MISSION PRODUCTS

AND

DATA PROCESSING REQUIREMENTS

FOR SMOS

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REFERENCES

1	System Requirement Document	2.1	Feb 2000
2	SMOS Proposal (COP16)		Nov 1998
3	Mission Requirement Definition	5.0	Mar 2001
4	EASE GRID definition		

ACRONYMS

ASC	Ascending (pass)
ATBD	Algorithm Theoretical basis document
CCSDS	consultative Committee For Space Data Systems
CEOS	Commitee on Earth Observation Satellites
CESBIO	Centre d'Etudes Spatiales de la BIOsphère
CFC	CNES 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
LST	Land Surface Temperature
NAO	North Atlantic Oscillation
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 temperature at antenna level and in antenna ref. frame
WS	Wind Speed

TABLE OF CONTENTS

1. INTRODUCTION

This document aims at being a skeleton of what could be the SMOS processing philosophy. It is thus a draft of how the SMOS ground segment could be organised. It is intended to cover all aspects from raw telemetry to final and elaborated products, e.g. not limited to level 2[1].

1.1 CRUDE LEVEL DEFINITION

So as to avoid ambiguities, in all the following we will try to stick to CEOS level definitions adapted in a way to SMOS specificities. The levels are explained in subsequent chapters and paragraphs but so as to give an outline, the basis definitions are:

1. **raw data;** what comes out of the instrument through the ground receiving station
2. **Level 0** raw data unpacked, organised and with adequate and available information (orbital, health, mode, etc…)
3. **Level 1** brithness temperatures in basic and nominal spatial and temporal resolution, calibrated.
4. **Level 2** geophysical variables (i.e., soil moisture and ocean salinity) at basic spatial and temporal resolution
5. **Level 3** geophysical variables with improved characteristics through temporal and/or spatial resampling or manipulations
6. **Level 4** Improved level 2 or 3 through the use of data from other sources, elaboration of other products (root zone soil moisture for instance)

1.2 BASIC CONSIDERATIONS

In the following, it is assumed that processing facilities consists of two parts: mission facilities (Payload Data Processing Centre or PDPC) working with the Expert Support Laboratories (ESLs) and developed through ESA, and a dedicated centre tentatively located in Toulouse and developed by CNES mainly working on levels 3 and 4 (CFC). This centre would also work on improvements on image reconstruction techniques and on improving the sensor's calibration (research and improvements) as well as on global retrievals of soil moisture; ocean surface salinity, and specific products over land, oceans and cryosphere

- The ground segment mission facility (the core where raw telemetry is transformed into calibrated brightness temperatures and level 2 products) is covered by ESA in the framework of the Earth explorer Opportunity missions. This facility will be located at Villafranca and will thus produce products up to level 2.

[1] It is understood that the ground mission segment will process up to level 2

- The second part is still TBC. In this document we will assume that a "CNES" centre will cover the production of levels 3 and 4. The goals of this centre will also be to work on improving algorithms and calibration, the results, once fully validated, being transposed in the mission ground segment at Villafranca. The CNES centre will develop and use "state of the art"[2] algorithms to generate and disseminate elaborated products (levels 3 and 4). It will also work on improving eventually level 1 and 2 algorithms, calibration, etc… In parallel to such "research" activities the centre will "industrialise" the level 3 and 4 algorithms so as to and process data accordingly and disseminate /archive the corresponding products

This note is divided in 4 parts: in the first we will describe the overall context, the second part will deal with the mission ground segment producing up to level 2 and located in Villafranca. The third part will describe what should be the CNES centre Finally the fourth part contains several potentially useful annexes.

[2] after approval bythe SMOS Science Advsiory Group.

2. CONTEXT

2.1 BACKGROUND

Issues related to the state and the evolution of the Earth system is currently considered as a significant problem to be addressed. Global change issues, forecasting of extreme events such as major floods, improvement of weather forecasts and better management of water resources are consequently under scrutiny. For this purpose it is necessary to achieve a better understanding of the climate system, the water cycle so as to be able to monitor it at a global scale and achieve realistic projection of trends and potential future evolutions, including anthropic effects. To achieve these ambitious goals it is necessary to improve existing models and to have access to global data sets of surface variables.

Satellite remote sensing is a key element as it enables to gather repetitively and globally relevant surface variables. However, to be useful, such data must be acquired and processed over relatively long periods of time in a consistent manner. It is also important that data is made available to the science community at large as its fosters use and leads to innovative approaches as to their use. After the algorithms are well tested and validated they can be transferred to the users community.

In this context, space agencies and the European Union have launched programmes aiming at the development of "observatories" of the environment based on a concerted implementation of complementary observing means (ground, A/C, and satellites) data collected by such means are to be integrated in entities able to ingest them into models for assessing and monitoring the environment. For efficiency purposes these observation means and data, their processing and analysis should be structured according to thematic considerations. It is now well admitted that, if remote sensing can provide useful information on several variables some basic ones such as soil moisture and sea surface salinity are cruelly missing.

