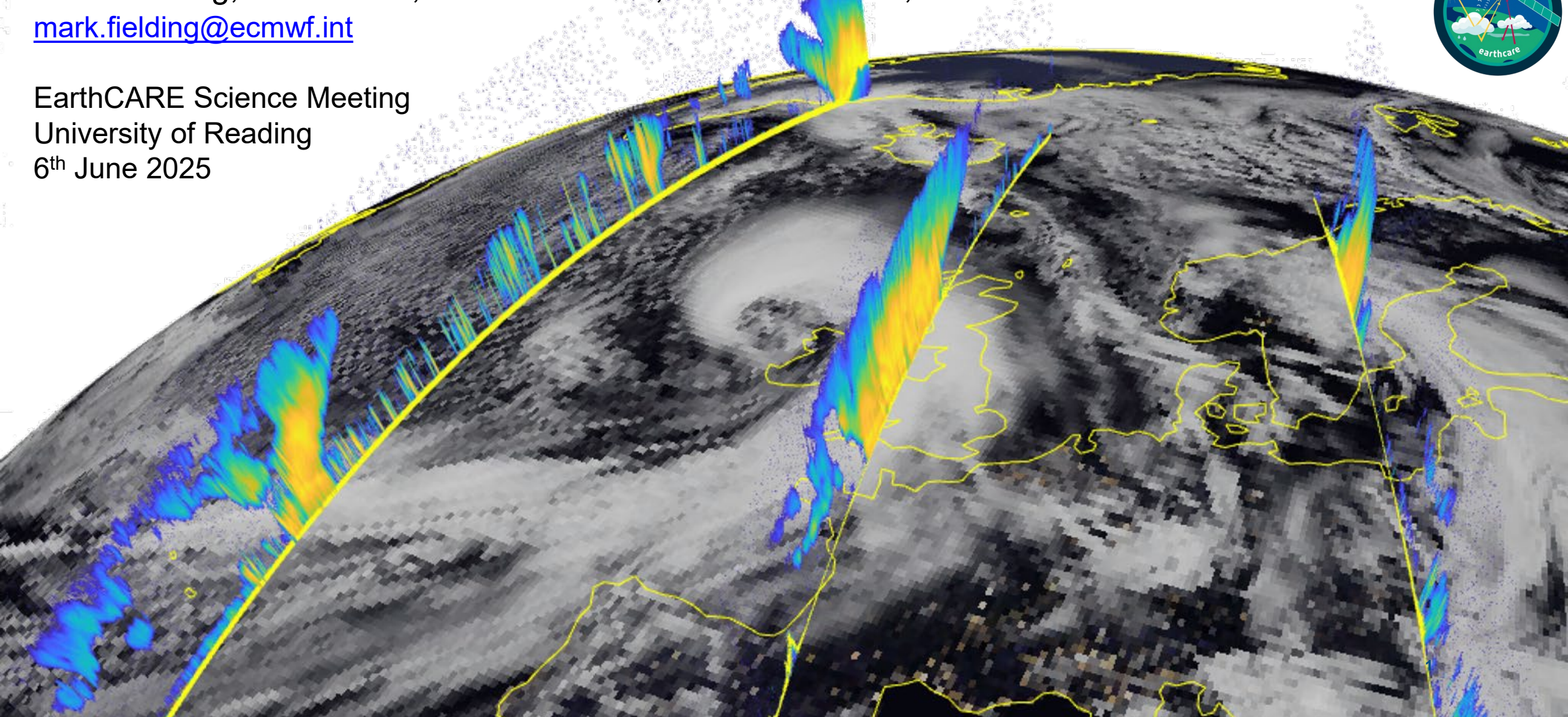# Data assimilation of EarthCARE at ECMWF: initial impacts on global NWP and atmospheric composition forecasts
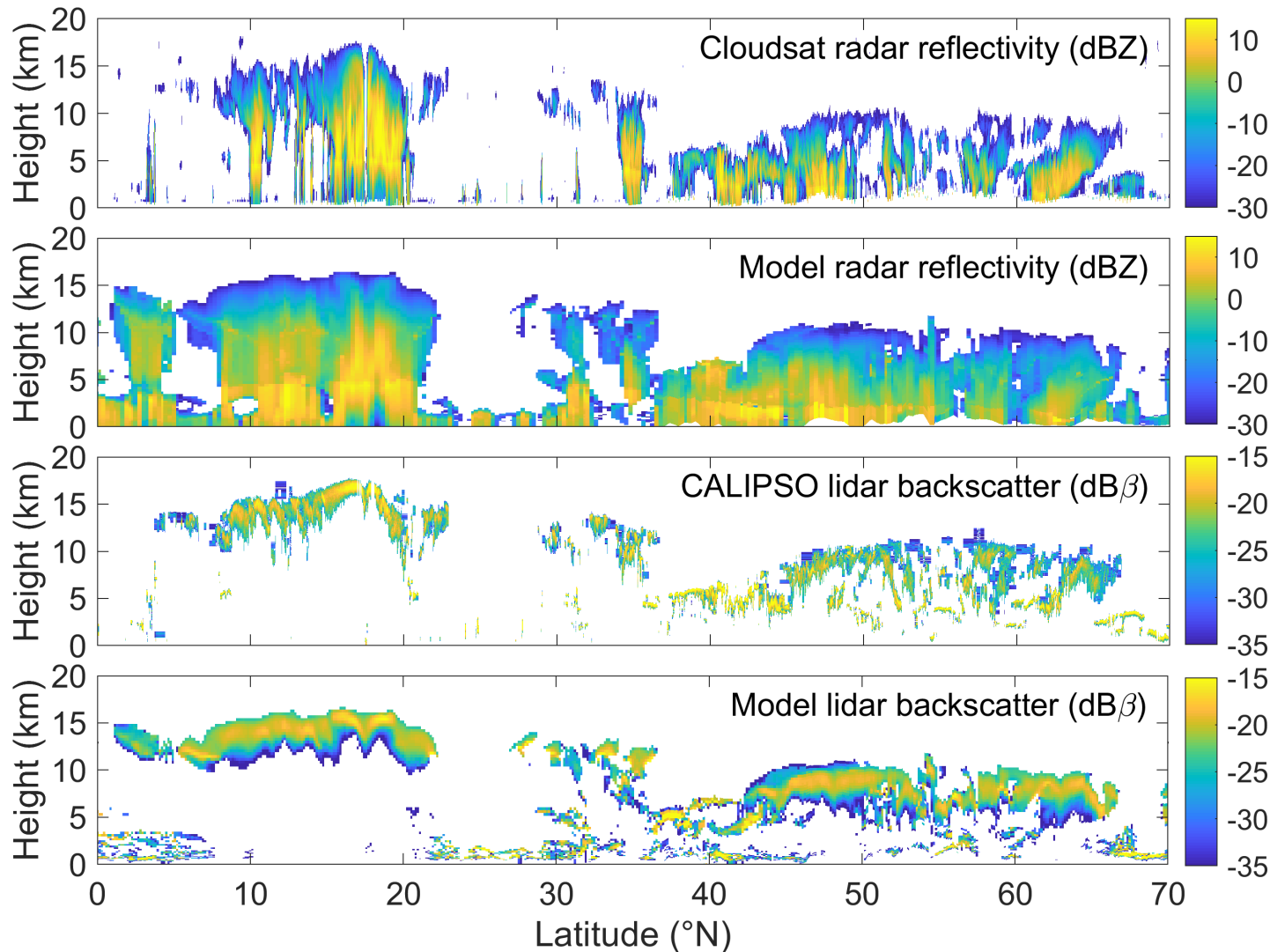
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EarthCARE Science Meeting
University of Reading
6th June 2025

ECMWF

Space-borne cloud radar and lidar provide a wealth of high-resolution information on the horizontal and vertical structure of clouds

Fielding and Janisková, 2020 (*QJRMS*)

EarthCARE will be the first satellite mission to provide cloud radar and lidar observations in NRT.

Potential benefits of including spaceborne cloud radar and lidar in an NWP assimilation system:

1) Direct improvement in forecasts through more accurate model initial conditions.
2) Indirect improvement in forecasts model evaluation.
3) Monitoring of satellite data against model to feed back to space agencies.

