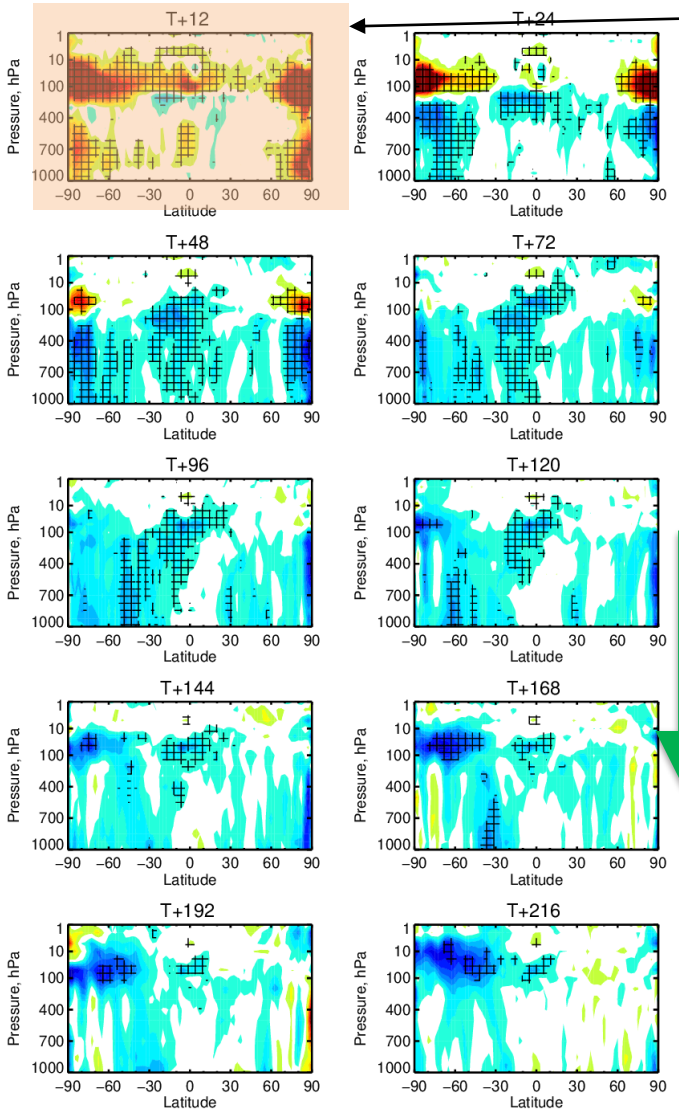
Better with Aeolus if < 100%

Slightly stronger positive impact compared to 1st reprocessed dataset: **Aeolus improves wind**, **temperature** and **humidity** background fits, most strongly in **upper troposphere**

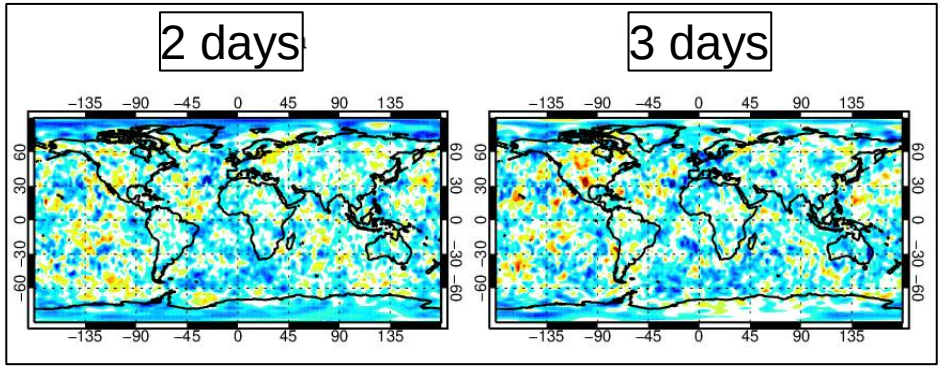
Impact of Aeolus; forecast root mean square error

Vector wind RMSE zonal average

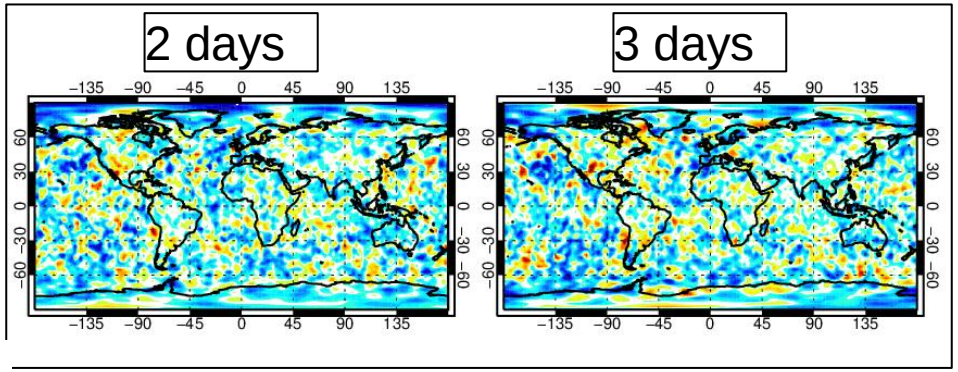
Short-range verification by analysis is not trustworthy