2.2 THE SMOS CASE

In all the following, we will endeavour to use classical definitions for the different levels. However, the characteristics of SMOS [1-3] entail some specific features that will have to be taken into account. These will be detailed below. Not specific to SMOS but quite important is the ancillary / auxiliary data point. To be processed efficiently such data sets will have to be available at the ground segment (also called PDPC for Payload Data Processing Centre). It is a dimensioning factor.

In the following we will use specific name for information additional to observation data, for the sake of clarity:

- **Ancillary data** are directly linked to the mission itself, whether coming directly with the telemetry (on board calibration data for instance) or through another path (e.g., improved satellite attitude from post processing of orbital data for a more accurate reconstruction).

- **Auxiliary data** will correspond to the data sets necessary for processing and variable with time such as TEC, SST and LST, snow, frost, etc….

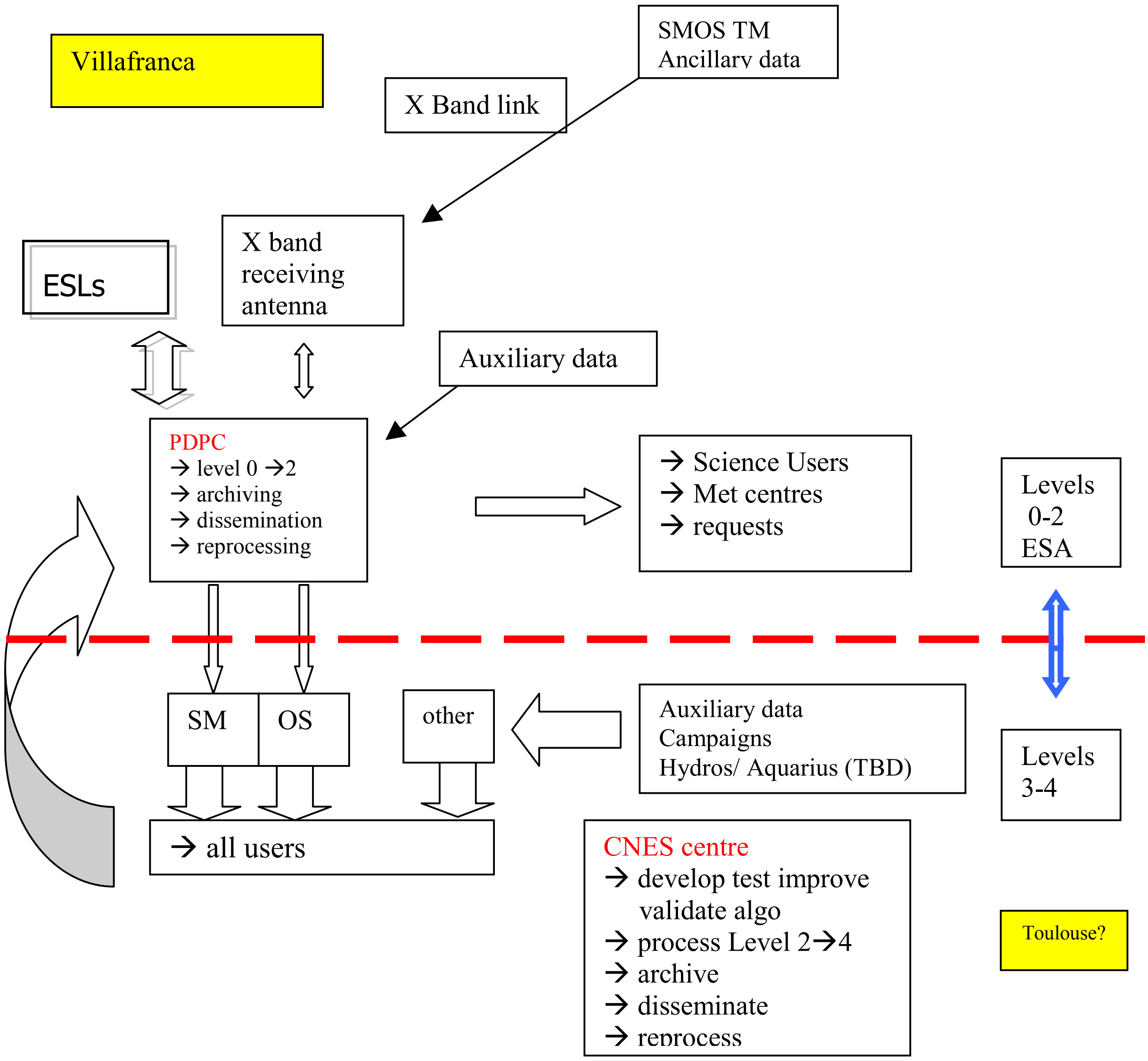

Figure 1 Schematic view

2.3 GENERAL REQUIREMENTS

2.3.1 ARCHIVING AND REPROCESSING

As SMOS is a demonstrator programme with new techniques and measurements involved, it is expected that during the first years of life the algorithms will be improved regularly and will hence require reprocessing. This is obviously true for any programme but especially for SMOS (new instrument with surface variables never measured before). Moreover the data will be useful for long term analysis and thus the whole data set must be maintained and eventually reprocessed (very similar in some respects to what was done within the Topex Poseidon programme).