Data assimilation of clouds at ECMWF in a nutshell

- Adjust control vector, **x**, to minimize 4D-Var cost function, $J(\mathbf{x})$:

Penalty for departure from background

$$J(x) = \frac{1}{2}\left(x - x^{\mathrm{b}}\right)^T \widetilde{\mathbf{B}}^{-1}\left(x - x^{\mathrm{b}}\right) + \frac{1}{2}d^T\widetilde{\mathbf{R}}^{-1}d$$

Cost function

Penalty for departure from observations

$$d = y - b - H(x)$$

Observations   *Model equivalent*

Bias correction

- Clouds are inferred from temperature and humidity via diagnostic cloud scheme; currently no cloud variables in control vector.

EarthCARE coverage in 12 hours (one data assimilation window)

20250316 2100 UTC - 20250317 0900 UTC
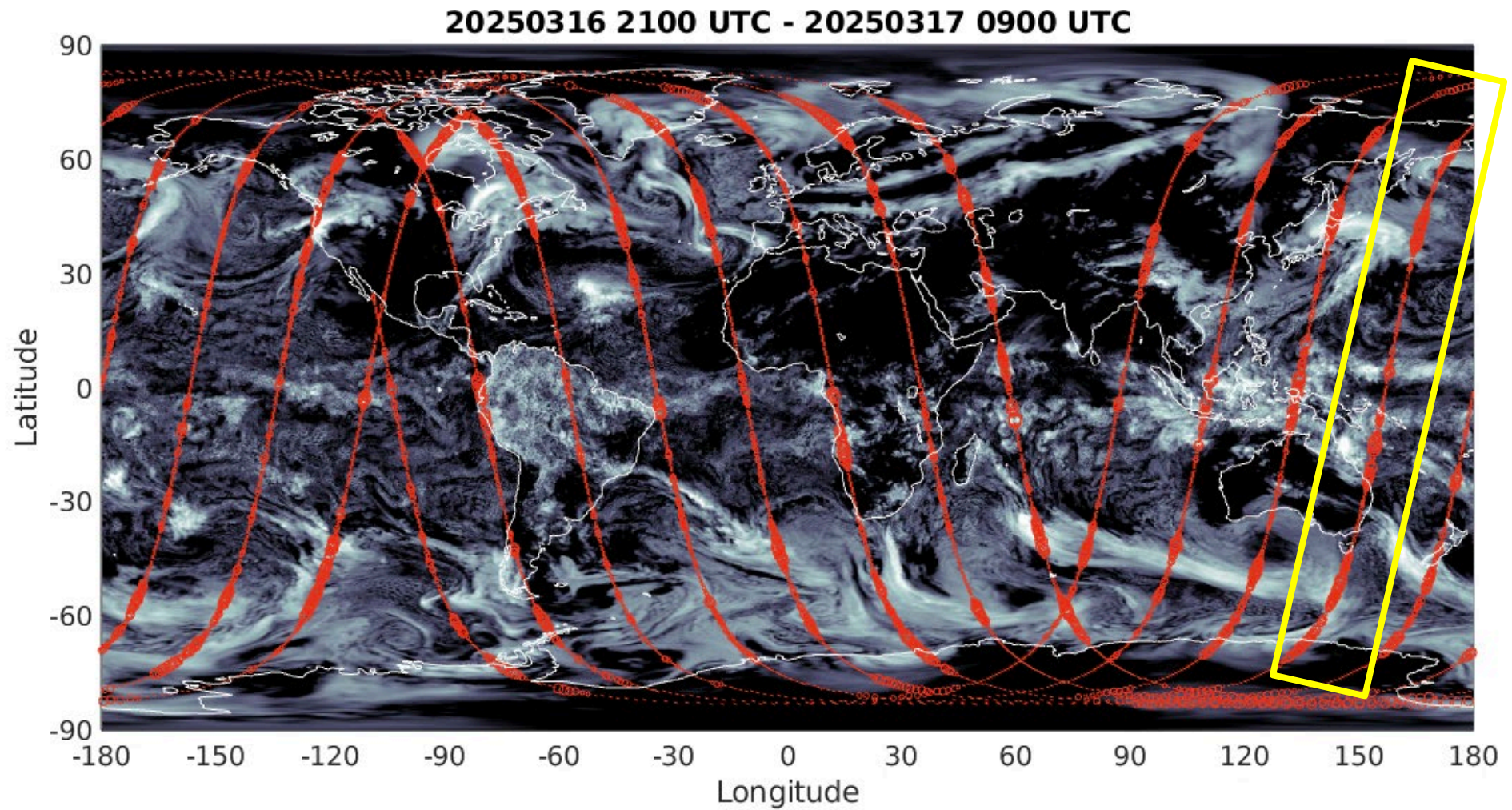
y

EarthCARE L1B reflectivity 'superobbed' to ~ 40 km
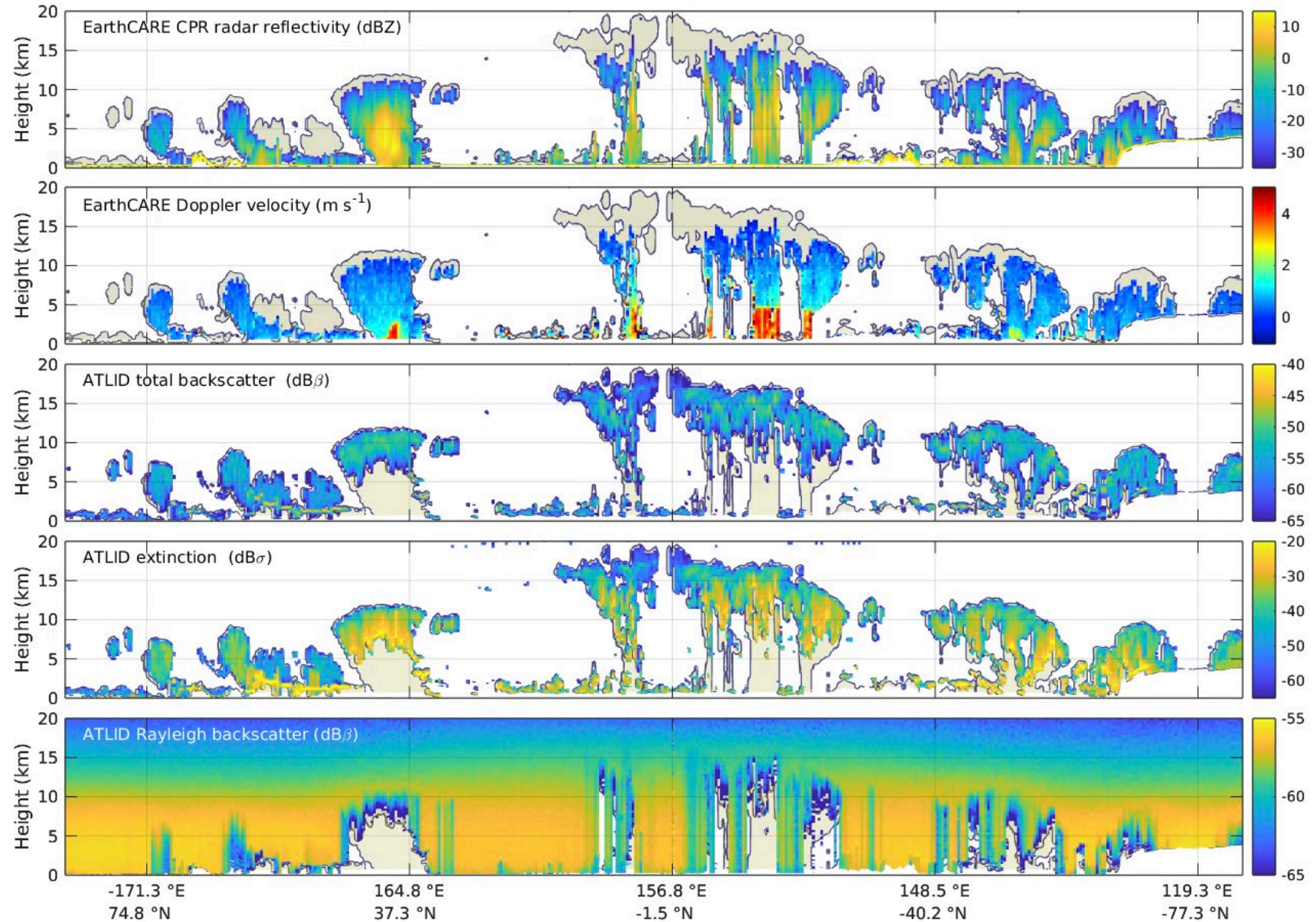
$H(x)$

'First Guess' model equivalent

b

Bias correction

$\widetilde{R}$

Observation error

Screening

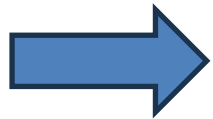EarthCARE CPR radar reflectivity (dBZ)

