SMOS Mission

Science report Phase A

Draft version

Introduction

This note aims at giving an overview of the status of the Soil Moisture and Ocean Salinity (SMOS) Earth Explorer Opportunity Mission shortly before completion of phase A activities. It focuses mainly on the scientific aspects. It should be noted however that at this level, scientific activities are dealing more with feasibility than application.

SMOS was proposed to ESA in November 1998 in the framework of the Call for Proposals for Earth Explorer Opportunity Missions (COP16). SMOS was recommended by the Earth Science Advisory Committee (ESAC) for implementation as the second Earth Explorer Opportunity Mission (ESA/PB-EO(99)24, ESA/ESAC(99)4).

The Executive proposed to initiate an extended phase A (ESA/PB-EO(99)37) which was approved by the PB-EO and the relevant activities started on all aspects of the programme. The Preliminary Requirements Review (PRR) for the SMOS Extended Phase A (SEPA) is scheduled for 15/10/2001

The document is organised in 3 parts:
- Background information on the mission and ESAC assessment of COP16
- Results of the scientific activities performed during phase A
- Summary of ongoing studies and campaigns

Appended to this report are listed relevant documents produced in the course of the SEPA (annex 1), SMOS related contributions in the academic sphere (annex 2) and the ESAC assessment report with comments indicating how the issues were addressed (annex 3).

1 Background information on SMOS

1.1 Mission objectives

The main objective of the SMOS mission is to deliver crucial variables of the land surfaces: soil moisture, and of ocean surfaces: sea surface salinity fields. The mission should also deliver information on root zone soil moisture, vegetation, and biomass, and foster significant research in the field of the cryosphere.
Over land, water and energy fluxes at the surface/atmosphere interface are strongly dependent upon Soil Moisture (SM). Evaporation, infiltration and runoff are driven by SM while soil moisture in the vadose zone governs the rate of water uptake by vegetation. Soil moisture is thus a key variable in the hydrologic cycle. Soil moisture, and its spatio-temporal evolution as such, is an important variable for numerical weather and climate models, and should be accounted for in hydrology and vegetation monitoring.
For the oceans, Sea Surface Salinity (SSS) plays an important role in the Northern Atlantic sub polar area, where intrusions with a low salinity influence the deep thermohaline circulation and the meridional heat transport. Variations in salinity also influence the oceans near-surface dynamics in the tropics, where rainfall modifies the buoyancy of the surface layer and the tropical ocean-atmosphere

heat fluxes. SSS fields and their seasonal and inter-annual variabilities are thus tracers and constraints on the water cycle and on the coupled ocean-atmosphere models.
Even though both SM and SSS are used in predictive atmospheric, oceanographic, and hydrologic models, no capability exists to date to measure directly and globally these key variables. The present proposal is aimed at filling this gap through the implementation of a mission that has the potential to provide globally, frequently, and routinely this information. It is also expected that the SMOS mission will provide significant information on vegetation water content, which will be very useful for regional estimates of crop production. Finally, significant research progresses are expected over the cryosphere, through improving the assessment of the snow mantle, and of the multi-layered ice structure. These quantities are of significant importance to the global change issue. Research on sea ice will also be carried out.

1.2 Mission characteristics

The SMOS mission is a mini satellite on a low earth orbit (polar and sun synchronous 6am-6 p.m.). The baseline payload is an L band (1.4 GHz) 2D interferometric radiometer, Y shaped, with three arms. The radiometer is accommodated on a generic PROTEUS platform (Silvestrin et al. 2001).
SMOS is an "ESA-lead" mission (Johannessen et al. 1999) with contributions from France as CNES is providing the platform, and Spain who provides the ground segment (data processing). ESA has the overall responsibility for the mission as well as for the payload, launch, and operations. CNES has the responsibility for the platform and assembly integration and tests. CDTI has the responsibility of the ground segment up to level 1B.

1.3 Specifications

SMOS aims at providing (Kerr et al. 2001a), over the open ocean, global salinity maps with an accuracy better than 0.1 PSU every few (#10) days, with a 200 km spatial resolution; over the land surfaces, global maps of soil moisture, with an accuracy better than 0.4 m^3/m^3 every 3 days, with a space resolution better than 60 km, as well as vegetation water content with an accuracy of 0.2 $kgm\text{-}^2$.

It is worth noting that, by the end of phase A, no significant changes were made to the overall characteristics of the mission and that the proposal commitments are being fulfilled.

1.4 Initial SMOS assessment

The SMOS proposal was reviewed by the ESAC and a number of comments and suggestions were then made. In annex III is given the ESAC Assessment Report with answers and clarifications added as notes.

2 Results of the scientific activities performed during Phase A

The comments made by the ESAC were quite up to the point and we endeavoured to address them during phase A. Due to the necessary time to set up, carry out and exploit campaigns, not all results can be laid on the table yet (they are planned for the end of phase B) but decisive progresses were made demonstrating the feasibility of the SMOS mission.

