# SUMMARY NOTE ON SMOS CALIBRATION ISSUES

| | |
|---|---|
| Project code | SO-TN-CBSA-SYS-0001-01.a |
| Version | 1.a |
| Date | 15/03/2004 |

| | ***Role*** | ***Name*** | ***Date and signature*** |
|---|---|---|---|
| **Written by :** | Lead investigator and project scientist | Yann Kerr CESBIO<br>Philippe Waldteufel SA | |
| Approved by**:** | CNES Project Manager | Michel Moulin | |
| Approved by : | SMOS Project Manager | Achim Hahne | |

## DOCUMENT STATUS SHEET

| version / Rev. | Date | Pages | Changes | Visa |
|---|---|---|---|---|
| 0.a | 02/01/2004 | | | |
| 0.b | 06/03/2004 | all | Draft reviewed and mamended after Barcelona meeting | |
| 1.a | 09/03/2004 | all | Document formatted | |
| | | | | |
| | | | | |

# DISTRIBUTION LIST

| ***ESTEC/EEM:*** | |
|---|---|
| A. Hahne | 1 |
| M. Zundo | 1 |
| B. Duesmann | 1 |
| H. Barré | 1 |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

| ***ESRIN:*** | |
|---|---|
| N. Wright | 1 |
| J. Benveniste | 1 |
| ***ESTEC/TOS*** | |
| M. Berger EOP/SML | 1 |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

| ***CNES*** | |
|---|---|
| M. Moulin | 1 |
| M. Venet | 1 |
| F. Cabot | |
| H. Marquier | |
| R. Moreno | |
| ***SAG*** | |
| Y.Kerr | 1 |
| P. Waldteufel | 1 |
| J. Font | 1 |
| Sag members | 1 |
| ***OTHER*** | |
| Documentation | 1 |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

# REFERENCES

| | | | |
|---|---|---|---|
| 1 | System Requirement Document | 4 | Jan 2004 |
| 2 | SMOS Proposal (COP16) | | Nov 1998 |
| 3 | Mission Requirement Definition | 5.0 | Mar 2001 |
| 4 | Note on SMOS calibration and validation | 02.b | Oct 2003 |

# ACRONYMS

| | |
|---|---|
| CESBIO | Centre d'Etudes Spatiales de la BIOsphère |
| ESA | European Space Agency |
| NIR | Noise Injection radiometer |
| PSU | Practical Salinity Unit |
| OS | Ocean salinity |
| Req | Required |
| SA | Service d'Aéronomie |
| SAG | Science advisory Group |
| SM | Soil Moisture |
| SMOS | Soil Moisture and Ocean Salinity Mission |
| SRD | System Requirement Document |
| SSS | Sea Surface Salinity |
| TB | Brightness temperature |
| TBC | To be confirmed |
| TBD | To Be Determined |
| TOA | Top Of Atmosphere |
| TP | Physical temperature |

# TABLE OF CONTENTS

# 1. PREAMBLE

We assume in the following that the reader is familiar with the SMOS concept.

## 1.1 QUALIFYING THE ROLE OF CALIBRATION

The user will want to get from SMOS the best possible soil moisture and ocean salinity fields. It is thus necessary to take a close look at calibration issues but it is crucial to consider the whole system in view of assessing its overall performances. For instance

- One cannot quantify deep sky calibration without taking into account the contribution from back lobes or the impact of warming / cooling
- Over ground target the performances are linked to the characteristics of the spatial sampling.

Obtaining good SM/SSS means before all good brightness temperatures (Tb); hence calibration is necessary to achieve this goal but not the only one. Calibration must not jeopardise data itself: for instance if 50% of the time is spent calibrating it is counterproductive.

Similarly using all three NIR all the time to possibly improve absolute calibration may degrade the measurements by decreasing the number of available LICEFS and thus reduce further the sensitivity. A trade off will have to be found

Finally, it is worth mentioning that sensors like SMMR were very poorly calibrated at the beginning. However, (and even though it took years!) we have now rather well calibrated SMMR data. On the other hand, the instrument also had some deficiencies, and these are not improved (almost 30 years after).