This means that the data set will have to be archived for all levels necessary for total reprocessing and that the processing speed must be adequate to avoid any bottleneck, i.e., a scene must be processed in about (rule of the thumb) a fifth of the time taken by the satellite to acquire it[3]. This has to be pondered by the useful operation time of the processing centres (e.g., 24/7 or only 8 hrs per working day) (TBC). This is a strong requirement to be considered in the definition phases for assessing the different processing centres.

2.3.2 REAL TIME CAPABILITIES

As to the delay between satellite acquisition and processed data delivery, during the initial stages, it is not assumed that near real time will be necessary and that a delay of 3 days could be acceptable[4]. Moreover, with the current SMOS system it is not possible to envision near real time operations.

2.3.3 MAIN PURPOSES

. Together with coarse flow charts and level definitions. The processing of SMOS data must be considered with three different perspectives:

- Produce Archive and disseminate SMOS data up to level 2 with reprocessing capability
- Provide an ability test assimilation in models by meteorological offices
- Produce, archive, and disseminate level 3 (and eventually higher) products with reprocessing capability

In the two next sections we will give a first outline of what is expected from the different processing centres

We will not address here the communication links between the centres and only suggest possible ways of disseminating the data.

[3] This is my estimate. It will have to be confirmed by more knowledgeable people

[4] The rationale here is that global coverage is obtained at the equator every 3 days and if the processing centre closes on Week ends ….

3. MAIN PROCESSING CENTRE

The mission processing centre called PDPC is located in Villafranca (Spain) and receives the telemetry from the satellite to produce everything up to **level 2** (1b in proposal) with corresponding archival and dissemination. The significance of levels for the specific SMOS case is described hereafter.

The PDPC will receive thus the telemetry, archive it and produce through the so-called image reconstruction algorithm, calibrated brightness temperature and basic geophysical products (soil moisture and sea surface salinity at nominal spatio temporal resolution).

It is proposed that this centre will process data that will be as described below.

3.1 PROCESSING STEPS AND CORRESPONDING (TENTATIVE) DATA LEVEL NAME

3.1.1 RAW DATA

Input:

Raw data is data as downlinked from the satellite to the Payload Data and Processing Centre. This might, with one ground receiving station, comprise up to 6 (TBC) consecutive orbits of data, on an "as acquired" basis. As all the orbits are not necessarily in the visibility range of the station.

Raw data should probably be separated between radiometric data and ancillary data (House keeping [HK-TM] and calibration).

Granularity: CCSDS "packets". (CCSDS stands for Consultative Committee for Space Data System and is a standard commonly used. This norm defines the elementary packets sent by the satellite by telemetry. These packets have to be "unscrambled" to release their information content)

Archiving duration: It would be nice to archive "for ever" but the option is maybe too costly. The very minimum is to archive until the next level is produced and checked (i.e. the next level is considered as valid and archived). The trade-off is probably with an archive duration of a minimum of (tentatively) **1 month**.

3.1.2 LEVEL 0 DATA

Input:

Raw data

Data processing:

- format into orbits (from South pole to South pole basis[5]),

Ancillary data processing and adding

- product header (orbit number, start geolocation, end geolocation, start time, end time), and
- ancillary files as needed: satellite location, time, attitude, instrument calibration, health).
- indication on operation mode: data take, dual pol /full pol, calibration mode, eventually moon calibration and drifting phase in or out of moon calibration)

Note: as PROTEUS can provide time, orbit state vector, and attitude state vector to the CCSDS science packets, there might be no need for getting any extra ancillary files (at this product level) except maybe update orbital and attitude data.

Granularity: CCSDS packets

Archiving duration: here again "for ever" is preferred. It can be considered that either raw or 0 are to be archived the other being archived for a limited period (possibly 1 year, subject to trade-off).

3.1.3 LEVEL 1-A

This is the last step to produce reversible basic products (TBC):

It is on a per orbit basis (separate ascending and descending or use a flag).

Data input: level 0

Data processing

- Convert to engineering units (e.g. digital counts to temperatures, voltages, and currents).

