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Overview of MWI and ICI missions: background and heritage, scanning characteristics, spectral properties

User Preparation Webinar on EPS-SG Microwave and Submm Sensors, 12 October 2021

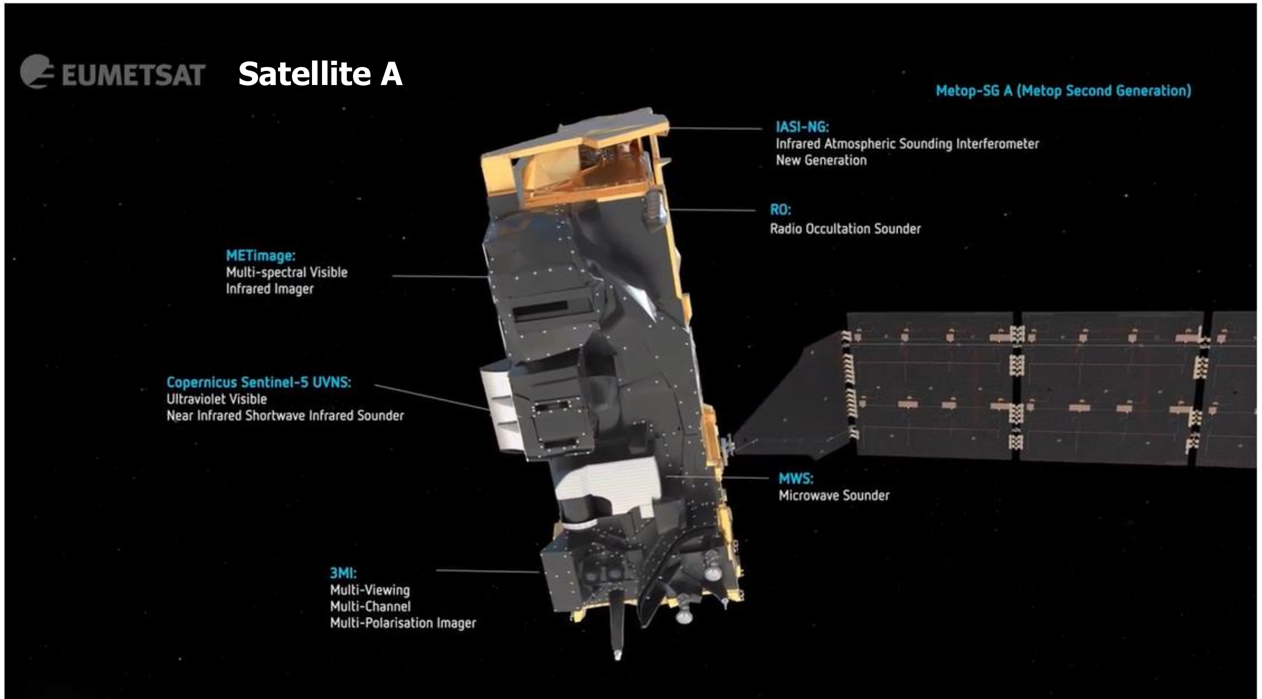
EPS-SG: EUMETSAT Polar System - Second Generation

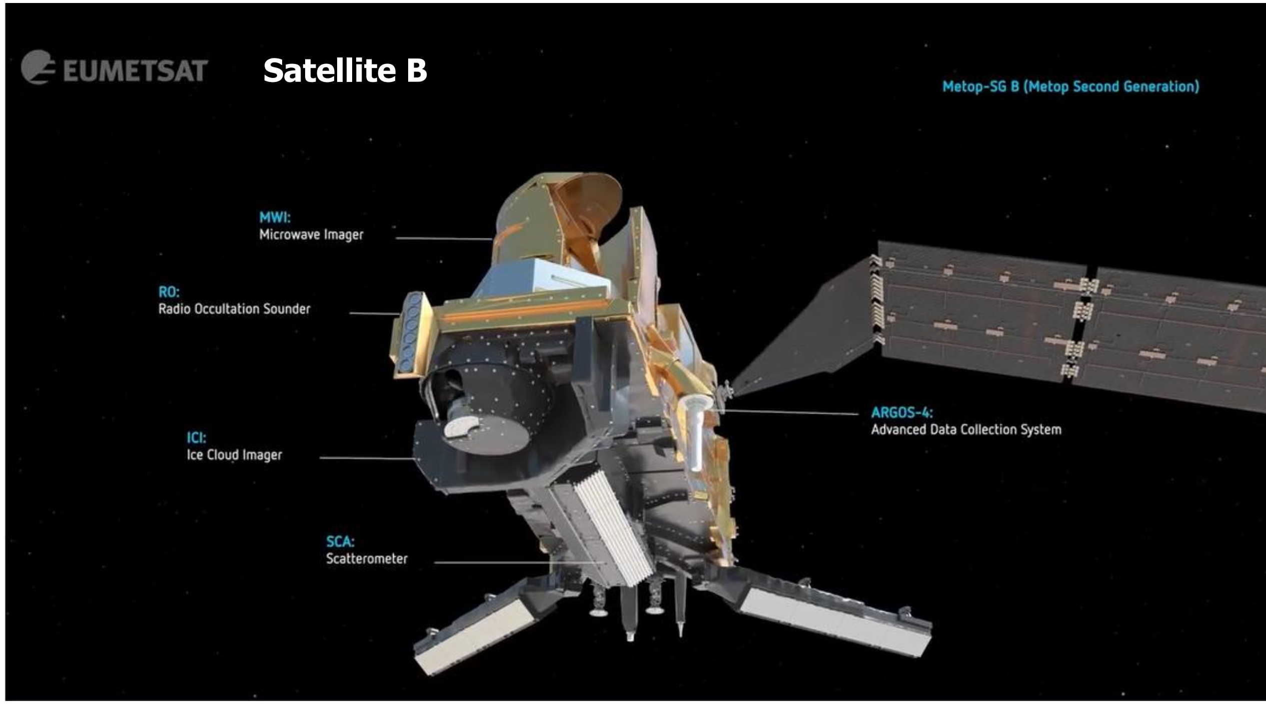
- **The EUMETSAT Polar System (EPS) in Low Earth Orbit (LEO) Second Generation system (EPS-SG): European contribution to the Joint Polar System**

- **Same orbit as Metop (sun-synchronous, 835 km mean altitude, 09:30 local time descending node, repeat cycle 29 days).**

- **Payload complementary distributed between the two parallel satellites Metop-SG A and B in the same orbital plane.**

- **Nominal lifetime of 7.5 years/spacecraft for an operational lifetime of the programme over 21 years.**





EPS-SG Microwave Imaging Missions Objectives

MicroWave Imager (MWI)

- Provision of cloud and precipitation products
- Support Numerical Weather Prediction at regional and global scales
- Nowcasting and very short-range forecasting at regional scales
- Support observations of sea ice parameters and snow cover, snow water equivalent, sea surface wind.
- Continuity of measurements of key microwave imager channels as observed by SSM/I, TMI, SSMIS, AMSR-E, GMI, in support of long-term climate records

Ice Cloud Imager (ICI)

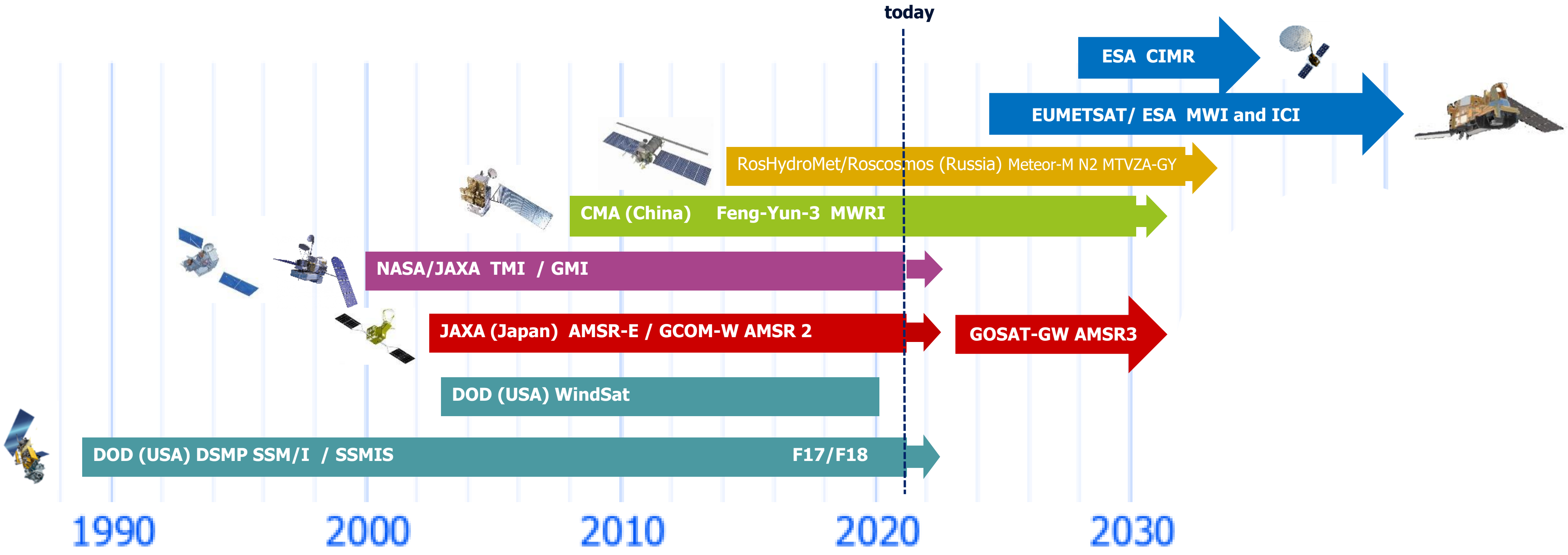
- Provision of ice cloud products for climate monitoring
- Support the validation of ice clouds models and the parameterisation of ice clouds in weather and climate models
- Fill observational gap: provide information on non-precipitating ice that are not covered either in the optical/thermal IR or in the mm-wave range

Background and heritage of MWI and ICI

Key microwave channels (10.65, 18.7/19.35, 23.8/22.235, 31.4/37.0, and 85.5/89.0 GHz) data are well suited for estimates of precipitation rate, column water vapour, and cloud liquid water, as well as surface parameters such as ocean surface wind speed, sea ice extent and concentration, snow cover, soil moisture, and land surface emissivity.