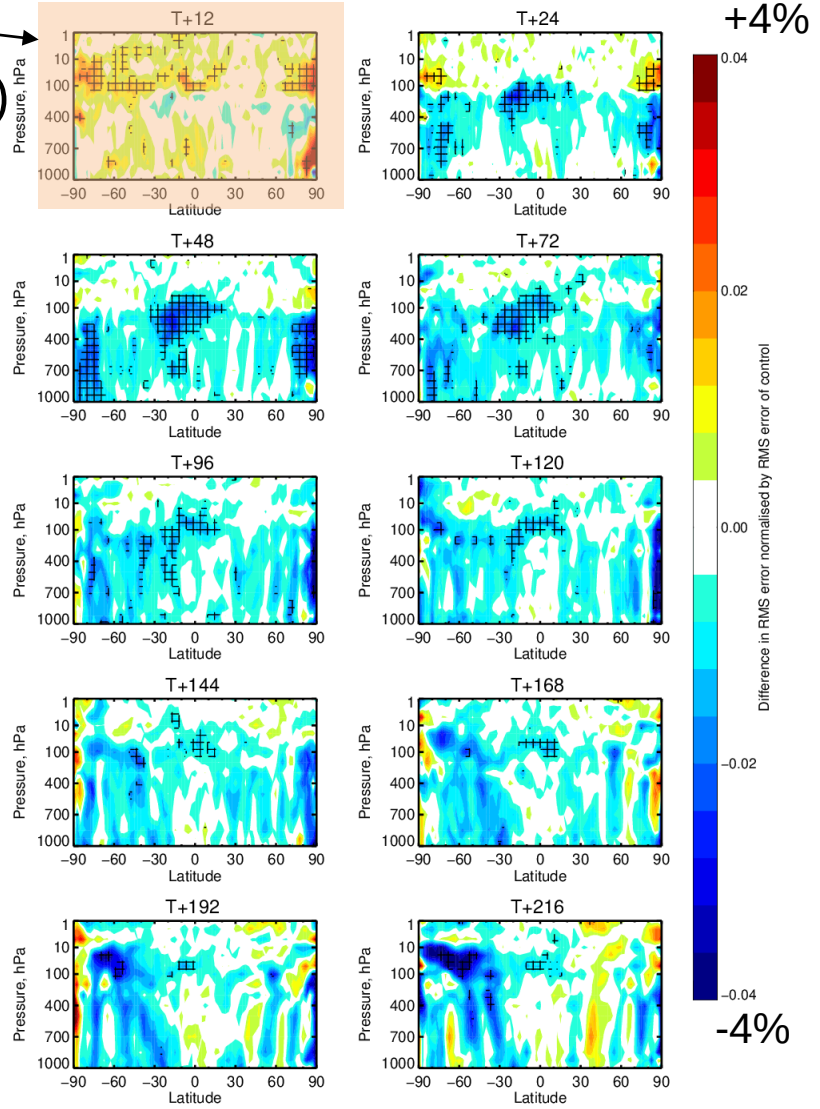
Vector wind RMSE 500 hPa map (±10%)



Temperature RMSE 500 hPa map (±10%)

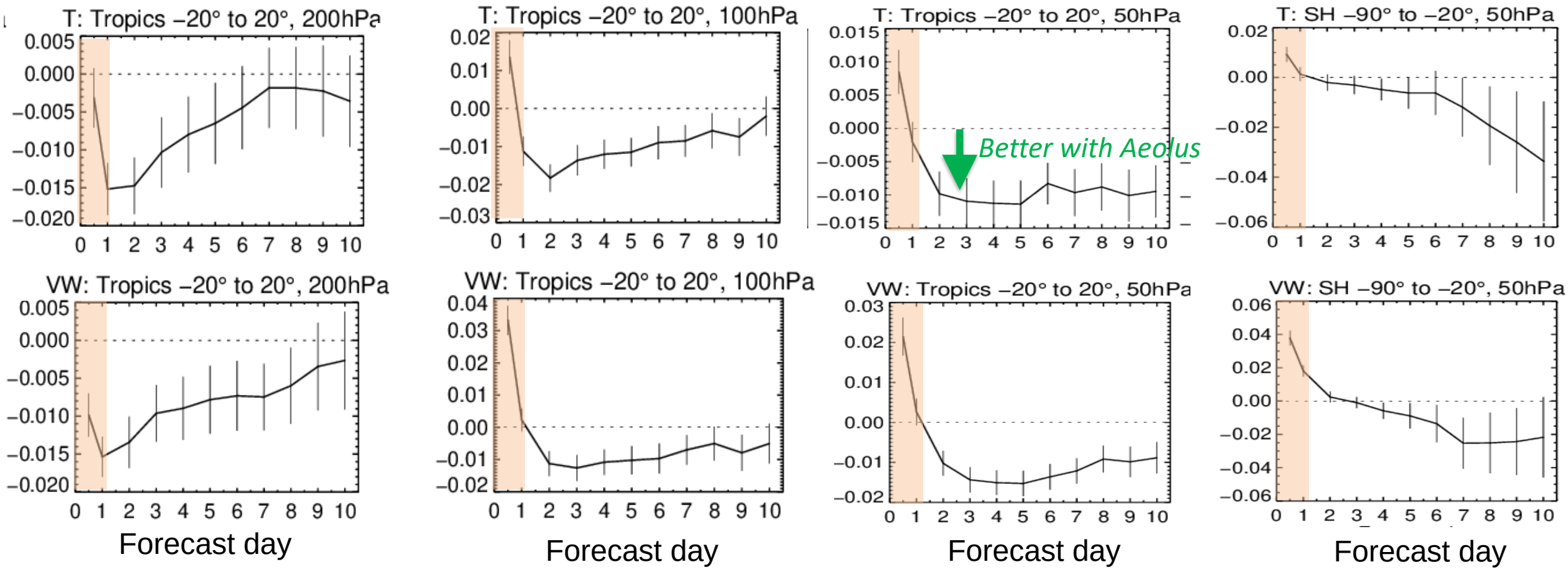


Temperature RMSE zonal average



- A lot of positive impact!
- Stronger impact than 1st reproc. dataset OSE; *will run 1st reproc. at same model resolution to confirm why*

Examples of largest Aeolus positive impacts; vector wind (VW) and temperature (T) RMSE in upper troposphere and lower stratosphere



Particularly good impact in:

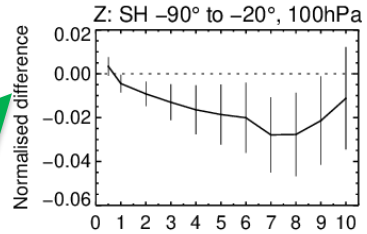
- Tropical UTLS; out to day 10 forecast range at 50 hPa – see talk by Nedjeljka Žagar for some thoughts on mechanism
- S. Hemi. LS temperature out to day 10 (~3%!)

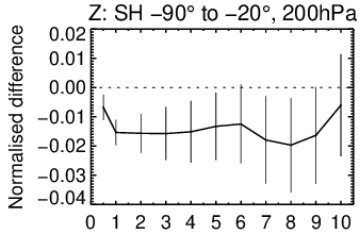
Aeolus impact on geopotential height RMSE – focus on verification of extratropics

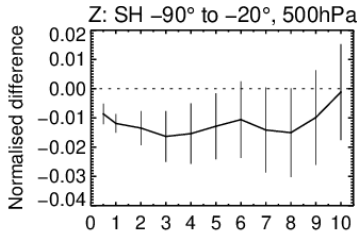
Positive impact on S. Hemi. Z 200/100 hPa to day 9 (~2%)!!

