# Lessons for EarthCARE from the assimilation of cloud-affected Aeolus backscatter

Mark Fielding

Marta Janisková, Karen Henry,
Will McLean, Angela Benedetti

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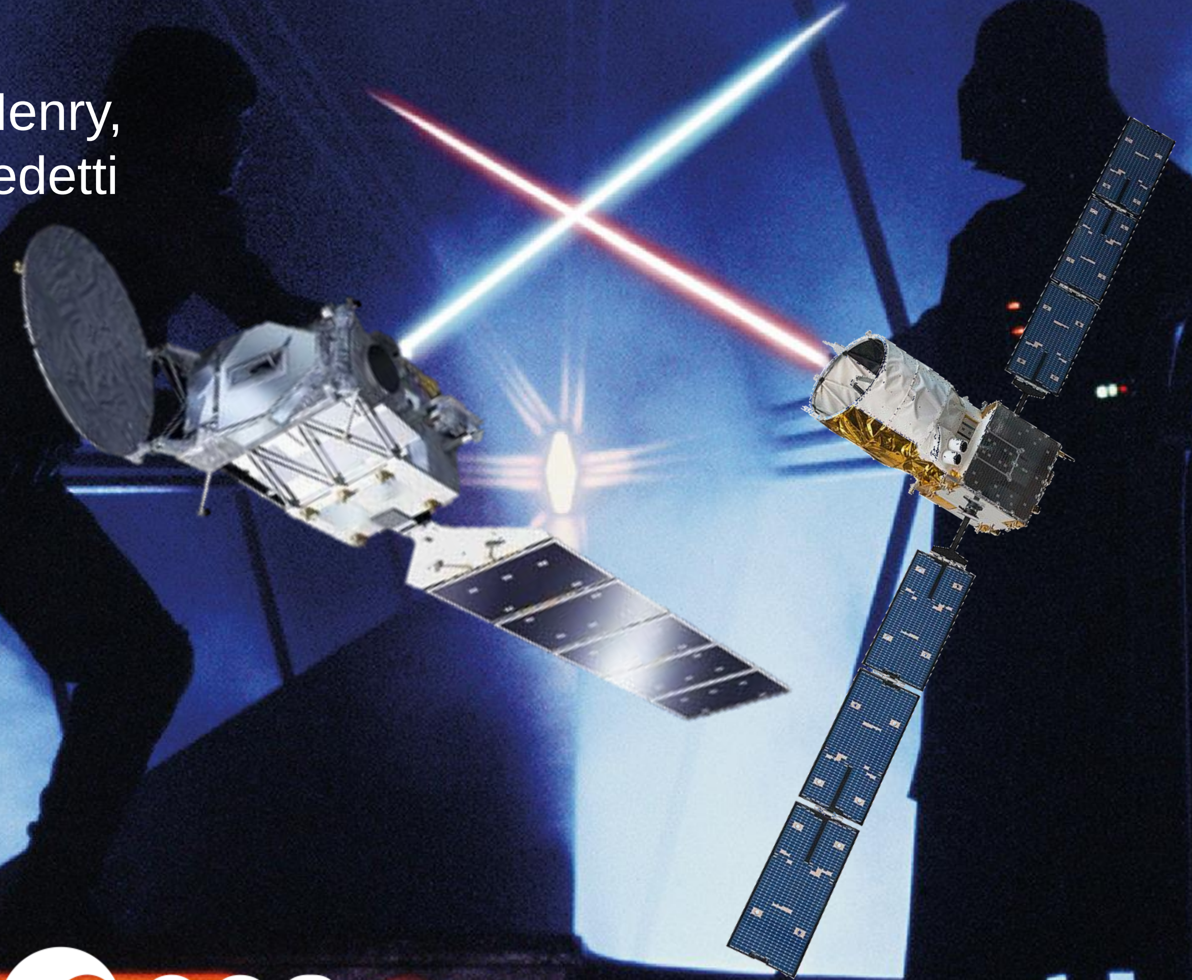

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# ATLID and ALADIN are on the same side!

- Previously, all cloud lidar assimilation experiments at ECMWF have used CALIPSO observations as a proxy for EarthCARE data.
- Aeolus ALADIN lidar is technically much closer related to EarthCARE's ATLID than the CALIPSO lidar, despite its primary goal of measuring line-of-sight winds.
- Several activities investigating the benefit of Aeolus aerosol backscatter (e.g., AEOLUS DISC), but, so far, cloud has mainly been seen as noise that must be removed.

➢ Can Aeolus observations be used to prepare for ATLID assimilation?

➢ How useful is Aeolus cloud backscatter for NWP?

➢ Can Rayleigh backscatter be assimilated?

# Vertical resolution and pointing angle are the major differences between ATLID and ALADIN

| Characteristic | EarthCARE ATLID | Aeolus ALADIN |
|---|---|---|
| Specification | 3° off-Nadir<br>355 nm<br>0.62 m diameter telescope<br>35 µrad receiver field of view | 37.5° off-Nadir<br>355 nm<br>1.50 m diameter telescope<br>19 µrad receiver field of view |
| Altitude | 400 km | 400 km |
| Resolution | 103 m vertical<br>0.285 km horizontal<br>0.03 km footprint | 500 m - 1000 m vertical<br>~5 km horizontal<br>0.009 km footprint |
| Misc. | High-spectral-resolution receiver with Rayleigh and Mie co-polar and total cross-polar channels | High-spectral-resolution receiver with Rayleigh and Mie copolar channels only |

…requires some adaptations to observation operator

## Observation-side

*Data products and pre-processing*

**ATLID**

Initially L2A total attenuated backscatter. Capability for individual HSRL channels

**ALADIN**

Mie attenuated backscatter

Rayleigh attenuated backscatter

*Observation screening*

ATLID: Comprehensive, based upon CALIPSO studies and L2A cloud mask.

ALADIN: Basic screening on FG departures and minimum backscatter values

*Observation errors*

ATLID: Error inventory approach, combining representativity error*, instrument error and forward model error

ALADIN: Fixed value of 10 dB

**see Fielding and Stiller 2019, JGR*

## Model-side

*4D-Var*

*Microphysical assumptions*

**ATLID**

**JOINT**

**ALADIN**

PSD: Field et al., 2007

Single scattering properties: Baran?? 2010 mixture with fixed lidar ratio (consistent with CAPTIVATE retrievals)

*Observation operator*

Triple column approach accounting for sub-grid condensate variability and cloud overlap. Platt approximation for multiple scattering. + adaptations for ALADIN

*Bias correction*

ATLID: Initially none, then climatological based upon temperature and region.