MWI has a long heritage form instruments such as DSMP Special Sensor Microwave–Imager (SSM/I) and Special Sensor Microwave-Imager/Sounder (SSMIS), TRMM Microwave Imager (TMI), Advanced Microwave Scanning Radiometer for EOS (AMSR-E), GCOM-W Advanced Microwave Scanning Radiometer–2 (AMSR 2), GPM Microwave Imager (GMI).

Continuous long-term record of high-quality global satellite microwave observations in support of long-term climate records, which now extends over 30 years.



Current and future passive microwave coverage

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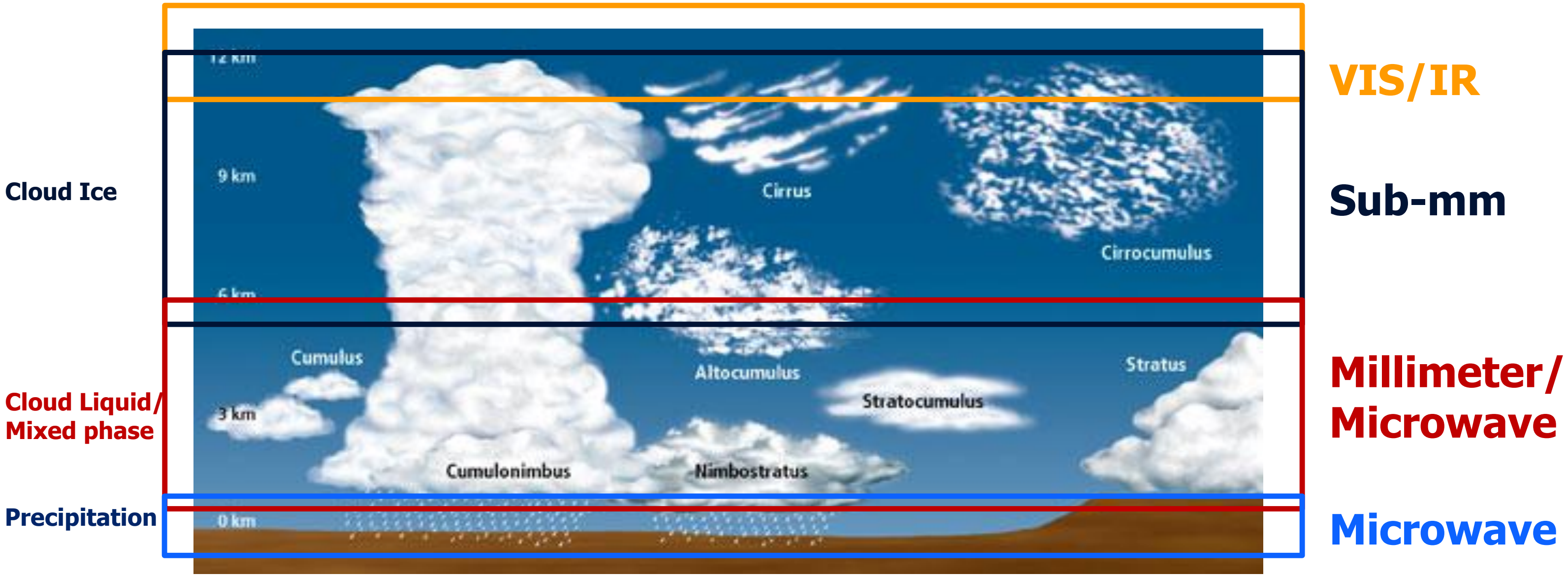
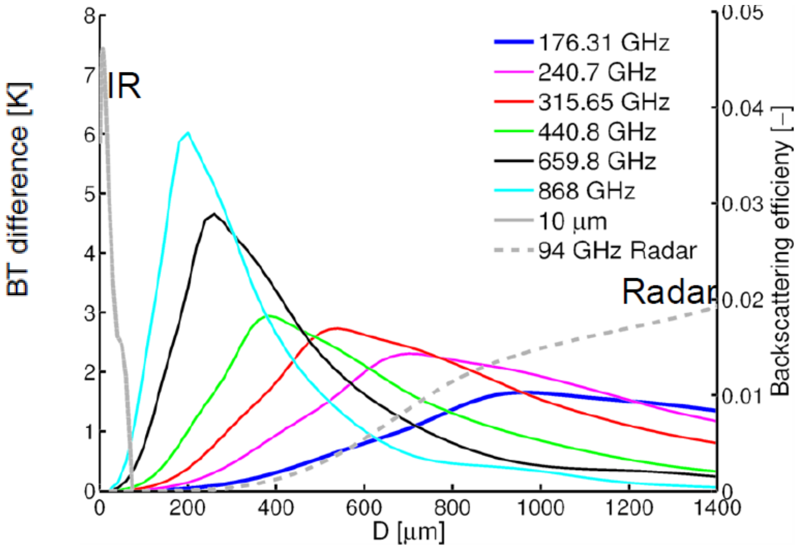
Sub-mm channels for ice cloud observations

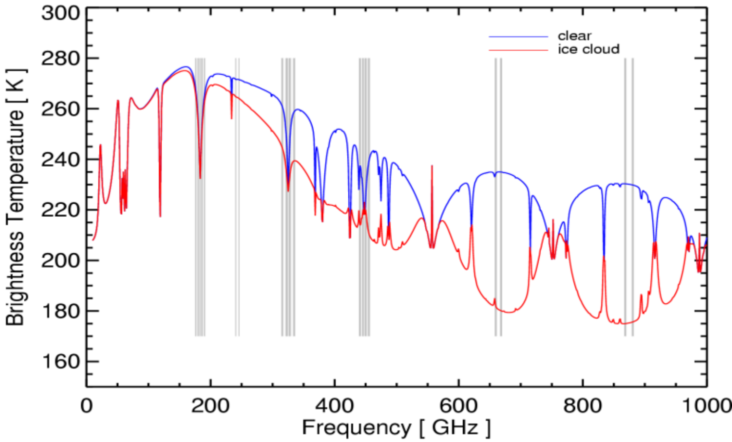
ICI is the first operational radiometer of this type designed with the objective of remote sensing of cloud ice. ICI will open up the sub-millimetre region for NWP and climate monitoring. Measurements by other instruments at such wavelengths already exist, mainly by limb sounding instruments such as Aura MLS, Odin/SMR and SMILES or demonstrational cubesat missions (ICECUBE). Pioneering airborne instruments were MIR (Millimeter-wave Imaging Radiometer), CoSSIR (Compact Scanning Submillimeter Imaging Radiometer) and more recently ISMAR (International SubMillimetre Airborne Radiometer).

Sensitivity of measurements at different frequencies to particle size *





Buehler et al., 2007



***: Buehler, S. A., Jiménez, C., Evans, K. F., Eriksson, P., Rydberg, B., Heymsfield, A. J., Stubenrauch, C. J., Lohmann, U., Emde, C., John, V. O., Sreerekha, T. R., and Davis, C. P., 2007: A concept for a satellite mission to measure cloud ice water path, ice particle size, and cloud altitude", *Q. J. Roy. Meteorol. Soc.*, 133, 109–128.**

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Main channels of EPS-SG MWI and ICI in spectrum

