# NOTE

# ON

# SMOS CALIBRATION AND VALIDATION

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## ACRONYMS

| | |
|---|---|
| ASC | Ascending (pass) |
| ATBD | Algorithm Theoretical Basis Document |
| CAS | On board CAlibration System |
| CCSDS | Consultative Committee For Space Data Systems |
| CEOS | Committee on Earth Observation Satellites |
| CESBIO | Centre d'Etudes Spatiales de la BIOsphère |
| CFC | CNES Funded Centre |
| CNES | Centre national d'Etudes Spatiales |
| DESC | Descending (pass) |
| ECMWF | European Centre for Medium-range Weather Forecasting |
| ENSO | El Nino Southern Oscillation |
| ESA | European Space Agency |
| ESL | Expert support Laboratory |
| GODAE | Global Ocean Data Assimilation Experiment |
| LST | Land Surface Temperature |
| NAO | North Atlantic Oscillation |
| NIR | Noise Injection Radiometer |
| PDPC | Payload Data Processing Centre |
| PSU | Practical Salinity Unit |
| OS | Ocean Salinity |
| SA | Service d'Aéronomie |
| SAG | Science advisory Group |
| SMOS | Soil Moisture and Ocean Salinity Mission |
| SRD | System Requirement Document |
| SSS | Sea Surface Salinity |
| SST | Sea Surface Temperature |
| SVAT | Soil Vegetation Atmosphere Transfer |
| TB | Brightness temperature |
| TBC | To Be Confirmed |
| TBD | To Be Determined |
| TEC | Total Electronic Content |
| TM | Telemetry |
| TOA | Top Of Atmosphere |
| TX, TY | Polarised brightness temperatures at antenna level and in antenna ref. frame |
| WS | Wind Speed |

# TABLE OF CONTENTS

# 1. CONTEXT AND PURPOSE

As for any space borne mission, SMOS data will have to be carefully calibrated to ensure maximum scientific return. As SMOS is an instrument of very specific characteristics (2D interferometer), the calibration approach is to be addressed in detail, and it seems necessary to adopt a common language so as to avoid misunderstandings.

The scope of this document is thus two folds: try to clarify definitions and establish a first draft of what could be the calibration procedure as well as starting to establish specs for calibration and possibly validation.

**It is intended to be a living and a working document**. This document is thus a first attempt, probably plagued par errors and inaccuracies, to be modified and improved through iterations with the technical and science teams involved with SMOS. The document will have to be also confronted with the project current plans.

Ideally, a calibration analysis should begin by analysing the available calibrations (from pre-flight measurements and the on-board calibration system) and their performances, next identify the problem areas which still appear to exist, suggest then additional methods to deal with such areas, discuss their implementation, assess their likely performances.

Indeed this is the general idea of this document; sections 3 & 4 are an attempt to follow this reasoning. However the result is still far off the mark. In some cases (mentioned in the text), one of the reasons it is difficult to progress is because the situation concerning pre-launch measurements and on-board calibration is still not completely clear.

# 2. DEFINITIONS

In order to speak the same language, we propose to set definitions for the different terms used in this document and hopefully, after iterations, during the whole mission. These definitions are as much based as possible on classic definitions (including CEOS) adapted to SMOS characteristics.

## 2.1 ERROR TYPES

The errors which may affect measurements can be separated into four different categories having each their own behaviour and characteristics. The calibration's goal will be to select the adequate approach so as to correct/account for each error type.

We also believe that the error budget and related calibration should only encompass **instrument factors**. In other words we should be careful not to include any error terms linked to geophysical quantities (TEC and Faraday rotation for instance).

However, in cases where such quantities are introduced at early stages of the processing (e.g. sky radiation maps), assessing the corresponding error contributions and accounting for them is unavoidable.

### 2.1.1 BIASES

It is a residual offset error, which usually appears after launch and expresses the difference between actual values once the satellite is operational and the pre-launch calibration. Per definition it is a stable and constant value through the satellite time life. See below comments on drift

In an imaging instrument such as SMOS, one might expect that the bias varies throughout the field of view, e.g. there are many biases, unlike a classical radiometer. Actually it is even more complicated, since there are many causes for biases but they refer to interferometric channels and baselines and therefore their effects are mixed up when considering the images.

### 2.1.2 LONG TERM DRIFT ERROR

This error is usually associated with the ageing of components. It corresponds to slowly varying behaviour and is sometimes difficult to separate from geophysical trends.

The long-term drift will be accounted for after some time. One may even think that only after the end of life we will be able to get a right value. Once established for good, the whole data set will probably have to be reprocessed with correct bias and drift coefficients.

### 2.1.3 HARMONIC ERRORS

This error corresponds to cyclic changes. It may be linked to the orbital period, to seasonal fluctuations, to the solar cycle etc.

#### 2.1.4 RANDOM ERRORS

Random errors are permanently present, owing to the nature of the radiometric signal. In most case the main contributor is thermal noise, but other contributors are possible such as EMC perturbations, AOCS oscillations. It should also be stressed that one should not forget that other errors might be considered as random even though they have deterministic origins, inasmuch as it can be hoped that averaging will diminish their amplitude.

### 2.2 PRECISION, ACCURACY AND STABILITY[1]

- **Precision** usually corresponds to absolute values, hence it is established after ALL the errors have been combined.
- **Accuracy** is a parameter, associated with a measurement, which characterises the dispersion of the values that can reasonably be attributed to the measurand. Usually it includes both random and systematic errors that have not been recognised and or corrected for. Finally calibration accuracy is the positive square root of the "total variance" resulting from all component variances of the corrections calibration process
- **Stability** will be of paramount importance, especially for ocean salinity retrievals. It should be separated into two categories: short term stability (within a fraction of an orbit) and long term stability. The latter will be important if temporal averaging is performed, but the most crucial is the short-term stability, i.e., the interval between calibrations.

  Another fine point is linked to the fact that we are not necessarily interested in the "raw" stability. If some variation in the radiometer response functions on short time scale can be corrected (based upon ancillary monitoring data), then the relevant performance is the stability accounting for such corrections.

### 2.3 CALIBRATION VERSUS VALIDATION

For the sake of clarity, we first dissociate completely calibration and validation. The CEOS definitions are as follows (*In Definition of frequently used terms in microwave radiometry for remote sensing*):

> **Calibration** is the process of quantitatively defining the system response to a known, controlled signal input; **Validation** is the process of assessing, by independent means, the quality of the data products derived from the system inputs

There are two ways of using external data available in addition to data provided by the instrument: either such external data are entered in the processing of SMOS data, or they are not.

[1] The definitions below are extracted from CEOS document: *Definition of frequently used terms in microwave radiometry for remote sensing*:

- In the first case, we shall speak of calibration data. For instance sea surface salinity of a well known area may be used to infer drifts of the instrument
- In the second case, if there is a possible comparison between external data and data retrieved from SMOS measurements which are expected to be the same, those external data are used for validation of a geophysical retrieval scheme (Alternatively, external data may be used for further scientific work by combining them with SMOS data).

Therefore, although SMOS provides values of physical quantities at different levels of elaboration (e.g. brightness temperatures $T_B$, surface parameters such as soil moisture), the distinction between calibration and validation does not depend on the nature of the data (their level of elaboration), but only on the purpose to which they are used. It can only be expected that calibration is carried out continuously while validation will consist more of time limited experiments Actually calibration and validation data may have exactly the same nature: assuming we have a set of $T_B$, there is nothing to forbid us to select half of this set for calibration purpose and then use the other half for validation.