2.1 Overview

Since the onset of phase A several activities were performed in parallel:
- A Science Advisory group was established and met 7 times (9-01).
- An Interagency Group was established (ESA, CNES and CDTI) and met twice
- Yearly international science workshops took place (Barcelona 99, Toulouse 00, and Wessling 01)[1].

[1] The reports are available on http://www.cesbio.ups-tlse.fr/indexsmos.html

- Close links with the US science community were established
- Production of documents to define the boundary conditions (MRD, SRD) and the requirements (Calibration, campaigns, sensitivity…) or their translation into System requirements (spatial resolution, swath, …)
- Scientific studies were initiated
  - 2 on salinity (ESA)
  - 1 on land (ESA) (a second one is pending)
  - 3 on land (CNES, CNRS, Région Midi Pyrénées)
  - 1 on sea (Region Midi Pyrénéees)
- Ground campaigns were initiated
  - LOSAC
  - WISE 1 and 2
  - Avignon
  - Toulouse
- An Aircraft deployment is planned for November 01 (EUROSTARRS)
- The development of instrumentation was initiated
  - L band polarimetric radiometer (TUD)
  - L band ground radiometer (ONERA)
  - L band interferometric radiometer (HUT)
- A phase A study on the mission and payload was initiated with CASA EADS (Spain)
- Supporting system activities were initiated with CNES
- The development of an End to End mission performance simulator was started
- An optimisation scheme was developed to find the optimal SMOS configuration.

Several activities performed by ESA in the framework of the MIRAS Demonstrator Pilot Project (Borges et al. 2000) should also be mentioned. They cover several aspects, which are of use for the SMOS project such as the work on the receivers, the DICOS, deployment mechanisms etc…
Similarly, ESA is also now supporting the development of the SMOS demonstrator developed at the Helsinki University of Technology (HUT).

All these actions were initiated almost in parallel to ensure a fast completion of the phase A activities. To ensure optimal feed back between the different activities, regular meetings took place. The main goals being to

a) assess the optimal SMOS configuration taking into account the science requirements and the technological possibilities, which required translating SMOS requirements into system requirements
b) progress on the theory of the instrument, emissivity modelling, use of ancillary data
c) Prepare the first version of the inversion algorithms.

Below are given the main outcome of these studies together with main actors and results. The presentation is organised in steps with (i) the general setting of the studies; (ii) instrument theory; (iii) theory of measurements, (iv) Retrievals and data processing, (v) application to the mission definition; and finally (vi) Scientific uses.

2.2 General setting of the project

Phase A studies are mainly around feasibility of the mission and for this the optimum must be found between the scientific objectives, the instruments characteristics and the platform capabilities.
The first constraint to be taken into account are linked with the fulfilment of the science objectives as expressed in the proposal (COP16) (Kerr 1998). So as to achieve this task the proposal was first translated into the Mission Requirement Document (MRD) (Kerr et al. 2001a) by the LI[2] and ESA to

[2] By LI is meant the group with the LI, Philippe Waldteufel, and the Co-LI.

be approved by the Science Advisory Group (SAG) which was constituted at the very beginning of phase A. So as to initiate the Industrial phase A (SMOS Extended Phase A: SEPA) the MRD was converted into engineering constraints in the SRD (ESA/ESTEC 2001) (ESA and LI). These two documents were regularly updated. Actually, with the progresses made on both instrument knowledge and scientific results, careful analysis of the Science requirements for both land and oceans was carried out so as to assess the main drivers in terms of system requirements (pixel size, swath width and revisit, sensitivity) and to translate them into engineering requirements during the phase A.
Obviously, in parallel work was performed in the industry to progress on the instrument design, to assess the sensitivity, antenna coupling and more generally to establish the various budgets (mass, power etc) for any given configuration.

The second constraint is linked to the adequacy of the characteristics of the mission (instrument and orbit) as found above and the possibilities of the platform (generic PROTEUS bus). The industry worked in collaboration to quantify the constraints (which were mainly on the weight, height of the centre of gravity (launcher dependent) and inertia (mainly for the Safe Hold Mode in the survival mode of the satellite)). Through an iteration process between the instrument design and the platform characteristics a final design was found for the instrument which is compatible with both PROTEUS and the science requirements.

The third and fourth constraints are the budget cap for the mission and the schedule. These are being currently analysed.

2.3 Instrument theory

As with any novel approach / instrument, several points were to be studied so as to finalise the instrument theory. These points are described below.

2.3.1 proof of concept

The SMOS mission is very innovative in the sense that it will enable retrieving surface variables (SM and OS) which have almost never been obtained by space measurements especially with an L band radiometer. Moreover the technique to used (2-D interferometry) is totally new in Earth observation. This is sometimes considered as a major risk so a "proof of concept" approach is necessary.