ALADIN: None

*See Fielding and Janisková 2020, QJRMS*

# Adapting the observation operator for ALADIN

Optical depth due to clouds

Platt coefficient

Optical depth due to gases

Apparent backscatter

$$\beta'(r) = (1-\delta)\beta(r)e^{\frac{-2\,(\eta\tau_{cloud}+\tau_{gas})}{\cos\theta}}$$

Slant angle

Depolorization ratio

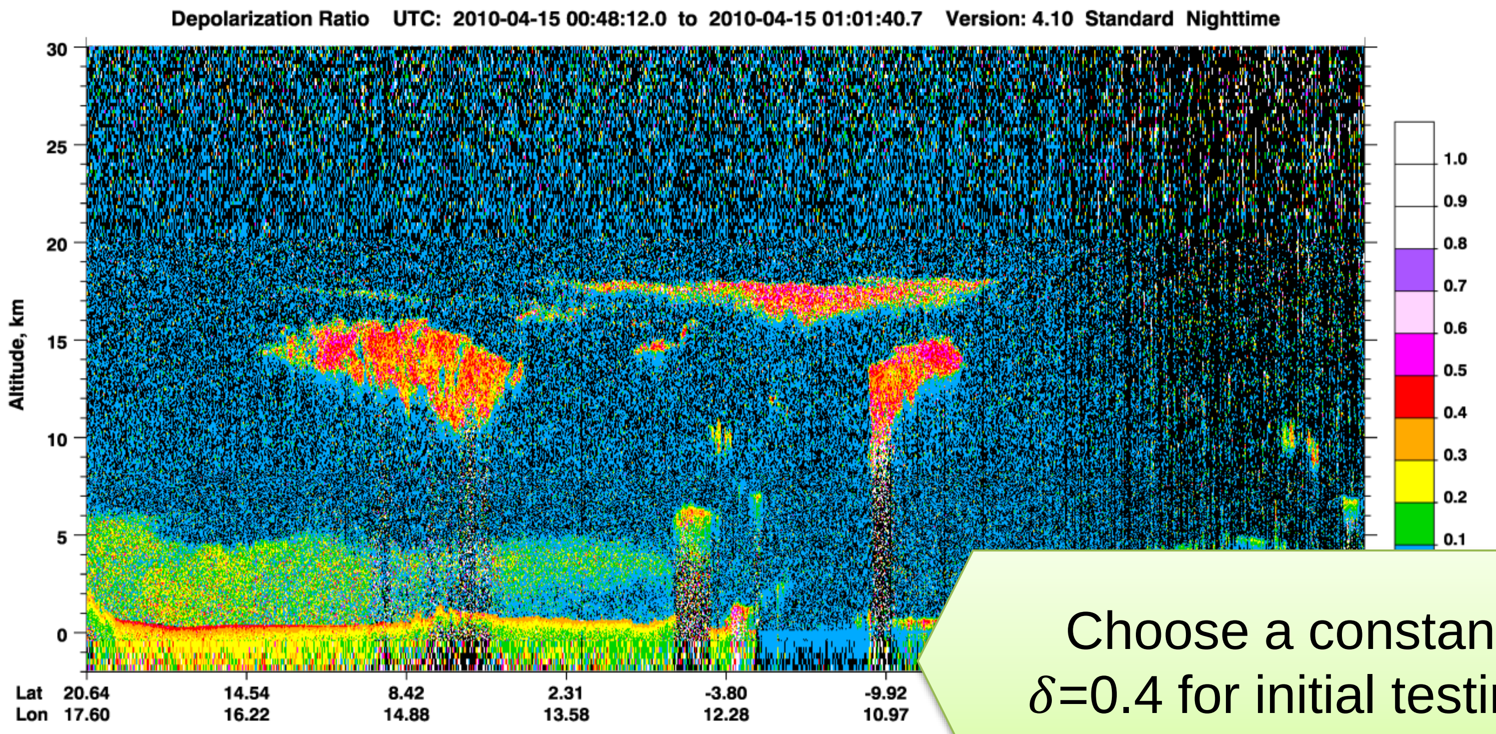
Unattenuated backscatter

Modifications for ALADIN

# Determining the depolarization ratio

- Unlike spherical particles, such as water droplets, ice particles are generally strongly depolarizing.
- Depolorization ratio can be measured empirically or computed numerically from assumed ice particle shapes.

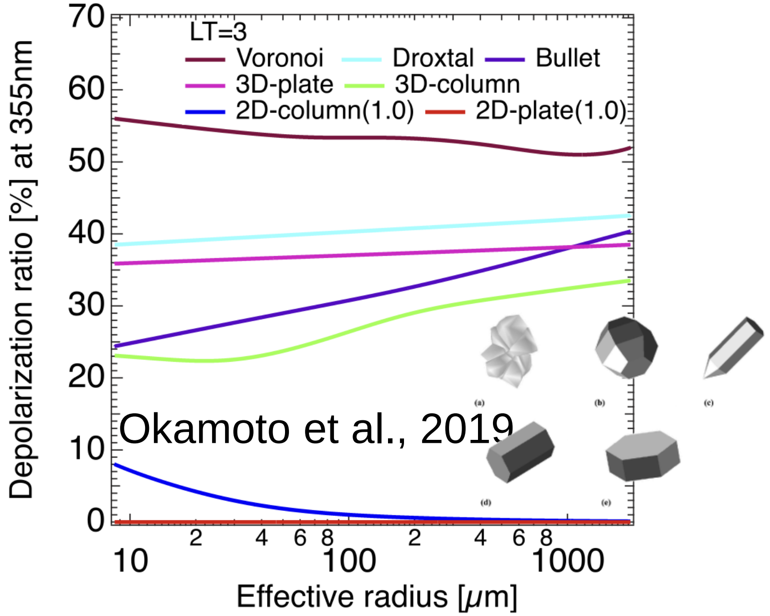
Observed using CALIPSO (532 nm)