FG radar reflectivity (dBZ)
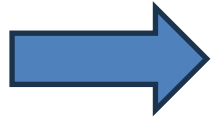
Bias correction (dB)
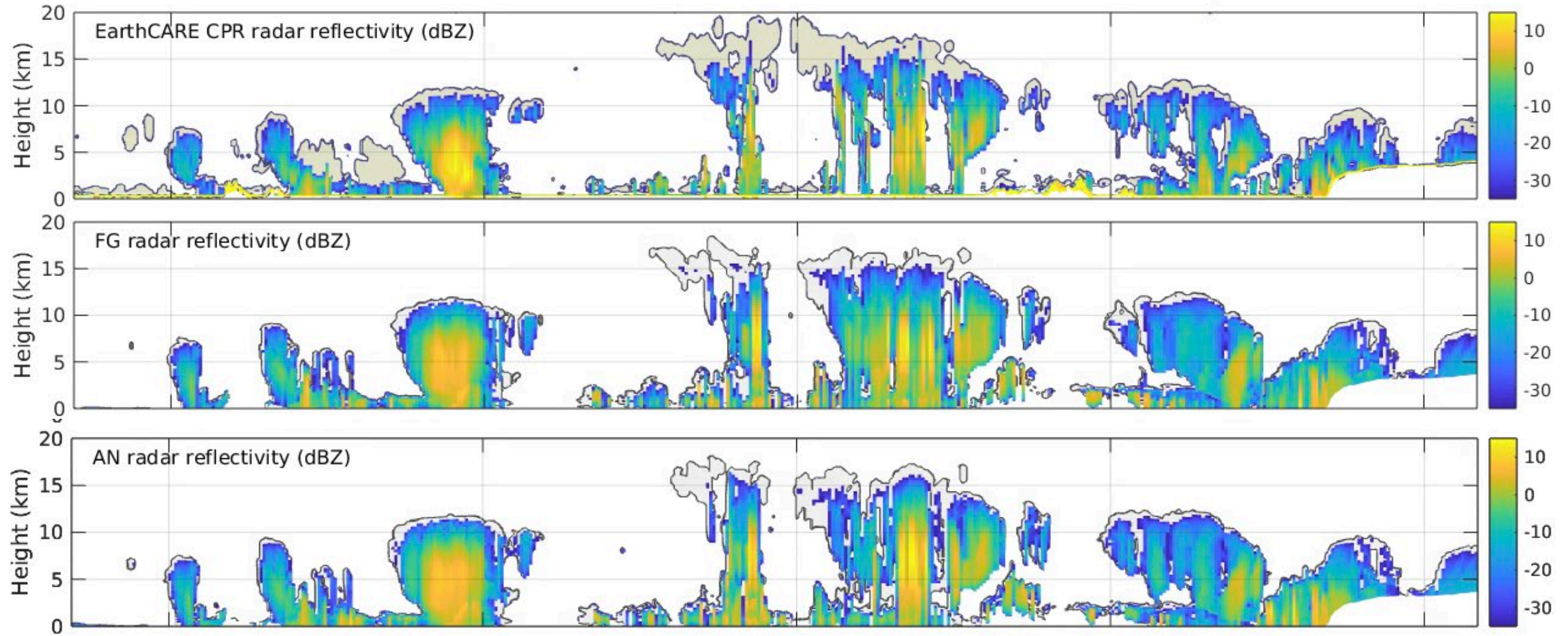
Observation error (dB)
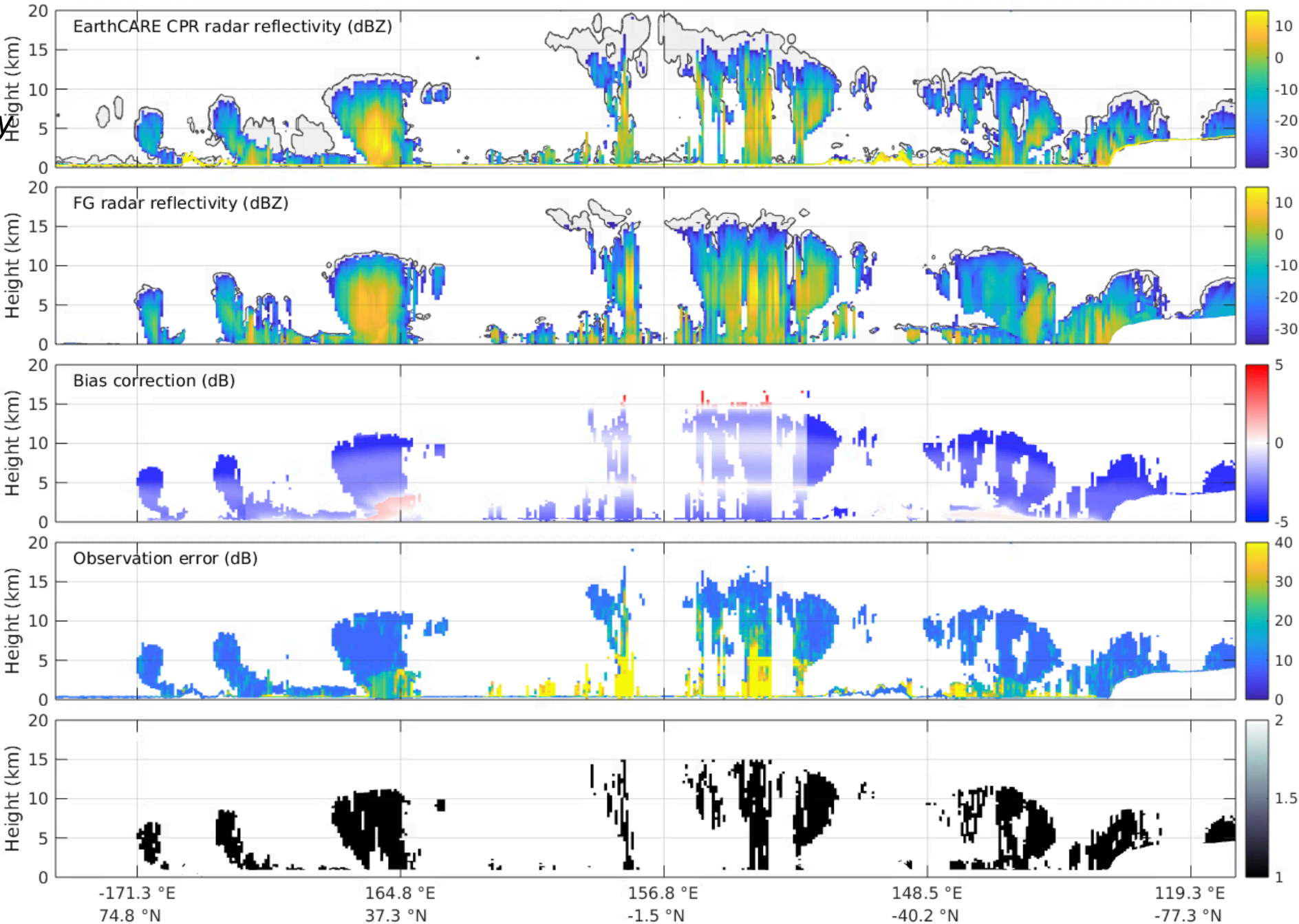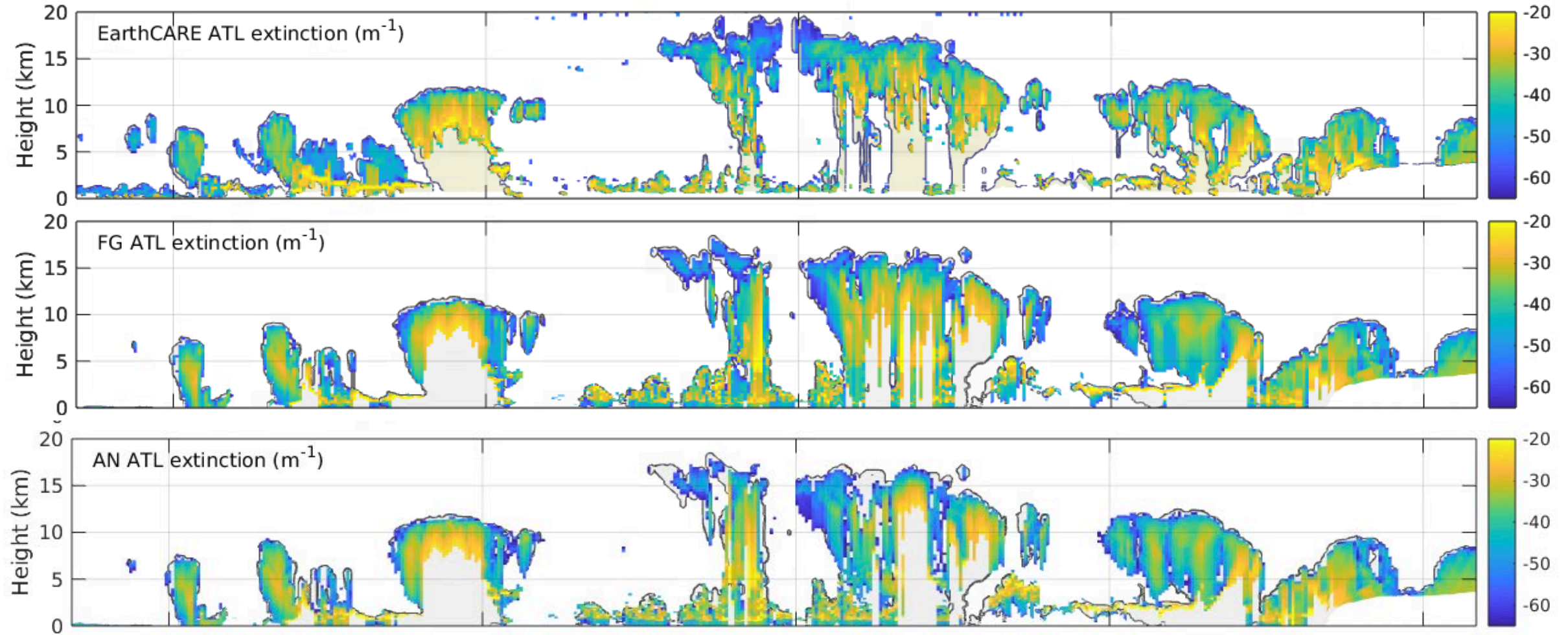
Which observations should we assimilate?

