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David I. Duncan, Niels Bormann, Mohamed Dahoui,
Emma Turner
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Executive summary

The first [MicroWave Sounder \(MWS\)](#) instrument of the [EUMETSAT Polar System Second Generation \(EPS-SG\)](#) programme is evaluated in this report, with its performance and assimilation impact assessed using the ECMWF data assimilation system. MWS is a European-built instrument that carries on the tradition of previous operational sounders like [AMSU-A](#) and [ATMS](#), sampling the 50-60 GHz oxygen band for temperature sounding and the 183 GHz band for humidity sounding, complemented with a set of suitable window channels. The Metop-SG-A1 satellite that carries the first MWS unit was launched in August 2025 and will be renamed Metop-D upon its commissioning. The satellite provides important continuity of coverage in the 9:30 morning orbit with enhanced capabilities, including more channels and finer spatial resolution.

The calibration of MWS is in line with heritage instruments, as evaluated using the [IFS](#) short-range forecast coupled with RTTOV v14 for radiative transfer, i.e. analysing mean background departures. For the requirements evaluated here, the calibration accuracy generally meets end-user requirements, as specified in the EURD. Several of the temperature-sounding channels exhibit non-negligible biases as a function of orbital position; while these biases are within specification they nevertheless require correction before assimilation. Temperature and humidity sounding channels' global biases are generally within ± 0.5 K of the IFS and within a few tenths of a Kelvin of other operational sounders, with a tendency for MWS to be slightly warmer.

MWS temperature sounding channels perform well, with effective noise performance similar to ATMS for tropospheric sounding and significantly better for stratospheric sounding. The 183 GHz suite on MWS had excellent performance up until an anomaly occurred on-orbit in early March of 2026, after which gain was significantly reduced and radiometric noise increased to levels well outside of specifications and far worse than the performance of heritage instruments. This degraded noise performance of the 183 GHz channels greatly reduces their assimilation potential in clear skies, though the measurements in this band still retain some useable information in cloudy scenes that is accessible through all-sky assimilation.

Trials have been conducted with MWS assimilated in various configurations using the all-sky assimilation method. The report focusses on trials that cover the period after the 183 GHz anomaly in early March, with results from earlier trials prior to the anomaly provided in an appendix. Assimilation trials indicate a good forecast impact from MWS. Positive impacts on temperature and humidity are seen in short-range forecasts, judged by fits to independent observations. Medium-range impact is positive for geopotential height and winds, particularly in the Southern Hemisphere and in the lower troposphere. The results also suggest that there is some limited benefit from including the 183 GHz channels in the assimilation despite their high noise levels.

The assimilation configuration detailed in the report paves the way for operational assimilation of MWS on Metop-D later in 2026, as the results presented are clearly positive. However, this configuration was purposefully conservative, focussing on assimilation of channels that are assimilated from equivalent instruments already in ECMWF operations. Relative to ATMS and AMSU, there are channels on MWS that exploit new parts of the spectrum, and these should be a focus for assimilation in future work. Full exploitation of the rich information provided by MWS is a worthy goal, and this report aims to be a reference document for the community in pursuing this.

1 Introduction

Satellite instruments that provide profile information of atmospheric temperature and moisture are a key component of the Earth observing system. Passive microwave radiometers are a key driver of forecast skill quality from Numerical Weather Prediction (NWP) models (e.g. [Duncan *et al.*, 2021](#); [Samrat *et al.*, 2025](#)) and underpin our knowledge of temperature trends due to climate change (e.g. [Mears *et al.*, 2003](#); [Hersbach *et al.*, 2020](#)). The operational legacy of microwave sounding goes back to the Microwave Sounding Unit (MSU) from NOAA that was flown from 1979 into the early 2000s. Its successor was the Advanced Microwave Sounding Unit (AMSU), which has been used operationally used from the late 1990s up through the late 2020s.

The [AMSU-A](#) instrument was flown on nine satellites led by three different space agencies: [NOAA](#), [NASA](#), and [EUMETSAT](#). AMSU-A formed a crucial component of the first-ever polar-orbiting programme from EUMETSAT, flying thrice on the Metop satellite series. As of 2026, AMSU-A and its complementary humidity sounder, MHS, are still active on the Metop-B and Metop-C satellites. The direct successor to AMSU and MHS is the [Advanced Technology Microwave Sounder \(ATMS\)](#), another American-built instrument that is currently operating on three satellites as part of the current NOAA polar programme.

For its second generation of polar-orbiting meteorological satellites, EUMETSAT commissioned development of a new, European-built instrument named the MicroWave Sounder (MWS). The primary objective of MWS is to support NWP at regional and global scales for temperature and humidity sounding (hereafter T- and H-sounding). Three satellites in the [EUMETSAT Polar System Second Generation \(EPS-SG\)](#) will hold an MWS instrument, those in the Metop-SG-A series ([Munro and Coauthors, 2026](#)). The first satellite in this series is Metop-SG-A1, which is renamed Metop-D after its commissioning phase in 2026. The Metop-D satellite was launched on August 13, 2025.

MWS continues a long tradition of exploiting measurements of microwave radiances in the 50-60 and 183 GHz bands to inform atmospheric profiles of temperature and humidity. Like its predecessors MSU, AMSU-A, and ATMS, the MWS instrument is expected to inform our knowledge of atmospheric structure for many years to come, with an operational lifetime expected to last from the 2020s into the 2040s.

In this report, the new measurements from MWS are analysed through the prism of an NWP model's data assimilation system. The approach of evaluating satellite instruments with an NWP model is well established, with applicability ranging from microwave imagers and sounders to infrared sounders ([Newman *et al.*, 2020](#); [Lawrence *et al.*, 2018](#)). This method has three key advantages:

- Analysing instrument performance with an NWP model permits rapid evaluation, as tens of millions of observations are compared against the model background on a daily basis
- The assimilation system already handles several other instruments observing the same radiometric bands as MWS (e.g. ATMS), providing many sources of direct comparison, also known as vicarious inter-calibration
- Technical work to analyse MWS lays the groundwork for assimilation of the data, supporting a key use case of the data

To analyse MWS, this study follows the method pioneered for sounders and applied to the [Arctic Weather Satellite \(AWS\)](#) radiometer in [Duncan *et al.* \(2025\)](#), hereafter D25, as AWS holds many similar channels as MWS and was launched twelve months before Metop-D. The following section contains information

on the MWS instrument and the operational requirements defined by EUMETSAT. Section 3 details the data flow of MWS in the [Integrated Forecasting System \(IFS\)](#), including brief description of the assimilation components relevant for MWS evaluation. Section 4 describes the results of NWP-based cal/val analysis. Section 5 then provides results from assimilating MWS data in observing system experiments (OSEs) in the IFS. The report closes with conclusions and suggestions for future work.

A difficulty in compiling this report is that midway through the evaluation period in March 2026, an on-orbit anomaly occurred that significantly reduced performance of the humidity sounding band at 183 GHz. The report largely focusses on the post-anomaly instrument performance, as the anomaly is likely not recoverable and thus the post-anomaly performance is indicative of its capability going forward for operational users. Some discussion of the pre-anomaly performance can be found at the end of Sec. 4 and in Appendix A.

2 Sensor characteristics and requirements

2.1 The MWS instrument

The MWS instrument is a cross-track scanning radiometer measuring between 23.8 and 229 GHz (Table 1). MWS has an integration time of 13.743 ms per sample with a scan period of 2.253865 s (about 0.44 Hz or 26.6 rpm). As with previous MW instruments like MHS, the MWS scan is optimised to spend over half of its scan period looking at the Earth, thereby maximising integration time and achieving lower radiometric noise than an instrument with constant rotation speed. Each Earth sample subtends a scan angle of 1.049 degrees, with 95 Earth samples between scan angle maxima of ± 49.83 degrees. For comparison, the ATMS instrument has a similar 96 Earth samples per scan and a slightly wider maximum scan angle of 52.725 degrees (Table 2); the AWS radiometer is more heavily oversampled with 145 Earth samples per scan and a much shorter integration time of 2.5 ms. The scan period of MWS achieves continuity of observations for all channels; the beam width of the narrowest channels is about 16 km at nadir, with the satellite covering a track of 14.8 km in one scan. The Metop-D satellite ground-track velocity is 6.58 km/s for an orbit period of 101.35 min ([MWS Science Advisory Group, 2019](#))

MWS holds 24 channels, detailed in Table 1. Many of the channel central frequencies and bandwidths are identical to those of channels on AMSU-A, MHS, ATMS, and others. As ATMS is the most similar instrument, ATMS equivalent channels are shown in the table. Only three channels on MWS do not have direct equivalents on ATMS: MWS-5, -7, and -24. There are no equivalents of 229 GHz on other operational platforms at present, whereas channel 5 has an equivalent on AWS and both 5 and 7 have equivalents on the [Chinese Meteorological Agency \(CMA\)](#) instrument, [MicroWave Temperature Sounder-3 \(MWTS-3\)](#). These new channels were justified as additions to the ATOVS and ATMS channel sets for purposes of cloud ice sensitivity ([Sreerekha et al., 2010](#)) and lower tropospheric T-sounding ([Sreerekha et al., 2007](#)), respectively. MWS-5 and -7 fill in an otherwise unused portion of the spectrum between 53 and 54 GHz. A table linking MWS channels to their equivalents on other cross-track sounders is found later in Sec. 3.

The estimated [Field of View \(FOV\)](#) sizes for MWS channels are also shown in Table 1. MWS FOVs are significantly smaller than those of heritage sounders for its lower frequency channels. For example, MWS has about 39 km FOVs at nadir for 23.8 and 31.4 GHz, compared to 75 km for ATMS; MWS has about 19 km FOVs at nadir for 50 GHz channels versus 32 km for ATMS and 48 km for AMSU-A. This resolution improvement is driven by the reflector aperture of MWS (35 cm effective diameter), which is significantly larger than that of heritage instruments and chosen to achieve the ambitious FOV

Table 1: MWS channel numbers with specified central frequency, bandwidth, and polarisation (*Quasi-Vertical (QV)* or *Quasi-Horizontal (QH)*). Field of view (FOV) sizes are taken from EUMETSAT estimates of nadir FOV at maximum altitude; at minimum satellite altitude, values are 3.2% smaller. Channels types signify window (W) or sounder (S); Jacobian peaks are for global mean clear-sky sensitivity at outer scan positions first and at nadir second; and equivalent ATMS channel is given (if applicable) in the last column.

MWS	Frequency [GHz]	Bandwidth [MHz]	FOV [km]	Pol.	Type	Peak [hPa]	ATMS
1	23.8	270	39.81	QH	W	-	1
2	31.4	180	38.72	QH	W	-	2
3	50.3	180	19.20	QH	W	-	3
4	52.8	400	18.65	QH	W	738-949	5
5	53.246 ± 0.08	140 x 2	18.65	QH	W	572-819	-
6	53.596 ± 0.115	170 x 2	18.65	QH	S	474-655	6
7	53.948 ± 0.081	142 x 2	18.65	QH	S	387-529	-
8	54.40	400	18.65	QH	S	280-392	7
9	54.94	400	18.65	QH	S	181-260	8
10	55.50	330	18.65	QH	S	126-170	9
11	57.290334=ν	330	18.13	QH	S	66-85	10
12	ν ± 0.217	78 x 2	18.13	QH	S	36-48	11
13	ν ± 0.3222 ± 0.048	36 x 4	18.13	QH	S	17-22	12
14	ν ± 0.3222 ± 0.022	16 x 4	18.13	QH	S	8-11	13
15	ν ± 0.3222 ± 0.010	8 x 4	18.13	QH	S	4-5	14
16	ν ± 0.3222 ± 0.0045	3 x 4	18.13	QH	S	2-3	15
17	89.0	4000	16.16	QV	W	-	16
18	165.5 ± 0.725	1350 x 2	16.09	QH	W	878-923	17
19	183.311 ± 7.0	2000 x 2	16.19	QV	W	750-791	18
20	183.311 ± 4.5	2000 x 2	16.19	QV	W	668-716	19
21	183.311 ± 3.0	1000 x 2	16.19	QV	S	599-649	20
22	183.311 ± 1.8	1000 x 2	16.19	QV	S	517-565	21
23	183.311 ± 1.0	500 x 2	16.19	QV	S	454-503	22
24	229.0	2000	16.37	QV	W	847-895	-

Table 2: Scan geometry parameters for the MWS and ATMS instruments.

	MWS	ATMS
Swath width [km]	2210	2500
Integration time [ms]	13.74	18
Scan spacing [km]	14.8	16
Beam width [deg]	1.049	1.11
Max scan angle [deg]	49.83	52.725
Full scan period [s]	2.254	2.67
Earth samples per scan	95	96

specifications (MWS Science Advisory Group, 2019). Unlike ATMS, MWS uses the same reflector for all frequency bands. The footprint increases as a function of scan angle, with larger FOVs at scan edge. For MWS specifications, this leads to edge of scan FOVs of about 67x132, 34x66, and 29x56 km for channel sets 1-2, 3-16, and 17-24, respectively (see MWS Science Advisory Group, 2019, their Fig. 8). MWS has co-located beams on the ground due to its quasioptics. This means that despite different FOV sizes, the beam centres share the same geolocation.

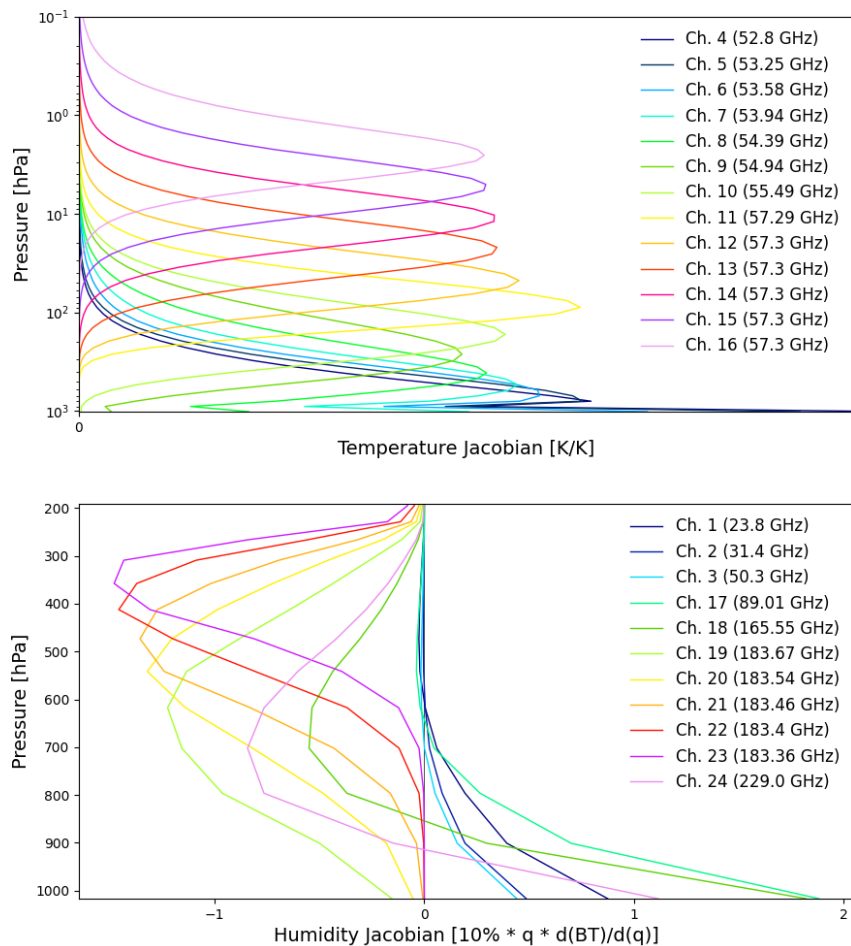


Figure 1: Temperature (top) and humidity (bottom) Jacobians for MWS channels, from RTTOV v14 using a mid-latitude profile and a nadir view.

The Noise Equivalent Differential Temperature (NEDT) requirements are specified in terms of the integrated noise over the -3dB FOV, swept out across-track. In this report we refer to this as the “footprint” NEDT. More relevant for NWP applications is the so-called “sample” NEDT, i.e., the noise inherent in each observation provided to the user. In contrast to a heavily over-sampled instrument like AWS, the spatial sampling of MWS is close to contiguous at high frequencies and slightly over-sampled at low frequencies. Thus the conversion between sample and footprint NEDT values is effectively 1.0 for MWS channels 3-24, and 1.53 for MWS channels 1-2 (MWS Science Advisory Group, 2019).

Lastly, the profiling capabilities of MWS are of course key to its use as a sounder. These are illustrated in Fig. 1, which shows Jacobians of the temperature and sounder channels separately for a typical mid-latitude profile as simulated for a clear-sky scene with RTTOV. Humidity Jacobians can change significantly with scene type, and plots are found in appendix B to illustrate this variation.

Table 3: MWS channel specifications from the EURD for lower and upper ends of the dynamic range, FOV size at the -3 dB level, footprint NEDT, and centre frequency stability.

Ch. #	Lower [K]	Upper [K]	FOV [km]	NEDT [K]	Stability [MHz]
1	80	315	40	0.25	± 5.0
2	80	315	40	0.35	± 10.0
3	100	310	20	0.50	± 5.0
4	100	295	20	0.35	± 3.0
5	100	285	20	0.40	± 5.0
6	100	280	20	0.40	± 2.0
7	100	270	20	0.40	± 1.0
8	100	260	20	0.35	± 2.0
9	100	250	20	0.35	± 2.0
10	100	240	20	0.40	± 2.0
11	100	245	20	0.40	± 0.5
12	100	250	20	0.55	± 0.5
13	100	270	20	0.60	± 1.2
14	100	290	20	0.90	± 1.2
15	100	295	20	1.20	± 0.5
16	100	295	20	2.00	± 0.2
17	80	315	17	0.25	± 130
18	80	315	17	0.50	± 40
19	80	310	17	0.40	± 30
20	80	305	17	0.40	± 30
21	80	300	17	0.60	± 30
22	80	300	17	0.60	± 30
23	80	295	17	0.75	± 30
24	80	315	17	0.70	± 100

2.2 Considered user requirements

The MWS performance is specified through user requirements, as given in the EURD (see appendix C). Below we list the requirements that are evaluated in the present study via comparisons between MWS observations and equivalents from a short-range forecast; requirements not relevant for our analysis are omitted. In some cases, the wording of requirements has been amended for brevity.

- **MWS-02080** The radiometric sensitivity requirement is given in Table 3. The values listed define one standard deviation and depend on the spectral channel. Values of NEDT refer to scene temperatures less than 280 K.
- **MWS-02090** The radiometric bias shall be 1 K for all channels and for the whole dynamic range.
- **MWS-02100** The orbit stability shall be such that variations of the radiometric bias of the measured TB during any single orbit shall be < 0.20 K.
- **MWS-02110** The lifetime stability shall be such that variations of the running average over one orbit of radiometric biases of measured TB shall be < 0.20 K.
- **MWS-02120** Inter-channel radiometric bias differences between TBs of the same spatial sample shall be < 0.5 K.
- **MWS-02130** Radiometric bias differences between TBs of the same spectral channel at different spatial samples shall be < 0.3 K.

Table 4: MWS EURD requirements linked with departure-based analyses. Titles given here are short descriptions—see Sec. 2.2 for fuller requirement descriptions.

