Microwave Sounder (MWS) instrument overview

User Preparation Webinar on EPS-SG Microwave and Submm Sensors, 11 October 2021

MWS: The Microwave Sounder of EPS-SG

1. EPS-SG Microwave Sounding Mission Objectives
2. Instrument Overview
3. Calibration Equations
4. Channel Selection
5. Sampling Properties
6. End-User Requirements
7. Summary of Main Applications
8. MWS Science Advisory Group

EPS-SG Microwave Sounding Mission Objectives

- The **primary objective** of the Microwave Sounding mission is to support Numerical Weather Prediction at regional and global scales.

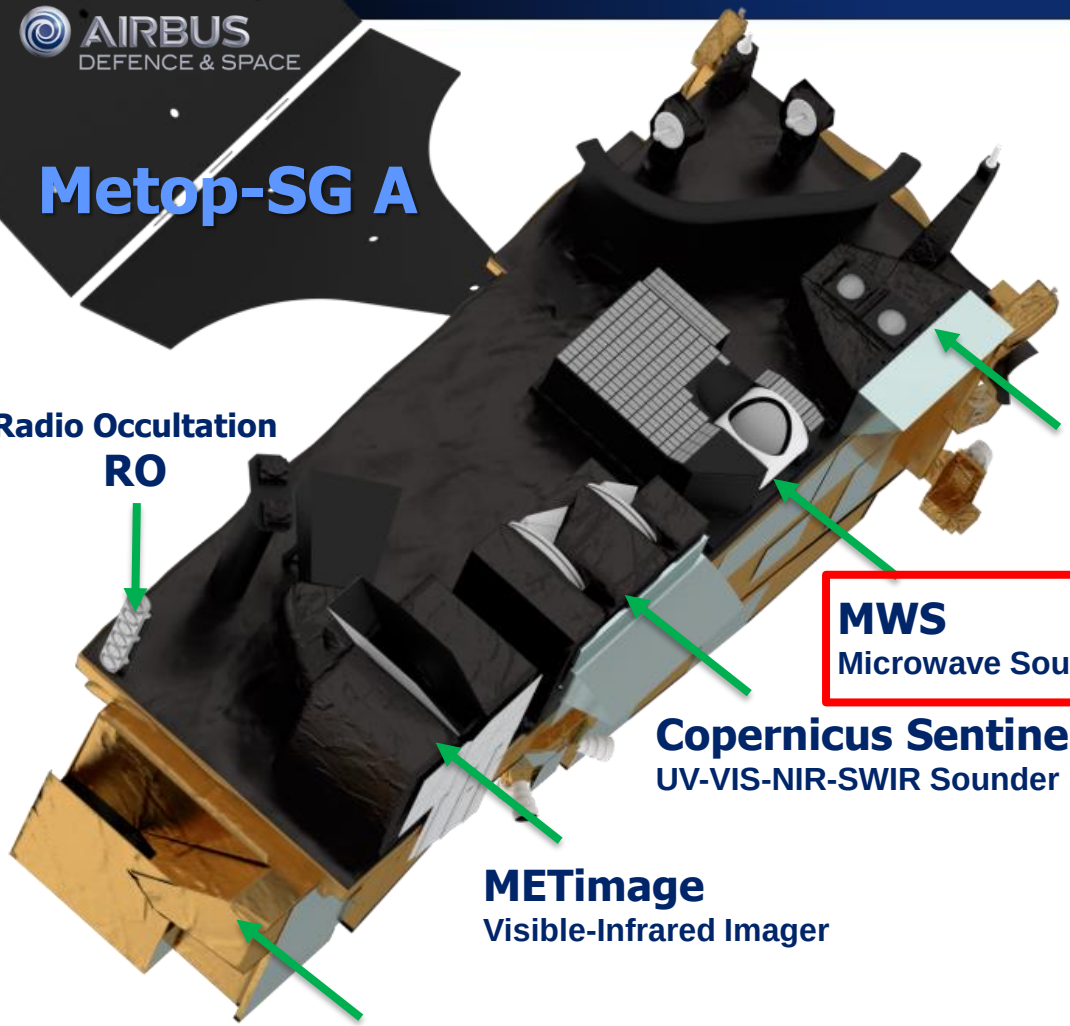
- The main users of the MWS mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF. Operational nowcasting services of National Meteorological Services may also be users of the MWS mission. The MWS mission is also relevant to non real-time users and services (e.g. the Climate Monitoring SAF) that will use data from the MWS mission to continue temperature and humidity sounding records, mainly for climate monitoring applications.

- The primary products to be derived from the MWS mission include in order of decreasing priority spectral radiances with information on:
  - Temperature profile
  - Water-vapour profile
  - Cloud liquid-water total column (droplet size < 100μm)
  - Further products to which MWS contributes are spectral radiances with information on:
  - Cloud liquid-water profile (droplet size < 100 μm)
  - Cloud ice total column

EPS-SG Satellites and Instrumentation

AIRBUS DEFENCE & SPACE

Metop-SG A



Radio Occultation
RO

3MI
Multi-viewing, -channel, -polarisation Imager

MWS
Microwave Sounder

Copernicus Sentinel-5
UV-VIS-NIR-SWIR Sounder

METimage
Visible-Infrared Imager

IASI-NG
Infrared Atmospheric Sounding Interferometer – New Generation

EPS-SG

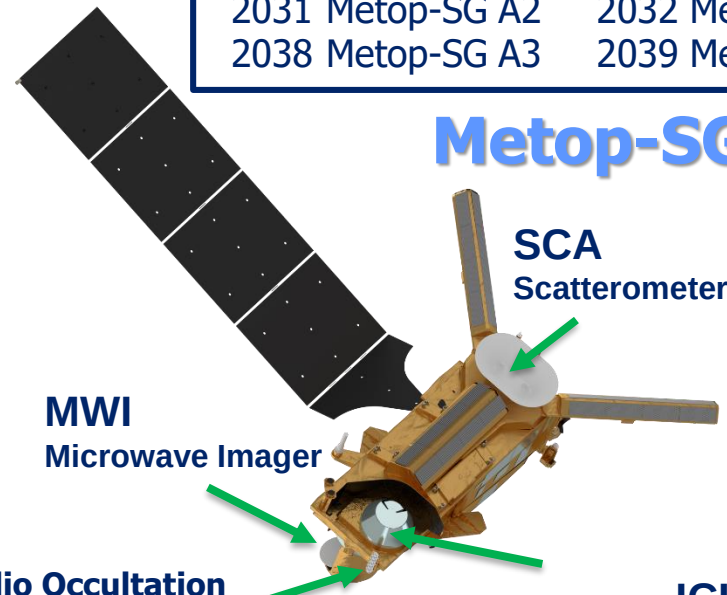
Two-satellite configuration Metop-SG-A and –B in the same orbital plane (Metop-like):

→ Sun synchronous (~98° inclination)
→ low earth orbit at 835 km mean altitude
→ 09:30 (descending node) Equatorial Crossing Time

