SMOS PAYLOAD PRE-LAUNCH PERFORMANCE

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1. ABSTRACT

The launch of SMOS has been recently confirmed for 2 November 2009. This paper includes the pre-launch performance of SMOS compared against the mission requirements at brightness temperature level (Level-1).

2. INTRODUCTION

SMOS is ESA's second Earth Explorer mission with the objective of producing global maps of Soil Moisture and Ocean Salinity over the Earth. It will fly a single payload, MIRAS, the first-ever spaceborne L-band Microwave Imaging Radiometer with Aperture Synthesis in two dimensions. The performance requirements of MIRAS are demanding in terms of spatial resolution, accuracy, stability and precision, all critical to fulfil its scientific objectives.

During the ground test campaigns both at payload and satellite levels the performance of the instrument was checked against the original system requirements. The verification of the requirements, written in terms of brightness temperatures (Level-1 data), included some image processing of the raw correlations (Level-0 data) acquired inside an empty anechoic chamber. All requirements are satisfied with some margin.

3. SMOS OBSERVATIONS: SOME FEATURES

SMOS is the first microwave radiometer that will be flown into space featuring an ultra-wide field of view of about 65° about boresight, this posing several challenges in the image processing level as well as in the retrieval of geophysical parameters. At imaging level, the interferometric processing has to recover the brightness temperature of the target from the so-called visibility function, which is the raw data set acquired by MIRAS. Loosely speaking, the visibility function provides the spatial frequencies of the image, and a transformation is necessary to obtain the angular distribution of brightness temperature, provided as a collection of observations over a range of incidence angles for every pixel inside the wide field of view. In the retrieval process, soil moisture and ocean salinity have to be extracted from such brightness temperatures records, taking advantage of the multi-incidence capability to disentangle the various contributions, as those from canopy over land or surface roughness over the sea.

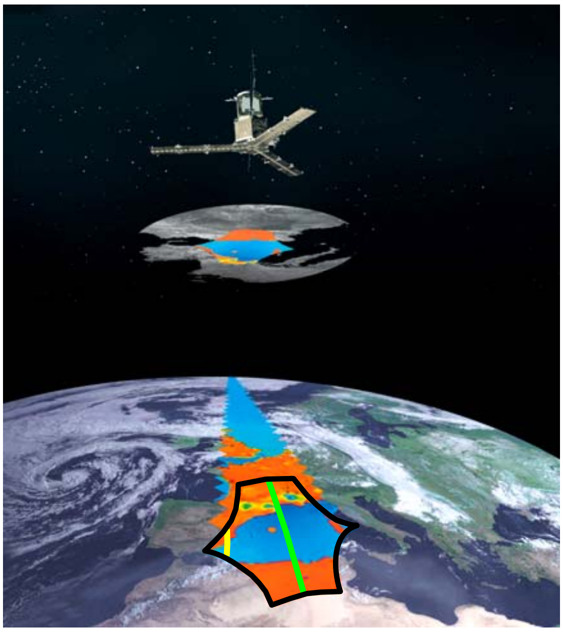

Figure 1. SMOS Field of View Charateristics

SMOS takes one snapshot every 1.2 s, or epoch, in a different polarisation state. In dual pol mode horizontal and vertical snapshots are alternately acquired. In full pol mode one mixed polarisation epoch is inserted in between those of the dual pol mode. The field of view is limited not only by the intrinsic receiving pattern of the antennas but also by the spatial sampling, which is determined by the separation between antenna elements, or spacing. The so called extended alias-free field of view is of about 900 x 900 km^2 (black line in Fig.1),

System Requirement Document	System Parameter	Specified Value (0° = boresight; 32° = edge of swath)	Measured Value (from Image Validation Test and RACT test)
R-4.5.1-008	Systematic Error	1.5 K rms (0°) 2.5 K rms (32°)	0.9 K rms in alias-free FoV
R-4.5.2-002-a,b	Level-1 SM Radiometric Sensitivity (1.2 s - 220 K)	3.5 K rms (0°) 5.8 K rms (32°)	2.23 K rms 3.95 K rms
R-4.5.3-002-a,b	Level-1 OS Radiometric Sensitivity (1.2 s - 150 K)	2.5 K rms (0°) 4.1 K rms (32°)	1.88 K rms 3.32 K rms
R-5.3.2-012	Stability (1.2 s)	4.1 K rms (< 32°) during 10 days inside EMC chamber	4.03 K rms
R-5.3.2-013	Stability (long integration)	0.03 K	< 0.02 K

Table 1. SMOS Level-1 Key Compliance Matrix

meaning that a pixel is seeing in multiple snapshots at a different incidence angle during one overpass. As many as 60 snapshots per polarisation can be acquired for pixels near the satellite ground track (green line in Fig.1), this number decreasing with the across track separation down to just a few (yellow line in Fig.1).

