Low Earth Orbit (LEO) Microwave Atmospheric Sounding Activities at NOAA

NOAA Microwave Sounding Workshop

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Background

- Microwave (MW) and Infrared (IR) sounders from LEO have been the backbone of NWP
  - 3 orbits supported by legacy POES, Metop, and JPSS (AMSU, ATMS, MHS, MWS (future), CrIS, IASI)
  - Other applications include precipitation, hurricane intensity, surface temperature, TPW, imagery
  - ATMS and MWS channels range from 23 GHz to 229 Ghz (see Table)
- The first LEO dedicated mission will focus on the MW Sounding measurements, which are critical to a variety of application.

Channel ATMS/ MWS	Central Freq. (GHz)	Bandwidth (MHz)	Pol.	Nadir FOV (km)
1/1	23.8	270	V/H	75/40
2/2	31.4	180	V/H	75/40
3/3	50.3	180	H/H	32/20
4	51.76	400	H	32
5/4	52.8	400	H/H	32/20
/5	53.246±0.08	2x140	/H	/20
6/6	53.596±0.115	2x170	H/H	32/20
/7	53.948±0.081	2x142	/H	/20
7/8	54.4	400	H/H	32/20
8/9	54.94	400	H/H	32/20
9/10	55.5	330	H/H	32/20
10/11	57.290344	2x155/330	H/H	32/20
11/12	57.290344±0.217	2x78	H/H	32/20
12/13	57.290344±0.3222±0.048	4x36	H/H	32/20
13/14	57.290344±0.3222±0.022	4x16	H/H	32/20
14/15	57.290344±0.3222±0.010	4x8	H/H	32/20
15/16	57.290344±0.3222±0.0045	4x3	H/H	32/20
16/17	88.2/89	2000/4000	V/V	32/17
17/18	164-167	2x1150 /2x1350	H/H	16/17
18/19	183.311±7.0	2x2000	H/V	16/17
19/20	183.311±4.5	2x2000	H/V	16/17
20/21	183.311±3.0	2x1000	H/V	16/17
21/22	183.311±1.8	2x1000	H/V	16/17
22/23	183.311±1.0	2x500	H/V	16/17
/24	229.0	2000	/V	/17

Sounder Mission Objectives

- Spearhead the formulation of disaggregated concepts (compared to launching large spacecraft with multiple sensors such as JPSS)
- Determine viability of meeting observational requirements while improving agility & infusion of new technology
- Contribute to the LEO constellation and improve NOAA forecasting ability with sounders providing global coverage
    - Resiliency of the backbone
    - Supplementing the backbone

Overview of Sounder studies at NOAA (1)

- NOAA awarded several contracts to industry via a Broad Agency Announcement in 2019 to explore integrated mission and instrument design concepts to form the basis for future acquisitions.
    - Support the design and formulation of an optimal, mission-effective, agile and cost-effective constellation of space-based observing systems.
        - Provide multi-orbit coverage
        - Risk tolerance and observing system risk management
    - Support a future satellite acquisition targeted at providing a constellation supporting high update rate LEO observational capabilities.
        - Sounding instrument designs (microwave, infrared, radio occultation)
        - Commercial launch, operations, and data services
        - Common satellite bus for flexibility in instruments flown
        - Support rapid launch cadence

Overview of Sounder studies at NOAA (2)

- SounderSat BAAs covered a wide trade space, setting Threshold, Target, and Objective requirements for Vertical Temperature and Moisture profiles.
- Microwave (MW) Instruments explored in the BAA span a range of capabilities, but generally fell into three classes based on waveband coverage:
  - HIGH – full ATMS channel set, and may include higher frequency bands
  - MID – reduced channels, drops lower frequency bands (K,Ka) in favor of higher frequency channels
  - LOW – limited channels, usually covering F, G, and W bands
- Instrument calibration accuracy, spatial sampling, NEDT, and bandwidth correspond loosely to class

General Guidance from NOAA Systems performance Assessment Team (SAT)

- The SAT is a NOAA technical team that has a diverse set of expertise in remote sensing, data assimilation, impact assessment, sensors engineering, calibration,..
- The SAT support includes providing performance assessment and expert feedback to NESDIS.
- Several SAT discussions were dedicated to microwave sounding capability to help a core-SAT guidance on how to link sounder performance capability (for NWP) to actual sensors characteristics.
- This guidance provided a set of prioritization of sensors characteristics as well as three tiers of options
- SAT guidance along with BAA learned lessons on what is technologically feasible, led to a set of three classes of instruments