The interferometric concept itself concept has been developed in radio astronomy and is now very well proven. However, to use it over extended targets of relatively low contrast was a challenge. During the 80s several attempts were made to see whether such an approach could be used for remote sensing. The first attempts were made with a set of two antennas placed at different locations on a fixed frame to sample the visibilities, demonstrating the feasibility of the approach. The successful trial were made first by TRW in the US and then by other groups in the US and in Europe (TUD, DLR,…). They produced images of artificial or natural targets and the tests allowed identifying the advantages and limitations of such an approach (Peichl et al. 2000; Peichl et al. 1998). From these results a first instrument was made in the US the Electronically Scanning Thinned Array Radiometer (ESTAR) (LeVine et al. 1994). This instrument is a 1-D mono-polarisation (H) interferometer operating at L band. It was first flown on an Aircraft in the early 90s and has been widely used since (Jackson et al. 1995). The ESTAR campaigns were very successful and it was then demonstrated that the SM retrieval with ESTAR were of the same quality, if not better, as those retrieved with a classical radiometer (the Push Broom Microwave Radiometer (PBMR) which operates at L band and H polarisation) (Schmugge 1998) (LeVine et al. 2000).
The concept being proven, Europe took the lead by proposing an improved concept using 2-D, dual polarisation interferometry (the MIRAS project) (Goutoule et al. 1996), (Kerr and Thibaut 1994). 2-D interferometry offers a number of advantages at the cost of an increased complexity. The main advantage is probably the fact that such an instrument images a whole scene enabling multi-view retrievals which are put to use to separate soil and vegetation contributions in the signal. To

demonstrate the feasibility of the 2-D interferometry, an 11-element demonstrator was built (Goutoule 1995). Unfortunately this instrument was not used for a long time. In 1999, after some refurbishing the instrument was implemented on a crane in Avignon for testing (Bayle 2001; Bayle et al. 2001). In spite of some hardware problems, images were successfully produced (with a limited quality), extending therefore the proof of concept to the 2-D case (Bayle et al. submitted 4/01).
To further validate this result, an airborne instrument is currently being developed in Finland by the Helsinki University of Technology (HUT). The instrument is expected to be operational in the spring 2002. It will be tested on the ground during winter 2001. This instrument will finalise the proof of concept (in particular the calibration scheme which will be used on SMOS), and will be used intensively for campaigns.
In parallel, in the US, an airborne 2-D interferometer is being developed in the framework of the Instrument Incubator Program. It should also be operational in 2002. Close collaboration with the NASA team is performed both through the SAG and through direct collaboration.

In summary, one may say that even though no SMOS demonstrator has been flown on an aircraft yet, there is sufficient evidence that the concept is proven. The HUT 36 element radiometer will enable to finalise the "proof of concept" especially for several aspects not fully validated yet such as internal calibration for instance, and will provide the community with an instrument enabling the community to have access to SMOS like data to address specific issues (mixed pixels, snow, forested areas, etc…) and to finalise the retrieval algorithms.

2.3.2 spatial resolution and swath

Due to 2-D interferometry, SMOS characteristics are specific and it was necessary to derive expression to define its resolution, sensitivity, and swath so as to be able to check the adequacy between instrument characteristics and science requirements. For this purpose, definitions were proposed (IPSL) in co-operation with ESA and eventually finalised and recommended by the SAG.
Sensitivity definition was worked out by giving the equation defining it as a function of instrument characteristics (Jong 2001).
The pixel resolution is defined through the characteristics of the ellipse approximating the 3-dB power pattern footprint on the ground. It is the geometric mean of the main and secondary axes. In addition, the SAG recommended that the FOV be limited to those pixels whose ration between the two axes is less than 1.5 (Waldteufel , 2000; Waldteufel , 2001).

Finally the half swath is defined as the distance to the subtrack axis where soil moisture retrievals in presence of vegetation (less than 3 $kg.m^{-2}$ water content) are better than 4% vol. accuracy (Waldteufel , 2001).

All the above mentioned options and definition where discussed with and endorsed by the SAG.

2.3.3 Polarisation and Stokes parameters

In the course of the study definition it was found that when doing the transformation of polarised brightness temperatures in the antenna plane to ground brightness temperatures, the rotation induced ambiguities due to polarisation mixing making the 2 parameter inversion impossible in a part of the FOV (at about 45°). The problem was identified by IPSL/CETP and the solutions found were either to use full polarimetric mode (at a cost since the integration time is divided by 2) or by using a two step approach. This approach consists, in short, in retrieving only soil moisture and vegetation water content in the areas where the 2-parameter retrieval is possible. The values obtained for vegetation water content are then used in a subsequent orbit in the area where the 2-parameter retrieval is not possible to retrieve soil moisture (Waldteufel and Caudal submitted).
This approach after being discussed through the SAG have been endorsed by it.