In what follows we consider some data to be used for either calibration or validation purposes. But there is no difference, until we decide how to use them.

### 2.3.1 CALIBRATION AIM AND APPROACHES

We will consider calibration as the operation by which the signal measured by the instrument is transformed into a "top of the atmosphere" (TOA) brightness temperature (or Stokes parameter) for any pixel in the useful field of view. Calibration covers thus engineering parameters. Of course an accuracy figure is attached to the calibration procedure. In general calibration allows assessing the biases, drifts and harmonics and removing them. There is thus a temporal aspect to be addressed as well.

The goal is to find the proper way to relate the output of the instrument to a physical quantity (brightness temperatures at the top of the atmosphere) without any inference from geophysical parameters. In the case of SMOS, this is not completely true, since building TOA quantities requires relying on some geophysical data; namely the map of sky radiation and possibly the total ionospheric electron content

To perform calibration, different steps must be considered and performed.

- The first step is **pre-flight calibration** (also called on ground calibration). It corresponds to the calibration of the system but at ground level (usually in dedicated facilities), if only to test the system. Such calibration is bound to be altered during launch and deployment but it gives at the minimum a “first guess” for in flight calibration. What is at stakes here is thus to characterise as much as possible all elements necessary response curves (for example as a function of ambient temperature). Obviously, in addition, correction laws allowing accounting for variations of the in-flight environment ought to be built and tested later on (during commissioning phase).
- During the flight, on-**board calibration** is performed by the instrument itself through hardware, using internal references.

- In addition, for several sensors, some on board calibration operations may require **external** well-known targets.

- Finally, in some cases a further step is required. It is very often called **"vicarious calibration"**; see [1] for an attempt of definition. Instead of using a well defined target of known **brightness temperature** (or even quantities closer to the actual measurements than brightness temperature), vicarious refers to situations where calibration is based upon either the use of statistical approaches (see for instance [2, 3]) or external measurements concerning high level products which imply to rely on **validated forward models**. This operation has to be distinguished from validation, even though it is operated on the same kind of quantities.

  The issues linked to vicarious calibration are quite general to almost any remote sensing mission. In the case of SMOS (see also [4-6], what makes this issue particularly important is that accuracy requirements on ocean measurements are so severe that there is probably no hope of meeting them otherwise than referring to actual salinity measurements. .

A number of notes on the topic have already been written for the project. Interested readers should refer to them. [7-10]

### 2.3.2 VALIDATION

Validation corresponds to a procedure established to verify the accuracy of the retrieved **geophysical parameters** with respect to their actual values. Validation is consequently subsequent to calibration and requires a different approach even thought the two operations ("Cal-Val") are linked.

Validation is to be applied to geophysical products at the surface, i.e., OS or SM. It is thus performed on at least level 2 products. During the validation process, the retrievals are compared to data collected at the ground level in terms of geophysical products (i.e., SM or OS).

The main validation difficulty – in the SMOS case – will be to be able to associate a ground measurement (sampling actually) to the value collected over a SMOS pixel by the instrument.

### 2.3.3 SYNTHESIS

External data can be used for both calibration and validation. However, whereas for external calibration it is foreseen to use both radiometric and vicarious data (i.e. geophysical data to which direct radiative models must first be applied), validation data only consist of geophysical quantities, to be compared with results of SMOS retrievals.

**Calibration** operations should allow to deal with every bias originating in instrumental errors, be it the SMOS interferometer or the NIR radiometers (see below), including systematic orbit variations as well as long term trends.

**Calibration** might be **"on board", external** (i.e. using targets of known brightness temperature) or **vicarious**, (i.e., comparing geophysical quantities to measurements through models or using statistical approach without even a specific target).

**Validation** should help to tune the retrieval algorithms and correct retrieval biases due to either functional errors in forward models or imperfect auxiliary data files. The management of SMOS data affected by spurious geophysical signals belongs to validation rather than calibration.

This is a basic, logical approach. In practice, the validation and calibration operations should be considered **together** and co-ordinated, as, when using external calibration data, it may turn out that errors due to the instrument and to the retrieval are difficult to separate and they will be corrected as a bulk. However one should strive at keeping a clear distinction as much as possible.

## 2.4 MATCHING CALIBRATION METHODS TO ERROR TYPES

- **Bias**: In principle the biases can be assessed at the end of the commissioning phase after an intensive calibration campaign and using external and vicarious calibration. However, as it is often difficult to assess all the other non-random errors, it can be expected that the biases will be assessed with more accuracy after some time (necessary to assess all the trends and cycles).

  Finding the right external/vicarious calibration target will be the issue for SMOS. Also, care will have to be taken to ensure that no bias is introduced by the building of external/vicarious data!

- **Drifts**: To assess drift the most obvious will be to use internal reference sources (noise diodes) but of course those will also age. Another approach will be to monitor target sources but they also may drift. It will thus be necessary to assess both the drifts of the instrument as well as the drifts of the calibration system and to identify stable and known targets. It is also possible to consider drifts as the (slow) evolution of bias, and thus correcting bias should remove drifts.

- **Harmonic components**: The quantification of these effects will have to be done even though it will not be trivial. Cycle lengths are known and thus orbital, seasonal or solar cycles will be identifiable. The major issue then is whether the effect of harmonic errors can be corrected in a deterministic way from ancillary data.

- **Random errors** are unavoidable and not to be removed by calibration. However they must be considered, since their presence makes accurate calibration more difficult. In principle, they can be artificially reduced by averaging over large samples (i.e. long enough periods), accounting for possible correlations between the quantities to be averaged.

# 3. NEED FOR EXTERNAL CALIBRATION

## 3.1 SMOS MEASUREMENTS

### 3.1.1 SOURCES OF BIASES IN THE SMOS PAYLOAD

The SMOS interferometric sensor consists of about 72 dual polarisation radiometers [11], with antennas which are as identical as possible (and well characterised individually), and set along identical orientations for each polarisation.

Considering the SMOS system, two categories of biases needing calibration can be identified.

1. The first one is related to the "absolute" value of the brightness temperature measured. The measuring concept relies on the use of several **noise injection radiometers** (NIR). For this topic, classical methods can in principle be used (calibration of the radiometer).
2. The second one corresponds to the relative errors in the maps of brightness temperatures reconstructed from interferometric cross correlation products and normalised using the NIR data. They are related to phase ands amplitude errors, correlator's offsets, pointing errors, etc. They are specific to the interferometry concept.