## 1.2 SMOS ERROR STRUCTURE

The complexity for SMOS calibration is two fold: a) the payload includes two types of sensors (although they have parts in common): the interferometer and the Noise Injection Radiometers (NIR). (b) the fact that SMOS relies on interferometry.

The interferometer provides data which would allow building **normalised** maps of TB. The NIR provide (as well as information necessary for on board calibration) the multiplying factors which allow converting these normalised maps into true (Kelvin) TB maps.

For the sake of simplicity, we consider here after only one NIR (when the redundant NIR may be used simultaneously at the cost of a reduced sensitivity). We also assume that all the elementary receivers (LICEFS) are operational (no failure)

The types of variations of the payload response curve considered are the following: radiometric, short term (orbit time scale), long term. There will be some bias. The initial overall bias is the only to consider: If the bias evolves, it will have to be accounted for through the drifts.

**For the short term variations**, the most likely source of variations will be caused by temperature variations. We assume the variations to be directly linked to those of the physical temperature TP . Not considered in this note (but to be kept in mind are:

- The (serious) sun issue.
- The possible errors due to imperfect knowledge of the **sky noise** map.
- The internal EMC problems, assuming they are solved

**For the long term variations** (drifts mainly) are assumed to be mainly due to ageing process (the LICEFs gradual failures should be eventually integrated into this item).

The aim of the **on-board calibration system** (CAS) is to provide information to both correct the interferometer response and to calibrate the NIR.

However, it must be noted that

- no internal on-board information is available to correct for potential evolutions / variations of **antenna patterns**, which therefore need to be considered specifically.
- Other front end components lie outside the on-board calibration loop; it may be that the physical temperature is the main driver for fluctuations of their characteristics.

The **pre launch** calibration as currently planned mainly addresses antenna patterns and some assumptions will have to be made as to the actual values after launch and deployment. Unless some means are developed to assess them once in orbit.

Possible calibration tools during the flight include both **direct** (i.e. visibilities or TB) and **vicarious** (i.e. geophysical quantities) external measurements. When considering TB, one must allow for an additional **reconstruction error**; when considering vicarious measurements, errors in the **whole forward radiation model** are to be accounted for.

A major issue is to define the content and duration of both internal and external calibration phases, and to define inter-calibration periods. The **commissioning** phase is an important opportunity to assess these points.

# 2. NIR CALIBRATION

## 2.1 THE NIR RESPONSE CURVE

The NIR calibration comes closest to the "classical" definition for calibrating a space borne radiometer.

The response curve for the NIR is nearly linear but probably not quite. It is expected that pre launch measurements will provide an accurate response curve as far as departures from linearity are concerned. In the operating range, we assume it is correct to write the NIR response curve as:

$$OUTPUT = A(TP) + B(TP)\ TS + C(TP)\ TS^2 \qquad (1)$$

Where TS is the scene temperature and TP the physical temperatures of the NIR subsystem, using a generic term as several temperatures are certainly relevant (i.e., we need some sort of a “model” of the whole NIR.

It is thus necessary to perform before launch a characterisation of each NIR providing accurate values for A, B, C, all over the relevant range of TP values. At least, they will provide a reference for a specific value TP0 of TP.

This approach is the simplest possible. We may rightfully question the assumption that A, B and C depend **linearly** on the physical temperature  It will most probably turn out that the actual dependence is more complicated because several TP (related to various components) have to be considered (hence the idea of the “model” or a characterisation of the NIRs).

## 2.2 CALIBRATION FREQUENCY FOR A STABLE RESPONSE CURVE

The recently proposed two-levels CAS for NIR allows full determination of A and B for the value of TP at the time of calibration. The accuracy is limited by radiometric errors. Taking this to be 0.2K for a 1.2s integration time, since we want 0.03K for sea measurements, the necessary duration for a NIR internal calibration is about **80s** for two levels.

A discussion of the inter calibration period in terms of TP drifts is presented in the SO-TN-UPC-PLM note, §7.2.2. The suggested necessary number of calibrations per orbit is about 10; then the total time needed for NIR calibration would be 800s per orbit, that is 12% of the time.

Even with such a prohibitive time spent calibrating, it is far from sure that it will warrant the needed 0.03K accuracy.

