Future EUMETSAT Microwave Imaging Missions and Plans for Making Use of Lunar Observations

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Outline

- Introduction
- EPS-SG passive microwave and sub-mm wave imaging missions:
  - Micro-Wave Imager (MWI)
  - Ice Cloud Imager (ICI)
- Characteristics
  - Spectral, geometry, resolution
  - Cold space view
- Handling of the moon intrusion in the cold space view
- Moon Calibration algorithm applied in the MWI-ICI L1B Processing
- Summary

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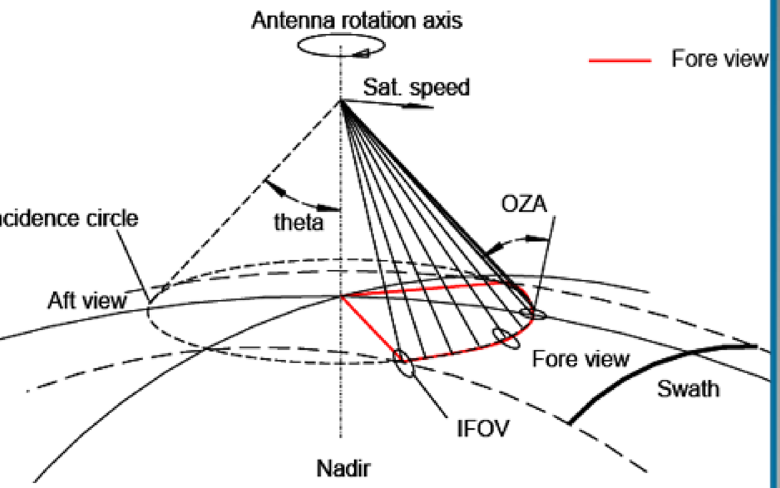
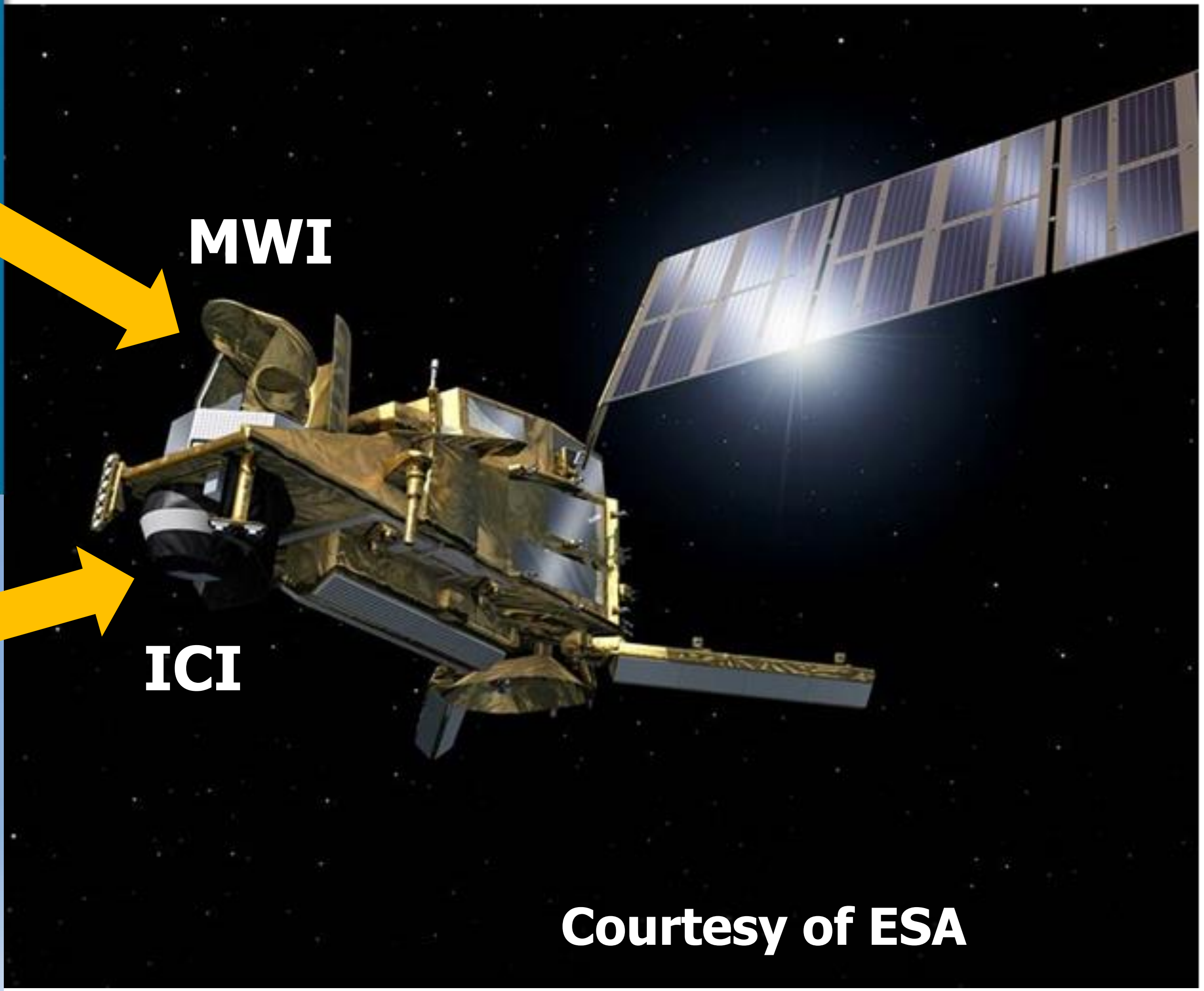
The MWI and ICI instruments on EPS-SG Satellite B





