OVERALL SYSTEM PERFORMANCE SYNTHESIS REPORT

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REFERENCES

Applicable documents

AD1.	System Requirement Document	4.0	SO-RS-ESA-SYS-0555
AD2.	SMOS system performances model and error budget	3.2	SO-TN-UPC-PLM-02
AD3.	Phase A2 SMOS satellite system budgets	1.0	SMOS-SO-NT-203-CNES
AD4.	Thermo Mechanical Analysis	2.0	SO-RP-CASA-PLM-0023

References

Boutin J., Waldteufel Ph., Martin N., Caudal G., and E. Dinnat, Surface salinity retrieved from SMOS measurements over global ocean: Imprecisions due to sea surface roughness and temperature uncertainties, *J. Atm. and Ocena. Tech.*, In press, 2004.

Camps A.J., Corbella I., Torres F., Bara J., and J. Capdevilla, RF Interference analysis in aperture synthesis interferometric radiometers : Application to L-Band MIRAS instrument, *IEEE Trans. Geos. And Remote Sens*., **38**, 2, 942-950, 2000.

Pellarin T., Calvet J.-C., and J.-P. Wigneron, Surface soil moisture retrieval from L-Band radiometry: A global regression study, , *IEEE Trans. Geos. And Remote Sens*., **41**, 9, 2037-2051, 2003.

ACRONYMS

AF-FOV	Alias Free Field Of View
CAS	On board CAlibration System
CERFACS	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique
CESBIO	Centre d'Etudes Spatiales de la BIOsphère
CNES	Centre national d'Etudes Spatiales
ECMWF	European Centre for Medium-range Weather Forecasting
ESA	European Space Agency
ESL	Expert Support Laboratory
FOV	Field Of View
GODAE	Global Ocean Data Assimilation Experiment
LICEF	Light Cost Effective Front-end
LST	Land Surface Temperature
NIR	Noise Injection Radiometer
PSU	Practical Salinity Unit
OS	Ocean Salinity
SMOS	Soil Moisture and Ocean Salinity Mission
SRD	System Requirement Document
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
TB	Brightness temperature
TBC	To Be Confirmed
TEC	Total Electronic Content
UPC	Universitat Politecnica de Catalunya
WS	Wind Speed

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1. INTRODUCTION

This document presents an overall synthesis of the SMOS system performances evaluation, at the present stage of development.

The basic principle of this error budget is to evaluate at each processing level what can be the expected noise level, and to assess how they add up through the whole processing chain. It is a compilation of various studies and error budget done at this point.

Next section, based on the work done at UPC, will summarize the error budget at levels 1b and c, including complementary error sources, such as sun and residuals from corrections based on auxiliary data sets.

Section 4 will present preliminary analysis of error propagation through level 2 processing, and its sensitivity to the various auxiliary data sets that are needed for that processing, for ocean salinity and soil moisture.

A basic estimate of the expected accuracy of level 3 will finally be given in section 5.

2. SYSTEM REQUIREMENTS SUMMARY

The system requirements addressed in this document concern the level 1 and 2 mission products. They mainly focus on:

Localization

Preliminary

The near real time localization accuracy of brightness temperature products geographical grid must be better than 1000m (R-4.2.4-001)

Final

After ground processing of orbit restitution elements and attitude determination, the final localization accuracy of brightness temperature products geographical grid must be better than 400m (R-4.2.4-006)

Level 1b

General

Systematic radiometric error on retrieved brightness temperature maps shall be lower than 1.5K RMS at boresight and lower than 2.5K within 32° from boresight, after calibration (R-4.5.1-008)

Soil moisture

Radiometric sensitivity on retrieved brightness temperature maps shall be better than 3.5K RMS at boresight and lower than 5.8K within 32° from boresight (R-4.5.2-002)

Ocean salinity

Radiometric sensitivity on retrieved brightness temperature maps shall be better than 2.5K RMS at boresight and lower than 4.1K within 32° from boresight (R-4.5.3-002)

Level 2

Soil moisture

Accuracy of the soil moisture data products outside mountainous, urban and partially frozen or snow-covered areas shall be better than 4% of volumetric soil moisture when the biomass is less than 4 kg/m2, after corrections using the auxiliary data (R-4.6.1-003)

Ocean salinity

Accuracy of the ocean salinity data products with a 50 km spatial resolution shall be better than 1.2 PSU (R-4.6.2-004)

3. LEVEL 1

3.1 RADIOMETRIC INSTRUMENT PERFORMANCES

Extensive work has been conducted at UPC to provide a complete instrument performance assessment (AD2). It is mainly based on SEPS simulations and verified by theoretical considerations. It is used here as a baseline for radiometric accuracy assessment at level 1.

