Forensic analysis of new satellite instruments' performance

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ECMWF Annual Seminar 2026

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Microwave radiances: MWS & AWS

All sounders great and small

Motivation / Comment

Two under-appreciated aspects of observation usage in operational DA:

→ *Total time in operational use*

→ *Observation quality needs to fit the application (and global NWP is very picky)*

As the paradigm in satellite meteorology shifts to *smaller platforms* with *shorter operational lifetimes*, our window to evaluate and assimilate new observations is getting smaller whilst observation quality may be less consistent

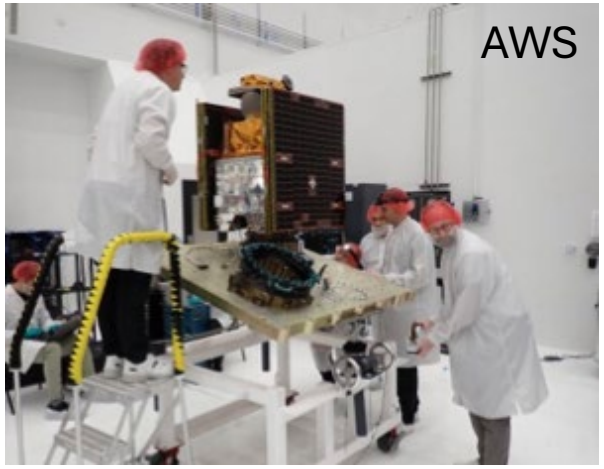
AWS & MWS

Two cross-track MW sounders with very different characteristics

→ *A bus-sized satellite vs. a washing machine*
→ A mixture of familiar and unfamiliar frequencies for NWP use

	AWS (MWR)	MWS
Satellite name	AWS PFM	Metop-SG-A1 / Metop-D
Satellite size	~1m^3 (125kg)	6.5x3x3.5 m (4040kg)
Channels	19	24
Spectral range	50 – 325 GHz	23 – 229 GHz
Scan width (deg)	109	99.66
Integration time (ms)	2.5	13.74
Co-located feedhorns	No	Yes
Scan spacing (km)	9	17
Launched	August 2024	August 2025


Metop-SG-A1


AWS

AWS & MWS

We can use the NWP model's short-range forecast in observation space (i.e. O-B) as a transfer standard to rapidly evaluate new instruments

→ This is particularly helpful when a limited sample of data are available

Leverage heritage instruments with known characteristics as vicarious calibration references (e.g. ATMS)

- **21 of 24 MWS** channels match closely with ATMS
- **12 of 19 AWS** channels match closely with ATMS

Centre Freq	MWS	AWS	ATMS	AMSU-A	MHS
23.8	**1**		(1)	1	
31.4	**2**		(2)	2	
50.3	**3**	(1)	(3)	3	
52.8	**4**	(2)	(5)	4	
53.246±0.08	**5**	(3)			
53.596±0.115	**6**	(4)	6	5	
53.948±0.081	**7**				
54.40	**8**	(5)	7	6	
54.94	**9**	(6)	8	7	
55.5	**10**	(7)	9	8	
57.290334=ν	**11**	(8)	10	9	
$\nu \pm 0.217$	**12**		11	10	
$\nu \pm 0.3222 \pm 0.048$	**13**		12	11	
$\nu \pm 0.3222 \pm 0.022$	**14**		13	12	
$\nu \pm 0.3222 \pm 0.010$	**15**		14	13	
$\nu \pm 0.3222 \pm 0.0045$	**16**		15	14	
89.0	**17**	9	16	15	1
165.5	**18**	(10)	17		(2*)
183±7	**19**	11*	(18)		5*
183±4.5	**20**	12*	(19)		
183±3	**21**	13*	(20)		(4)
183±1.8	**22**	14*	(21)		
183±1	**23**	15*	(22)		(3)
229	**24**				

All-sky cal/val sampling

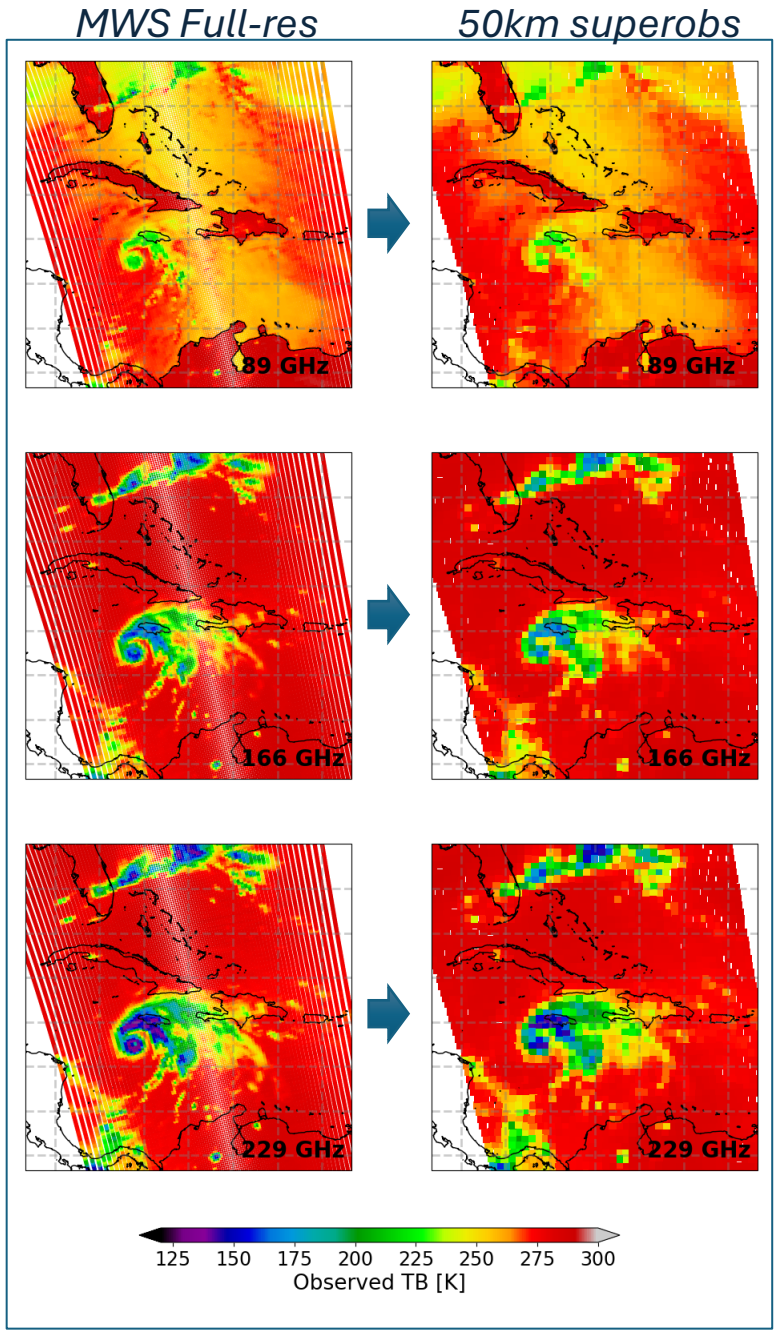
We apply spatial averaging (superobbing) to sounder radiances

Treat MWS, AWS, MHS, etc. the same – 50 km superobs

→ *Noise reduction is key for temperature sounding channels (~1/sqrt(N))*
→ *Grid-based superobbing*
→ *Homogenise data if channels are not co-located*

Direct apples to apples comparison for cal/val between instruments

Cal/val sample:
- Balanced sampling by *including all-sky RT effects*
- *Maximise size of sample* across regions, surfaces, etc.
- *Screen out heavily cloud-affected scenes*



All-sky cal/val sampling

Screening removes largest model biases

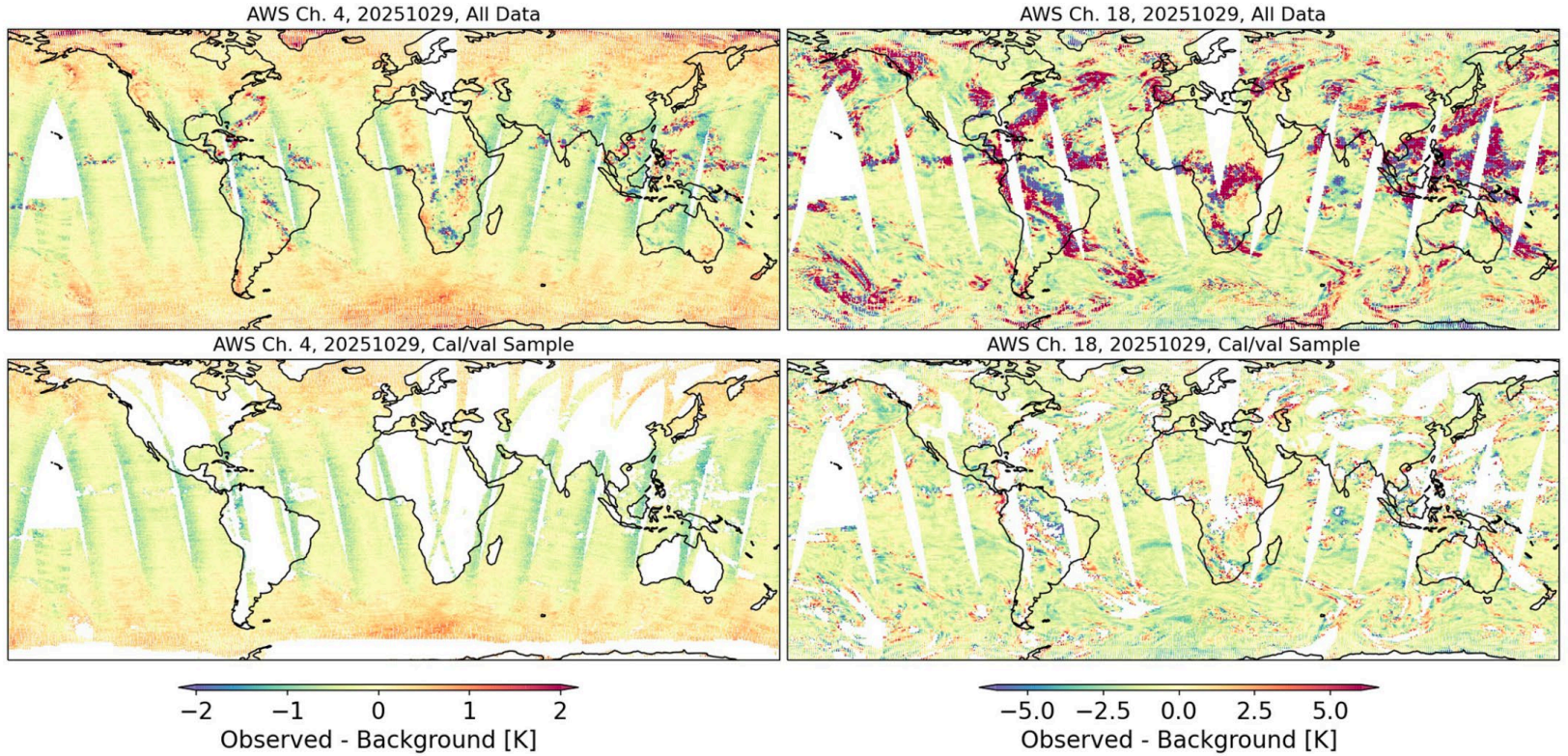
Large fractions of data retained (62% and 71% here)

AWS-4 (53.596 GHz)

AWS-18 (325±4.1 GHz)