### 2.3 ALLOWING FOR TP FUNCTIONAL DEPENDENCY

It is suggested that the best approach for NIR consists of obtaining a deterministic variation of the TP functions A, B, C in equation (1) above.

The aim would be to monitor TP and to have a stable "**TP compensated NIR response curve**", rather than a stable NIR response curve for the periods between to calibrations. For this it would be necessary to perform:

- An extensive pre launch characterization (this might not be mandatory: if it is possible to estimate most TP dependencies from in-flight measurements, provided the TP monitoring is adequate)
- Extensive NIR calibrations during the commissioning phase. The detailed plan is TBD.
- During nominal flight, the drift must be **monitored** by dedicating for example one full orbit every 4 weeks to NIR calibration, as already sketched.

### 2.4 WEAKNESSES

Several weaknesses can already be stated:

1. A possible bias exists due to imperfect *a priori* determination of the noise injection levels;
2. The variation of these levels themselves with TP have to be accounted for;
3. Variations outside the NIR calibration loop (antenna patterns, switch) are not accounted for.

So as to address these weaknesses we may say that for points 1 and 3, the only possibility seems to be **external** calibration while for point 2 **pre-flight** measurements are absolutely required.

# 3. INTERFEROMETER

There are many causes for errors in the retrieved interferogram: some affect channels, some other affect channel pairs and correlation products and ultimately visibilities. The CAS system addresses them carefully, leaving only **residual** errors. The only point worth recalling at this level is that the antennas are outside the calibration loop.

However, similarly to the NIR case, most of the in-flight variations of the interferometer responses are expected to be driven by TP variations. Then, the question arises whether it would not be appropriate to attempt to correct these variations **deterministically** from monitored TP data.

## 3.1 VISIBILITIES

Visibilities can in principle be calibrated over a perfectly known scene. The only possible and realistic candidate appears to be the **deep sky**. However deep sky is perhaps not as perfectly known as might be necessary. In addition, observing the deep sky raises a problem concerning the physical temperatures of the payload system, hence it may be difficult to extend the results of a deep sky calibration to nominal, Earth looking, operating conditions. Moreover the role of the back-lobe might induce a significant contribution.

An additional, very different possibility consists in using the redundant visibilities to set **constraints**. Difficulties here stem from the mixing of contributions of every subsystem, including antennas. In addition, the radiometric uncertainty on measurements may limit the robustness of such constraints. This is a matter for research, and it will be left aside for the time being.

## 3.2 TB FIELDS

The consequences of error propagation from correlation products (through visibilities) to TB maps are unclear, because the matter is complicated and there are so many error sources.

Specifically,:

- when considering the resulting pattern of instrument errors in the Field of View, are we going to obtain a **random** field, or a **deterministic** field, or something **in between**?
- What is the influence of the **scene** itself?

As long as there are no indications on these issues, it will be is difficult to forge ahead.

Assuming some knowledge on such properties becomes available (**SEPS** is the right tool for addressing this), some overall controls remains mandatory. This would be the role of **vicarious** calibration.

# 4. VICARIOUS CALIBRATION

There is no way to use vicarious calibration (VC) over a whole Earth scene, because no such scene will be known accurately enough due to the size of the concerned area. **Deep sky** is the only possibility, with many caveats however. Therefore, leaving deep sky aside, calibrations of the NIR and of the interferometer cannot be separated.

Then, the major difficulty of using vicarious calibration is that every error source is present: NIR, interferometer, bias, reconstruction, as well as forward model, including uncertainties on physical parameters.

Only ocean surfaces need be considered, since:

- The required calibration accuracy is higher over the ocean by more than an order of magnitude, hence when compliance is achieved at best over ocean one need not to worry about land surfaces.
- Most of the time spatial gradients are much smaller and smoother over the ocean, so that point measurements (unlike land surfaces) are representative of area values.

**Bulk** statistical vicarious methods are valuable to assess long term drifts. However it is not clear that they allow achieving accuracy better than 0.1K. They are not considered here.

The data basis for VC will be assumed to consist in a **network of salinity buoys** spread over the global oceans, complemented by SST maps, and sea state data. The last topic is still an open one.