Factors Impacting Performances				
Priority#	Factor impacting performances	Tier 1: Ideal capability if we can afford it and if technology allows.	Tier 2: Status Quo capability (consistent with current capability)	Tier 3: Walkaway Acceptable capability (potentially degraded capability but still useful)
1	Channels for direct Temperature Sounding	*20 Channels or more around 50-60 GHz (ATMS spectral locations) band and 118GHz line	*13 Channels or more around 50-60 GHz band	*12 Channels or more around 118 GHz O_2 line (TROPICS-type)
2	Channels for direct Moisture sounding	*10 Channels or more around 183 GHz	*5 Channels or more around 183 GHz	*TEMPEST-type Channels around 183 GHz (or mm/sub-mm freqs like 325 GHz)
3	Channels for cloud, precip, ice detection for direct all-sky assimilation and NWP QC	At least 4 channels at low freqs such as 22-23 (priority#1) , 31-37 (priority#2) and 89 GHz (priority#3) and 18 GHz (priority#4) if possible, channels for TPW integration,cloud/precip detection and surface signal distinction	At least 2 channels at 22-23, 31-37, 89 or around 18-19 GHz channels	Use channels in the 200-300 GHz band for cloud, rain, and ice detection.
4	Spatial coverage (daily global coverage)	Global	Global	Global
5	Swath width and impact on orbital gap* (scan angle)	No orbital gap at equatorial crossing (TBD: consistency across columns)	JPSS-type gap (or better) at equatorial crossing	NOAA AMSU Type of orbital gap
6	Satellite Altitude	Not directly relevant for performances. Listed here because it is usually a driving factor for the swath width and it is a question that gets asked by sensor/satellite design engineers.	Not directly relevant for performances. Listed here because it is usually a driving factor for the swath width and it is a question that gets asked by sensor/satellite design engineers.	Not directly relevant for performances. Listed here because it is usually a driving factor for the swath width and it is a question that gets asked by sensor/satellite design engineers.
7	Noise Level (NEDT) for Temperature sounding channels (real values,not requirements)^	ATMS-type NEDT levels (ATMS_NEDT) or better	ATMS_NEDT x 1.5	ATMS_NEDT x 2
8	Noise level (NEDT) for moisture sounding channels (real values,not requirements)^	ATMS-type NEDT levels (ATMS_NEDT) or better	ATMS_NEDT x 1.5	ATMS_NEDT x 2
9	Spatial horizontal resolution	ATMS-type or better spatial horizontal resolution or better: About 15 kms at	About 25 kms or better at nadir (changing with angle and channel)	About 50kms at nadir or better (changing with angle and channel)

Microwave Sounder Instrument Classes

Instrument Properties Summary

Class	Possible Channels	NEDT (T or q)	Spatial Sampling	Calibration Accuracy
ATMS	K, Ka, V, W, G bands; 22 channels; analog			
MW-HIGH	K, Ka, V, W, F, G bands, +229GHz; 20-30 channels Potentially utilizing digital bands	ATMS-type NEDT levels (ATMS_NEDT) or better	Oversampling	0.75 K – 1 K
MW-MID	V, W, F, G, +229GHz; 20-25 channels Analog, or mixture of digital and analog channels	ATMS_NEDT x 1.5 or better	Contiguous footprints	1K -1.5 K
MW-LOW	F, G, and higher frequency bands; 12 channels, analog	ATMS_NEDT x 2 or better	Non-contiguous footprints	1K – 2K

Overall guidance recommendations for classes of instruments, not to be construed as instrument designs

MW-HIGH – Notional Specifications

- All numbers are notional; not to be construed as design
- Channel performance (if channel present)
- Number of channels in each frequency band will be set by science need
- NEDTs are approximate; Horizontal resolution varies by altitude