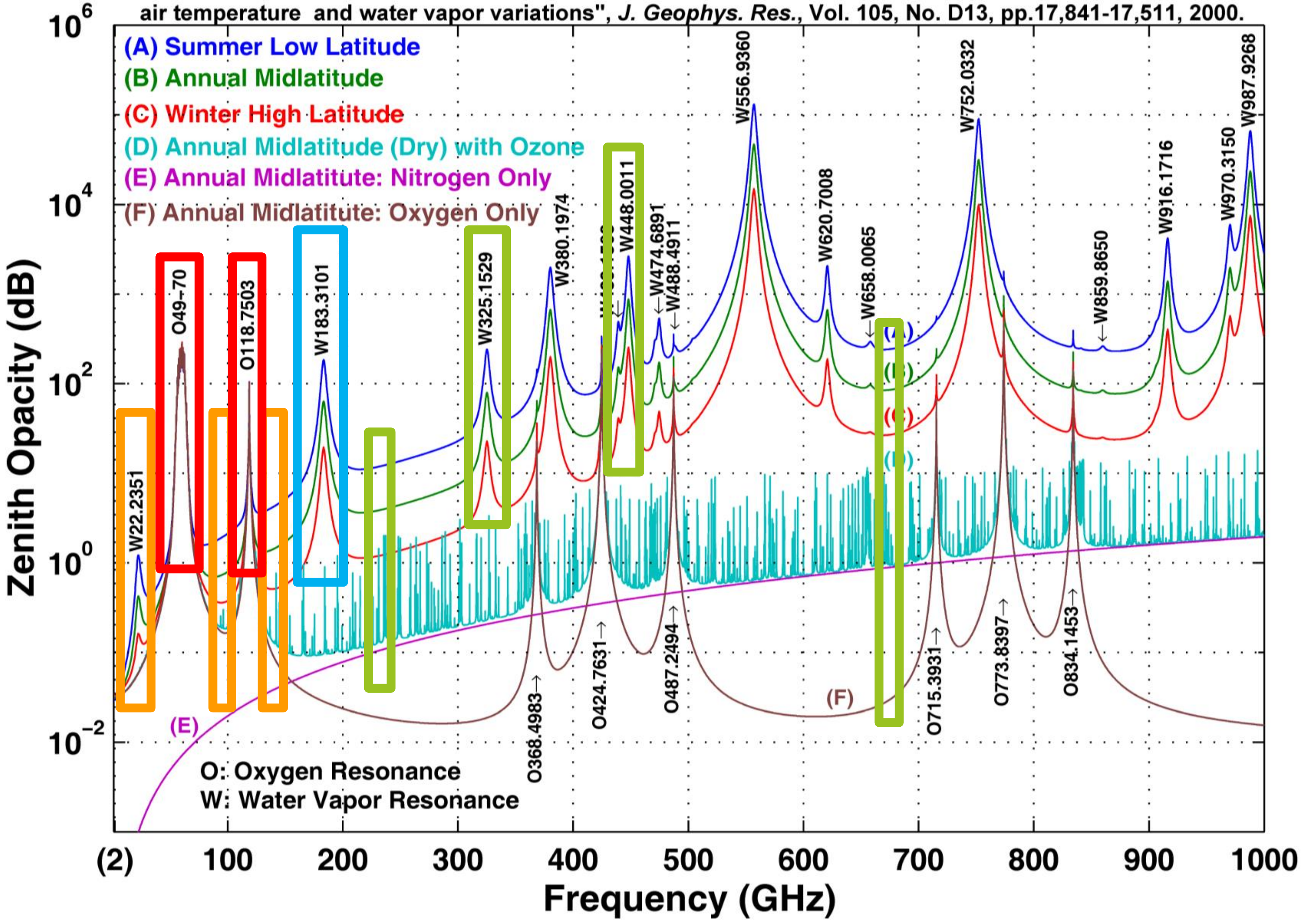
Imaging channels in the “windows”

Temperature sounding in the 60-118 GHz line

Humidity sounding in the 183 GHz line

..and beyond: Ice Cloud Imager (ICI)

Klein, M., A.J. Gasiewski: "Nadir sensitivity of passive millimeter and submillimeter wave channels to clear air temperature and water vapor variations", *J. Geophys. Res.*, Vol. 105, No. D13, pp.17,841-17,511, 2000.



MWI channel performance requirements

- Continuity of key microwave imager channels for weather forecast (e.g. SSM/I, AMSR-E, GMI) for precipitation over sea, total column water vapour, cloud liquid water and surface parameters

- All MWI channels up to 89 GHz measured with both vertical (V) and horizontal (H) polarisations.

- Innovative set of channels in the oxygen absorption band near 50–60 GHz and 118 GHz. Precipitation over sea and land including light precipitation and snowfall

- Channels MWI-13 to MWI-18 provide information on water vapour profiles and snowfall. Less sensitive to surface, more usable globally and enabling cloud slicing.

Channel	Frequency (GHz)	Bandwidth (MHz)	NEΔT (K)	Polarisation	Footprint Size 3dB (km)
MWI-1	18.7	200	0.8	V, H	50
MWI-2	23.8	400	0.7	V, H	50
MWI-3	31.4	200	0.9	V, H	30
MWI-4	50.3	180	1.1	V, H	30
MWI-5	52.70	180	1.1	V, H	30
MWI-6	53.24	400	1.1	V, H	30
MWI-7	53.750	400	1.1	V, H	30
MWI-8	89.0	4000	1.1	V, H	10
MWI-9	118.7503±3.20	2x500	1.3	V	10
MWI-10	118.7503±2.10	2x400	1.3	V	10
MWI-11	118.7503±1.40	2x400	1.3	V	10
MWI-12	118.7503±1.20	2x400	1.3	V	10
MWI-13	165.5±0.75	2x1350	1.2	V	10
MWI-14	183.31±7.0	2x2000	1.3	V	10
MWI-15	183.31±6.1	2x1500	1.2	V	10
MWI-16	183.31±4.9	2x1500	1.2	V	10
MWI-17	183.31±3.4	2x1500	1.2	V	10
MWI-18	183.31±2.0	2x1500	1.3	V	10

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ICI channel performance requirements

- In support of a synergetic use of MWI and ICI both instruments carry common spectral channels at 183 GHz.
- Set of channels providing information related to total vertical column of cloud ice and ice particles size
- Use of channels around weak absorption lines (around 325.15 GHz and 448 GHz) allows performing cloud slicing
- ICI-4 and ICI-11 measure both V and H polarisation providing information on ice hydrometeors habits and orientation

Channel	Frequency (GHz)	Bandwidth (MHz)	NEΔT (K)	Polarisation	Footprint Size 3dB (km)
ICI-1	183.31±7.0	2x2000	0.8	V	16
ICI-2	183.31±3.4	2x1500	0.8	V	16
ICI-3	183.31±2.0	2x1500	0.8	V	16
ICI-4	243.2±2.5	2x3000	0.7	V, H	16
ICI-5	325.15±9.5	2x3000	1.2	V	16
ICI-6	325.15±3.5	2x2400	1.3	V	16
ICI-7	325.15±1.5	2x1600	1.5	V	16
ICI-8	448±7.2	2x3000	1.4	V	16
ICI-9	448±3.0	2x2000	1.6	V	16
ICI-10	448±1.4	2x1200	2.0	V	16
ICI-11	664±4.2	2x5000	1.6	V, H	16

MWI Instrument description

AIRBUS

OHB ITALIA

MWI is composed of one rotating part and one fixed part.

- The rotating part includes the main reflector antenna, the feed assembly, the receivers and the control and data processing unit (CDPU), which acquires the measurement data and performs the thermal control of the rotating part.
- The fixed part contains the hot calibration target, the reflector antenna for viewing the cold-sky, the instrument control unit (ICU) responsible for the instrument control and interface with the platform.
- A tubular structural design minimizes the sun intrusions inside the instrument cavity.

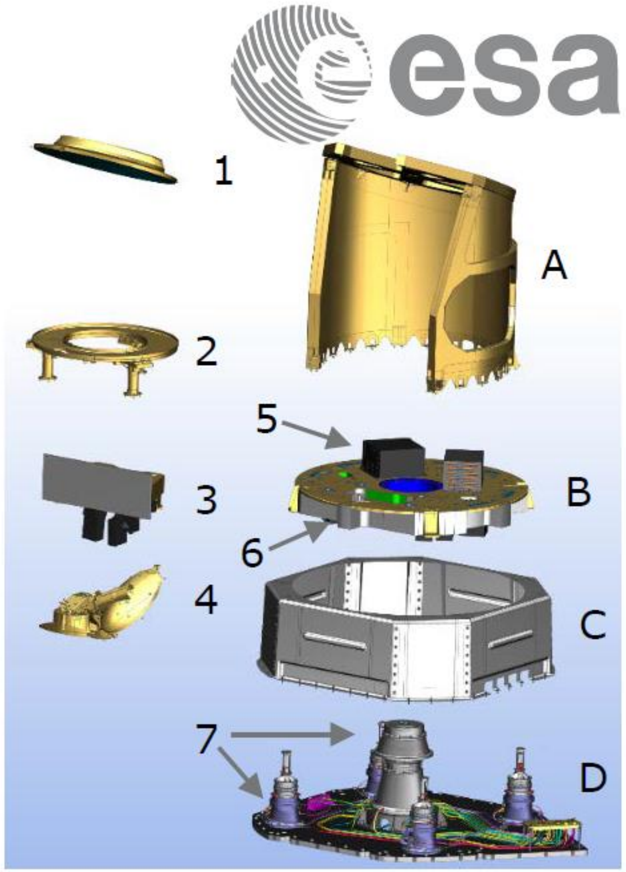
Antenna: offset parabolic reflector with feed cluster of 7 horns

Receivers:

- direct detection at 23.8/31.4 and 89 GHz; heterodyne detection for other frequencies.
- internal noise diodes for lower frequencies MWI-1 to MWI-3.
- RFI mitigation filter on MWI-1

Few data:

- **mass: 250 kg**
- **height: 1.8 m**
- **reflector diameter: 80 cm**



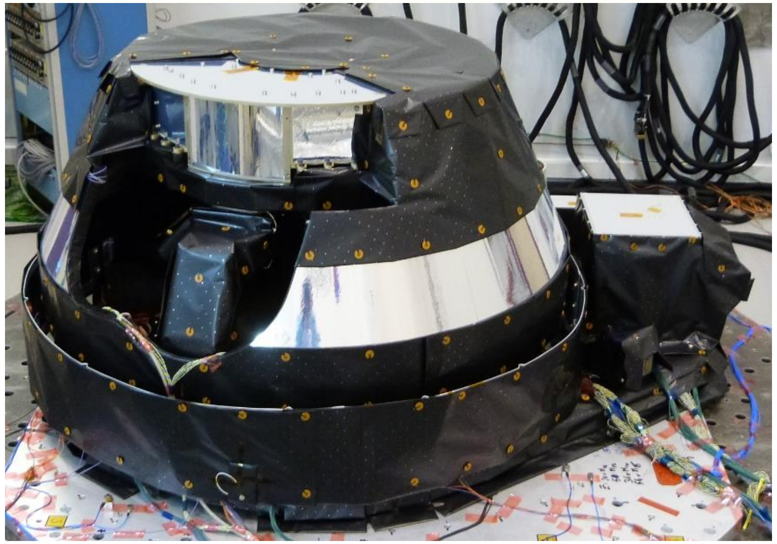

Instrument Control Unit and Scan Control Electronics are housed in the Satellite bay