Intended launch dates:

2024 Metop-SG A1	2025 Metop-SG B1
2031 Metop-SG A2	2032 Metop-SG B2
2038 Metop-SG A3	2039 Metop-SG B3

Metop-SG B



SCA
Scatterometer

MWI
Microwave Imager

Radio Occultation
RO

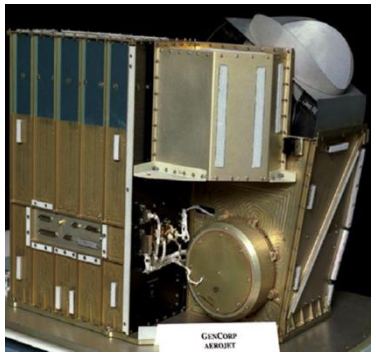
ICI
sub-mm wave Ice Cloud Imager

EUMETSAT

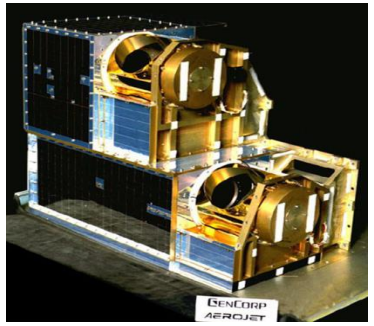
MWS: Instrument Heritage and Basic Design

NOAA 15 16 17 18 19, Aqua, Metop ABC

AMSU/A2:
- 2 channels
- 1 antenna system
- 23-31 GHz
- 30 pixels/scan
- 3 years lifetime
- 54 kg
- 75x30x60 cm



AMSU/A1:
- 13 channels
- 2 antenna systems
- 50-89 GHz
- 30 pixels/scan
- 3 years lifetime
- 50 kg
- 75x70x65 cm



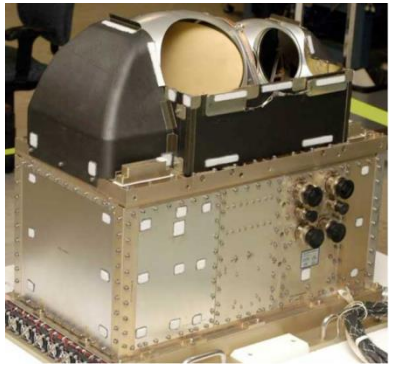
NOAA 18 19, Metop ABC

MHS:
- 5 channels
- 1 antenna system
- 89-191 GHz
- 90 pixels/scan
- 4 years lifetime
- 50 kg
- 75x56x69 cm

credit: http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesignI

S-NPP
NOAA-20
JPSS-2

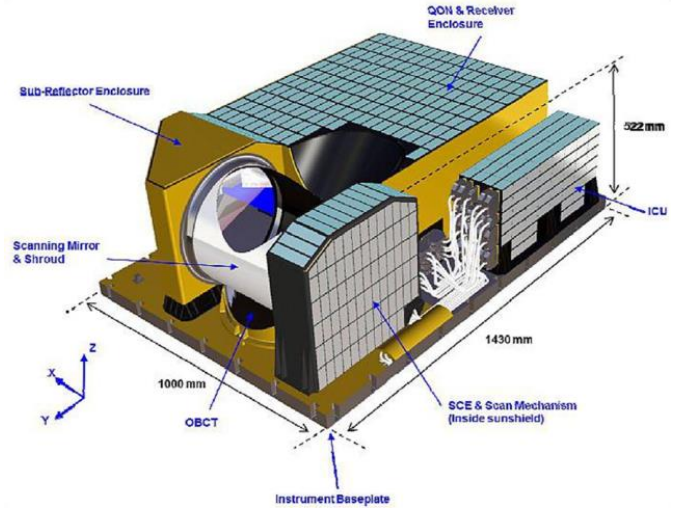
ATMS:
- 22 channels
- 2 antenna systems
- 96 pixels/scan
- 8 years lifetime
- 85 kg
- 70x40x60 cm



(credit: http://npp.gsfc.nasa.gov/atms.html)

Metop-SG A1
Metop-SG A2
Metop-SG A3

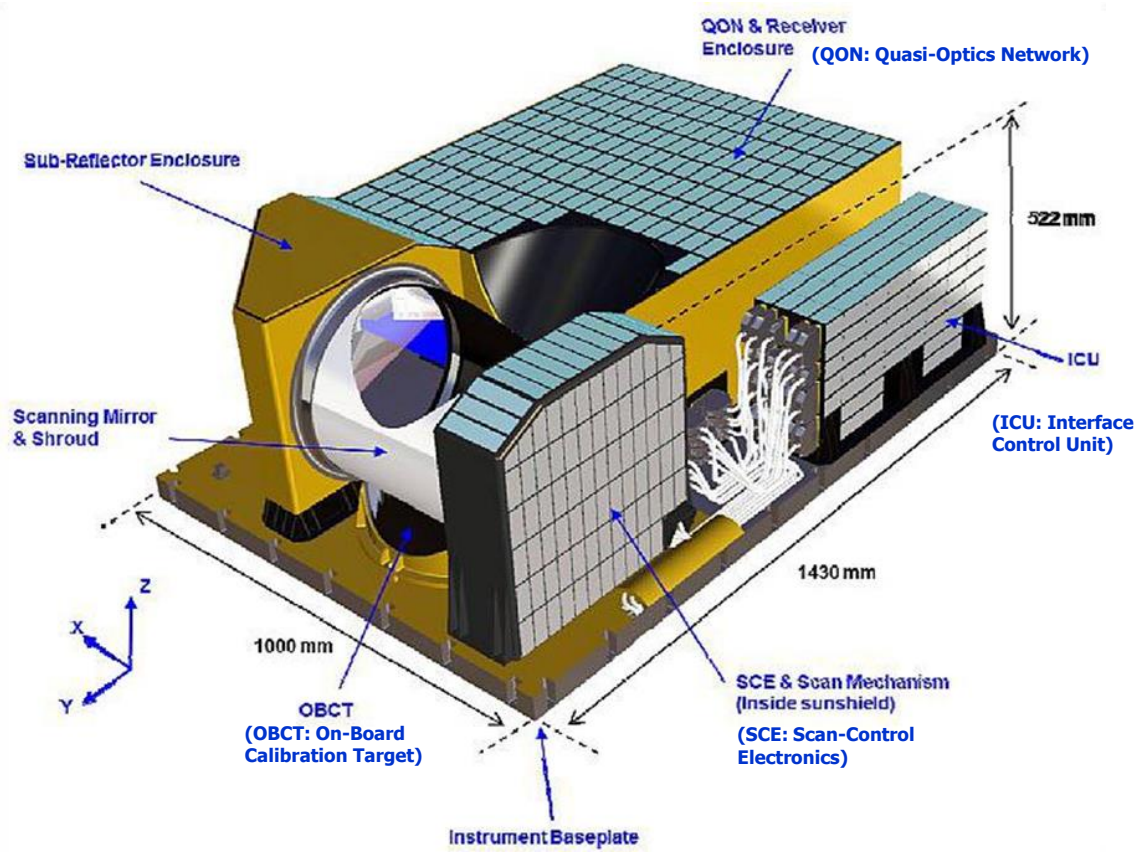
MWS:
- 24 channels
- 1 antenna system
- 95 pixels/scan
- 7.5 years lifetime
- 110 kg
- 143x100x52 cm