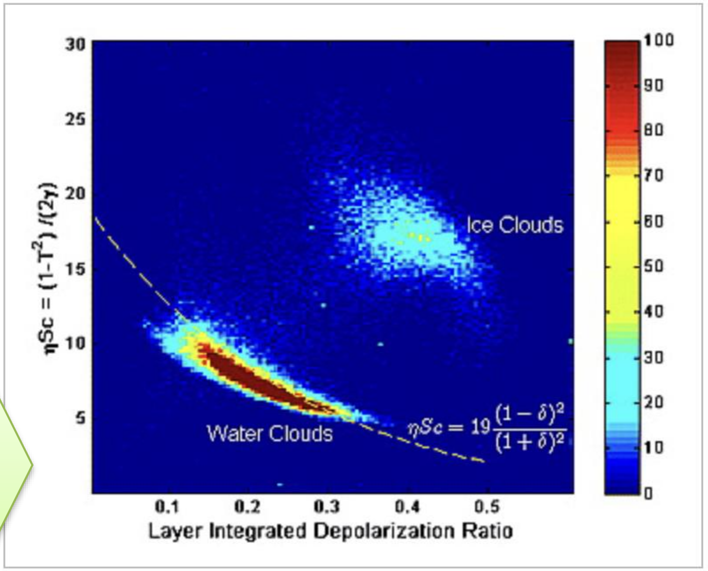



Choose a constant $\delta$=0.4 for initial testing

Courtesy NASA (CALIPSO user guide)

Theoretical (355 nm)