A. Tube and Roof structure
B. Rotating Deck
C. Baseplate cover
D. Baseplate
1. Main reflector
2. OBCT Racetrack
3. Front End SubAssembly
4. Calibration Assembly
5. FEE, CDPU
6. Low Frequency receivers
7. Scan Mechanism, LLDs

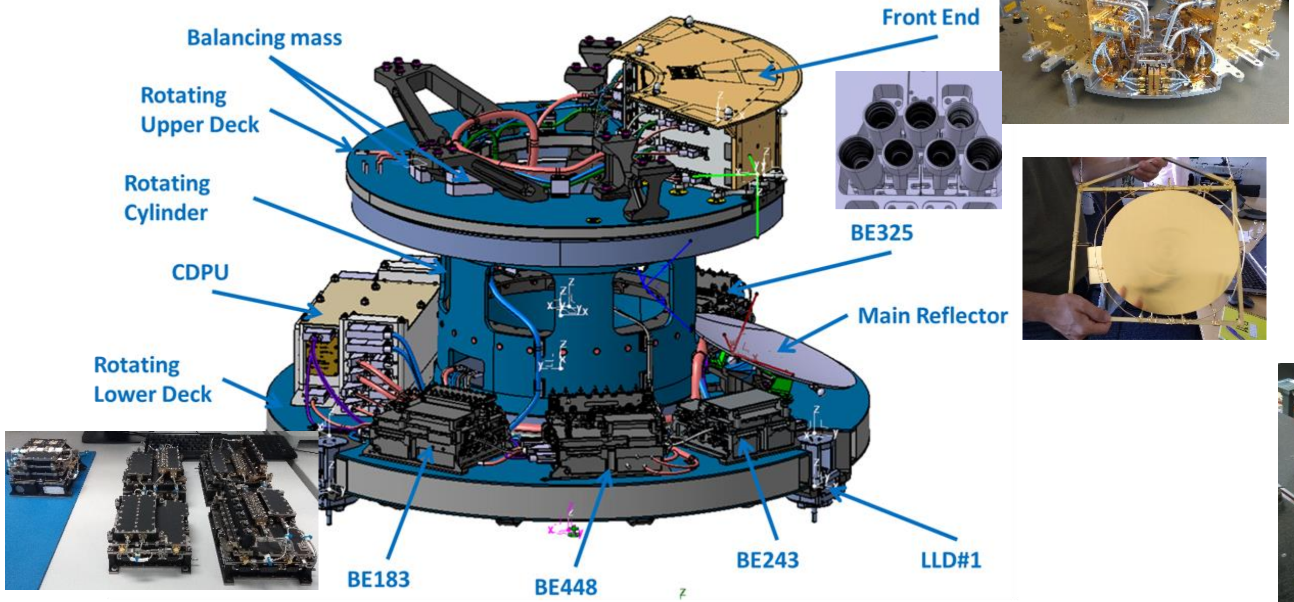
ICI Instrument description

- ICI consists of a fixed and a rotating part. A scan mechanism assembly interfaces between both parts.
  - The rotating part includes the main reflector antenna, the feed assembly, the receivers and the CDPU.
  - The fixed part contains the hot calibration target, the cold-sky reflector, the ICU.
- Feed cluster made of 2 rows of 7 horns (4 and 3 per raw). Implementation of a different horn/receiver per polarization.
- Receivers technologies: heterodyne detection, double side band mixer.

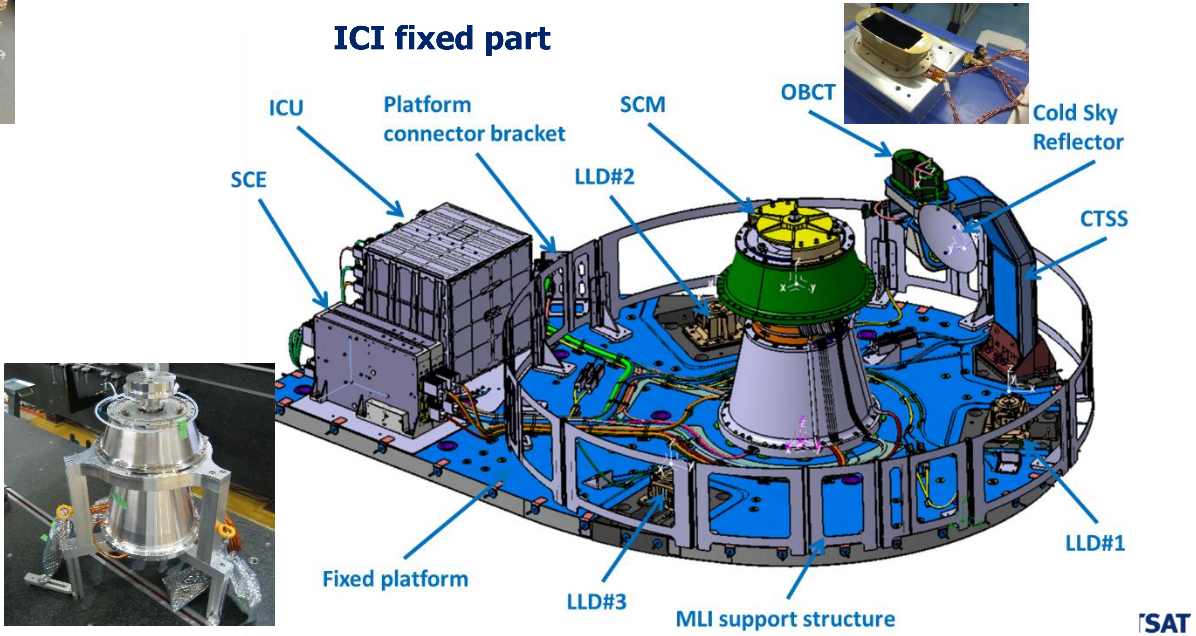
Few data:
- **mass: 175 kg**
- **height: 0.7 m**
- **reflector diameter: 30 cm**