However, as most of the data are digital correlation data not processed in this step, the level 0→ 1-A processing might be rather trivial.

Ancillary data processing and adding

- Geolocation information (satellite level) is generated and appended to each packet.

Data processing

Processing from correlation products to visibilities at antenna level (noted here TBX and TBY[6] for the two polarisations) using calibration information. There are still issues to be addressed at this level:

[5] Ordinarily the orbits are "cut" at the equator ascending node). As this choice is very arbitrary and as we will eventually separate the orbits n between ascending and descending it seem more rational to separate at the south (or north) pole

- The visibilities are rather straightforward to retrieve from correlations when the system noise contribution can be subtracted, which in turns requires to be able to perform in flight calibration.
- It might very well be at this level as well that one has to subtract the sky background so as to expand the alias free zone. This in turn requires knowledge of the background and pointing.

So for this level there are two types of processing to be considered:

- The correlation products are processed to visibilities using all the onboard calibration information (but for the fringe wash and NIR) as it is necessary to account for all the system noises, phase errors and correlation offsets.
- As the alias free zone *stricto sensu* is small, it is enlarged at this level by subtracting the sky contribution, extending thus the alias free zone to the earth replicas (up to when the Gibbs phenomenon is small enough actually). Of course when imaging the sky this does not apply and what will have to be done then is TBD.

A good level 1-a would possibly be between these two bullets. This will require more thoughts.

Ancillary processing and adding:

Necessary calibration data (in particular antenna pattern for reconstruction so could be added later)

Granularity: packets

Archiving duration:

This data set is the **main one up to now**. Some trace of it should be archived for the **mission lifetime at leas**t and should contain all what is needed to go further in the processing. However, as explained above, even this is not trivial. The ideal would be to archive a product without any correction /calibration but with all the relevant data to do so, even the possible apodisation functions (probably fixed after initial fine-tuning). The archived product would then be provided together with each data product (an "Extractor Programme" which applies the (user selected) calibration, sky noise correction, apodisation etc .. to the data "on the fly". (This has been successfully applied to other projects; applicability to SMOS needs to be discussed).

Such a level 1-a can be considered as a product and would be delivered to specific and well identified users (developers of reconstruction algorithms for instance) and the ESL/CFC

Main uses → reprocessing, test of reconstruction algorithms

[6] This notation is temporary and should be made compatible with the standard SMOS reference frames notations

3.1.4 LEVEL 1B RECONSTRUCTION STEP AT INSTRUMENT LEVEL (TOA[7])

This is done on a per orbit basis eventually separating ascending and descending and polarisation (for either full pol or dual pol)

Inputs:

Level 1-a

land /sea/lakes mask to be able to select apodisation window and start flagging the pixels

It is the step of image reconstruction for the brightness temperature scenes of X and Y polarisation, at the original spatial resolution of the frames, (i.e., pixel sizes and elongations as well as viewing angles vary across the swath/image, in other words, nothing is done with the data. [8]

Ideally it should be done with two or more apodisation windows, one corresponding to land and the other to oceans (TBD). The issue is to decide whether we want to do the apodisation either on visibilities (very simple and fast but requires to do the reconstruction once for every apodisation window) or on the TB through convolution (no so direct) …. So it is really a computing question.

Adaptative processing could be considered but we consider that it should be first tested at the level at the CFC. It will make sense only if apodisation is applied **after** reconstruction most probably.

There are two options for reconstructing TX and TY angular data sets in the antenna frame (director cosines): It will be necessary to select one most probably.

Option 1: reconstruct TX and TY on a uniform grid in the director cosine plane which would correspond to a fraction of the angular resolution

or (preferred option)

Option 2: reconstruct TX and TY in a non-uniform grid (in the antenna frame), but chosen so as to correspond to a uniform geographical grid. (size better than 15 km).

In both cases: compute radiometric sensitivity. Then:

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[7] actually TOA is not exactly top of the atmosphere but rather immediately underneath the satellite!

[8] I am not sure the azimutal dependence plays a role and thus wind direction might not be necessary current studies show some small effects. TBC though

Option 1: incidence angles, pixel characteristics taken from look up tables

Compute pixel centre co-ordinates, relevant angles

Option 2 (preferred) compute and store director cosines, relevant angles, and pixel characteristics (pixel centre co-ordinates = nodes of geogr. grid taken from look up tables). It will be necessary to locate TX and TY (or 4 stokes) to take into account the displacement due to switching (1.2 sec)

Granularity: pixels in antenna reference system

Reversibility **to be checked**

Ancillary data: best possible orbit and attitude. This is to be provided by CNES in an adequate delay (TBD) not to hamper processing. We currently believe that standard PROTEUS information on orbit will be adequate. This should be the solution sought for. If it is not possible, the whole issue will be to see whether more accurate information will be available routinely and if yes with which time lag.