Conically scanning instruments

MWI: clockwise rotation

ICI: counterclockwise

- **Incidence angles within 53°±2°**
- **Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath)**
- **Scan rate: 45 rpm**

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The Microwave Imager (MWI)

- Continuity of key microwave imager channels for weather forecast (e.g. SSM/I, AMSR-E, GMI).

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

- Channels in the oxygen absorption band near 50–60 GHz.

- Innovative set of channels at 118 GHz. Enabling the retrieval of information on weak 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.

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

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	52.7	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

MWI expected performance

The Ice Cloud Imager (ICI)

ICI is the first radiometer of this type designed with the objective of remote sensing of cloud ice.

- **In support of a synergetic use of ICI and MWI, 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).**

- **Channels in the atmospheric windows at 243 and 664 GHz, implemented with dual polarisation.**

•Few data:
- **mass: 170 kg**
- **height: 1.3 m**
- **reflector diameter: 30 cm**

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

ICI expected performance

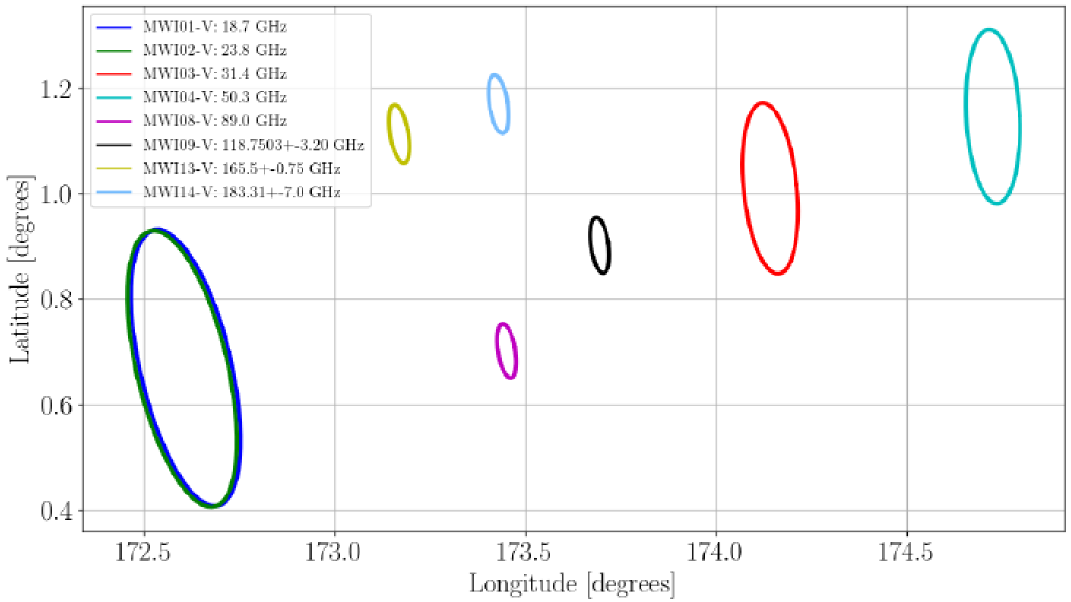
MWI-ICI -3dB footprints

MWI

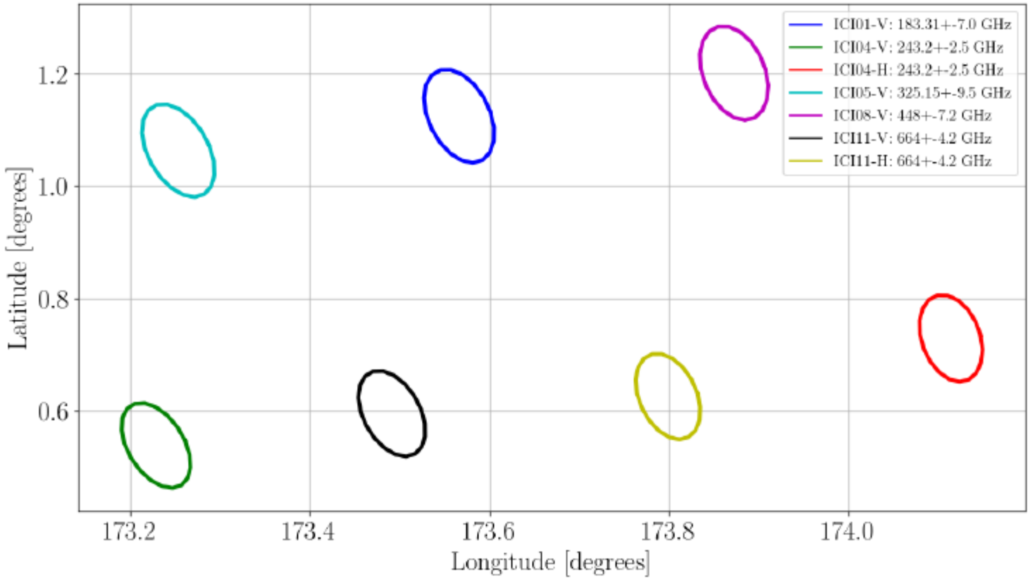
footprint: 50 km (18.7, 23.8 GHz); 30 km (31.4 – 53.75 GHz); 10 km (118.75 – 183.31 GHz).
Footprints overlap ~ 20%. Spatial sampling ~7 km. MWI swath ~ 1400 samples

ICI

footprint: 16 km (ICI-1 to ICI-11); Footprints overlap ~ 40%. Spatial sampling ~7.5 km. ICI swath ~ 800 samples