ICI rotating part showing the main elements



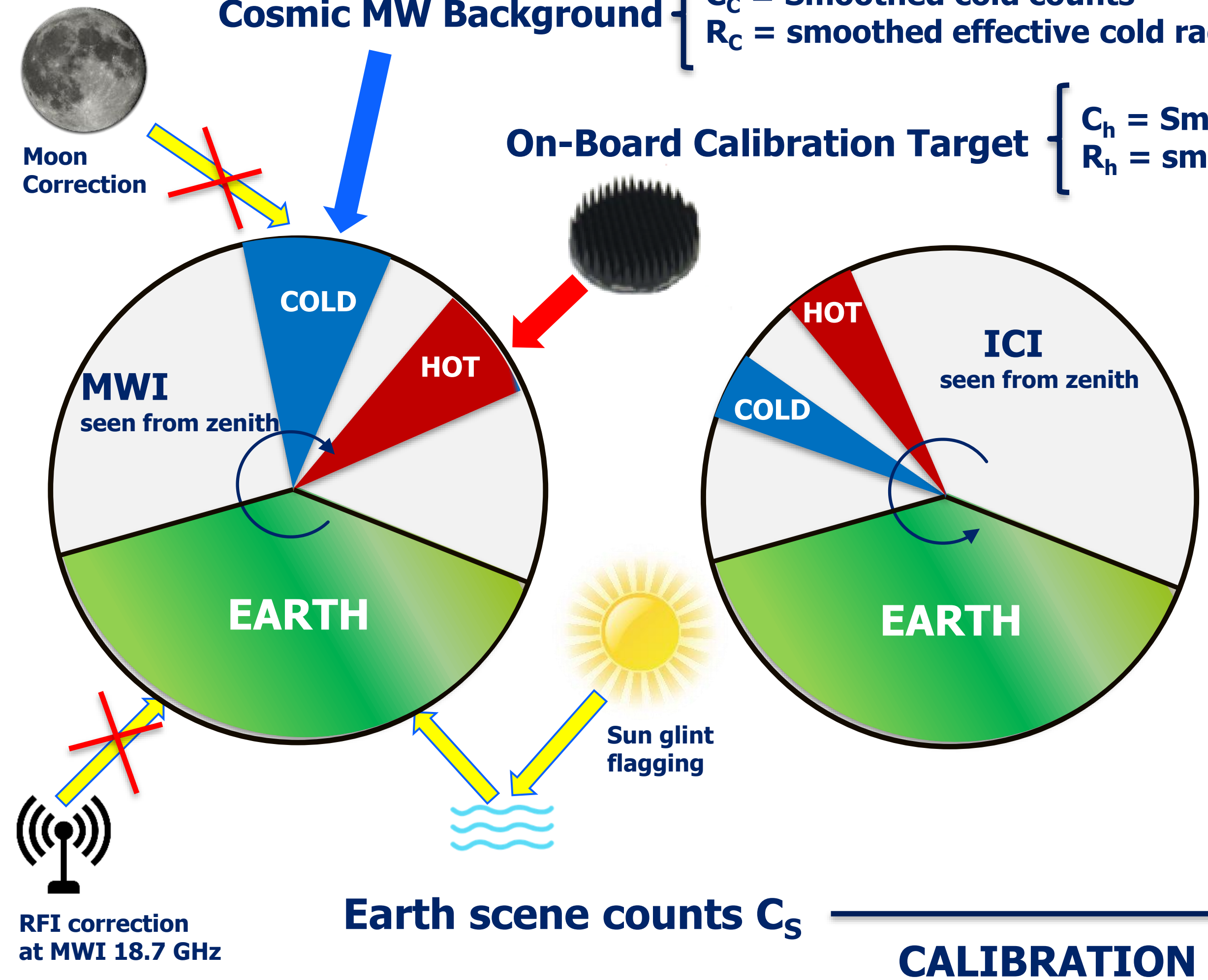
ICI fixed part

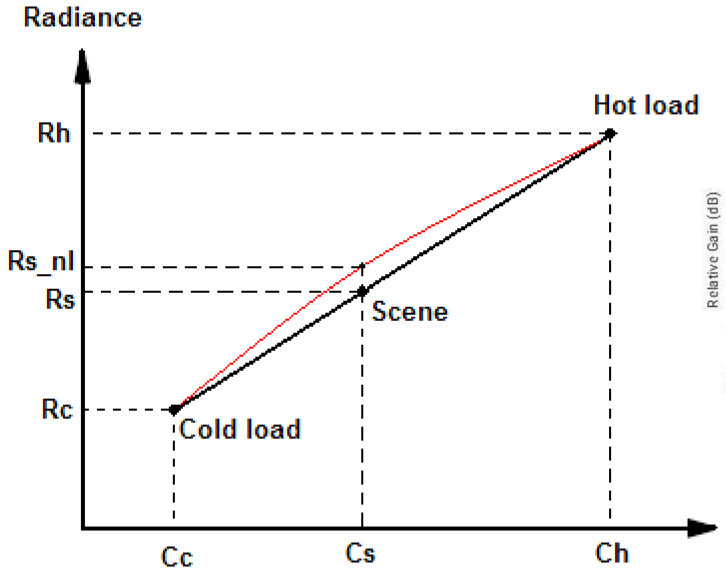


Calibration approach

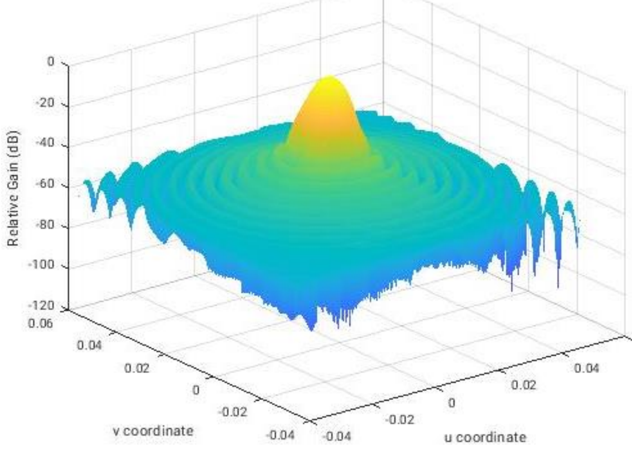
Cosmic MW Background: C_C = Smoothed cold counts; R_C = smoothed effective cold radiances

On-Board Calibration Target: C_h = Smoothed hot counts; R_h = smoothed effective OBCT radiances





MWI simulated antenna pattern at 89 GHz



Earth scene counts C_S → **CALIBRATION** → **Antenna scene radiances R_S** → **APC** → **TOA radiances**

Calculation of gain, offset and non-linear parameters

MR Spillover and losses
Cross-polarization
Near/Far sidelobe

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Calibration Equations

the non-linear radiometer transfer function is expressed as a third-order polynomial of the actually measured Earth view counts

$$R_S^a(i, k_e, j) = a_3 C_S^3 + a_2 C_S^2 + a_1 C_S + a_0 = a_3 C_S^3 + a_2 C_S^2 + \frac{C_S}{g_{nl}} + R_o^{nl}$$

$$R_o = R_c - \frac{C_c}{g}$$

Linear offset

$$\frac{1}{g} = \frac{R_h - R_c}{C_h - C_c}$$

Linear gain

Non linearity parameters

Non linear offset

$$a_0 = R_o^{nl} = R_o - a_2 C_C C_h - a_3 C_C C_h \cdot (C_C + C_h)$$

Non linear gain

$$a_1 = \frac{1}{g_{nl}} = \frac{1}{g} - a_2(C_c + C_h) - a_3\left(C_c^2 + C_c \cdot C_h + C_h^2\right)$$

$$a_2 = \frac{\alpha_2}{g\beta}$$

$$a_3 = \frac{\alpha_3}{g\beta}$$

$$\beta = \alpha_1 + \alpha_2(C_c + C_h) + \alpha_3\left(C_c^2 + C_c \cdot C_h + C_h^2\right)$$

α_1, α_2, α_3 parameters are derived from on-ground characterization

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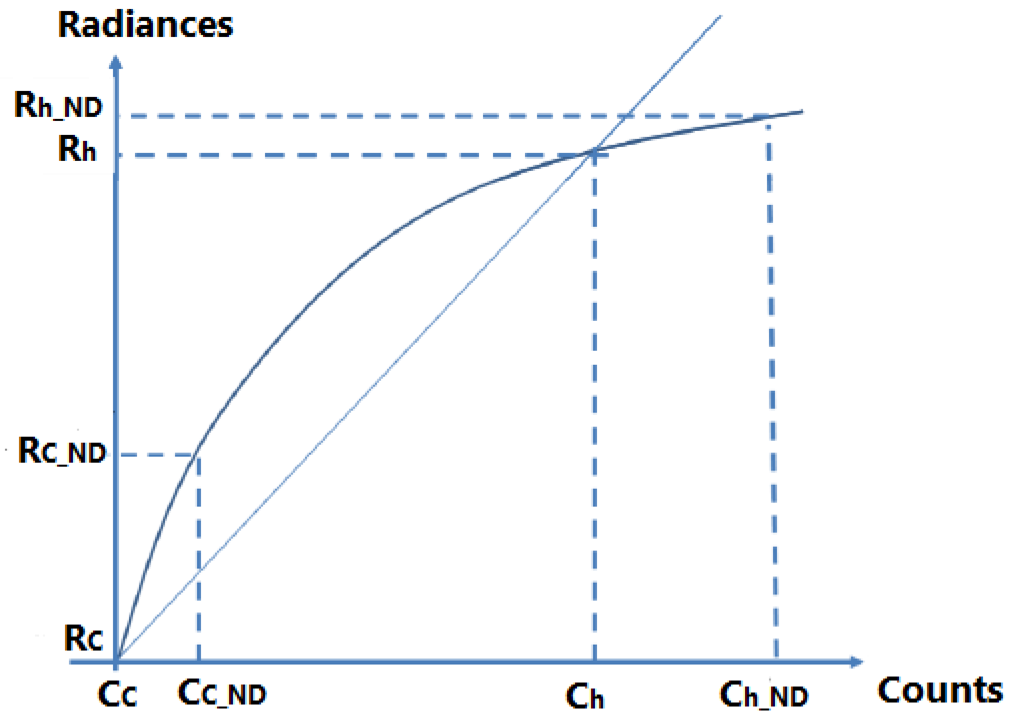
Calibration approach for MWI-1 to MWI-3

- Channels MWI-1 to MWI-3 implement noise diodes, that are activated every other turn of the instrument;

- The noise diodes provide two additional calibration points ($[C_{C\_ND}, R_{C\_ND}]$, $[C_{h\_ND}, R_{h\_ND}]$), which are exploited to explicitly calculate the non-linear term of the calibration curve.

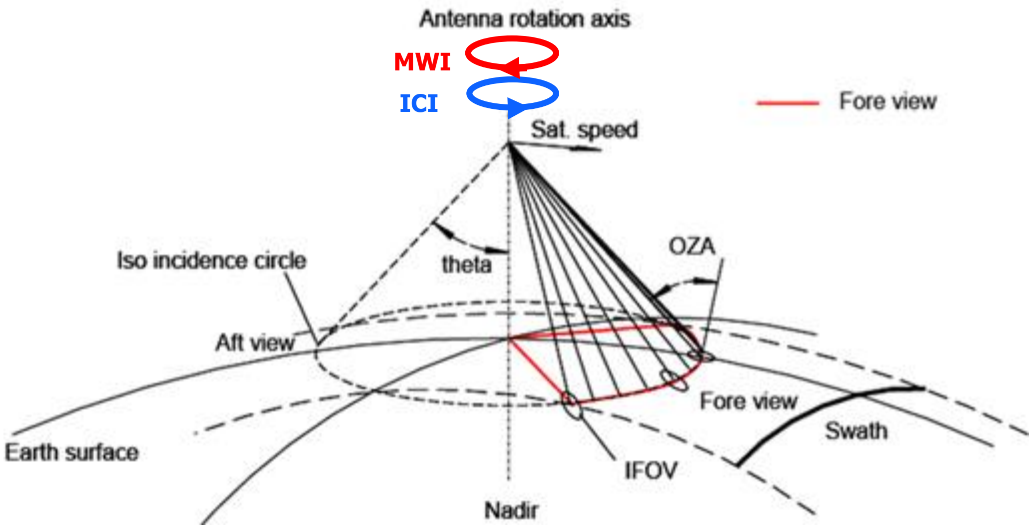
- The calibration points provided by the noise diodes can also be used for a back-up calibration approach, in case of calibration anomalies for cold or hot load (the calibration load without anomalies used as low reference radiance (e.g. $[C_h, R_h]$) and its measurement with noise diodes activated as high reference radiance (e.g. $[C_{h\_ND}, R_{h\_ND}]$).