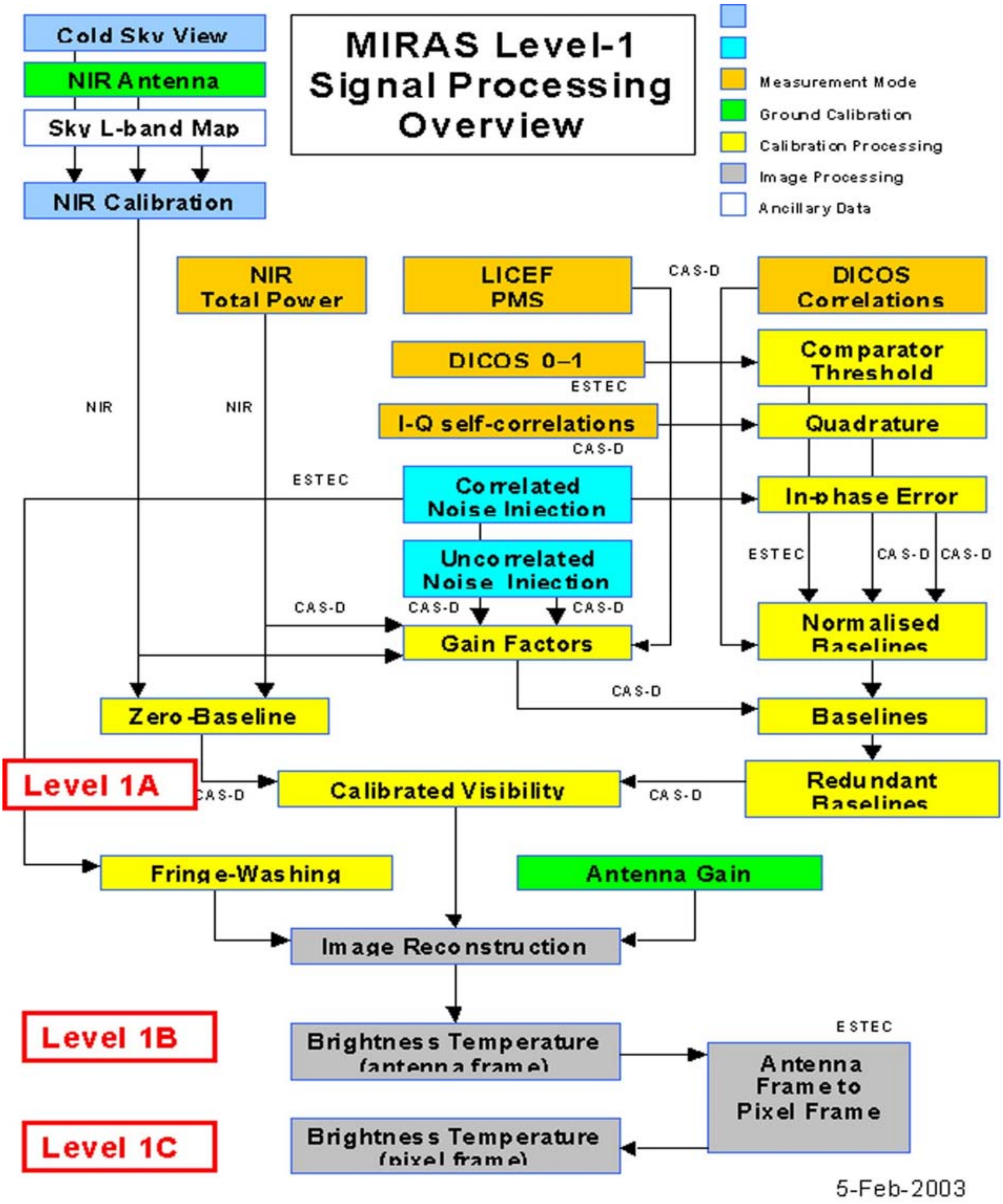
Some errors may also be due to the reconstruction process itself, but these last errors are likely to be scene dependent. This is still an issue for research. Our main concern at this stage ought to be to avoid the possible impact of the scene structure on external calibration operations, by selecting scenes as homogeneous as possible.

### 3.1.2 SMOS LEVELS AND PRODUCTS

We recall here the main steps of level 1 processing, in order to define the quantities on which the issue of calibration may arise.

**Graph 1** shows the tentative flow chart, as drafted by the SMOS technical team (M. Martin Neira) at the beginning of 2003. At the same time, it gives an idea of the complexity of on-board calibration operations. One should keep in mind the following anchor points:

- Level 0 (top of chart): correlation products
- Level 1a: calibrated visibilities
- Level 1b: brightness temperatures reconstructed in the antenna frame
- Level 1c: brightness temperatures or Stokes parameters at surface level.




**Graph 1 : draft for SMOS level 1 flow chart**

## 3.2 ACCURACY REQUIREMENTS

As random errors are unavoidable, it is useful to review them briefly in order to draw conclusions about the requirements that should be set to calibration operations.

### 3.2.1 RANDOM ERRORS

Considering below only thermal type of random errors, one may consider that

- A "snapshot" measurement will suffer an uncertainty ΔA due to radiometric sensitivity, that is

  $\Delta\langle T_X \rangle \approx (N + \langle T_X \rangle ) / \text{sqrt}( \beta\ \tau)$

  Over the ocean, assuming a bandwidth β=20 MHz, for the elementary snapshot integration time τ = 1.2 s, a noise temperature N = 180 K, the scene temperature = 100K yields Δ ≈ 0.06 K
- NIR case: the Dicke operating scheme results in a larger figure: $\Delta_{NIR} \approx 0.09$ K
- Interferometric data: the **order of magnitude** of the radiometric uncertainty due to the C factor over the "denormalised" $T_B$ values A x C is close to the product of the radiometer error by the number of elementary radiometers, which is about 70. There is some reduction (by a factor of about 2.2) due to apodization over the reconstructed $T_B$ map, some increase due to the 1 bit correlation (about 1.4), some decrease due to redundancies (about 20%).

  Finally, for a snapshot over an ocean scene, the resulting uncertainty is of the order of 0.057 x 70 / 2.2 x 1.35 x 0.8 # **2 K** (near the antenna axis). On the edges of the field of view, this figure must be doubled.

<u>**Note 1**</u>: the random uncertainty on reconstructed TB due to NIR normalisation of visibilities is negligible.

<u>**Note 2:**</u> this covers only PLM thermal noise, one should also consider the different other potential types of random noise (AOCS oscillations, EMC) until they are completely characterised, eradicated or proved to be negligible.

### 3.2.2 RATIONALE FOR ACCURACY REQUIREMENTS

The accuracy requirement for SMOS is mainly driven by the salinity retrieval requirements. It is known that the sensitivity of the $T_B$ to the surface salinity is of the order of 1 K for 3 PSU. Therefore reaching the GODAE requirements calls for an accuracy on the $T_B$ of about 0.03 K.

As just indicated, the random uncertainty over a snapshot (1.2 seconds) $T_B$ measurement is of the order of **2 to 4 Kelvin**. In order to decrease this figure, it is planned to accumulate data in a "GODAE box". Selecting a 200 km x 200 km x 10 days averaging space-time domain, one obtains:

- A factor of about 30 due to the multi-angular diversity;
- A factor 2 for dual polarisation;

- A factor of 50 for space integration (5 across track for mean 40 km pixel size, 12 along track for independent 16 km long samples)
- A factor of 4.2 for time integration over several revisits (at the equator)

Overall, ≈ 12 000 independent samples are obtained, allowing to bring the initial random average uncertainty (3 K) down to about 0.027 K over the ocean, a figure compatible with GODAE requirements.

#### 3.2.3 CONCLUSION

Some improvement may be expected over warm seas (increased sensitivity to salinity) and at high latitudes (improved orbital coverage). On the other hand, correlations in auxiliary surface data may reduce the impact of averaging.