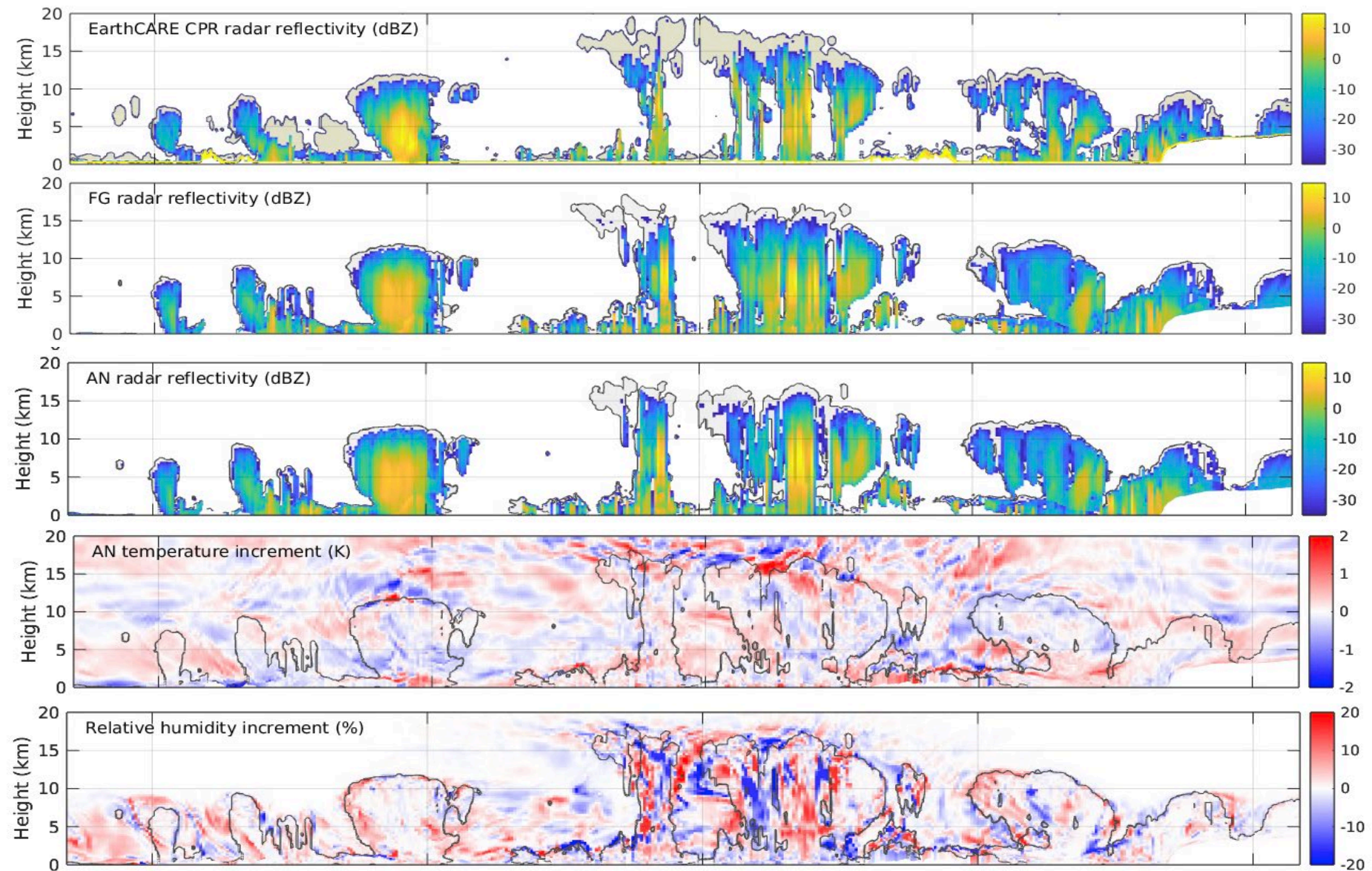# Which observations should we assimilate?
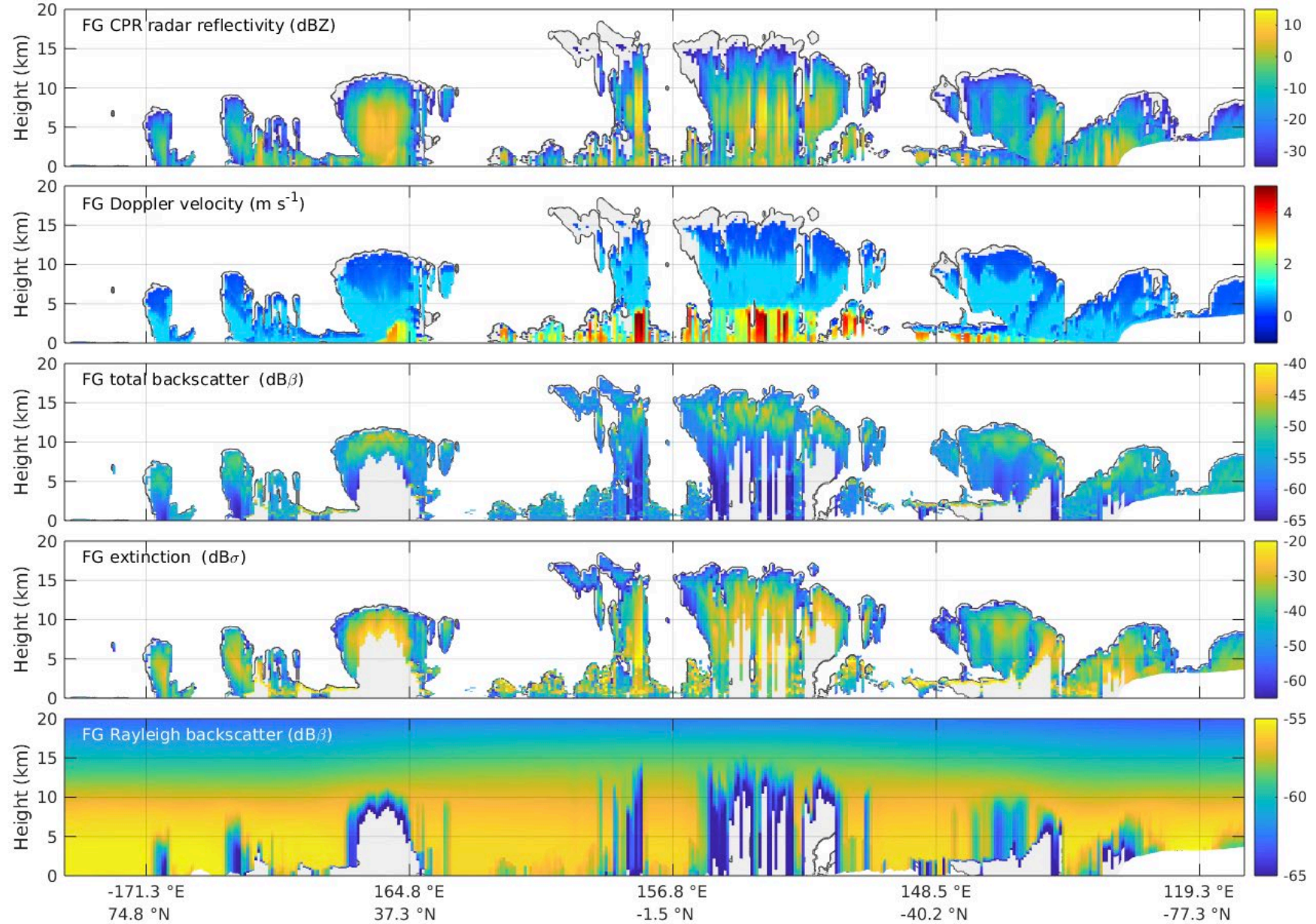
How close does the analysis get to the observations?