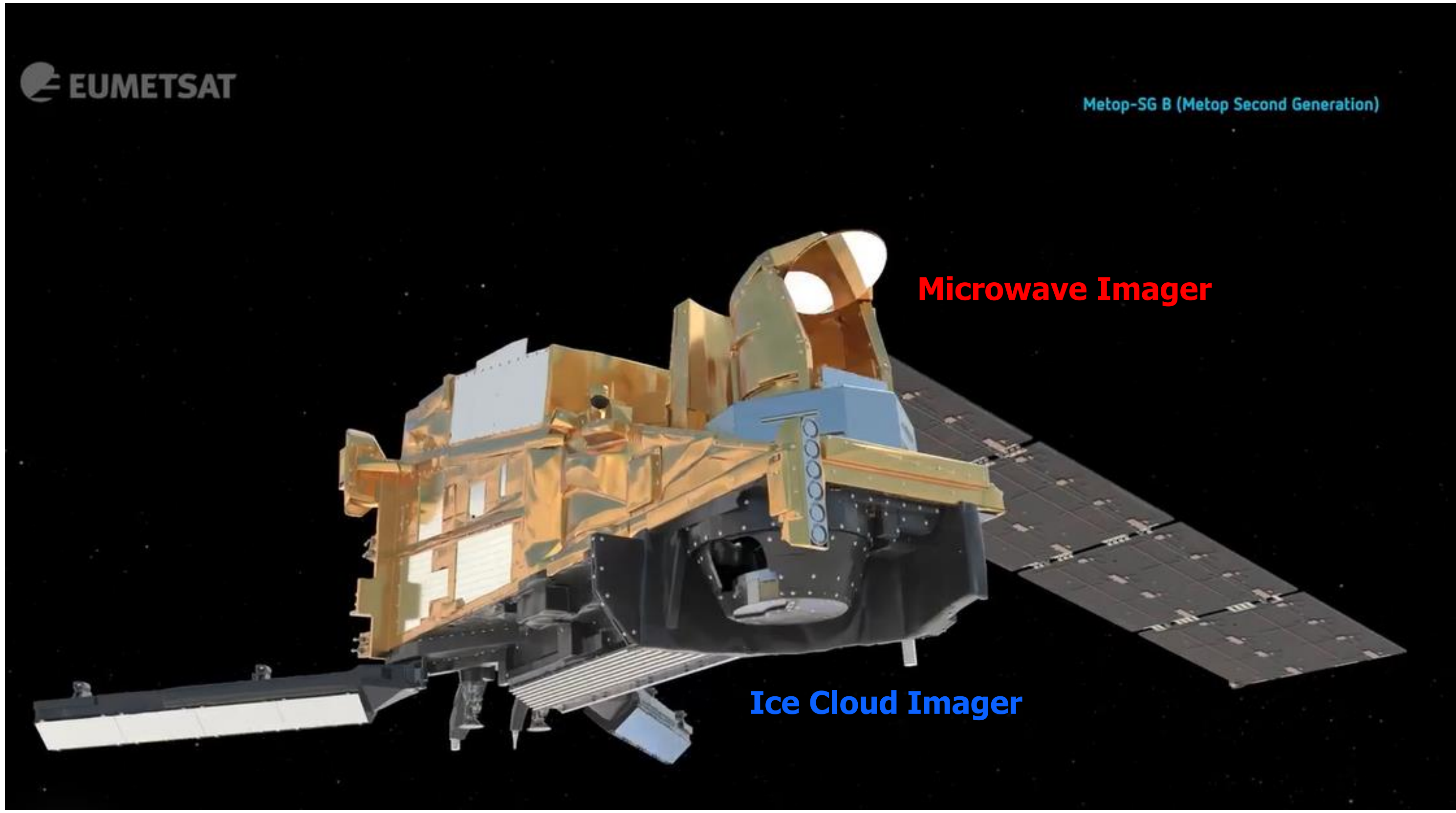


MWI and ICI scanning characteristics

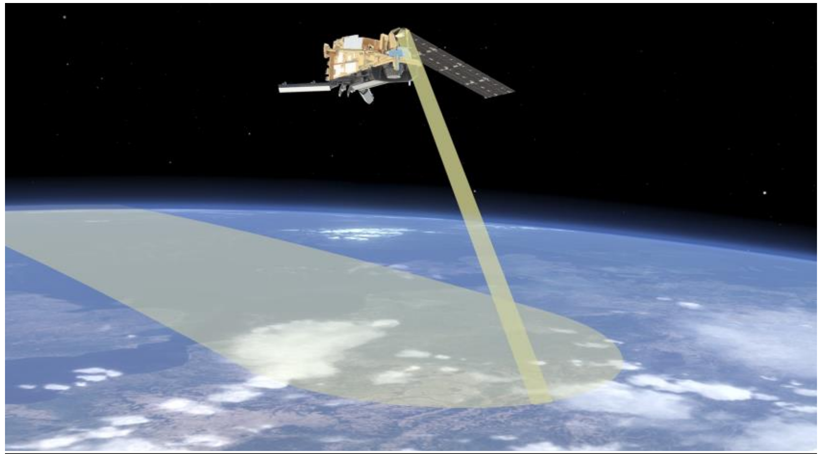
Conically scanning at 45 rpm (about 1.3333 seconds). Incidence angles within 53°±2°. Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath).

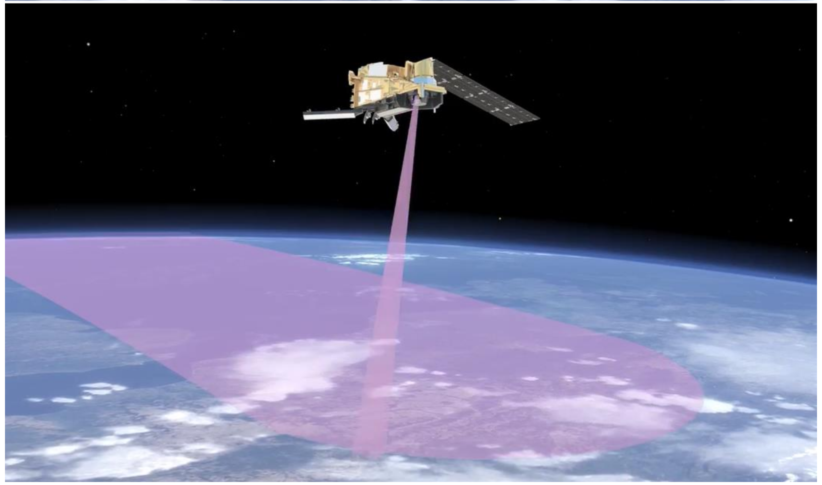
ICI: conically scanning counterclockwise, MWI: conically scanning clockwise (as seen from zenith) and are not synchronized.