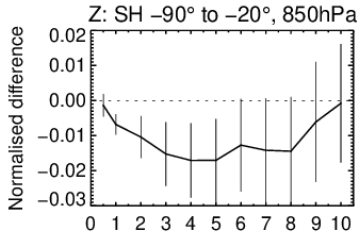
Positive at ~1 week for Z 500 hPa in S. Hemi. (~1-1.5%)

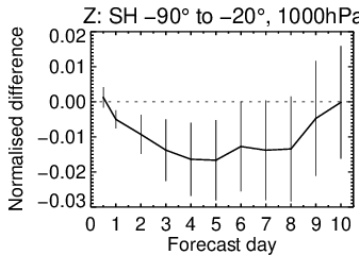
Positive at 1 week near surface in S. Hemi.



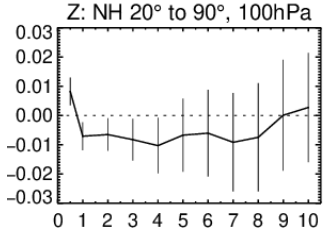


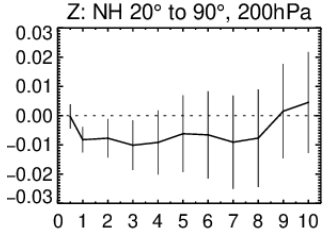


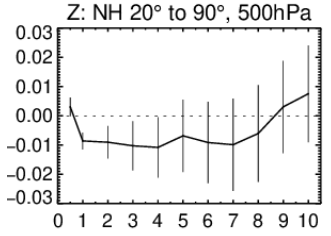


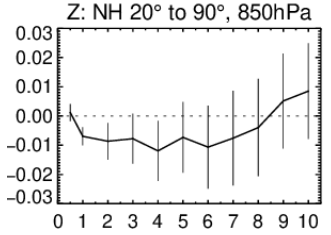


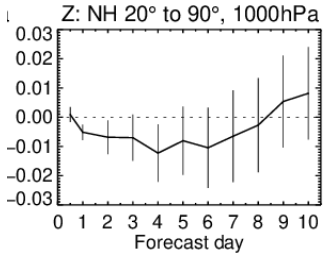
S. Hemi.











N. Hemi.

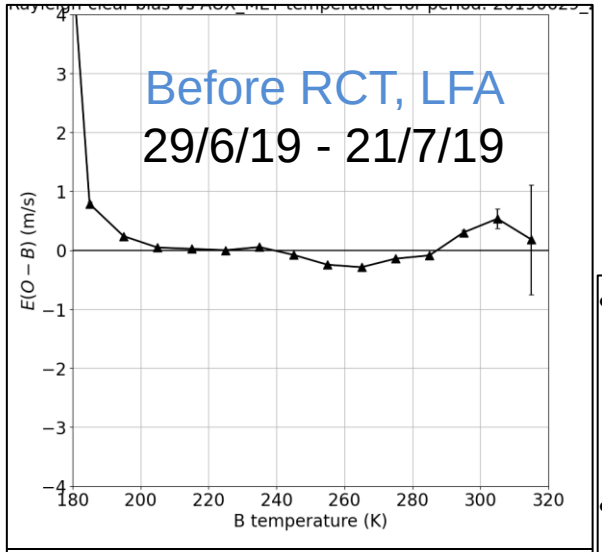
Even see **positive impact on Z in N. Hemi.** to day 4 (~1%)!!

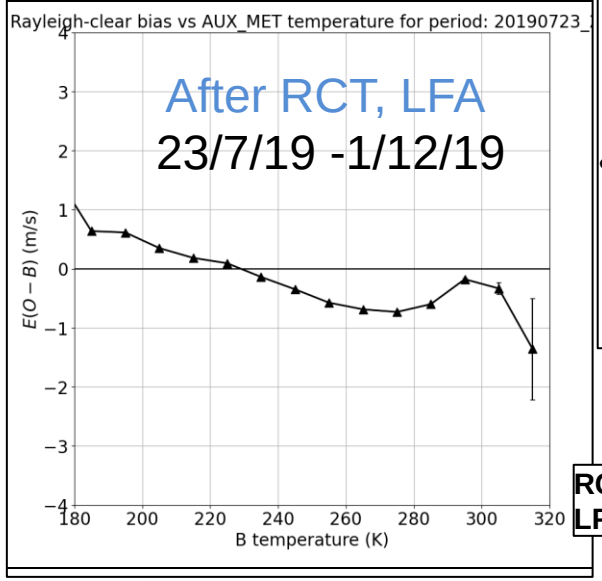
Similar in stdev(error); so not just a bias change