Requirement(s)	Topic	Analysis
02080	Noise	NEDT will be assessed from $SD(O - B)$ global mean time series for T-sounding channels, with gross violations of NEDT investigated for H-sounding and window channels if necessary; effective NEDT for T-sounding can be estimated roughly following D25
02090	Radiometric bias	Evaluate $mean(O - B)$ over a suitable period, by channel and by scene temperature
02100/10	Orbital stability	Monitored over multi-day periods with Hovmöller diagrams showing orbital angle vs. time for $mean(O - B)$; intra-orbit stability can be examined as a function of scan line for shorter periods as needed
02120	Inter-channel bias	Assessed via $mean(O - B)$ with reference to other instruments where appropriate, over a suitably long time period
02130	Inter-sample bias	$mean(O - B)$ as a function of scan position is evaluated using a special experiment in which superobbing (spatial averaging) is not performed

Table 4 links the EURD requirements listed above to specific analyses based upon IFS departures. We will return to these in Sec. 4.

3 MWS and the IFS

Here relevant background information is provided that informs the cal/val monitoring and assessment of MWS in the IFS. For more general descriptions of all-sky radiance assimilation in the IFS, these can be found in the literature (e.g. [Geer *et al.*, 2014, 2022](#); [Duncan *et al.*, 2026](#)). Full documentation of the IFS can be found at <https://www.ecmwf.int/en/publications/ifs-documentation>. Most of the method as applied to MWS follows the method for AWS detailed by D25.

3.1 Pre-processing of MWS data

MWS level 1 data are acquired from EUMETCast Terrestrial in BUFR format, with all 24 channels co-located and sharing the same viewing geometry. This is in contrast to some instruments like AWS that have feedhorns pointing in different directions and therefore require special consideration. The pre-processing of MWS level 1 radiances is simpler in comparison.

Pre-processing of MWS observations follows that of most MW instruments, with radiances superobbed prior to ingestion to the IFS. For sounders like MWS, a Gaussian grid of approximately 50 km spatial resolution is used for superobbing. This is illustrated in Fig. 2, with native-resolution observations on the left and 50 km superobs on the right. Given the scan spacing of 14.8 km and 95 spots per scan, this leads to a maximum of about 12 observations per 50 km superob near nadir, with fewer observations per superob at higher view angles.

The superobbing step serves multiple purposes for MW radiances ([Duncan *et al.*, 2024](#)). First, it homogenises observations between different instruments in a way that is beneficial for cal/val and assimilation alike. For example, despite AWS having quite different spatial sampling and integration time, it is immediately comparable to MWS when superobbed to the same resolution. This is a key consideration for the “double difference” approach with vicarious cal/val monitoring, as each instrument is averaged and screened in the same way. Second, it reduces representation error for cloud-sensitive channels and significantly reduces effective noise for sounding channels. Third, superobbing reduces the data volume by almost an order of magnitude—one 12 hr long-window data assimilation cycle has about 1.8m MWS observations per channel, versus about 270k after superobbing.

In contrast to the “3x3” averaging commonly applied to ATMS radiances for clear-sky assimilation ([Bormann *et al.*, 2013](#)), grid-based superobbing is applied for all-sky sounders in the IFS (AWS, MHS, and MWHS-2). The grid-based superobbing allows for more of the total swath to be used for assimilation, but does have the side effect that effective noise reduction differs between low and high view angles. This is particularly relevant for T-sounding channels, for which instrument noise dominates over representation error in clear-sky regions. This needs to be taken into account when specifying observation errors for assimilation. We will return to this in Sect. 3.2.3. In this report, ATMS cal/val results use the same data treatment as applied to MWS (50 km superobs and forward modelling in all-sky conditions) to permit direct comparison of radiometric behaviour. Furthermore, the only MW sounder not superobbed in the IFS is AMSU-A, whose 48 km footprints at nadir are similar to the 50 km superobs without any averaging applied.

3.2 Processing in the IFS

After pre-processing, MWS radiances are ready for ingest to the IFS in ODB format. In this report, all results come from experiments running IFS Cycle 50r1, which is the operational version of the IFS as of

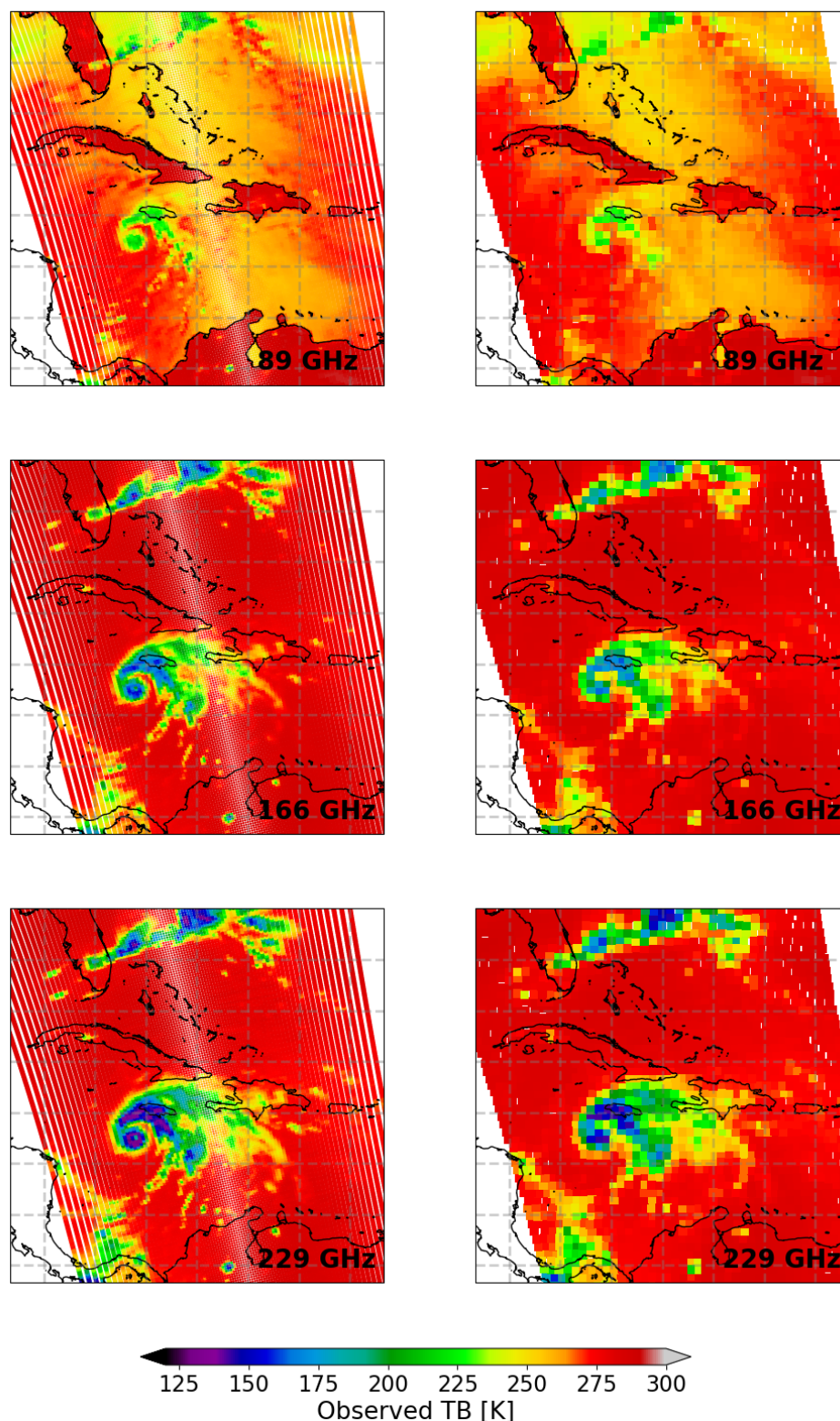


Figure 2: Observed TBs for three MWS window channels (17, 18, 24) over major hurricane Melissa, 28th October, 2025. The left panels show full-resolution observations; the right panels show the data after 50 km superobbing has been applied. Channel centre frequencies are labelled. Plotted pixel sizes do not correspond to the footprint sizes.

May 2026. IFS Cycle 50r1 uses RTTOV-SCATT v14.0 as the forward model for all-sky MW radiances, simulating scattering and emission from atmospheric gases and hydrometeors, with scattering properties unchanged from RTTOV v13 (Geer *et al.*, 2021) and sea surface emissivity given by SURFEM-Ocean (Kilic *et al.*, 2023). For MWS, the RTTOV absorption coefficients are derived from pre-launch laboratory measurements of the [Spectral Response Function \(SRF\)](#), publicly available from the [NWP-SAF](#), considering oxygen, water vapour, and ozone as variable gases.

3.2.1 Departures and bias correction

With observed brightness temperatures (TBs) and an all-sky forward model (RTTOV-SCATT), observations minus model background (or $O - B$) are computed in every data assimilation step to compare the short-range forecast with observed TBs. The data assimilation method (in this case, incremental 4D-Var) iterates to optimally blend the a priori information from the background in observation space (B) with the observations (O). To do this, observational biases need to be removed by variational bias correction (VarBC; Dee (2004)). For MWS, the application of VarBC follows the implementation of heritage sounders, with various air-mass, scan angle, and other predictors applied in linear combination, dependent on the channel sensitivities. The BC term shown below encapsulates the net correction, which is a linear combination of several bias predictors and coefficients that are updated in every data assimilation cycle.

$$D = O - B \quad (1)$$

$$D_{BC} = (O - B) - BC \quad (2)$$

The main parameter discussed in this study is $O - B$ (sometimes called the departure, D), given in Kelvin. Means and standard deviations (SD) of $O - B$ are helpful for diagnostic evaluation of observations as well as for analysis of model behaviour. In practice for NWP, $O - B$ is almost always analysed after bias correction (D_{BC}). However, for cal/val purposes most departure statistics use $O - B$ without bias correction (D), as assessment of biases is one of the key topics of interest.

Background departures are available for all channels (both with and without bias correction applied) after the IFS has run the background trajectory for a given assimilation cycle—the short-range forecast of 12 hours.

3.2.2 Cloudiness proxies

As in D25, we define the cloud indicator (CI) as a useful parameter to quantify cloudiness for both cal/val screening and observation error modelling:

$$CI = |(O - BC) - B_{clr}|/2 + |B - B_{clr}|/2 \quad (3)$$

Here the model background is used from both all-sky simulations (B) and clear-sky simulations (B_{clr} , excluding radiative effects from clouds and precipitation). CI gives equal weight to modelled and observed cloud signals, providing a per-channel, per-scene indication of cloudiness in observation space (i.e., in Kelvin), and we use a subscript to indicate the channel number. For example, CI_5 for channel 5 yields smaller values on average than CI_{17} , as MWS channel 17 is much more cloud-sensitive in TB space.

In addition to CI , the scattering index (SI) is defined following Geer *et al.* (2014). In Eq. 4 below, TB_{low} and TB_{high} signify low and high frequency channel pairings, respectively. For MWS, one instance of SI is used: a difference of 89 and 165.5 GHz (channels 17 and 18). C_{SI} is the symmetric cloud predictor following Geer and Bauer (2011), with observed and simulated halves to capture cloud signals in both observation and model.

$$C_{SI} = [(TB_{low,O} - TB_{high,O}) + (TB_{low,B} - TB_{high,B})]/2 \quad (4)$$

3.2.3 Observation errors

With $O - B$ calculated, the data assimilation system needs to know how much weight to give an observation in the minimisation. All-sky observation error models (Geer and Bauer, 2011) provide the total error for assimilation (which includes instrument noise, forward model error, and representation error), with prescribed errors increasing as a function of a cloudiness proxy. Observation error models are determined empirically by analysing several weeks of $SD(O - B)$ as a function of cloud amount and fitting a curve that encapsulates the main behaviour. Cloudiness proxies vary depending on the channel sensitivities.

All-sky observation error models for MWS follow those of AWS and heritage sounders like MHS. The observation error parameters are provided in Table 5, with cloud proxies defined as CI_3 for channels 1 and 2, CI_4 for channels 6-11, and C_{SI} for channels 19-23. The stratospheric channels 12-16 have a flat observation error that does not depend on surface type or cloud amount. An illustration of the observation errors over ocean and land for all-sky channels assimilated in this report is given in Fig. 3, with departure statistics for a fortnight. The dashed lines show the total all-sky observation error as a function of cloudiness (σ_{allsky}), with values in Table 5 giving the σ_{clr} and σ_{cld} that determine the total error following Geer and Bauer (2011). For MWS, the clear-sky proxy (C_{clr}) is 0 in all channels and thus not shown, with C_{cld} defining the maximum cloud proxy, i.e. where the error model maximises at σ_{cld} .

As described in D25, T-sounding channels that are superobbed on a fixed grid exhibit effective noise characteristics that vary as a function of scan position, and this needs to be accounted for in the observation error model. Thus Table 5 has a column for σ_{zen} , an empirically derived term that increases observation errors at higher zenith angles (θ) where fewer observations are superobbed together and effective noise is therefore larger. Taken from D25, below are the equations for noise scaling ($f_{scale}(\theta)$) and total observation error for T-sounders (σ_{total}). The noise term is added in quadrature to the term from the traditional all-sky error model that scales as a function of cloud amount (σ_{allsky}) as shown in Eq. 6.

$$f_{scale}(\theta) = 0.1 + 0.9 \exp(-0.8\theta^2) \quad (5)$$

$$\sigma_{total} = \sqrt{\sigma_{allsky}^2 + (\sigma_{zen}/f(\theta))^2} \quad (6)$$

This augmentation of the all-sky error model for T-sounder channels is illustrated in Fig. 4, with observation errors and $RMS(O - B)$ shown across the MWS scan. The patterns are symmetric around nadir as expected, with larger $RMS(O - B)$ at outer scan positions where zenith angles are larger and fewer observations constitute a single superob. Where the normalised departures (dashed) line is relatively flat across the plot, this signifies that the effective noise variation has been handled adequately by the observation error model. Some slight variations exist, such as a mild “W” shape in channel 10, for example, and slight under-weighting of scan edges for channel 8. On the whole, however, the method as originally

Table 5: Components of the all-sky observation error model for MWS channels assimilated in this report. The σ values are in Kelvin, and C_{cld} is in units of Kelvin. The last column (A , unit-less) signifies the a priori probabilities of gross error for VarQC following [Andersson and Järvinen \(1999\)](#).

Ch	Surface	σ_{clr}	σ_{cld}	C_{cld}	σ_{zen}	A
1	Sea	2.60	16.0	15.0	0.0	0.50
2	Sea	2.40	30.0	15.0	0.0	0.50
6	Sea	0.21	2.2	3.6	0.08	0.20
6	Land	0.25	6.5	8.0	0.08	0.20
8	Sea	0.14	0.54	4.0	0.06	0.10
8	Land	0.14	1.8	8.0	0.06	0.10
9	Sea	0.11	0.25	4.0	0.08	0.02
9	Land	0.12	0.45	8.0	0.08	0.02
10	Sea	0.12	0.19	4.0	0.10	0.01
10	Land	0.12	0.25	8.0	0.10	0.01
11	Sea	0.13	0.20	4.0	0.10	0.003
11	Land	0.13	0.22	8.0	0.10	0.003
12	All	0.20	-	-	0.16	0.003
13	All	0.27	-	-	0.22	0.15
14	All	0.40	-	-	0.35	0.15
15	All	0.58	-	-	0.50	0.15
16	All	0.90	-	-	0.85	0.05
19	Sea	3.0	27	26	0.0	0.50
19	Land	3.0	39	22.4	0.0	0.50
20	Sea	3.0	20	30	0.0	0.50
20	Land	3.0	33	22.4	0.0	0.50
21	Sea	3.0	16	34	0.0	0.30
21	Land	3.0	23	24.5	0.0	0.30
22	Sea	3.0	11	36	0.0	0.30
22	Land	3.0	16	24.5	0.0	0.30
23	Sea	3.0	8	37	0.0	0.30
23	Land	3.0	11	24.5	0.0	0.30

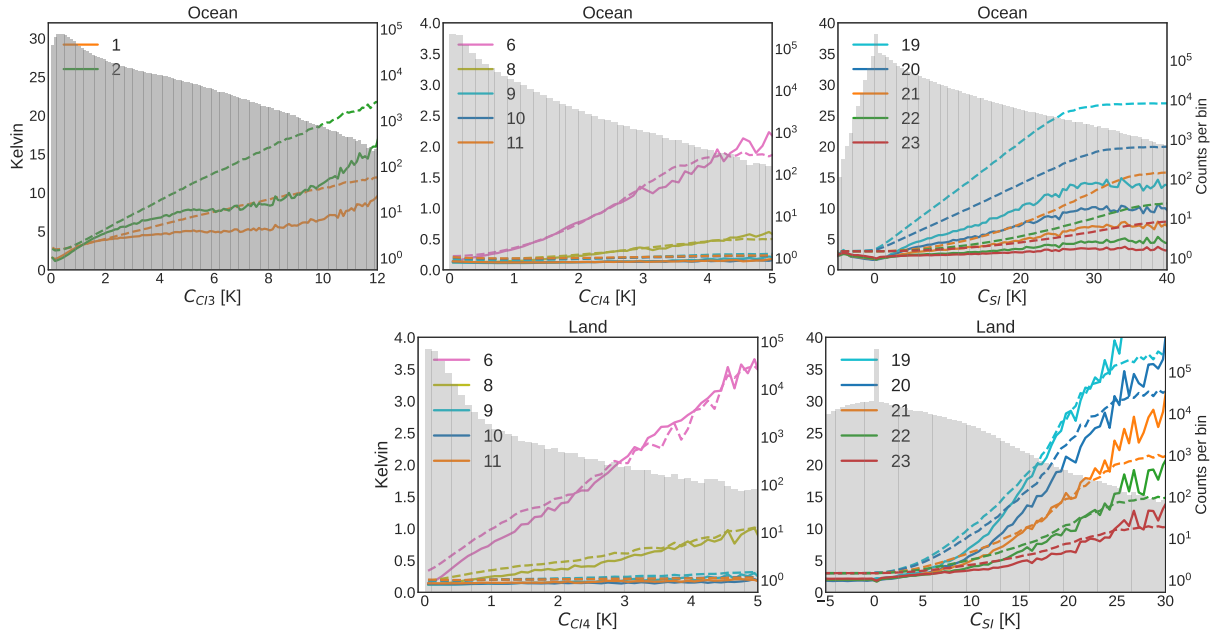


Figure 3: Observation error models (dashed) and $SD(O - B)$ (solid) for MWS channels assimilated in this report, split up by surface type with ocean (top) and land (bottom). Channels are grouped by the all-sky cloud proxy used, and the channels displayed are given by their channel number in the legend of each panel. Data plotted represent statistics for assimilated observations (after all QC measures) from an experimental period spanning April 2-15, 2026 (i.e., after the 183 GHz anomaly). Grey histogram bars show the counts per bin.

formulated for AWS tropospheric channels appears to work well from mid-tropospheric through upper stratospheric T-sounding channels on MWS.

The normalised departures for the stratospheric channels are very conservative, averaging about 0.4. These particularly cautious observation errors for stratospheric channels are driven by historical experience with AMSU-A in particular, as prior instances led to larger observation errors than might be expected from analysis of departures alone. This setting may warrant reconsideration in the future, as the excellent noise performance of MWS stratospheric channels is likely being under-utilised in the assimilation at present.

3.3 Other sounders in the IFS

Several MW sounders are actively assimilated in the IFS as of early 2026. These provide important context for MWS, in terms of both cal/val assessment and gauging assimilation impact. They include five instruments (AMSU-A, ATMS, AWS, MHS, MWHS-2) on a total of eight satellites. Some conically-scanning MW imagers include sounding channels (SSMIS, GMI), but these are not considered here due to their different viewing geometry.