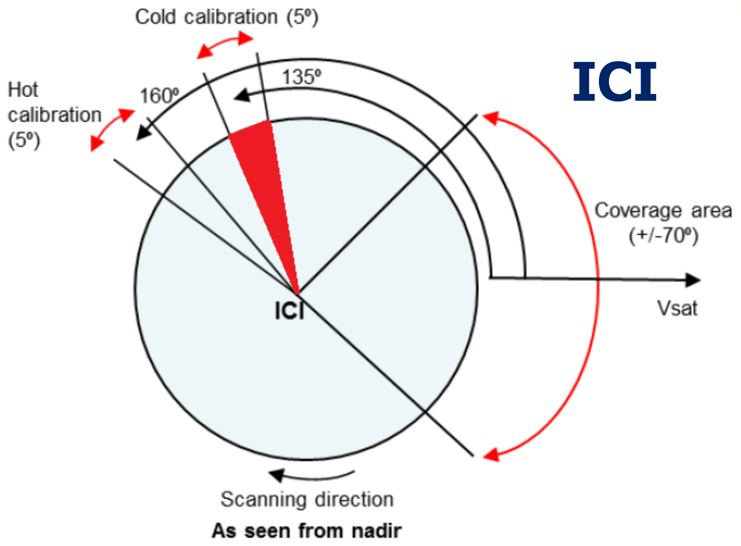
instantaneous, relative positions of -3-dB footprints on the geoid for MWI channels.

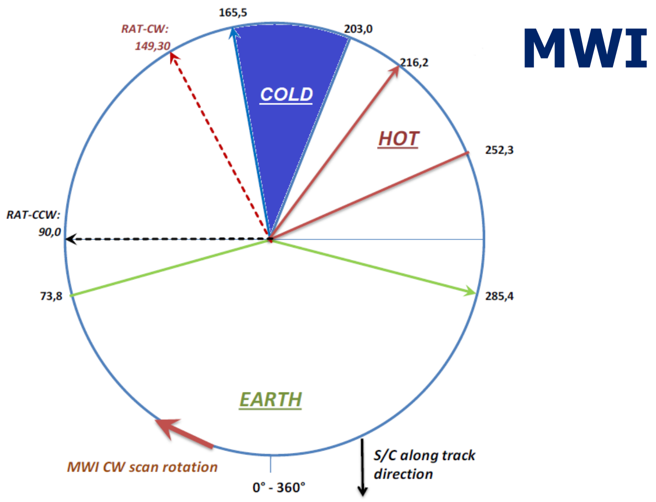


instantaneous, relative positions of -3-dB footprints on the geoid for ICI channels.

Cold space view observations

- During the calibration cycle the rotating feed horns look at a fixed calibration reflector over a small angular section (the Space View or Cold Space Reflector, SVR), collecting the energy coming from the cold sky (T ~ 2.73 K).
- 352 space observations are acquired in this angular section for MWI and 52 for ICI (~ 50 for MWI and ~ 30 for ICI in the “optimal” observation window).
- The projection of the rotating feed horn beam over a fixed reflector leads to a distortion of the antenna pattern in the fixed SVR reference frame during the cold space window.
- Counts relative to the cold space view can be affected by the Moon presence, deteriorating the calibration.