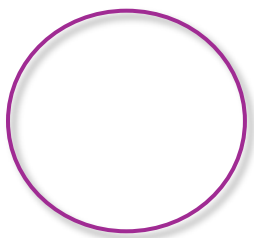
All Data

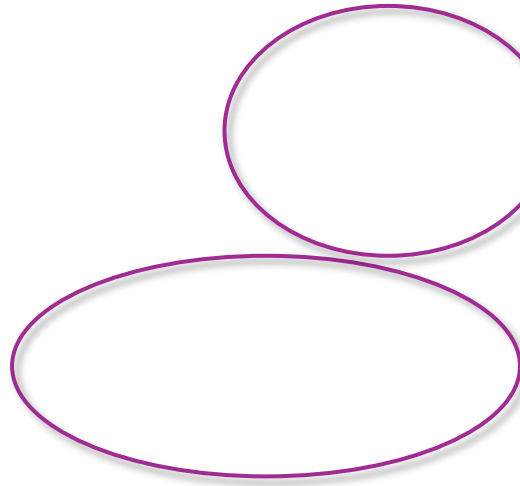
Cal/val sample



Cal/val results

- With our sampling strategy applied the same way across instruments, we can now directly compare similar channels
- Here we show AWS & MWS against AMSU-A, MHS, and ATMS
- PDFs of background departures (O-Bs) can be very instructive as a first look
  - *Gaussian PDFs are a good sign*
  - *Width of 50 GHz channels' PDFs largely determined by instrument noise*





Cal/val results



MWS channels

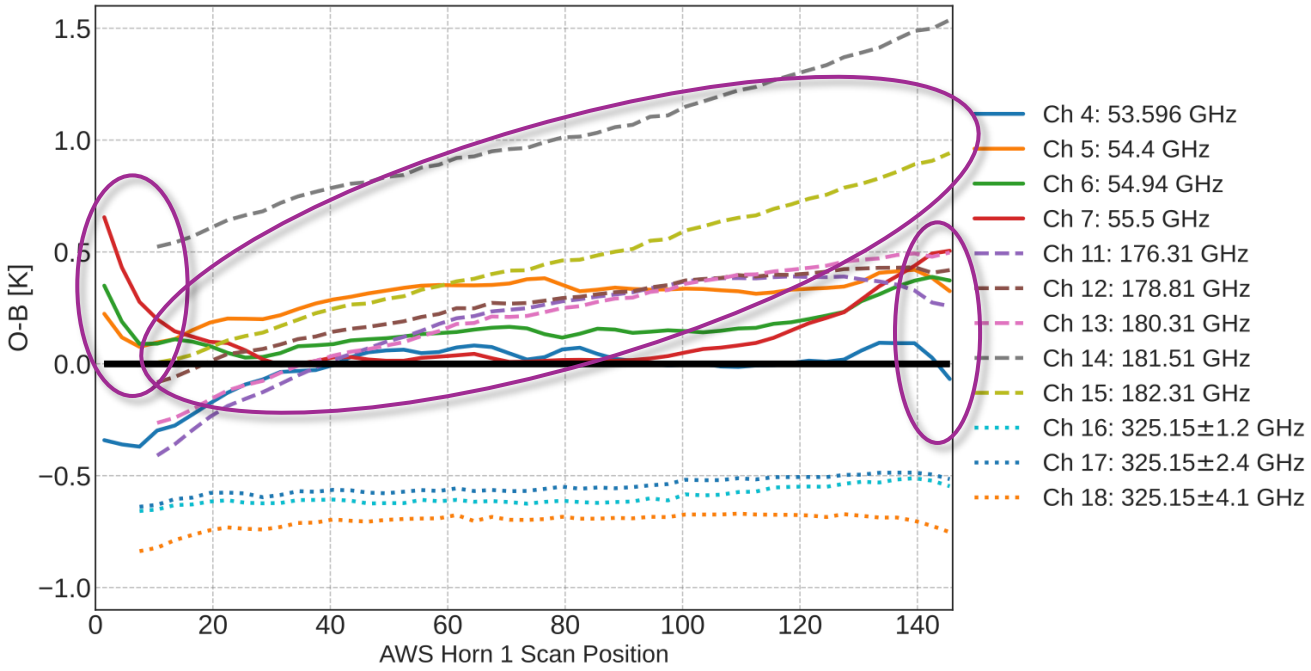
- Global biases are shown against the model background
- Double-differences are easily done by eye

- MWS is within 0.5K of IFS/RTTOV reference for all sounding channels; window channels (1-3, 17) see larger biases
- *Spread in global biases is typically tenths of degrees for sounding channels with well-established calibration*

Biases that need correction?

- Scan-dependent biases are common for MW sounders, requiring correction before assimilation
- AWS biases vary by feedhorn / channel group
- Scan edge biases harder to correct if they are sharp (seen for AWS channels 4-7)
- New 325 GHz channels have good calibration

- The sloping bias of AWS channels 11-15 was traced to likely debris that entered the feedhorn after commissioning!
  - *We can correct this bias easily, so we told ESA not to do any kind of rotation/manoeuvre that might dislodge the debris*



Biases that need correction?

AWS 183 GHz bias slope *identified after pointing at the Sun*

→ Slide courtesy of Ville Kangas, ESA

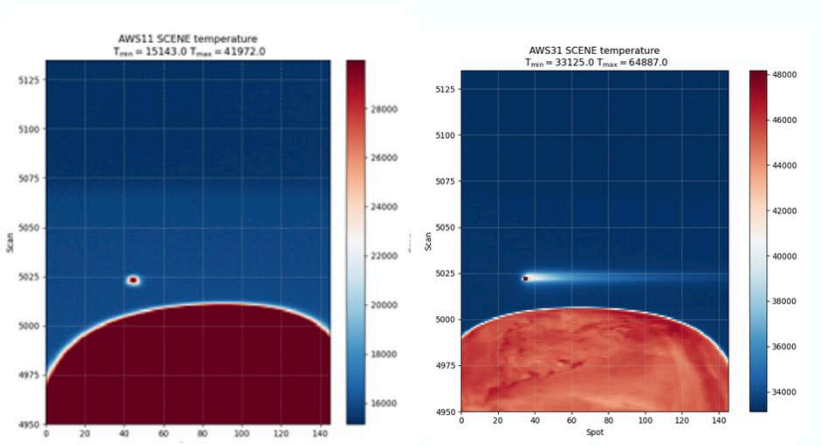
October 2024 – Change of 183 Channels behaviour during orbit transfer

esa

- Symptoms we saw:
  - Receiver noise increased from ~510K to ~650K, small dependency on in-orbit positioning
  - Impacts all 183 GHz channels
  - Slopes seen in OBCT, Cold Sky and Scene (different in size and direction)
    - Slope is repeatable between scans
- Orbit dependency occurring at point in orbit, when the Satellite comes out of eclipse and sun is directly hitting the 183 GHz feedhorn.
- → decision to look at sun directly

When facing sun directly, heating effect was seen in 183 channel, not visible in other channels

→ Likely a debris in feedhorn that block part of the path (=increase in noise) as cooling down is fast, has very small mass.

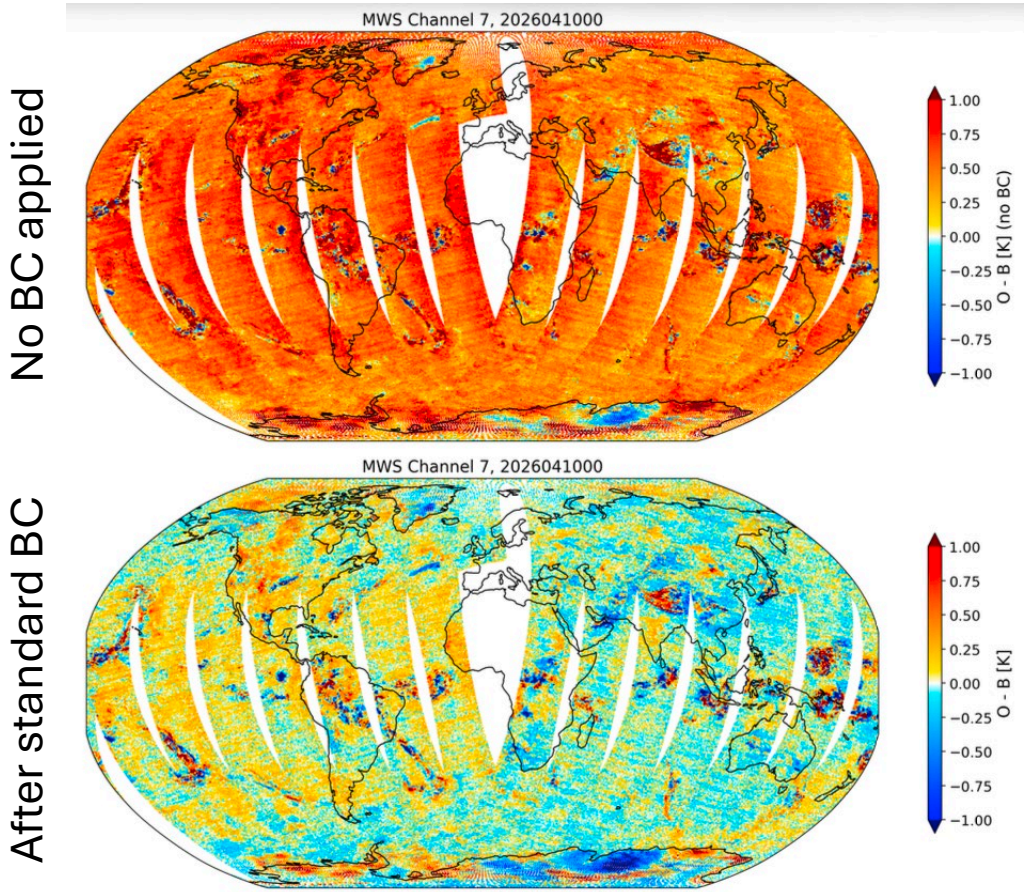


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→ THE EUROPEAN SPACE AGENCY

Biases that need correction?

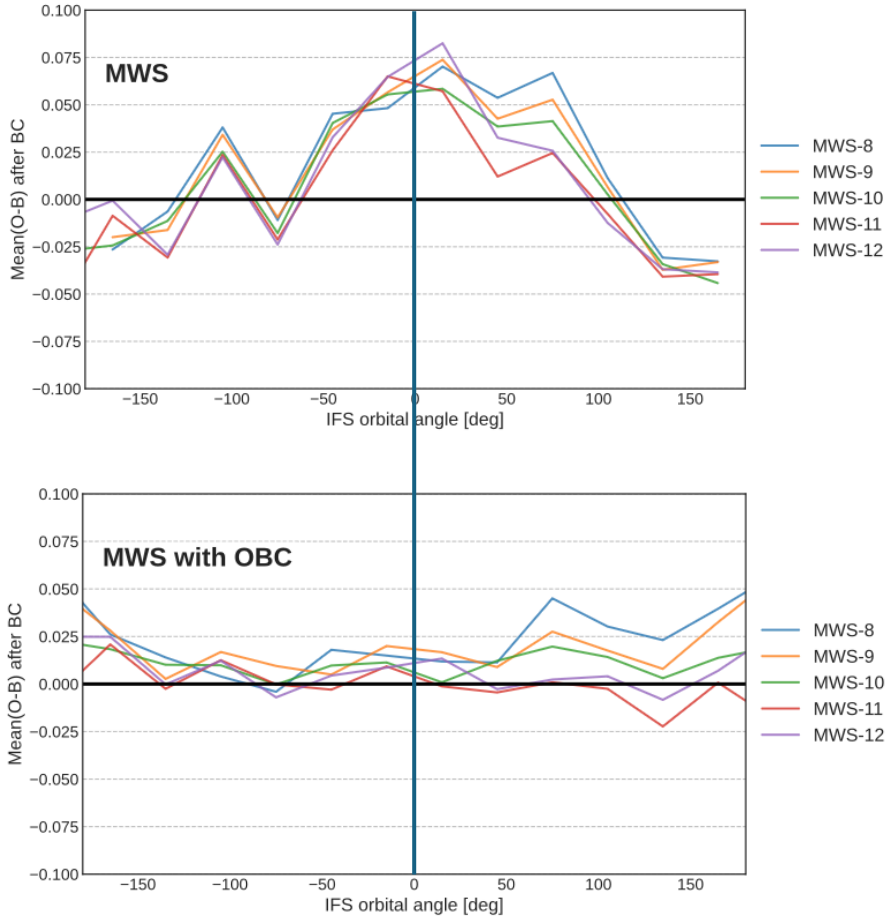
- Orbital biases are trickier to correct (or even properly identify)
- MWS temperature channels exhibited a small bias when comparing *ascending and descending parts of the orbit* – clearly visible after standard bias correction



Biases that need correction?