Anyway, it is seen that there is not much room in the error budget for additional contributions to thermal random errors. As a first step, it is consistent to require for systematic errors a performance comparable to the overall requirement; this is the initial objective and natural benchmark for the calibration efforts. Whenever possible, one should furthermore strive at achieving accuracies **significantly better than the overall requirement**.

### 3.3 NEEDS TO COMPLEMENT PRE-LAUNCH & ON-BOARD CALIBRATION

#### 3.3.1 NOISE INJECTION RADIOMETERS

##### *3.3.1.1 NIR CALIBRATION*

NIR scene temperature measurements are used both for on-board calibration purposes and to transform the interferometric products (in counting units) into Kelvin.

The NIR are carefully designed Dicke radiometers. As indicated above, the random error is estimated around 0.1 K and certainly better than 0.2 K (formal requirement) over the elementary 1.2 s period.

Assuming the response curve is accurately determined for linearity before launch, two calibration points are necessary.

The on-board internal calibration yields one of these points as a warm load. In order to bring the random error down to say 0.03 K, the duration of this calibration should be several tens of seconds. To get substantially below the overall requirement, the necessary duration may reach up to a couple of minutes.

This leaves open the issue of the **second (cold) calibration point**: here, the only possibility will be an external calibration target.

It has been recently proposed to implement two distinct levels for the "warm load»; this allows in principle to achieve internally the whole NIR calibration. In such a case, the need for an external "cold" source should be discussed.

### 3.3.1.2 HARMONIC EFFECTS ON NIR

As the continuous availability of NIR data is essential to the SMOS payload operation, the NIR calibrations cannot be operated very frequently. Keep in mind that one orbit takes about 100 minutes.

Then, it is expected that substantial variations of the NIR response curve will be due to **variations of the physical receiver temperatures Tp along the orbit**. This is the major error cause in the "harmonic" category spelled out above. In order to correct for this, we must rely on monitoring the physical temperature and on applying corrections.

Correction laws will be measured in the pre-launch calibration operations.

In addition, during the **commissioning phase**, it will be appropriate to run frequent NIR calibration phases throughout orbits, in order to check the consistency and constancy of these laws.

During the **nominal** flight phase, this whole orbit NIR warm load calibration should be repeated at a **TBD** frequency, possibly about once a month, in order to check the stability of correcting laws.

### 3.3.1.3 SUMMARY

The main points as far as we are concerned are as follows:

- The critical issue concerning the NIR, rather than stability over intervals between calibrations, is stability **after** the response function has been corrected for drift in environment parameters such as physical temperature (One might call this: "**compensated stability**"). Great care should therefore be brought to pre-launch derivation and post launch verification of laws for correcting the variations due to thermal variations. Until these laws are established and assessed against the accuracy of thermal sensors, **we do not have** a full error budget for the NIR contribution to overall accuracy.
- We must, with this issue in mind, define a specific (reinforced) strategy for the **commissioning** period.
- Concerning the **calibration** itself, it is not fully clear whether **internal** sources will provide the necessary couple of calibration points or whether an **external cold** source is necessary. In any of these cases, it is not clear that the NIR calibration will meet the 0.03 Kelvin criteria.
- If the "**compensated stability**" of the NIR over intervals between calibrations does not meet the requirement, this will impact unavoidably the measurement accuracy. If the NIR **calibration** does not meet the requirement, it will be necessary to resort to vicarious calibration.

There are some more loose ends:

- As there are 3 NIR on board, several issues are raised: calibrating them simultaneously or not, deciding how best to use these 3 sets of data which ought to be identical (but that is not expected to be fully the case.).
- The matter of NIR measurements and calibration for Stokes parameters 3 and 4 is not quite clear.
- Finally let us keep in mind that there is no on board calibration for the **antenna pattern** and front-end switch.

### 3.3.2 VISIBILITIES

The on-board calibration system (CAS) is designed to monitor system imperfections so as to eliminate the biases that may appear when computing visibilities from correlation products. The main sources of error due to the hardware that are dealt with in the calibration loop are:

1. the receivers' errors which can be attributed to a receiver: amplitude, in-phase, quadrature errors, noise injection network errors;
2. the receivers' errors which cannot be attributed to a receiver: phase and amplitude errors,;
3. other baseline errors: offsets in correlators.

Considering the 3rd point, the performance of the CAS system is certainly adequate to set a limit on possible internal interference effects. However, assuming these effects are eradicated, as they hopefully should be, the actual correlator offsets should be much smaller than the limit detected by CAS. This is worth mentioning since correlator's offset is a non-negligible part of the proposed error budget (see below).

A number of issues are still at least partially open as far as visibilities (level 1A) are concerned.

- **No explicit error budget** is known for visibilities.
- An error budget for instrument errors has been estimated on reconstructed TB The computed residual (after calibration) error budget totals about 1 K bore-sight (sea scenes) and 1.5 K (land scenes) according to phase A PRR reports. This is estimated for a single pixel of the TB field after reconstruction, without accounting for redundancies.

  However, when thinking in terms of retrieved surface salinities, the instrument errors benefit from substantial reductions. It has been estimated ([13]) that, accounting for FOV averaging and redundancies, the resulting error is brought down to about 0.05 K.
- The above error budget includes antenna errors, probably estimated on the base of mechanical building margins. Since the front end, up to the input switch, lies outside the calibration loop, there is however no on-board correction factor for the impact of possible variations due to antenna patterns and related phenomena (coupling) during the flight. To be considered are element position and pointing, oscillations of the arms, antenna voltage ripples (phase and amplitude), cross polarisation, impact of thermal variations. These, by design, can be assumed to be small or even non-existent. However, it is not yet sure that after sky pointing, or orbit maintenance, nothing will have transitory movements / oscillations.

- Recent updating of the instrument error budget leads to a large increase with respect to the figure quoted above. Some contributions are still lacking or very poorly estimated.
- When computing visibilities over the extended alias-free zone, contributions from the **sky** must be subtracted. We are in one of these cases where one cannot avoid considering errors on geophysical data, even at calibration stage.

  The accuracy of the sky L band data is claimed to be 0.5 K for a 0.5° angular resolution. Inasmuch as this is a random error, the resulting uncertainty on the scale of the SMOS angular resolution (about 2°) ought to be reduced by about 4 (i.e., 0.12 K). This back of the envelope estimate should be consolidated. Further, It is not clear that this estimated 0.5 K error is completely random. However the general feeling is that sky radiation is quite stable. In such a situation, an attempt to improve the accuracy of the sky map from SMOS observations is certainly warranted.
- The CAS system supplies calibration data and corrections (TBD) for every type of channel error. But the largest ones are due to thermal variations and it is anticipated, naturally, that the resulting errors may be much larger than residual errors after operating the CAS. While many physical temperatures are monitored, **it is not yet known how accurate the correcting laws will be** between calibrations. If the ground calibration is properly performed, (e.g., thermal characterisation of instrument response and proper implementation of probes), using the full orbit calibration should enable using the CAS with adequate correcting laws. The key issues will be to assess exactly what are the representative temperatures. And how to extrapolate when getting out of the expected, correction applicable range.
- The duration and adequate frequency of calibration phases throughout an orbit **are not decided**. A single calibration while above a polar zone was initially considered, but this is not relevant for thermal variations along the orbit and could only address drift corrections. In order to check the efficiency of correction laws, calibration sequences over a whole orbit have been identified as necessary (typically once every 4 weeks).

