A Hyperspectral Microwave Sounding Mission for Australia

The Bureau of Meteorology

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1 Introduction

In 2022, the Bureau began working with the Australian Space Agency and the Australian National Concurrent Design Facility at the University of New South Wales Canberra Space to design three satellite missions to support our operational requirements. One of the instruments chosen is a Hyperspectral Microwave Sounding Mission, due to the criticality of microwave sounding data for Bureau numerical weather prediction (NWP) performance.

This poster summarises the user requirements for microwave sounding to meet our future NWP and tropical cyclone nowcasting and monitoring needs, and will provide an overview of the proposed mission, along with results of our user requirements survey. We would like to thank the ITSC members who contributed to the survey, and hope that it may inform the development of the future global microwave sounding observing network.

Proposed areas for improvements over existing instrumentation:

- Higher vertical resolution via software-controlled digital spectrometer "hyperspectral" sounder, also delivering better possibilities for RFI mitigation
- Higher temporal resolution: via a constellation of low-earth orbit satellites.
- Pathfinder instrument is proposed for Sun Synchronous Orbit with LTAN 05:30
- Better spatial resolution – lower orbit delivering smaller footprints.
- Better noise performance through new technology Low Noise Amplifiers etc.

2 User requirements and survey results

Various efforts internationally have set out the needs for microwave sounding in support of NWP. Three main resources have been studied:

- WMO observation requirements (noting that these are not mission requirements, and not even satellite requirements) [1]
- NOAA Future Satellite Architecture requirements for microwave SounderSat missions [2]
- EUMETSAT MWS user requirements [3]

The MSM user requirements build from a base of a combination of the NOAA requirements and microwave sounder (MWS) requirements. We conducted a survey of Bureau users and external experts including the global Satellite NWP DA community from 1-9 September 2022 (total 36 participants, 13 of whom from the Bureau). This provided an opportunity for general discussion and questions. The survey allowed us to prioritise the following requirements for the mission.

- **Excellent radiometric noise performance** (NEΔT)
- **Higher spectral resolution**
- **Higher spatial Resolution** (a footprint of 10 km or less)
- **Higher temporal Resolution** (hourly or better temporal coverage).