- Orbital biases are trickier to correct (or even properly identify)
- MWS temperature channels exhibited a small bias when comparing *ascending and descending parts of the orbit* – clearly visible after standard bias correction
- This is *only ~0.1 K in magnitude**, but consistent across MWS channels; comparisons to AWS and ATMS equivalents showed that MWS was the outlier
- If we include orbital bias correction (OBC) terms in VarBC, most of the bias is mitigated

Equator



Orbit angle

**EUMETSAT performance specification is <0.2 K orbital bias drift*

Assessing noise performance

Radiometric noise predicts std(O-B) performance in temperature-sounding band

Superobbed noise performance is key for assimilation

- *Ideal (white noise) reduction should follow 1/sqrt(N)*
- *Due to grid-based superobbing, we see greater noise reduction near middle of scan*

MWS exhibits noise as low as ATMS

→ Stratospheric channels of MWS are the lowest-noise of any MW instrument ever launched (not shown)

AWS is not as low, but compares well against AMSU-A

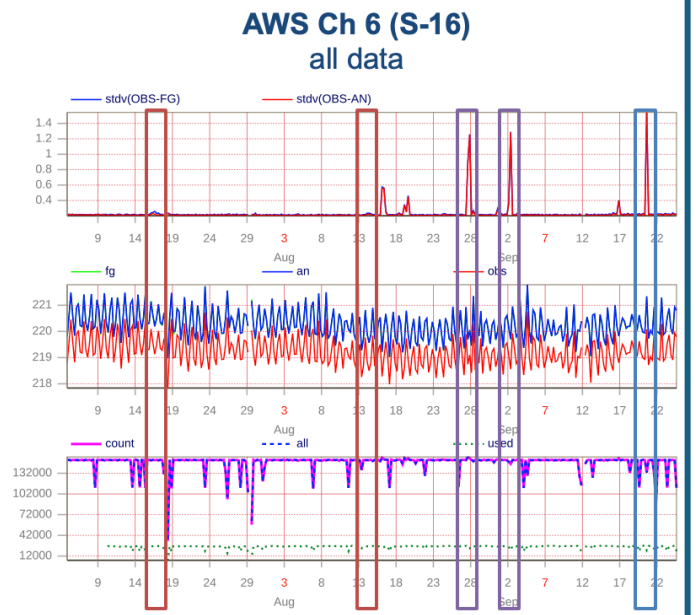
Monitoring performance

- Near-real-time monitoring uses existing infrastructure for operational monitoring of observations

- Can feed back to space agencies **rapidly**
  - ➢ *Key in the early part of a mission!*

Three different causes?

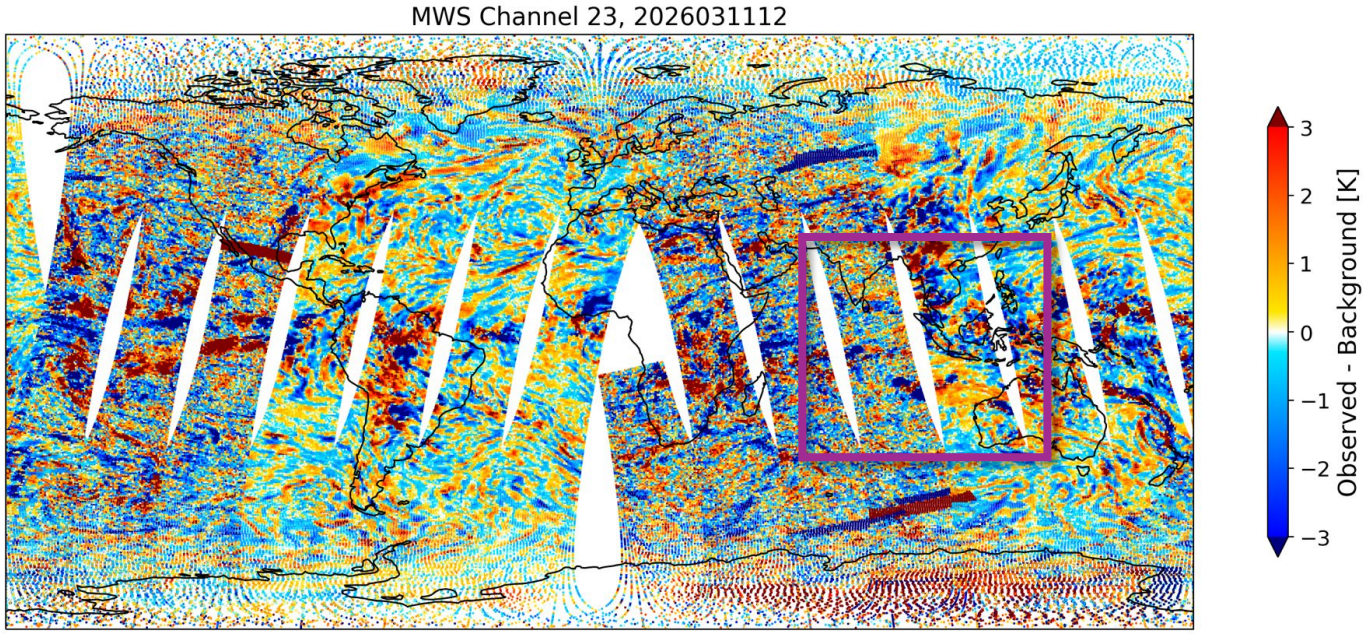
- ➢ Lunar intrusions (16th July & 14th Aug)
- ➢ Unclear calibration issues (28th Aug & 2nd Sept)
- ➢ Unclear calibration / scanning issues (20th Sept)

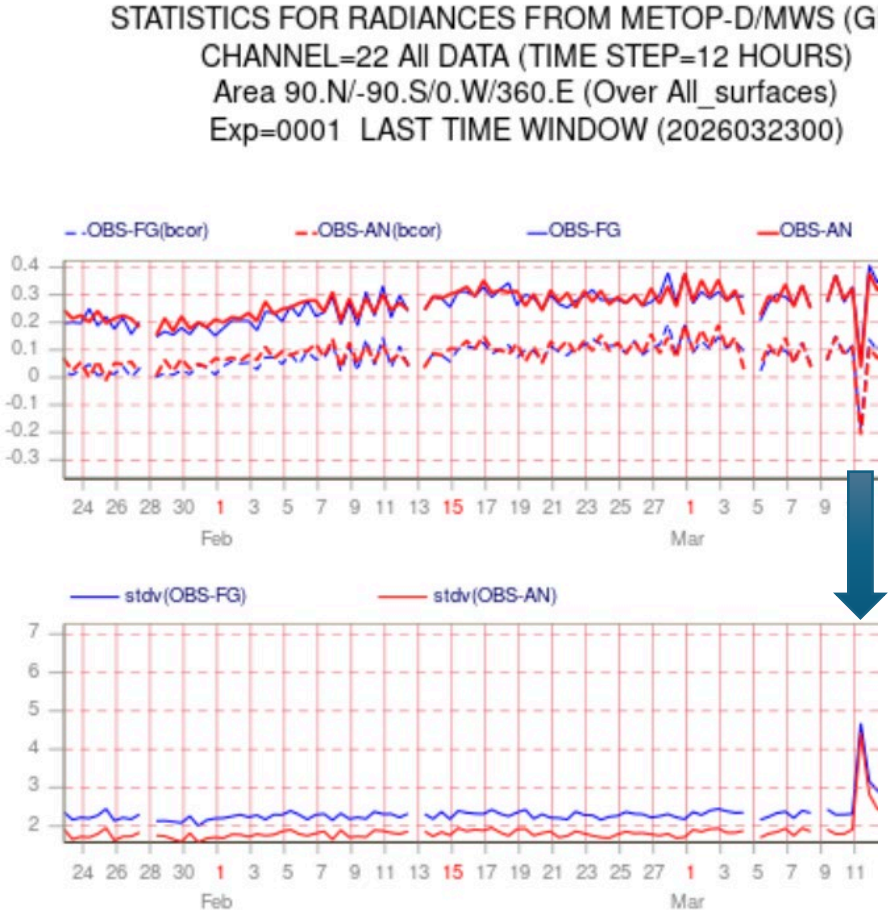


Slide shared with ESA last autumn on AWS performance blips

Monitoring performance

- A jump in 183 GHz performance was seen in std(O-B) for MWS in mid March 2026
- *White noise increased abruptly, going from in-spec to well outside specification*
- Clear in monitoring statistics and visually in O-B map

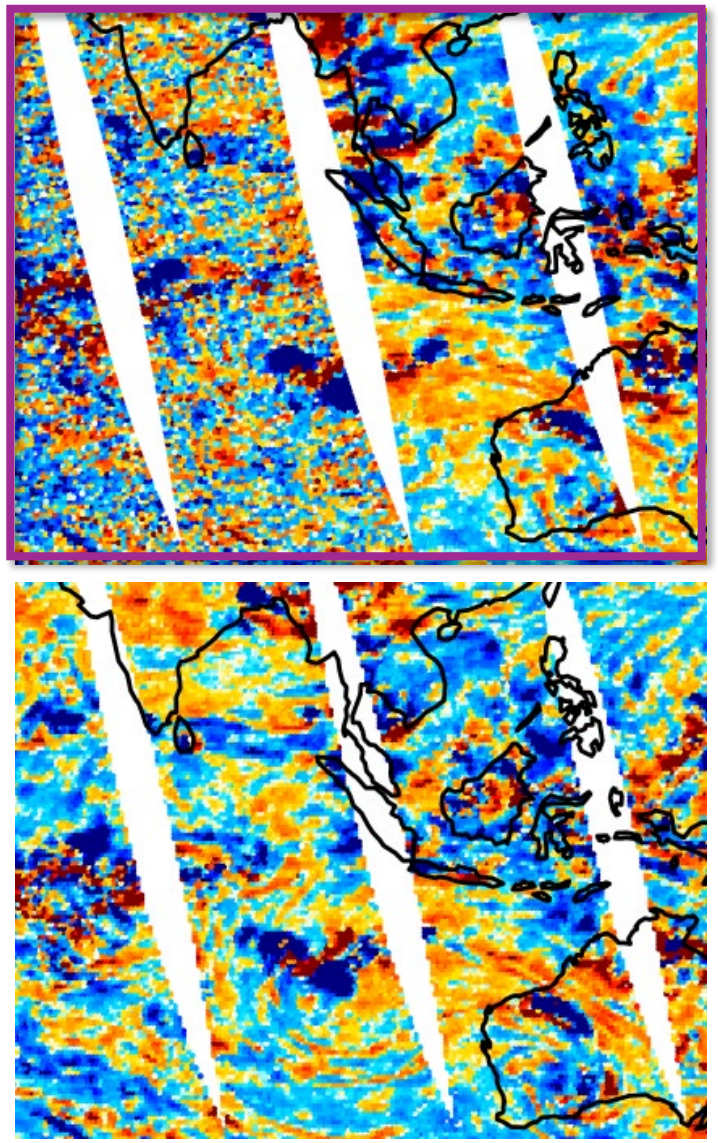




Monitoring performance

- With Metop-D flying very close to Metop-B and -C, we can visually compare O-B maps from this date to see the sharp increase in noise
- *MWS went from a low-noise humidity sounder to a very noisy one after this anomaly in March*

- Unfortunately, this anomaly was not recoverable, and MWS noise levels in the 183 GHz band remain outside specifications