2.4 Theory of measurements

2.4.1 Land emissivity

Over land the emissivity issue it self is already solved for the most, that is for smooth terrain, moderately vegetation covered areas which represent about 65% of land surface and correspond to the most significant target of interest for both science and prospective applications. Further work to be carried out is mainly related to emissivity changes due to frost/snow on the surface and to improve emissivity models for forests. Getting a first glance at the behaviour of urban areas would also be interesting.
To achieve these goals several studies were initiated in the framework of the ESA AO 3652 as well as several studies in France (Kerr and Bahurel, 2000) and in the UK (Simmonds 2000; Simmonds et al. 2001).
In the framework of ESA's ITT 3652, an emissivity model for forests was developed. Existing models for snow were inter-compared so as to build an integrated model for land surfaces including bare soil, different types of vegetation, water bodies, snow covered areas and atmospheric contribution. This model is now being used to generate a realistic L band brightness temperature map.
In parallel, all existing ground measurements at L band were pooled (including measurements at various angles over a large range of surface types (roughness, moisture, soil type, vegetation cover, …) so as to derive expressions for surface roughness contribution (Wigneron et al. accepted), and so as to analyse the polarisation and angular behaviour of vegetation opacity and single scattering albedo (Pardé et al., 2001).
Finally a field campaign was performed in Avignon (May -July 2001) to assess, with the TUD radiometer, the polarimetric signature over land.
These efforts will be complemented with the EUROSTARRS campaign planned for November 2001 (Lopez-Baeza and al. 2001) and which is an aircraft campaign with the upgraded SLFMR (STARRS - (Goodberlet 2001)). During this campaign several flights will be performed over forested areas (deciduous and conifers), and over an urban areas The aim is to address forest emissivity model validation, and assess urban emissivity.

The remaining issue over land is the soil covered by snow. This issue will be addressed when the HUT instrument is operational with planned flights in Northern Europe. The influence of dew and frost will be addressed during the Fauga-Pyrrène experiment near Toulouse where an L band radiometer will be operated continuously during 18 months. Currently the work concentrates on improving existing models.

The preliminary results will be presented and discussed at the 7th SAG meeting (end of September 2001).

2.4.2 Ocean emissivity

Retrieving sea surface salinity requires taking into account sea state. To address this issue several investigations were initiated. An ESA support study (AO 3618) was kicked of in September 2000. It aims at:

- ♦ analysing and quantifying the importance surface roughness, foam coverage, precipitation and diurnal SST variations on surface emissivity and derive the resulting SSS retrieval accuracies over incidence angles ranging from 0 to 50° (SMOS configuration)
- ♦ Examining and quantifying the impact of SSS retrieval accuracy over different ocean regions.

The mid-term meeting took place in June 2001 and the study is progressing satisfactorily. Several models were implemented and inter-compared. The preliminary results were presented and discussed during the 6th Sag meeting.

Nevertheless, such approaches mainly rely on existing and eventually improved models but uncertainties still remain (exact influence of wind speed, or foam for instance) To address these points, several field campaigns were organised.

The first one took place last winter over the Casablanca drilling platform East of Barcelona. This campaign, included several radiometers and field data collection (Camps et al. 2001) (salinity, temperature, wind, foam coverage etc..). Data is currently being analysed and will be used in AO 3618. The experiment will take place again in November 2001 with, in addition, over flights with airborne sensors operating at L band (TUD and STARRS) so as to encompass more conditions around the monitored point (Casablanca), the latter being used for reference. The aircraft will also fly over buoys in the Atlantic to assess wind effects, as well as salinity and temperature gradients so as to validate emission models.
The second experiment (LOSAC) took place in colder seas (North Sea) with flights of the TUD L band polarimetric radiometer (Rotboll et al. 2001). The goal is to quantify more accurately the influence of wind speed and to assess the usefulness of polarimetric measurements.
In parallel, in the US, co-operative studies are being initiated to improve the relationship between salinity and emissivity. Experiments at sea are also being designed in collaboration with European research institutes (Belkin et al. 1998; Lagerloef et al. 1995).

2.4.3 Perturbing factors

Several potential perturbing factors, mainly due to the atmosphere and linked to SSS retrievals (where the requirements are the strongest) have been investigated and discussed during various SAG meetings and with our US colleagues.
Faraday rotation due to the ionosphere is one of them (LeVine and Kao 1997). The choice of the 6 a.m. orbit is in part linked to this effect. To infer or correct Faraday rotation, several approaches were tested, Use of the full polarimetric mode, using TEC measurements to correct for it were two of them. However a simpler solution was found by simply using the two polarisations to cancel Faraday rotation effect (Skou, 2001; Waldteufel, 2000).

Sky reflection, atmospheric contribution will also have to be accounted for. This will be done by using ancillary data (typically sky map and model outputs) and should not pose significant problems (Floury 2001).

Sun glint, has more severe effects on the measured signal and will have to be accounted for or, more probably the affected area (estimated with geometrical considerations) will have to be either masked or flagged. Considering the orbit equator crossing time, it is not expected to have severe pollution by sun glitter.
All these points are being studied at ESA in collaboration with members of the support studies and CETP/IPSL. There are also considered in the frame of co-operation with US colleagues.

Finally the cloud and rain influence on the signal over oceans are being addressed in ESA's ITT 3618.