Table 6 lists the centre frequencies of MWS and the equivalent channels that are available from other instruments. The term “equivalent channel” is meant to confer similar geophysical sensitivity, despite possible differences in bandwidth, centre frequency, or polarisation. For example, MWS channel 23 is equivalent to AWS channel 15 because both are sensitive to upper tropospheric humidity with nearly identical jacobians, despite AWS channel 15 having a single-sideband at 182.31 GHz in contrast to MWS with dual sidebands at 183.31 ± 1.0 GHz. That said, some of the polarisation and frequency differences

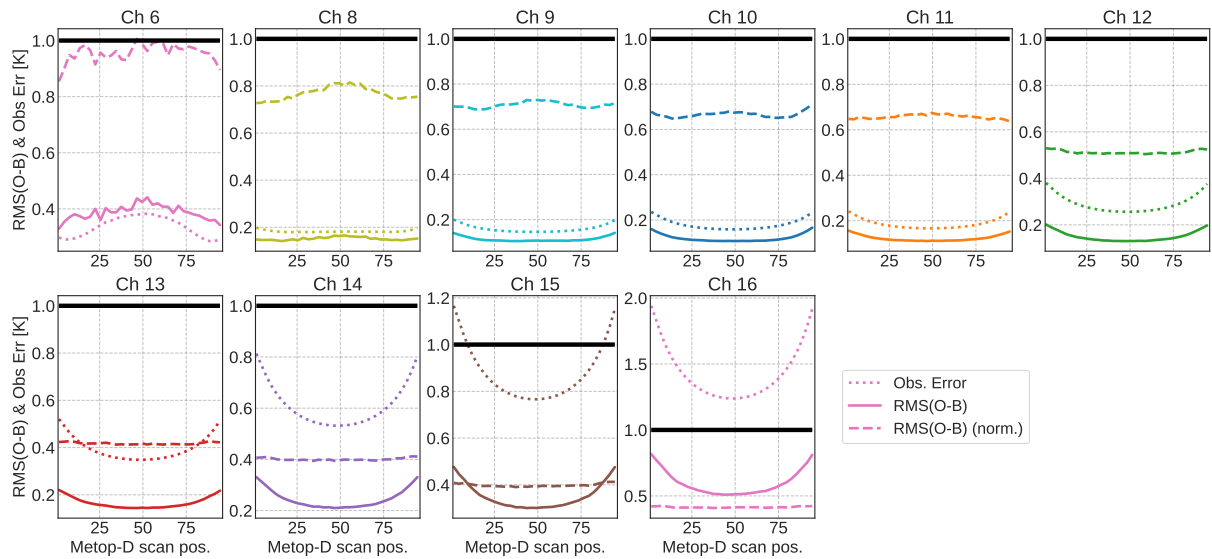


Figure 4: Observation errors (dotted line) shown as a function of MWS scan position, along with $RMS(O - B)$ (solid) and the $RMS(O - B)$ normalised by observation error (dashed). Data come from the same sample as Fig. 3, showing the T-sounding channels assimilated in this report.

are worth bearing in mind when interpreting results. For instance, ATMS has **QV** polarisation at 23.8 GHz in contrast to MWS with **QH**.

Due to the significance of comparisons with ATMS, it is worth discussing the scan geometry differences between MWS and ATMS in detail (Table 2). As with their channel complements, this table illustrates how the two instruments are quite similar but differ in crucial ways. For example, despite a nearly identical number of samples per scan, MWS scans more rapidly and with a shorter integration time than ATMS. These details are important especially when contrasting the instruments' noise performance at the level of un-averaged observations.

Metop-D has an **Equator crossing time** of 21:30 local time on its ascending node (**LTAN**), following the orbital plane of Metop-B¹ and -C. The approximate LTANs of satellites with MW sounders that are assimilated in the IFS as of early 2026 are given in Table 7.

The local time of observations is a key consideration in the context of OSEs, with impact in the assimilation system potentially dependent on how an instrument's orbit overlaps or complements the orbits of other instruments. For example, observations late in the assimilation window typically have a larger impact on the analysis (McNally, 2019), an effect that was visible in several ways with AWS (Duncan et al., 2026) and also FY-3E before (Steele et al., 2023). As of spring 2026, Metop-D is very close to Metop-C for purposes of tandem flying for EUMETSAT's cal/val evaluation, with Metop-B and AWS fairly close ahead and behind, respectively. While very useful for cal/val, the positioning is suboptimal for NWP impact, as observations more evenly spaced in the assimilation window provide a greater constraint on the analysis. This is indeed the driving philosophy behind the EPS-Sterna constellation (Eresmaa et al., 2026; Lean et al., 2025), whereas the Metop series needs to cover the 21:30 orbit by international agreement.

¹The orbit of Metop-B has been drifting in recent months to a slightly earlier LTAN than its previous 21:30.

Table 6: MWS equivalent channel numbers on selected other cross-track instruments. Channels with an asterisk (*) constitute significantly different frequency matches (e.g., 157 vs. 165 GHz or single vs. double passband). Parentheses () indicate a different polarisation (e.g. QV vs. QH) than MWS.

Centre Freq. [GHz]	MWS	AWS	ATMS	AMSU-A	MHS	MWHS-2
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=v	11	(8)	10	9		
$v \pm 0.217$	12		11	10		
$v \pm 0.3222 \pm 0.048$	13		12	11		
$v \pm 0.3222 \pm 0.022$	14		13	12		
$v \pm 0.3222 \pm 0.010$	15		14	13		
$v \pm 0.3222 \pm 0.0045$	16		15	14		
89.0	17	9	16	15	1	(1)
165.5	18	(10)	17		(2*)	10*
183±7	19	11*	(18)		5*	15
183±4.5	20	12*	(19)			14
183±3	21	13*	(20)		(4)	13
183±1.8	22	14*	(21)			12
183±1	23	15*	(22)		(3)	11
229	24					

Table 7: Satellites holding passive microwave sounders assimilated in the IFS as of early 2026, plus MWS on Metop-D. Local equator crossing times given for ascending node (LTAN) are approximate, as some are drifting in time.

Satellite(s)	Sensor(s)	Launch	LTAN
FY-3D, -3E	MWHS-2	2017, 2021	15:40, 17:40
SNPP, NOAA-20, -21	ATMS	2011, 2017, 2022	13:30
Metop-B, -C	AMSU-A, MHS	2012, 2018	21:00, 21:30
Metop-D	MWS	2025	21:30
AWS	AWS	2024	22:15

Table 8: Following D25, channel-based data selection criteria for window and sounder channels, separated into stringent and dynamic criteria. “Land” means the model land fraction. Any land scenes used must be snow-free as currently determined for similar channels (see Geer et al. (2022)) and exclude high altitude land. Window channels’ stringent criteria requires model SST > 277 K. See text for discussion of σ_{clrtot} .

Channel Group	Stringent	Dynamic
Window chs.	land < 1%, $CI < 2K$, $SST > 277K$	land < 1% or land > 99%, $CI < 2K$
Sounder chs.	$\tau < 0.02$ or land < 1%, $CI < (1.5 * \sigma_{clrtot})$	$\tau < 0.10$, $CI < 2K$

3.4 Data selection for cal/val

The selection of appropriate observations for cal/val analysis is a key element of the NWP-based vicarious cal/val method. As this method is unchanged from D25, it is summarised here briefly. For further details, please see that previous report.

3.4.1 Channel-specific selection

In this study, the main cal/val selection criteria used is channel-specific, as this permits balancing channel- and scene-specific sensitivity with maximising the volume of data analysed. Window and sounder channels are defined a priori, based upon the average atmospheric transmittance as simulated by RTTOV in clear skies, with surface-to-space transmittance (τ) larger than 0.02 defining a window channel. These are found in Table 1, with MWS 1-5, 17-20, and 24 defined as window channels, and the remainder as sounder channels. The definitions are applied the same way across equivalent channels (Table 6), and hence equivalent channels have the same sampling definitions applied.

The channel-specific selection criteria are found in Table 8. The “stringent” population is the main cal/val sample that we analyse in this study. The “dynamic” criteria defines a more relaxed sample, designed to better capture the dynamic range of the instrument. The dynamic sample includes land observations for window channels, but notably still does not cover the full dynamic range given in Table 3. To do this, deep convective and frozen scenes would need to be included, but these remain excluded as the representation errors associated with these scenes are considered too large. As in D25, it remains aspirational to expand the dynamic criteria in the future to better sample the coldest TBs for cal/val analysis.

As discussed by D25, the needs for cloud screening differ significantly between sounder channels, as their sensitivities to cloud vary considerably. The sounder channels thus employ a CI check that is a function of the total clear-sky observation error (σ_{clrtot}). This term is defined as $\sqrt{\sigma_{clr}^2 + \sigma_{zen}^2}$ (Table 5). By following the lead of the assimilation system, this accounts for typical background errors and instrument noise implicitly, including the increase of effective noise at higher zenith angles caused by grid-based superobbing.

3.4.2 Unified data selection

Some cal/val analyses require a homogeneous sample across the full set of channels. For example, biases between channels should ideally be examined with a consistent data sample. Thus a “unified” data selection is applied evenly across all channels. This is naturally a smaller data sample than channel-specific selections, as significant cloud biases need to be removed from every channel—even the most

cloud-sensitive ones. The unified data sample is limited to ocean scenes.

The unified criteria consists of *CI* checks at several of the most cloud-sensitive frequency bands. For MWS these channels and their main geophysical sensitivities are:

- Ch. 1 (23.8H) – surface and column water vapour
- Ch. 17 (89.0V) – liquid cloud and precipitation
- Ch. 18 (165.5H) – liquid and frozen hydrometeors

For each channel, $CI < 2K$ must be met for the scene to remain in the unified cal/val sample. MWS has a novel 229 GHz channel, and inclusion of this channel for the unified criteria has some advantages relative to 165.5 GHz, as it is more sensitive to snow. However, the 165.5H channel allows for better cross-comparison with instruments like ATMS and soon MWIICI, and so we leave 165.5H as the highest-frequency channel used for the unified criteria *CI* check.

3.4.3 Outcome of data selection

The stringent screening is illustrated in Fig. 5 for a variety of MWS window and sounding channels: 1, 4, 6, 9, 20, and 24. In each panel, *O – B* is shown without bias correction for MWS data on April 10th, 2026. As expected, the more cloud-sensitive channels like 1 and 24 have the most data removed by the screening outlined above. The purer sounding channels have a large majority of total points accepted into the cal/val sample, such as for MWS-9 which peaks in the upper troposphere with little cloud sensitivity.

Table 9 covers the same date shown but provides percentages for the data volume retained in each cal/val sample. The unified sampling is the strictest, with about 15% of data retained across all channels. The stringent channel-based criteria produces a range for window channels, from 19 to 44%, versus 58 to 100% retained for sounder channels. The dynamic criteria produces a slightly larger sample than the stringent criteria by relaxing land screening primarily.

Figure 5 highlights that the sampling criteria as defined work well for MWS. Most of the obvious cloud signals are removed by the screening, but weaker cloud signals are typically retained in the sample. For example, more data are kept for channel 20 than for channel 24, as it is less cloud-sensitive, but even these frequencies that are quite sensitive to all-sky radiative effects retain about a third of all observations for cal/val analysis.

The real grey area for the selection criteria lies in sounder channels with surface sensitivity, such as MWS-4 to -6 or MWS-19 and -20. In these cases, whether or not they are classified as a window channel greatly reduces the volume of data that passes the screening. To take channel 20 as an example, it is classified as a window channel and thus 2 K cloud signals are removed by the criteria, whereas channel 21 uses the sounder criteria of $CI < \sigma_{clr} * 1.5$, leading to 4.5 K cloud signals being screened out due to the large 3 K observation errors for the MWS 183 GHz channels (see appendix A). Another example of the criteria not working optimally is for channel 6, where fewer points are retained in the dynamic sample than in the stringent sample; this is due to the $\tau < 0.1$ criterion, which unfortunately excludes several points over ocean as the mean transmittance for channel 6 is close to 0.10 near nadir. These examples demonstrate that it is difficult to produce a simple but coherent set of selection criteria that apply to such a wide range of geophysical sensitivities. However, the results here show that the selection criteria are performing well overall.

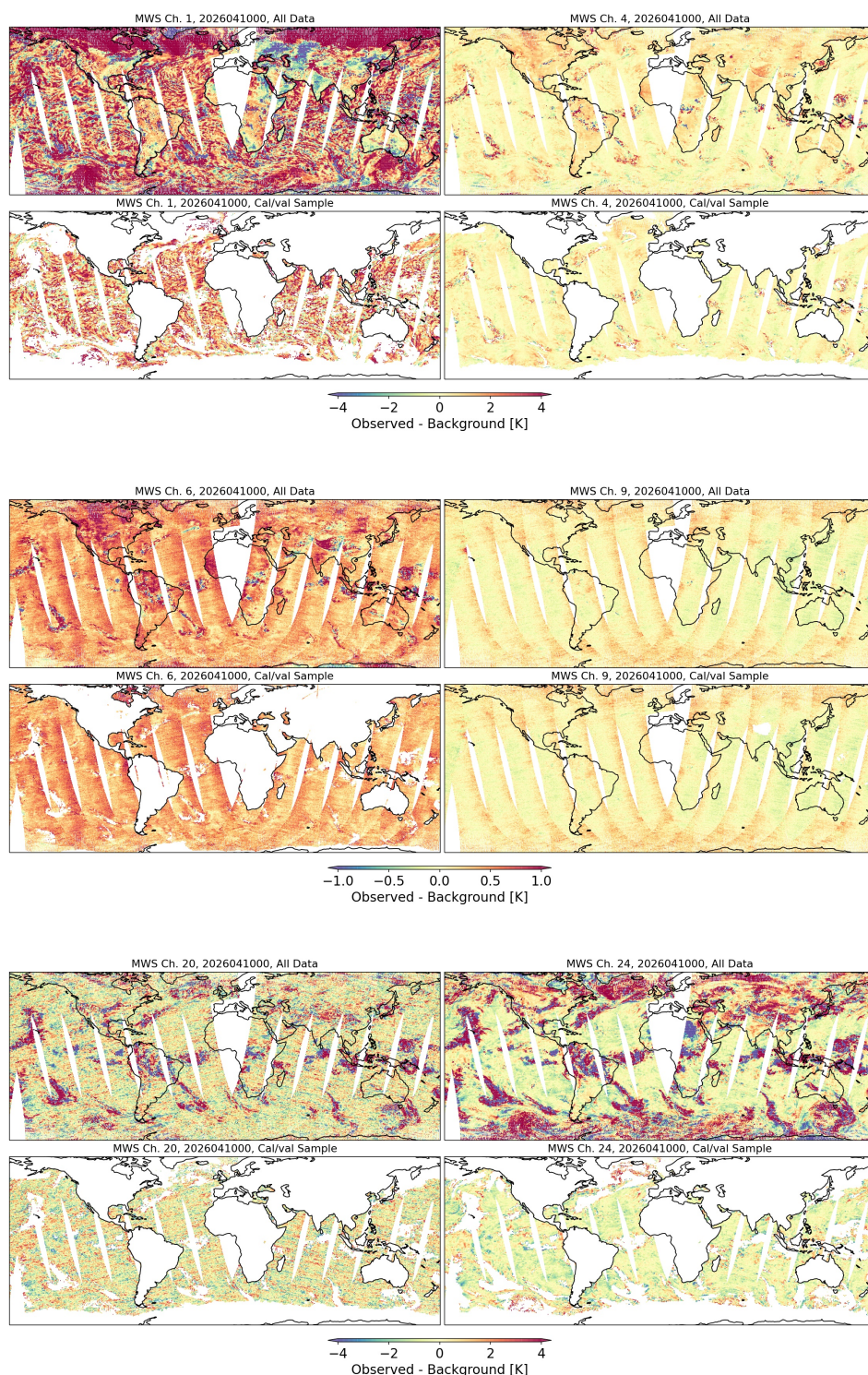


Figure 5: Swath-level departures without bias correction, shown for the OZ long-window on 10th April 2026. In each set, the top panel shows all departures, with those passing the stringent criteria shown below. Channels shown are grouped into 1 and 4 (top), 6 and 9 (middle), 20 and 24 (bottom). Note the tighter colourbar in the middle panels to accentuate T-sounder biases.

Table 9: Percentages of total MWS data (superobs) retained by cal/val screening. Statistics are from the same date as the previous two figures, April 10, 2026. Total number of superobs per channel was 266,525 in this 12 hr period.

Ch	Stringent	Dynamic	Unified
1	25.51	32.92	15.46
2	21.63	29.32	15.46
3	27.37	36.17	15.46
4	43.16	52.24	15.46
5	44.02	53.19	15.46
6	58.04	55.27	15.46
7	68.11	89.06	15.46
8	84.85	96.22	15.46
9	97.64	99.77	15.46
10	99.98	99.98	15.46
11	99.99	99.99	15.46
12	100.00	100.00	15.46
13	100.00	100.00	15.46
14	100.00	100.00	15.46
15	100.00	100.00	15.46
16	100.00	100.00	15.46
17	18.91	26.96	15.46
18	31.40	38.63	15.46
19	35.46	42.98	15.46
20	37.05	44.97	15.46
21	77.54	78.91	15.46
22	83.77	88.05	15.46
23	87.78	91.93	15.46
24	32.44	39.16	15.46

4 Results of cal/val analysis

In this section the bias and noise characteristics of MWS radiances are analysed relative to the IFS and equivalent channels on other operational MW instruments. When relevant, discussion of these analyses will be linked back to the performance requirements outlined in Sec. 2.2. The focus is on the key aspects found; the full set of departure monitoring plots can be found on the dedicated MWS monitoring website made available to EUMETSAT.

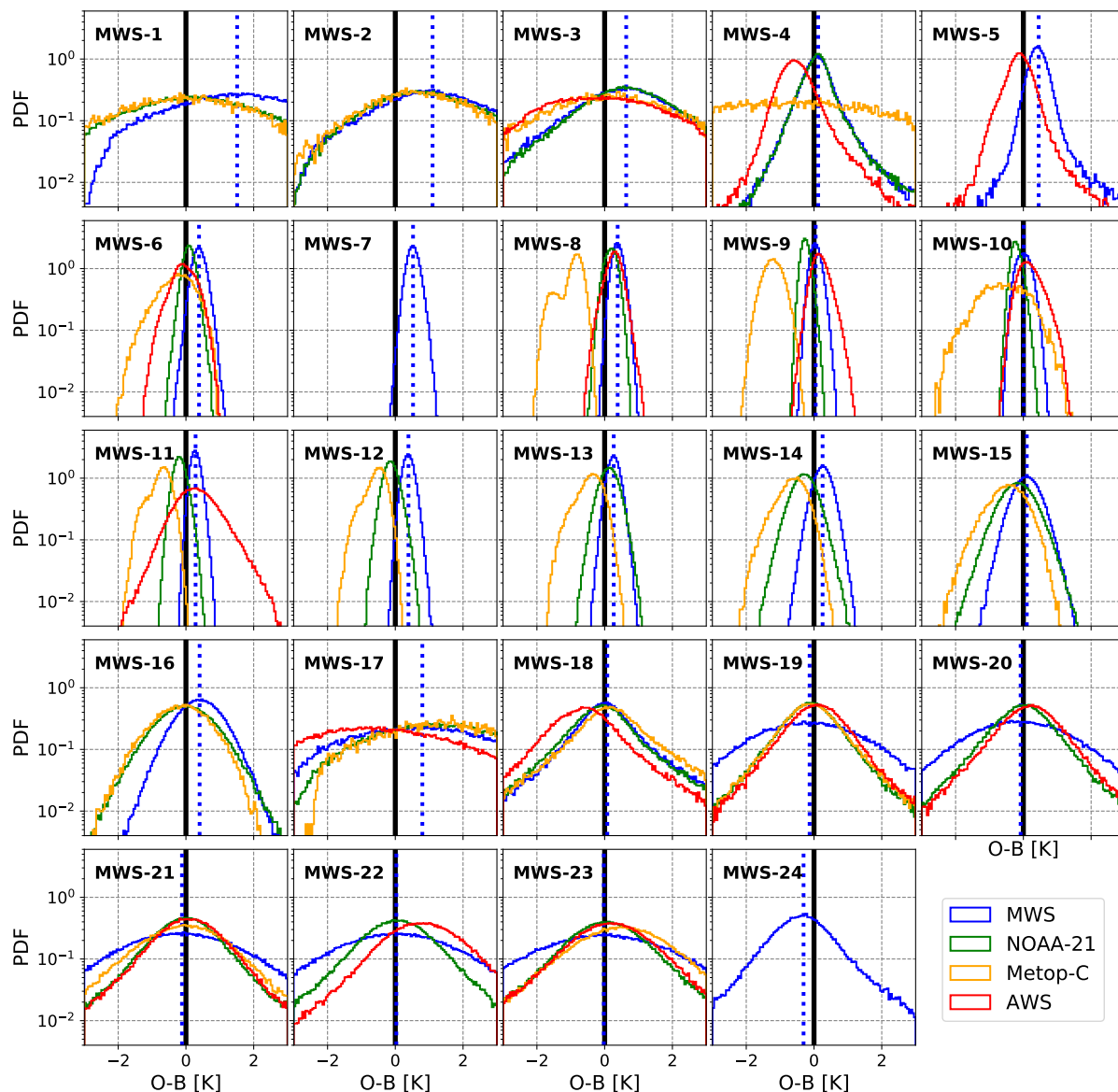


Figure 6: $O - B$ PDFs for stringent cal/val sample from MWS and four other sounders: AWS, ATMS on NOAA-21, MHS and AMSU-A on Metop-C. See Table 6 for equivalent channel numbers on other instruments. Data from the same time window as Fig. 5. Data are shown without bias correction applied and the MWS cal/val sample mean is given by a dotted vertical line.