Conclusions on AWS & MWS

Every MW instrument can provide different challenges for cal/val assessment:

- Some imperfections in performance are very subtle (orbital biases)
- Some are very large (183 GHz anomaly, space debris)
- *Very rarely plug and play!*

Careful analyses of biases and noise performance are crucial for full NWP exploitation

- Rapid feedback to space agency / data provider
- Enable earlier assimilation trials

These assessments ultimately determine which channels are viable for assimilation trials and what the observation errors should be

At ECMWF, AWS has been assimilated operationally since July 2025; MWS since August 24th, 2026 ☺

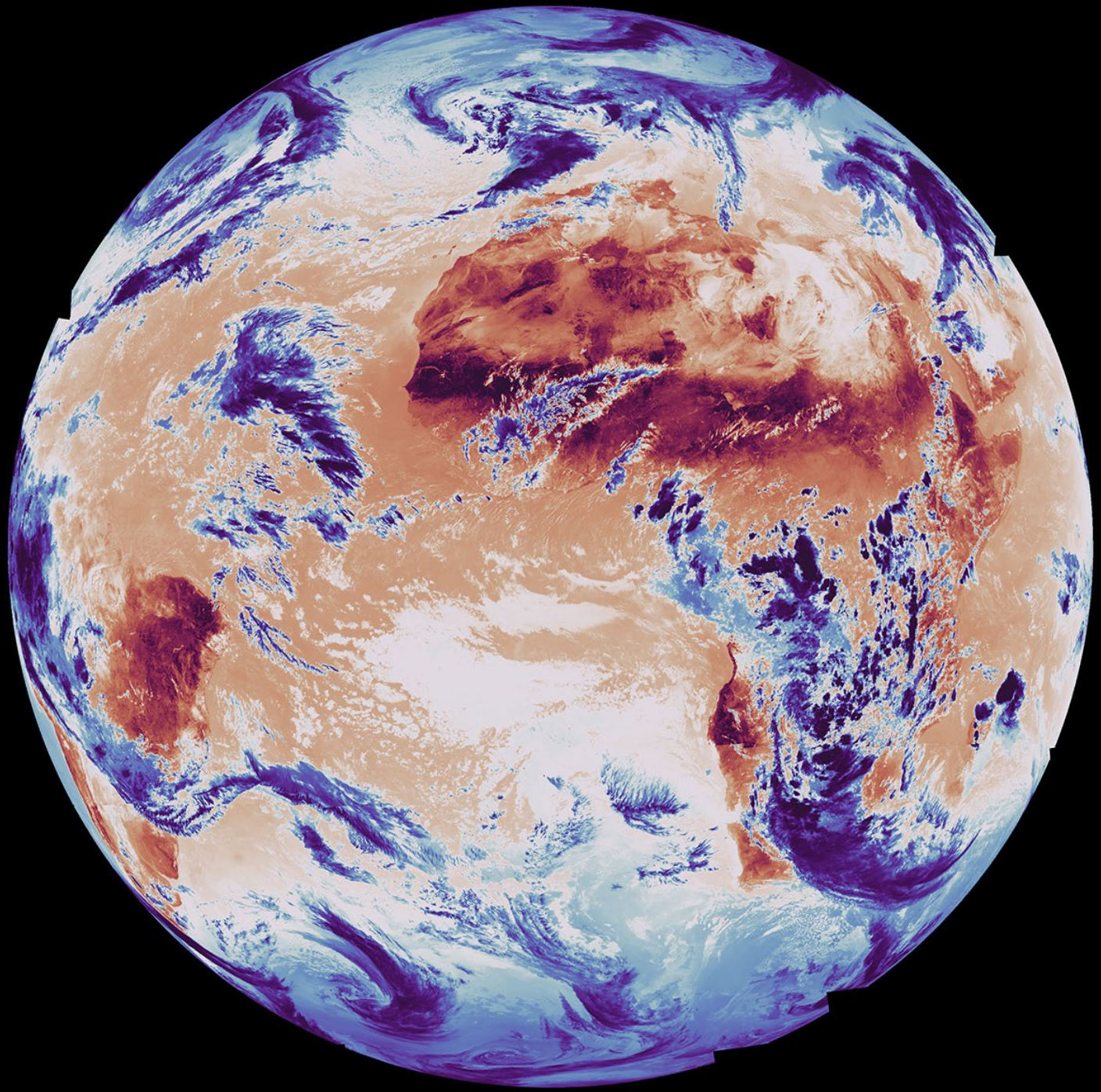
Hyperspectral infrared observations: MTG-IRS

Meteosat Third Generation – InfraRed Sounder (MTG-IRS)

- The **MTG-S1** sounder satellite was launched on the 1st of July 2025.
- It carries the **IRS** sounder instrument.
- This is the first European hyperspectral infrared sounder in a **geostationary orbit**!
- Unlike previous instruments in this orbit which have no more than 16 spectral channels, IRS has **1953 channels**.
- Its spatial resolution at nadir is **4km**.



EUMETSAT



EUMETSAT

Acknowledgements

- At EUMETSAT, Pierre Dussarrat and Guillaume Deschamps from Dorothée Coppens's team have been excellent collaborators. Many of our findings were shared and discussed with them immediately. Thanks for this fruitful communication.

- At ECMWF, thanks to the following people: Volkan Firat, Tomas Kral, Marijana Crepulja, Peter Lean, Cristina Lupu, Samuel Quesada-Ruiz, Angela Benedetti, Niels Bormann, Francis Warrick and Tony McNally.

- Thanks to Nigel Atkinson at the Met Office, the architect of the IRSPP software package that we use to process the compressed data.

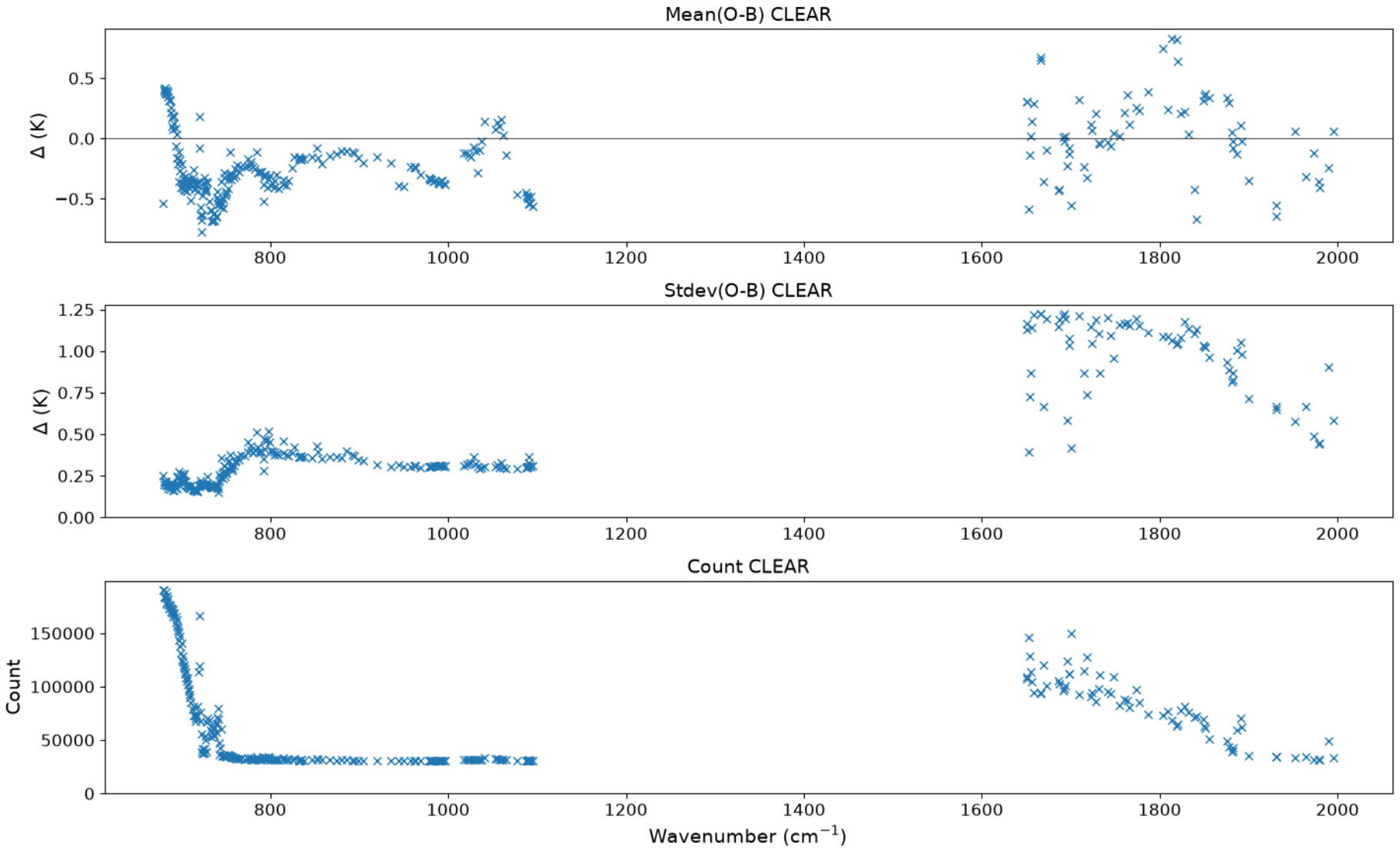
- Naoto Kusano from JMA has visited us twice, and some of his plots appear in this presentation.

Before assimilating, we use first guess departures (O-Bs) to assess data quality

- Although not the “truth”, model fields act as valuable references:
  - For **any date/time/geometry** we can always compute a model equivalent of an observation (unlike co-locations with other instruments).
- and the main drawback (currently) is:
  - For infrared, we only perform comparisons for scenes/channels that are **not affected by cloud**.

- Some of the things we focus on for hyperspectral infrared instruments:
  - **Noise**, i.e. a contributor to stdev(O-B),
  - **Radiometric accuracy**: associated with mean(O-B),
  - **Consistency between detectors**,
  - **Spectral calibration.**
- For each of these (particularly the second), care is needed, because the model and radiative transfer can impart their own errors to the O-Bs.