2.4.4 Calibration and random errors

While there is no much doubt that the SMOS mission will deliver useful data over land, sea surface salinity is more of a challenge for the instrument. The main challenges are related to the absolute calibration of the system and the bias averaging. Calibration is under study at ESA and some aspects (hardware and related software) will be tested with the HUT radiometer (which has the same calibration as SMOS). Considering below neither hardware calibration nor techniques linked to the interferometric instrument which is also studied (see (Torres et al. 1996) and (Lannes 1998; Lannes 1999; Lannes and Anterrieu In press), we will concentrate on other issues (Waldteufel, 2000; Drinkwater, 2001).
For sea salinity retrievals it is important to have a very high sensitivity and accurate calibration. To address the first point spatio-temporal averaging is used but it implies good stability. The points to be addressed and which are currently under study are thus

- whether it is possible to average systematic errors and to take into account

- cyclic errors (orbit, eventually seasonal)
- Calibration and stability of instrumental biases

Nevertheless calibration is important for sea salinity retrievals. If satisfactory it will be more than satisfactory for land surfaces considering the requirements (the temperature difference between the two targets is not an issue thanks to the high quality Noise Injection Radiometer (NIR) located at the centre of the interferometer).

a) The first point to be addressed is to verify that a large number of systematic errors behave as random errors which can be reduced by space and time averaging. This point is currently under study (CERFACS/IPSL). These errors can be either due to the instrument or the geophysical parameters. Using the existing and planned network of SSS buoys deployed in the framework several programs will allow to have access to a large number measurements for calibration, typically:

- ARGO (3000 floats available surfacing every 10 days, hence about 100 hits /day for SMOS),
- TAO TRITON (about 70 buoys hence at least 25 sampled every day)
- Surface Drifter Array if equipped with salinity sensors (about 200 planned) would enable about 70 hits/day
- Volunteer Observing ships with thermosalinographs would allow about 3 hits per day

These measurements will be scattered all over the FOV and will be seen hence several times during any pass. It is not expected to have biases across the swath as with classical radiometers. In any case this assumption will have to be verified (statistical methods) during the commissioning phase.

b) The second point to be taken into account is linked to periodical errors (orbit, oscillations). This issue is to be addressed during phase A/B. mainly through orbital simulations and instrument modelling.

c) The third point is the short-term stability of the instrument (excluding regular variations depicted above). However one could expect that a similar approach to that described in a) could be applied. This will be tested as well.

d) Finally long term stability can be addressed using similar techniques to that developed by C. Ruf for SSM/I (Ruf 2000). Such approach (with use of climatological means) is applicable to SMOS.

It is also considered currently to use a more global calibration scheme that would actually merge in a way calibration and validation. SMOS data over the oceans would confronted with all available SSS measurements with an unknown error function including a bias a wind speed dependence and possibly a couple of other dependencies) which would be adjusted by forcing SMOS SSS retrievals to the measurements.
There are other potential means to perform calibration. We are considering currently the use of point sources such as the Moon (Delahaye et al. Submitted 2000) (it is feasible on the satellite point of view but the signal will be weak (Kerr, 2001) and on extended targets. Considering the way such a 2-D interferometer works, the latter is rather complex and it is not sure we will find targets of sufficient dimension of homogeneous and known properties (the element beam width is of about 70°). Currently under investigation, a part of Antarctica (Dome C or Concordia) is probably the most suited target (Drinkwater 2001).
To validate the soil moisture retrievals, we intend to use large-scale field experiments (such as SGP) with aircraft coverage as well as the different sites implemented in the framework of the AMSR missions.

2.5 Data processing

2.5.1 Reconstruction

It is obvious that this is the core of the ground segment as it allows transforming data coming from the satellite (visibility functions) to useful brightness temperatures. The subject has already been given extensive attention in the previous years (Thibaut and Kerr 1990) and several algorithms do exist (Camps et al. 1996; Lannes et al. 1996). The effort now is to inter-compare these algorithms and this is done for a good part within the simulator study (SEPS). Nevertheless we are also working on the optimal choices for the reconstruction algorithm by finding the most appropriate apodisation function in view of the science objectives. The first results are described in (Anterrieu and Waldteufel 2001; Anterrieu et al. Submitted).
To further test reconstruction algorithms several synthetic scenes were constructed.

3.5.2 Land algorithms

An important effort was performed during phase A to work on retrieval algorithms. The work is still underway and is carried out in the framework of various programmes be it ESA support studies or studies supported at National level. A short description is given below.
It is also important to start working on the retrieval algorithms so as to assess more accurately SMOS capacities of course, but also to be used in the SMOS mission simulator, to be used in the mission optimisation and to start dimensioning the ground segment.

