Space-Based Intercomparisons for the Tomorrow.io Microwave Sounders

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TMS Mission Profile

Essential Sensor Characteristics and Orbital Coverage

Reference Sensor Double Differences

We perform double difference calculations against **ATMS** (NPP, NOAA20, and NOAA21). These are used to inform post-launch calibration parameters for some channels post-launch.

Independent validation is assessed with **GMI** double differences.

GNSS-RO Single Differences

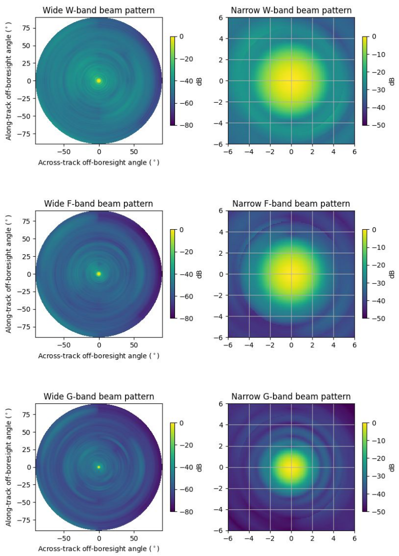
GNSS-RO missions provide a plethora of high-vertical resolultion profiles of temperature and humidity.

Comparisons to TMS observations are conducted via radiative transfer model.

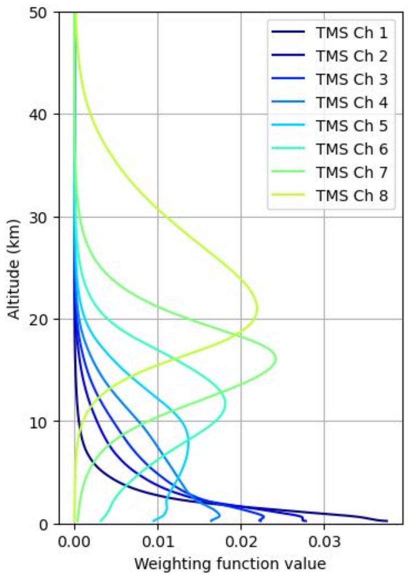
TMS MISSION PROFILE

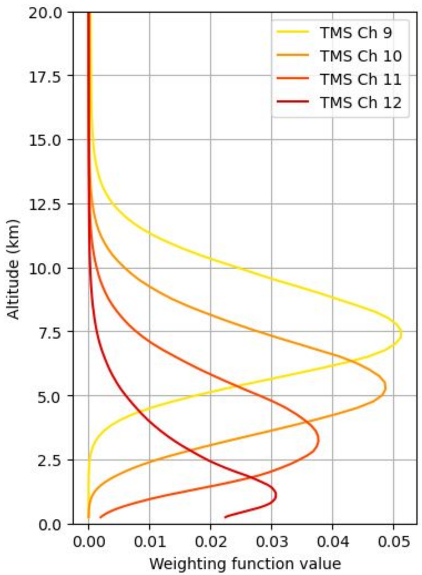
3Q25

TMS Instrument Specifications



Channel	TMS Center Freq. (GHz)	TMS Bandwidth per sideband (GHz)	TMS NEDT Post-launch mean (K)
1 (W)	91.65	2	0.35
2 (F1)	118.75±3.5	1	0.57
3 (F2)	118.75±2.625	0.75	0.64
4 (F3)	118.75±1.875	0.75	0.62
5 (F4)	118.75±1.25	0.5	0.70
6 (F5)	118.75±0.75	0.5	0.70
7 (F6)	118.75±0.375	0.25	0.95
8 (F7)	118.75±0.125	0.25	0.94
9 (G1)	184.41	2	0.39
10 (G2)	186.51	2	0.43
11 (G3)	190.31	2	0.45
12 (G4)	204.8	2	0.43





Orbit Altitude	Swath Width
450 km	1780 km
500 km	2016 km
550 km	2265 km
600 km	2528 km

Band	Beamwidth	Beam Efficiency	FOV* @ nadir	FOV* (scan mean)
W (91 GHz)	2.94°	91.1%	27.7 km	44.3 km
F (114-122 GHz)	2.47°	97.6%	23.5 km	37.6 km
G (184-190 GHz)	1.47°	96.6%	15.1 km	24.2 km
G (204 GHz)	1.44°	97.7%	14.9 km	23.8 km