Summarising, the main points as far as we are concerned are:

- The need to clarify the situation about **correcting laws** to be applied between calibrations in order to compensate harmonic thermal effects;
- The issue of sky radiation map accuracy, which suggests having sequences oriented towards the observation of the sky itself.
- The lack of information about **antenna** variations during the flight. This leads to wonder whether recording visibilities from vicarious scene might not be useful. Certainly, it would be useful in particular to be able to record visibilities from a **point source**.

### 3.3.3 BRIGHTNESS TEMPERATURES

From calibrated visibilities, the fields of brightness temperatures are reconstructed (level 1B). Additional error sources at this step include:

- The **fringe-wash** contribution, which is assumed to be adequately modelled from data supplied by the CAS system;
- The **reconstruction errors**. Even if the reconstruction method is error free, some spurious contributions appear due to the limited extent of the star shaped domain explored by the interferometer in the space of baselines. Steep gradients associated to discontinuity lines or bright spot generate Gibbs oscillations; high frequency components present in the scene are partly folded back into the frequency domain covered by the reconstruction operation.
- Finally, errors suffered in anterior stages of the data flow obviously **propagate** to the reconstructed TB field.

This is a complicated topic; research supported by ESA is right now going on about reconstruction performances and methods (including thus tools to evaluate performances and "accuracy".

On the bright side, it may be possible, through specific processing at the level of reconstruction, to make use of redundant visibilities in order to set **constraints** on some instrument properties and therefore contribute to instrument calibration. The performance of such constraints is presently a research issue; they would be particularly valuable if they give access to information concerning antenna patterns.

For obtaining level 1C (surface level), an extra error source to consider is the **Faraday rotation**. However, for calibration purposes, it is always possible to select cases where this possible error can be neglected

In any case, it is difficult to imagine that no calibration operation on SMOS would go beyond the visibilities.

But we must accept that, with the exception of extraterrestrial sources (and excluding man made active sources in the L band), there is no way to calibrate the brightness temperature themselves. The calibrations will thus have to be "fully" vicarious; i.e. they will call for the use of direct radiative models.

## 3.4 SUMMARY BEFORE ADRESSING EXTERNAL CALIBRATION SCHEMES

### 3.4.1 PRE-LAUNCH OPERATIONS

We will assume that all is done correctly to achieve a perfect knowledge of the instrument as well as maximising the probability to retain this knowledge after launch, or to be able to monitor changes/alterations.

Particularly critical issues are:

- **Antenna patterns** (and switch) properties, as these subsystems are not included in the on board calibration loop. The performance of possible in-flight pattern measurements (through looking at a point source) will unavoidably be limited; see discussion below.
- Building and validation of correction laws for thermal effects on receivers.

### 3.4.2 POST LAUNCH ON BOARD INTERNALCALIBRATION

In previous documents by CASA it was stated that the on board calibration could be done over the poles almost during each orbit.

This is to be developed and refined; strategies during the commissioning versus nominal flight have to be discussed and clarified. Indeed, some calibration runs will have to be done during a whole orbit (360°) so as to capture potential harmonic errors. Ideally this could be performed once a month (enabling to capture potential seasonal signal and drift) (TBC). External calibration on sky – see below - would then be performed also once a month but with a two weeks shift.

### 3.4.3 LEVELS & CORRESPONDING ERRORS

The next table (1) summarises the discussion in previous paragraphs: it sketches levels, errors and their origins, possible expected calibration tools.

Random radiometric uncertainties are left out. They will have to be considered nevertheless when assessing the duration necessary to obtain meaningful Cal/Val SMOS measurements.

| Quantities / Levels | Errors (Spurious signals) | Errors (Instrument) | Errors (Processing) | Errors (Auxiliary data) | Calibration data |
|---|---|---|---|---|---|
| NIR scene temperatures / Level 1A | sun contribution, RFI | ageing / drift, thermal mechanical. constraints, power supply internal RFI | | | CAS (warm load) Tp monitoring Sky (cold source) |
| Calibrated visibilities / Level 1A | sun, sun-glint, alias, RFI | ageing/drift, thermal mech.. constraints, internal RFI | | Sky map | CAS Tp monitoring Redundancies ?Sky visibilities |
| Antenna patterns | | thermal mech.. constraints, | | | Sky point source Redundancies ? (Sun, moon) |
| Reconstructed TB / Level 1B | | | reconstruction error | | CAS (FringeW) Sky Sun ? |
| Surface TB / Level 1C | | | | Faraday Geolocation | |
| Ocean quantities / Levels 2 & 3 | | | fwd model | Roughness data | Surface scenes |
| Land quantities / Level 2 | | | fwd model | soil data cover data | Surface scenes |

Table 1

# 4. EXTERNAL IN-FLIGHT CALIBRATIONS FOR SMOS

## 4.1 LIMITATIONS OF EXTERNAL AND VICARIOUS CALIBRATION.

### 4.1.1 ERRORS ON THE SET OF SMOS DATA

**Random errors** have to be indeed very small in order to detect 0.03 K necessary to have 0.1 psu in "average conditions": over the ocean. The specification is at least the same as for the measurement (not mentioning pointing and other sources of error). It is worth remembering that equivalent random errors on TB are about 2 to 4 K for each pixel in a single reconstructed snapshot (2 x 1.2 second), about 0.5 K when including multi-angular and dual polarisation values, slightly below 0.03 over a "GODAE" box, around 0.025 K over the whole field of view (also when including multi-angular and dual polarisation values).

The snapshot (one polarisation) random error over a scene temperature is about 0.06 K on each interferometric channel (about 0.09 K for the NIR); the same error is foreseen for normalised visibilities, noting that some correlation is present.

**Systematic biases**: they are not very likely to occur undetected. However, if calibration targets are systematically acquired in specific conditions, biases may occur. This can be avoided with calibration targets scattered at **various locations** along the orbit. Errors on calibration data sets

It is very likely that (at least) **random** errors will also be present in the calibration set, in which case the necessary number of data will be higher.

The **accuracy of calibration data** also has to be considered. We have the actual physical values at the surface (with some uncertainty) and must reconstruct Tb through modelling with the required accuracy. It is thus necessary to know perfectly well the direct mode as well as every relevant surface parameter. It is also necessary to separate random and systematic errors (in the modelling as well). Finally, one must be aware that, especially when looking at extended targets, the required accuracy makes it necessary to account for contributions from the atmosphere, the ionosphere, and, in addition, to account for smearing effects on incidence angles in SMOS data.

## 4.2 POST LAUNCH CALIBRATION SCHEMES

### 4.2.1 NIR COLD SOURCE CALIBRATION

#### *4.2.1.1 THE FIELD OF VIEW PROBLEM*

Although the NIR are classical radiometers, the main (specific) difficulty when considering their external calibration is their wide field of view. Brightness temperatures must be integrated over a very large solid angle (representing about 2500 km on each side to reach grazing incidence), whereas when talking about calibration areas one mostly thinks in terms of data available for calibration over a (comparatively) small area, the size of a few SMOS pixels.

#### 4.2.1.2 SKY: ENGINEERING ISSUES

The sky is proposed to provide the external (cold) source. The integration time must allow bringing radiometric uncertainty down to levels compatible with the salinity measurements. This can probably be achieved using a few minutes.