# How close does the analysis get to the observations?

Analysis increments of temperature and humidity are largest in tropics

4D-Var experiment setup

- CY49R1 4D-Var experimentation using TCo639 grid (~18 km) for 2.5-month period between 17 March 2025 – 1 June 2025.

- Measurements of CPR L1B radar reflectivity and ATLID L2 **extinction** (at 355 nm) superobbed to (O320-> ~38 km) and model vertical levels

- Investigate impact of CPR+ATLID, CPR only, ATLID only

<u>After subtracting model bias compared to CloudSat</u>

EarthCARE CPR L1B reflectivity
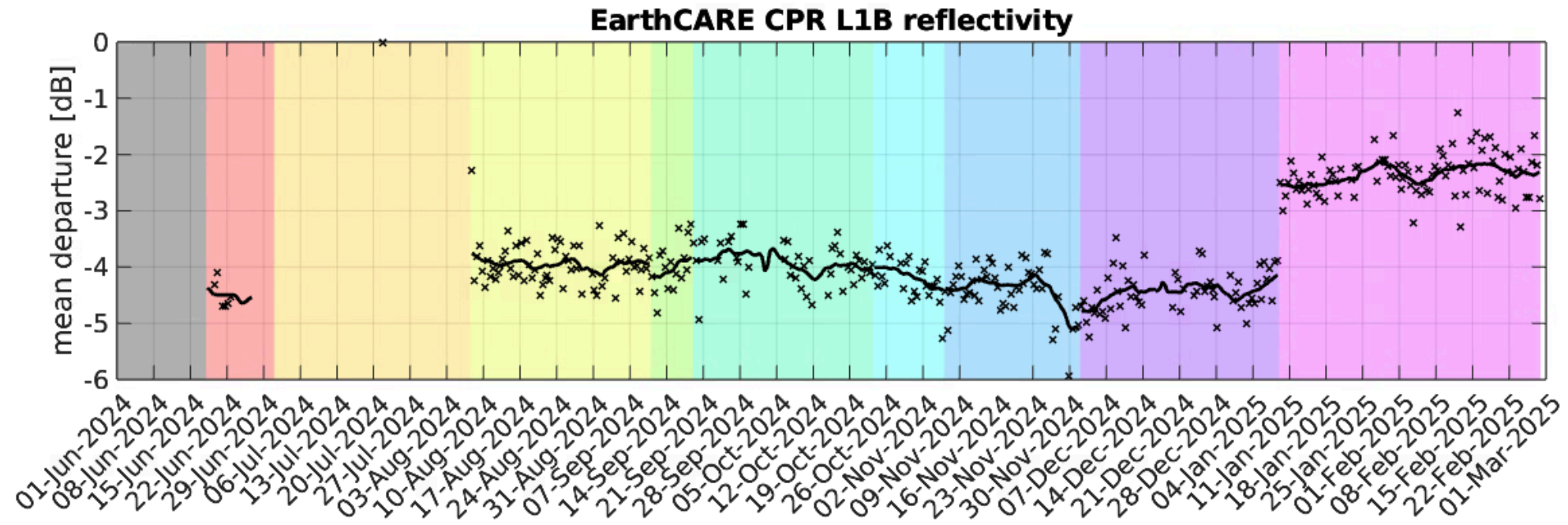
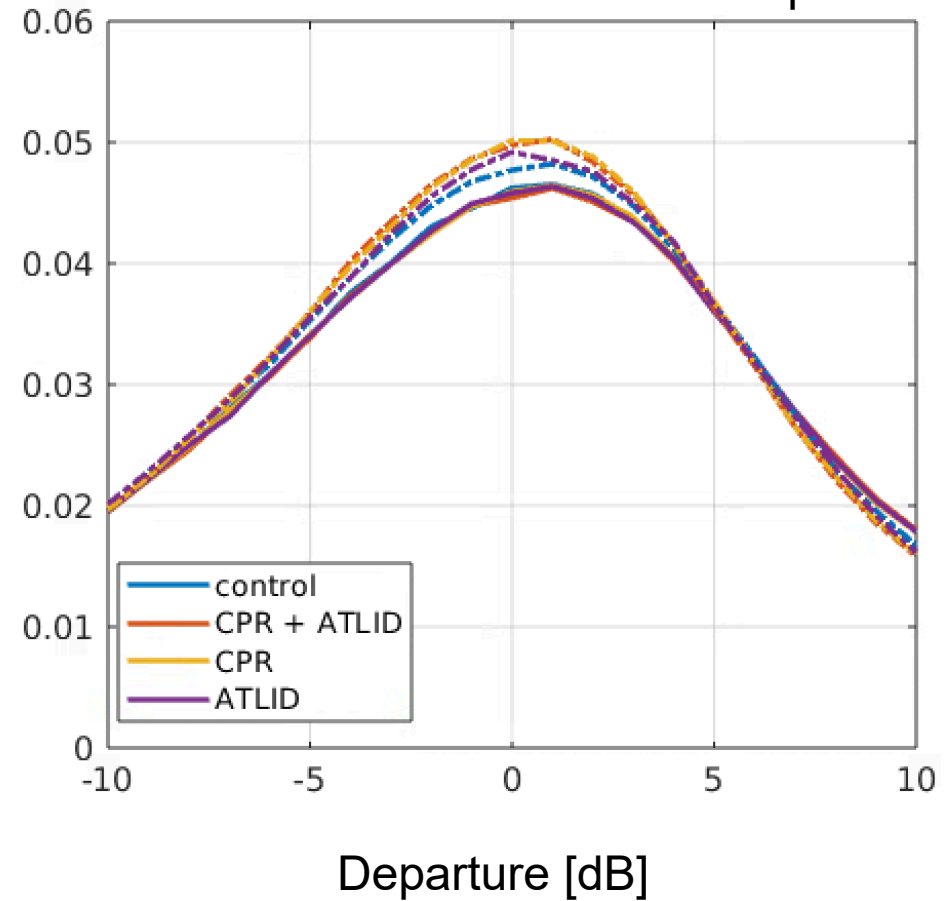# Assimilating EarthCARE improves fit to AN departures of reflectivity