Over land several studies have been concluded and a basic retrieval algorithm has been established (and used for the mission design optimisation (Kerr et al. Submitted 10-2000; Kerr et al. 2001b; Wigneron et al. 1995; Wigneron et al. 1999; Wigneron et al. 2000). We are now addressing through ESA AO 3652 and the French programme, others aspects of retrievals. Actually, the above mentioned studies were done for homogeneous areas, it is thus necessary to address the issue of mixed pixels. A first study was performed (Mathiaud 2000) to assess retrieval accuracy when the pixel is partly covered with free water or forested areas. Provided some *a priori* knowledge is available, retrievals are possible. Similarly, while a pixel is viewed with varying angles, its size varies inducing similar effects to those of in-homogeneities. To address further these points, the EUROSTARRS campaign will cover a patchy agricultural area with varying footprint sizes. And this will be done in conjunction with AO 3652 where a complex scene (i.e., realistic) is simulated. However, over land, the errors caused by these effects are not significant when compared to overall radiometric errors.

Another topic of interest is the influence of topography on the signal. The Eurostarrs campaign will also over fly a mountainous area (the Pyrénnées) to have a first evaluation of this feature. In parallel satellite data at higher frequencies but similar resolution to SMOS (SMMR and SSM/I) are being studied.
Partially snow covered areas will be addressed with the HUT radiometer when available even though in the ITT 3652, this point is being addressed by simulation.

2.5.4 Sea salinity algorithms

Over the oceans retrieval algorithms will be tested with the EUROSTARRS data, but several experiments in the US (ESTAR, SLFMR) showed the feasibility and the ESA AO 3618 is addressing the retrieval algorithms. Consequently, the basic feasibility of the retrievals has been proven but, as stated above, the main issues of concern are linked currently with the theory of measurements before retrieval algorithms can really be tested. The goal of the on going campaigns (WISE) and future campaigns (EUROSTARRS) will be to test the obtained algorithms with real data. It is worth noting that simple experiments can be done at ground level on land, but at deep sea, the practicalities are much more difficult (need for a platform, brine on the instruments etc…) and expensive. The need for aircraft measurements is thus crucial and significant progresses are expected both in collaboration with US Experiments and with the availability of European airborne instruments (TUD, HUT).

With our current knowledge of the instrument and physics of the signal, it is difficult to guarantee 0.1 psu. We are thus targeting an absolute accuracy of 0.1 K (which translates into 0.2 psu for warm oceans with minimal revisit). This is not as good as in COP16 but still compatible with the GODAE requirements. One should also be aware that such performances are equivalent to those of current and planned space-borne classical radiometers.

2.5.6 Ancillary data

Another point is being studied for both land and sea: it is the use of ancillary data to improve retrievals. It aims at assessing what ancillary data is necessary, with which accuracy and the impact on the retrieval accuracy. This is currently being studied in the framework of the ESA support studies.
Over oceans it will be necessary to get access to SST and wind for the surface and atmospheric characteristics (cloud, rain, and water vapour mainly) At the current stage of the studies, it seems that the temporal coverage and accuracy of existing sensors of model out put should be sufficient
Over land a rough estimate of surface temperature should be enough (model out puts or IRT data). But it is most probable that maps of water bodies will be necessary (mixed pixels). Existing DEMs should be sufficient.

2.6 Simulator

Currently CASA EADS and GMV in Spain are building a SMOS end to end simulator. This tool will enable to simulate the SMOS mission from natural surface emission to retrieved surface variables. It includes an instrument model, the orbit propagator, reconstruction module. On the geophysical part the results from the above mentioned studies will be fed in the simulator to improve its realism. In other words there are many interactions between the various studies and the simulator that will eventually be used to test the full retrieval algorithms including all instrument and orbit constraints. The simulator will also be used to inter compare different schemes / algorithms /approaches and will be both the focal point in phases BCD and the test bed for the ground segment.
While the simulator is being developed, several studies are underway on improved elements of this simulator as reflected above. Simplified simulators where already built (excluding accurate orbit propagator or sophisticated instrument model), allowing to optimise SMOS configuration and to assess how a complex scene is viewed as the satellite progresses in space and the corresponding retrieval accuracies across the FOV.

2.7 Optimisation

The mission configuration optimisation was carried out during the first part of the phase A and was concluded during and just after the Preliminary Concept Review (PCR) (4/2001). The end of the phase A being devoted to the consolidation of this configuration and the cost and schedule analysis.

In a nutshell it may be said that oceanographic applications are drivers for the instrument sensitivity (somewhat levied by the possibility to do spatio-temporal aggregation), stability, and availability and quality of ancillary data. Over land the drivers are the spatio temporal sampling, the range of view angles (to separate soil and vegetation contributions) and sensitivity.
To assess the optimal configuration, an optimisation scheme was developed, taking into account instrument characteristics, orbital possibilities, surface characteristics and a straightforward inversion algorithm to quantify, in a parameterised way, the mission performances over various targets as a function of the mission characteristics. This optimisation was carried out for land surfaces, as ocean retrievals were not the drivers. The optimisation scheme allows then to assess the optimal range of values for the SMOS configuration (Kerr and Waldteufel 2001). The approach is described in (Waldteufel et al. 2001). (Waldteufel and Caudal submitted).