1st reprocessed dataset

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

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

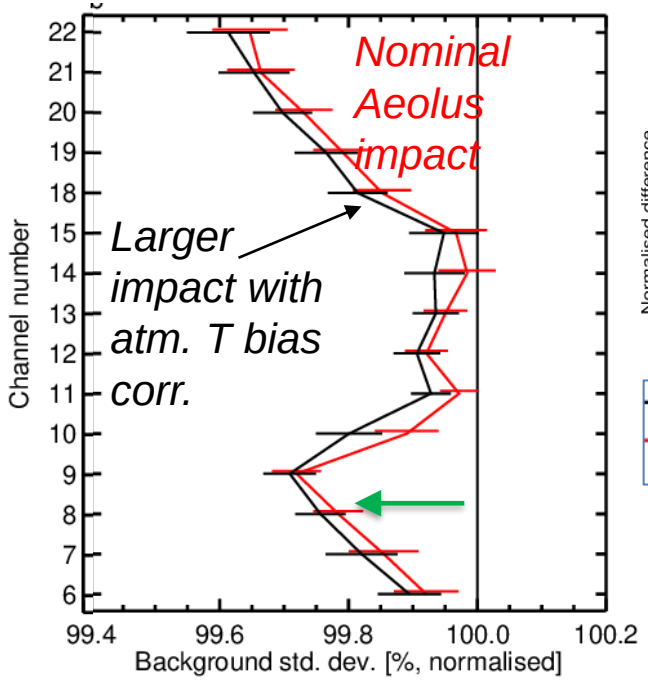




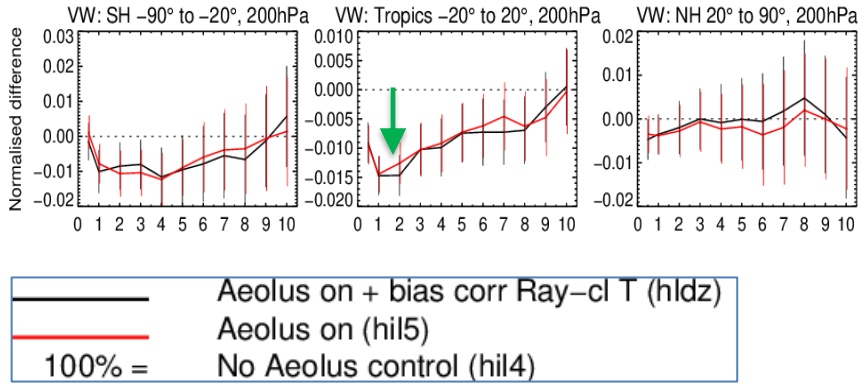
- Bias structure changed after RCT and LFA (on 22 July 2019)
- Further evidence of sensitivity to applied Rayleigh-Brillouin calibration
- Bias probably more correctly fixed in the RBC directly