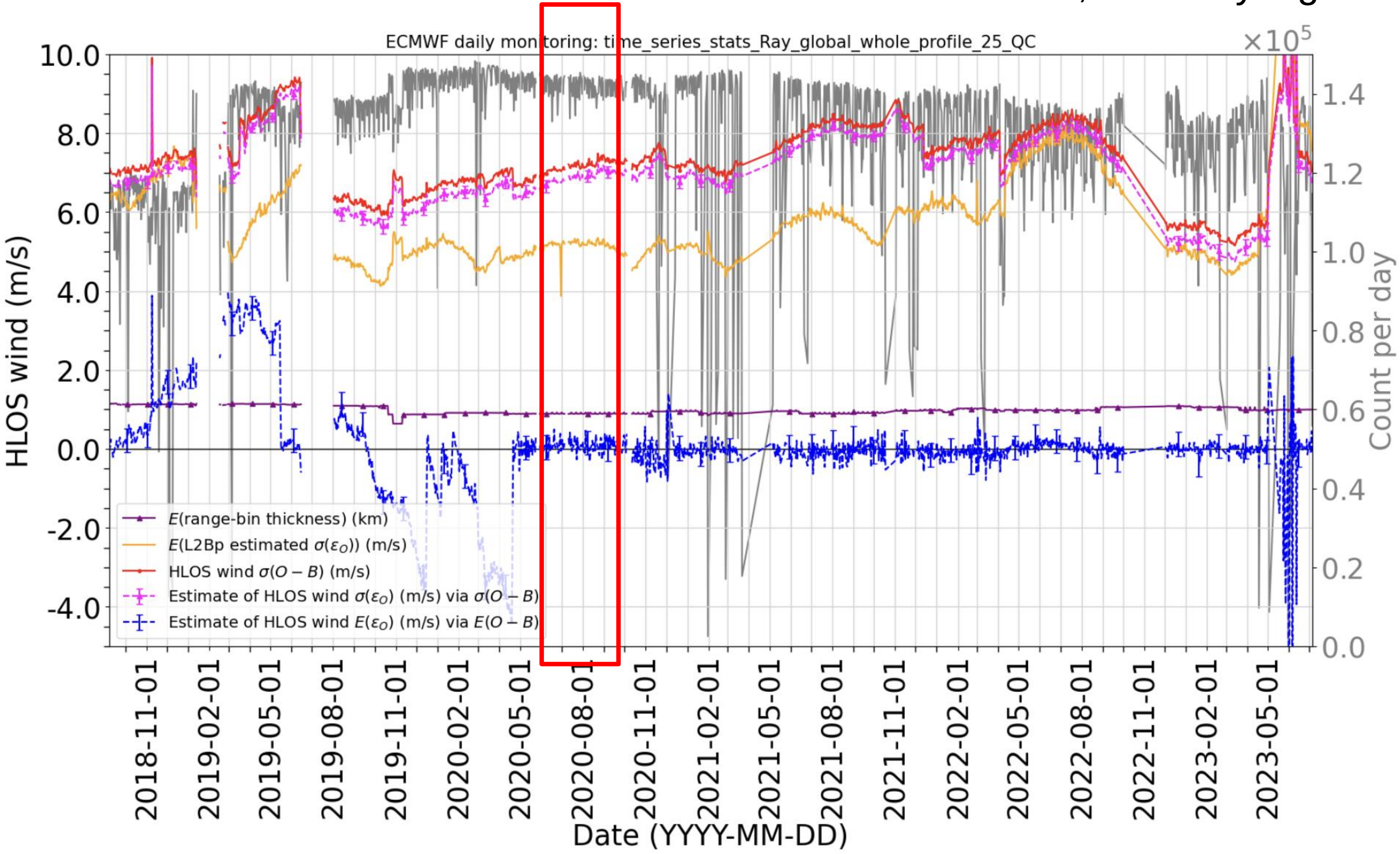



Hu, 2007

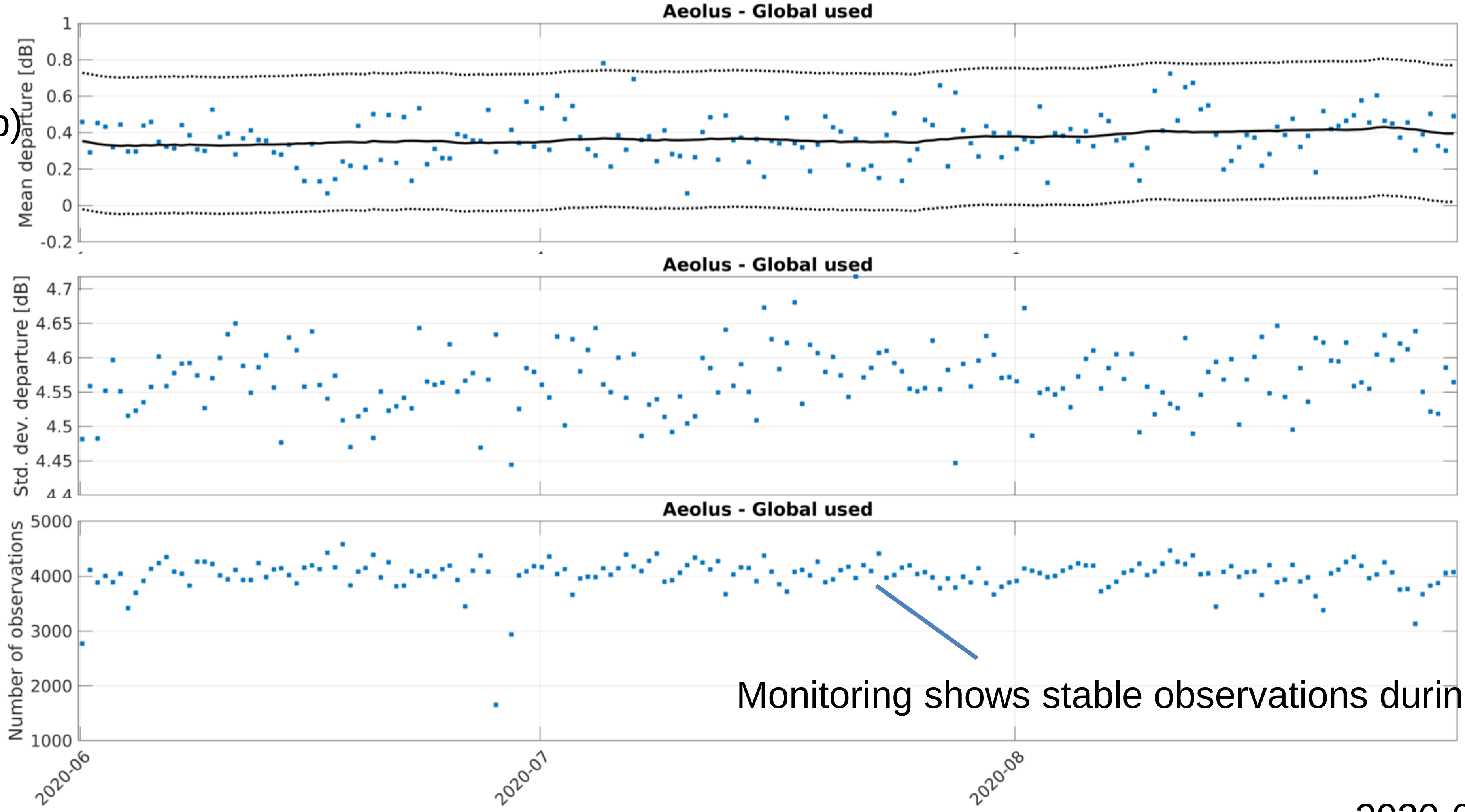
# Choosing test period --- ECMWF monitoring of Aeolus HLOS winds

Mid-mission: lower errors, relatively high laser energy




Rennie and Isaksen, 2023