Before diving into details, a lot can be learned from quickly analysing PDFs of $O - Bs$. Figure 6 shows all 24 channels of MWS from one 12-hour period from the stringent cal/val sample (matching Fig. 5),

contrasted with data from equivalent channels on selected sounders: ATMS, AMSU-A, MHS, and AWS. Several features here are worth discussing. First, MWS performs quite similarly to ATMS at most channels except the 183 GHz suite; it is immediately apparent that MWS 183 GHz channels are noisier than their counterparts on other sounders. While the bias relative to the IFS is close to zero for these channels, the distribution of the departures is much wider. This is a result of the anomaly that occurred in March 2026 for these channels; for more details on the performance prior to the anomaly see appendix A. Second, the window channels 1-3 and 17 have very wide $O - B$ distributions for all instruments shown, but the comparison does indicate that MWS-1 is a slight outlier by being rather warmer than IFS and ATMS at 23.8 GHz. Third, no obvious large bias structures are immediately apparent in the MWS PDFs of $O - Bs$, and their shape is largely Gaussian. In contrast, several AMSU-A channels show non-Gaussian behaviour, and further investigation shows that the lopsided PDFs in several channels are the result of biased outer scan positions that are not assimilated as a consequence (Duncan *et al.*, 2022). Fourth, several of the stratospheric channels show significantly tighter PDFs than their ATMS and AMSU-A equivalents, with noticeably better noise performance than ATMS for channels 12 to 16. Lastly, the novel 229 GHz channel (MWS-24) has a relatively symmetric shape similar to MWS-18 or the 183±7 GHz channels (MWS-19 equivalents) on other sounders, indicative of good radiometric performance in this brand-new channel.

4.1 Analysis of biases

4.1.1 Global

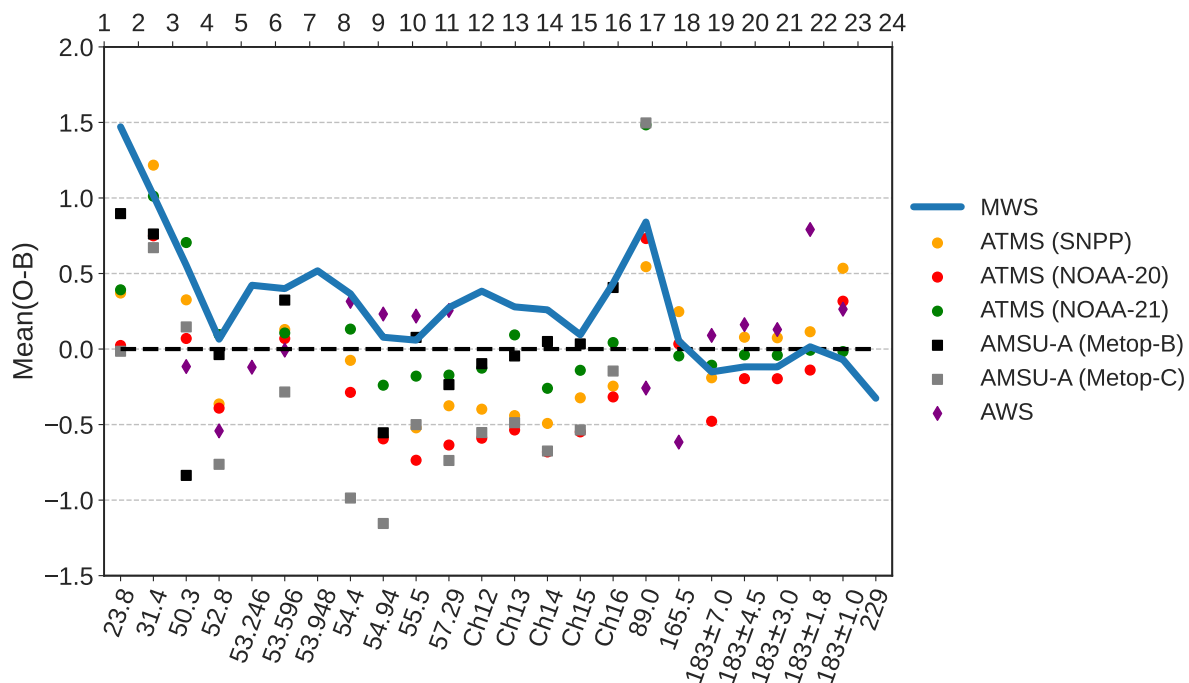


Figure 7: Global $O - B$ biases for MWS and equivalent channels from three ATMSs, two AMSU-As, and AWS. Data points represent global means of the stringent cal/val sample, 10-19 April, 2026. Labels at the top provide MWS channel numbers, with frequencies (in GHz) on the bottom.

Global biases for MWS are shown in Fig. 7, representing the stringent cal/val sampling applied to all

instruments over a time period of ten days in April 2026. The T-sounding channels are typically 0.0-0.5 K warmer than IFS and roughly 0.5 K warmer than ATMS or AMSU-A with some variability seen between satellites. The 183 GHz suite on MWS is effectively unbiased against IFS and in close agreement with ATMS. The window channels are more varied in their biases, for example with MWS-1 1.5 K warmer than IFS and the 23.8 GHz channel on other instruments; MWS-3 is warmer than IFS but within the range of ATMS biases at 50.3 GHz; 89 GHz is about 0.8 K warmer than IFS, similar to two ATMSs but cooler than one ATMS and Metop-C AMSU-A; the “dirty window” channels at 165.5 and 229 GHz are within a few tenths of a Kelvin of IFS, with MWS-18 matching ATMS closely.

The 1 K global calibration requirement is met for all sounding channels on MWS, though the full dynamic range is not assessed here (stated in MWS-02090). The inter-channel bias requirement of < 0.5 K can be assessed from this plot as well; while strictly this should be performed based on the unified cal-val sample, in practice the results are very similar. Groups of sounding channels exhibit close inter-channel biases, with the T-sounding channels within 0.5 K and the same being true for the H-sounding channels. However, the tropospheric temperature channels are slightly more than 0.5 K warmer than the 183 GHz suite, and so this requirement is not entirely met. The forward model errors are considerably larger for window channels due to surface emissivity model errors (Newman *et al.*, 2020), but it appears that the window channels MWS-1, -2, and -17 are outside this strict inter-channel bias requirement as well.

That said, none of the global biases discussed are problematic from an assimilation standpoint. All sounder channels are within 0.5 K of IFS and within 1.0 K of reference-quality instruments AMSU-A and ATMS. The H-sounding channels are effectively unbiased against IFS and match closely with ATMS. The window channels are outliers in terms of inter-channel biases but generally exist within the range of biases for equivalents on other instruments.

4.1.2 Scan biases

Next we can examine the quality of the calibration across the scan by assessing biases as a function of scan position. Figure 8 shows mean $O - B$ for the stringent cal/val sample as a function of the MWS scan position (1-95). Here the MWS channels are grouped by geophysical sensitivity, with window channels, T-sounding channels for troposphere and stratosphere, and the H-sounding channels. The sounding channels all show relatively flat scan-biases, with at most a few tenths of a Kelvin difference in bias across the scan. No edge of scan issues are present, in contrast to other sounders like AMSU-A, AWS, or MWHS-2 for which this limits their viability for assimilation of the full scan width at some channels (Duncan *et al.*, 2022, 2026; Steele *et al.*, 2023). In terms of EURD specifications, the requirement of inter-sample bias differences of < 0.3 K is met for all sounder channels (MWS-02130).

It is less clear how well the window channels in the first panel of Fig. 8 are performing relative to this strict EURD specification of inter-sample bias. These channels are biased warm against IFS as we saw in Fig. 7, but there is also an “M” shape in the bias of channels 1-3 that spans about 0.5 K for channels 1 and 3, whereas MWS-2 shows the same shape but more muted in magnitude. In contrast, MWS-17 at 89 GHz exhibits relatively flat bias across much of the scan but appears warmer at higher zenith angles. In this respect, it is very useful to compare to ATMS.

Shown in the right column of Fig. 8 are ATMS channels from NOAA-21. The patterns look similar for window channels in the first row, with channel 3 at 50.3 GHz looking nearly identical. ATMS biases are stronger at outer scan positions, which are at higher zenith angles than for MWS outer scan positions. For channels 1 and 2, the scan bias patterns appear inverted between MWS and ATMS, and may correspond to the QV versus QH polarisation difference between them (see Table 6). In contrast, the 89 GHz pattern

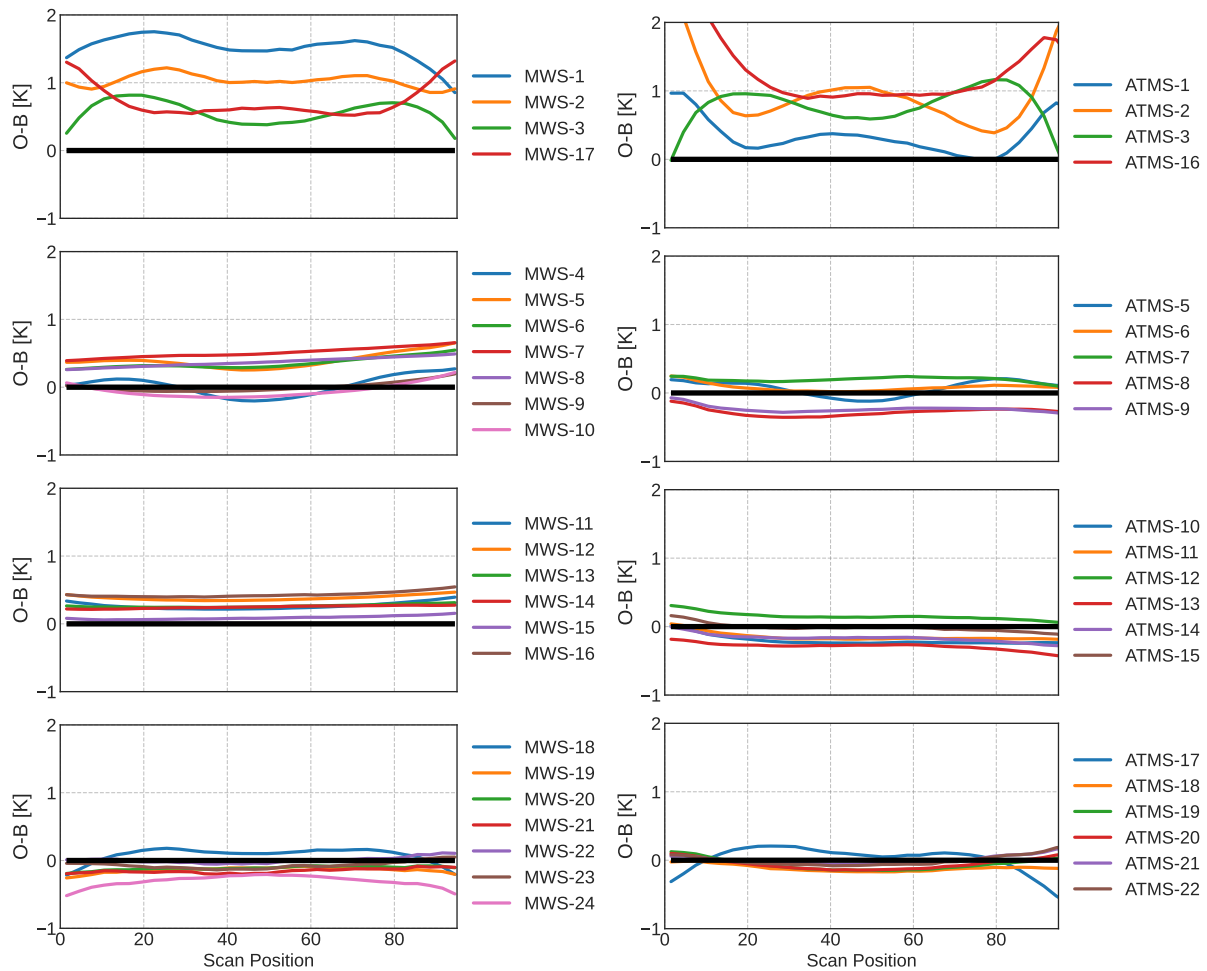


Figure 8: Mean $O - B$ from MWS (left) and ATMS on NOAA-21 (right) shown as a function of scan position, stringent cal/val sample from the same 10-day period as analysed above. MWS channels are split into panels by sensitivity, from window channels (top), tropospheric T -sounding (second), stratospheric T -sounding (third), H -sounding (bottom). In most panel pairs the colours correspond to equivalent channels, but not in the second row.

is similar between the two instruments, with increasing bias at higher zenith angles, and these share QV polarisation. These results may indicate surface emissivity model deficiencies as a function of zenith angle from SURFEM-Ocean. Similarly, other surface-sensitive sounding channel pairs at 52.8 GHz (MWS-4 and ATMS-5) and 165.5 GHz (MWS-18 and ATMS-17) also share mild but consistent bias patterns across the scan.

4.1.3 Orbital biases

Biases that manifest as a function of orbital position are relatively common for MW radiometers, often caused by differential heating of components on the spacecraft that varies around the orbit. Orbital biases as analysed in the IFS have ranged considerably, with the most complex patterns seen for MW imagers such as SSMIS and TMI (e.g. Bell *et al.*, 2008; Geer *et al.*, 2010). Smaller orbital biases have recently been found for temperature-sounding channels for AMSU-A and ATMS, reaching the magnitude of the instrument noise for some satellites (Bormann *et al.*, 2023). While this has not prevented successful

assimilation of the data over many years, an orbital bias correction (OBC) has nevertheless been found beneficial for NWP, and this is applied operationally since May 2026 for tropospheric T-sounding on AMSU-A and ATMS, but not AWS.

We find that subtle but persistent biases are present in the T-sounding channels of MWS. These orbital biases become obvious after standard bias correction models for air-mass and angular biases have been applied. This is illustrated in Fig. 9 which shows maps of departures for channel 7 of MWS. First, uncorrected $O - B$ s are shown with a very tight colour scale. Second, bias-corrected departures are shown from a VarBC configuration that lacks OBC terms, i.e. the same configuration as used by AWS. The pattern of positive departures in the ascending nodes of the orbit is seen across several T-sounding channels (Fig. 10). While the AMSU-A and ATMS instruments also show orbital biases of similar magnitude, the patterns seen for MWS are different for equivalent channels on other instruments, and the consistency between channels is stronger. This indicates that the orbital bias is likely due to an instrument or calibration issue, rather than the result of model biases projecting onto the orbital angle. The biases in MWS average around 0.1 K in peak-to-peak amplitude, and they are hence within the requirement for orbital stability of < 0.2 K (MWS-02110). However, recent experience with AMSU-A and ATMS (and early experimentation with MWS, not shown) have highlighted that such biases nevertheless affect the assimilation of the data. Therefore, even though the orbital bias is within specification, mitigation should be a priority for EUMETSAT going forward.

The above findings motivate the introduction of an orbital bias correction for MWS, as recently introduced for AMSU-A or ATMS. The third panels in Fig. 9 and Fig. 10 show the result of adding the same “alternating Fourier” terms in VarBC as used in Bormann *et al.* (2023), highlighting that with this modification orbital biases generally drop to within a few hundredths of a Kelvin after bias correction, in line with AWS.

4.1.4 Scene temperature dependent biases

No significant scene-dependent radiometric biases have been identified for any MWS channels over the range of scene-temperatures covered in the dynamic cal/val sample. This is illustrated in Fig. 11, showing 2-dimensional histograms of departures as a function of the scene temperature, for two rather different channels, MWS-7 and MWS-24 as examples. Note, however, that the dynamic range of the x-axis in these plots is far short of the dynamic range expressed in Table 3 for the requirements specification, and the requirement can hence be only partially assessed. The very dynamic MWS-24 has no scenes with observations below 200 K in even the “dynamic” cal/val sample, whereas the requirement for dynamic range is from 80 to 315 K. To truly assess bias across this vast dynamic range, deep convective scenes and possibly frozen surfaces would need to be included in the cal/val sample, and the magnitude of uncertainties in forward modelling of these scenes is currently far too large to permit rigorous cal/val evaluation. For other channels, the dynamic range is smaller and the absence of clear trends over the range of scene-temperatures considered is nevertheless reassuring.