*geometric mean from 525 km altitude

TOMORROW.IO TMS1.1 LTANs (LAST 3 MONTHS)

A combination of sun-synchronous, 45°, and (future) 88° ***inclined*** orbits provide round-the clock coverage

REFERENCE SENSOR DOUBLE DIFFERENCES

MATCHUP CRITERIA

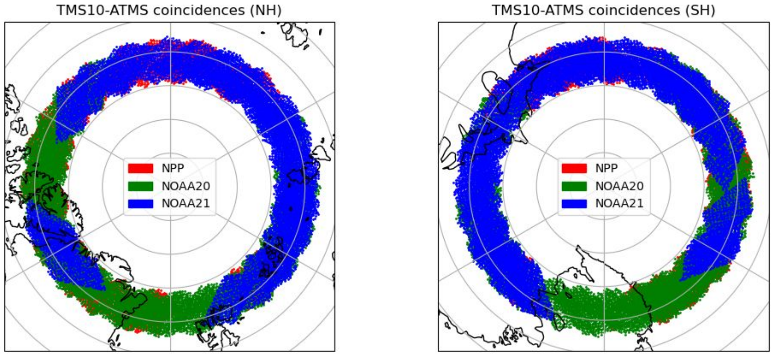
ATMS

Must be within 15 minutes and 15 km; both TMS and ATMS sensor viewing angle must be less than 15°.

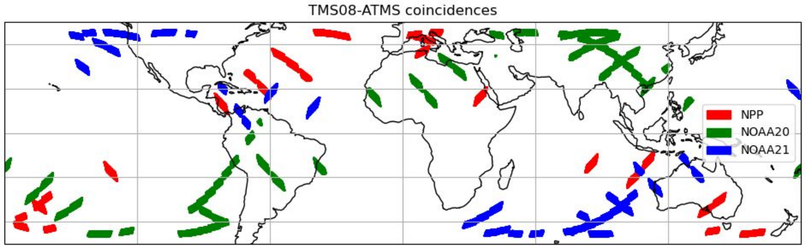
GMI

Must be within 15 minutes and 15 km; TMS must be within 1.5 degrees of GMI incidence angle (52.8°@ 89 GHz; 49.1°@183 GHz).

Additional filters are imposed to remove clouds and inhomogeneous surfaces.