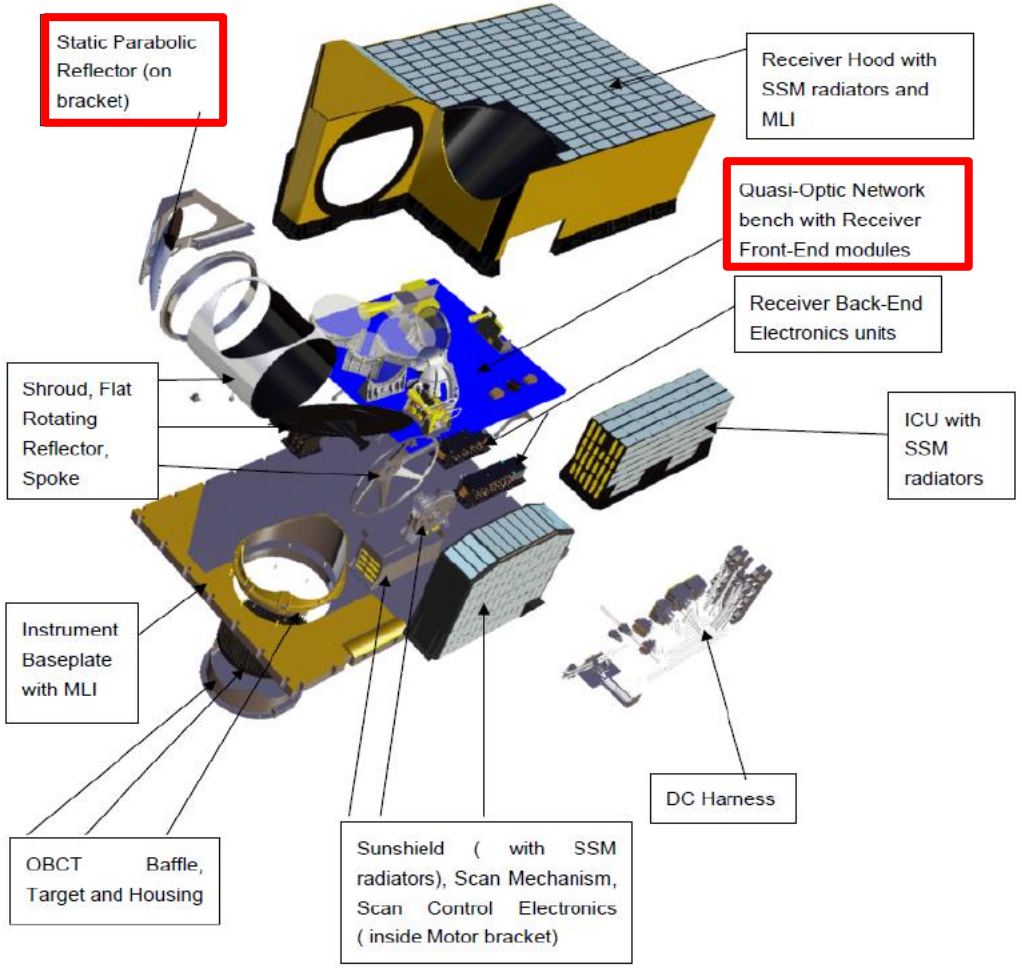
(credit: https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg)

EUMETSAT

MWS Instrument Modules



(credit: https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg)

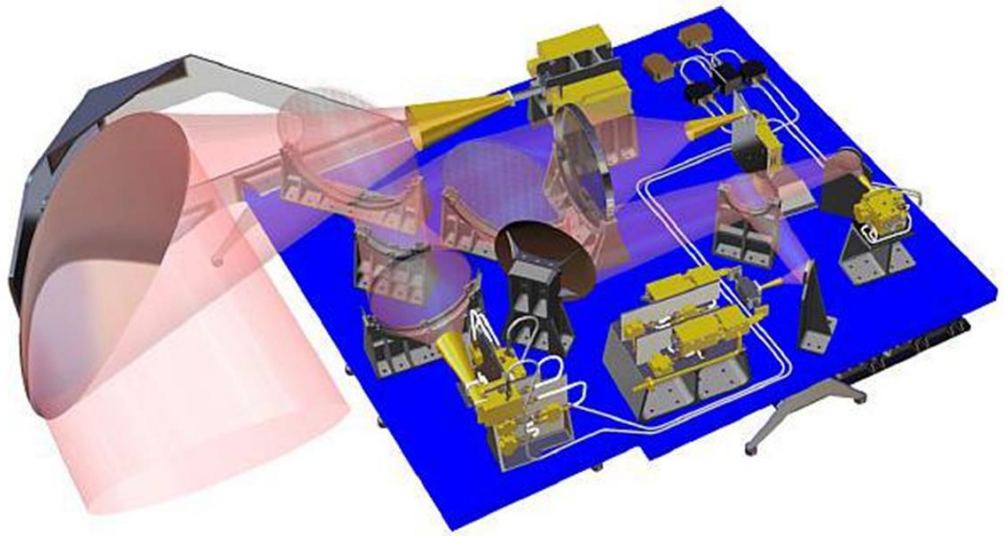


(D'Addio et al., IEEE 2014, pp.599-604)

EUMETSAT

MWS Beam Path and Scan Cycle

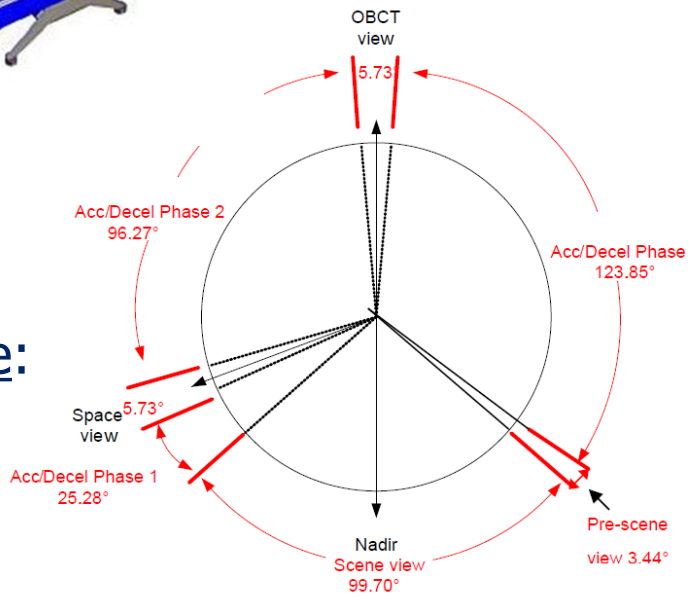
QON & Receivers:



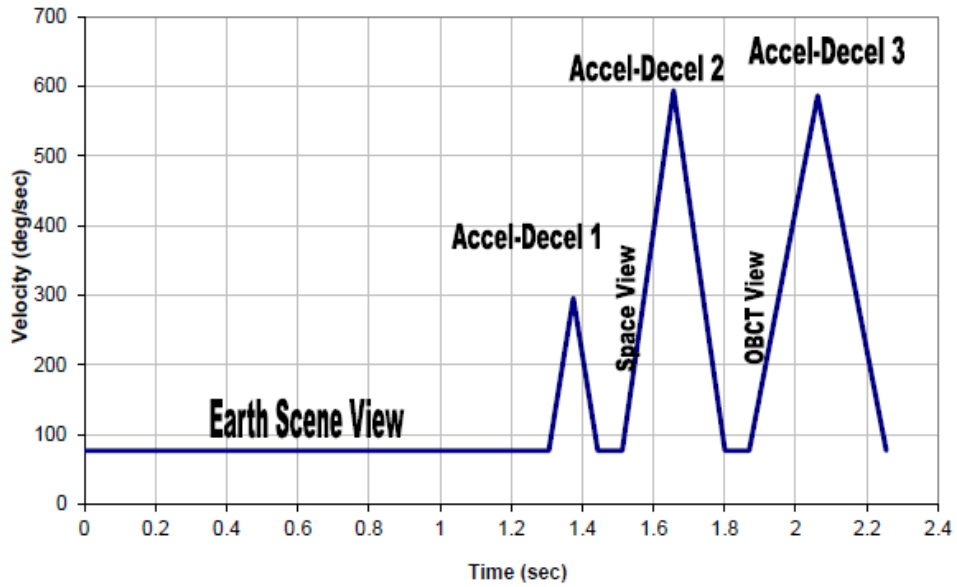
(credit: https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg)

1. 23.8 and 31.4 GHz channels (QH polarisation)
2. 54 GHz channels. This feedhorn has 2 separate outputs, one at QH polarisation (nominal) and one at QV polarisation (backup). This provides redundancy with no performance penalty.
3. 89 GHz (QV polarisation)
4. 229 GHz (QV polarisation)
5. 183 (QV polarisation)
6. 166 GHz (QH polarisation)

Scan Cycle:

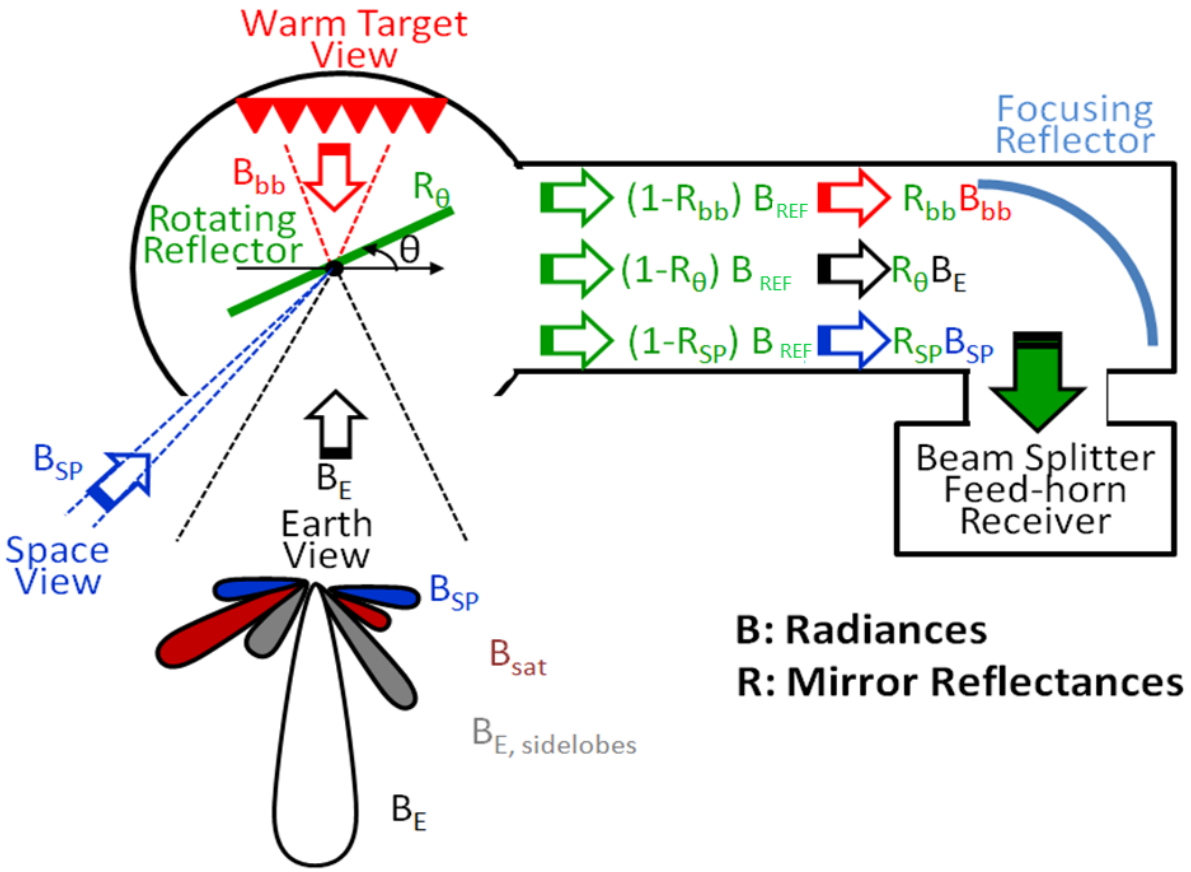


(Acc/Decel: Accleration/Deceleration)



MWS Calibration Equations

Radiance Signal Contributions Schematic:



$$a_0 + a_1 C_E + a_2 C_E^{\ 2} = (1 - R_\theta) B_{REF} + R_\theta B_E$$

$$a_0 + a_1 C_{SP} + a_2 C_{SP}^{\ 2} = (1 - R_{SP}) B_{REF} + R_{SP} B_{SP}$$

$$a_0 + a_1 C_{bb} + a_2 C_{bb}^{\ 2} = (1 - R_{bb}) B_{REF} + R_{bb} B_{bb}$$

Known quantities:

- **Blackbody radiance B_{bb}, radiance of space B_{SP}**
- **Mirror reflectivities at different scanning positions θ: R_θ, R_{SP}, R_{bb}**
- **Mirror temperature (radiance B_{REF})**
- **Measurements counts C_E (Earth), C_{bb} (blackbody), C_{SP} (space)**

Unknown quantities:

- **Calibration coefficients a_0, a_1, a_2**
- **Earth view radiance B_E**

MWS: Solving the Calibration Equations

$$B_E = \frac{a_0 + a_1 C_E + a_2 C_E^{\,2} - (1 - R_\theta) B_{REF}}{R_\theta}$$

With: $$A = \frac{R_{bb}(B_{bb} - B_{REF}) - R_{SP}(B_{SP} - B_{REF})}{(B_{bb} - B_{SP})}$$

$$a_0 = R_{bb} B_{bb} - C_{bb}\left(\frac{A}{g}\right) + a_2 C_{bb} C_{SP} + B_{REF}(1 - R_{bb})$$

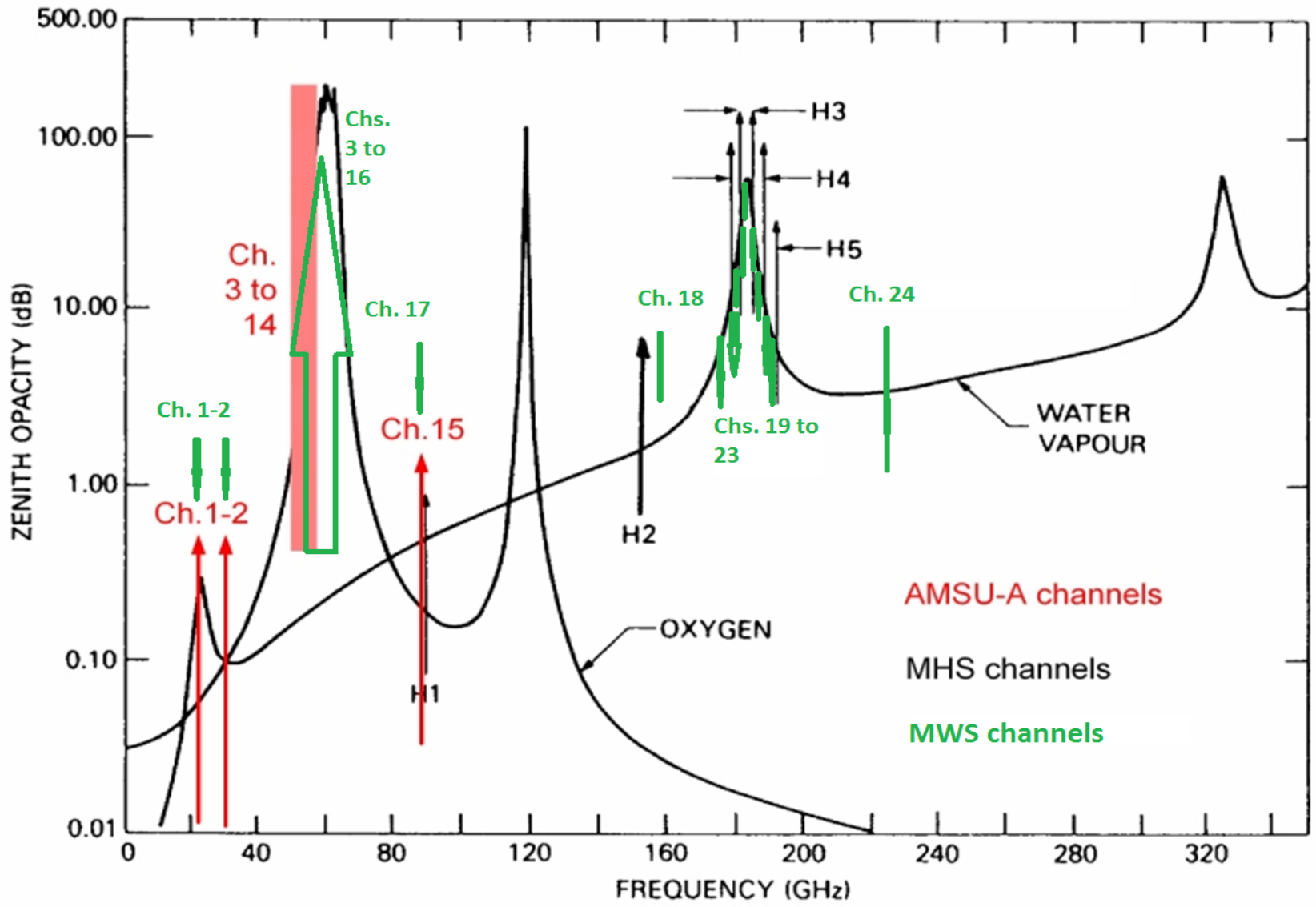
$$g = \frac{C_{bb} - C_{SP}}{B_{bb} - B_{SP}}$$

$$a_1 = \left(\frac{A}{g}\right) - a_2 (C_{bb} + C_{SP})$$

$$a_2 = \frac{\mu}{g^2} = \mu' \left(\frac{A}{g}\right)^2$$

μ': Pre-launch-determined non-linearity parameter depending on the instrument temperature

MWS: Frequency Range of Measurements



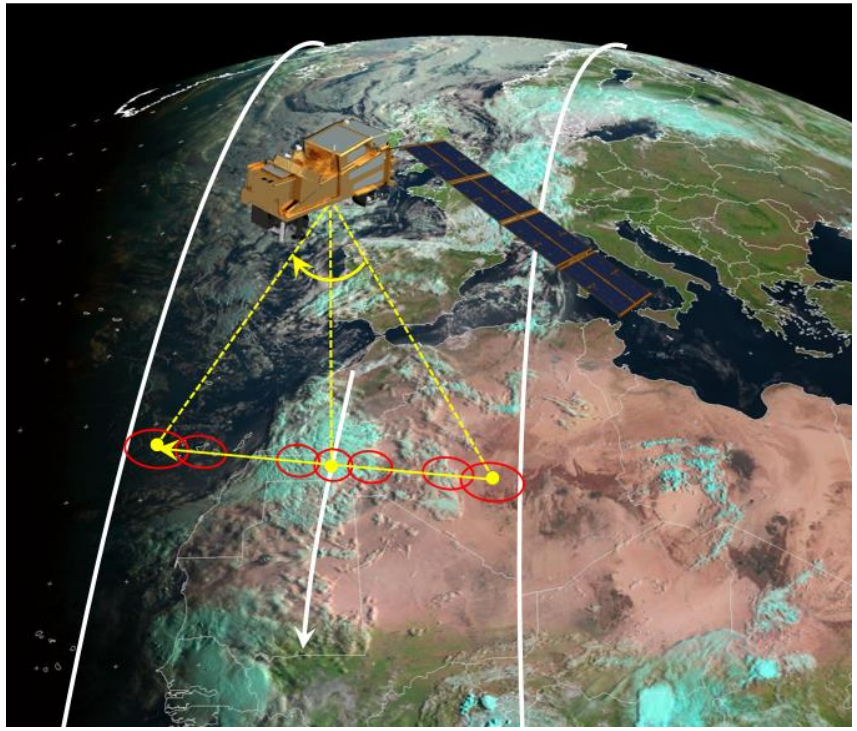
MWS: Channels Comparison with Heritage Instruments