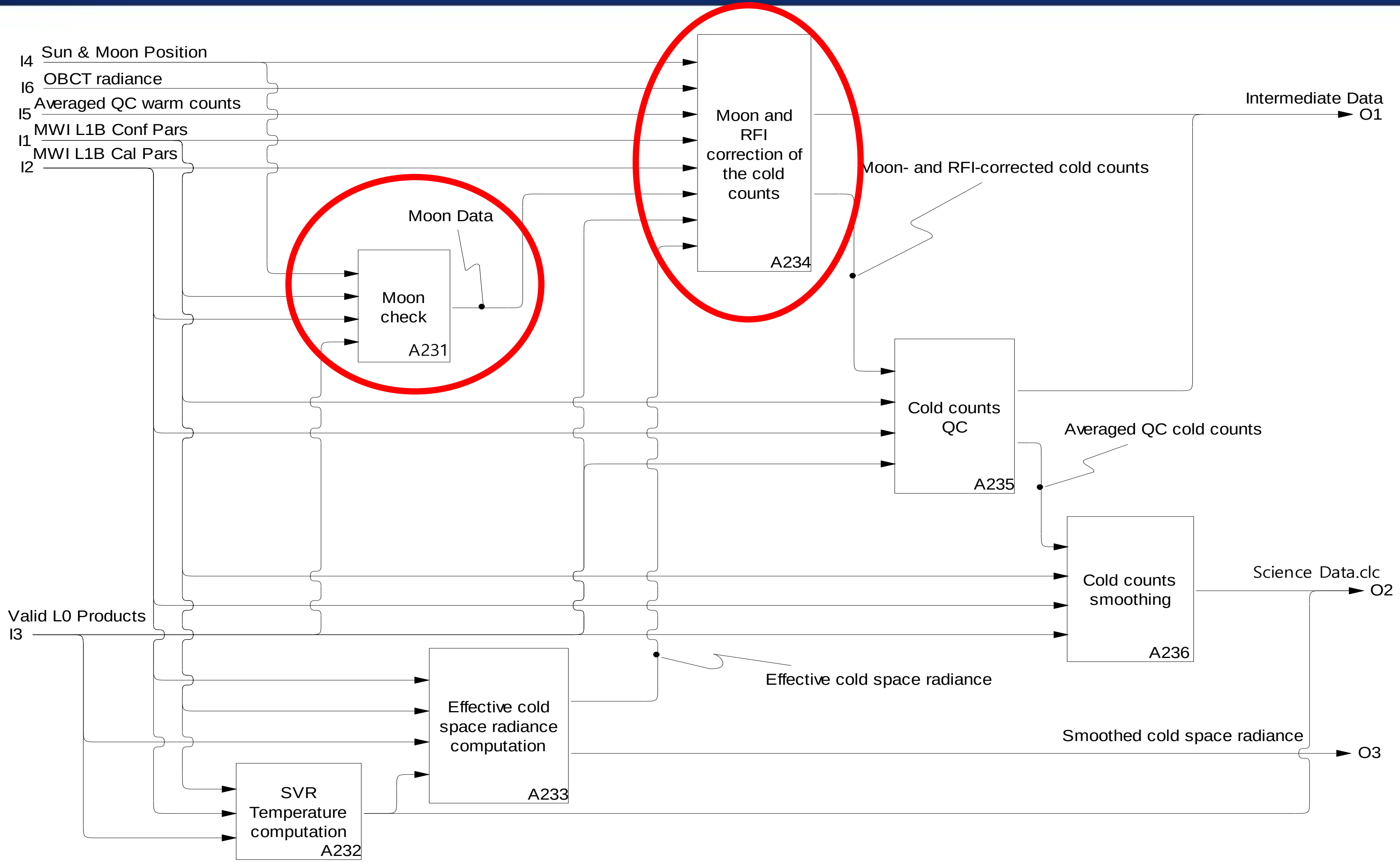


Processing of the cold space view: handling of Moon intrusion

- The Moon intrusion is handled in the MWI-ICI L1B processing through two steps:

1) Moon gross check;

2) Correction of the cold view counts affected by the presence of the Moon.



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Moon gross check

- The lunar contamination occurs when there is sufficient alignment between the unit vector centred on the Moon and directed to the satellite ($\widehat{r_M}$), and the unit vector pointing in the boresight direction of the SVR ($\widehat{r_B}$). Both vectors are represented in the SVR reference frame.

- Given the rotating geometry of the instruments, $\widehat{r_B}$ can be evaluated on ground for each cold space view sample and for each channel.
  $\widehat{r_M}$ is computed by the EOCFI software (ESA) used for the geolocation of the pixels;

- The condition indicating possible lunar contamination is: $|cos^{-1}(\widehat{r_M} \cdot \widehat{r_B})| < \zeta_c(j)$