Auxiliary data: sun and sky (galactic noise), TEC (tbc)

Ancillary data: pointing

Archiving duration: short term according to further processing needs Ideally the data is archived until the next level is produced and checked.

It is currently our belief that the soundest option is option 1. The processing flow would then be as the one described on figure 3 below.

3.1.5 LEVEL 1C TB ON GEOGRAPHICAL GRID

Should be on an orbit basis but separated into ascending and descending as well as polarisation. Ideally the Faraday rotation correction should be done at this level.

Input:

Level 1b

Possibly data files for next steps (TBD) i.e., atmospheric characteristics, soil maps, WS, SST, and LST…. etc… These data *per se* are only useful for subsequent steps so it might not be cost efficient to carry them along. However, it simplifies the next step processing as everything is there and can be checked but also and mainly because users could start easily with such a "exhaustive" product.

Together with info on sun sky, and TEC

From TX and TY compute TH and TV scenes (resp full pol scenes in full pol mode) Compute covariance matrices for TH and TV (resp full pol scenes in full pol mode)

<u>If Option 1 chosen:</u> interpolate to geographic grid TH and TV values, pixel characteristics, incidence angles

<u>If Option 2</u>: interpolation already done.

<u>Granularity</u>: Polarised pixels (the data is organised with the elementary unit being pixels)

Archive total for at least 10 years.

During the elaboration of this level all the geolocation points (including yaw and pitch) will have to be sorted out.

3.1.6 SUMMARY

In the original proposal context the PDPC was to be limited to level 1-b It is now considered to go up to level 2.Nevertheless levels 0 and 1 are already products useful for several users.

- 1-A for those working on calibration and reconstruction algorithms
- Levels 1b-c for the ESL/CFC, some identified and dedicated centres, and for potential users such as met offices (note that even though data is at so called ground level, it is only in terms of projection, not with atmospheric corrections, though the necessary data could be included. Ideally ionospheric correction should either be performed or angle rotation indicated).

It should be noted also that for each pixel there will be a set of Tb values (angular). The granularity is thus maybe changed

In this context, the level 1c product is thus TB on a lat lon grid with polarisation information at ground level (not instrument level), calibrated, and for a set of angles, as well as associated quality indices and processing ancillary quantities.

The data format could either be on a frame basis (full available FOV, not recommended) or on a swath basis. In this case data will be organised as "seen" by the sensor from pole to pole, each pixel being actually a set of angular and polarisation brightness temperature /angle measurements.

Ascending and descending orbits should be separated

The basic resolution at ground level could be 15 km all over the globe (preferred) or a quarter of a degree (about 25 km). It is important to retain a resolution fine enough to avoid loosing information in subsequent steps.

To make things clearer although naive the data could be under the form:

Descriptor! ASC or DESC 1 full or dual pol[9]

One header type block to describe latitude longitude time spans and number of blocks N, general auxiliary /ancillary data, quality index…

N blocks with actual data (lat lon, time, nb incidences, Tbs and corresponding angles auxiliary data and flags A first attempt to detail these measurements is indicated below.

So, organised by ascending and descending orbits, and on a lat lon grid for each imaged point (pixel and angle), the following information is contained in level 1c:

Number N of measurements and for each

- Pixel value (and pol if not separated) with either faraday rotation or all elements to do it later
- radiometric sensitivity
- centre co-ordinates, lat/long
- pixel orientation: angle of long axis w.r.t. north/south direction
- pixel distance to sub track
- elongation ratio, equivalent circle diameter,
- time of acquisition
- line-of-sight angle (with the sat.)
- sun illumination angle (az, el) at ground level
- sun glint flag
- land/sea/mixed pixel flag (percentages)

Data gaps flagged
Flag to state whether we are in narrow or full swath?
Operation mode
Calibration info
And possibly TEC, SST; WS, LST, atmosphere characteristics
And an auxiliary file with
Land use, soil maps

NB the projection grid would be lat/lon (plate caree) with either nothing (no data) or, along the considered orbit, the above mentioned

Dimensioning considerations

Ideally the centre should work continuously with a maximum processing time of less that a fifth of the actual acquisition time (to allow for reprocessing the data set when the reconstruction algorithm is improved) TBC.

[9] Incidentally, this would mean that the smallest full pol dual pol mode option should be the half orbit….

The centre should be able to do post calibration (during a reprocessing run?) when the CFC has provided new, better and validated calibration coefficients from vicarious calibration or other means (hence probably regular reprocessing). .It is still considered the possibility to use vicarious calibration data directly in the CNES centre in an assimilation mode provided that the data flow is well ascertained and that there is always a back up solution when for some reason data is not available is a timely fashion.

Data dissemination.