17 March 2025 – 31 April 2025
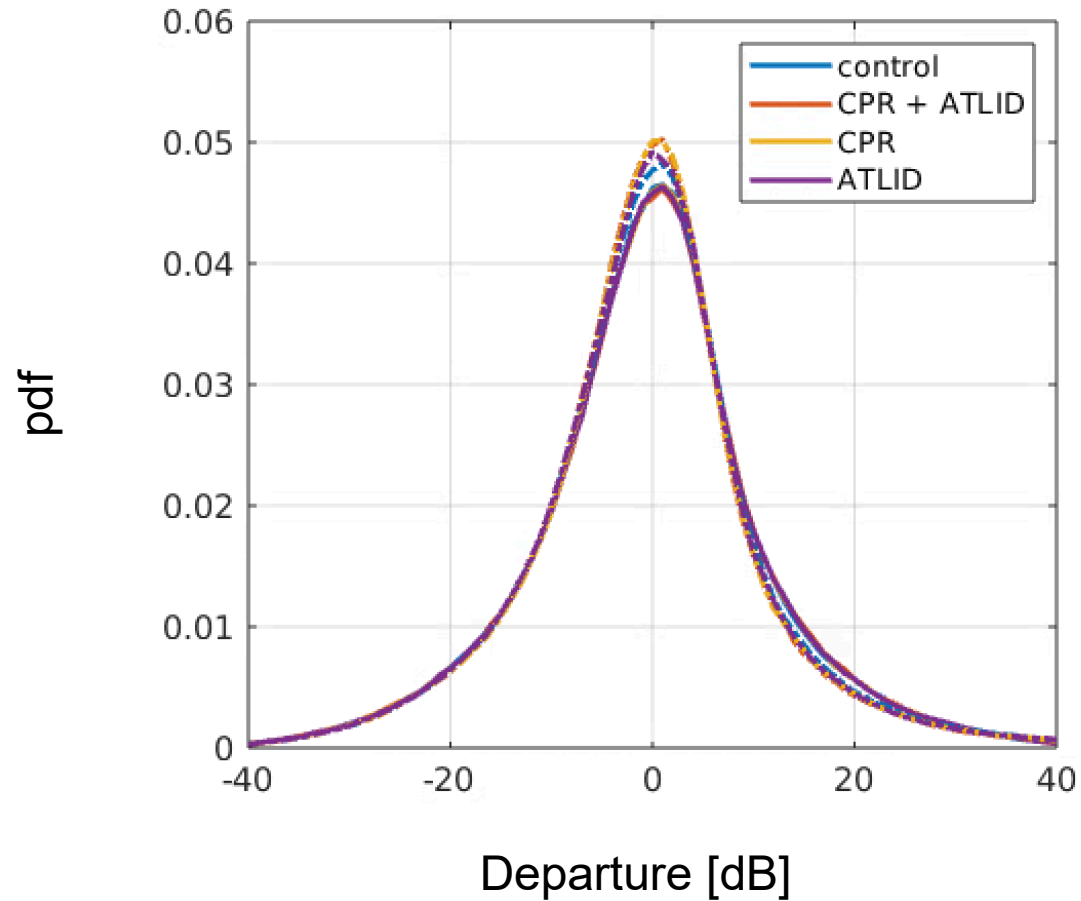
Solid lines FG departures
Dashed lines AN depatures

# Assimilating EarthCARE improves fit to BBR observations
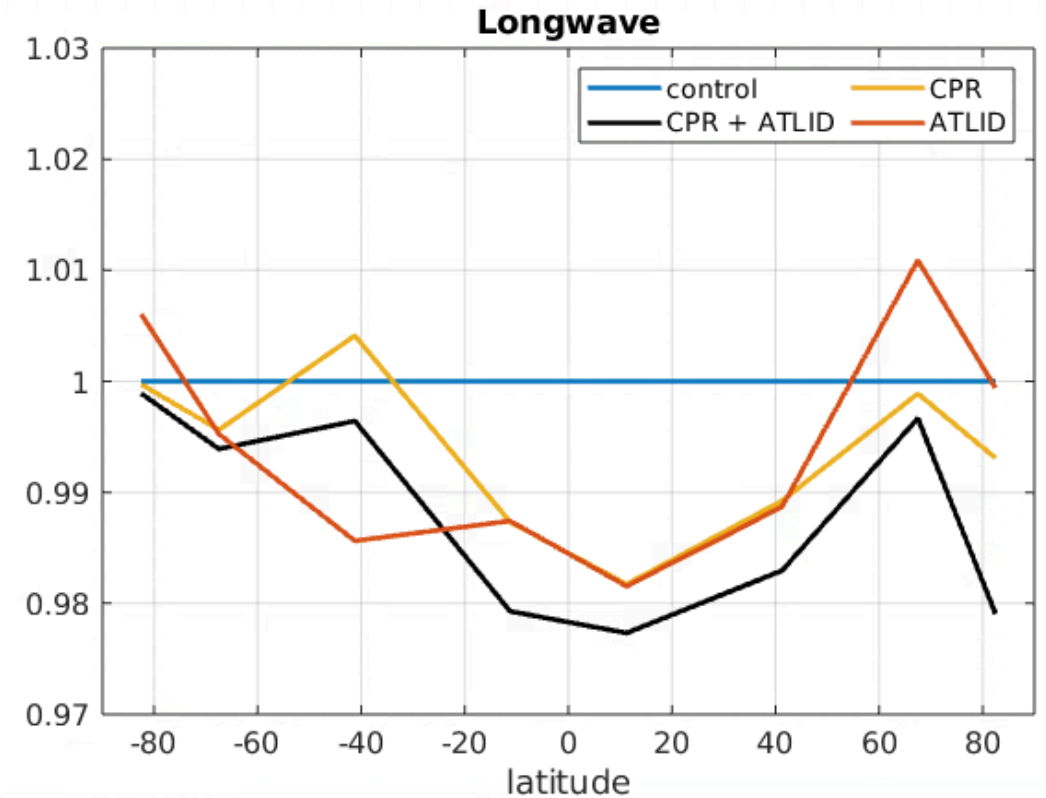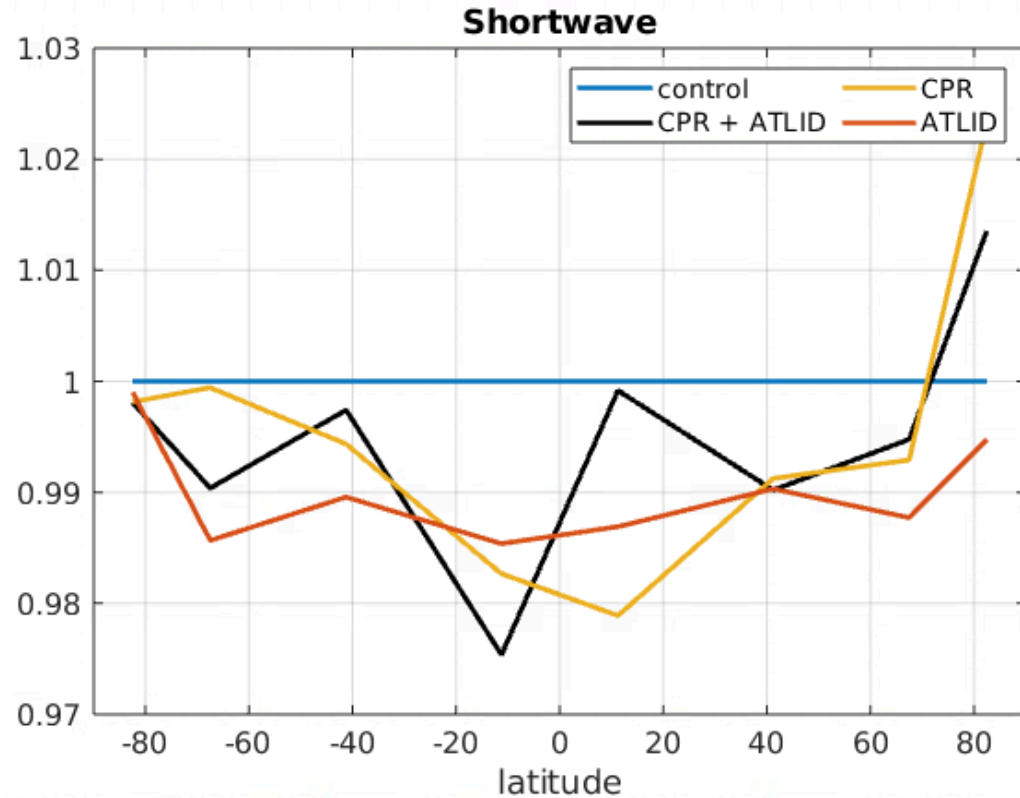
➢ Greatest impact seen in tropics

Synergy with passive microwave observations

EarthCARE has frequent co-locations with ATMS on NOAA-20 and GMI on GPM. These co-located observations should be the most sensitive to EarthCARE assimilation.

- Analysis departures for GMI are reduced when assimilating EarthCARE radar and lidar.

- Clear-sky ATMS humidity channel analysis departures are also reduced. Temperature-sensitive channels are more neutral.

- For GMI, std(AN departures) is sensitive to outliers caused by deep convection.