The final sensitivity at bore sight estimated can be summarized as follows:

	Dual-polarization
Soil moisture	2.87K
Ocean Salinity	2.42K

The representative case for soil moisture is assessed with an antenna temperature of 250K and the ocean salinity case with a temperature of 150K.

The overall radiometric accuracy is estimated at **3.82K** for SM and **2.62K** for OS.

Residual biases are estimated as follows (in antenna frame):

	X polarization	Y polarization
Soil moisture	0.72K	2.85K
Ocean Salinity	0.49K	1.93K

Still, these biases being mainly related to NIR receiver temperature, on-ground characterization and in-flight monitoring is expected to account accurately for them, they are not included in the following error budget, but they raise the open issue of on-ground calibration for thermal dependence and aging behaviour of this dependence. One important contribution to these biases appears to be the fact that the brightness temperature measured by the NIR and used for the reconstruction of the TB maps inside the AF-FOV is actually representative of the whole FOV. Important biases can therefore be expected if the TB outside AF-FOV is significantly different than the TB inside AF-FOV. Since this bias is highly dependent on the scene, it will be uneasy to characterize. Only effort at the reconstruction stage can minimize this contribution.

On the other hand, these figures do not account for the following contributors:

External RFI:

Provided the emitters comply with ITU recommendations, the RFI level is not expected to exceed **0.02K**. Airborne experiments show strong evidence of non complying emitters. Based on these campaign results, the levels of expected interference at satellite level has to investigated.

Sun

Has to be analysed in at least two specific ways

Impact of direct sun in the antenna.

This impact can be evaluated by computing the brightness temperature as seen by the instrument, that can be partially corrected. The residual impact is the accuracy to which we can evaluate this temperature through the antenna pattern, accounting for our incorrect knowledge of antennas pointing. In a very simple way, we can assume the following: in the range 60-80° from nadir, where the sun is observable, the sensitivity of the gain pattern is about 3K/K/°, that is with the pointing knowledge described below an overall sensitivity of about 0.24K/K. In 2007, this would amount to about 1.2K residual. This is to be compared to what has estimated by UPC after application of a sun cancellation algorithm with SEPS, leading to an additional radiometric noise of **2.42K**.

It has been made clear through various simulations that this direct contribution has to be removed from the visibilities before proceeding to image reconstruction to avoid larger contamination through Gibbs effect.

Impact of reflected sun glint on the surface.

This impact is far more complicated to assess because of the influence of the sea surface state on the way the instrument sees the sun. The need is to address this problem on L2-OS, and at a lesser extent on L2-SM.

Galactic noise:

Apart from the reflection on the surface than can be as low as , the impact of the galactic noise that is aliased on the earth view, and of the residual of its correction, has to be analysed.

Calibration is addressed in a separate report, but basic performances can be inserted here for completeness. The basic principle of calibration is to assess absolute offset based on deep sky views, and slope by means of internal four views noise sources. It is assumed in this report that calibration residuals are included in the preceding error budget.

From all these figures, we sum up an overall radiometric accuracy at level 1 of:

	Dual-polarization
Soil moisture	4.54K
Ocean Salinity	3.59K

This budget is obviously highly dominated by the sun contribution. Reducing this contribution must be thoroughly investigated, because it will actually make the compliance of the mission.

3.2 GEOMETRY

The pointing budget can be estimated, based on end of phase A assessed performances for SMOS satellite (AD3) and preliminary thermo-elastic and mechanic studies (AD4). The final localization budget should account for the following contributors, presented here with their contributions after bias calibration and ground processing:

	ΔX(m)	ΔY(m)	ΔZ(m)	ΔαX(°)	ΔαY(°)	ΔαZ(°)
Orbit restitution	30	30	30			
Timing	0.1	0	0	0	0	0
Satellite attitude				0.008	0.013	0.013
Arms and Hub thermo elastic deformation				0.06	0.06	0.06
Instrument alignment				0.02	0.02	0.02
Star tracker alignment				*0.053*	*0.053*	*0.053*

The error sources are expressed in the satellite reference frame and around each axis of this frame.

The basic assumption is to estimate the overall localization as the barycentre of the elementary boresights. This results in assuming that the final localization is the average of all the elementary pointings and that the dispersion around this mean introduces a radiometric error that is accounted for in the radiometric error budget made by UPC.