RCT= Rayleigh Cover Temperature
LFA = Laser Frequency Adjustment

Short-range forecast fit to ATMS microwave radiances



Medium-range vector wind RMSE

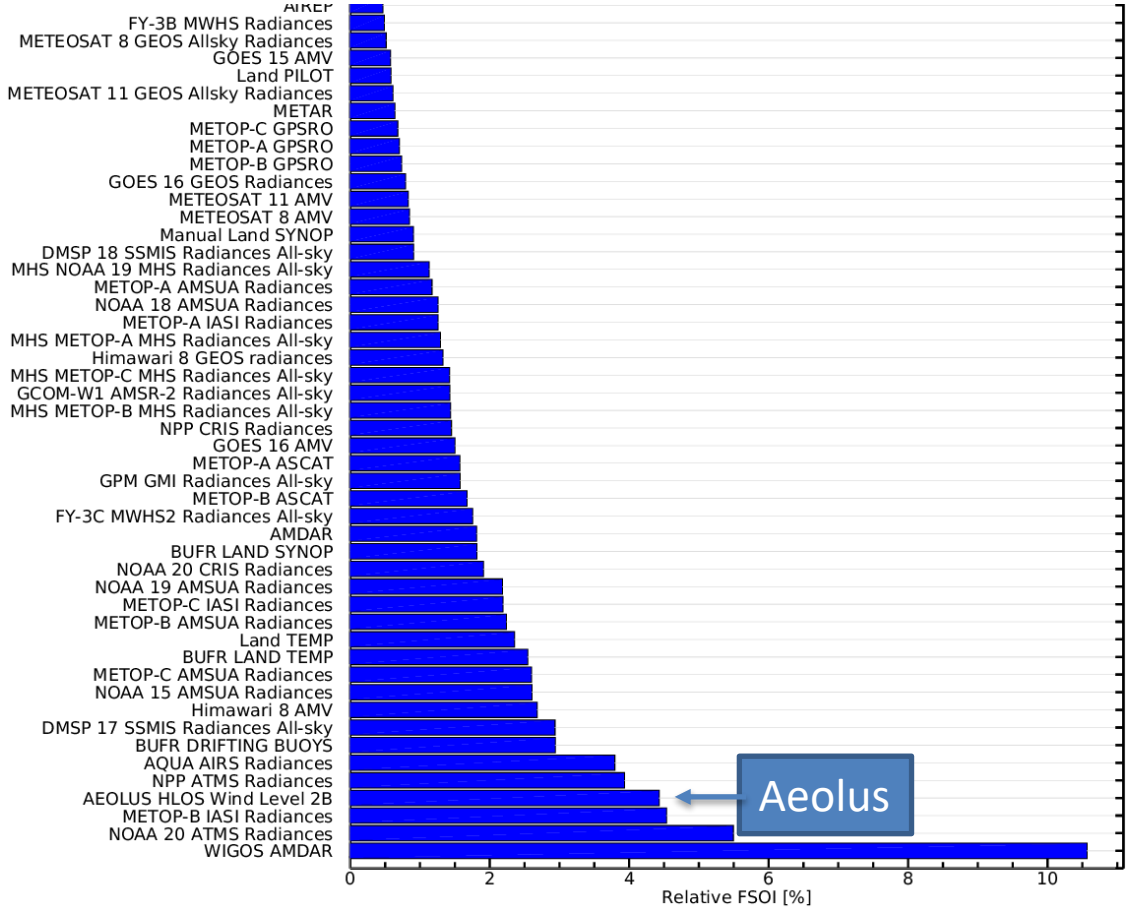


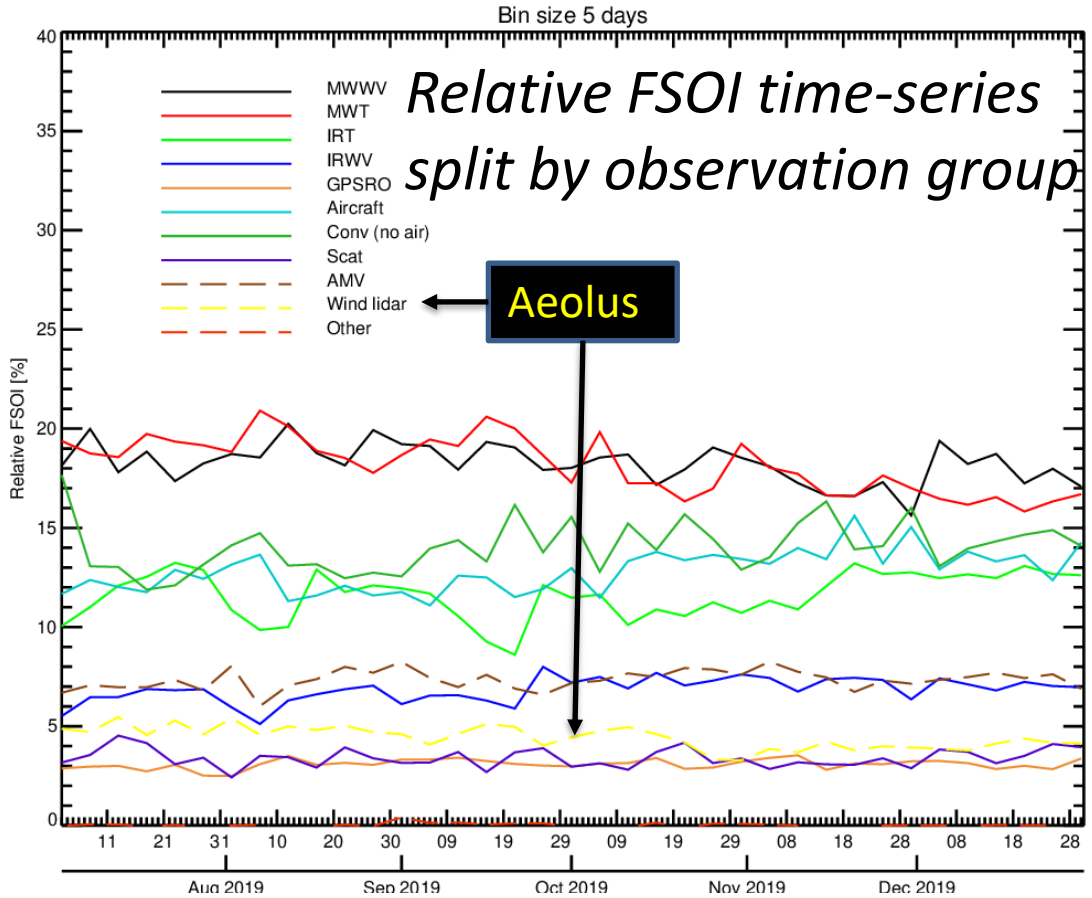
- NWP impact from bias correction is positive for **short-range forecast** fit to other observation types
  - e.g. ATMS, NH conventional winds
- But impact on longer range forecasts **is *mixed***
- See also, Maurus Borne's talk

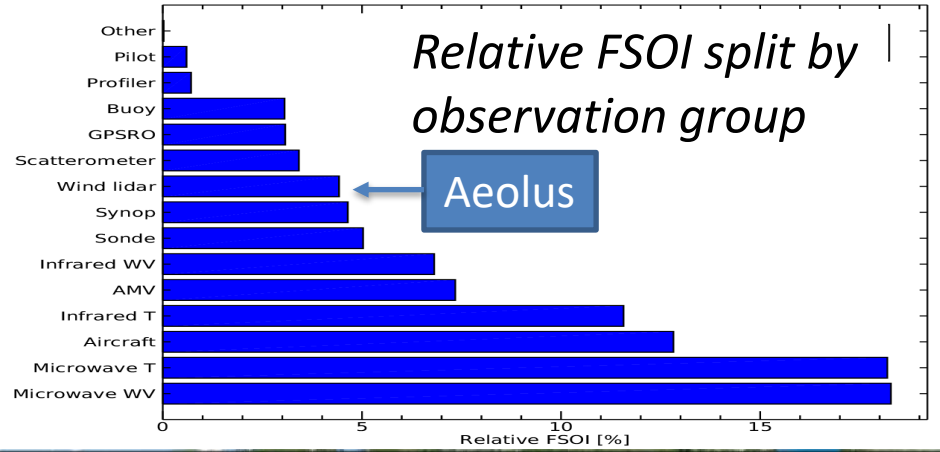
FSOI-based assessment of Aeolus NWP short-range impact