# 12-hourly monitoring of Aeolus L2A Mie attenuated backscatter




mean (FG dep) (dB)

s.d. (FG dep) (dB)

Number of observations

+ 3 s.d.

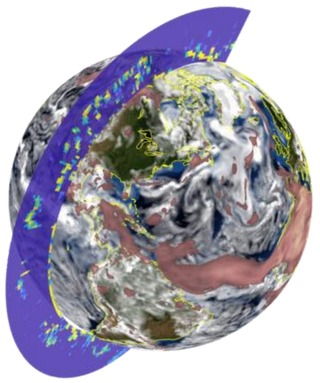
- 3 s.d.

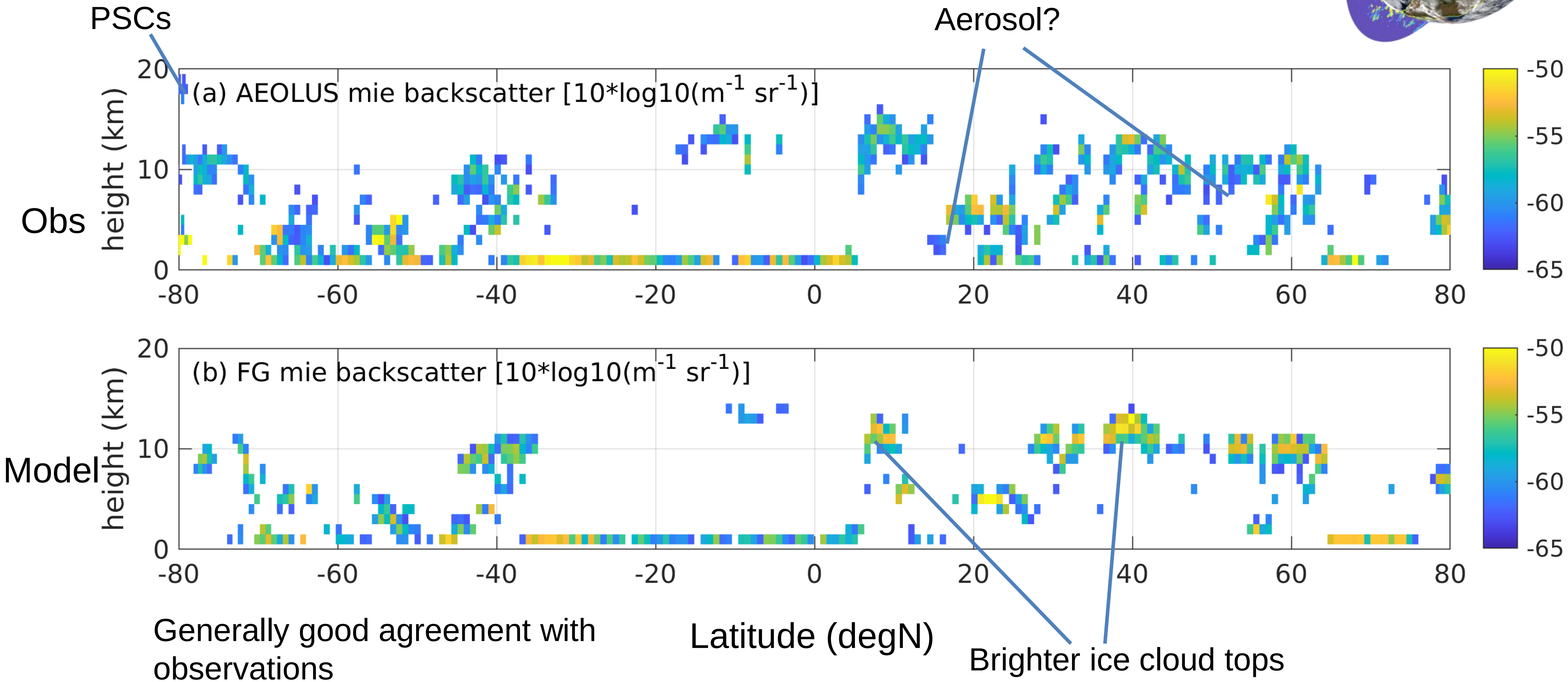
Monitoring shows stable observations during period