Statistics for a subset of channels

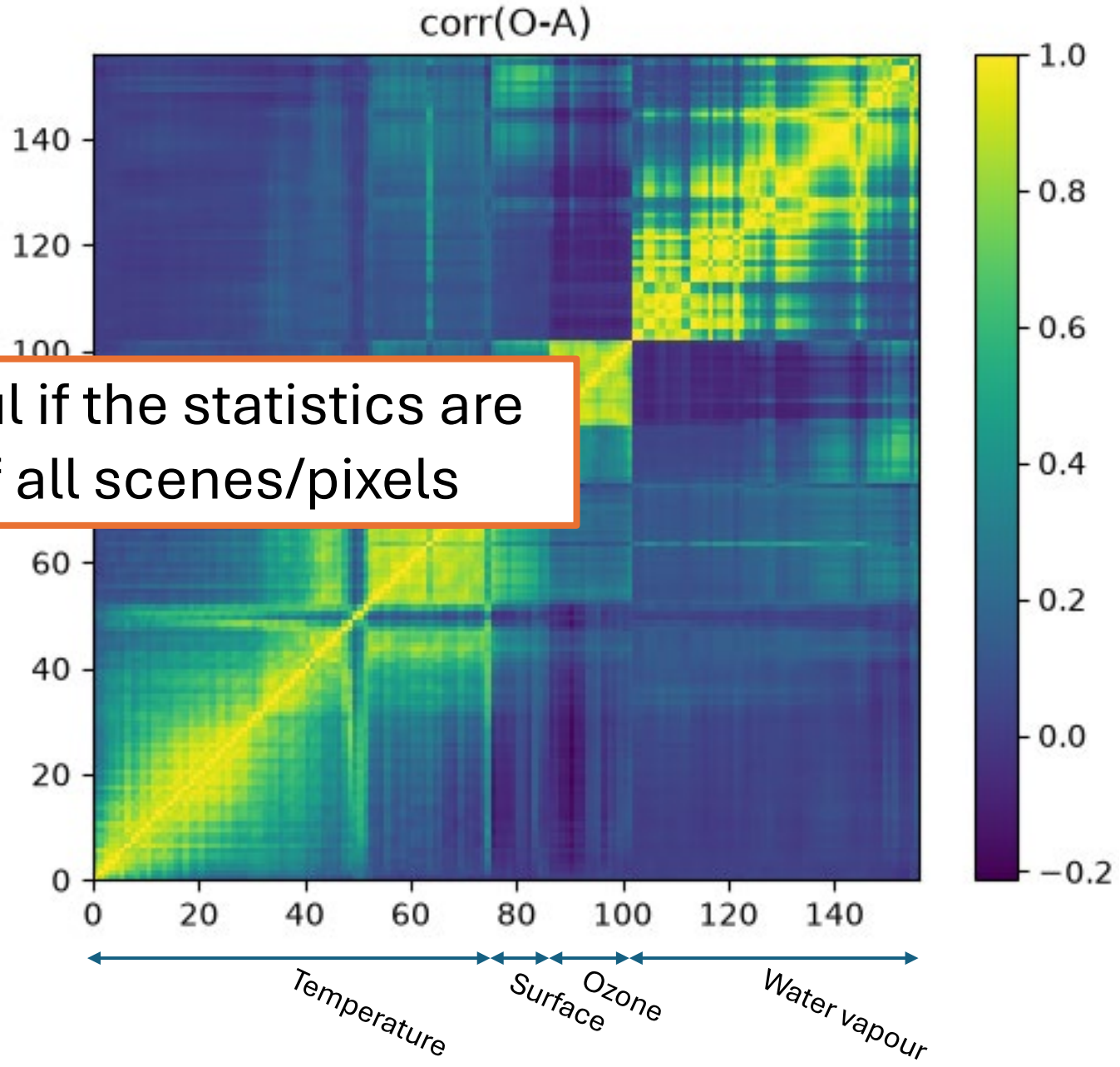


- These statistics are for clear-sky observations only (that's why there are so few observations for window channels (750-1200 cm^{-1}).
- For NWP we don't worry too much about constant biases as we use bias correction 🙄.
- The standard deviation includes instrument noise and model/RT errors.

Inter-channel error correlations

- The correlation of (O-B), or **(O-A)** in this case, shows the statistical connections between the used channels.
- The strong correlatic from the model.
- Instrument specific details can also be seen when zoomed in. For example a penta-diagonal pattern in regions where consecutive channels are used (due to the strong **apodisation**).

This is only useful if the statistics are representative of all scenes/pixels



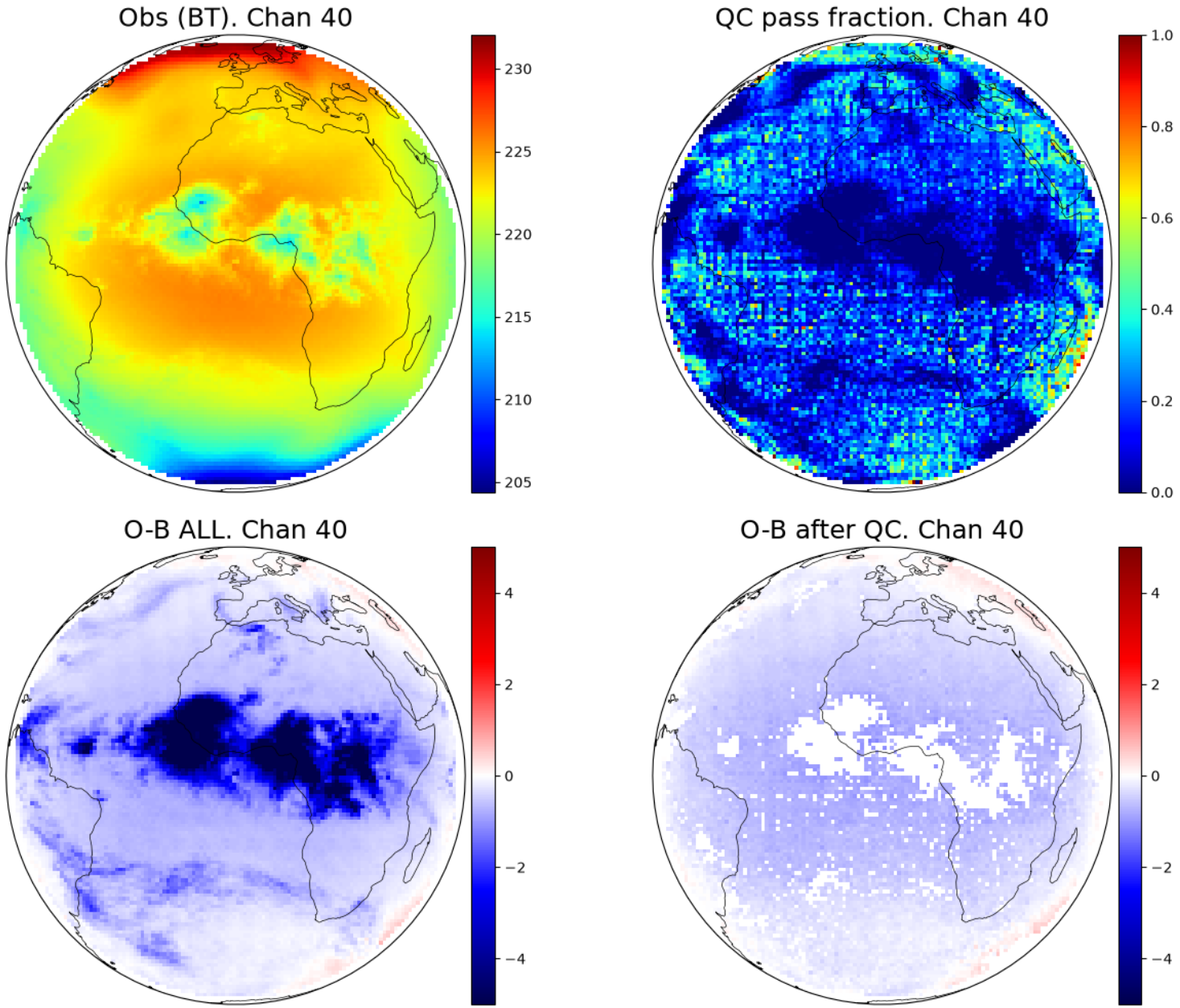
Map plots of statistics

- These give a clear indication of spatial uniformity, as well as helping to check aspects of our QC, particularly cloud detection.

- The following four slides show examples of the following:
  - A temperature sounding channel
  - A window channel
  - An ozone channel
  - A water vapour channel