It is anticipated that such measurements will require alternatively one orbit every 2 weeks. However the most critical performance is the NIR stability between calibrations, or more exactly the adequacy of the correcting functions of the thermal monitoring data. To this end, it will probably be necessary, during the commissioning phase, to increase the frequency of NIR calibration operations above the nominal frequency quoted above. A prerequisite is nevertheless a complete and reliable modelling of the thermal behaviour and a good monitoring of internal temperatures during operations.

The sky is a good target in the sense that it is rather well known (Reich and Reich see also [14]), with the caveat that there are large sources to be accounted for, and that looking a the sky requires manoeuvres,  and may imply for the sensor-satellite system a different thermal regime which could lay outside the normal or modelled range. Moreover back-lobes may prove to be a significant issue.

Concerning manoeuvres, the first idea was to slightly tilt the platform forward to view deep sky through the top tip of the FOV. This was not deemed very useful, as it will be very difficult to avoid contribution from the Earth etc.

The other solution is thus to tilt completely the satellite so that it looks at zenith for calibration purposes.

It is now necessary to evaluate this possibility and to start identifying potential caveats so that the technical feasibility can be assessed together with the scientific outcome (i.e., improvement of calibration) wrt induced "costs" to the mission. Obviously we do not want to jeopardise the mission.

The practicalities were described in [7] so we will not deal with them here as it is now in the hands of the project.

Similarly, we do not know yet how the sky observation will impact the **thermal conditions** of the payload.

#### 4.2.1.3 TARGET KNOWLEDGE POWER REQUIREMENTS

Looking at the sky has no meaning unless we can be sure that we are looking at a source that is perfectly known. This raises 3 conditions:

- Avoid **galactic sources**; this is probably impossible a large fraction of the time. Then, the sky temperature is basically 2.7 K there are many sources contributing to 0.5 K above the cosmic background.
- check that the sun contribution is negligible

- Address successfully the issue of the **rear lobe**. This is probably difficult. Nothing much is known about the rear lobe (since deep sky calibration was never considered) until full anechoic chamber measurements are performed. Typically this might be very irregular. The rear lobe will collect emission from inhomogeneous sources (the visible part of the Earth is about 5000 km wide, so the chances of homogeneous ocean everywhere are scarce). Of course, there is also the variation with incidence angle. Assuming 25 dB below and an average 150 K up-welling TB, the resulting contribution would 0.5 K, probably impossible to know within better than 10%. Preliminary antenna measurements suggest this is pessimistic as first measurements indicate about 40 dB.

Consequently the geometry will have to be carefully studied.

Provided the matter of the rear lobe is properly settled, the sky observation should provide a cold source measurement with an accuracy better than most other calibration data, and would be therefore very useful. More quantitatively, it appears that we should expect, when looking at the deep sky scene, about 3.5 K from the front plus the rear lobe. There is no point in trying to achieve on the sky radiation a better performance than on the rear lobe contribution. Now, since the operational range for scene temperature is about 120 to 240 K, possibly the required accuracy on the cold source is not drastic; this has to be evaluated form the NIR operation modelling.

There is a possibility to obtain an independent information by assessing the **standard deviation** of the measured brightness temperature. Then the necessary time would probably be much longer (TBD)

### 4.2.2 SEA SURFACE SCENES FOR NIR

The emphasis in this vicarious scheme is on the mean value of the retrieved salinity. Unfortunately we cannot expect to carry out the NIR calibration with such a scene. It would require an area of about 5000 x 5000 km homogeneous (temperature and salinity) with almost no wind. To achieve 0.03 K it is necessary to have an integration time of about 60 s (400 km) all without land in view.

It can be envisioned nevertheless to use ocean surface to be used with statistical vicarious method (see below 4.2.4).

### 4.2.3 SUN AS HOT SOURCE FOR NIR CALIBRATION ?

It has also been suggested to use the sun (if only to check possible drifts in hot load?) but it does not seem very either easy or relevant. The idea to use the sun during descending pass when it is seen at the very edge of the FOV has also been suggested. This raises the issue of the antenna gain (how well known is it and impact on global error, and, even more an issue, the sun seen in this position might give too small a signal to be of significant value. Finally, the accuracy with which the source is known is probably not sufficient.

### 4.2.4 STATISTICAL VICARIOUS CALIBRATION FOR NIR DRIFTS

So as to monitor potential instrumental drifts, we may rely on vicarious statistical approaches for long term drifts

The idea at this level is to consider methods such as those developed for SMMR or SSM/I and further developed by C. Ruf (see [15]) the method is particularly applicable to SMOS as the number of acquisitions is quite significant.

Statistical approaches are believed to be particularly relevant for estimating trends and detecting possible events. However the consideration of sea roughness effect still requires analysis. Statistically, a sufficient number of samples might be collected on time scales as small as a few days. It seems that the accuracy of statistical vicarious calibration might reach about 0.1 K.

### 4.2.5 DEEP SKY CALIBRATION OF VISIBILITIES OR TEMPERATURES

A synthetic map of visibilities when looking at the sky can be computed and compared to observed level 1A data.

There are several reasons why considering visibilities rather than brightness temperatures. The radiometric uncertainty on SMOS data is then fairly low.

Mainly, we must keep in mind that while the ultimate purpose of calibrating the interferometer is to correct for possible inhomogeneities of the instrument response curve throughout the FOV, actual misalignments of the instrument parameters will be located in channels and baselines, and therefore much less difficult to locate when calibration data are provided in terms of visibilities.

Visibilities radiated by the sky scene have to be computed from sky temperature maps provided by radio-astronomy surveys; this will introduce uncertainties over calibration data. However the radiometric errors on SMOS snapshot TB field are so large that the option to work in the visibility domain seems the only practical one. Moreover, if one were to go into the reconstructing process, the alias free zone would be smaller than when looking at the Earth, since there would be no way to extend it to cases where ambiguous zones origin from the sky, as the sky is the target itself.

As mentioned in section 3, if the a priori knowledge of the sky map needs confirmation, then this operation allows to some extent control of one part of the sky map and of its stability in time.

Alternatively, the aim will be to check instrument parameters, check the consistency of redundant visibility samples. For N interferometric channels, sky calibration provides $N^2$ accurate data per polarisation (including PMR outputs); the optimum way to use this data set calls for a **specific study**.

As indicated above, it is necessary to check that the thermal regime of the interferometer when looking at the deep sky stays within normal operating conditions. (i.e., not outside the capabilities of the thermal control)

This calibration step, although aimed at the interferometer, implies the use of the NIR radiometer. The same operation, however, allows (see below) to provide a cold source for the NIR. Assuming the errors on sky L band surveys are random and can be averaged over the solid angle pattern, the temperature of the sky scene would be known to better than 0.01 K.

### 4.2.6 VICARIOUS CALIBRATION OF THE INTERFEROMETER

#### *4.2.6.1 OPEN SEA SCENES*

If a sufficiently homogeneous sea area could be found (including weak and homogeneous sea roughness, total absence of coasts and islands, no sun contamination whatsoever), and satisfactorily covered by surface measurements, a vicarious interferometer calibration could be considered on level 1C. The necessary area is at least 5000 km wide in every direction. Such an approach is not realistic.