2020-06-01

2020-09-01

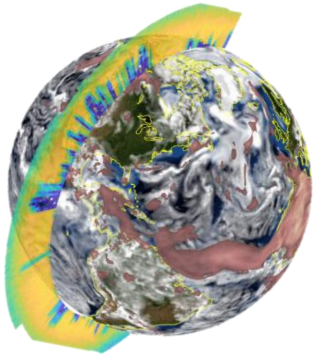
# Aeolus orbit– 1st June 2020
# Mie attenuated backscatter

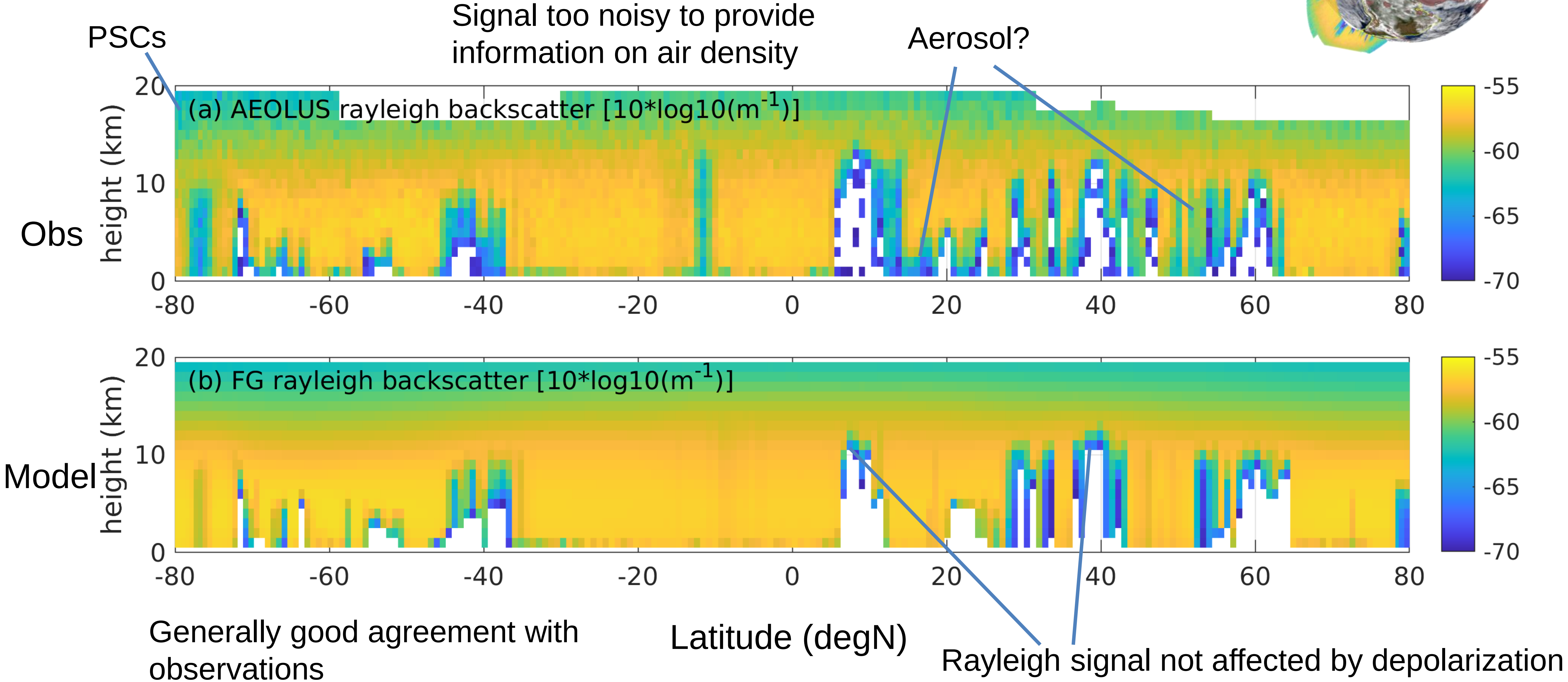





Generally good agreement with observations

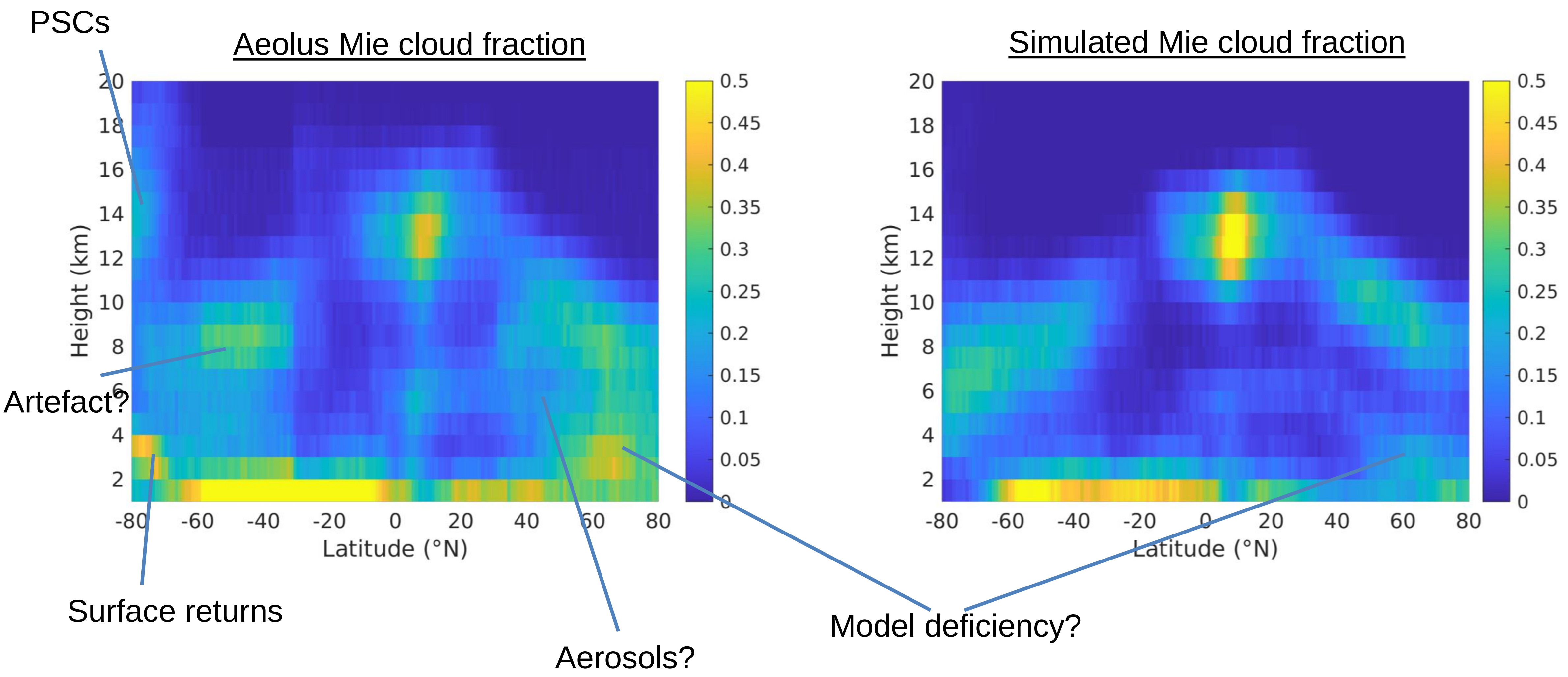
# Aeolus orbit– 1st June 2020
# Rayleigh attenuated backscatter






Generally good agreement with observations

# Climatology of observed and simulated cloud fraction – June 2020

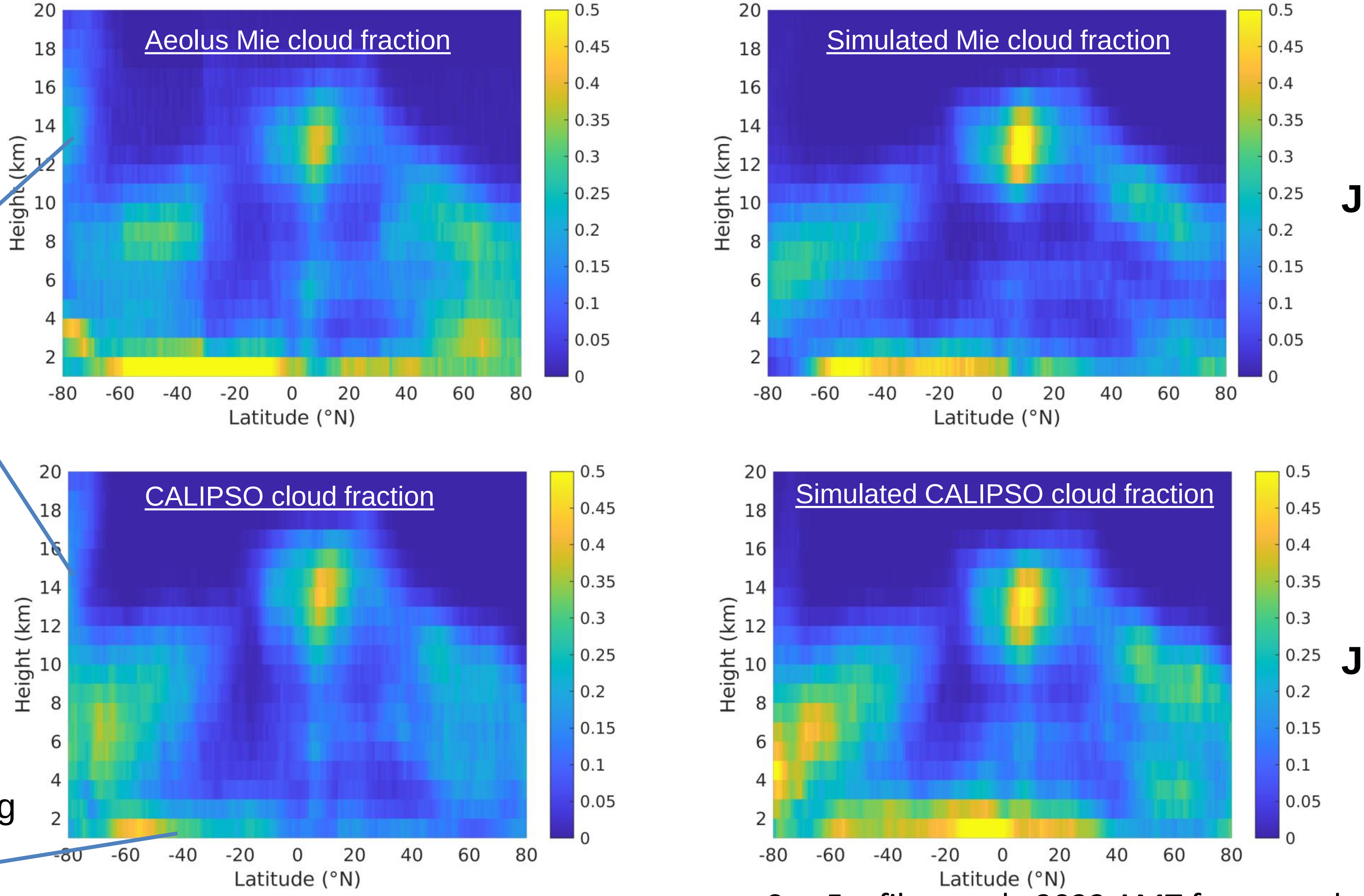


# Comparison of Aeolus and CALIPSO observed cloud amount

More noise in Aeolus backscatter?