*All co-locations are within 30 minutes and 50 km of EarthCARE*
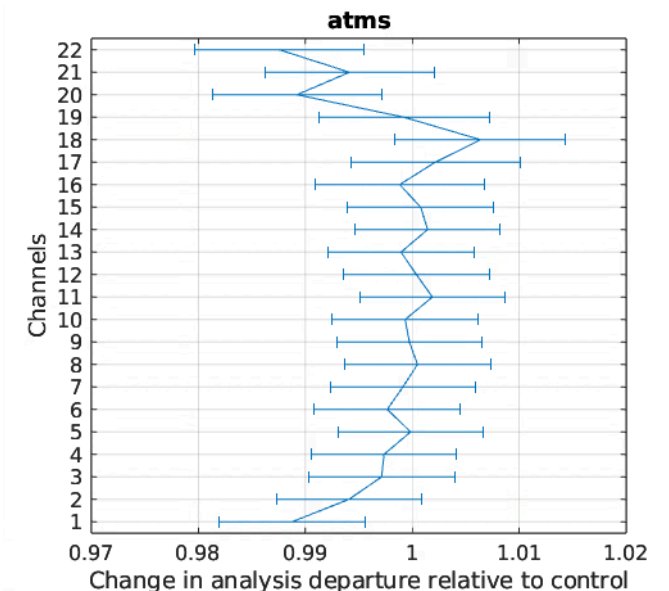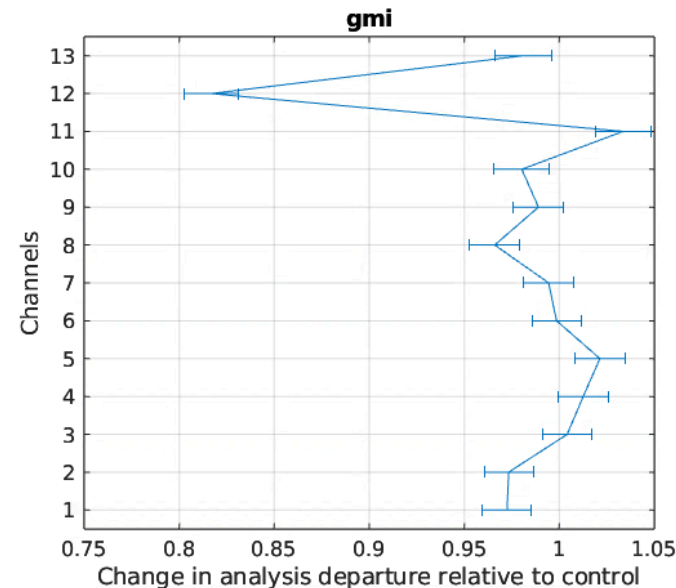
Positive impact on forecast skill in medium-range beginning to emerge

Winds

Relative humidity

ATLID has smaller impact, but still positive at short lead times

Winds

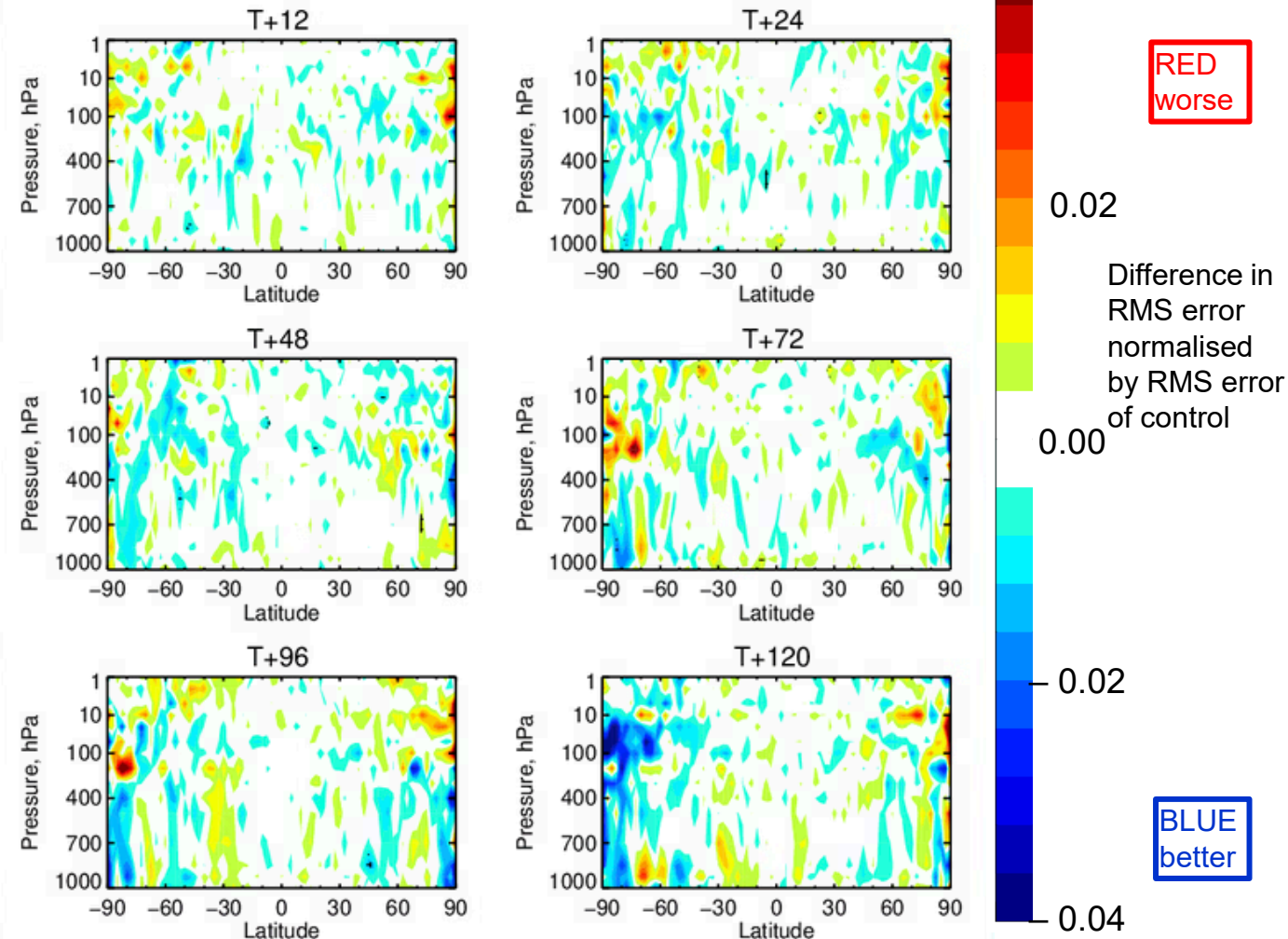Change in RMS error in VW (ATLID only−49r1 control)

17−Mar−2025 to 1−Jun−2025 from 134 to 153 samples. Verified against own−analysis.
Cross−hatching indicates 95% confidence with Sidak correction for 20 independent tests.
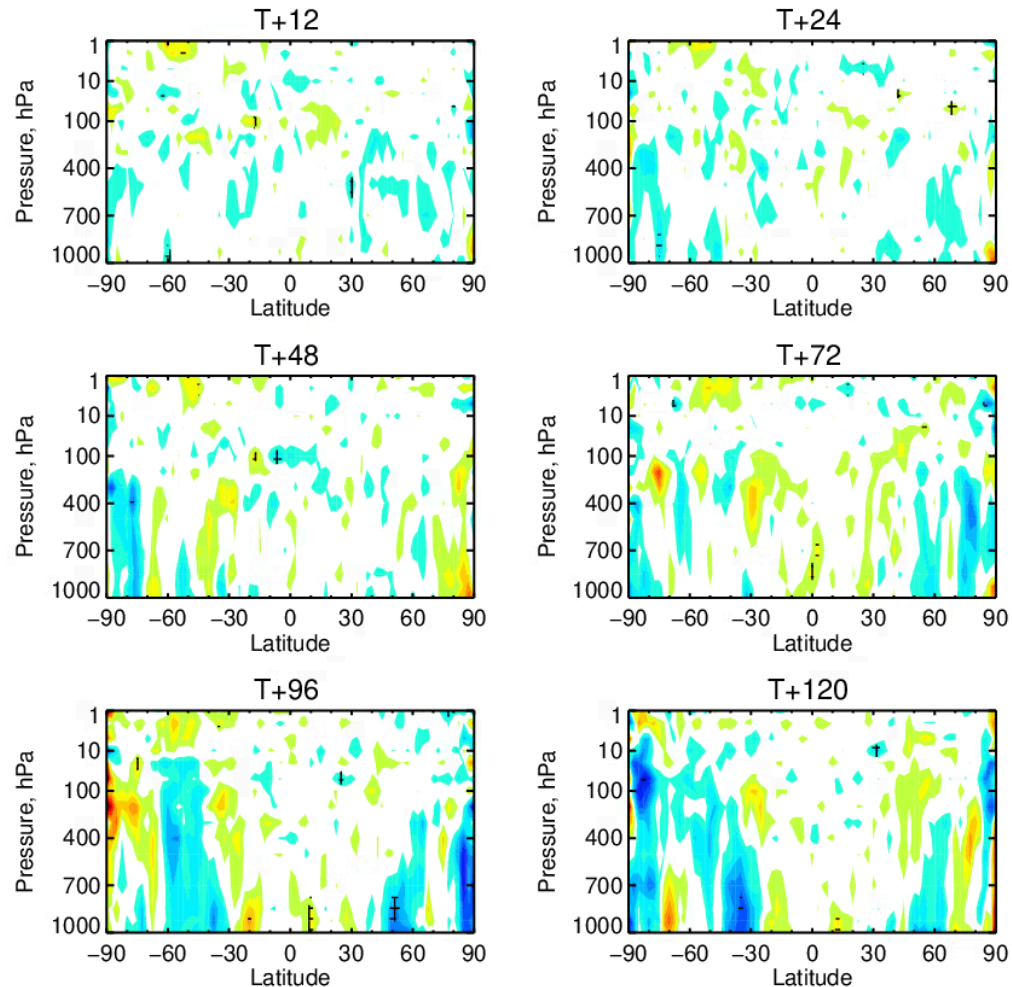
Relative humidity

