Performance Evaluation of Bureau Proposed Microwave Sounder Mission to Track Weather from Space

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1 Background

- 95 % of observations assimilated by Numerical Weather Prediction (NWP) are satellite observations. The Bureau is entirely reliant on international partners for this.
- We worked with the Australian Space Agency (ASA) in 2022 on a sovereign meteorological satellite capability, aiming to make meaningful contributions to the global observing system and to develop self-reliance for critical observations.
- A hyperspectral microwave sounder was one of the instruments selected in a previous study, due to the high impact of microwave observations on NWP performance and recent technological advances in the field. We then developed the following research questions to establish the potential impact of the Microwave Sounding Mission (MSM) for NWP.

Research Questions:

- How well does this proposed MSM perform in an appropriate operational NWP environment?
- What is the effect of different estimates of observation error?
- What is the sensitivity of the information content on the spectral resolution?

2 Approach and Data

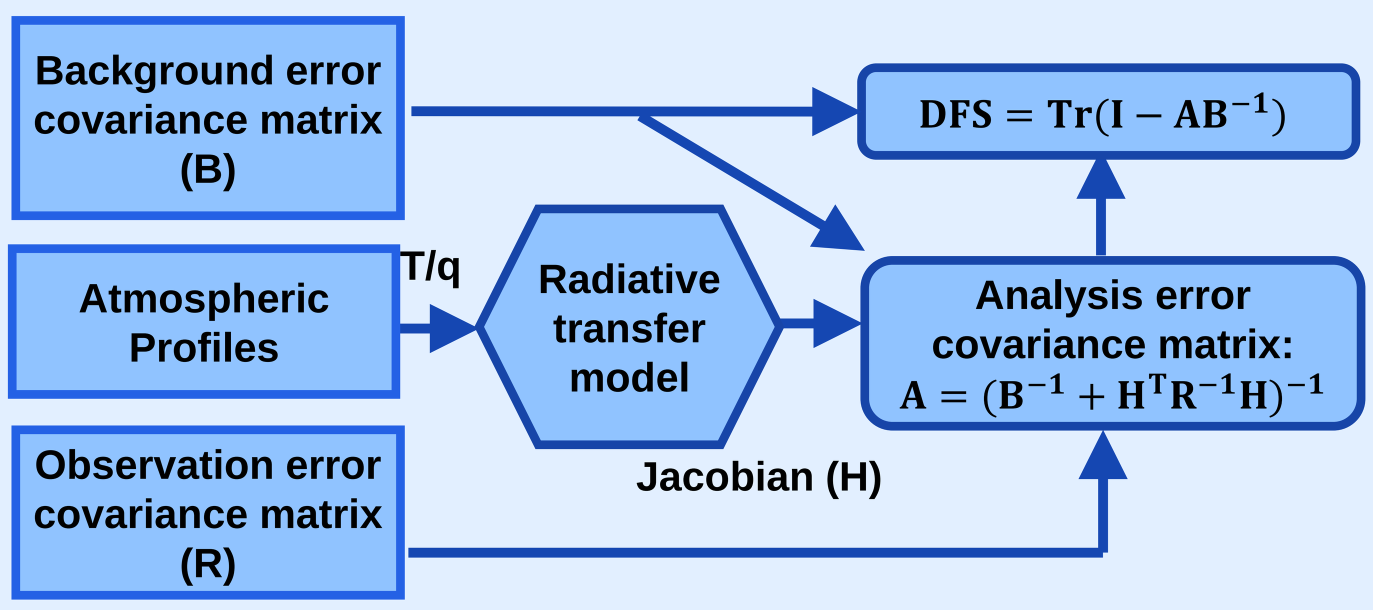
Proposed MSM Mission:

- The MSM mission requirements were developed in pre-Phase A study report based on user perspectives and a survey.
- In the survey, users prioritized the instrument's noise performance, and the study report indicates that the mission can meet many of the performance requirements at the "Objective" Level, the highest of the three levels of requirements [1].
- In this study, based on user requirements, MSM channels were chosen in three bands: 50-60 and 118 GHz for temperature (T) and 183 GHz for humidity (q) sounding.