The radiometric uncertainty will be large, therefore this calibration will use as much along track averaging as possible and should be compounded over several orbits.

However, a nicely placed island of known characteristics and adequate size might be useful as a point source.

This calibration step, although aimed at the interferometer, implies the use of both the NIR radiometer and a forward ocean surface model. Its specific use here consists of detecting inhomogeneities in the retrieved salinity maps whereas the ground truth is homogeneous. This might give hints about some instrumental errors.

The possibility of detecting residual effects (after on board calibration) from surface calibration data needs to be assessed (This is a case where the SEPS could be put to good use to simulate different calibration frequencies)

#### *4.2.6.2 OTHER POSSIBLE SURFACE TARGETS*

The only realistic use of such limited targets is to perform a complete calibration (on either SM or OS) covering the NIR, the interferometer and eventually the direct model. One should never the less bear in mind that the radiometric accuracy for 1 pixel (30 angles and 2 polarisation is roughly 0.5 K. The scene has to be known and possibly homogeneous of course and the direct model accurate. If the target can be extended the figure can be improved (SQRT of number of independent samples). So as to satisfy the different requirements the number of options is very limited [9] The first options which can be considered are:

- The area on Antarctica around Dome C
- Well monitored "homogeneous" area over land (large test site with extensive ground measurements)

### 4.2.7 POINT SOURCES

#### 4.2.7.1 PURPOSES

There are several purposes in the use of point sources:

- One is to be able to verify / characterise the antenna diagrams, for this the best potential source is the sun if we know its evolution quite well. Ideally the sun should be scanned through the bore-sight
- A second is for the DLR reconstruction method. The point source (sun) is scanned throughout the FOV so as to be seen in every pixel[2]. From current information this does not seem really feasible.
- A third is for calibrating the radiometer. Such point sources are to be known and to be found in a cold background. In this context, we can disregard the moon. Sun is certainly an option but it requires important manoeuvres (and imply severe constraints on the instrument). Using the sun when at the extreme of the FOV is not practical for this purpose.
- To assess the interferometer the moon may be useful as a relatively weak source (equivalent to 10 K over a known background (3-6 K) but this has to be studied further. The Sun in this case is probably not fully adequate (relatively strong and messy).

#### 4.2.7.2 USING THE MOON AND / OR THE SUN

So as to have an external / vicarious calibration target for SMOS, the possibility to use the Moon and the Sun as point sources was considered. Even though this option is still under study it is necessary to estimate the requirements for the mission specifications. It should be noted that there are other potential sources (Cygnus for instance, which is at least 15 times higher than the Moon) but here again the feasibility is to be studied.

The Moon and the Sun offer the possibility to view a "hot" point source with a cold background. This being said things are not so simple as:

- The background is not that uniform and can vary significantly wrt to the target position.
- The Sun's emission does vary significantly with time. If we do not have easy access to data from monitoring centres (i.e., accurate monitoring 1% expected?), such target can only be used as a hot source vs cold background (i.e. interferometer calibration). Actually the Sun is monitored at L band but we are going towards an “active period” for the Sun.
- The Moon also varies with time (if only Moon phases and reflected solar contribution about 1% on average?), and its brightness temperature is not fully known. Moreover it is not very high ( 250 K) and, as the Moon (and Sun) intercepts a small percentage of a basic "pixel" (about 6 %) the contrast will be even smaller (about 15 K)

[2] A single diagonal pass done from time to time could eventually be used but this option has to be studied further both in terms of feasibility and of interest

#### *4.2.7.3 SYNTHESIS*

It seems that the Moon is not a good candidate but the Sun is maybe the only possibility to be able to measure in flight the co-polar antenna diagrams. For this we need to know the source stability, follow the sun and have stable NIR. This point is thus still to be studied.

Such external calibration is possible but with an outcome that is not 100% ascertained. We suggest considering this option further, but, in the mean time, no hard constraints should be put on the mission, as the current characteristics seem sufficient.

One should keep in mind during this calibration exercise that we will have eventually to cope with the following constraints:

1. The SMOS mission is aimed at providing data globally and frequently: the calibration should take only a small portion of the time.
2. When moving the platform (towards the sun or the sky or whatever), we may be in a configuration where downloading is not possible which may jeopardise even the data acquired itself
3. Manoeuvres consume fuel and hence reduce lifetime if too frequent.
4. Manoeuvres change completely the thermal constraints and hence may distort measurement or damage the PLM.
5. And finally, as already stated, back-lobes may be an issue.

As per the sources themselves, the conclusions may be that:

- The **Moon** is not useful (TBC) for calibrating the NIR elements and interferometer (small contrast over the large main lobe; side and back lobes contributions to be taken into account)
- The **Sun** might be useful as a point source target. But in this case:
    - Only use the Sun when "calm" or if monitoring data is available (which should not be a problem TBC)
    - Investigate the feasibility of using the sun “seen on the side”
- This would require:
    - Fine choice of occurrences when optimal viewing conditions are met
- Finally checking for other radio-sources might be useful but, when observed, the targets should be in a "calm" area in terms of galactic noise (i.e. avoid galactic plane) and in known areas.

## 4.3 SEA SURFACE NETWORK (VICARIOUS) CALIBRATION/ VALIDATION

This method which could be considered as a validation as is uses geophysical data and retrievals, is actually using multiple acquisitions of both satellite and ocean measurements to calibrate in a sort of assimilation mode the system. The idea is to gather data over a large range of SST SSS and WS and assimilate them to compare with retrievals. More details are given in the validation part.

It must be clear that ultimately the consistency between SMOS salinities and data provided by a surface network will be required. Due to the accuracies of in situ salinity and temperature measurement, and provided the range of the sea roughness can be restricted, bearing in mind that then the surface is homogenous on large scales, it is felt that adequate samples of the surface network data will turn out to be the main calibration driver.

While this approach is unavoidable and should be the most conclusive, it may turn out to be very complicated. Through direct comparison between surface data and level 2 retrievals, one hopes at the same time to check the NIR calibration, to account for possible inhomogeneities of the interferometer response, and to tune (with some degree of empirical fitting) the retrieval algorithm, This calls for a carefully designed process.

## 4.4 SMOS AQUARIUS / HYDROS INTERCALIBRATION

SMOS is a stand-alone project but as for any other such project many gains will be available if two similar missions fly together (see ERS tandems Vegetation and SPOT tandem scenarii etc). There will be also a unique opportunity for both calibration and possibly validation to use either Aquarius or HYDROS should they fly at the same time as SMOS. Already, with Aquarius, plans are being made to share common approaches (see 5.3). The simplest way to inter-calibrate is to compare separately to the same surface data each time the acquisitions are synchronous. However it may be worth attempting to avoid the vicarious step included in this approach. Both systems, having real antennas will provide measurements with quite different error sources when compared to SMOS, and a higher sensitivity. This might proved to be the ultimate external calibration source

This part will thus have to be expanded once more is known on the two other missions.