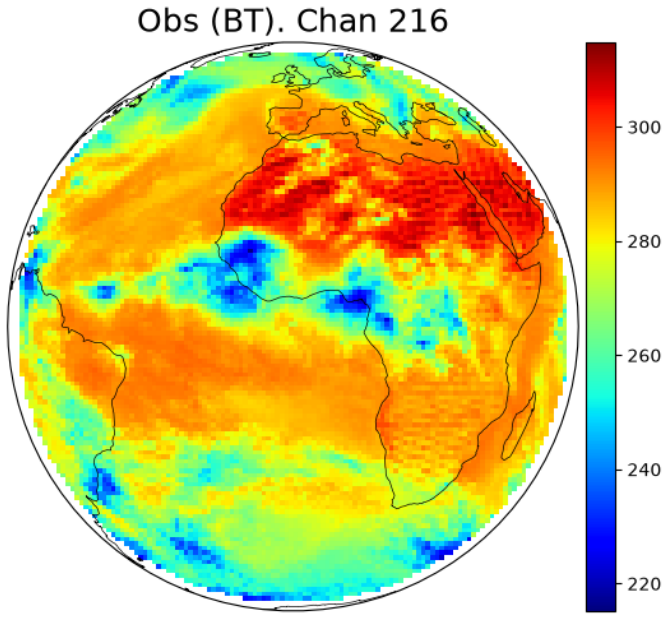
Temperature sounding channel

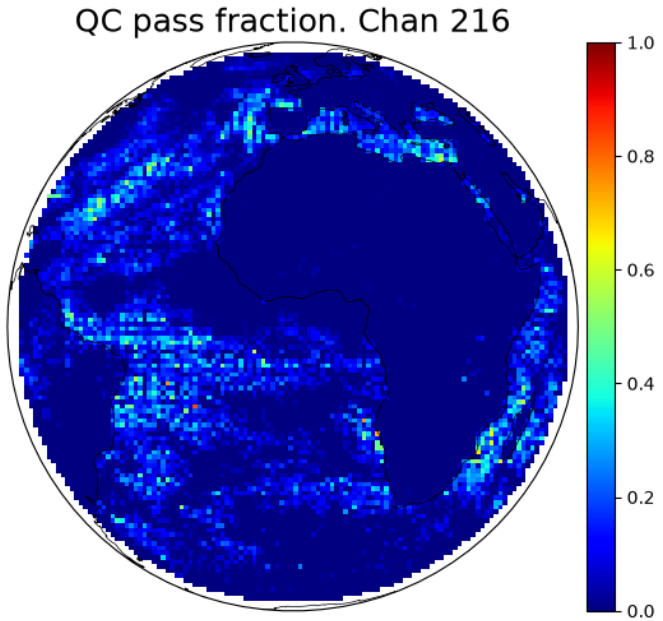
~160 hPa
703.115 cm^{-1}

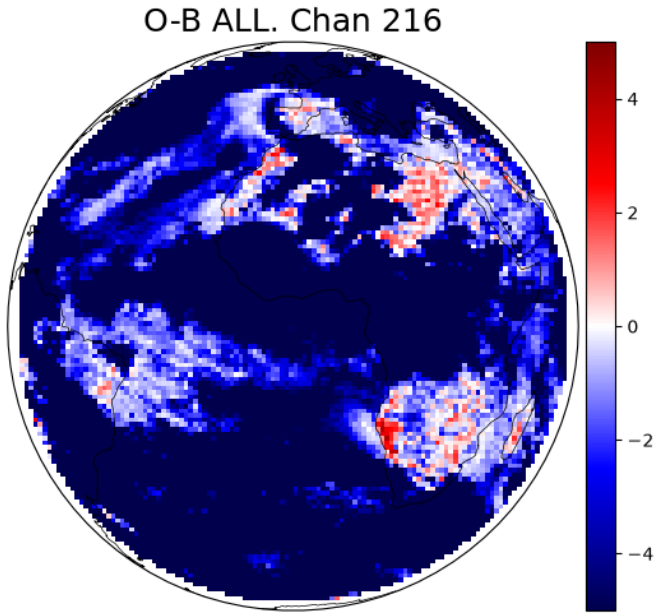


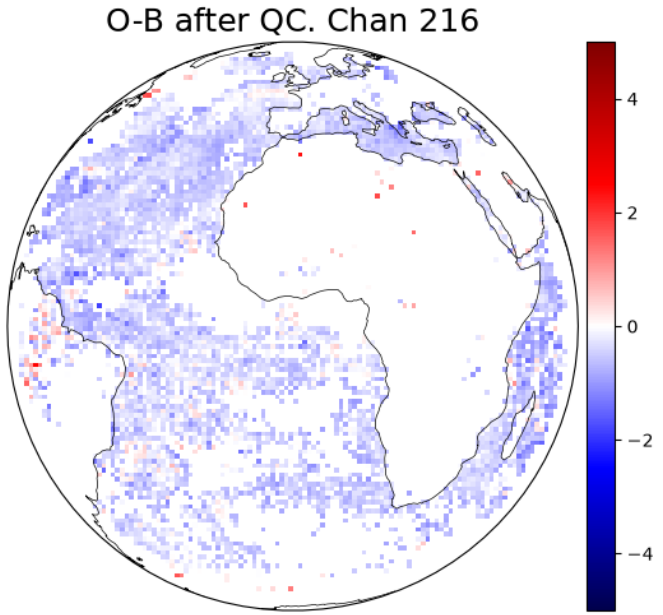
Window channel

809.702 cm^{-1}



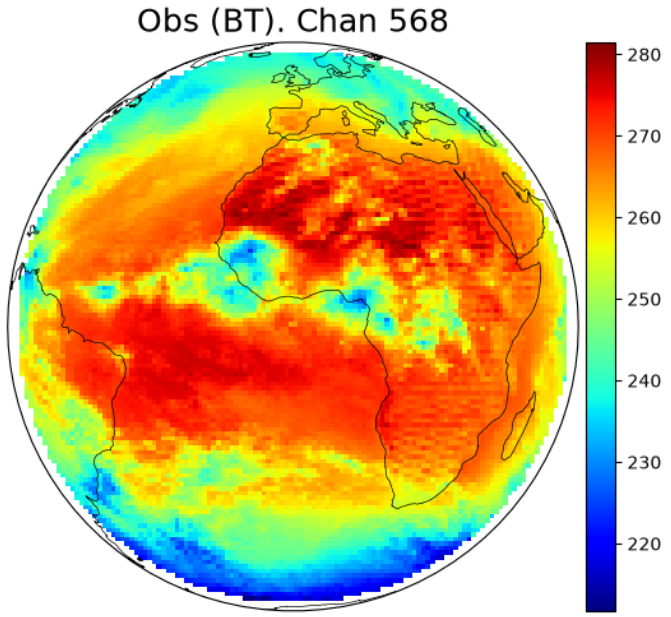


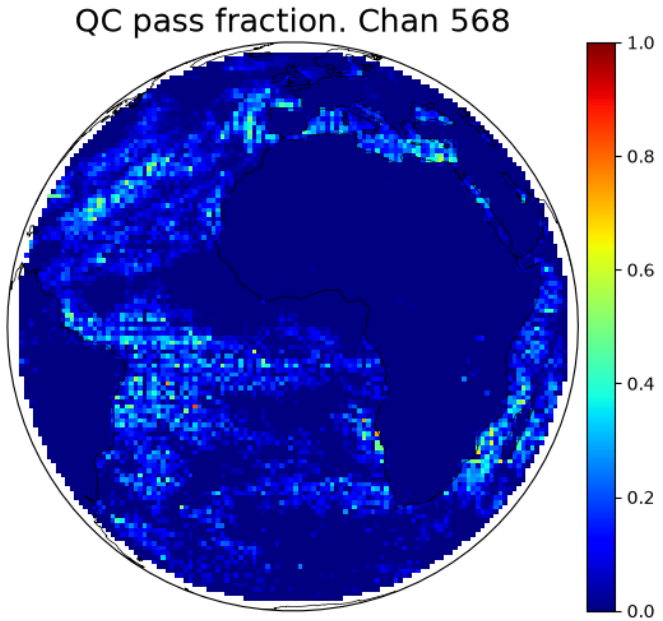


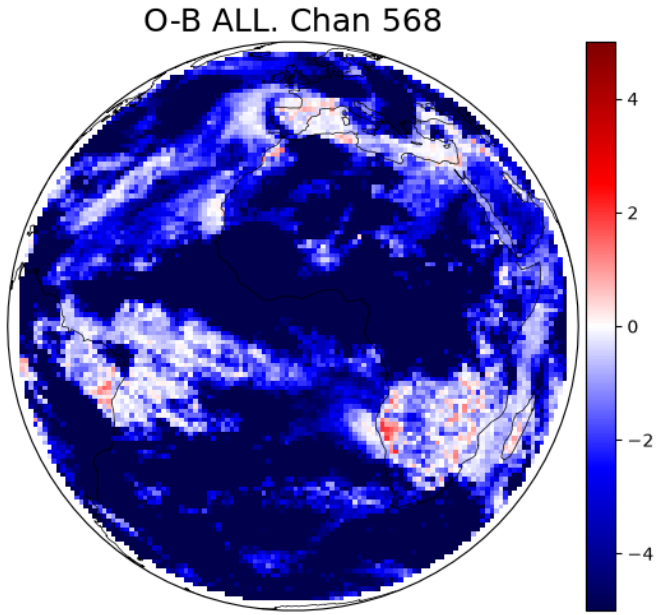


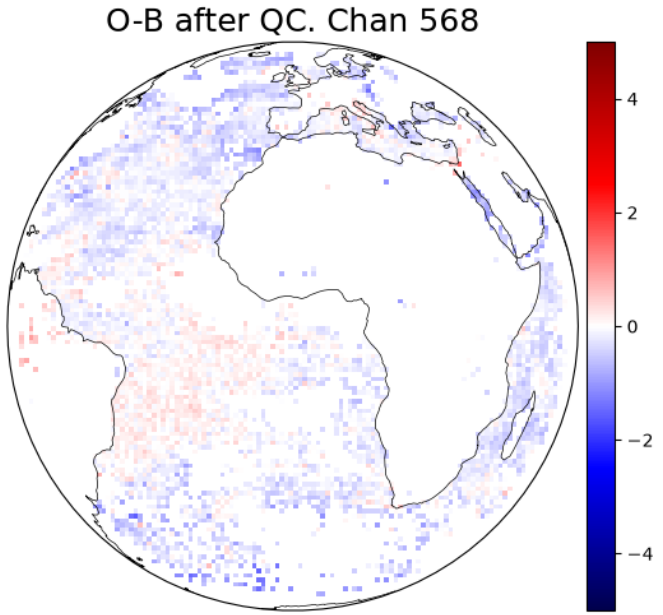
Ozone channel

1022.877 cm^{-1}



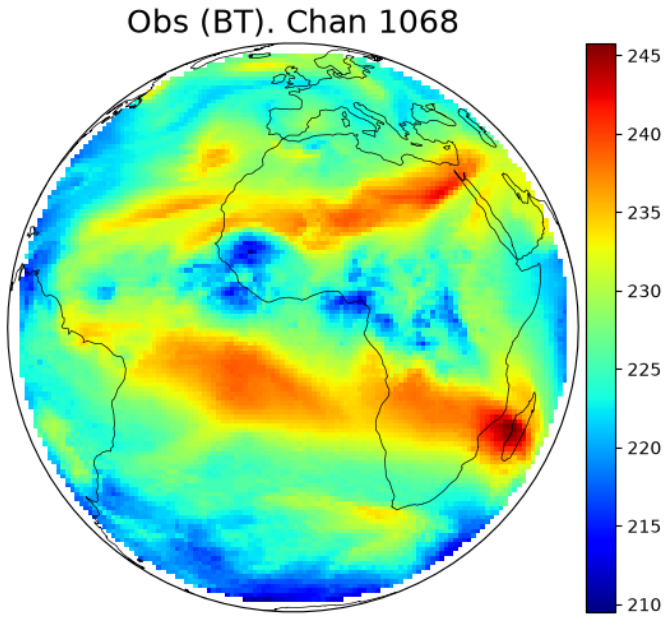


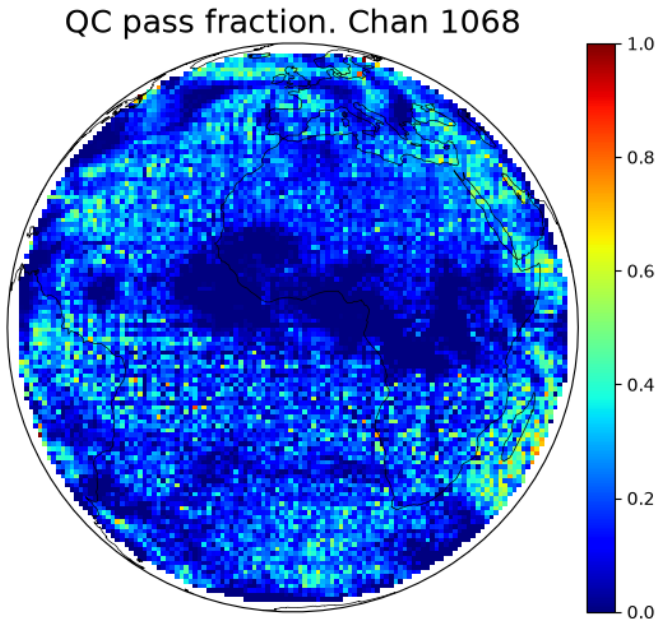


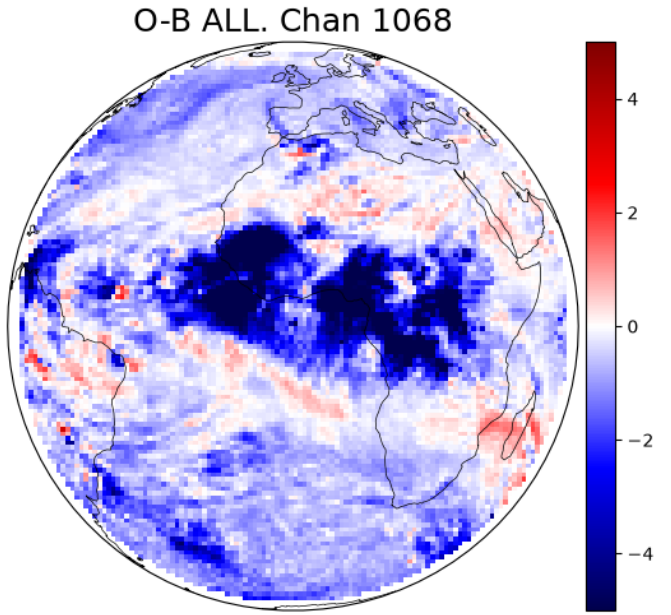


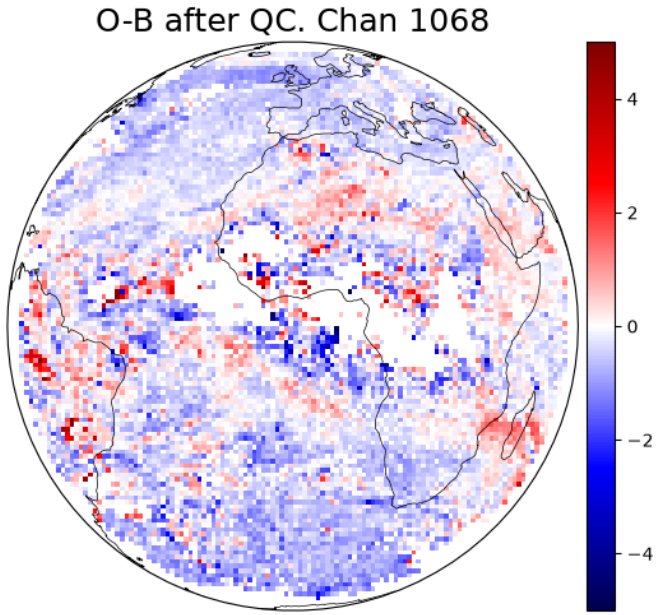
Water vapour channel

~280 hPa
1714.879 cm^{-1}

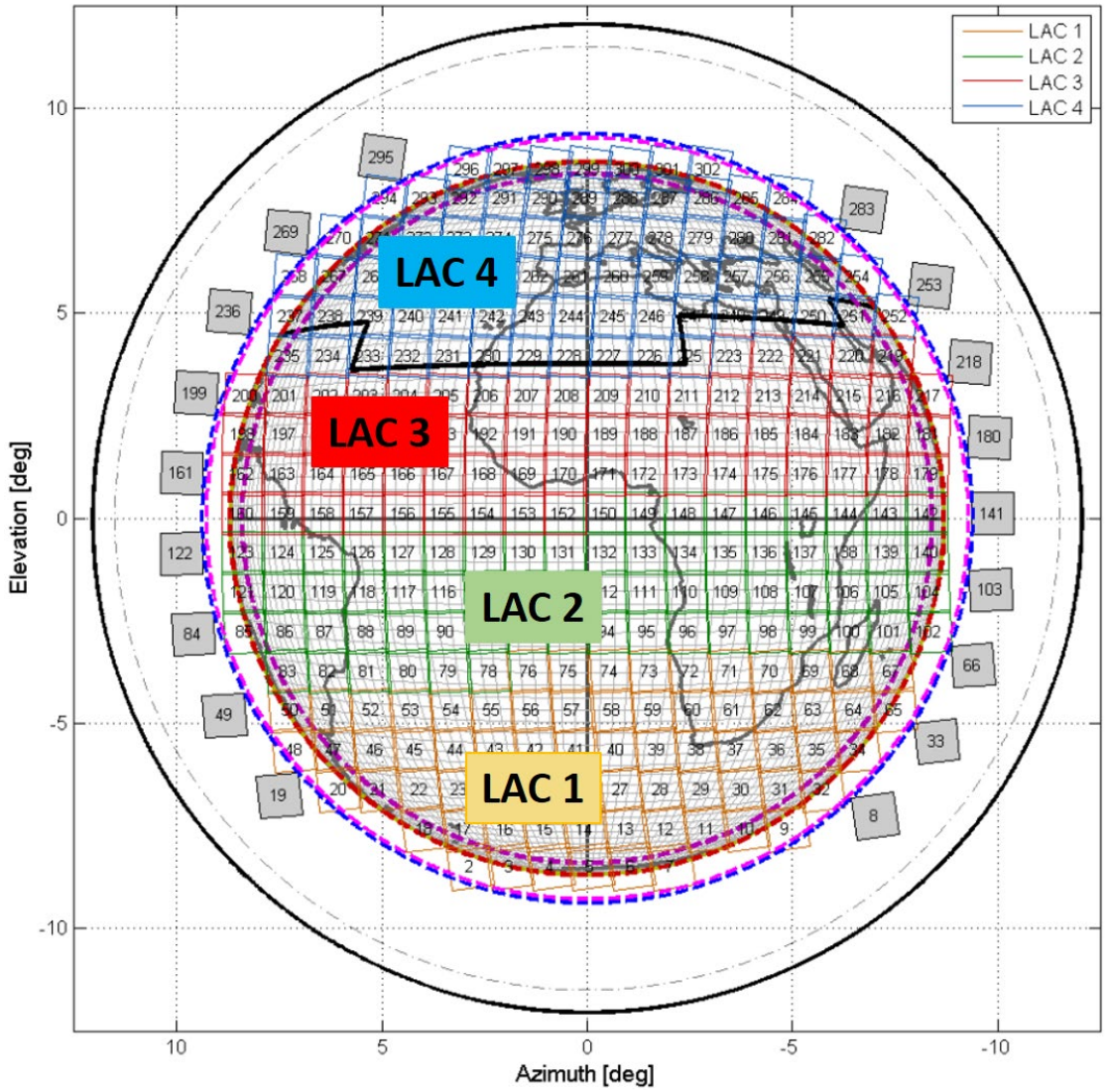






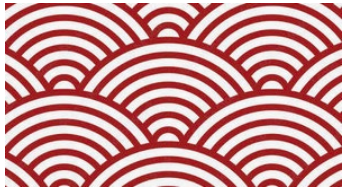