Workflow:

- The performance of the MSM is examined via information content calculations for T and q profiles, with input assumptions appropriate for NWP applications.
- This study's chosen measure of information content is degrees of freedom for signal (DFS), derived from the linear optimal estimation theory [2-4].

- **H** estimated using RTTOV
- **B** matrix from ACCESS obs processing system (OPS).
- Atmospheric profiles from ACCESS-G



- **Three different R matrix estimations were used:**
- **Obs. error method 1**: computed by following the method described in [4] using instrument NEΔT at 280K scene temperature.
- **Obs. error method 2**: reduce the errors of method 1, consistent with footprint averaging of the incoming brightness temperatures over 3 scan positions + 3 scan lines (averaging consistent with operational use of ATMS).
- **Obs. error method 3**: method 2 + other errors (e.g., radiative transfer model error). Estimated from the ATMS observation error used in the Bureau's operations, subtracting off the ATMS instrument noise and adding the MSM error from method 2.

Table 1: NEΔT of MSM for different spectral resolutions (indicated in blue lines).

Frequency Range [GHz]	Res. 1		Res. 2		Res. 3		Res. 4		Res. 5		Res. 6	
	N Chan	NEΔT	N Chan	NEΔT	N Chan	NEΔT	N Chan	NEΔT	N Chan	NEΔT	N Chan	NEΔT
50-60	10 MHz		20 MHz		40 MHz		100 MHz		200 MHz		500 MHz	
	1000	2.56	500	1.80	250	1.27	100	0.80	50	0.57	20	0.36
118	20 MHz		40 MHz		80 MHz		160 MHz		320 MHz		500 MHz	
	400	4.09	200	2.89	100	2.04	50	1.44	25	1.02	16	0.82
183	40 MHz		80 MHz		160 MHz		400 MHz		560 MHz		Single side-band	
	350	3.25	175	2.30	87	1.62	35	1.02	25	0.87	Double side-band	

Initial comparison against ATMS:

Table 2: DFS value of ATMS and MSM .

Instrument	Ch.	R matrix	B mat. Zone 1 (lat: -90, -30)		B mat. Zone 2 (lat: -30, 30)		B mat. Zone 3 (lat: 30, 90)	
			DFS T	DFS q	DFS T	DFS q	DFS T	DFS q
ATMS	22	ATMS NEΔT using method in [4]	0.91	0.87	0.63	1.77	0.72	0.91
ATMS	22	OPS ATMS Error	0.52	0.68	0.3	1.47	0.35	0.7
MSM	1394	ATMS NEΔT using method in [4]	5.38	3.74	4.6	5.98	4.54	3.77
MSM	1394	OPS ATMS Error	7.44	4.51	6.78	6.97	6.74	4.52

3 How Well Does MSM Perform?

Information Content:

The results are shown for:

- Three spectral bands, 50-60, 118 and 183 GHz
- Double side-band channels at 118 and 183 GHz
- 3 climatological zones via the **B** matrix
- 3 **R** matrix methods.
- Different spectral resolutions or channel widths (x-axis).