Change in RMS error in R (ATLID only−49r1 control)

17−Mar−2025 to 1−Jun−2025 from 134 to 153 samples. Verified against own−analysis.
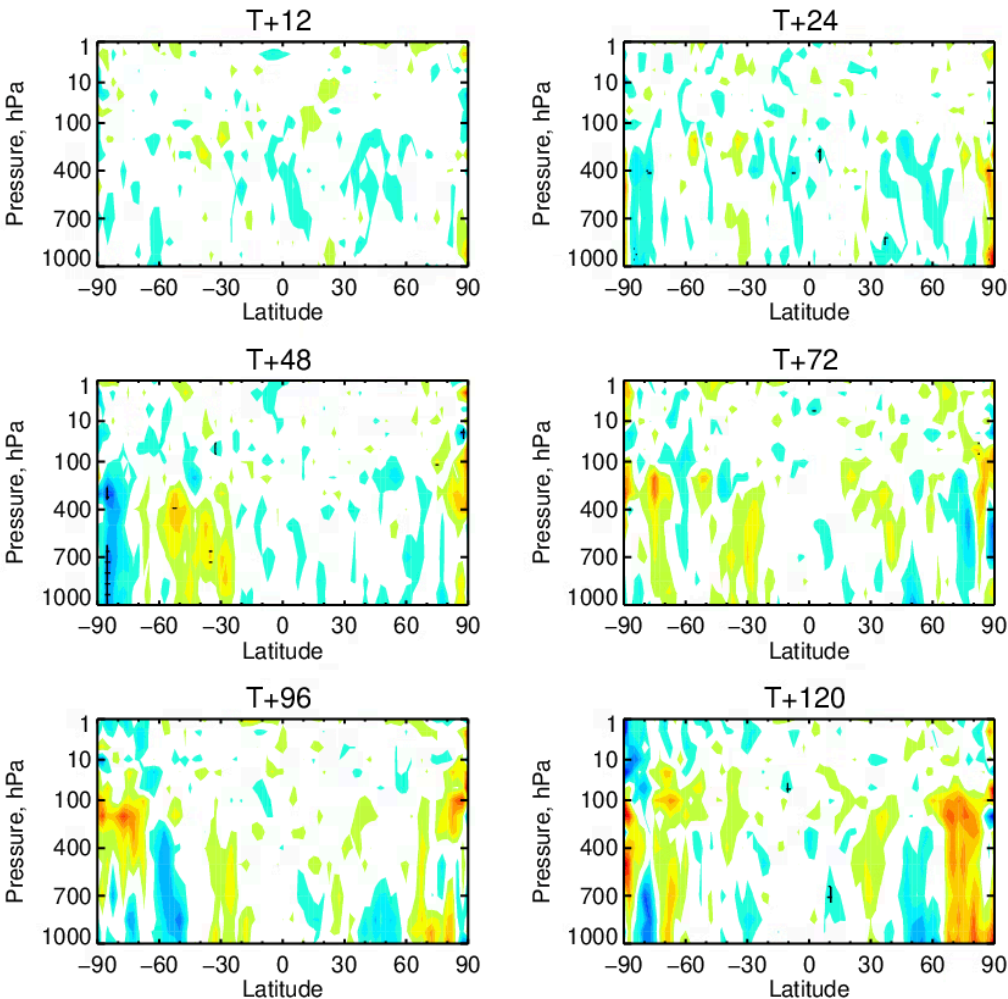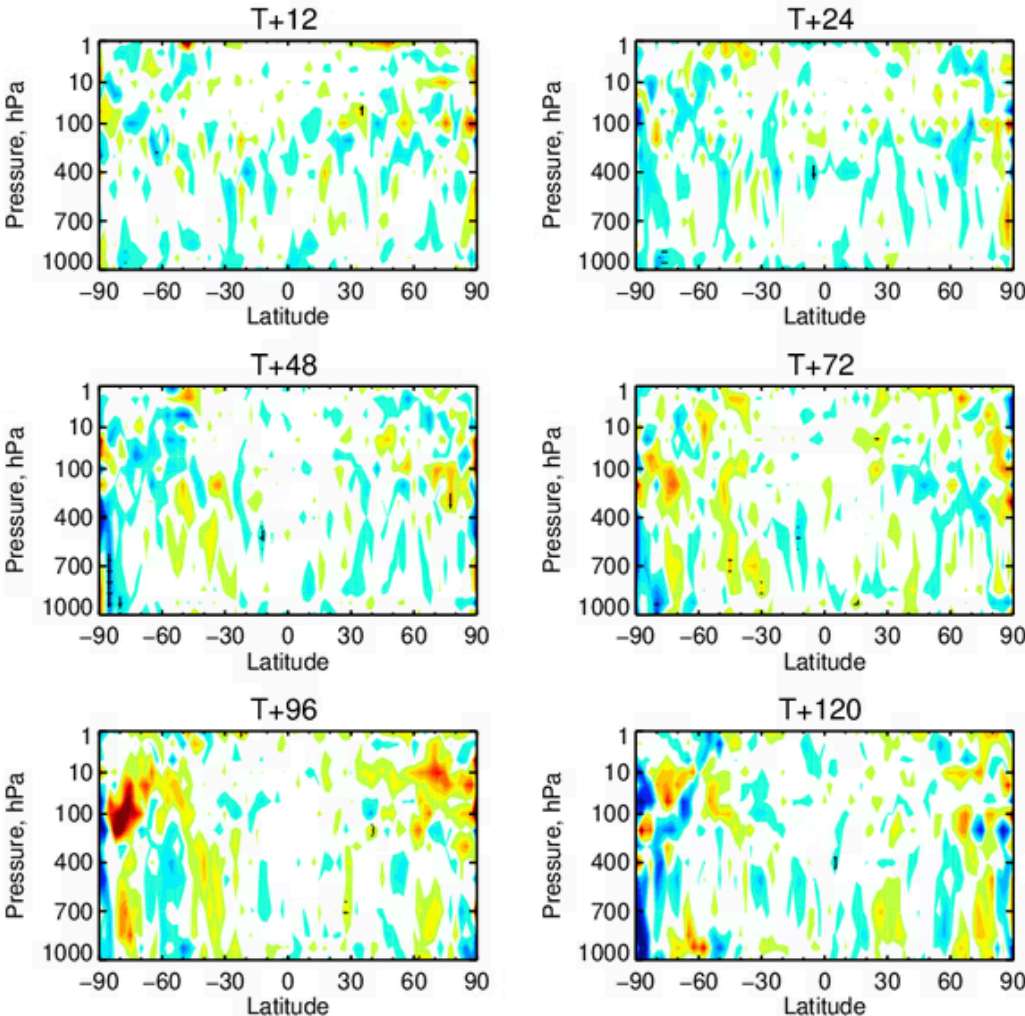Cross−hatching indicates 95% confidence with Sidak correction for 20 independent tests.

RED worse

Difference in RMS error normalised by RMS error of control

BLUE better

Conclusions

- Operational EarthCARE assimilation of radar reflectivity and cloud extinction coming soon! Targeting Autumn 2025.

- Assimilating EarthCARE has a clear positive impact on analysis, more subtle impact on forecasts seen so far.

- Additional benefit expected through error tuning, correcting model cloud biases and exploiting other EarthCARE observations.

- Aerosol assimilation results are promising; currently improving cloud screening to avoid biasing analysis.