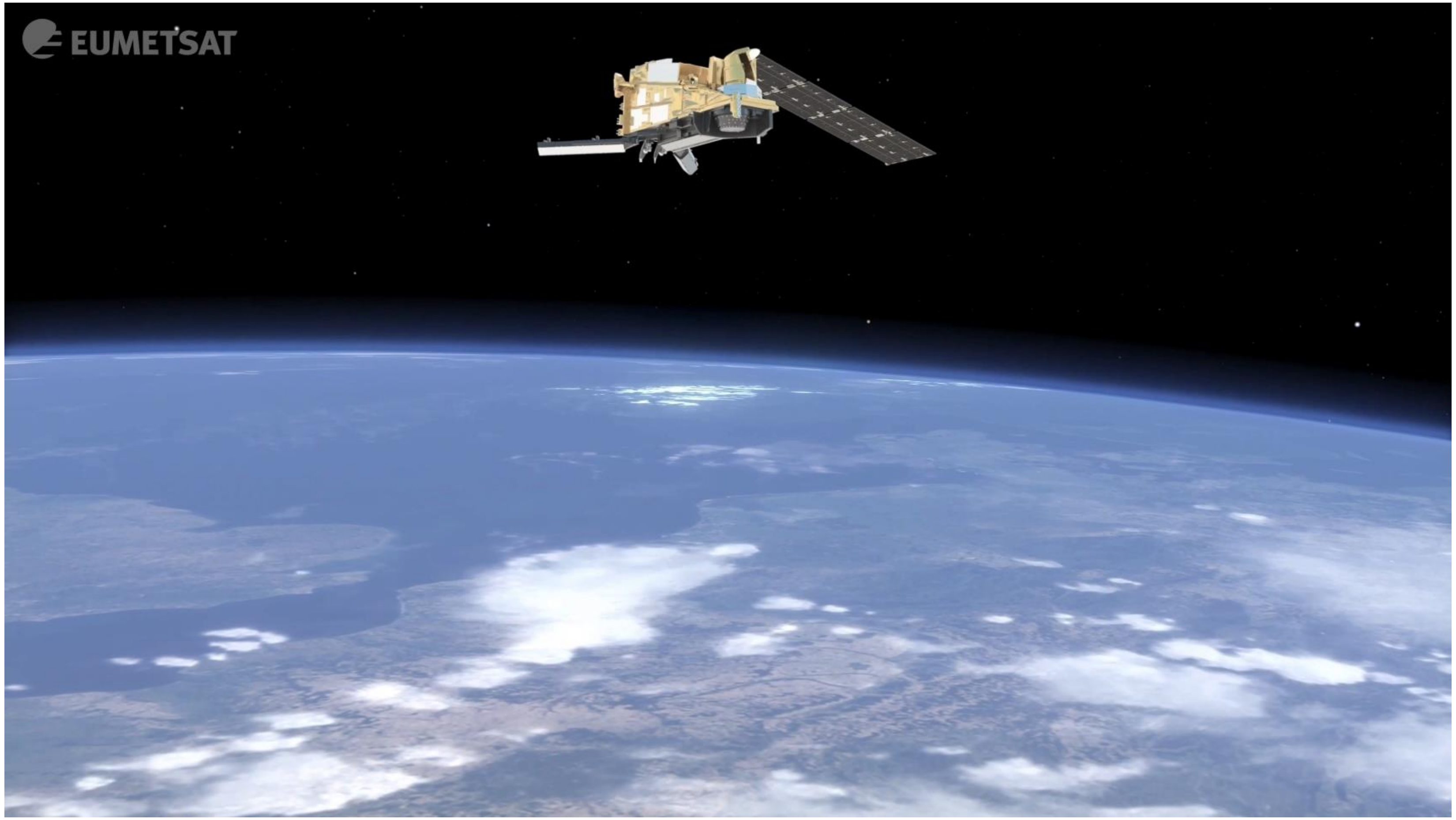




MWI and ICI scanning characteristics





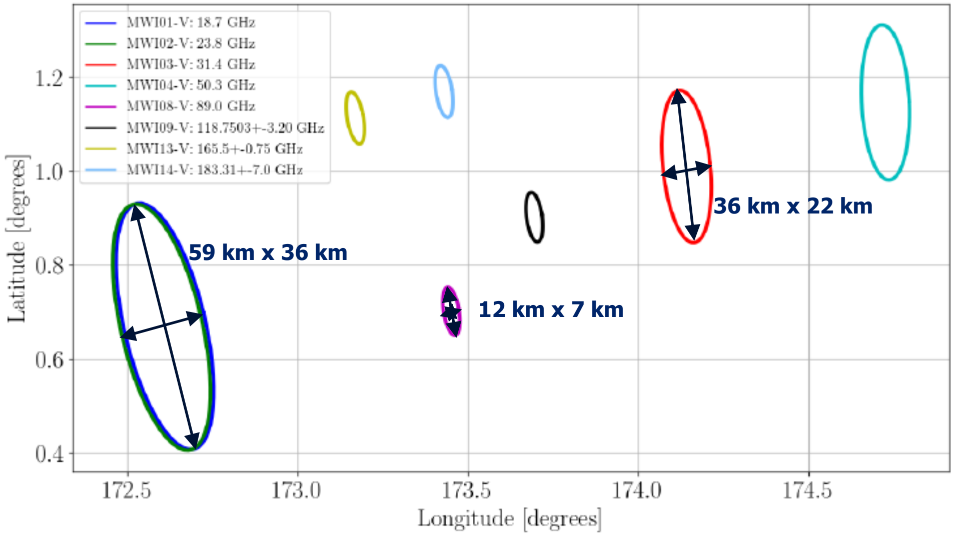


MWI Swath - about 1400 samples per scan

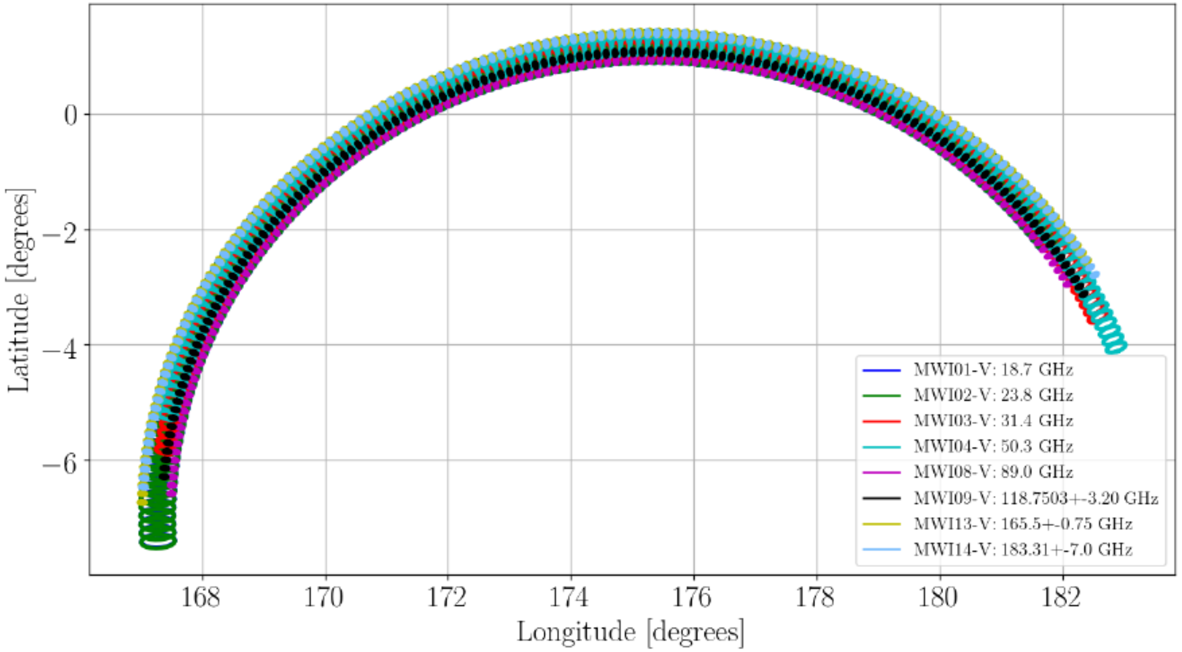
MWI footprint: MWI-1/2 (18.7 / 23.8 GHz): 50 km (59km x 36km); MWI-3/7 (31.4 / 50-54 GHz): 30 km (36km x 22km); MWI-8-18 (89/118/165.5/183 GHz): 10km (12km x 7km)

The number of samples is 1394 for all the channels. The sampling time is about 0.394 ms. The oversampling factor is about 20 for MWI-1 and MWI-2, about 10 at MWI-3 to MWI-7, and 3-5 for MWI-8 to MWI-18.

The distance along-track between subsequent scans will be about 9 km. Footprints overlap along-track requirement is 20%.



Instantaneous, relative positions of -3-dB footprints on the geoid for MWI channels.



Relative positions of -3-dB footprints on geoid for MWI channels of a complete scan.

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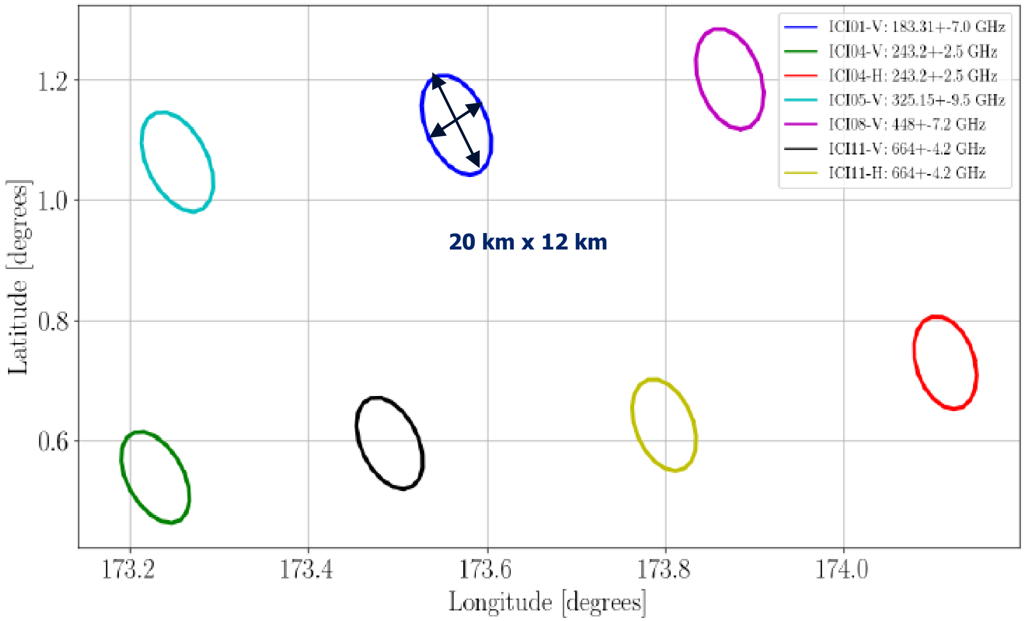
ICI Swath - about 800 samples per scan

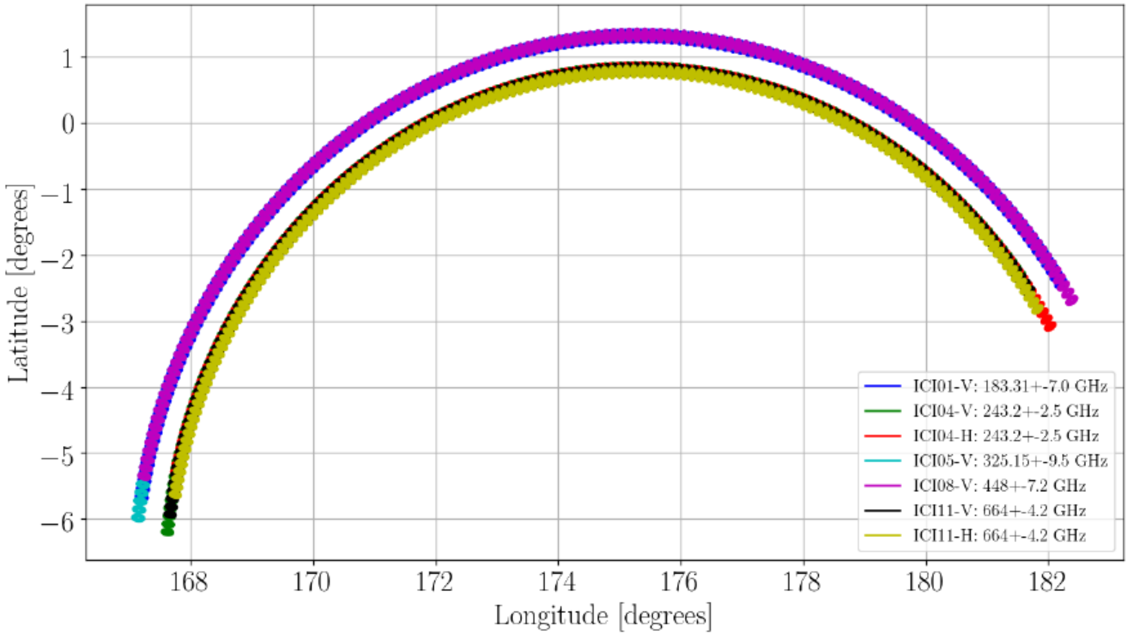
ICI footprint: 16 km requirement (ICI-1 to ICI-11): about 20 km along-track and about 12 km across-track for the footprints (at -3 dB).