Figure 1

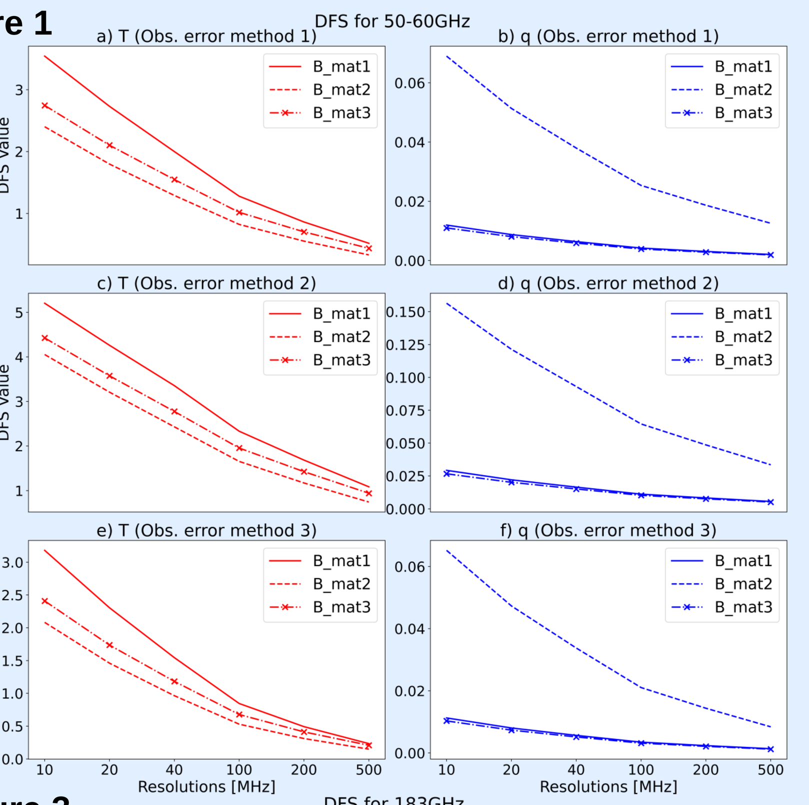


Figure 2

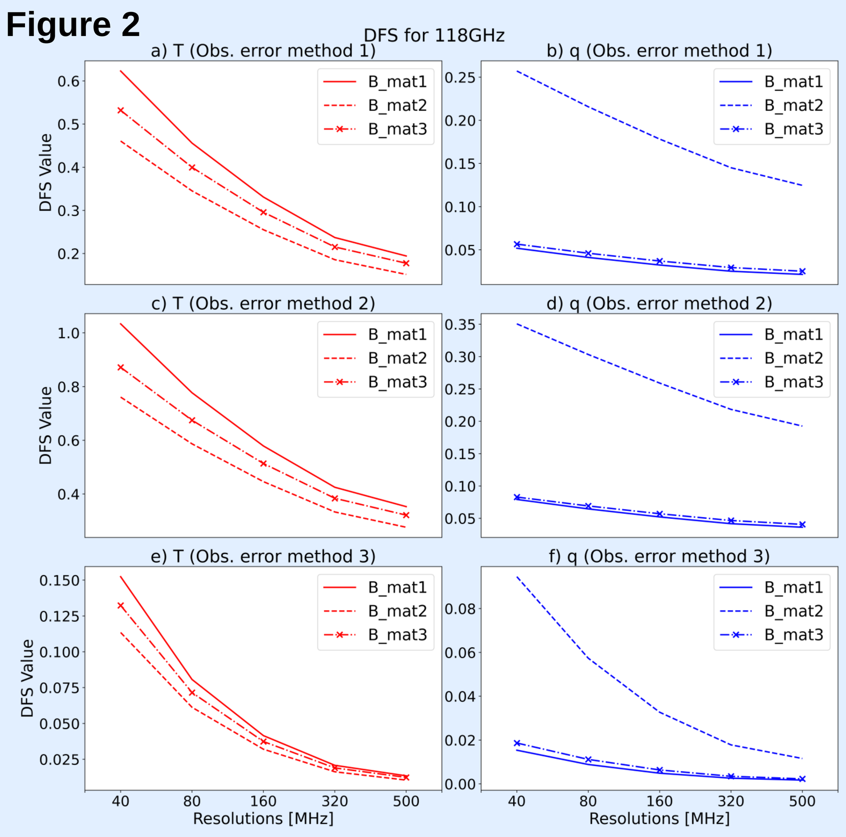


Figure 3

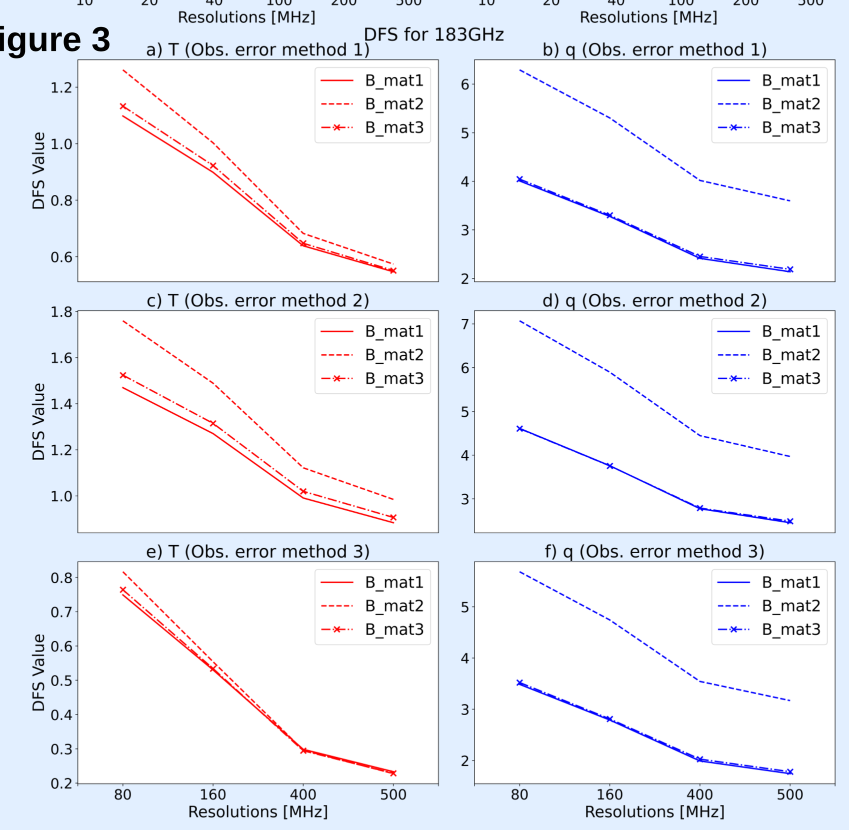


Figure 1-3: DFS value at 50-60 (1), 118 (2) and 183 (3) GHz range for different spectral resolutions for different R matrix case.

Furthermore, a sensitivity test has been performed to very high spectral resolutions by (not shown in this poster):

- **Computing averaging kernels** for T using $\mathbf{AK} = (\mathbf{B}^{-1} + \mathbf{H}^{\mathbf{T}}\mathbf{R}^{-1}\mathbf{H})^{-1}\mathbf{H}^{\mathbf{T}}\mathbf{R}^{-1}\mathbf{H}$
- ✓ The averaging kernels span more of the atmosphere at higher spectral resolutions.
- **Analysing the Jacobians** (amplitudes and altitudes of the peak for T).
- ✓ Suggest that the amplitude is higher, and channels sound high at higher spectral resolutions.