2.8 Scientific use

2.8.1 Assimilation in ocean models

It is being performed by analysing *in situ* data (e.g. thermosalinographs) and model outputs in the Atlantic (MERCATOR simulations). The analysis consists in spectral analysis and a characterisation of the main spatial and temporal scales of SSS (Kerr and Bahurel, 2000). To characterise the signals as a function of spatial and temporal scales the SSS fields obtained were filtered (LOESS 2D/3D) with different wavelengths and cut off (200 to 1000 km, 10 days to 3 months). The objective is to characterise the signals which will be seen by SMOS (i.e. small scales less than 200 Km) and to quantify the part of SSS variations which are due to mesoscale to those directly linked to large-scale ocean dynamics and E-P forcing. As a function of the SMOS sampling and instrument characteristics (noise) the extend to which SMOS will be able to measure these different effects will be quantified.

By then comparing Mercator's outputs with *in situ* data it will be possible to quantify where the model has deficiencies which could be corrected by using SMOS data. This will enable preparing the assimilation scheme for SMOS SSS data in MERCATOR.

2.8.2 Assimilation in land and hydrologic models

SMOS will deliver data on SSS, SM and vegetation water content. However, through assimilation procedures it is possible also to infer root zone soil moisture as it has already been proven (Calvet and J. 2000; Calvet et al. 1999; Calvet et al. 2001; Wigneron et al. Submitted June 2001) Further tests will be performed using the data collected during the FAUGA Pyrrène experiment near Toulouse.
We are also considering assimilation to infer surface variables directly with SMOS data over both the ocean and land. Such approaches, widely used in the field of meteorology, should enable to improve retrievals and are currently being studied in the framework of the French and UK preparatory programme for SMOS in collaboration with the US (MIT).

2.8.3 Assimilation land hydrology

We are currently assessing how the pixel information can be dis-aggregated by coupling a SVAT and a hydrologic simple model. A study is underway and the first results are encouraging (Boulet et al. 2001; Pellenq et al. 2001a; Pellenq et al. 2001b). With such an approach it seems possible to infer SM distribution within a pixel with use of a SVAT and topographic data.

2.9 Overall mission design.

The selected configuration consists of an instrument flying on a polar orbit at a mean altitude of about 756 km (sun-synchronous 6am/pm). The instrument is made of three arms at 120°, one being perpendicular to the orbit (30° steer angle). Each arm consists of 3 segment having each 6 elements. Aligned to each arm, on the central part (hub) are 6 other elements and the noise injection radiometer (at the centre). The elements spacing is about 0.875 λ. The antenna plane (hence the whole spacecraft) is tilted by about 32 °.
The data downlink can either be performed at S band if several high latitude receiving stations are used or with an X band link. The last option, preferred as it enables more flexibility and on board processing, is feasible and currently under study (accommodation on the platform).

With such a configuration, over land, the critical points (radiometric sensitivity impact, soil moisture obtained globally with an accuracy of 4% or better ever 3 days at worst and with a spatial resolution better than 50 km) are all satisfied for vegetation cover contents less than about 4 kg m-2 The optimisation work was performed with a basic but well proven model and with some margins. Now the

remaining actions to be performed during phase B will be to extend the emissivity theory so as to improve those results, to address mixed pixels and the variable size of the pixels. And performed campaigns to start addressing retrievals under forested areas, mountains etc… In the proposal these areas were not considered (assumed to be too difficult to address before launch) but we now feel that some progresses can already be made.
Over ocean surfaces the chosen configuration is predicted to give an accuracy better than 0.1 psu every 10 days over 200 x 200 km pixels, when random errors due to radiometric uncertainties are considered.. However several critical points are still be addressed (sea state, instrument biases). To address these several campaigns are underway or planned (LOSAC, WISE 1 and 2, EUROSTARRS). Instrumental biases are also being studied through simulations. Stability and calibration are still to be addressed during the next few months.

3 Summary of support studies

As they are described in the previous section we will not go into much details on the support studies but simply list them (a chart at he end give an overview of the schedules)