PSCs brighter at 355 nm

More screening in CALIPSO obs?




**June 2020**

**June 2010**

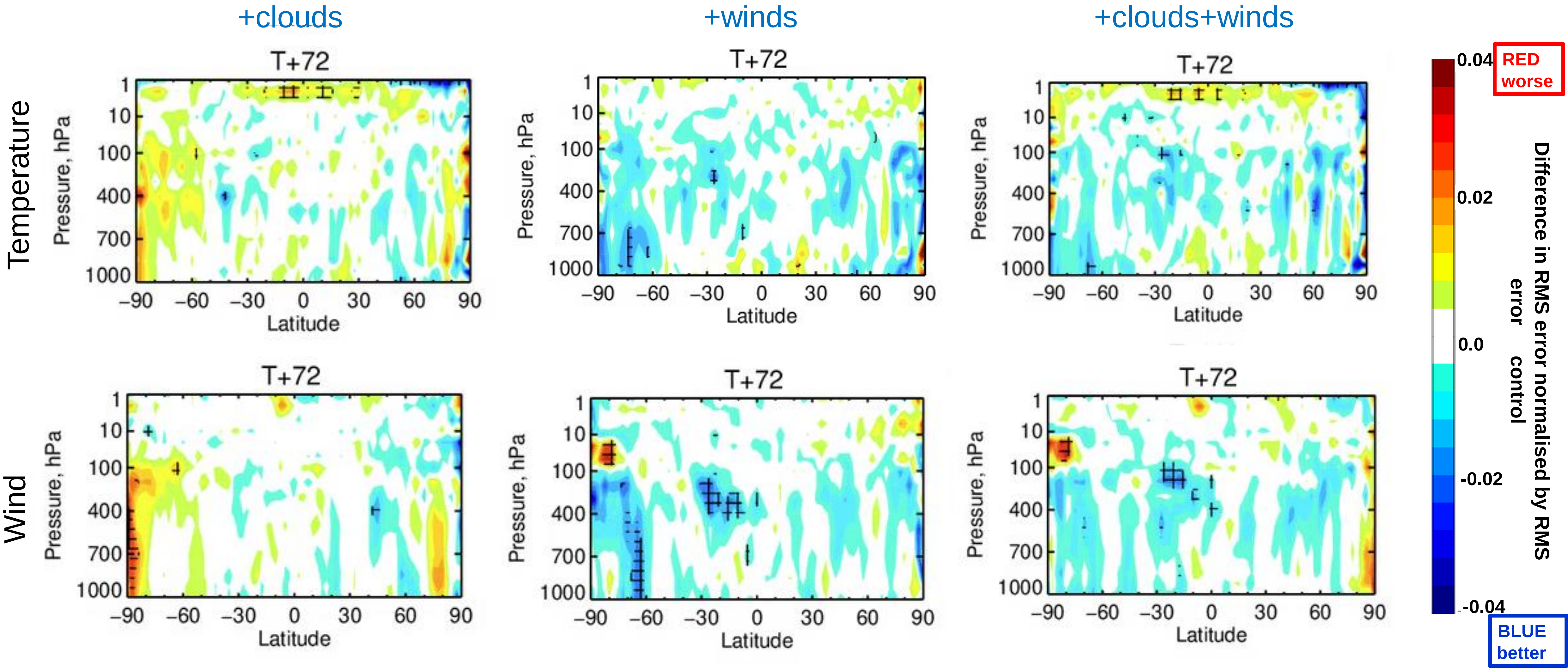
See Feofilov et al., 2022 AMT for more detailed analysis

# 4D-Var experiment setup

- CY48R1 4D-Var experimentation using a horizontal resolution of TCo639 spectral truncation (corresponding to ~ 18 km on a cubic octahedral grid) and 137 levels:
  - 3-month period: 1 June 2020 – 31 August 2020
- Measurements of L2A Mie and Rayleigh attenuated backscatter (at 355 nm, ALADIN) superobbed to (O160-> ~72 km) and 1 km vertical heights.
- Performed experiments:
  - Control – reference run, run with all regularly assimilated observations except Aeolus winds
  - +winds – operational configuration including Aeolus HLOS winds – see Rennie et al., 2021
  - +clouds – experimental run including attenuated Mie and Rayleigh attenuated backscatter lidar observations on top of other regularly assimilated observations
  - +winds+clouds - experimental runs including attenuated Mie and Rayleigh attenuated backscatter lidar observations and HLOS winds

Rennie, et al., 2021: The impact of Aeolus wind retrievals on ECMWF global weather forecasts. *QJRMS*