TMS SSO-ATMS coincidences occur in fixed latitude bands…

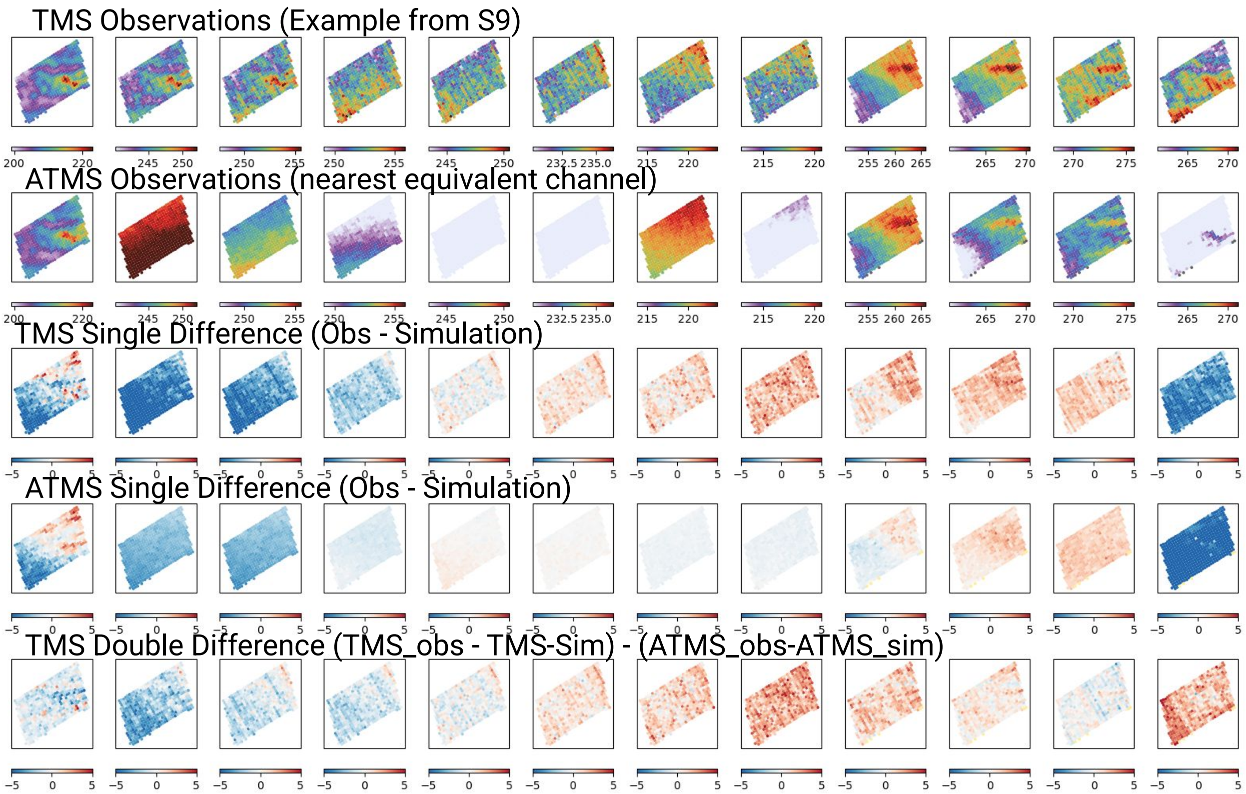


…whereas TMS 45°-ATMS coincidences occur at all latitudes.

DOUBLE DIFFERENCE METHODOLOGY

Double differences minimize bias from RTM and/or background state error

1. The ATMS-MiRS derived profile is used as the background state, as this should be consistent with the ATMS observations.
2. ATMS and TMS brightness temperatures are simulated by convolving high-spectral-resolution monochromatic simulations with each instrument/channel’s unique spectral response function.
3. Single differences with ATMS are used to filter observations affected by clouds and precipitation
4. Doubel differences are calculated; the reference observation becomes the ATMS observation plus the predicted TMS-ATMS difference.



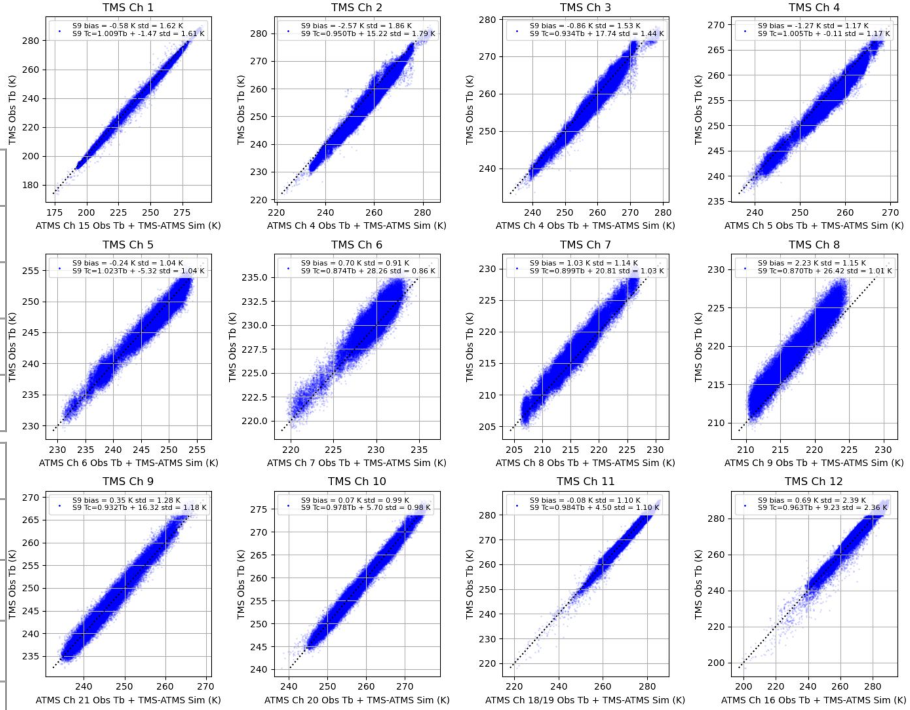
ATMS DOUBLE DIFFERENCE RESULTS

Each TMS sensor is evaluated with data from a different time period from that used for post-launch calibration.

Channels 1, 9, 10, and 11 have direct equivalents on ATMS; other channels have indirect equivalents (double differences may not represent true bias).