3.1 ESA Support studies:

- **Scientific requirements an impact of space observations of ocean salinity for modelling and climate studies (AO 3618)** Kicked off in September 2000 this study had the mid term meeting in June 2001This study is intended to clarify observation requirements. To achieve this a range of simulation experiments will be performed at various scales (i.e. global, regional and local) to establish requirements for global observations of salinity for the modelling of: - mixed layer processes including surface fluxes such as evaporation through the air-sea interface; - the thermohaline ocean circulation including overturning and deep water formation. From these simulations a set of observation requirements will be derived and used to define the performance specification to be met by a space-borne mission.
- **The soil moisture requirement study (AO 3652)** It should include the EUROSTARRS Campaign in its second phase. Kicked off in November 2000 the study is under way. The main goal is to produce realistic brightness temperature maps (fine scale for restituting a single SMOS pixel and a global map) from ground data (surface characterisation) and forcings (Arpège). This will be then validated with aircraft and ground campaigns. It will also be sued for testing and validating retrieval algorithms.
- **The Salinity Data processing study (AO 3751)** has just been kick off: Its objectives are (i) to advance the definition of the data processing for salinity retrieval; (ii) to advance the understanding of the physics of the interactions for the given system characteristics and for several types of sea targets; (iii) to assess issues specifically related to space-borne acquisitions such as the impact of inhomogeneous surfaces and of variable pixel sizes, the need for high-quality ancillary data and for well-monitored sea areas to serve as references for the relative calibration of the SMOS system, by means of integrated models, finally used also to develop improved models for the simulation of brightness temperature from geophysical parameters; (iv) to develop algorithms to retrieve OS from the measured brightness temperature and evaluate realistic performance targets.
- **The soil moisture retrieval study (AO 3886)** is currently open for tender. This study has the objective to analyse existing soil moisture retrieval methods (and if necessary to develop new retrieval methods) using L-band microwave radiometry data by in particular accounting for the data characteristics as expected being delivered from the SMOS mission. Special emphasis shall be put on the heterogeneity of land cover and its spatial and temporal variability, the shape of the SMOS footprints as well as aliasing and singularity effects within the SMOS swath. The study shall also provide recommendation on the baseline operation mode (dual or polarimetric operation mode) for the SMOS mission.

3.2 Other studies are currently underway outside ESA programmes.

- The main one is funded by the French SMOS preparatory program (TAOB) with three folds: one on image reconstruction, one on land and one on oceans. Most of the funding is devoted to instrumentation (a large ground based radiometer is under construction, as well as drop sondes for SSS *in situ* measurements) work on the mission optimisation and on reconstruction algorithms and work on emissivity modelling, assimilation, SVAT coupling, and dis- aggregation.
- The French national programme for remote sensing funded the Avignon Experiment with TUD in 2001 an the MIRAS 99 experiment
- The Région Midi Pyrénées funded with CNES the Fauga Pyrrène experiment near Toulouse (ground measurements).

3.3 Campaigns

The campaigns are designed to help address the different points stated in section 3. We will just give a brief description.

3.3.1 Ocean studies

WISE 1 ground based (platform at sea) influence of wind and foam on radiometric signal
WISE 2 same as WISE 1 but with A/C over passes
LOSAC Aircraft experiment in the North Sea to assess polarimetric signal and wind influence at L band
EUROSTARRS aircraft campaign designed to measure SSS and SST over a gradient as well as wind influence over buoys.

3.3.2 Land studies

MIRAS 99 ground level Proof of concept for SMOS
AVIGNON 2001 Ground level: Polarimetric signal and measurements over other crop types (corn) to supplement data base
Fauga Pyrrène ground level: long term monitoring of SM including special events (frost dew) over bare soil and grass (not measured yet in other experiments). Improvement of assimilation procedures.
EUROSTARRS aircraft campaign covering a large number of sites to address crop in arid environment, orchards and forests, scaling issues, urban area signatures, influence of topography.

4 Conclusion

Being now close to the end of phase A we have now enough material and proofs to show that not only the SMOS mission is feasible but also that all the commitments made in the proposals are fulfilled. Moreover the comments or questions from ESAC are almost all covered Over land we respect all the requirements with margins and can even envision improvements with respect to forested areas most of the results are published or in press showing the acceptance of our approaches through peer review. Over the oceans, some issues are still being investigated but all results obtained so far allow us to be confident.
It is certain that we are still addressing some of the issues as described above. All the support studies haven't been launched so far and it takes some time to complete them but one may note that we are addressing now issues more relevant to later phases than phase B. Similarly, it takes some times to organise, perform and analyse a campaign and all results are not available yet. However, here again first results and results obtained in the US allow us to be very confident.

It may also be noted that the three constraints (science, instrument and platform) have converged towards a good optimisation. The whole SMOS mission is technically feasible and satisfies the science objectives.
The most urgent actions currently are to finalise the points under study for SSS (stability calibration, averaging of systematic errors) and the mixed pixels over land.

To summarise the project advances at a steady pace and the schedules are currently all kept. The next steps are getting the final support studies output, get access to the mission simulator and to the HUT demonstrator. It is very encouraging to see how collaboration with other countries outside Europe (and especially with the US) is gaining much momentum.

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Attached Documents

PCR documents
PRR documents
Studies interim reports.
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SEPS and SEPA Reports

ANNEX 2

SMOS Related publications

Books and part of books

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ANNEX 3
ESAC Assessment Report on SMOS
And comments

See attached Documents

a) Reports and comments
b) Letter To Dr. Readings

c)

Annex 4
The SMOS SAG

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Dr Jordi Font	ICM Barcelona Spain	Co-Chair
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Dr. David Le Vine	NASA/GSFC, Greenbelt, USA	Instrument (US Rep.)
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ANNEX 5
Schedule