4.2 Radiometric noise performance

4.2.1 T-sounding channels

For T-sounding channels, bias-corrected $SD(O - B)$ is a good way to evaluate radiometric noise, as background errors are typically small for these channels (around 0.1 K in clear-sky regions for tropospheric

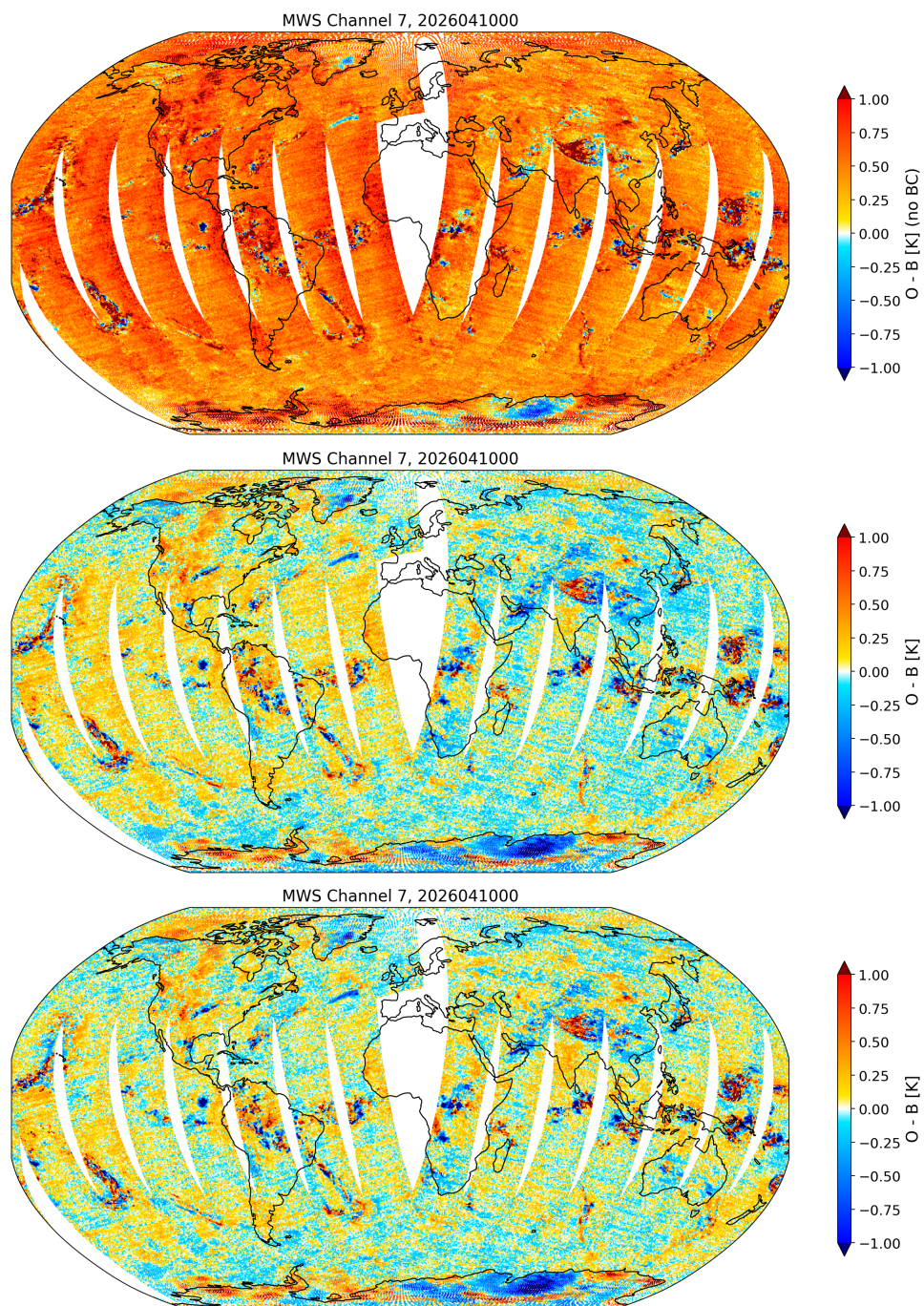


Figure 9: $O - B$ from MWS-7 on 10th April, 2026, with no bias correction applied (top), bias-corrected but without OBC (middle), and with OBC (bottom). All data shown with no screening applied.

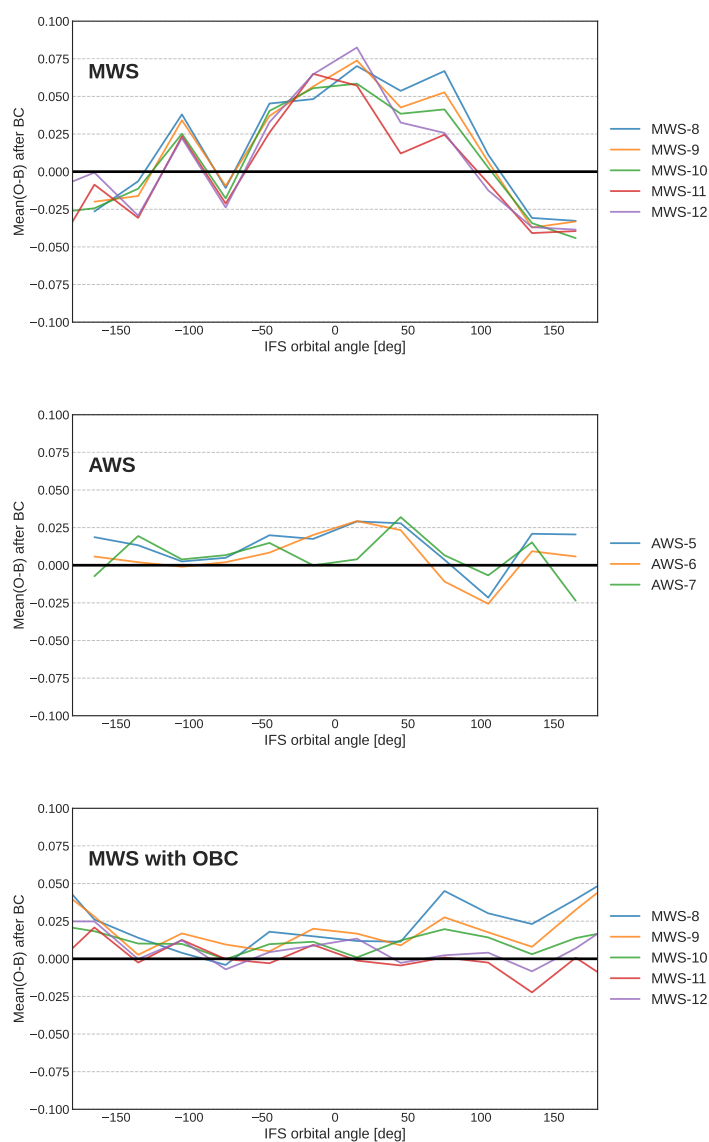
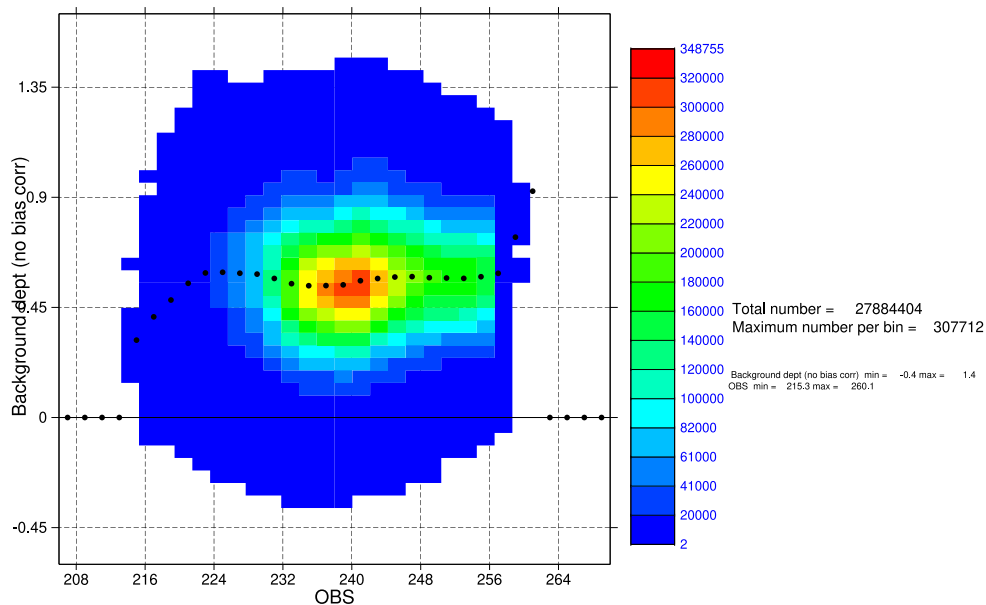


Figure 10: Average $O - B$ s from the stringent cal/val sample over the same 10-day period in April 2026, averaged over 30 degree bins of orbital angles. Panels show MWS without OBC (top), AWS without OBC (middle), and MWS with OBC (bottom). Here orbital angles are shown using the convention from [Bormann et al. \(2023\)](#), with 0 degrees at the equator on the ascending node.

SCATTER PLOT OF OBS VERSUS BACKGROUND DEPT (NO BIAS CORR)

TB, CHANNEL 7

EXP = MWS ; PERIOD = 2026030212 - 2026053100
(ALL-SKY STRINGENT) - GLOBE

SCATTER PLOT OF OBS VERSUS BACKGROUND DEPT (NO BIAS CORR)

TB, CHANNEL 24

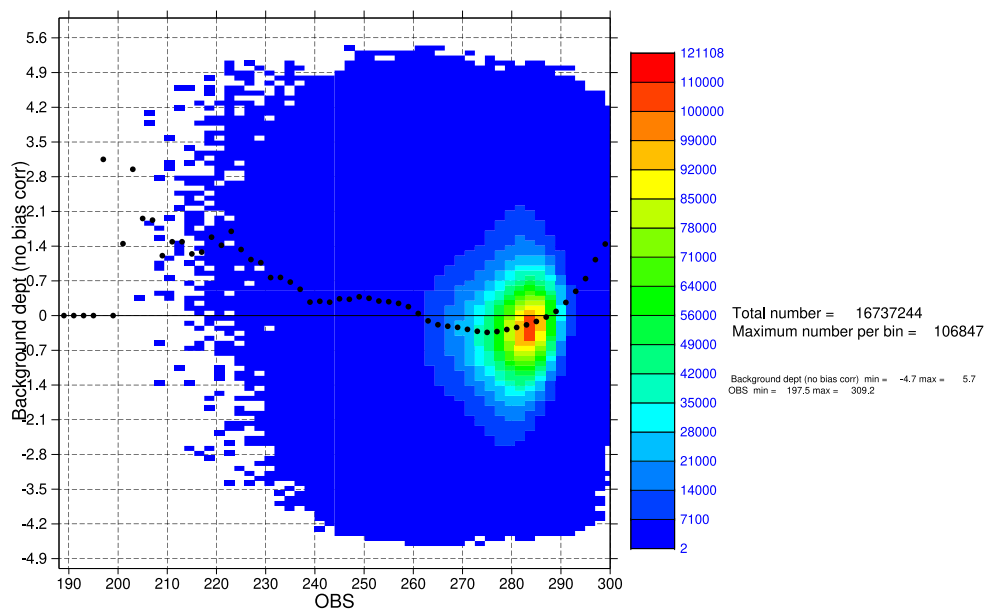
EXP = MWS ; PERIOD = 2026030212 - 2026053100
(ALL-SKY DYNAMIC) - GLOBE

Figure 11: 2D histogram of departures against scene temperature for MWS-7 (top, stringent cal/val sample) and MWS-24 (bottom, dynamic cal/val sample). Dots indicate bin means. Figures taken directly from ecCharts monitoring website.

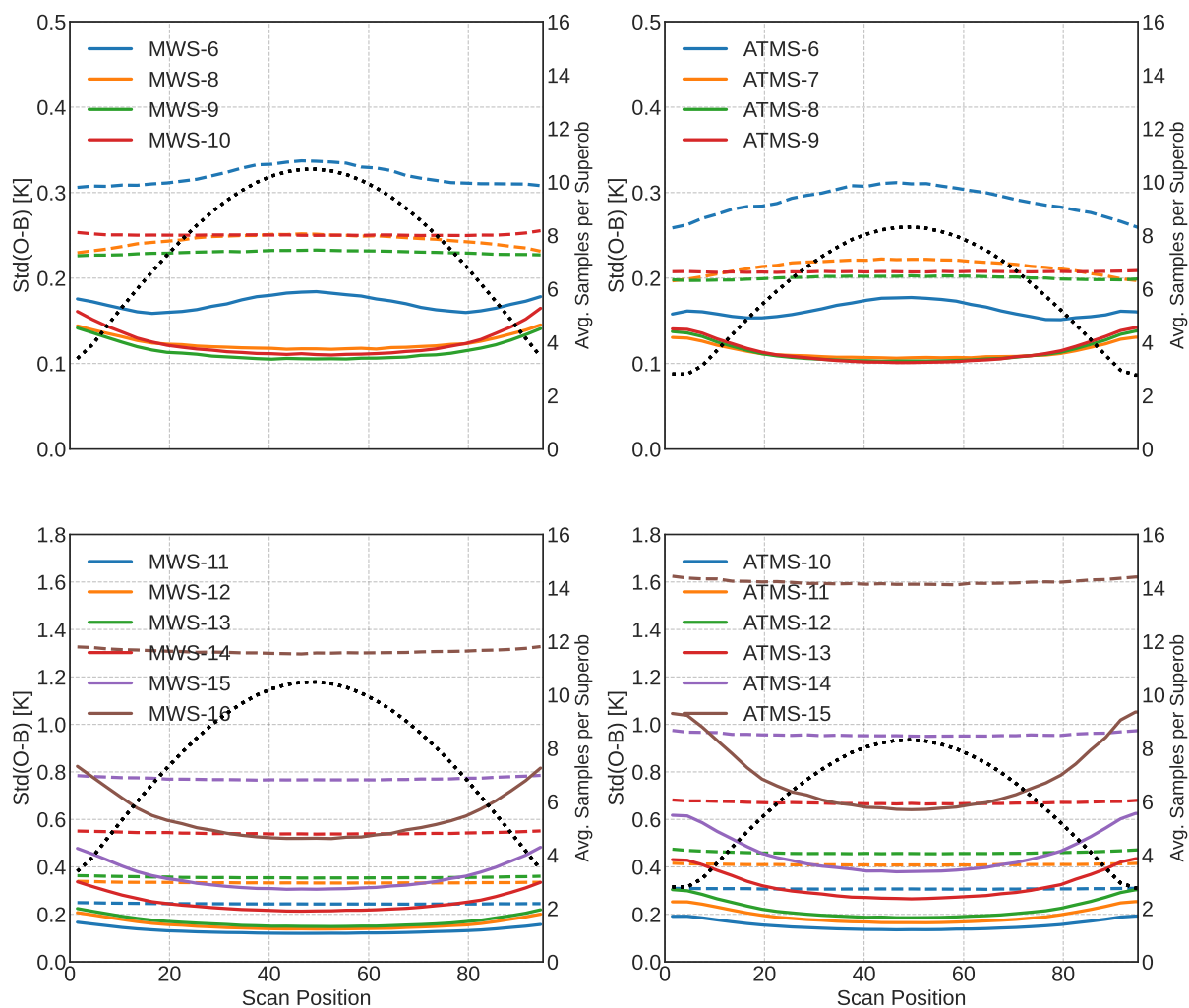


Figure 12: $SD(O - B)$ as a function of scan position for MWS (left) and NOAA-21 ATMS (right), shown for tropospheric (top) and stratospheric (bottom) T-sounding channels. In each panel, solid lines denote superobbed radiances and dashed lines denote un-superobbed radiances. Mean observations per superob are indicated by dotted black line on the secondary y-axis. Data from 1-9 April 2026, stringent cal/val sample after bias correction.

channels, [Bell et al., 2008](#); [Bormann et al., 2013](#)) and hence comparable or smaller than the instrument noise. $SD(O - B)$ is thus dominated by radiometric noise and allows an independent verification of NEDT as estimated by other methods. To do this, we can analyse $SD(O - B)$ on either native-resolution observations or superobs; here we will examine both, as the un-superobbed data provide a clearer picture of NEDT but the superobbed noise performance is most relevant for data assimilation.

Figure 12 shows T-sounding channels from MWS and ATMS on NOAA-21, with $SD(O - B)$ of native observations and superobs shown as a function of scan position. In general, un-superobbed curves should be flat across the scan while the superob curves are lowest in the middle where more observations constitute a superob and thus the noise is reduced (by $1/\sqrt{N}$ in the ideal case of a white noise distribution). The exception to this is the more deeply penetrating channels like MWS-6 and MWS-8, as background errors are larger near nadir and a bump is seen in $SD(O - B)$ for low scan angles in both curves. In these figures, the number of observations per superob is the same for all channels due to the co-located geolocations, ranging from an average of about 3 at scan edges to about 10.5 near nadir for MWS and 8.5 for ATMS. This is a consequence of finer scan line spacing and a thinner beamwidth for MWS (Table 2).

First, it is clear from Fig. 12 that all MWS channels shown are within the EURD specification levels for NEDT (see Table 3, MWS-02080). In most cases, the un-superobbed curves are significantly below NEDT spec, such as 0.35 K at MWS-8 or 0.90 K at MWS-14, which display $SD(O - B)$ of about 0.23 and 0.56 K, respectively. Second, MWS native resolution $SD(O - B)$ is slightly higher than ATMS for tropospheric channels but consistently lower for all stratospheric channels. This is notable because MWS has a significantly smaller FOV than ATMS (19 vs. 32 km) and finer spacing of scan lines. Third, the effective noise performance at 50 km superob resolution is very similar to ATMS at tropospheric channels but much better for higher peaking channels.

To further compare the effective noise performance for the crucial T-sounding channels, Fig. 13 provides similar curves but now shown as a function of zenith angle to better compare with AWS and AMSU-A as well. It is clear that MWS and ATMS are the lowest-noise T-sounders in orbit, achieving approximately 0.10 K $SD(O - B)$ for 50 km superob in the swath middle. AWS and AMSU-A are slightly higher noise than MWS and ATMS, but only by a few hundredths of a Kelvin in this view. Some channels and instruments are better than others, as for example NOAA-21 and NOAA-20 achieve lower noise than SNPP.

4.2.2 H-sounding channels

In most circumstances, it is difficult to assess the radiometric noise of H-sounding channels from NWP departures alone. Background errors in humidity are about an order of magnitude larger in observation space than for temperature, i.e., 1.0 versus 0.1 K, and cloud radiative impacts are more pervasive. As errors add in quadrature, a few tenths of a Kelvin in NEDT for a humidity sounder can be effectively hidden in $SD(O - B)$. For example, with 0.4 and 0.6 K NEDT (MWS specs for 183 GHz) along with 1.5 K background errors, $\sqrt{0.4^2 + 1.5^2} = 1.55$ and $\sqrt{0.6^2 + 1.5^2} = 1.62$. This effect is compounded when examining superobbed TBs, as the averaging reduces random noise. Furthermore, humidity sounding frequencies are very cloud-sensitive, and small differences in cloud screening can affect $SD(O - B)$ significantly. However, after the March 2026 anomaly in the 183 GHz band on MWS, the instrument noise increased by such an extent that background errors in humidity are now significantly smaller than NEDT for native observations. It remains difficult to screen out cloud signals from these channels, but noise performance is now more readily accessible from the statistics.