Pixel uniformity



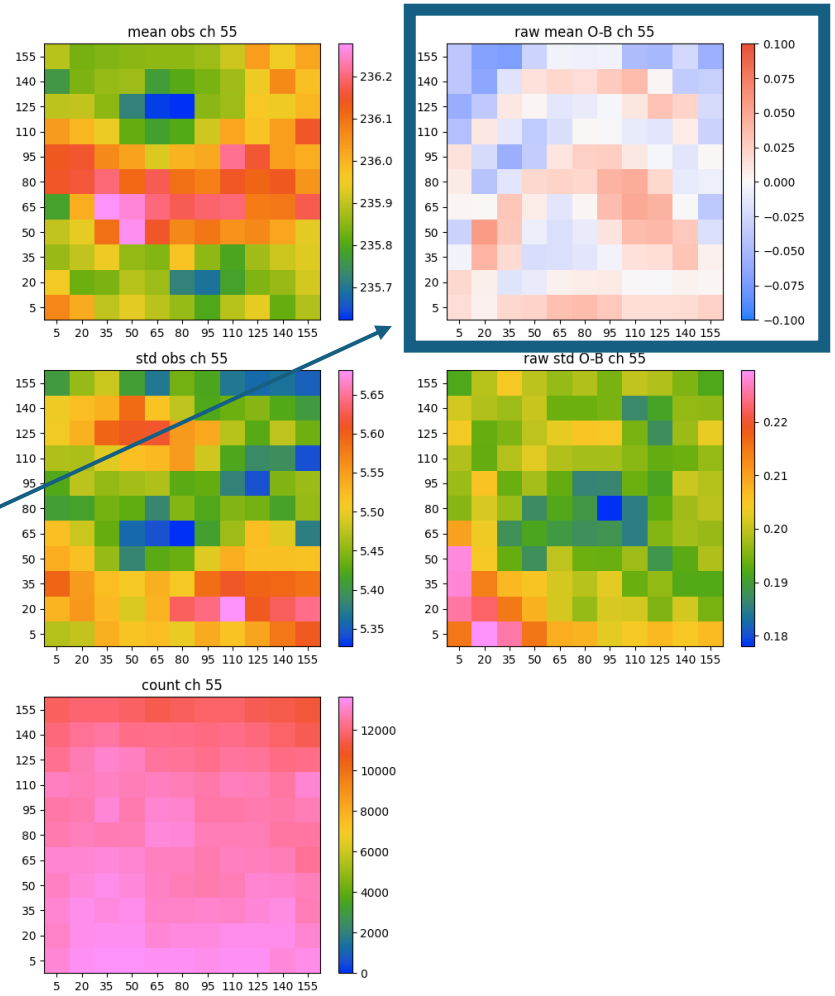
- The instrument has a **square detector array** comprising 160x160=25,600 pixels.
- Assimilation systems can't handle this amount of data, so we conservatively have selected a regular subset of **11x11 pixels**.
- [In fact, at each of these points, we average a grid of 3x3 pixels to give 12km x 12km pixels (comparable to IASI and CrIS).]

These statistics show small but measurable bias variations across the detector array (analysis performed by JMA visiting scientist Naoto Kusano)

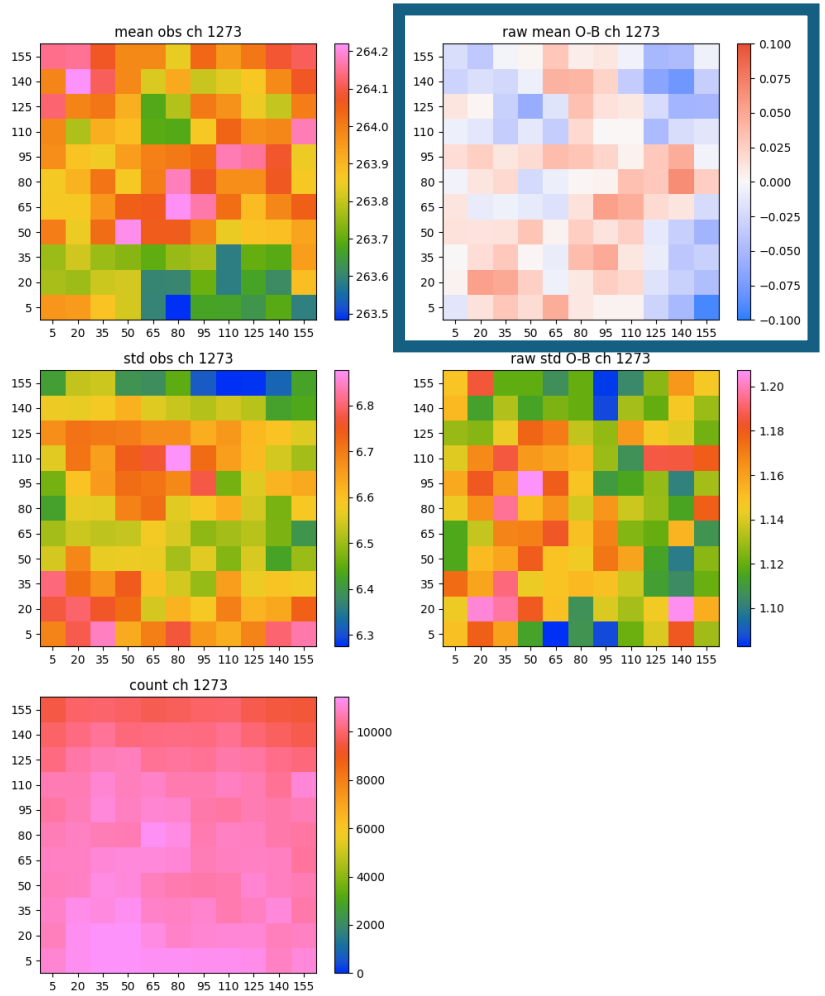


“Seigaiha pattern”

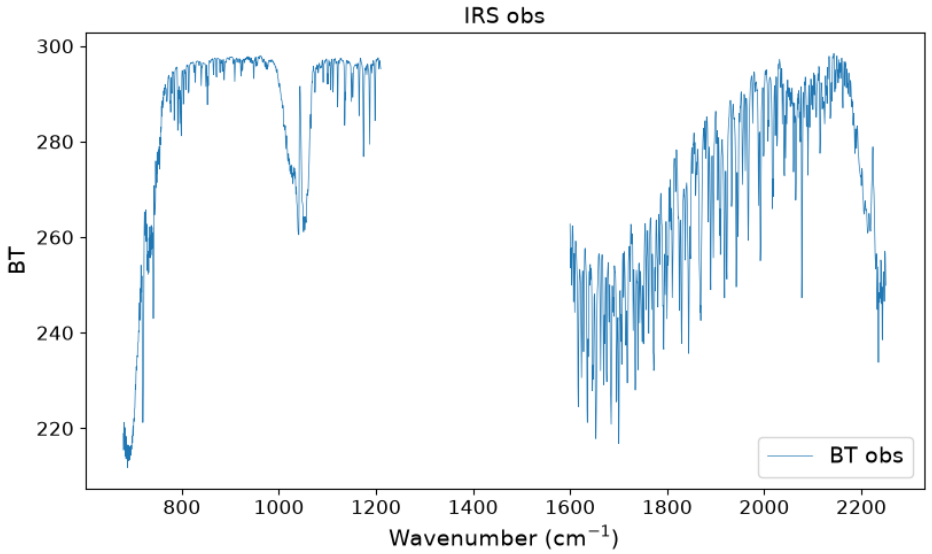
Ch55 (712.19874 cm^{-1})

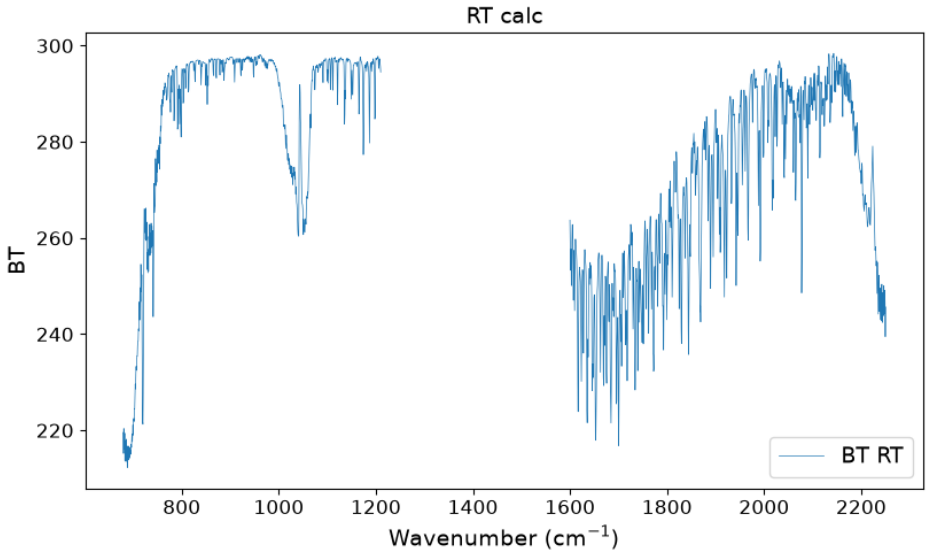


Ch1273 (1838.92628 cm^{-1})