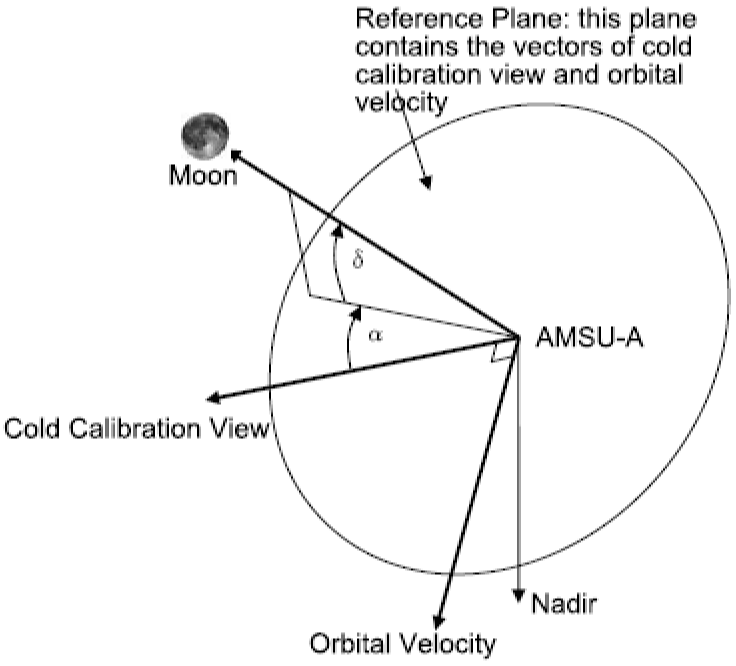
- Since the Moon will contaminate only a portion of the cold space view, the processor can choose to correct the contaminated cold space view counts or to flag them and use only the non-contaminated counts for the calibration.

Moon intrusion correction: overview

- The method of Mo and Kigawa (2007) has been adopted to correct the cold counts in case of Moon intrusion in the cold space view.
- It has been tested on operational cross-track microwave sounders (e.g. AMSU – Mo, 2018, ATMS – Yang and Weng, 2016)
- This method is described in the following slide and its applicability to the MWI-ICI processing is also discussed.

- Mo, T., and S. Kigawa, 2007: A Study of lunar contamination and on-orbit performance of the NOAA-18 Advanced Microwave Sounding Unit-A, J. Geophys. Res., 112, D20124, doi:10.29/2007JD008765.
- Mo, T, 2008: Post-Launch Assessment of the METOP-A AMSU-A Performance, Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International , Vol.2, no., II-1188,II-1191, 7-11 July 2008. doi: 10.1109/IGARSS.2008.4779213.
- Hu Yang and Fuzhong Weng, 2016, “Corrections for On-Orbit ATMS Lunar Contamination”, IEEE Transactions on Geoscience and Remote Sensing, Vol. 54 Issue: 4, page(s): 1-7.

Method by Mo and Kigawa 2007



G antenna pattern gain

Cold counts correction

$$\Delta C_c = \left[\frac{C_w - C_c}{T_w - (T_c + \Delta T_c)}\right]\Delta T_c.$$

$$\Delta T_c = G(\alpha, \delta)\beta T_{moon}\, r,$$

Antenna Pattern parameterization

$$G(\alpha, \delta) = \exp\left[-\frac{(\alpha - \alpha_0)^2}{2\alpha_S^2}\right]\exp\left[-\frac{(\delta - \delta_0)^2}{2\delta_S^2}\right]$$

$$\beta = \frac{\pi(0.259)^2}{\int\int G(\alpha, \delta)d\delta\, d\alpha},$$

where

- C_w blackbody count;
- T_w blackbody temperature;
- T_c deep space cosmic background temperature;
- C_c observed space counts, including lunar contamination;
- α lunar azimuth angle;
- α_0 FOV center of lunar azimuth angle;
- α_S azimuth size factor;
- δ lunar elevation angle;
- δ_0 FOV center of lunar elevation angle;
- δ_S elevation size factor;
- β area ratio of lunar disk to FOV convolved with the antenna pattern powers. In equation (8), the 0.259 is the half cone angle that the lunar disk subtends at the satellite at its normal distance;
- r distance ratio = $(60.3 \times 6378/\mathrm{d})^2$, where d is the distance (in km) between the satellite and Moon. The range of r is from 0.94 to 1.06.