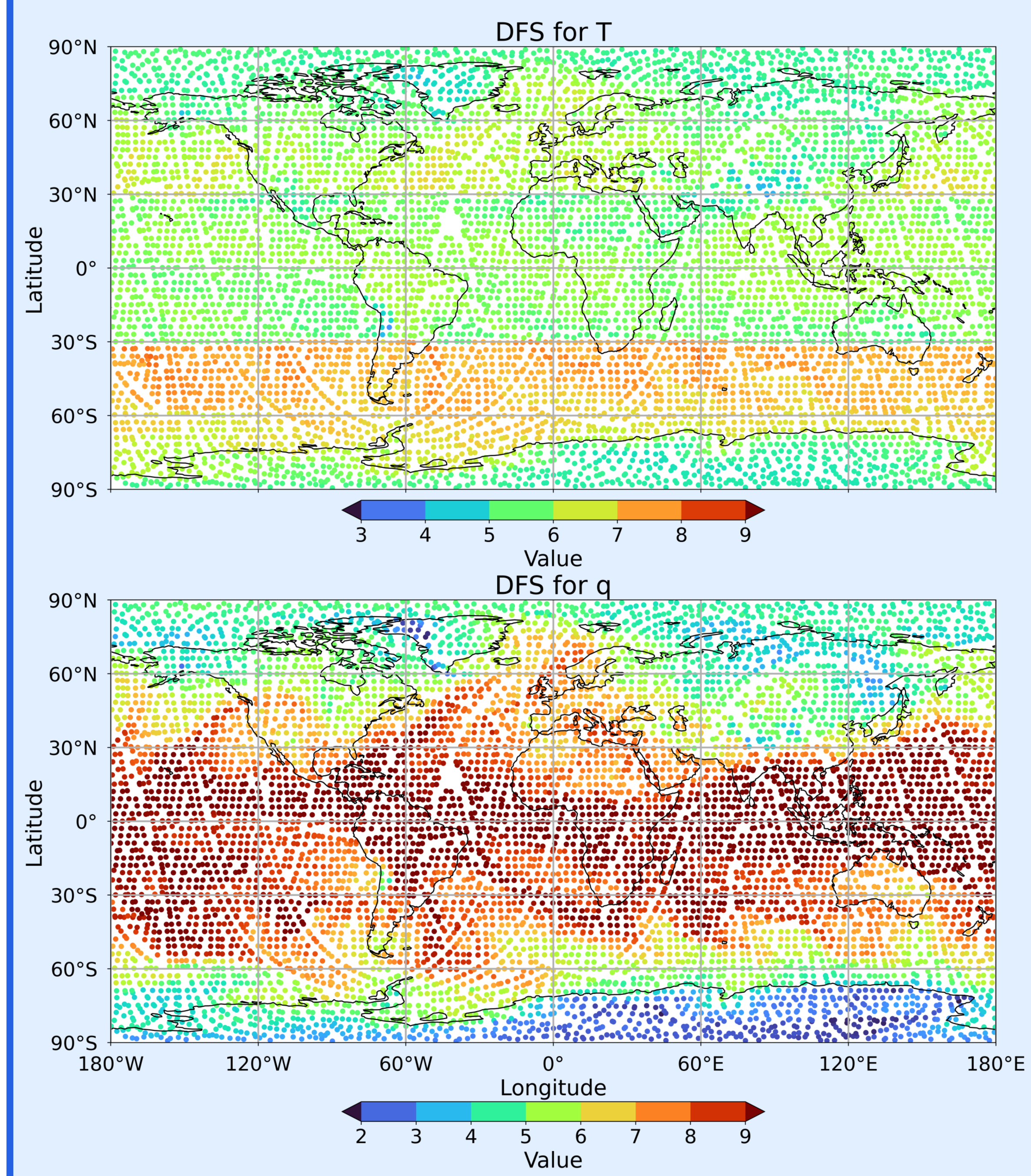


Figure 4: The DFS map for the complete frequency range package of MSM (~1750 channels) based on obs. error method 2.

No significant difference was seen for single vs. double sideband channels at 118 and 183 GHz, but single was slightly better.

The maximum DFS was found for:

- highest spectral resolutions (single side-band widths of 10, 20 and 40 MHz respectively)
- reducing observation errors by 3x3 footprint averaging (Method 2)

This configuration is used to show a map of DFS for projected satellite footprints in (Figure 4). Impact is highest for T in the Southern Hemisphere and for q in the Tropics

4 Closing Remarks and Insight

- The Bureau articulated an ambition for Australian operational meteorological satellite sensing capabilities in the 2030s and supported the Earth Observation Roadmap of ASA.
- This preliminary information content assessment demonstrates the potential of the proposed MSM mission under clear-sky conditions in the context of the NWP system.
- Overall analysis indicates that averaging a 3x3 set of footprints significantly improves the NEΔT increasing information content and improving sounding performance.

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