Bias vs. ATMS (K)	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ch 1 (91 GHz)	-0.06	-0.03	0.06	0.55	0.10	0.17	0.20	0.45	-0.58
Ch 9 (184 GHz)	-0.12	0.26	0.01	0.18	5.99	4.35	0.30	0.02	0.35
Ch 10 (186 GHz)	0.52	0.28	0.02	0.18	4.90	3.83	0.22	-0.1	0.07
Ch 11 (189 GHz)	0.05	0.07	-0.21	0.23	2.24	1.80	0.19	-0.21	-0.08

Std vs. ATMS (K)	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ch 1 (91 GHz)	1.67	1.87	1.89	1.32	1.50	1.71	1.59	1.47	1.62
Ch 9 (184 GHz)	1.04	1.06	1.17	1.19	1.77	1.49	1.74	1.39	1.28
Ch 10 (186 GHz)	1.04	0.95	0.82	0.96	1.46	1.64	1.62	1.39	0.99
Ch 11 (189 GHz)	1.08	1.07	0.88	0.94	1.40	1.44	1.41	1.12	1.10



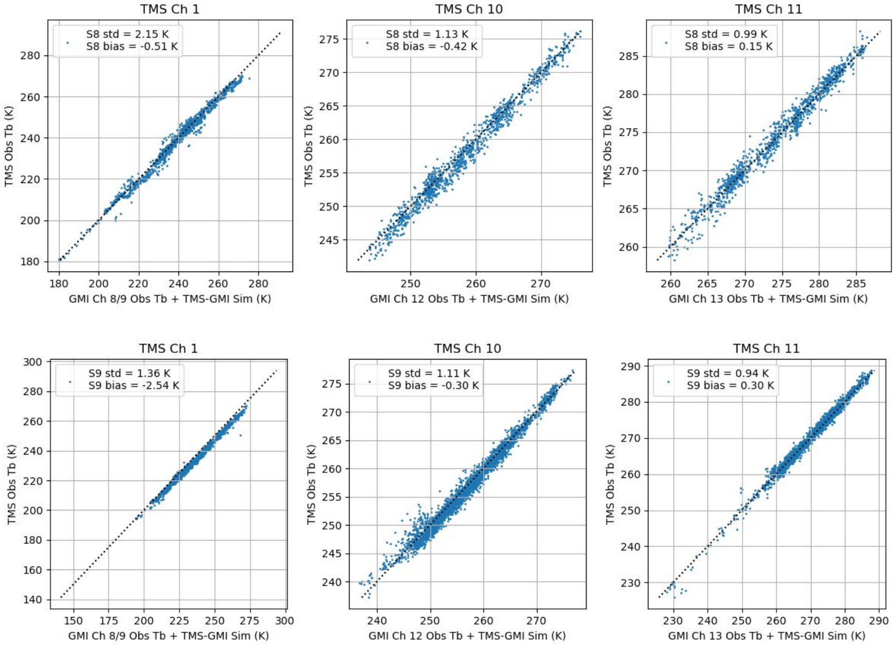
Double difference scatter plot example from Tomorrow-S9

GMI DOUBLE DIFFERENCE RESULTS

GMI double differences occur at a wide range of latitudes for all TMS orbits and at far off-nadir incidence angles, providing independent validation of the post-launch calibration and antenna pattern correction, but only in channels 1, 9, and 10.

Bias vs. GMI (K)	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ch 1 (91 GHz)	-0.68	-0.18	-1.74	-2.15	-1.52	-0.69	-1.47	-0.51	-2.53
Ch 10 (186 GHz)	-0.01	0.02	-0.16	-0.25	0.31	0.23	0.50	-0.42	-0.30
Ch 11 (189 GHz)	0.39	0.54	-0.03	-0.82	1.01	1.30	0.96	0.15	0.30

Std vs. GMI (K)	S1	S2	S3	S4	S5	S6	S7	S8	S9
Ch 1 (91 GHz)	2.44	2.16	2.11	2.39	2.03	2.41	2.68	2.15	1.36
Ch 10 (186 GHz)	0.88	0.89	0.94	1.26	1.54	1.61	1.43	1.13	1.11
Ch 11 (189 GHz)	1.04	0.90	0.99	1.30	1.14	1.44	1.25	0.99	0.94



Double difference scatter plot example from Tomorrow-S8 (top) and Tomorrow-S9 (bottom)