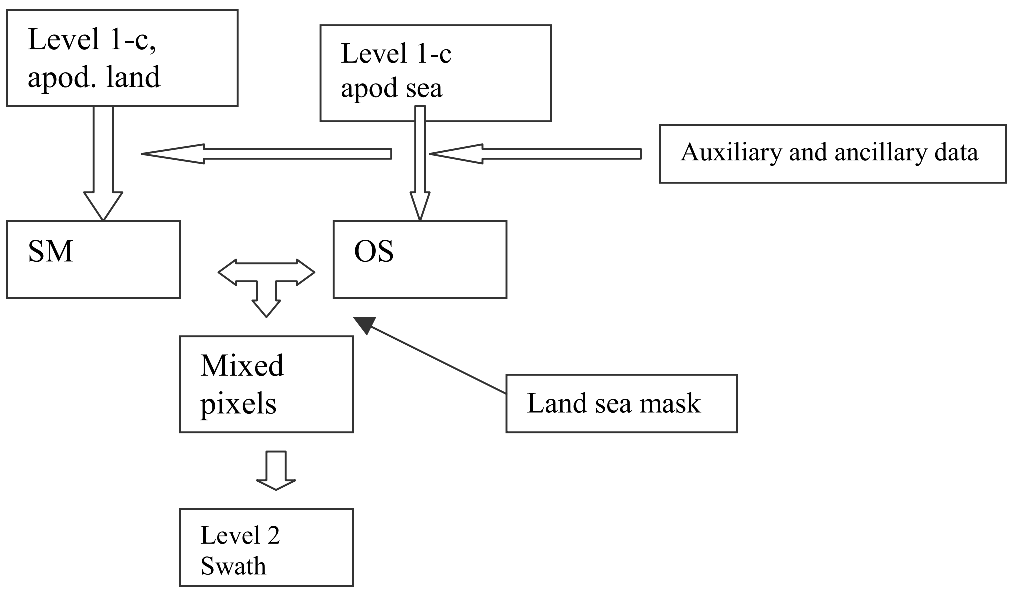
The level 1-a will only be made available to a handful of centres working on the reconstruction / calibration algorithms and locally when reprocessing is required

The Tb data set will be made available for the centres either testing the use of data in simulated near real time (met offices, ECMWF) or for development and validation purposes (ESL,CFC)

3.2 LEVEL 2

3.2.1 GENERAL SCHEME

Level 2 is also covered by the PDPC. It might be necessary to distinguish two products but the question is to assess exactly how different these two products should be as, on one hand, the mission should deliver SM and OS products, and, on the other hand, it does not make much sense to separate the processing for land and oceans before level 2 since **apart** from potentially the apodisation window, data characteristics in terms of outputs are the same for land and sea. Also, if processing is different, the basic structure and organisation of boxes will be, most probably, similar. One should also note that coastal areas need to be processed over land and ocean, and that global external /vicarious calibration will be performed partly over oceans and applied everywhere.



So we will detail below the specificities for the main targets knowing that they will be processed as one "package".

Inputs
Level 1c
Flags for big clouds/precipitations?
Flag for ionospheric storms
Calibration data

Land → Level 2 of previous passes
LST maps (Other satellite or met centres output[10])
Land use map including forested areas
Water bodies
Snow/frost? (met outputs temporal contrast)
Topography
Soils map (texture)

Ocean → SST (sat or met outputs)
WS (sat or met outputs)
Faraday (is it really necessary?)
Atmosphere (weather)
Data from in situ measurements (network)

3.2.2 LAND PROCESSING

The goal here is to produce soil moisture retrievals. The basis is still the per orbit (90 S -90 N and 90N - 90 S) on a lat lon grid. For the two step[11] approach it is necessary to have data from previous passes. **It must be noted that accurate retrieval of SM will rely on the so called "two steps" approach, making it rather a level 3 than the level 2 products for the purists.**

Annex 1 gives typical sequences of overpasses to show the feasibility of the approach.

Currently, the option to replace SM estimates by an estimate of dielectric constants below canopy is investigated for all ambiguous or very special targets in the frame of the ESA SMR retrieval study.

The inversion is done with three, possibly 4 parameters; error estimates are stored with results on all cells having sufficient data. This will have to be updated more exactly before end of phaseB.

[10] these data sets corresponding to fast time varying quantities should be available for the time of overpass with a possible need for temporal interpolation as they are often available at UTC time. Seasonal quantities should be updated on a monthly basis. Their granularity would probably be on a pixel basis and global estimates.