	K	Ka	V	W	F	Window	G	Window
Center Freq	23.8 GHz	31.4 GHz	50-57 GHz	88 GHz	114-119 GHz	160-167 GHz	170-190 GHz	200-300 GHz
Horizontal Resolution - Current	75 km	75km	32km	32km			16km	
POR NEDT (K), real	0.23	0.28	0.22-1.6	0.21		0.32	0.35-0.58	
Approx Channels	1	1	13	1	5	0-1	6	0-1
Horizontal Resolution at Nadir (832 km alt.)	75 km	75 km	32 km	32 km	16 km	16 km	16 km	16 km
Crosstrack Resolution (Edge of Scan)	±52.725° 123 km	±52.725° 123 km	±52.725° 52 km	±52.725° 52 km	±52.725°	±52.725° 26 km	±52.725° 26 km	±52.725°
NEDT (K)	0.3	0.3	0.3-1.5	0.2	0.3-0.4	0.3	0.2-0.4	0.3

MWS-MID – Notional Specifications

- All numbers are notional; not to be construed as design
- Channel performance *(if channel present)*
- Number of channels in each frequency band will be set by science need
- Trade studies show that instruments may provide optimal resolution at lower altitudes
- NEDTs are approximate; Horizontal resolution varies by altitude

	K	Ka	V	W	F	Window	G	Window
Center Freq	23.8 GHz	31.4 GHz	50-57 GHz	88-91 GHz	114-119 GHz	160-167 GHz	170-190 GHz	200-300 GHz
Horizontal Resolution - POR	75 km	75km	32km	32km		16km	16km	
POR NEDT (K), real	0.23	0.28	0.22-1.6	0.21		0.32	0.35-0.58	
Approx Channels			8	1	6	0-1	5	1
Horizontal Resolution at Nadir (500 km & 824 km)			18 km 30 km	18 km 30 km	18 km 30 km	9.6 km 16 km	9.6 km 16 km	9.6 km 16 km
Crosstrack Resolution (Edge of Scan) @ 500km			±50° 28 km	±50° 28 km	±50° 28 km	±50° 15 km	±50° 15 km	±50° 15 km
NEDT (K)			1	0.2	0.4	1	0.5	0.3

MWS-LOW – Notional Specifications

- All numbers are notional; not to be construed as design
- Channel performance *(if channel present)*
- Number of channels in each frequency band will be set by science need
- Trade studies show that instruments may provide optimal resolution at lower altitudes
- NEDTs are approximate; Horizontal resolution varies by altitude

	K	Ka	V	W	F	Window	G	Window
Center Freq	23.8 GHz	31.4 GHz	50-57 GHz	88-91 GHz	114-119 GHz	160-167 GHz	170-190 GHz	200-300 GHz
Horizontal Resolution - POR	75 km	75km	32km	32km		16km	16km	
POR NEDT (K), real	0.23	0.28	0.22-1.6	0.21		0.32	0.35-0.58	
Approx Channels				1	5-7	1	3-5	1
Horizontal Resolution at Nadir (550 km)				30 km	24 km	16 km	16 km	16 km
Crosstrack Resolution (Edge of Scan) @ 500km				±56° 51 km	±56° 41 km	±56° 28 km	±56° 28 km	±56° 28 km
NEDT (K)				0.6	1	0.6	0.6	0.5

Questions to the Community

Constellation Configuration – Based on your experience…

- What is the ideal configuration for a MW sounder backbone?
  - What measurements are needed (MW frequencies, orbits, spatial resolution, NEDT etc)?
- What additional MW measurements would be ideal to augment the backbone?
  - What measurements are needed at increased temporal, spectral, spatial coverage/resolution to provide additional benefit to NWP models and related products?
  - What do you like to see more of (temporally and spatially) and how do you capture the impact that justifies these measurements
  - Additional measurements (to augment the backbone) are likely not going to be at the same level of accuracy/precision. What is the level of acceptable degradation in terms of noise, number of channels, resolution, etc?

Channel Selection – Based on your experience…

- Which MW frequencies are most critical/impactful for NWP models?
  - At which frequencies will improving temporal coverage be most impactful? (i.e., which layers of the atmosphere change the fastest)
  - What would be the impact of having mid and high frequency channels only (MW-MID- level instruments) in supplemental orbits?
  - What would be the impact of having limited channels only (MW-LOW- level instruments) in supplemental orbits?

- Which MW frequencies are used/required in other applications?
  - Hurricane intensity
  - Precipitation, Total Precipitable Water (TPW)
  - Surface temperature and emissivity
  - Snow, ice cover

Thank You!