GNSS-RO SINGLE DIFFERENCES

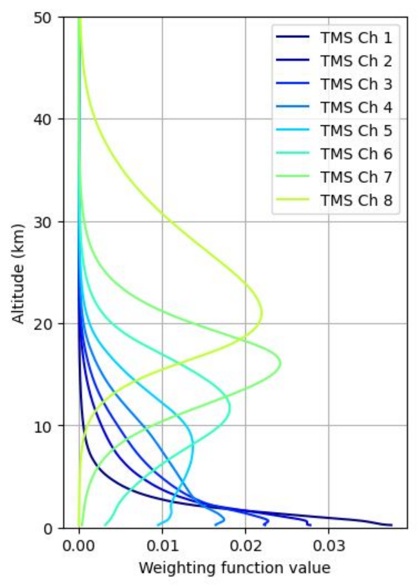
GNSS-RO MATCHUP CRITERIA

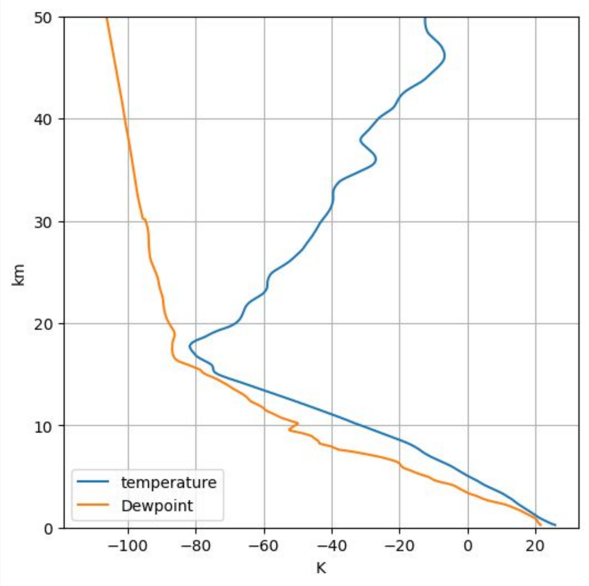
We used the “WetPf2” product from UCAR for the COSMIC2, PlanetIq, and Spire RO constellations.

GNSS-RO profiles do not represent a single fixed location, but have a location that depends on altitude. We select RO profiles that are within 25 km and 15 minutes of a TMS observations at the 15 km altitude of the RO profile.

Profiles with minimum dewpoint depressions < 2°C were rejected as possibly cloud contaminated.

Brightness temperatures were simulated assuming clear sky conditions. Surface emissivity was derived from the 91 GHz and 204 GHz channels for channels 2-8 and 9-11, respectively.

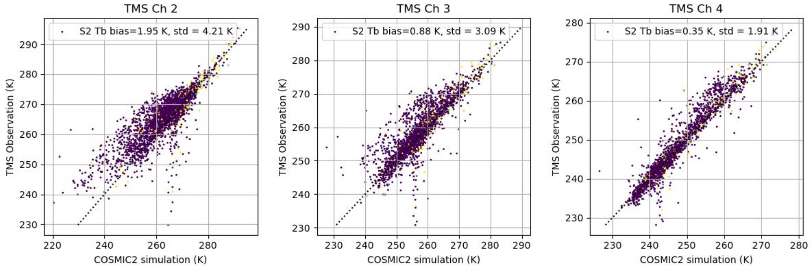




GNSS-RO profiles provide high (250m) vertical resolution data throughout the atmospheric layers covered by TMS weighting functions