## 4.5 SUMMARY TABLE

The following (draft) table proposes external calibrations together with purposes, difficulties and aims. Filling adequately this kind of table might be proposed as a first test for the consistency of the calibration document.

| Target | purposes | Implementation problems | SMOS data problems | Target problems | Hoped for performance |
|---|---|---|---|---|---|
| Deep sky scene | Cold source for NIR | rotation every month<br>stability | | Knowledge of target<br>back lobe | down to 0.15 K? |
| Sea scene (vicarious) | NIR | None | | Find it…<br>fwd model and knowledge | |
| None: internal warm load | Check NIR correcting laws | Frequent during commissioning | none | none | down to 0.03 K |
| Deep sky on visibilities | Check sky map<br><br>MIRAS errors | rotation every month | stability throughout rotation; | stability<br>back lobe<br>Random errors<br>Knowledge of target | |
| Deep sky on TB | Check sky map<br><br>MIRAS errors | rotation every month | Random errors FOV | ditto | Difficult to interpret |
| Sun on scene temperature | antenna patterns | Rotation and tilt? | | Power stability | less than 1% of axis gain |
| Sun on visibilities | MIRAS transfer function | Rotation and tilt? | | background scene | TBD |
| Moon | | | | | |
| Other sources | Antenna patterns | rotation | stability | Back lobes | |
| Antarctic (vic) | Every error | None | Random error | fwd model | |
| Sea area (vic) | overall | None | Random error | fwd model | |
| Land area (vic) | overall | None | Random error | fwd model<br>RFI | |
| Ocean network (vicarious) | overall | Data access | Random error | select sample | Down to 0.03 K for 300 data points |
| statistical TB (mean, median, tail slope)<br>(stat vicarious) | overall calibration drift | possible frequency up to 1 per a few days | remove flagged data | every geophysical error<br>Sea state (tbc) | down to 0.1 K |
| SMOS vs AQUARIUS | overall? | synchronous observations | | | TBD |

Table 2

# 5. VALIDATION: FIRST PRACTICAL SUGGESTIONS

## 5.1 MEASUREMENTS TO BE USED IN VALIDATION.

Over the ocean, the main validation parameter is sea surface salinity. Inasmuch as wind speed is a secondary retrieved parameter, it may be considered for validation.

Over land, the main validation parameter is soil moisture. Inasmuch as vegetation optical thickness is a secondary retrieved parameter, it may be considered for validation. However there is no reliable ground truth measurement for both variables.

Both over sea and land, it is expected that several hundred measurements are available every day

The SMOS measurement uncertainty for a single pixel measurement, due mainly to radiometric sensitivity, is of the order of 1 PSU for salinity and 4% for soil moisture.

## 5.2 SCALE ISSUES

A major limitation is due to the fact that SMOS measurements concern an area of size about 40 km, while ground truth essentially consists of point measurements. For validation it will be necessary to either monitor exhaustively a very large area (at least 100 km) of fairly homogeneous surface

Over the ocean, this is not of too much consequence, as the scale of variation of sea surface conditions is larger than that at least for salinity and SST. However care should be exercised concerning wind conditions

Over land, It is necessary to identify areas as homogeneous as possible. Privileged validation sites should include a network of ground sensors, so as to characterise the actual sub-pixel variability of soil moisture. Several such sites do exist currently but are adequate at different levels (long term or type of measurements routinely performed) and will be evaluated in depth during the Cal/Val preparatory programme.

## 5.3 SEA SURFACE NETWORK CALIBRATION / VALIDATION

Ground data measurements over sea are the only ones to offer an adequate accuracy to perform absolute calibration/validation of the SMOS payload.

Assuming that several hundred surface measurements spread over the whole oceans are available every day, the main Cal/Val scheme consist of removing pixels flagged for any event (heavy rain, sun image) and carrying out a multivariate statistical analysis in order to detect possible trends depending on sea roughness, wind direction, latitude, season.

It is therefore necessary that surface data cover wide ranges for all these variables.

Surface data available should be used partly (initially) for tuning the sea surface algorithm, partly for validation.

As a result, all land ground data and about 2/3rd of sea surface data should be available for validation.

## 5.4 DYNAMIC RANGE AND VERSATILITY OVER LAND

Accounting for the complexity of forward modelling and the measurement uncertainty, single point measurements are inadequate. The calibration strategy should provide **large time series**, allowing to sample a **large dynamic range** of both soil moisture and vegetation cover over land, and provide large numbers in order to allow statistical analysis.

Over land, possible biases will come from erroneous auxiliary parameters (soil structure, forest thickness)

## 5.5 LAND PIXEL OTHER THAN VEGETATED SOIL

There is a possibility to use other surface types such as very large areas at high latitudes, rain forests, large ice sheets (Antarctica), but it is clear that each one of them poses various types of different problems, some being very delicate to cope with. Specific studies will most probably be necessary before assessing exactly the validity of such targets especially as we will not be dealing necessary with SM or opacity.

A special mention should also be made of other methods that even though they might not validate per se the products, might help in giving some confidence. We are thinking of model outputs, retrievals from other satellites, analysis of time series etc…

# 6. CONCLUSIONS

This document intends to be a first step towards the definition of a calibration procedure for SMOS. It is intended thus to be a working document open for discussions. It seems that for achieving a good calibration we will have to work on several levels, which are unfortunately closely interrelated with all the complexity it will entail.

The first point is the instrument calibration itself with both the hardware (i.e., antenna +receivers) and interferometry. This will not be sufficient and vicarious calibration will be required as well, leading to specific issues as explained above (targets, temporal variations, modelling). These issues can only be addressed through further studies and use of the end to end simulator.

The second point is related to the protocol for external / vicarious calibration. The issues are linked to the choice of suitable targets (i.e., size, stability and knowledge) and corresponding time scales. If long-term stability could probably be addressed with use of time/space averages (with the caveat of climatic trends) short-term stability will have to be derived (requiring being able to simulate the orbit cycling).

The third point is the distinction between absolute and relative calibration. The first one requires a large target to be viewed (and known) and very good NIR. Relative calibration will require a good knowledge and modelling of the instrument (errors in receivers will translate into errors in Tbs) and of the reconstruction. It will be necessary to use long-term calibration here as well (random errors precludes the use of "single shot" acquisitions).

It must be noted that this document does not cover yet completely effects linked to abnormal event such as RFI or sun glint and sun aliases etc in the field of view.

Similarly the special issue of "thresholding" and flagging special events (heavy rain, TEC burst even solar flares, or large rain water ponds, etc.. it yet to be addressed.

So to summarise, the main conclusions are that the main calibration points should be:

- Before flight:

A complete and very detailed characterisation of the SMOS System with an accuracy compatible with the radiometric requirements when computed /estimated for orbital environment including:

  - *Antenna patterns*
  - *Thermal behaviour (hence accurate instrument model) and means to monitor it in flight.*

- During flight

- The on-board calibration should be sufficient to monitor and adjust the above parameters.
- Make full use of the on-board calibration.
- Do not put any constraints related with the use of the moon as a target which could only be useful for visibilities
- The assimilation of buoys data (and possibly AQUARIUS/HYDROS acquisitions) are probably the safest methods
- Some ground targets might be of use
- Viewing deep sky will certainly be useful but not self sufficient
- A reliable point source will be necessary. The sun is probably the best candidate but it raises many an issue. It certainly needs further studies.

This note is yet to be improved. Table 2 should be probably used to ascertain the priorities. Finally this document is incomplete. It lacks much information on the payload itself and does not give many quantitative requirements. It may also give the impression that several redundant approaches are presented. Considering the complexity of the task to calibrate and validate SMOS, we believe that, any option, which has no large impact on the system, should be pursued.