AMSU/MHS			ATMS			MWS		
Ch.	*GHz*	*Pol.*	*Ch.*	*GHz*	*Pol.*	*Ch.*	*GHz*	*Pol.*
1	23.8	QV	1	23.8	QV	1	23.8	QH
2	31.4	QV	2	31.4	QV	2	31.4	QH
3	50.3	QV	3	50.3	QH	3	50.3	QH (QV)
			4	51.76	QH			
4	52.8	QV	5	52.8	QH	4	52.8	QH (QV)
						5	53.246 ± 0.08	QH (QV)
5	53.595±0.115	QH	6	53.596±0.115	QH	6	53.596±0.115	QH (QV)
						7	53.948 ± 0.081	QH (QV)
6	54.4	QH	7	54.4	QH	8	54.4	QH (QV)
7	54.94	QV	8	54.94	QH	9	54.94	QH (QV)
8	55.50	QH	9	55.50	QH	10	55.50	QH (QV)
9	57.290344	QH	10	57.290344	QH	11	57.290344	QH (QV)
10	57.290344±0.217	QH	11	57.290344±0.217	QH	12	57.290344±0.217	QH (QV)
11	57.290344 ±0.3222±0.048	QH	12	57.290344 ±0.3222±0.048	QH	13	57.290344 ±0.3222±0.048	QH (QV)
12	57.290344±0.3222±0.022	QH	13	57.290344±0.3222±0.022	QH	14	57.290344±0.3222±0.022	QH (QV)
13	57.290344±0.3222±0.010	QH	14	57.290344±0.3222±0.010	QH	15	57.290344±0.3222±0.010	QH (QV)
14	57.290344±0.3222±0.0045	QH	15	57.290344±0.3222±0.0045	QH	16	57.290344±0.3222±0.0045	QH (QV)
15	89.0	QV						
16	89.0	QV	16	88.2	QV	17	89.0	QV
17	157.0	QV	17	165.5	QH	18	164-167	QH
18	183.311±1.0	QH	22	183.311±1.0	QH	23	183.311±1.0	QV
			21	183.31 ± 1.8	QH	22	183.311±1.8	QV
19	183.311±3.0	QH	20	183.311±3.0	QH	21	183.311±3.0	QV
			19	183.311±4.5	QH	20	183.311±4.5	QV
20	191.31	QV	18	183.311±7.0	QH	19	183.311±7.0	QV
						24	229	QV

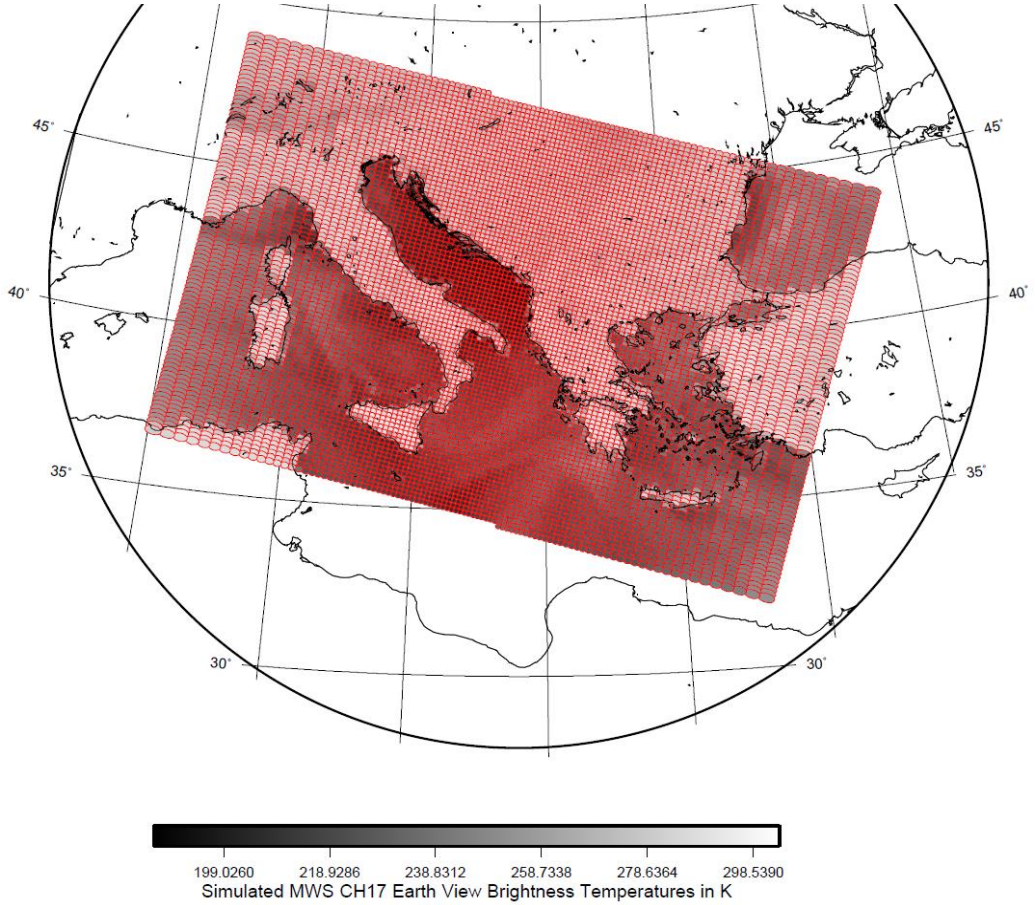
Matched Specificat.	Pol. is Different	Unique Passband	Pol. is Different and Unique Passband	New channel

MWS Scanning Characteristics

- Cross-track scanner
- 95 pixels per scan line for each channel
- 2.25 seconds scan duration
- 49.85° maximum scanning angle
- ~2250 km swath width



MWS Channel 17 scan pattern and brightness temperature simulations.