# Assimilating Aeolus cloud obs. broadly neutral on forecasts of large-scale variables



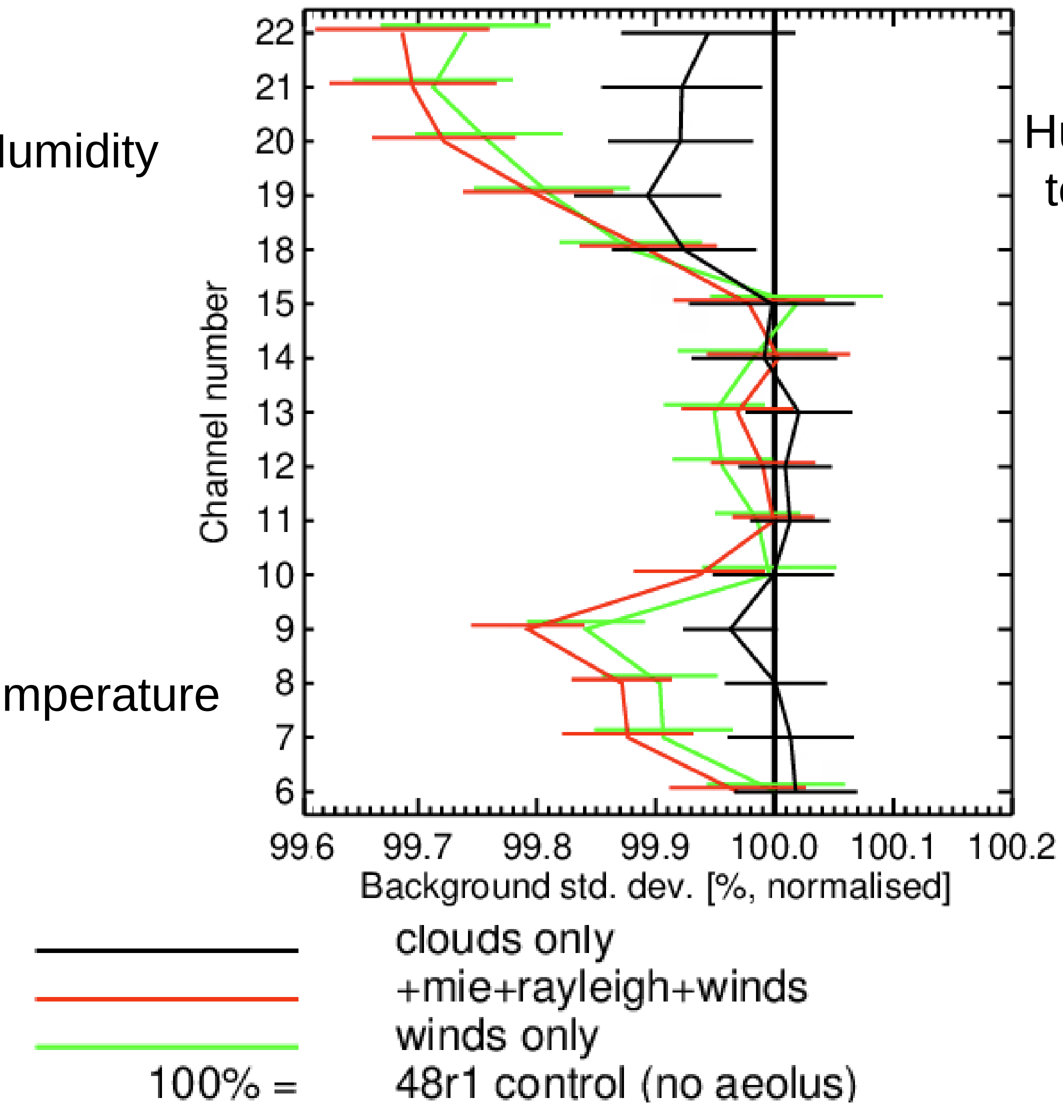

3-month period: 1 June 2020 – 31 August 2020

# Assimilating Aeolus cloud Mie and Rayleigh backscatter has slight positive benefit on microwave all-sky obs!

**ATMS**

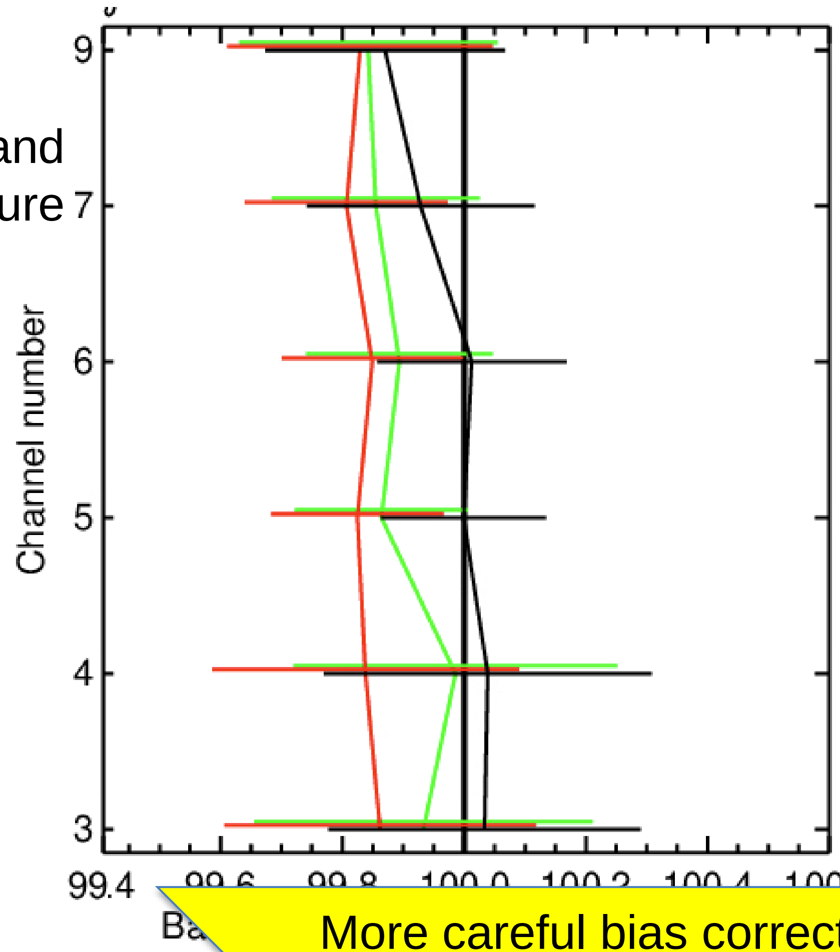
Humidity

Temperature




**MWRI**

Humidity and temperature




More careful bias correction and observation error tuning should increase impact

# Summary

- Aeolus cloud backscatter observations have been assimilated into a global model for the first time!
- Initial results show impact is broadly neutral, but slight additional positive benefit when simultaneously assimilating winds and cloud information.
- Cloud observations from Aeolus could be useful for model evaluation – Aeolus sees clouds at different point in diurnal cycle. PSCs are clearly visible!
- More careful cloud/aerosol screening required for comparison with CALIPSO

  - ➢ Can Aeolus observations be used to prepare for ATLID assimilation? YES
  - ➢ How useful is Aeolus cloud backscatter for NWP? YES
  - ➢ Can Rayleigh backscatter be assimilated? YES (but more analysis required)

☺