It works very well with cross track sounders because the viewing geometry does not change over the cold space view

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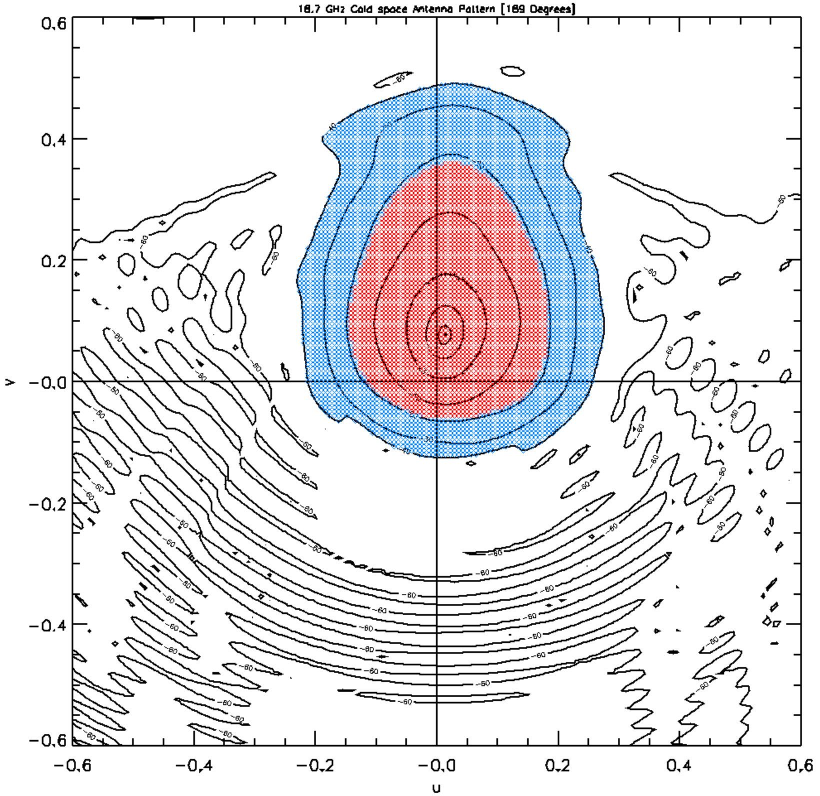
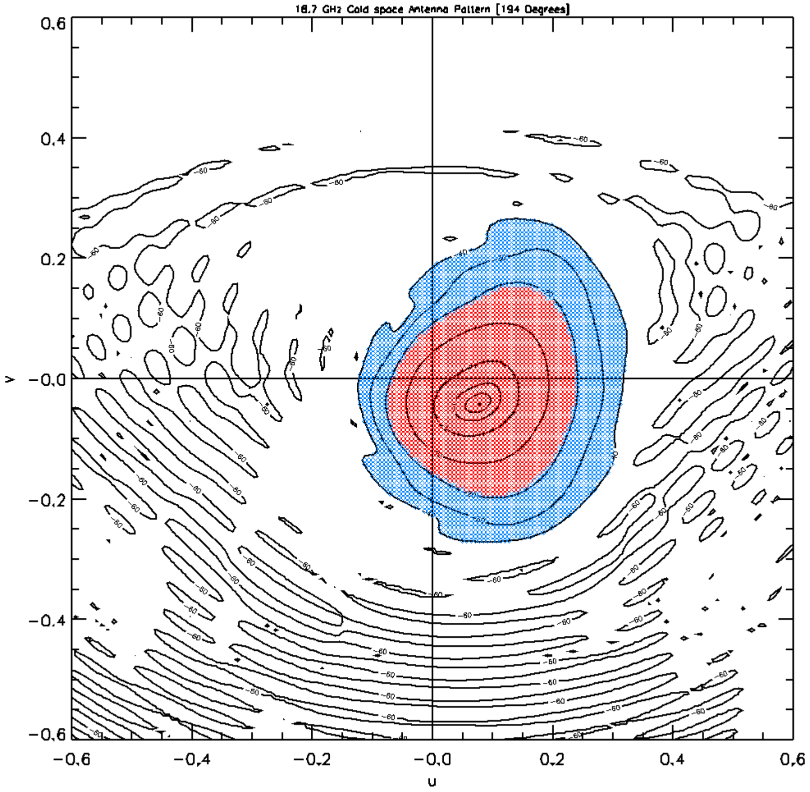
MWI cold space view: 18.7 GHz example