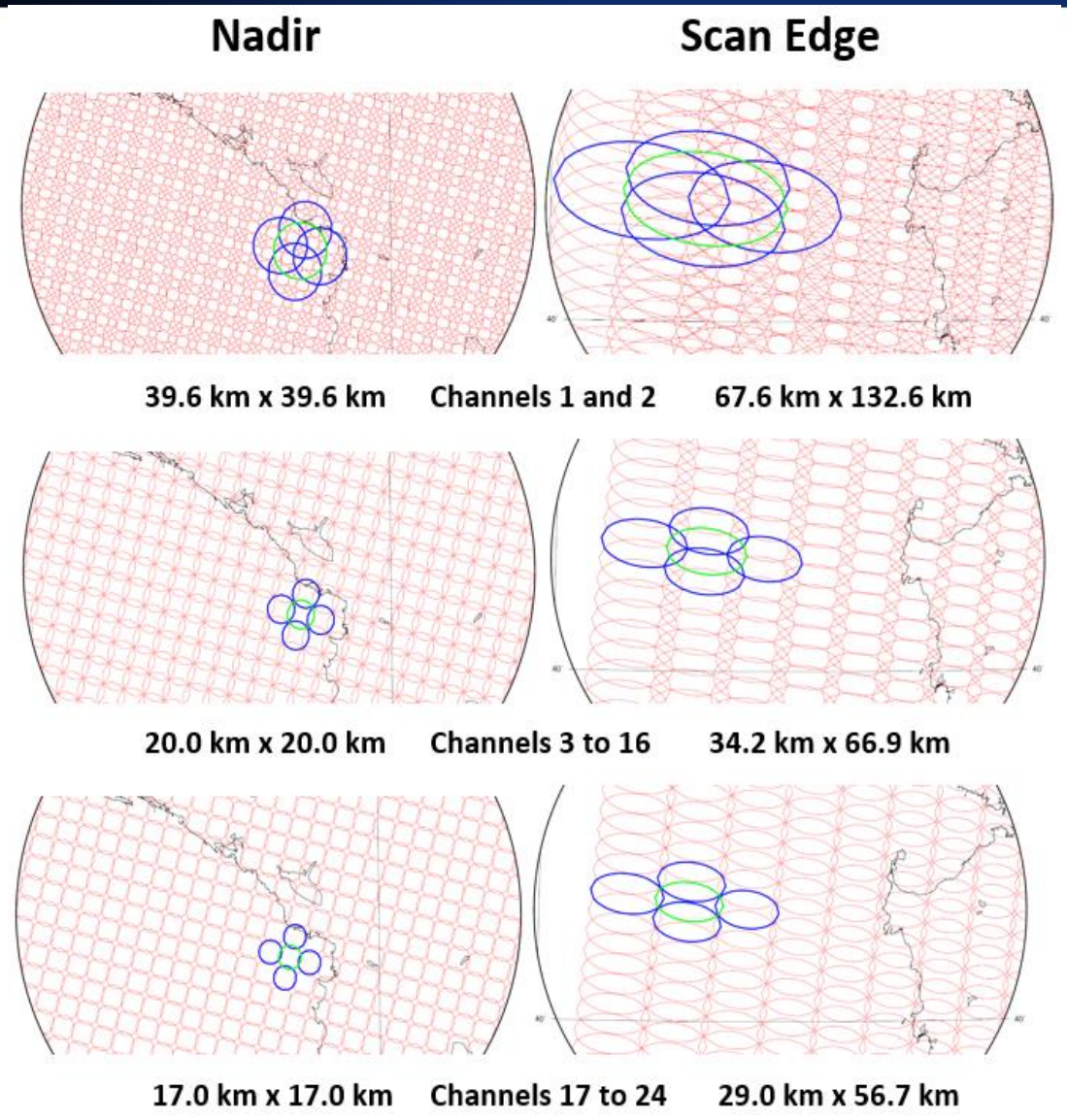


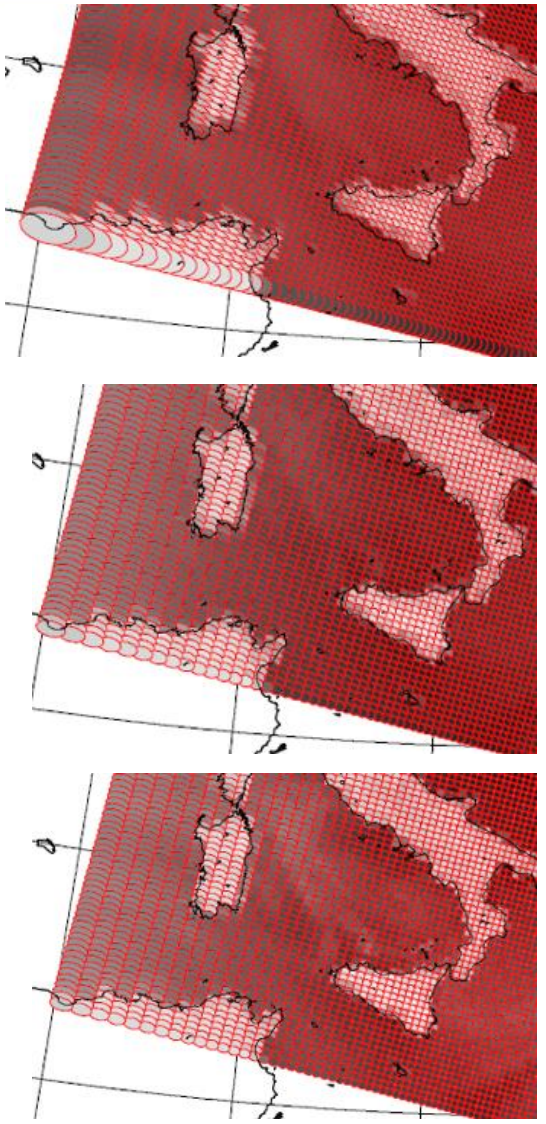
MWS: Pixel Size Comparison with Heritage Instruments

Instantaneous Footprint Diameters (3dB level) near Nadir

Observation Frequency (GHz)	AMSU-A/MHS	ATMS	MWS
23.8	48 km	75 km	40 km
31.4	48 km	75 km	40 km
50-58	48 km	32 km	20 km
89	48 km/ 16 km	32 km	17 km
157-167	16 km	16 km	17 km
183-191	16 km	16 km	17 km
229	N/A	N/A	17 km

MWS: Range of Footprint Sizes





Note: Pixel representations are displayed as Instantaneous Field of Views (3dB level)

MWS: Channel Performance Requirements

Channel	Frequency (GHz)	Bandwidth per passband (MHz)	Utilisation	NEΔT Threshold (K)	Footprint (IFOV) Size at 3dB (km)	Centre frequency stability (B/T) (MHz)	Lower End of Dynamic Range (K)	Upper End of Dynamic Range (K)
MWS-1	23.8	270	Water-vapour column	0.25	40	±5.0/±10.0	80	335
MWS -2	31.4	180	Window, water-vapour column	0.35	40	-/±10.0	80	335
MWS -3	50.3	180	Quasi-window, surface emissivity	0.5	20	±5.0/±10.0	100	320
MWS -4	52.8	400	Temperature profile	0.35	20	± 3.0/±5.0	100	320
MWS-5	53.246 ± 0.08	2x140	Temperature profile	0.4	20	±5.0/±10.0	100	320
MWS -6	53.596±0.115	2x170	Temperature profile	0.4	20	±2.0/± 5.0	100	320
MWS-7	53.948 ± 0.081	2x142	Temperature profile	0.4	20	±1.0/±2.0	100	320
MWS -8	54.40	400	Temperature profile	0.35	20	±2.0/±5.0	100	320
MWS -9	54.94	400	Temperature profile	0.35	20	±2.0/±5.0	100	320
MWS -10	55.50	330	Temperature profile	0.4	20	±2.0/±5.0	100	320
MWS -11	57.290344	330	Temperature profile	0.4	20	-/±0.5	100	320
MWS-12	57.290344±0.217	2x78	Temperature profile	0.55	20	-/±0.5	100	320
MWS-13	57.290344 ±0.3222±0.048	4x36	Temperature profile	0.6	20	-/±1.2	100	320
MWS-14	57.290344±0.3222±0.022	4x16	Temperature profile	0.9	20	±1.2/±1.6	100	320
MWS-15	57.290344±0.3222±0.010	4x8	Temperature profile	1.2	20	-/±0.5	100	320
MWS-16	57.290344±0.3222±0.0045	4x3	Temperature profile	2.0	20	±0.2/±0.5	100	320
MWS-17	89.0	4000	Window	0.25	17	±130/±210	80	335
MWS-18	164-167	3000	Quasi-window, water-vapour profile	0.5	17	±40/±80	80	335
MWS-19	183.311±7.0	2x2000	Water-vapour profile, precipitation	0.4	17	±30/±70	80	320
MWS-20	183.311±4.5	2x2000	Water-vapour profile	0.4	17	±10/±30	80	320
MWS-21	183.311±3.0	2x1000	Water-vapour profile	0.6	17	± 30.0/±70	80	320
MWS-22	183.311±1.8	2x1000	Water-vapour profile	0.6	17	±10/± 30.0	80	320
MWS-23	183.311±1.0	2x500	Water-vapour profile	0.75	17	±30.0/±50	80	320
MWS-24	229	2000	Quasi-window, water-vapour profile	0.70	17	±100.0/±350.0	100	310