It has to be pointed out that all these contributors have impacts only on the overall localization of the image, that is they do not introduce any distorsion within the image. This is due to the way the images are reconstructed from visibility measurements.

The preliminary localization does not benefit of final orbit restitution and filtered attitude knowledge. It only makes use of real time GPS positioning, assuming selective availability remains switched off, estimated at 30m and pointing knowledge.

Timing, benefiting from GPS clock accuracy, does not impact significantly the budget, and the impact of positioning uncertainties on local nadir and yaw steering laws also appear negligible.

The alignment on the LICEFs sitting on the arms and hub need a specific way to account for. In this report, we chose to average the deformation over all the antennas, assuming the overall localization is a linear combination of the bore sights of all elementary antennas. The uncertainties given in the above table are thus reduced to 0.026 on 3 axis. This preliminary approach is unfortunately highly optimistic, since the displacements of the antennas are not independent. This contribution has been separated in two separate terms for static realisation of the antenna plane, at the deployment of the arms and the dynamic behaviour of the arms and hub through thermo elastic deformations, this contribution being again separable in harmonic and random terms. The former being highly dominant, random terms amount to about 2 arcsec.

The poor alignment performance of the star tracker stated in the above table has not been considered for this budget, given that its knowledge after realisation must be far better than this figure. It can be expected from previous missions that this contributor can be taken to negligible level.

From these inputs, the overall localization budget can be computed at boresight to show errors of **1646m**. Obviously this performances are way out of requirements. Despite this, we can note that the multipolarization relative final localization is expected to be somewhat better (**226 m**) and multi angular relative final localization as well (**398 m**). This is due to the short term stability of both the satellite and arms.

Further refinements of the geolocalization can be envisioned by making use of the reconstructed images, but from a geometrical point of view it is very unlikely that, given the final resolution, theses processing can reach an accuracy better than 5% of that resolution.

3.3 RECONSTRUCTION

When concerned with radiometric accuracy, one should only consider the error propagation and amplification of a given reconstruction algorithm.

Many of the contributors that can be classified in this part are accounted for in the SMOS performance model provided by UPC, but closely linked to a specific reconstruction algorithm. If we want to keep this overall performance budget more general, we need to express reconstruction errors in less specific way.

An example is provided by CERFACS, who states an error amplification of 0.5 and a specific noise of 0.94K. The resulting noise is estimated by the sum of specific and amplified input noise.

In the context of this preliminary report, however, the reconstruction added noise is assumed to be accounted for in the SEPS based error budget.

Minimizing the amplification of the noise can be achieved by selecting carefully the LICEFs that will be installed on the hub, so that the low spatial frequencies will be less noisy.

3.4 AUXILIARY DATA

At level 1, the following auxiliary data are required:

	Source	accuracy	Resolution	Timely availability	sensitivity	Geo location
sky map	Reich et al.	0.1K				NA
sun Tb	NGDC	10-22W/m²	1sec	1 day		
TEC	ESOC	2°	0.5°		0.1K/°	
Land sea mask	SRTM		1km/once			80m

We should be aware at this point that the coregistratrion of the various auxiliary data sets between them and with SMOS brightness temperature maps is not known.

4. LEVEL 2

4.1 INVERSION

4.1.1 SOIL MOISTURE

Based on inversion studies, we can estimate the error propagation as it has been done for reconstruction: by separating model specific errors and noise amplification.

A global inversion study (Pellarin *et al.*, 2003), based on global model regression show that the error can be separated in a specific noise of about 0.0197m3/m3 and a noise amplification term of 0.0055m3/m3/K. This results show both the effort to be done on the model, and the robustness of the regression with respect to noise in the input data.

A global estimate of the overall accuracy expected for soil moisture from the above assumptions is **4.95%vol.**

This figure, out of specification, is again highly dependent on efficient sun correction. At this level, just as at level 1, the sun contribution can make the mission compliant or not.

4.1.2 OCEAN SALINITY

Global studies based on simulated data sets show that the sensitivity of L2-OS products can be expressed in the same way as for SM, with following figures: specific noise around 0.04 and noise amplification of 0.5 psu/K. This error model is dominated by the influence of the knowledge of the surface of the ocean, as described in Boutin *et al*., 2004. The influence of sea surface temperature being secondary, and sun glint effect yet to analyse.

From what precedes, we can estimate the overall salinity retrieval accuracy to **1.93psu.**

The same remark as for soil moisture applies here, with a secondary and poorly analysed contribution due to sun glint.