## 4.1 COMMISSIONING PHASE

- **Interferometer**: the aim of vicarious calibration is to assess:
  a. Whether there are systematic trends over the FOV,
  b. whether such eventual trends depend on TP,
  c. whether the on board calibration data are effective in removing such trends.

This is **not** strictly speaking a vicarious calibration, inasmuch as the task can be carried out in a **relative** sense. However the knowledge of surface data is necessary in order to ensure that the scene is sufficiently (TBD) uniform. A hypothesis on the incidence angle dependence of roughness effects is necessary; hence the control should be restricted to zones with low wind speeds.

- **From the interferometer to NIR**: the natural strategy consists of first assuming that the relative trend of instrument errors throughout the FOV is negligible, next (hopefully) correcting for it. Then, considering first low wind speed areas, one is left with a combination of initial NIR bias, **mean** instrument error and forward model error (for the dielectric constant part). This is to be sorted out in an iterative manner (initial bias and dielectric constant bias should not vary), after which the matter of sea roughness can be addressed.

Over a given SMOS pixel, the standard deviation over the retrieved salinity is on the average close to 1 PSU. Consequently a relevant number of surface data for NIR calibration is of the order of **one hundred**.

## 4.2 NOMINAL FLIGHT

During the nominal flight conditions, the idea is to set up the calibration procedure according to the findings of the commissioning phase to organise the calibration procedure. The goal should then be to put the emphasis on data collection, and retain a capacity to evolve.

Similarly, the need for vicarious calibration should not generate specific requirements for observation. A part of the surface data will be kept for calibration, and a part left for validation.

# 5. ANTENNA PATTERNS

During the flight, monitoring changes in the antenna patterns requires a strong quasi point source, and the only one around is the sun.

Tracking the sun may be a costly and complicated manoeuvre. Also, the thermal setting of the payload will change, in such a way that the representativity of measurements will have to be assessed carefully. Additionally, when tracking the sun, there is little chance of obtaining absolute calibrations (owing for example to the fluctuations in the energy of the source), so that one will need a series of angular transects including the bore-sight in order to ensure at least relative consistency. Finally, although the sun is strong, the back lobe and its variable contribution when pointing all over the sky may not be negligible.

Inasmuch as pattern and front end variations are driven by physical temperature, the question arises whether some quantitative indications can be obtained before the flight. And whether sun pointing will bring useful information for calibration. Unless the possible aim of sun observations is the G Matrix reconstruction considered by DLR proves useful and efficient..

# 6. CONCLUSIONS

Basically, direct calibration of either the NIR or the interferometer during the flight does not seem globally feasible. Consequently the general philosophy is that ultimately, fine calibration could only be made through vicarious methods. The most accurate one certainly relies on salinity measurements. We shall have to live with the fact that vicarious approaches include the radiative models in the external calibration loop.

Defining vicarious calibration scheme seems a natural field for cooperation with the other L-Band missions and teams, especially Aquarius. It is recommended that next studies (such as the SMR extension study) devote some attention to this point as there is still much work to be done.

This means that, as a first approach, continental sites will be devoted to validation rather than calibration.

Concerning the payload, then, the major issue seems to be to ensure either stability of the instrument during the intervals between calibrations or a good monitoring of the changes as thermal fluctuations on the time scale of one orbit twill drive the operating point. Hence, a crucial point is whether we are able to obtain a "thermally compensated" stability and to rely on ancillary physical temperature data to achieve the required performance.

Obviously, it is interesting to check this ability during pre flight calibration steps. Simulations using the SEPS may help also. Ultimately, detailed calibration phases during the commissioning phase are able to yield the correcting laws we need. However we should make sure that the monitored data correspond to physical temperatures that are truly representative.

Looking to the deep sky will certainly bring interesting information. It is not clear whether this should be included in the baseline calibration scheme. Again, the purpose of the SEPS is to provide preliminary answers to such questions.

Tracking the sun is the only way to obtain antenna patterns during the flight. It is necessary to determine whether and how often it is practicable, and which type of relative accuracy can be granted in such manoeuvres.

Finally, the bulleted assumptions in the 1rst section remain significant concerns.