[11] So strictly speaking this is actually level 3 but it is impossible to retrieve SM without making use of all the angles, and sometimes (border of the swath) without knowledge of vegetation canopy opacity

NB: *eventually calibration will be updated whenever possible. Is there a need for some sort of filtering of the data as a function of spatial resolution?*

3.2.3 OCEAN PROCESSING

This processing is in level 2 and thus corresponds to the first level of requirement for SSS (50 km, daily, 1-4 psu). It is not not necessarily of great use due to the very poor basic sensitivity of the instrument. However one of the ideas is to use OS retrievals merged with in situ data to improve calibration and to have rough estimates for mixed pixels. OS might also be of use (with full spatial resolution) in some coastal areas. The main objective of this product is nevertheless to be used to produce level 3.

Processing

Sum TBh and Tbv (faraday)?

Create a file with SST, WS in situ data and atmospheric corrections?

Do further averaging or keep all angular values knowing that it will require contiguous orbits to merge data?

Perform inversion along dwell lines with error bars? One should be aware that "high resolution" data might (i.e. 50 km resolution) be useful near the coast/estuaries….

Compute mean pixel size.

It might be worthwhile to consider making quality indices (when many small land pixels are to be expected, when heavy rains might induce presence of rainwater on the sea surface, possible icebergs, … .

3.2.4 COASTAL AREA PROCESSING FOR MIXED PIXELS

For pixels located along or near cost lines a mixed pixel approach will have to be taken along the general lines and flagged accordingly:

- lots of land little sea → land processing with "forced" sea values
- lots of sea very very little land → sea processing with assumed land values or neighbouring pixel values
- In between →TBD the estimation of the scene dielectric constants for instance

Out put

2 "maps"[12] every day (asc and desc)?

For each pixel

TBh and TBv at 48 and 30°?[13]

Land /sea mask

Auxiliary info used

Error estimates

[12] "map" is probably an ambiguous term here as it corresponds more *stricto sensu* to level 3 products. But i cannot find a better term

[13] This is not per se a level 2 product but is meant to be used as a kind of QL or quality indicator …

Mean pixel size and elongation
Ocean Sea/coast flag
Land → SM value
τ value (estimated or used)
LST value
Flags as above plus eventually one if strong difference with either expected value or previous measurements exist (implying storms, snow fall, flooding, freezing, etc.).
We can either only keep pixels which satisfy the resolution criteria or keep them all and flag accordingly.
Ocean → SSS value

Granularity pixel (lat lon grid)
Long term archive.
The EASE-GRID format and procedure could be used.

4. CNES CENTRE (CFC)

The CNES Centre (CFC) is here the name given to the thematically oriented centre. In the case of SMOS, it will receive from PDPC SMOS data (level 0-2; 1 and 2 routinely) and auxiliary information to produce higher-level data products (3 to 4). The CFC will have several goals as it will be mixing research expertise and algorithm development experts coupled with mass data processing and dissemination.

In other words the task of the CFC will be to:

- Develop, improve and validate algorithms for 0 to 2, which, once validated, will be used to specify the algorithms (ATBD) for transfer to the PDPC.
- Provide "hot line " support to the PDPC or high level users when a bug or a problem has been identified
- Develop test and validate algorithms for level 3 and 4 in close collaboration with the scientific community.
- Propose new improved calibration for scientific studies campaigns etc..
- Finally the CFC will produce and disseminate (together with the capacity to reprocess) level 3 and possibly level 4 on terms and conditions TBD.

The CFC should have at least two folds (SM and OS) as the processing involved differ. A third fold (cryosphere) could also be considered.

We will only detail the OS and SM parts below.

4.1 LEVEL 3

Level 3 is directly based upon level 2 with spatial and temporal aggregation and improvement on accounting for instrument error (i.e., calibration) for ocean salinity. Level 3 corresponds to re-sampled and temporally accumulated data. In some cases, due to the time required to do the accumulation, it will be necessary to perform some sort of assimilation.

4.1.1 LAND GLOBAL SM MAPS

Inputs

The last 3 days of level 2 (eventually 1). Every day a product is made with the updating from the last day's orbits

Products

- Two soil moisture global maps are produced (ascending and descending) on a regular grid (0.15x0.15 deg) At higher latitudes such grid does not necessarily make sense but there are more values to put in more "bins"…but the best option is probably to "filter" or average and have a coarser longitudinal resolution. The use of the EASE-Grid format is worth considering

- Every day an update weekly map of vegetation water content
- Possibly (still tbd) maps of dielectric constant when inversion was not possible,
- flags for inundated areas, of freeze /snow affected areas, of rain affected pixels ….