Several types of requirements:

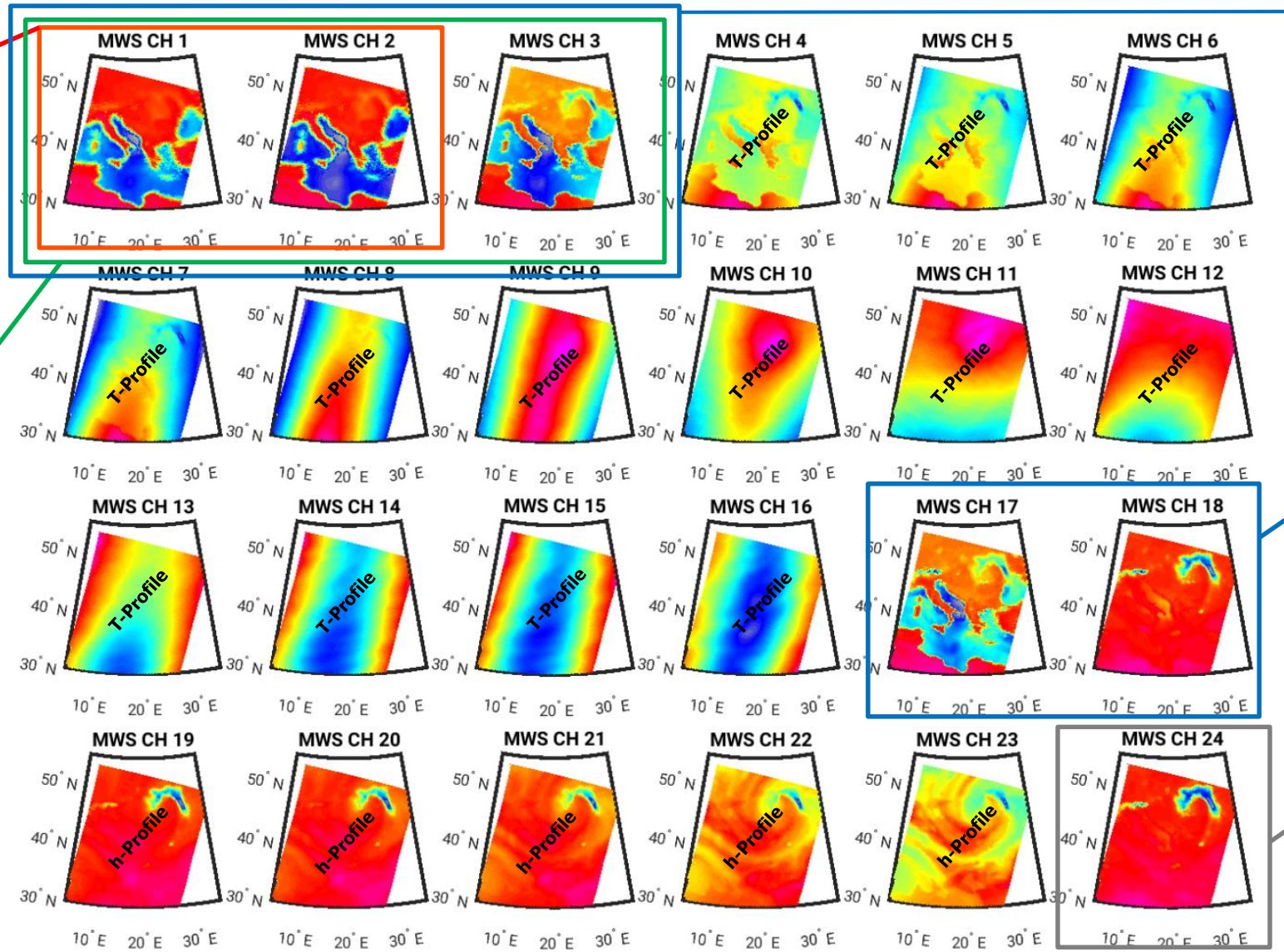
- **Acquisition requirements**
- **Spectral requirements**
- ***Level 1* radiometric requirements**
- ***Level 1* geometric requirements**

In addition, timeliness requirements shall be met.

MWS: Radiometric Data (Level 1) and main applications

Total Column Water Vapour over water surfaces: 23.8 GHz and 31.4 GHz using the forecasted surface temperature and wind field (optional)

Sea Ice and Land Surface Temperature: 23.8 GHz, 31.4 GHz and 50.3 GHz



Ice Water Path and Rain Rate: 23.8 GHz, 31.4 GHz, 50.3 GHz, 89 GHz, and 164 GHz

Cirrus Cloud Detection: 229 GHz

MWS Science Advisory Group

- The MWS Science Advisory Group (SAG) was established in 2014.
- The MWS SAG, co-chaired by ESA and EUMETSAT, is composed of scientific experts in the area of passive microwave remote sensing.
- MWS SAG members meet in intervals of six to ten months.
- MWS SAG is providing a frame for scientific support and advice to ESA and EUMETSAT during the development of the MWS mission from Phase B up to D/E.
- MWS SAG is commenting on all aspects related to the proposed MWS product processing, product format, archiving, dissemination, reprocessing, and Cal/Val.
- MWS SAG is not primarily reviewing of the user/mission requirements but aims at highlighting the research and development necessary to achieve the mission objectives and to provide a longer term outlook of the potential evolution of those objectives (i.e., emerging science and applications).
- MWS SAG and external experts have drafted the MWS Science Plan which is available via:

https://www.eumetsat.int/science-plans-future-missions