This report will not attempt to quantify the effective NEDT of MWS H-sounding channels from the

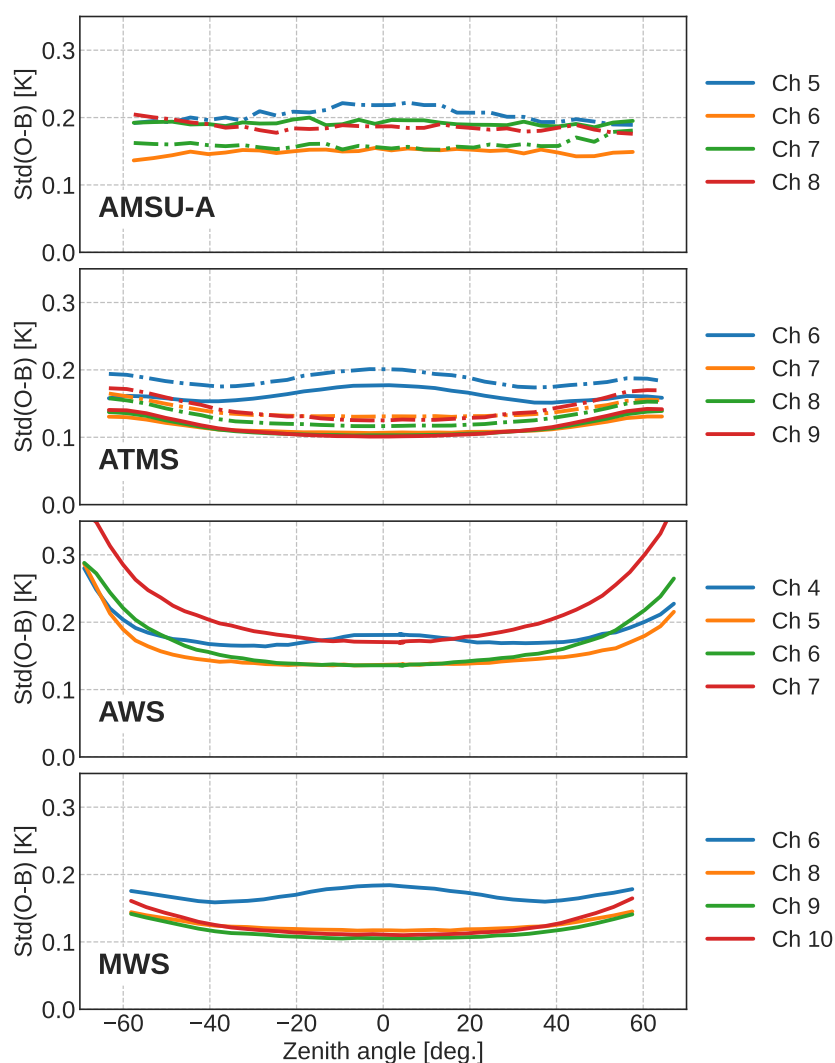


Figure 13: $SD(O - B)$ as a function of zenith angle for AMSU-A (top), ATMS (second), AWS (third), and MWS (bottom) for the equivalents of MWS channels 6, 8, 9, and 10. For AMSU-A, Metop-B (dash-dot) and Metop-C (solid) are shown; for ATMS, SNPP (dash-dot) and NOAA-21 (solid) are shown. Statistics are from the stringent cal/val sample after bias correction, 10-19 April, 2026. AMSU-A is at native resolution while the others represent 50 km superobs.

departures alone, as quantification of background errors for humidity is out of scope for this analysis. In the L1 data from EUMETSAT, cold and warm NEDT estimates are provided. For example, covering the dates analysed in the plots, the L1 NEDT estimates for raw observations are typically in the range of 2.2 to 3.2 K post-anomaly for the 183 GHz suite, versus a range of 0.27 to 0.52 K pre-anomaly. These values appear congruent with the behaviour seen in Fig. 21 in the appendix. For a qualitative view of MWS H-sounding channels before and after the anomaly, see Appendix A.

4.3 Cal/val summary

To summarise this section of the report, Table 10 provides an overview of the EURD requirements (Sec. 2.2) and the assessment reached from the analysis discussed above.

Table 10: Restated requirements from the EURD (with numbers from the EURD in parentheses), a simplified assessment (met, partially met, or not met), and comments on this assessment.

Requirement	Assessment	Comments
Radiometric noise as given in Table 3 (080)	Partially met	With exception of the 183 GHz suite, sounding channels meet NEDT requirements, in many cases by a wide margin; for window channels, background errors are too large for quantitative assessment to be feasible
Radiometric bias < 1.0 K for whole dynamic range (090)	Partially met	Every sounder channel exhibits global bias within this range, but MWS-1 does not meet this; full dynamic range analysis is not possible with current cal/val sampling strategy
Orbital stability < 0.20 K for any single orbit (100/110)	Met	T-sounder channels do exhibit noticeable orbital bias but on order of 0.10 K; no clear evidence of orbital bias in other channels that can be disentangled from model bias; lifetime stability not evaluated here
Inter-channel biases < 0.5 K (120)	Partially met	Inter-channel biases range from about -0.2 (MWS-19) to 0.5 K (MWS-7) for sounding channels, slightly outside the requirement, but T-sounding and H-sounding channels meet this within each band; the clear outliers are MWS-1 and -2, which are warmer than IFS and most of their equivalents
Inter-sample biases < 0.3 K (130)	Met	The requirement is met for all sounding channels; window channel inter-sample biases exceed the threshold but are in line with those of equivalent instruments

5 Assimilation results

In this section, the assimilation impact of adding MWS to the IFS is evaluated. This is primarily done by comparing a control experiment without MWS against an experiment that includes MWS in the assimilation. In both experiments, all other observation types are assimilated following the data selection of the operational system, including all of the MW sounders listed in Table 7.

The experiments use IFS Cycle 50r1 with a model resolution of approximately 27 km (Tco399) horizontally and 137 vertical levels. The period of experimentation runs from 25 March to 11 July, 2026; this follows the anomaly to the 183 GHz suite and subsequent testing by EUMETSAT that caused some interruptions to the data stream. The assimilation uses incremental 4D-Var with three outer loops and a final inner loop resolution of 80 km. Background errors are flow-dependent, coming from the operational EDA. For analysis-based verification below, this is verified against the operational analysis to avoid own-analysis verification artefacts at short lead times. A latter set of experiments covers the pre-anomaly period of December 27 to March 10, clearly delineated from the first set of experiments.

Unless stated otherwise, the assimilation of MWS includes all channels shown in Table 5. That is: window channels 1 and 2, temperature channels 6 and 8-16, and humidity channels 19-23. All sounding channels are used over both land and sea following Geer *et al.* (2022), with channels 1 and 2 assimilated over sea only. MWS-7 is excluded for these initial trials because an equivalent does not exist on currently assimilated sounders (Table 6), and the configuration follows that of heritage sounders as closely as possible. The exception to this is an experiment which added MWS to the assimilation but withholding the 183 GHz suite; this comparison is intended to gauge the impact of the noisy 183 GHz suite, and whether it is worthwhile assimilating these channels despite their diminished capabilities.

5.1 Impact on short-range forecasts

Short-range forecast impact is typically analysed via changes in $O - B$ statistics for independent observations, evaluating whether the 12 hour forecast fits the other observations more or less closely after new data have been added. Figure 14 shows the change in $SD(O - B)$ for a suite of independent observations, covering sensitivity to temperature, humidity, and winds. Here we compare the experiments that both include and exclude the 183 GHz suite. First we will discuss the experiment that assimilates the full MWS channel set (purple line), and latterly discuss the difference.

The results indicate significant improvements in short-range forecasts of temperature and humidity. Fits to ATMS are improved across all channels, with the strongest impacts for upper tropospheric temperature and the upper stratosphere. This signal matches well with GNSS RO in panel (e), which sees small but significant improvements in fits for these altitudes. Radiosonde temperature shows a slight improvement in the upper troposphere as well, with IASI wavenumbers sensitive to temperature mostly seeing a neutral or slightly positive impact from MWS assimilation.

For humidity, there are also positive signals across several observation types. ATMS H-sounding channels (18-22) show a small benefit from MWS assimilation, as do IASI humidity channels (wavenumbers 1367cm^{-1} and up). The geostationary infrared radiances exhibit an interesting pattern, with positive impacts seen in GOES-18, Meteosat-9 and MTG-I1, with neutral impacts seen for GOES-19 and Himawari-9. This result is familiar from AWS trials (Duncan *et al.*, 2026), and driven by observation locations for which Metop-D has an overpass late in the assimilation window. To some extent, it is surprising to see a significant impact on humidity from MWS as the period examined is after the 183 GHz anomaly in March. However, the 23.8 GHz channel is primarily sensitive to total column water vapour, and its com-

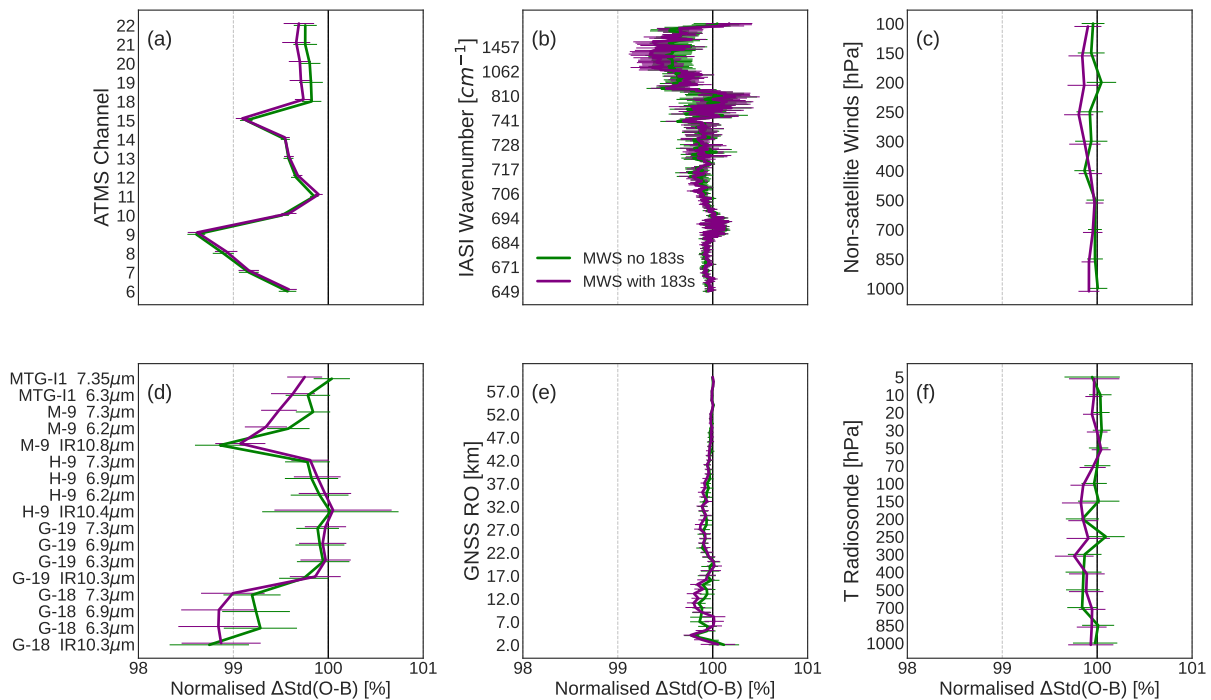


Figure 14: Normalised changes in $SD(O-B)$ given as a percent, comparing experiments with MWS assimilated versus a control without MWS, i.e., the 100% line indicates neutral impact on $SD(O-B)$ with points to the left indicating a positive impact. The purple lines signify the experiment containing the full set of MWS channels assimilated; the green lines an experiment that excludes MWS-19 to -23. Panels cover (a) ATMS, (b) IASI, (c) non-satellite winds, (d) geostationary infrared radiances, (e) GNSS radio occultation, and (f) radiosonde temperature. In panel (d): M is short for Meteosat, H for Himawari, and G for GOES.

bination with the high-noise 183 GHz channels appears to be sufficient to provide some positive impact on short-range humidity.

The impact on winds is not as strong, with small but slightly positive signals seen for non-satellite winds in panel (c). It is typical with all-sky assimilation to see significant impact on winds due to the 4D-Var tracer effect. It is quite interesting to note the improved wind fits in the upper troposphere, a feature that is visible for this experiment in which the 183 GHz channels are assimilated despite their noise performance, but not present in an experiment that denies assimilation of the 183 GHz suite (green line). This implies that the 183 GHz suite is still able to provide benefit to the assimilation in cloudy scenes despite their noise being outside specifications, as one would expect from data assimilation theory.

Comparing the purple and green lines, there is not a large impact from adding the now-noisy 183 GHz channels to the assimilation, but there are some tangible benefits for humidity, as suggested by a range of observations. Background fits to ATMS humidity channels are slightly improved, as are fits to geostationary and IASI infrared radiances. This is good evidence that it is worth retaining the 183 GHz suite in active use, as the all-sky assimilation method is able to extract information on humidity and winds from cloudy scenes. The results without the 183 GHz channel further confirm that a large part of the humidity impact seen in the experiment with the full channel set originates from the 23.8 GHz channel.

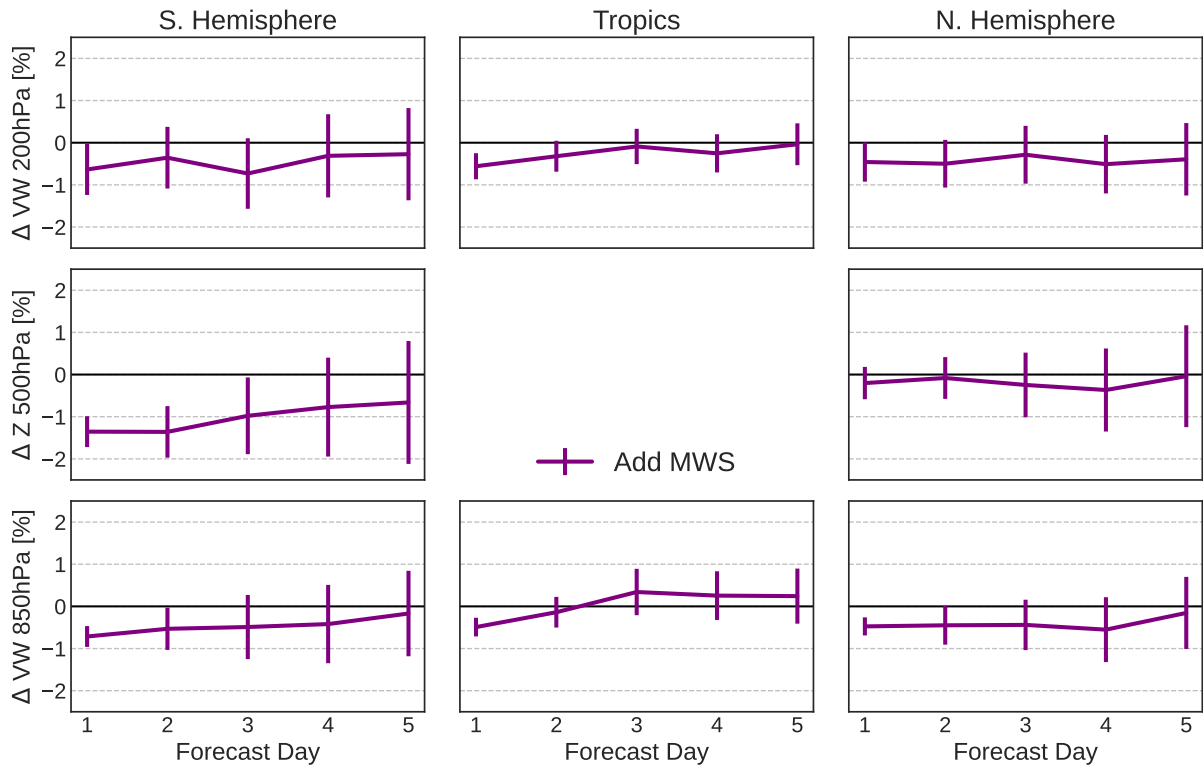


Figure 15: Analysis-based forecast verification of the impact of adding MWS to the assimilation (including the 183 GHz suite), displayed as regional changes in RMSE of vector winds at 200 hPa (top row), geopotential height at 500 hPa (middle row), and vector winds at 850 hPa (bottom row). Forecast ranges shown are 1 to 5 day lead times, verified against the operational analysis. Vertical bars indicate the 95% confidence interval (Geer, 2016). Northern Hemisphere is defined as 20-90N, Tropics is 20N-20S, and Southern Hemisphere is 20-90S. Geopotential scores in the tropics are not informative and hence not included.

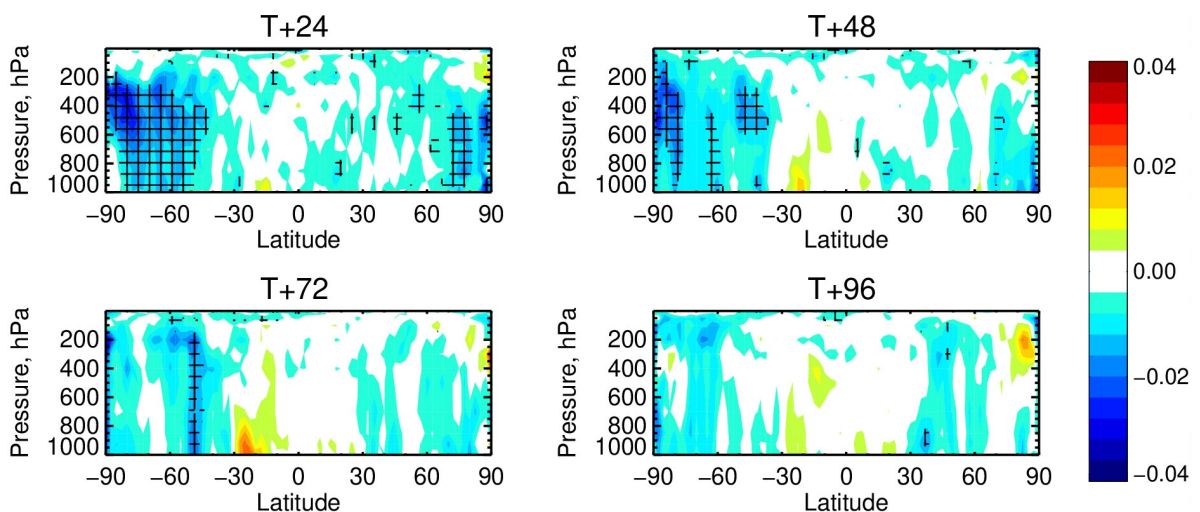


Figure 16: Normalised changes in RMSE of vector winds, comparing an experiment with MWS assimilated versus a control without MWS. Forecast ranges shown are from 24 to 96 hour lead times, verified against the operational analysis. Hatching indicates statistical significance at the 95% confidence level (Geer, 2016).

5.2 Impact in medium range

For the medium range impact we examine analysis-based forecast verification, limited to the experiment in which 183 GHz is active, following the results above that prove it is the preferred configuration for MWS assimilation. Figure 15 plots the change in forecast RMSE as a function of lead time, from 24 hours to 5 days, and broken down by latitude. Due to the length of the experiments (3.5 months), some of the scores do not exceed the 95% confidence intervals for statistical significance. That said, some scores do stand out as being significant. Z500 in the Southern Hemisphere shows about 1% reduction in RMSE through forecast day 3. Winds at 850 and 200 hPa are improved by about 0.5% at the 24 hour lead time in each region. As temperature and humidity scores are much more sensitive to model biases and the verifying analysis, they are not analysed here.

Providing a different view, Fig. 16 shows the change in wind forecast errors averaged over longitudes and presented as a function of latitude and pressure levels. These plots show that MWS assimilation improves wind forecasts throughout the troposphere in both hemispheres. This geographical distribution of forecast impact is familiar from AWS (Duncan *et al.*, 2026) and consistent with activation of other sounders in IFS, in that impact is generally clearest at higher latitudes with more muted effects seen in the tropics.

5.3 Discussion of assimilation trials

In this section one set of assimilation experiments has been presented, spanning a time period that follows the 183 GHz anomaly in March of 2026. It is one realisation of MWS assimilation over a limited time period, and likely does not represent full exploitation of the rich information content available from this instrument. The choices made to assimilate MWS in this report have largely followed previous experience with other instruments, especially AMSU-A and AWS. This notably means that channels not present or not assimilated from these instruments such as MWS-4, -5, -7, -18, and -24 have not yet been considered for assimilation. Especially in the wake of the anomaly for the 183 GHz band, it may be worth exploring assimilation of the dirty window channels MWS-18 and MWS-24 to improve clear-sky profiling capabilities of humidity at low latitudes. These channels are no replacement for the 183 GHz suite in terms of vertical sensitivity (seen clearly in Fig. 1), but would be a worthy target of assimilation in future work.

Along these lines, it is of more than academic interest to gauge the impact of MWS at its full strength, prior to the anomaly in March 2026. Metop-D holds the first MWS of three, with two more to launch in the 2030s. Assimilation trials were performed for the pre-anomaly period, spanning from the end of 2025 to early March of 2026. The experimental configuration was identical, with only clear-sky observation errors changed for the 183 GHz suite. Figures 17 and 18 provide the same views of short-range and medium-range impacts as given above for the post-anomaly period.