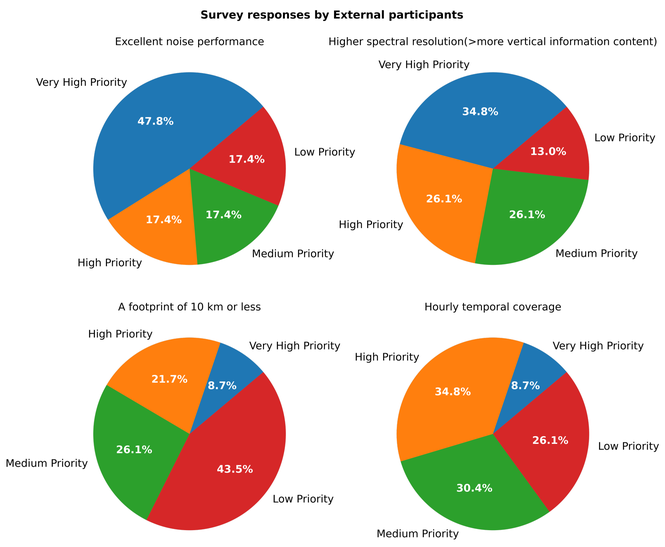

Figure 1: The rank distribution of priority from external users

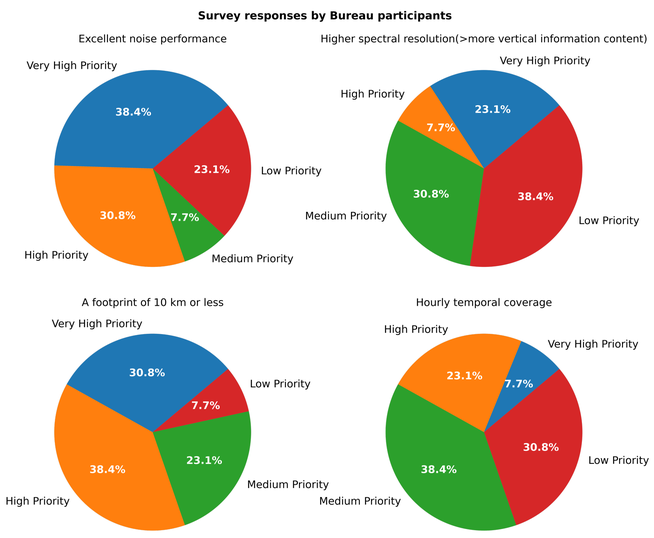

Figure 2: The rank distribution of priority from Bureau users

Figures 1 and 2 show how the different user groups (Global NWP Users and Microwave Experts, and Bureau Users) prioritised these competing requirements

Bureau users surveyed included scientists forecasters and customer-focused roles, including TC forecasters.

Although global data users have more of a preference for excellent noise performance, Bureau users even outside the NWP community also ranked noise performance most highly. There is a strong desire from Bureau users to provide instrumentation on a par with current operational missions.

There is a much stronger desire to push for a small footprint among Bureau users than Global Users. This is partly because of the need for better than current spatial resolution to support TC forecasting, but also our strong focus on high-resolution forecasting. Hence we added 118 GHz channels and spatial oversampling to the requirements..

3 Overall User Priorities

The threshold spectral coverage required is at least 50-60 GHz, 183 GHz, and 80-90 GHz. For the other high priority parameters we find 1) Excellent noise performance, 2) Higher spectral resolution, 3) Footprint of 10 km or less, and 4) Hourly temporal coverage [order calculated based on the score: (very high priority+high priority)-(medium priority+low priority)].

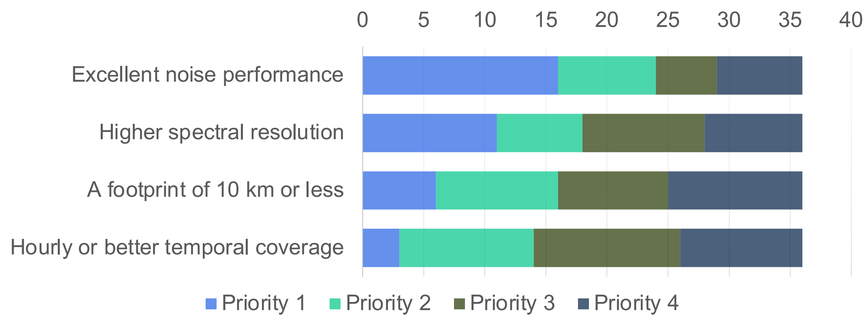

Figure 3: The rank of the four high priority requirements from the survey of all users.

4 The Proposed Mission Parameters

This table gives a summary of our mission requirements from a user perspective, proposed on three levels (Objective, Breakthrough and Threshold). The outcome of the pre-Phase A study was that the mission requirements can be met mostly at Objective Level whilst remaining within programmatic budget for, size, weight, power and cost.