Relative FSOI with 1st reprocessed dataset; 29 June to 31 December 2019

Relative FSOI split by instrument

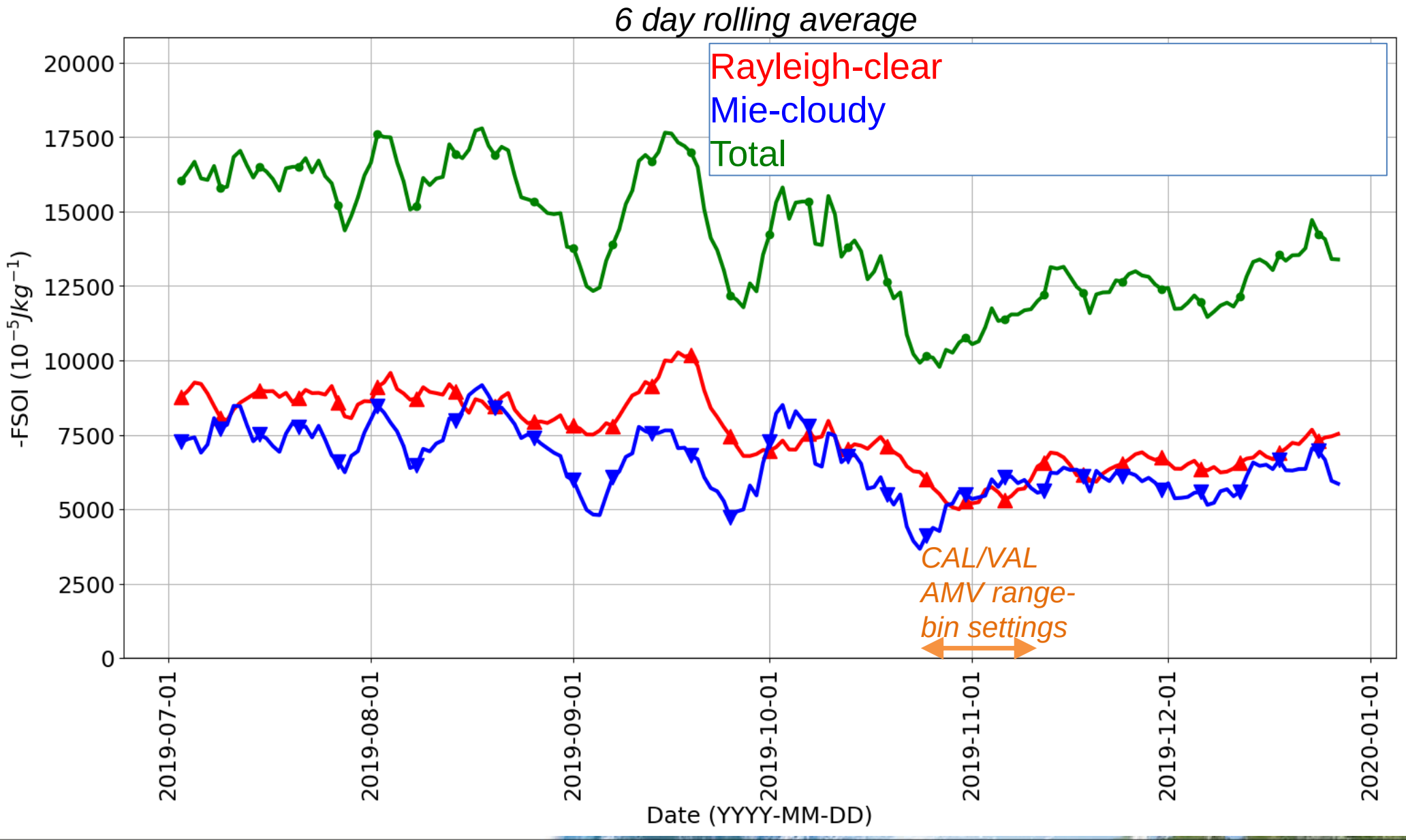






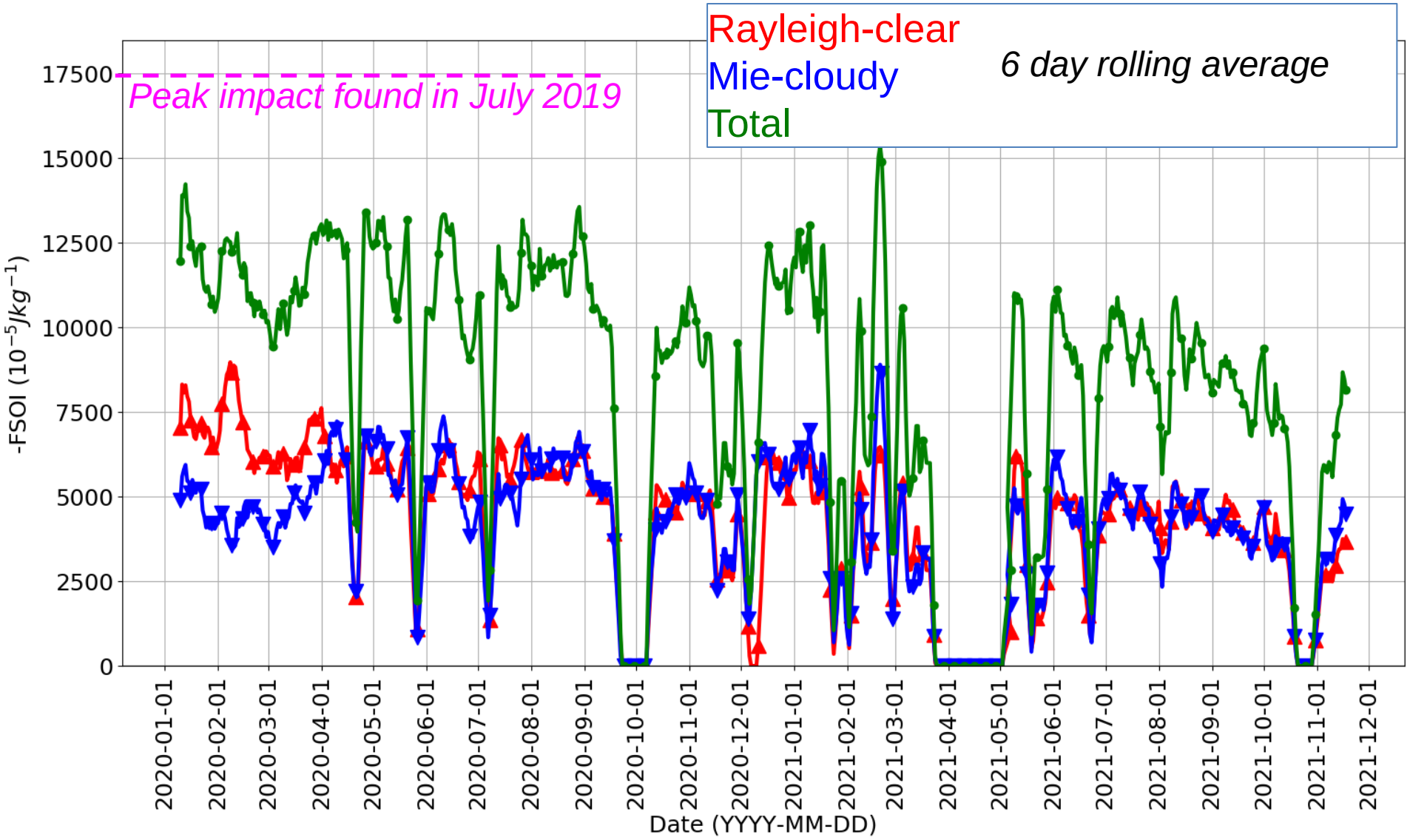
- Aeolus does well for **one satellite instrument**
- Aeolus relative FSOI impact decreases with time:
  - ~5% in July 2019; ~4% in Dec. 2019

Time-series of absolute FSOI for 1st reprocessed dataset (3 July to 30 Dec 2019); split into Mie-cloudy and Rayleigh-clear



Decreasing impact in this period seems most likely to be related to increasing noise as atmospheric signal decreased

Operational FSOI time-series for Mie-cloudy, Rayleigh-clear and combined from 9 January 2020 to 21 November 2021



Still have positive impact:

- But magnitude reducing with time
  - ~2% relative FSOI now, versus ~5% in July 2019;
  - Mostly the Rayleigh-clear noise increase causing this
- Many NRT data gaps

Aeolus NWP impact assessment at ECMWF summary

- **Short-to-medium range forecast impact via OSEs:**
  - 2nd reprocessed dataset OSE shows the **best impact** we have seen so far from Aeolus
  - **Statistically significant and good magnitude** positive impact on **wind, temperature, geopotential and humidity** forecasts in **tropics and polar regions:**
    - Up to **10 days** in tropics and S. Hemi. extratropics at 50 hPa
    - **Even N. Hemi. Extratropics geopotential at 500 hPa is improved to day 4!**
  - **1st reprocessed dataset additional testing:**
    - **Bias correction** of **Rayleigh-clear *vs* temperature** shows benefit at short-range forecasts, but mixed in medium-range. Suggests more impact is possible with improved Rayleigh T, p dependent calibration in L2B processing
- **Short-range forecast range impact via FSOI:**
  - **1st reprocessed dataset FSOI** shows **Aeolus has 3rd largest impact of individual satellite** instruments (similar to IASI on MetOp B) and has **similar impact to radiosondes (a bit less)**
  - Operational **FSOI** shows that Aeolus still provides **some positive impact recently**
    - **But significantly weaker of late**: ~2% in late 2021 *vs* ~5% in July 2019
    - A simplified data assimilation linear relationship **NWP impact** and **Rayleigh signal levels** seems valid; explaining the impact drop