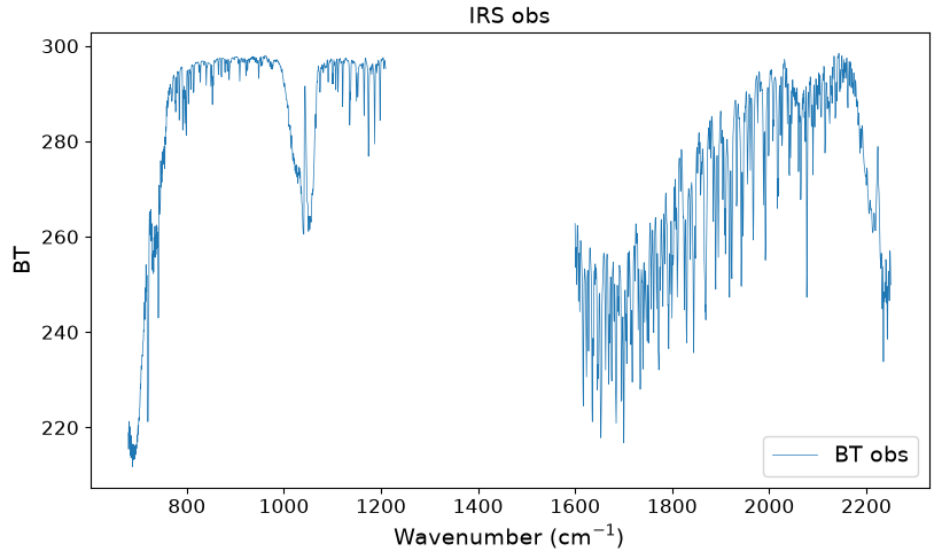


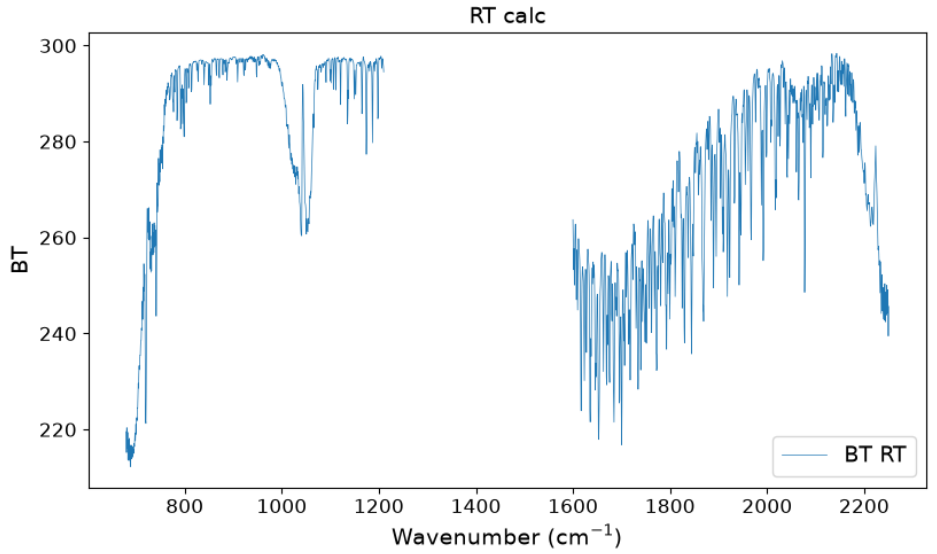
Spectral calibration. Comparison with radiative transfer simulations which are trained on highly accurate spectroscopic line positions

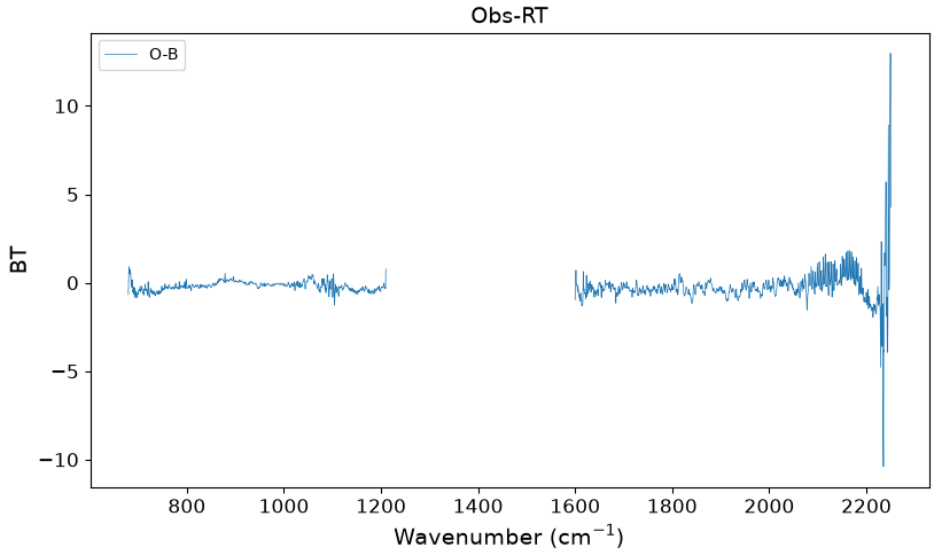


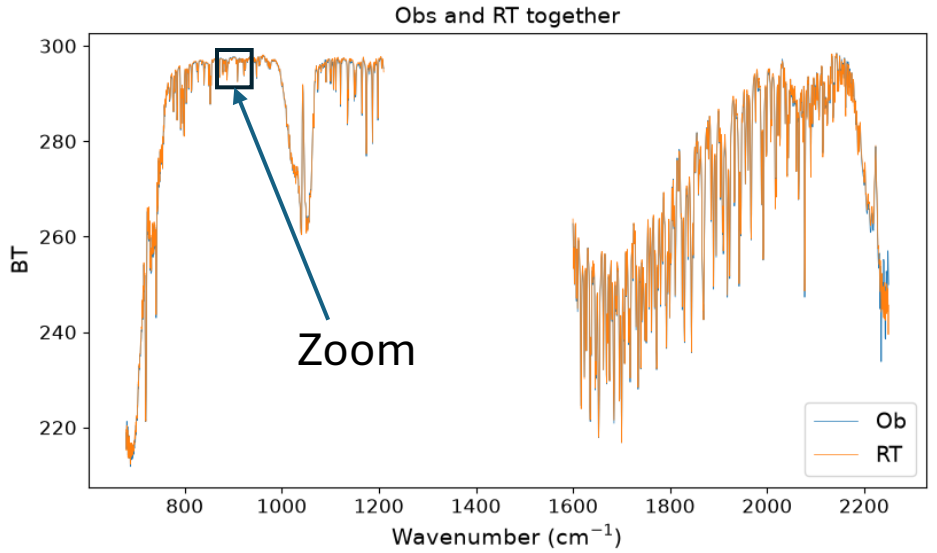


Spectral calibration. Comparison with radiative transfer simulations which are trained on highly accurate spectroscopic line positions

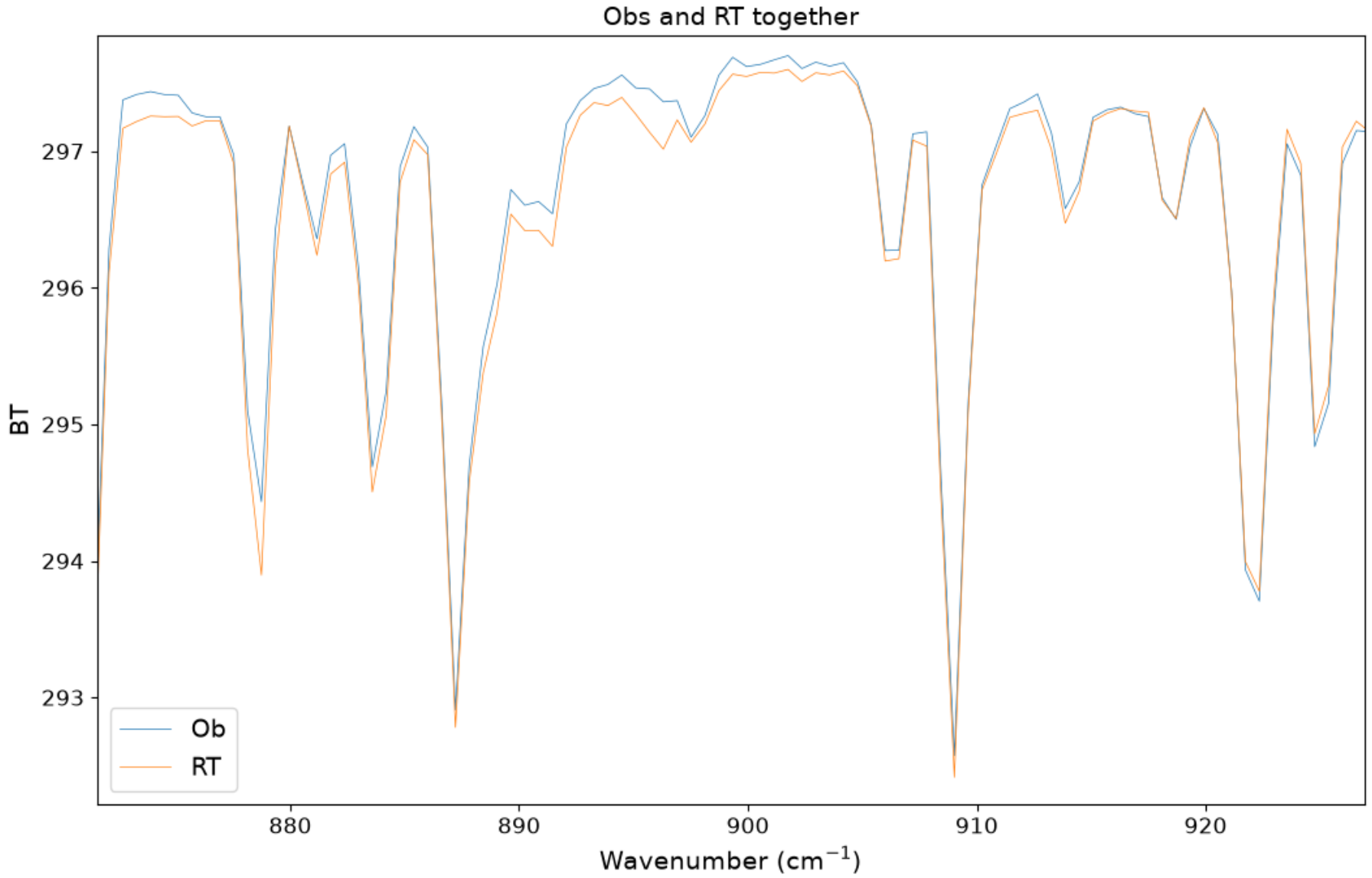








Zooming in, the spectral lines coincide very well in terms of wavenumber, indicating a good spectral calibration



Conclusions on MTG-IRS

- An analysis of O-Bs can provide quality information on:
  - Noise
  - Radiometric accuracy (to an extent)
  - Spatial consistency
  - Spectral calibration

- This is useful feedback to data providers **and** allows us to prepare our assimilation methodology accordingly.

- We are receiving MTG-IRS data in real time, and will begin **monitoring it operationally** very soon, with **active assimilation** to follow shortly after.


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