We need to be careful in over-interpreting these figures vis-a-vis the post-anomaly plots—the statistics cover a different period and are thus not a fair comparison. That said, most signals are consistent with expectations for the 183 GHz impact. Background fits to humidity-sensitive observations are better in the pre-anomaly period, with larger improvements in $SD(O - B)$ seen for ATMS-18 to -22, IASI larger wavenumbers, and GOES-18 radiances, for example. Other signals in the short-range forecast are similar between experiments in the pre- and post-anomaly periods, likely reflecting the stable performance of the temperature-sounding channels between the two periods. For medium-range forecast scores, the RMSE for upper level winds is maybe slightly larger pre anomaly, as might be expected from more effective humidity tracing, and there are hints of a better performance for other variables, but the differences in the

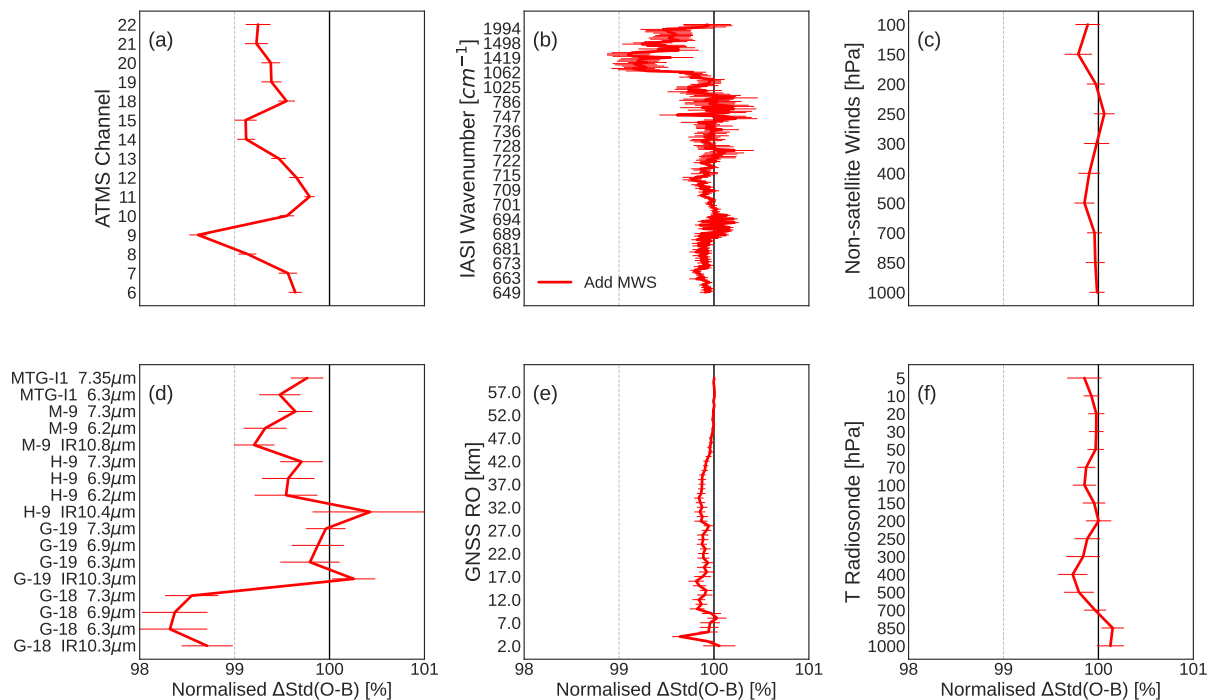


Figure 17: As Fig. 14, but for the pre-anomaly period (27 December to 10 March).

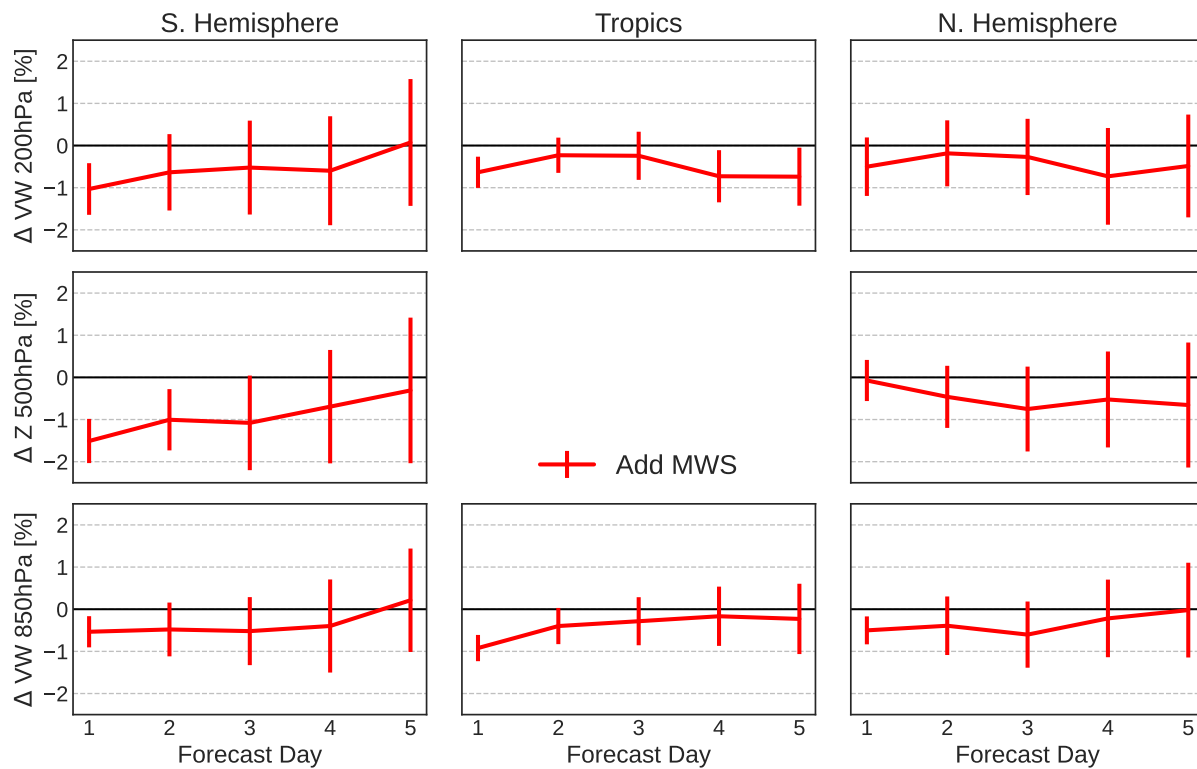


Figure 18: As Fig. 15, but for the pre-anomaly period (27 December to 10 March).

impact are not statistically significant. Longer experimentation would be required to establish differences in medium-range impact, and the different periods make it impossible to draw firm conclusions.

The assimilation impact of MWS is almost certainly limited by the prevalence of MW sounder data in and near the 9:30 orbit as of spring 2026. This is especially the case for addition of 183 GHz channels, as MHS and AWS currently provide a total of 11 channels in this band (with 325 GHz channels additionally assimilated from AWS). In this report we have not attempted to quantify the impact of MWS in the absence of sounders in the morning orbit, as it would require another suite of assimilation trials and this felt premature until a viable assimilation configuration was established for MWS. Future experimentation could examine the impact of MWS without one or two of its Metop predecessors in orbit (and possibly excluding AWS as well) to better gauge the impact of MWS relative to AWS and the previous Metops. The current results may be influenced by how closely the Metop-B, -C, and -D platforms are spaced during the time period examined, and an OSE with a depleted set of MW sounders would be a good way to avoid this difficulty in interpreting overall impact.

6 Conclusions

This report introduces the first MWS instrument of the EPS-SG programme, flown on Metop-D. The radiometric performance of MWS has been assessed using a state-of-the-art NWP system and an established method. Results from early trials have been presented in which MWS radiances are assimilated in the all-sky framework of the ECMWF data assimilation system.

Radiometric performance of MWS is generally in line with expectations for a reference quality, “backbone” instrument of the global observing system. The clear exception to this is the noise performance of the 183 GHz band, which degraded to far outside of specifications in March 2026 and is not expected to recover. Performance of other key bands is overall within specifications for the requirements assessed in this report. The stratospheric channels on MWS provide the lowest noise performance of any MW sounder yet launched and tropospheric channels are in line with ATMS performance. NWP users will need to mitigate the small but persistent orbital bias in the T-sounding suite. This bias is within EURD specifications and mitigated by additional bias correction terms, but should ideally be corrected at source by EUMETSAT to ensure fullest exploitation of these critical channels.

Assimilation trials have been carried out using ECMWF’s all-sky framework, with the majority of MWS channels assimilated. In the trial presented, most sounding channels are assimilated in all conditions over most surfaces, with two window channels assimilated over sea. The impact is positive in the short range as judged by improved fits to independent humidity- and temperature-sensitive observations. In the medium range, positive signals are seen in wind and geopotential forecasts at day 1 and 2, particularly in the Southern Hemisphere. It is worth noting that the time examined is not yet long enough to make strong statements about medium-range forecast skill changes (Geer, 2016), and thus experimentation will be extended for a future publication on MWS forecast impacts. The 183 GHz channels still make a small positive contribution to the MWS impact when assimilated in an all-sky framework, despite their increased noise, provided that appropriately larger observation errors are assigned.

This report has focussed on an initial assimilation configuration that is very close to that of heritage sounders and AWS, a decision driven by the limited time available to test different configurations. Future work should focus on addition of channels not yet assimilated here, such as lower tropospheric T-sounding and the new window channel at 229 GHz. Quantification of MWS impact could also be considered from a baseline observing system with no data in the morning orbit, so as to better compare against AWS and the previous Metop satellites.

The first MWS instrument of the Metop-SG series is an important addition to the legacy of MW sounders that stretches back several decades. Work remains to fully exploit this MWS to its full potential for NWP, but its assimilation already leads to notable forecast skill improvements in the experimentation presented here. Operational assimilation of MWS at ECMWF is expected to begin later in 2026.

A Appendix: Pre-anomaly performance of 183 GHz suite

MWS suffered an anomaly to the 183 GHz channels on March 11, 2026. This caused an immediate and sustained increase in radiometric noise, with recovery attempts to reverse the loss unsuccessful. The 183 GHz channels are now far outside specified noise performance. However, MWS on Metop-D is the first of three in the series. So despite the anomaly occurring before Metop-D was declared operational, there are still a few months of data that can inform expected future performance of fully functional MWS instruments on Metop-SG-A2 and -A3.

The incidence of the 183 GHz anomaly is shown in Fig. 19, contrasting MWS-23 with its equivalents on MHS from Metop-B and -C. This upper-tropospheric humidity channel (183 ± 1 GHz) mainly shows humidity and cloud displacement errors in the background. The anomaly occurred in the middle of the 12 Z long-window on 11th March. The top panel with Metop-B shows a relatively crisp picture, with $O-B$ of order 1-2 K common. The middle panel with Metop-C is blurrier, as this MHS has known issues with striping, and consequently it requires larger observation errors in clear skies. The bottom panel with MWS shows crisp, low-noise $O-B$ s over about half the picture, with the last three full orbits being much noisier still than Metop-C MHS. This single image illustrates how MWS went from a high-performing H-sounder to a noisy one. The image also shows several patches with non-nominal consecutive scans, caused by the anomaly but fixed by EUMETSAT in their L1 processing in June. The figure shows one channel, but the whole 183 GHz suite of five channels was similarly affected.

As a consequence of the sharp increase in noise for the 183 GHz suite, observation errors in clear skies needed to be increased, commensurate with the radiometric performance. Compared to the 3.0 K observation errors in clear skies shown in Table 5, earlier assimilation trials had commensurately lower errors due to the low noise performance of pre-anomaly MWS 183 GHz (ranging from 1.60 to 2.30 K). These lower clear-sky observation errors were used in the experimentation presented in Sec. 5 on assimilation impact in the pre-anomaly period.

One way to visualise the performance of the 183 GHz channels is to plot $SD(O-B)$ across the scan, and compare these to ATMS. This approach has numerous caveats for window and H-sounding channels (spelled out in Sec. 4), and it is especially difficult to perform effective cloud screening on un-superobbed data due to larger effective instrument noise. Figure 20 shows pre- and post-anomaly statistics for un-superobbed MWS humidity-sensitive channels, with window channels on top and 183 GHz channels on bottom. For comparison, ATMS equivalents from NOAA-21 are shown in the middle. This set of plots indicates that the window channels and 183 GHz channels of MWS were delivering similar noise performance as ATMS in the pre-anomaly period. Then in the panels on the right, it is clear that the window channel performance remains consistently good whilst the 183 GHz channels have degraded considerably. The $SD(O-B)$ metric here is almost certainly over-stating the noise increase due to more cloudy scenes entering the cal/val sample, but as a qualitative impression this remains a useful comparison.

Figure 21 shows PDFs of departures for the MWS humidity sounding channels before and after the anomaly to the 183 GHz suite. In the top set of panels are superobbed $O-B$ s, with native resolution $O-B$ s in the bottom panels. To avoid difficulties in interpretation from differential cloud screening, these PDFs show all departures over sea with no cloud screening applied. The effect of the anomaly on noise performance in the 183 GHz suite (MWS-19 to -23) is clearly visible, with the window channels MWS-18 and -24 unaffected. Comparison of the top and bottom sets of plots is also illustrative for the effects of superobbing. The before and after curves in each case indicate that the anomaly did not cause a significant change in bias behaviour.

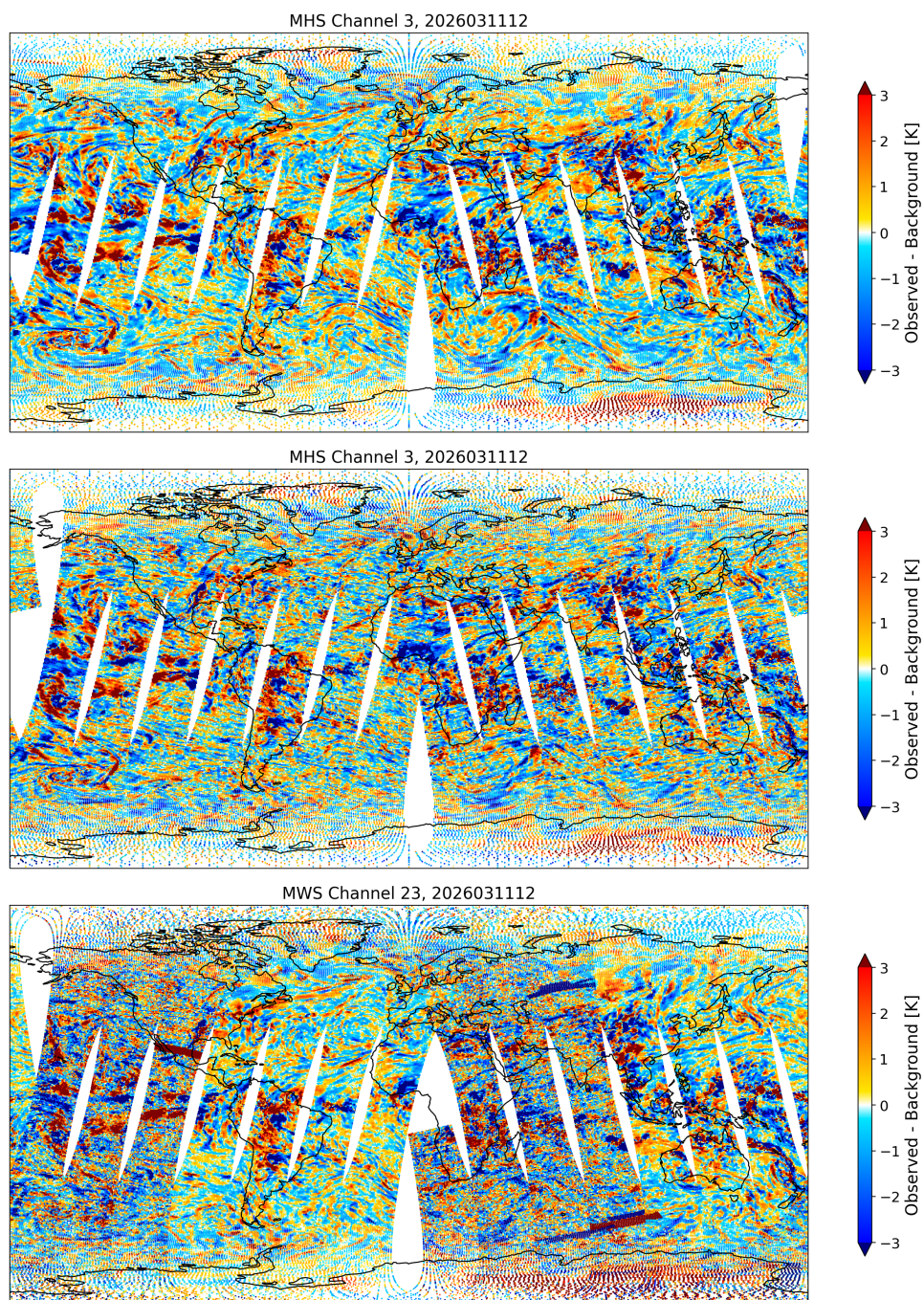


Figure 19: $O - B$ after bias correction for MHS-3 on Metop-B (top) Metop-C (middle) and MWS-23 from Metop-D (bottom), 12 Z long-window on 11th March, 2026.

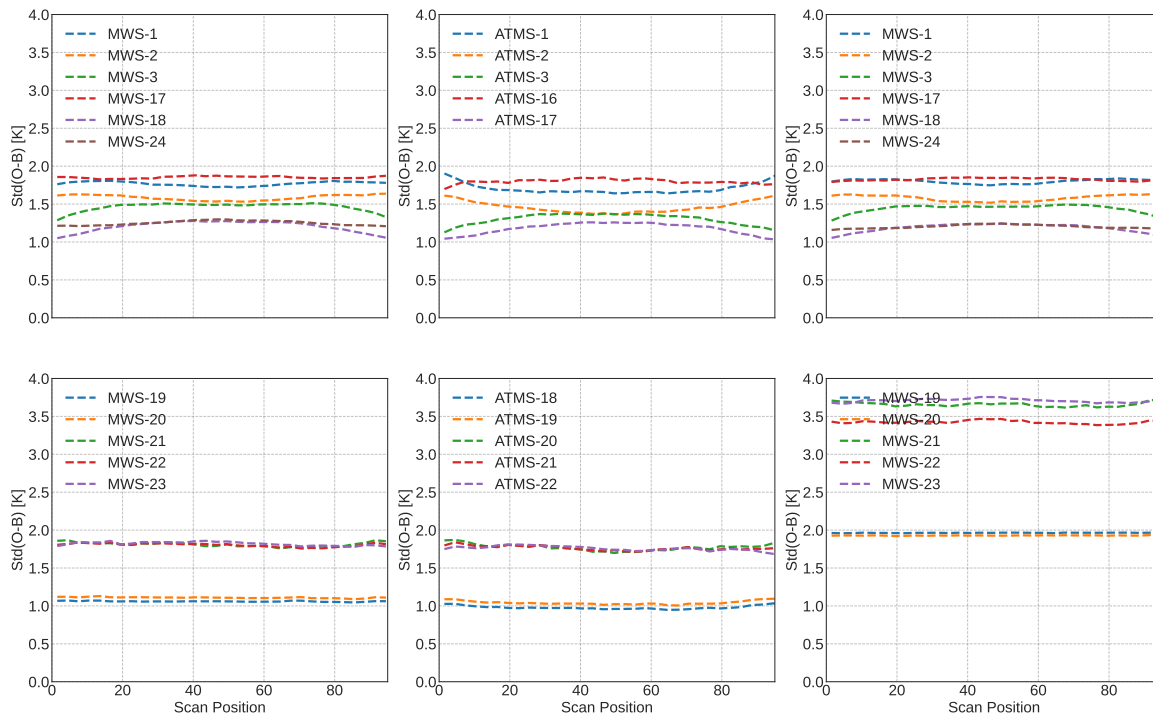


Figure 20: $SD(O - B)$ after bias correction as a function of scan position for MWS pre-anomaly (left), NOAA-21 ATMS (middle), and MWS post-anomaly (right). Data cover separate pre-anomaly (25-31 December) and post-anomaly (1-9 April) periods for MWS, with ATMS data from the December period. Stringent cal/val selection applied for un-averaged radiances.