ID	Parameter	Objective-O	Breakthrough-B	Threshold-T	Notes
MSM-USR-01	Spectral Bands	50-70 GHz, 90 GHz, 183 GHz, Plus: 118 GHz, 150GHz Plus: 31.4 GHz,36-7 GHz, 23.8 GHz, 19 GHz OR: Complete spectral coverage between 19 and 183 GHz	50-60 GHz, 90 GHz, 183 GHz, Plus: 118 GHz, 150 GHz	50-60 GHz, 90 GHz, 183 GHz	
MSM-USR-02	Number of channels	Approx. 1800	Approx. 1100	Approx. 400	
MSM-USR-03	Spectral resolution ν /Δν	5000 (T) 4575 (WV)	2500 (T) 1830 (WV)	1250 (T) 915 (WV)	
MSM-USR-04	Spatial Coverage	Global	Global	Full coverage of Australia, including its surrounding area	
MSM-USR-05	Swath width	>=2200 km (tied to orbit height and viewing geometry)	>=2052 km (tied to orbit height and viewing geometry)	>=1800 km (tied to orbit height and viewing geometry)	
MSM-USR-06	Noise Level (NEΔT)	≤ ATMS actual * 0.5 for spectrum integrated to ATMS SRF and IFOV	≤ ATMS actual * 0.66 for spectrum integrated to ATMS SRF and IFOV	≤ ATMS actual for spectrum integrated to ATMS SRF and IFOV	
MSM-USR-07	Spatial resolution (footprint)	≤5 km at nadir	≤15 km at nadir for temperature sounding. ≤7 km at nadir for humidity.	≤25 km at nadir for temperature sounding. ≤15 km at nadir for humidity.	Assumed a 10 km resolution throughout this study, acknowledging this requires a detailed design of the antenna. This is relevant to the data budget.
MSM-USR-08	Geolocation accuracy	≤10% spatial resolution	≤ 17% spatial resolution	≤25 % spatial resolution	The attitude knowledge system was sized to determine the spacecraft's attitude within 1 km on the ground.
MSM-USR-09	Viewing Geometry	Up to +/-55°, multiple view angles per ground footprint	Up to +/-55°	Up to +/-55°	The objective requirement requires a conical scanner which was ruled out
MSM-USR-10	Polarization	Low-frequency channels (≤37 GHz) polarised	Single linear polarization changing with scan angle (as ATMS)	Single linear polarization changing with scan angle (as ATMS)	Not discussed in detail in this study.
MSM-USR-11	Spatial sampling	Oversampling (Nyquist at minimum)	Contiguous Footprints	Non-contiguous	A conservative sampling frequency of 200 Hz was assumed.
MSM-USR-12	Calibration mechanism	2-point calibration -40 to -50 dB return loss from onboard source	2-point calibration -40 to -50 dB return loss from onboard source	2-point calibration	
MSM-USR-13	Calibration accuracy	≤0.2 K	≤0.5 K	≤1 K	
MSM-USR-14	Temporal Refresh	Sub-hourly	≤Every 3 hours	≤Every 6 hours	For a single pathfinder, once every 12 hours is acceptable
MSM-USR-15	Instrument lifetime	7 years	5 years	3 years	for a single pathfinder, a 2year lifetime is acceptable
MSM-USR-16	Global data timeliness	90% within 1 hour	90% within 2 hours	NRT - 90% within 3 hours 30 mins	for single pathfinder, there is no NRT timeliness requirement
MSM-USR-17	Local data timeliness	90% within 10 mins	90 % within 15 mins	90 % within 20 mins	

5 Summary and future work

- In the 2021 Earth Observation Roadmap [4] developed by the Australian Space Agency, the Bureau articulated an ambition for Australian operational meteorological satellite sensing capabilities in the 2030s. The Bureau has undertaken a pre-Phase A study into a microwave sounder for NWP and TC monitoring.
- Overall, survey evidence suggested that NWP users would prioritise 50-60 GHz band capability and the instrument's noise performance for future MWS missions.
- For TC applications, imaging capability at 89-90 GHz is a requirement.
- The next step is to conduct simulation-based impact assessments and information content studies based on the preferable requirements parameters suggested by the users.
- We hope to run a Phase A study to further develop the payload concept this year.

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[3] MWS Science Advisory Group: "EPS-SG MicroWave Sounder (MWS) Science Plan", 2019, https://www-cdn.eumetsat.int/files/2020-04/pdf_science_epssg_mws_plan.pdf
[4] https://www.industry.gov.au/publications/earth-observation-space-roadmap-2021-2030