4.2 AUXILIARY DATA

At level 2, the following auxiliary data are required:

Common	source	accuracy	resolution	Timely availability	sensitivity
Rain					0.0005K/mm/h
Land/sea, water bodies mask					
Pressure	ECMWF	10mbar	0.5°/6hours		0.0024K/mb

Air temperature	ECMWF	20K	0.5°/6hours		0.001K/K
Water vapour content	ECMWF		0.5°/6hours		0.002K/g/m2
land cover	ECOCLIMAP, MODIS				
snow cover	MODIS				
Soil Moisture					
Biomass, vegetation type, optical depth, VWC	ECOCLIMAP, MODIS	1.15 LAI rms	1km/10days, 1km/8days		1.6K
topography	GTOPO30		1km		
soil texture	ECOCLIMAP		1km/10days		
land surface temperature	ECMWF	2K	50km/6hours, 1km		0.85K/K
Land cover	ECOCLIMAP, MODIS		1km/10days, 1km/3months		
snow cover	ECMWF		50km/6hours		
frozen soils	ECMWF		50km/6hours		
Ocean Salinity					
sea state: roughness, foam	QuickScat	2m/s	50km/1day		0.15K/m/s
sea surface temperature	AMSR				

Once again, it must be stressed that the coregistration of all these data sets together, as well as with SMOS data is not known.

4.3 RESAMPLING

The baseline of resampling process to the final geographic grid is achieved in two steps. First the brightness temperature maps are reconstructed in the antenna frame and then this frame is projected onto the selected geographical grid. Since at least one of these grid is equally spaced, the selected interpolation algorithm has to be spatially compact and thus introduces an additional noise.

Therefore we have to account for an additional error source due to the interpolation function that will be used at this step.

Again, this error contribution is highly dependent on choices yet to be done, like the final geographic grid, intermediate grid in the antenna frame, and interpolation function.

As an baseline, we can consider the error introduced by nearest neighbour, bilinear or bicubic interpolation which are 1.11%, 0.59% and 0.25%.

Obviously, this error contribution can be avoided by operating the reconstruction directly in the final geographic grid, if the selected reconstruction process allows it.

5. LEVEL 3 IMPACTS

There is no requirements at this level that can be addressed in this document.

G-4.7.2-005 The accuracy of the ocean salinity maps outside coastal areas, after averaging over 200 km x 200 km x 10 days space-time domain, shall be better than 0.1 PSU, after corrections by using vicarious calibration, namely by periodical imaging of one or more well-known reference sources.

G-4.7.2-006 The goal for the radiometric accuracy to retrieve ocean salinity through (multi-angle) data processing of observations acquired over a period of 10 days (TBC) is 0.03 K RMS.

G-4.7.2-007 In order to support vicarious calibration, the system shall ensure a stability of the systematic component of the radiometric error (including: bias, drift, periodic and other errors such as thermo-elastic effects) better than 0.02 K/day.

For soil moisture, the situation is not yet clear as how the independent measurements issued from level 2 will be used to derive level 3 products, if we assume an inversion process that allows to retrieve biomass and soil moisture for the narrow swath and then use the biomass on all acquisitions up to the next access in the narrow swath, we can evaluate the impact of biomass stability through time on the retrieved soil moisture that make use of this retrieval.

For ocean salinity, preliminary studies show that averaging does not reduce the noise as if all samples were independent. Presumably some correlation still exist in the data sets and error sources so that the resulting errors do not combine as gaussian independent error sources. Still, at this stage we can assume that the error is reduced according to a gaussian law. Based on this, we need a bit less than 100 views to any given zone to comply with level 3 salinity goal.

6. OPEN ISSUES

The following is a list of the issues, summarized from what precedes, that should be addressed in the final development phase:

Calibration:

Thermal dependence	in-depth attention must be given to the thermal variations of the sensor response. The proposed 3 temperatures characterization needs to be assessed as sufficient or not.
Ageing	non linearity, sensor response with time need to be assessed. Deformation of antenna pattern also needs to be assessed.
Out of AF-FOV bias	The reconstruction process must account for TBs measured on the whole NIR FOV that are applied only to AF-FOV.

Sun:

Direct impact	Already identified as a major contributor to error budget
Sun glint over ocean	
Specular and sun glint over land	

Galactic noise:

Reflexion over ocean	Coupling with sea surface state makes this effect uneasy to correct efficiently.
Aliased deep sky	

Auxiliary data:

The presented tables must be completed for all missing information.