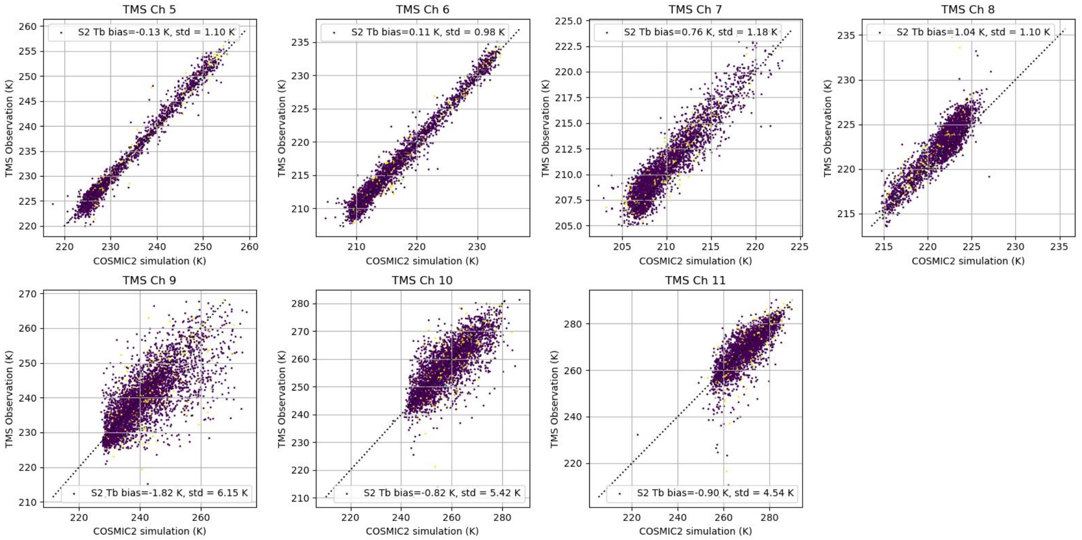
GNSS-RO DETAILED RESULTS - S2

COSMIC2 profiles gave standard deviations significantly larger than ERA5 profiles for channels 2-5 and 9-11 - indicating limitations of RO in the lower-mid troposphere. Standard deviations were comparable in channels 6-8. For these channels, PlanetIQ and Spire profiles gave slightly larger standard deviations, possibly due to their reduced signal-to-noise ratio (1000 V/V and 600 V/V, respectively, vs 2000 V/V for COSMIC2).



Bias vs. RO (K)	COSMIC2	PlanetIQ	Spire
Ch 5 (118.75 +- 1.25 GHz)	-0.08	-0.06	-0.16
Ch 6 (118.75 +- 0.75 GHz)	0.18	0.19	0.17
Ch 7 (118.75 +- 0.375 GHz)	0.86	0.86	0.88
Ch 8 (118.75 +- 0.125 GHz)	1.13	1.13	1.13

Std vs. RO (K)	COSMIC2	PlanetIQ	Spire
Ch 5 (118.75 +- 1.25 GHz)	1.09	1.13	1.17
Ch 6 (118.75 +- 0.75 GHz)	0.88	0.95	1.01
Ch 7 (118.75 +- 0.375 GHz)	1.09	1.15	1.19
Ch 8 (118.75 +- 0.125 GHz)	1.01	1.03	1.01



GNSS-RO SUMMARY RESULTS

(COSMIC2 only)

Bias vs. RO (K)	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
Ch 5 (118.75 +- 1.25 GHz)	-0.10	-0.08	0.61	-0.19	-0.09	-0.06	-0.45	0.11	0.10
Ch 6 (118.75 +- 0.75 GHz)	0.20	0.18	0.85	1.01	0.32	0.17	-0.03	0.46	0.48
Ch 7 (118.75 +- 0.375 GHz)	0.84	0.88	1.20	1.26	1.20	0.94	1.00	1.07	1.09
Ch 8 (118.75 +- 0.125 GHz)	1.02	1.15	1.03	1.33	1.34	0.87	1.04	1.28	1.32

Std vs. RO (K)	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
Ch 5 (118.75 +- 1.25 GHz)	1.12	1.10	1.13	1.17	1.09	1.05	1.20	1.28	1.28
Ch 6 (118.75 +- 0.75 GHz)	1.01	0.89	1.20	1.08	1.00	0.94	1.06	1.27	1.20
Ch 7 (118.75 +- 0.375 GHz)	1.20	1.10	1.29	1.35	1.25	1.16	1.28	1.49	1.44
Ch 8 (118.75 +- 0.125 GHz)	1.09	1.02	1.15	1.21	1.14	1.04	1.11	1.27	1.26

2025

SUMMARY

TMS post-launch calibration and monitoring utilizes space-based intercomparison sources.

Double differences against reference sensors are the preferred technique but not available for all channels. Single differences against GNSS-RO profiles are an alternative for upper troposphere/stratosphere 118 GHz channels.

Comparisons show most channels are within accuracy and stability design requirements (2.0 K at W-band, 1.5 K at F-band, and 1.0 K at G-band).

TMS Level 1 products will be upgraded to V2 this summer - with improved quality flags, calibration stability, and geolocation accuracy.

TMS Calibration References:

1. ERA5 clear-sky simulations;
2. ATMS double differences;
3. GMI double differences;
4. GNSS-RO single differences;
5. Radiosonde single differences

THANK YOU