The number of samples is 782 for all the channels. The sampling time is about 0.663 ms. The oversampling factor is about 3-4.

The distance along-track between subsequent scans will be about 9 km. Footprints overlap along-track requirement is 40%.



Instantaneous, relative positions of -3-dB footprints on the geoid for ICI channels.



Relative positions of -3-dB footprints on geoid for ICI channels of a complete scan.

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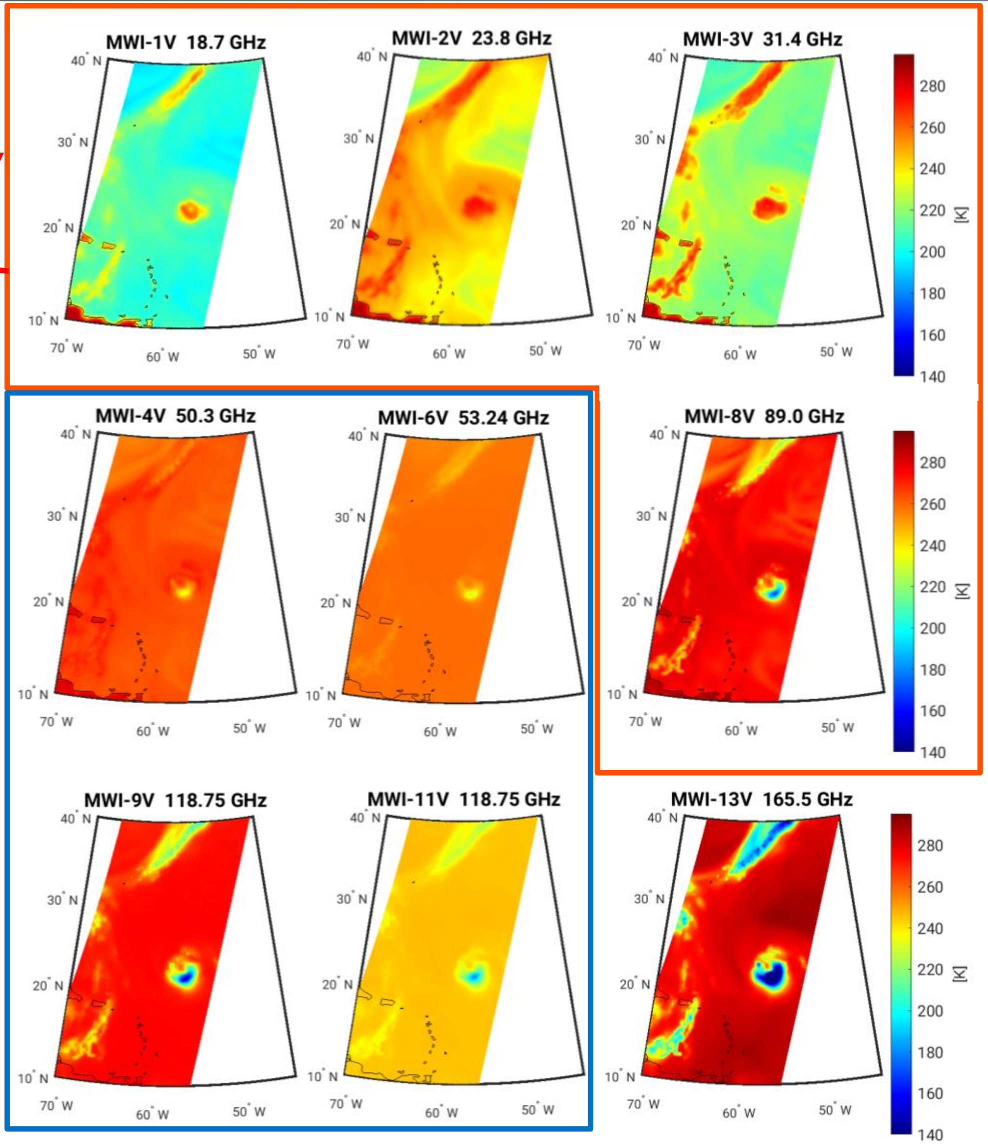
MWI and ICI TB simulations (hurricane "IKE" , 06/2008)

Total Column Water Vapour, liquid and frozen hydrometeors, sea ice, snow cover, wind speed, surface emissivity

light precipitation and snowfall, cloud slicing

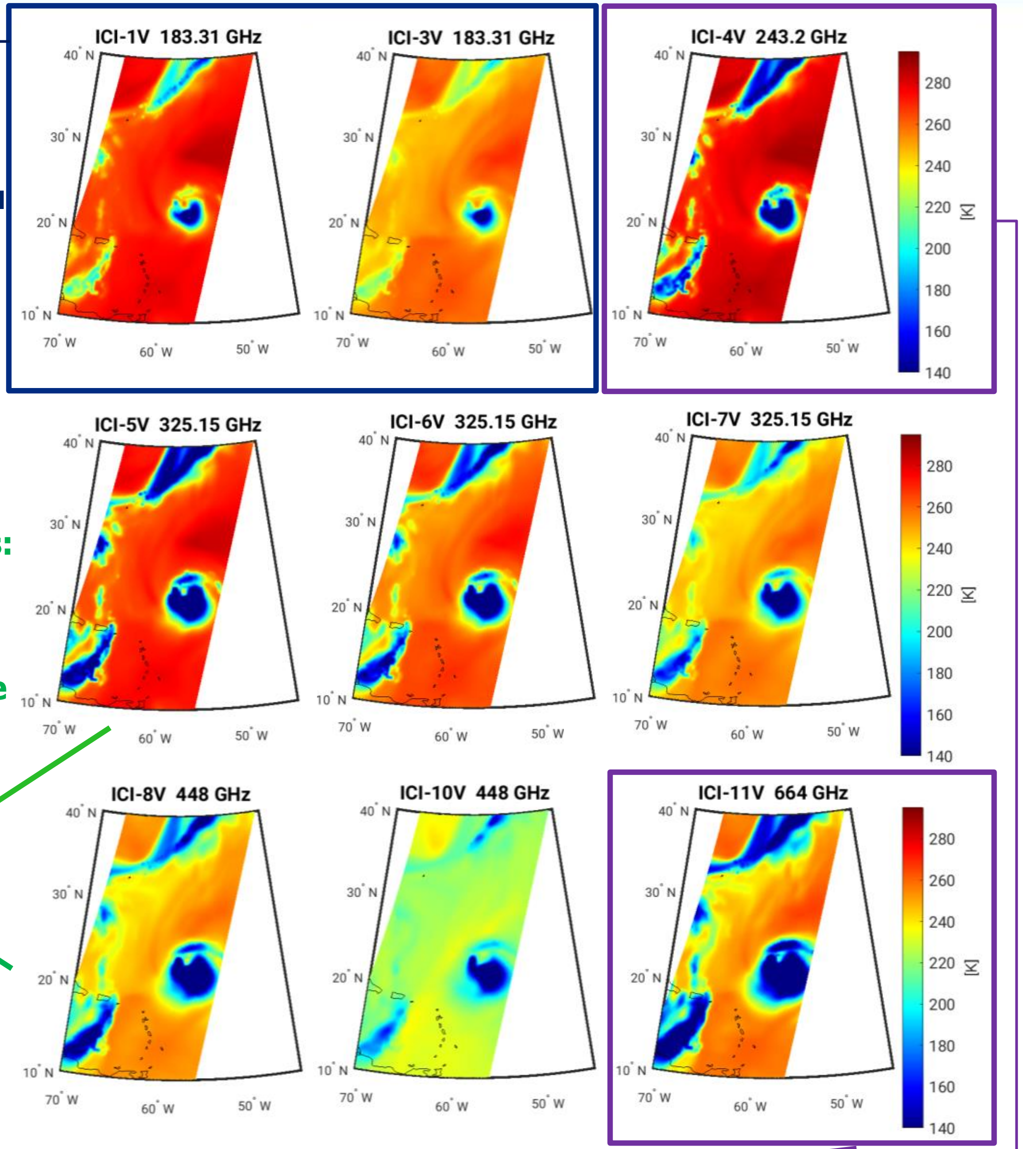


183.31 GHz water vapour profiles and snowfall. Cloud slicing

ICI channels:

Ice Water Path and ice particles size

Cloud slicing



243.2 and 668 GH V and H polarisation for ice habits and orientation

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MWI-ICI Science Advisory Group

The MWI-ICI Science Advisory Group (SAG), co-chaired by ESA and EUMETSAT, is composed of scientific experts in the area of passive microwave remote sensing.

- providing a frame for scientific support and advice to ESA and EUMETSAT during the development of the MWI and ICI missions.

- ➢ commenting on all aspects related to the proposed product processing, product format, archiving, dissemination, reprocessing, and Cal/Val.

- ➢ 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).

MWI-ICI SAG has drafted the MWI-ICI Science Plan which is available via:

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

Thank you!

Metop-SG B (Metop Second Generation)