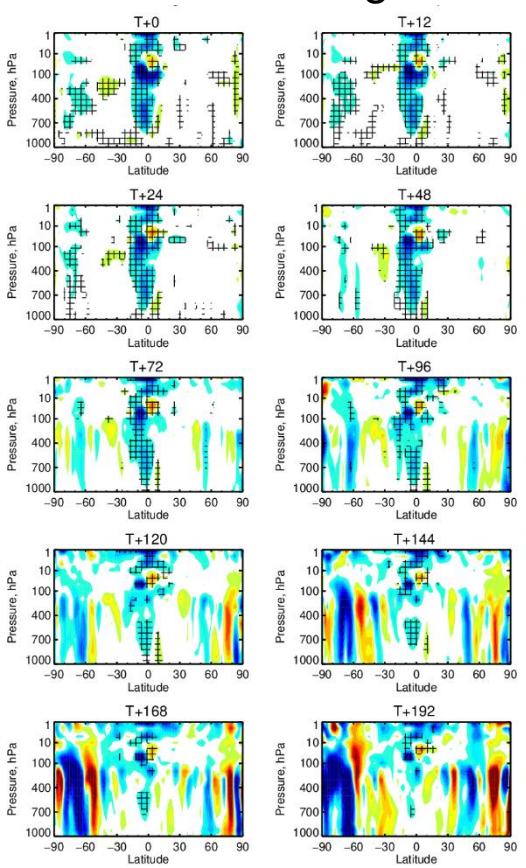
$$1-\frac{\sigma_A}{\sigma_B}=1-\frac{1}{\sqrt{1+\left(\frac{\sigma_B}{\sigma_O}\right)^2}}\approx\frac{1}{2}\left(\frac{\sigma_B}{\sigma_O}\right)^2\propto S.$$

See QJRMS paper

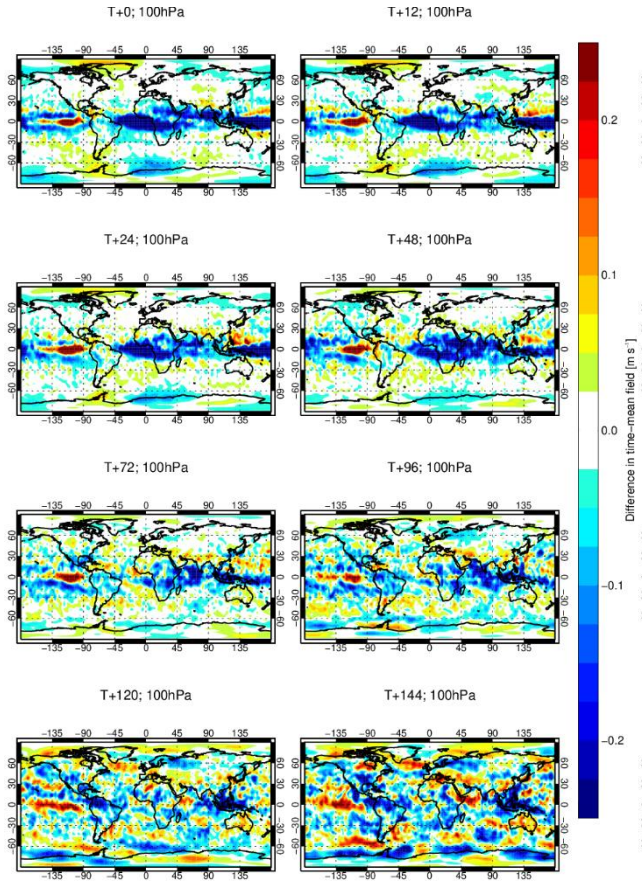
Thanks, any questions?