The antenna gain is maximum in the pixel of the field of view which is at boresight and decreases by up to 64% at the edge of the swath. This decrease in antenna gain in proportion to the angular separation from boresight, together with the lesser number of available views, translates into a across track distance dependent performance. Accuracy and precision of SMOS are best near the satellite track and gently degrade towards the edges of the swath. For this reason SMOS requirements are given at both boresight and edge of swath.

4. SMOS CALIBRATION

SMOS is based on the Corbella equation, which is a generalisation of the Van Cittert-Zernike theorem employed in radio-astronomy for any array of antennas, and in particular for an instrument as MIRAS consisting of small antennas clustered together at very short spacings (below one wavelength). This equation reveals a practical way to calibrate, in flight, such a complex interferometer, simply by comparing the measurements of a uniform target to the Earth scenes. The cosmic background microwave radiation of the universe provides, at L-band, a suitable natural stable and uniform target that can be used as reference.

Such a differential operation allows to remove most of instrumental errors, including those ones coming from the limited knowledge of the antenna radiation patterns, the most difficult to handle in most radiometer applications. For the purpose of acquiring the so called Flat Target Response of the instrument, SMOS is flipped over once a month and pointed towards the region around the poles of our Milky Way galaxy. The Earth scene measurements are then Flat Target Transformed and instrumental errors calibrated out in the process.

In addition, internal hardware errors are first accounted for by the on-board calibration system, using one entire long calibration orbit twice a month, and short periodic noise injections to track any temperature related local oscillator fluctuations.

5. SMOS PAYLOAD TEST CAMPAIGNS

The performance of SMOS was assessed on ground, at payload and satellite level, in three main test programs: (a) payload tests over temperature in space simulated conditions using ESTEC's Large Space Simulator (LSS) facility, during winter 2007; (b) payload image validation tests, at room conditions, in ESTEC's Maxwell Electro-Magnetic Compatibility test anechoic chamber, in spring 2007; and (c) electromagnetic compatibility tests at satellite level in TAS' Compact Antenna Test Range facility, during spring 2008.

6. MIRAS LEVEL-1 KEY COMPLIANCE MATRIX

The main requirements on MIRAS are included in Table 1. The systematic error is the accuracy of the measurements assuming infinite integration time. By accuracy it is understood the difference between the measured value and the true value of the brightness temperature. The accuracy was evaluated with MIRAS placed inside the Maxwell EMC anechoic chamber, which behaves as a blackbody. The brightness temperature measurements of MIRAS were compared directly against the physical temperature readings provided by three temperature sensors available in the ceiling of the chamber. As it has been explained, MIRAS absolute calibration relies on cold sky observations, but these are not possible from ground. For this reason, factory characterisation data were used in the calibration of the chamber images. For the worst polarisation, the spatial ripple of the deviations from the physical temperature was at a level of 0.9 K rms within the alias-free field of view, fulfilling the requirement (<1.5 K rms).

The sensitivity of the MIRAS was also assessed with the instrument inside the Maxwell EMC chamber. Several hours of data were recorded and the temporal standard deviation of the 1.2 s snapshot images was computed for each pixel in the alias-free field of view. This set the sensitivity of the instrument when observing a blackbody at a physical temperature of 293.5 K. Using a worst case receiver noise temperature of 220 K, this sensitivity was scaled down for the two reference target temperatures appearing in the requirements of Table 1, namely, 220 K for land and 150 K for ocean. The resulting sensitivities at boresight were of 2.23 K for land and 1.88 K for ocean, both inside the requirements of 3.5 and 2.5 K respectively. With the typical degradation factor of 64%, the requirements were seen to be fulfilled also at the edge of the swath.

The stability requirement at 1.2 s is the accuracy evaluated using only 1 single epoch, the worst one in a period of several days inside the Maxwell chamber and in the worst polarisation. Over 6 days, the worst case snapshot error was found to be of 4.03 K at the edge of the swath, without any drift been noticeable. Therefore this figure was taken as the verification of the 10 day single epoch stability requirement of 4.1 K.

The last stability requirement, defined over a long integration time, is difficult to assess because the EMC chamber itself, which is our only reference, presents tiny fluctuations in its physical temperature over a time within a span of some hours. For this reason, the long term stability was evaluated by cross-comparing the brightness temperatures measured by the three identical Noise Injection Radiometers of MIRAS, over a period of several days. This way the tiny fluctuations of the physical temperature of the room are cancelled out and only instrumental drifts are measured. All 15 possible pairs of NIR units were formed and compared to each other. The worst pair exhibited deviations smaller than 20 mK rms after integrating the raw brightness temperatures using a 10 minute sliding window, to be compared against a requirement of 30 mK.

7. CONCLUSIONS

As seen from Table 1, all key MIRAS requirements are satisfied with some margin, at the level of brightness temperature, or Level-1. This level of performance will be re-checked in orbit, during the commissioning phase.

At the level of geophysical parameters, or Level-2, the performance depends on factors external to the instrument which can only be properly evaluated with in-flight data.