Beginning of cold space view



End of cold space view



View in SVR reference frame

In a conically-scanning geometry a rotating antenna points to a fixed Space View Reflector

Main Issues to compute G(α,δ) following Mo & Kigawa 2007:

- **Beam: not a Gaussian shape!**
- **Beam rotating and translating at each cold sample/channel from beginning to the end of cold space view**
- **Definition of azimuth and elevation angles is not straightforward**

Moon intrusion correction

- These issues indicate that the method needs to be tailored for MWI and ICI.

- G cannot be simply parametrized. The computation of G(α,δ) needs to be performed in one precise location, corresponding to the position of the Moon.

- The idea is to directly use the antenna pattern function, provided to the processing on a regular grid in u-/v-coordinates in the SVR frame.

- G is evaluated by finding the closest point in the regular grid corresponding to the position of the Moon, given by $\widehat{r_M}$, for each cold sample/channel.

Moon correction algorithm outline

Offline calculations:

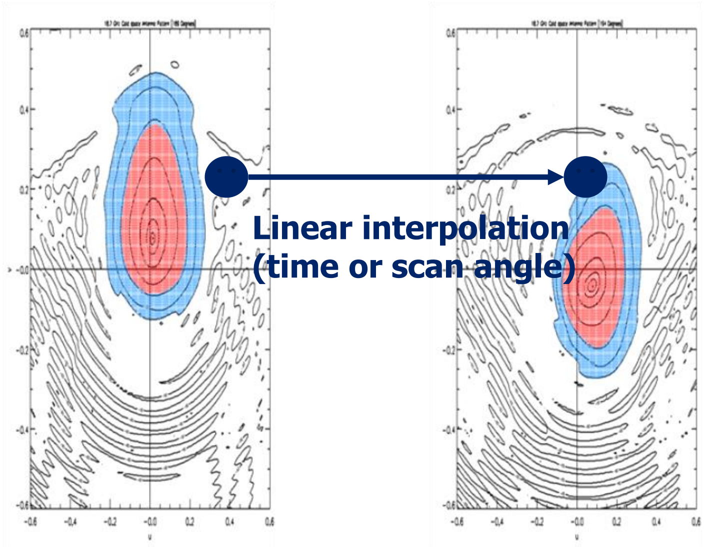
1. Perform the linear interpolation of the antenna pattern (measured only at three angular positions – start, middle and end of the cold window) for each cold sample/channel.
2. Evaluate the unit vector pointing in the boresight direction of the SVR ($\hat{r_B}$) for each cold sample/channel

Processing steps:

1. Compute Moon position in SVR reference frame (EOCFI).
2. Moon gross check (angle threshold check)

If the moon correction is activated according to a processing flag:

3. Find the value of the antenna pattern function G in the regular grid closest to the moon position in the SVR frame.
4. Compute correction, following Mo and Kigawa, 2007



Advantages: This implementation of Mo and Kigawa, 2007 simplifies processing

- no computation needed of azimuth and elevation angles;
- no use of parametrized antenna pattern;
- Little impact to store antenna pattern data in a static auxiliary file.

Summary

- **ICI provides an unprecedented set of microwave passive measurements from 183.3 GHz up to 664 GHz.**
- **MWI (on the same platform with ICI) will continue and enhance important measurements of cloud and precipitation. Synergy among missions.**

- **The Moon correction algorithm applied in the MWI-ICI L1B processing is the one proposed by Mo and Kigawa, 2007, tailored for a conically-scanning radiometer, like MWI and ICI.**
- **The use of actual antenna pattern in the SVR reference frame, interpolated at the Moon position, is proposed.**
- **The most computationally-demanding operations are performed off-line, leading to a simplified algorithm.**