This analysis and the assimilation trials described at the end of Sec. 5 indicate that MWS was a high-performing humidity sounder prior to the anomaly in March. Its early performance bodes well for future MWS instruments if the issue that caused the anomaly can be identified and fixed for the latter two launches.

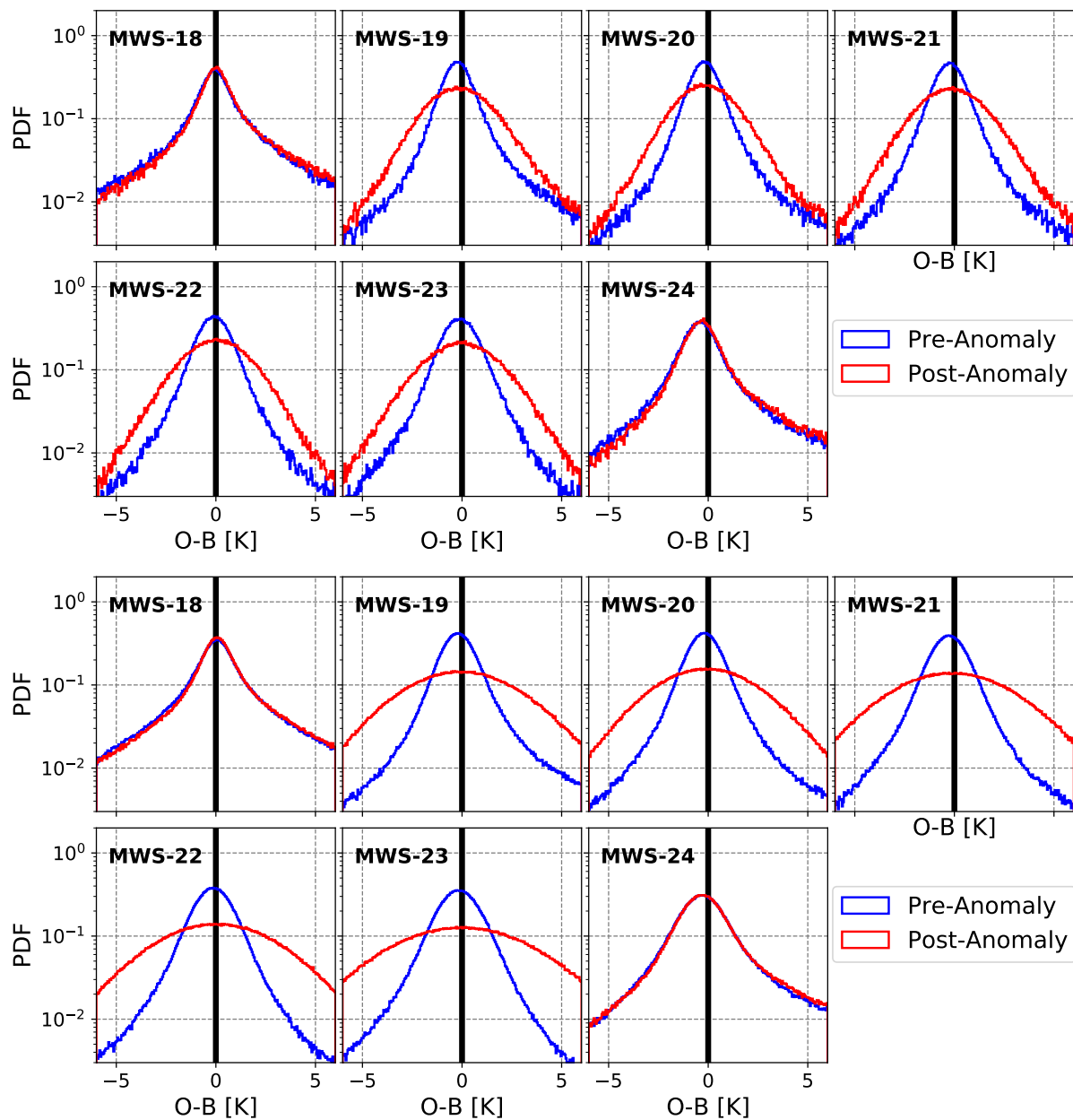


Figure 21: PDFs of $O - B$ following Fig. 6 but for all data (i.e. not limited to the cal/val sample). Top panels show superrobbed PDFs and bottom panels show $O - B$ with no averaging applied. Pre-anomaly data from 10th March (blue lines) and post-anomaly data (red lines) from 10th April, 2026.

B Appendix: More Jacobians

Shown below are RTTOV Jacobians for three atmospheric profiles at the nadir view geometry: polar winter, mid-latitude daytime, and tropics.

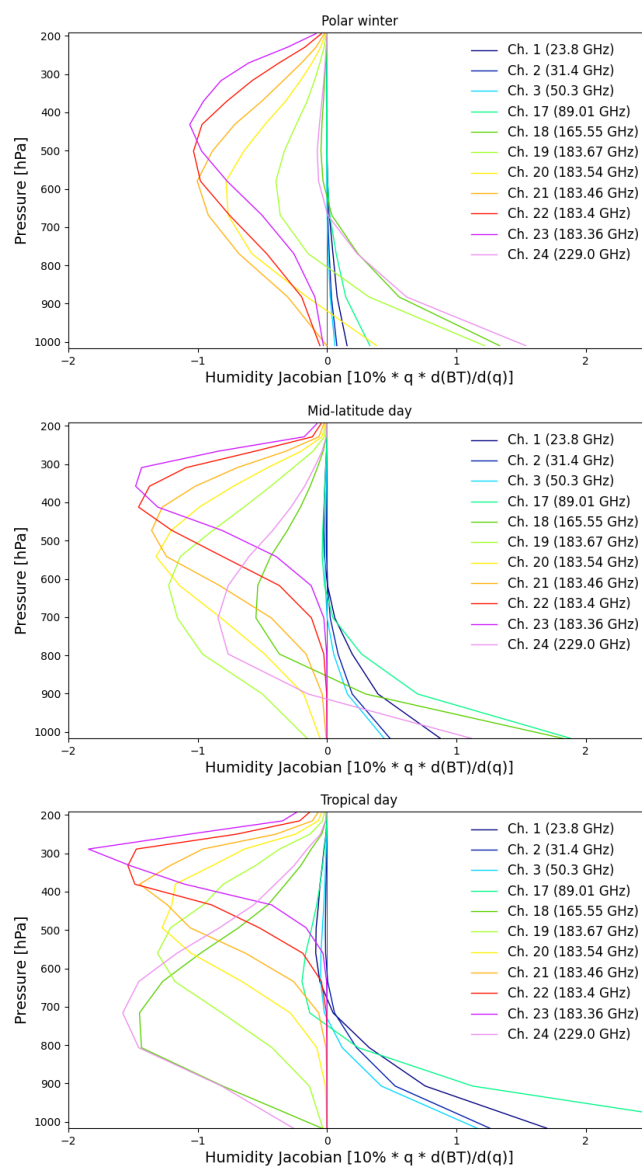


Figure 22: Humidity Jacobians for MWS channels from RTTOV v14 using a polar winter (top), mid-latitude daytime (middle), and tropical (bottom) atmospheric profile. Viewing geometry is nadir-pointing.

C Appendix: Applicable EUMETSAT internal documents

This appendix lists the relevant EUMETSAT internal documents for this study. The EURD is currently restricted, whereas the PFS is publicly available.

- EPS-SG End User Requirements Document (EURD): EUM/PEPS/REQ/09/0151, v9, 17 Jun 2024, 173 pp
- EPS-SG MWS Level 1B product Format Specification (PFS): EUM/LEO-EPSSG/SPE/14/777550, v5, 20 Mar 2024, 90 pp

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Glossary

AMSU-A Advanced Microwave Sounding Unit-A. [3](#), [4](#)

ATMS Advanced Technology Microwave Sounder. [3](#), [4](#)

ATOVS Advanced TIROS Operational Vertical Sounder. [5](#)

AWS Arctic Weather Satellite. [4](#)

BUFR Binary Universal Form for the Representation of meteorological data. [10](#)

CMA Chinese Meteorological Agency. [5](#)

ECT Equator crossing time. [16](#)

EDA Ensemble of Data Assimilations. [34](#)

EPS-SG EUMETSAT Polar System Second Generation. [3](#), [4](#)

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites. [4](#)

EURD End User Requirements Document. [9](#)

FOV Field of View. [5](#)

GMI Global Precipitation Measurement (GPM) Microwave Imager. [15](#)

IFS Integrated Forecasting System. [3](#), [5](#), [10](#)

LTAN Local time ascending node. [16](#)

MWS MicroWave Sounder. [3](#)

MWTS-3 MicroWave Temperature Sounder-3. [5](#)

NASA National Aeronautics and Space Administration. [4](#)

NEDT Noise Equivalent Differential Temperature. [7](#)

NOAA National Oceanographic and Atmospheric Administration. [4](#)

NWP-SAF Numerical Weather Prediction Satellite Application Facility. [12](#)

ODB Observational DataBase. [10](#)

PDF Probability Density Function. [22](#)

QH Quasi-Horizontal. [6](#), [16](#)

QV Quasi-Vertical. [6](#), [16](#)

SRF Spectral Response Function. [12](#)

SSMIS Special Sensor Microwave Imager Sounder. [15](#)

References

- Andersson, E. and Järvinen, H. (1999). Variational quality control. *Quart. J. Roy. Meteor. Soc.*, **125**(554), 697–722, doi:10.1002/qj.49712555416, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.49712555416>.
- Bell, W., English, S. J., Candy, B., Atkinson, N., Hilton, F., Baker, N., Swadley, S. D., Campbell, W. F., Bormann, N., Kelly, G. and Kazumori, M. (2008). The assimilation of SSMIS radiances in numerical weather prediction models. *IEEE T. Geosci. Remote Sens.*, **46**(4), 884–900, doi:10.1109/TGRS.2008.917335, URL <https://ieeexplore.ieee.org/abstract/document/4468717>.
- Bormann, N., Fouilloux, A. and Bell, W. (2013). Evaluation and assimilation of ATMS data in the ECMWF system. *J. Geophys. Res. Atmos.*, **118**(23), 12,970–12,980, doi:10.1002/2013JD020325, URL <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2013JD020325>.
- Bormann, N., Magnusson, L., Duncan, D. and Dahoui, M. (2023). Characterisation and correction of orbital biases in AMSU-A and ATMS observations in the ECMWF system. *Technical Report 912*, ECMWF Tech. Memo., doi:10.21957/d281dc221a, URL <https://doi.org/10.21957/d281dc221a>.
- Dee, D. P. (2004). Variational bias correction of radiance data in the ECMWF system. In *ECMWF workshop proceedings: Assimilation of high spectral resolution sounders in NWP, 28 June – 1 July, 2004*, pp. 97–112, ECMWF, Reading, UK, URL https://www.ecmwf.int/sites/default/files/elibrary/2004/74143-variational-bias-correction-radiance-data-ecmwf-system_0.pdf.
- Duncan, D., Bormann, N., Dahoui, M. and Crepulja, M. (2025). Assessment of the Arctic Weather Satellite in NWP. *Technical Report RFQ/21/1383948*, ECMWF, Reading, UK, doi:10.21957/232efc59cf, URL <https://www.ecmwf.int/en/elibrary/81681-assessment-arctic-weather-satellite-nwp>.
- Duncan, D. I., Bormann, N., Crepulja, M., Dahoui, M., Geer, A. J., Accadia, C., Di Michele, S., Hewison, T. J. and Kangas, V. (2026). Arctic Weather Satellite assessment and assimilation at ECMWF. *Atmos. Meas. Tech.*, **19**(11), 3581–3599, doi:10.5194/amt-19-3581-2026, URL <https://amt.copernicus.org/articles/19/3581/2026/>.
- Duncan, D. I., Bormann, N., Geer, A. J. and Weston, P. (2022). Assimilation of AMSU-A in all-sky conditions. *Mon. Weather Rev.*, **150**(5), 1023 – 1041, doi:10.1175/MWR-D-21-0273.1, URL <https://doi.org/10.1175/MWR-D-21-0273.1>.
- Duncan, D. I., Bormann, N., Geer, A. J. and Weston, P. (2024). Superobbing and thinning scales for all-sky humidity sounder assimilation. *Mon. Weather Rev.*, **152**(8), 1821 – 1837, doi:10.1175/MWR-D-24-0020.1, URL <https://journals.ametsoc.org/view/journals/mwre/152/8/MWR-D-24-0020.1.xml>.
- Duncan, D. I., Bormann, N. and Hólm, E. (2021). On the addition of microwave sounders and numerical weather prediction skill. *Quart. J. Roy. Meteor. Soc.*, **147**(740), 3703–3718, doi:10.1002/qj.4149, URL <https://doi.org/10.1002/qj.4149>.
- Eresmaa, R., Dahlgren, P., Hagelin, S., Schönach, D. and Dybbroe, A. (2026). Estimating the potential impact of the EPS-Sterna satellite constellation in regional numerical weather prediction. *Quarterly*

- Journal of the Royal Meteorological Society*, **152**(776), e70149, doi:<https://doi.org/10.1002/qj.70149>, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.70149>.
- Geer, A. J. (2016). Significance of changes in medium-range forecast scores. *Tellus A*, **68**(1), 30229, doi:10.3402/tellusa.v68.30229, URL <https://doi.org/10.3402/tellusa.v68.30229>.
- Geer, A. J., Baordo, F., Bormann, N. and English, S. (2014). All-sky assimilation of microwave humidity sounders. *Technical Report 741*, ECMWF Tech. Memo., doi:10.21957/obosmx154, URL <https://www.ecmwf.int/node/9507>.
- Geer, A. J. and Bauer, P. (2011). Observation errors in all-sky data assimilation. *Quart. J. Roy. Meteor. Soc.*, **137**(661), 2024–2037, doi:10.1002/qj.830, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.830>.
- Geer, A. J., Bauer, P. and Bormann, N. (2010). Solar biases in microwave imager observations assimilated at ECMWF. *IEEE T. Geosci. Remote Sens.*, **48**(6), 2660–2669, doi:10.1109/TGRS.2010.2040186, URL <https://ieeexplore.ieee.org/document/5424018>.
- Geer, A. J., Bauer, P., Lonitz, K., Barlakas, V., Eriksson, P., Mendrok, J., Doherty, A., Hocking, J. and Chambon, P. (2021). Bulk hydrometeor optical properties for microwave and sub-millimetre radiative transfer in RTTOV-SCATT v13.0. *Geosci. Model Dev.*, **14**(12), 7497–7526, doi:10.5194/gmd-14-7497-2021, URL <https://gmd.copernicus.org/articles/14/7497/2021/>.
- Geer, A. J., Lonitz, K., Duncan, D. I. and Bormann, N. (2022). Improved surface treatment for all-sky microwave observations. *Technical Report 894*, ECMWF Tech. Memo., Shinfield Park, Reading, doi:10.21957/zi7q6hau, URL <https://www.ecmwf.int/node/20337>.
- Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., De Chiara, G., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R. J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., de Rosnay, P., Rozum, I., Vamborg, F., Villaume, S. and Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quart. J. Roy. Meteor. Soc.*, **146**(730), 1999–2049, doi:10.1002/qj.3803, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.3803>.
- Kilic, L., Prigent, C., Jimenez, C., Turner, E., Hocking, J., English, S., Meissner, T. and Dinnat, E. (2023). Development of the SURface Fast Emissivity Model for Ocean (SURFEM-Ocean) based on the PARMIO radiative transfer model. *Earth Space Sci.*, **10**(11), e2022EA002785, doi:10.1029/2022EA002785, URL <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2022EA002785>.
- Lawrence, H., Bormann, N., Geer, A. J., Lu, Q. and English, S. J. (2018). Evaluation and assimilation of the microwave sounder MWHS-2 onboard FY-3C in the ECMWF numerical weather prediction system. *IEEE T. Geosci. Remote Sens.*, **56**(6), 3333–3349, doi:10.1109/TGRS.2018.2798292, URL <https://doi.org/10.1109/TGRS.2018.2798292>.
- Lean, K., Bormann, N., Healy, S., English, S., Schüttemeyer, D. and Drusch, M. (2025). Assessing forecast benefits of future constellations of microwave sounders on small satellites using an ensemble of data assimilations. *Quart. J. Roy. Meteor. Soc.*, **151**(768), e4939, doi:<https://doi.org/10.1002/qj.4939>, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.4939>.

- McNally, A. P. (2019). On the sensitivity of a 4D-Var analysis system to satellite observations located at different times within the assimilation window. *Q. J. Roy. Meteor. Soc.*, **145**(723), 2806–2816, doi: <https://doi.org/10.1002/qj.3596>, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.3596>.
- Mears, C. A., Schabel, M. C. and Wentz, F. J. (2003). A reanalysis of the MSU channel 2 tropospheric temperature record. *J. Climate*, **16**(22), 3650–3664, doi:10.1175/1520-0442(2003)016<3650:AROTMC>2.0.CO;2.
- Munro, R. and Coauthors (2026). EUMETSAT Polar System - Second Generation: Continuation of observations and advancing applications from low earth orbit. *Bull. Amer. Meteor. Soc.*, pp. BAMS-D-24-0307.1, doi:10.1175/BAMS-D-24-0307.1, URL <https://journals.ametsoc.org/view/journals/bams/aop/BAMS-D-24-0307.1/BAMS-D-24-0307.1.xml>.
- MWS Science Advisory Group (2019). EPS-SG MicroWave Sounder (MWS) science plan. *Technical report*, EUMETSAT, URL <https://www.eumetsat.int/media/43204>.
- Newman, S., Carminati, F., Lawrence, H., Bormann, N., Salonen, K. and Bell, W. (2020). Assessment of new satellite missions within the framework of numerical weather prediction. *Remote Sens.*, **12**(10), doi:10.3390/rs12101580, URL <https://www.mdpi.com/2072-4292/12/10/1580>.
- Samrat, N. H., Candy, B., Lewis, O., Cotton, J., Smith, F., Halloran, G., Harlow, C., Lawrence, H., Migliorini, S., Smith, A. and Thomas, C. (2025). Observation impact evaluation through data denial experiments in the Met Office global numerical weather prediction system. *Quart. J. Roy. Meteor. Soc.*, **151**(771), e5002, doi: <https://doi.org/10.1002/qj.5002>, URL <https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.5002>.
- Sreerekha, T. R., Doherty, A. and English, S. (2010). Potential of 229-GHz channel for ice-cloud screening. *IEEE Trans. Geosci. Remote Sens.*, **48**(5), 2183–2188, doi:10.1109/TGRS.2009.2032174.
- Sreerekha, T. R., English, S. J. and Rayer, P. J. (2007). Report on oxygen sounding channel frequencies and polarisations. *Technical Report EUM/CO/06/1557/PSF*, EUMETSAT Technical Report, Darmstadt, Germany, URL https://www-cdn.eumetsat.int/files/2020-04/pdf_peps_rep05.pdf.
- Steele, L., Bormann, N. and Duncan, D. I. (2023). Assimilating FY-3E MWHS-2 observations, and assessing all-sky humidity sounder thinning scales. *Technical Report 62*, EUMETSAT/ECMWF Fellowship Programme Research Report, Shinfield Park, Reading, doi:10.21957/f42a9d9542, URL <https://doi.org/10.21957/f42a9d9542>.