Mean changes in zonal wind due to assimilating Aeolus – 2nd reprocessed dataset

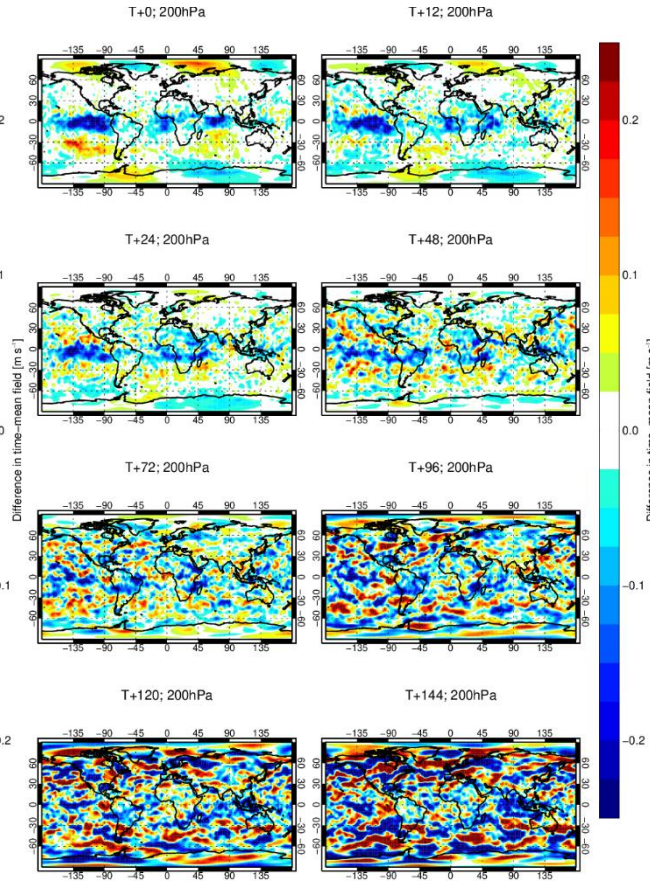
Zonal average



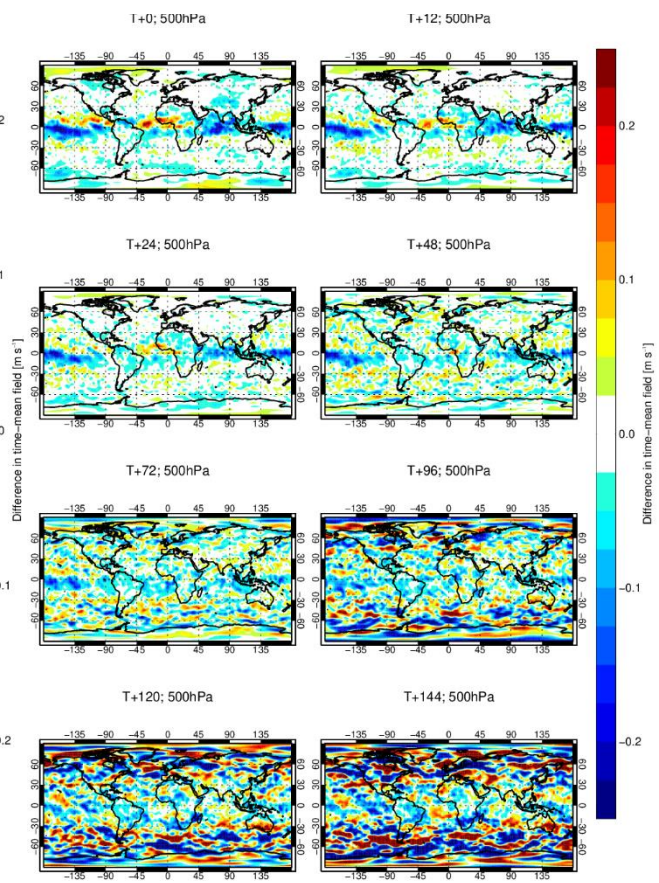
100 hPa



200 hPa

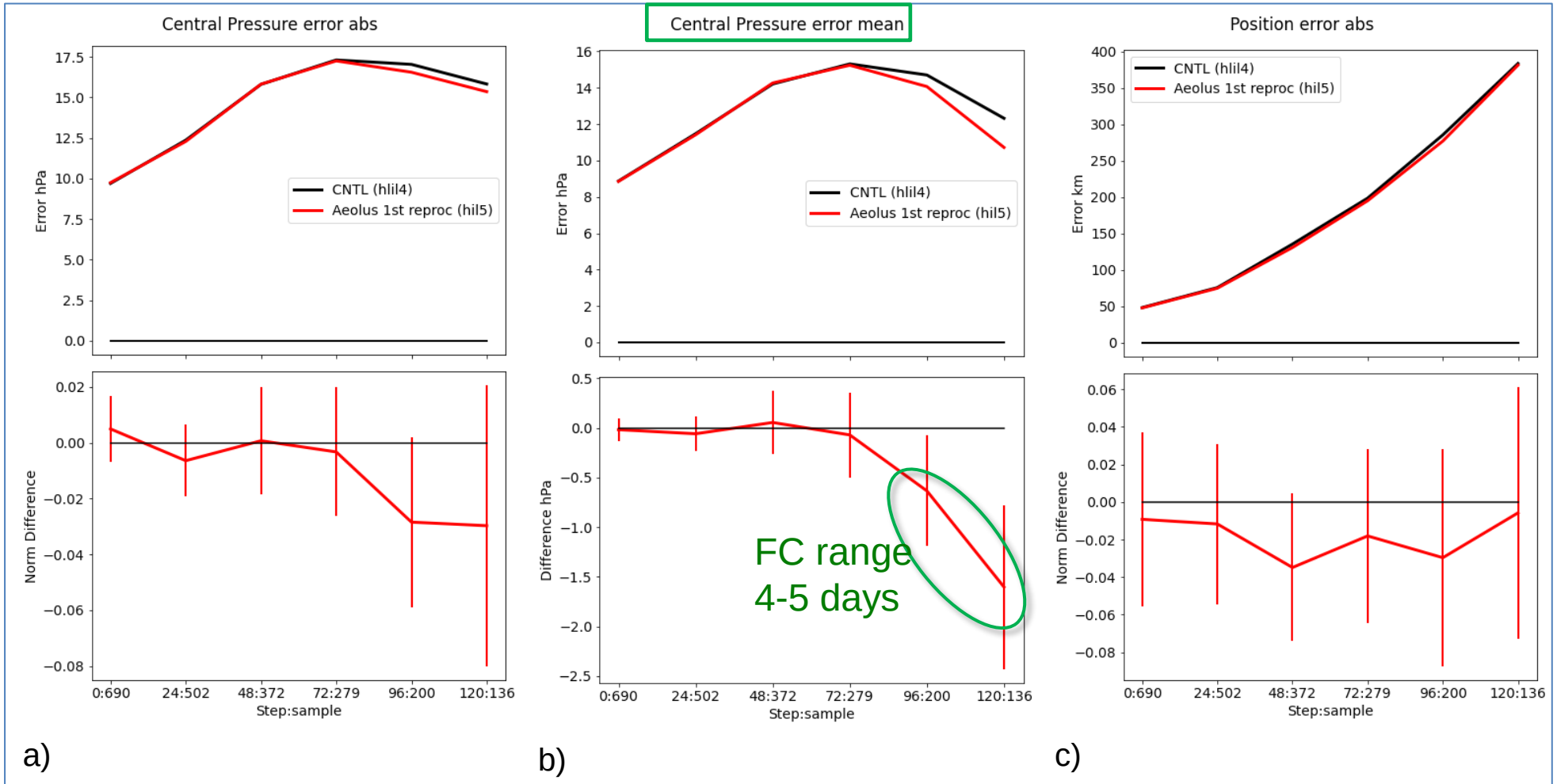


500 hPa



ECMWF's first statistically significant positive impact from Aeolus on tropical cyclones

Verification from 1st reprocessed dataset OSE (Tco399)



- However, these results may not be reliable – impact is sensitive to model resolution (TBC)

Figure 1. The impact on tropical cyclones from assimilating Aeolus (Rayleigh-clear and Mie-cloudy) for the period 29 June 2019 to 31 December 2019. On the upper plots, black lines are the control without Aeolus and red lines are with Aeolus. Negative values on the lower plots indicate a reduction in error from assimilating Aeolus. Verified against ?. a) central pressure absolute error (hPa) and normalised difference b) central pressure mean error (hPa) and difference (hPa) c) absolute position error (km) and normalised difference. Plots produced by a tool of Linus Magnusson (ECMWF).