Output format
Data very similar to that of level 2 with the addition of flags (e.g. when rain has occurred…)

4.1.2 OCEAN

Inputs
Level 2 data (last 10 days, moving window, day and night separated). Eventually level 1C data.
In situ data if not already available

Processing
Filter "bad" pixels (sun glint, sun aliases, islands?, storms, ….)
Build averages on GODAE elements (200 x 200 km, 10 days or whatever is finally chosen
Estimate errors
Fine tuning of instrument parameters
Assess sudden transients.
Flag "anomalies" in the temporal sense
Keep relatively high spatial resolution near coasts/estuaries
Perform calibration with in situ data

Outputs
High resolution coarse (1 psu?) SSS maps near coast and estuaries → users and land centre
Updated calibration → users and processing centres
Updated fine error instrument model parameters
Global maps of SSS with GODAE specs (5 day sliding maps at 1°)

NOTES:

These are the two basic products. It is quite sure that the level 3 will be asked for other outputs such as daily temporal evolution over an area (land), or different spatio temporal averaging over oceans etc… It is expected to advance on these points during future SAG meetings and SMOS workshops.

The basic products (SM and OS should be made routinely and possibly archived. The other could be made upon request only.

4.2 LEVEL 4

There are a number of level 4 products which one might think of. Some are fairly feasible and necessary, and should thus be produced in the expert centres; some others are more research products and could be investigated outside the centre. We will give below a short overview of such products

- Assimilation of SM fields to estimate root zone soil moisture for applications in meteorology and water resources management
- Merge with optical data to use in SVATS for carbon cycle studies and flux assessment (latent and sensible) , use in vegetation growth models etc
- Statistical analysis of SM temporal evolution for climate studies, for assessing precipitations, detecting anomalies (floods, droughts. freeze, snow?))
- Produce regional maps and dis-aggregate over basins
- Maps of rainfall affected areas (semi arid environment)?
- Merge of AQUARIUS (HYDROS) and SMOS data and produce finer products if possible
- Assimilate SSS in Ocean Circulation Models (Mercator like)
- Use SSS for monitoring ENSO and NAO
- Fire risks
- ….

5. THE CALIBRATION VALIDATION ISSUE

The calibration Validation of SMOS data should be covered at least at ESLs and CFC. We reckon that Validation is more of level 3 type. For calibration we will not cover here on board calibration and concentrate on vicarious/external calibration. Currently the plans are to use several sources of information to carry out calibration. These include

- Sky measurements[4] (eventually the moon). They will be performed regularly and could easily be implemented at level 1b for a general correction of the instrument calibration
- The "Ruf" method [5]which could be done routinely as well and with a relatively high frequency. They could be done (TBC) at level 2
- The use of in situ measurements (buoys, vessels of opportunity, ...)over the ocean which could also be done routinely and applied at level 2
- The identification of ground targets (small Islands,)for performing specific calibration tasks
- The use of data from other missions (Aquarius[6], Hydros [7]) which are still TBD pending more info on these mission and whether they fly in the same timeframe.

In all cases the idea would be to improve calibration at level 1c (general correction of the calibration) or at level 2 (specific methods often statistical and latitude / target dependent) but applied everywhere. History of these calibration would be kept and eventually applied during later reprocessing as on the fly calibration with external data sets might pose some issues with the ground segment definition and applicability.

This is a preliminary outline. The part on calibration validation is described further in another document.

6. REFERENCES

[1] Y. Kerr, J. Font, P. Waldteufel, A. Camps, J. Bará, I. Corbella, F. Torres, N. Duffo, M. Vall.llossera, and G. Caudal, "Next Generation Radiometers: SMOS A dual pol L-band 2D Aperture Synthesis Radiometer," presented at 2000 IEEE Aerospace conference, Big Sky, Montana, March 18-25, 2000., 2000.

[2] Y. H. Kerr, "The SMOS Mission: MIRAS on RAMSES. a proposal to the call for Earth Explorer Opportunity Mission," CESBIO, Toulouse (F), proposal 30/11/1998 1998.

[3] Y. H. Kerr, P. Waldteufel, J.-P. Wigneron, J.-M. Martinuzzi, J. Font, and M. Berger, "Soil Moisture Retrieval from Space: The Soil Moisture and Ocean Salinity (SMOS) Mission," *IEEE Trans.Geosci.and Remote Sens.*, vol. 39, pp. 1729-1735, 2001.

[4] Y. H. Kerr and P. Waldteufel, "SMOS Vicarious calibration: Sun and Moon options and requirements," CNRS, Toulouse (F) 5 july, 2001 2001.

[5] C. F. Ruf, "Statistical Analysis of a Lower Bound on Microwave Radiometer Brightness Temperatures from Space," presented at IGARSS'00, Honolulu (Hawai-USA), 2000.

[6] G. Lagerloef, J. Font, C. Koblinsky, and R. Colomb, "The Aquarius salinity mapping mission and synergies with SMOS," presented at IGARSS'03, Toulouse France, 2003.

[7] D. Entekhabi, E. Njoku, Y. Kerr, and P. Houser, "Synergy of The Hydrosphere State (HYDROS) and Soil Moisture and Ocean Salinity (SMOS) Missions For Global Mapping of Soil Moisture," presented at IGARSS'03, Toulouse France, 2003.

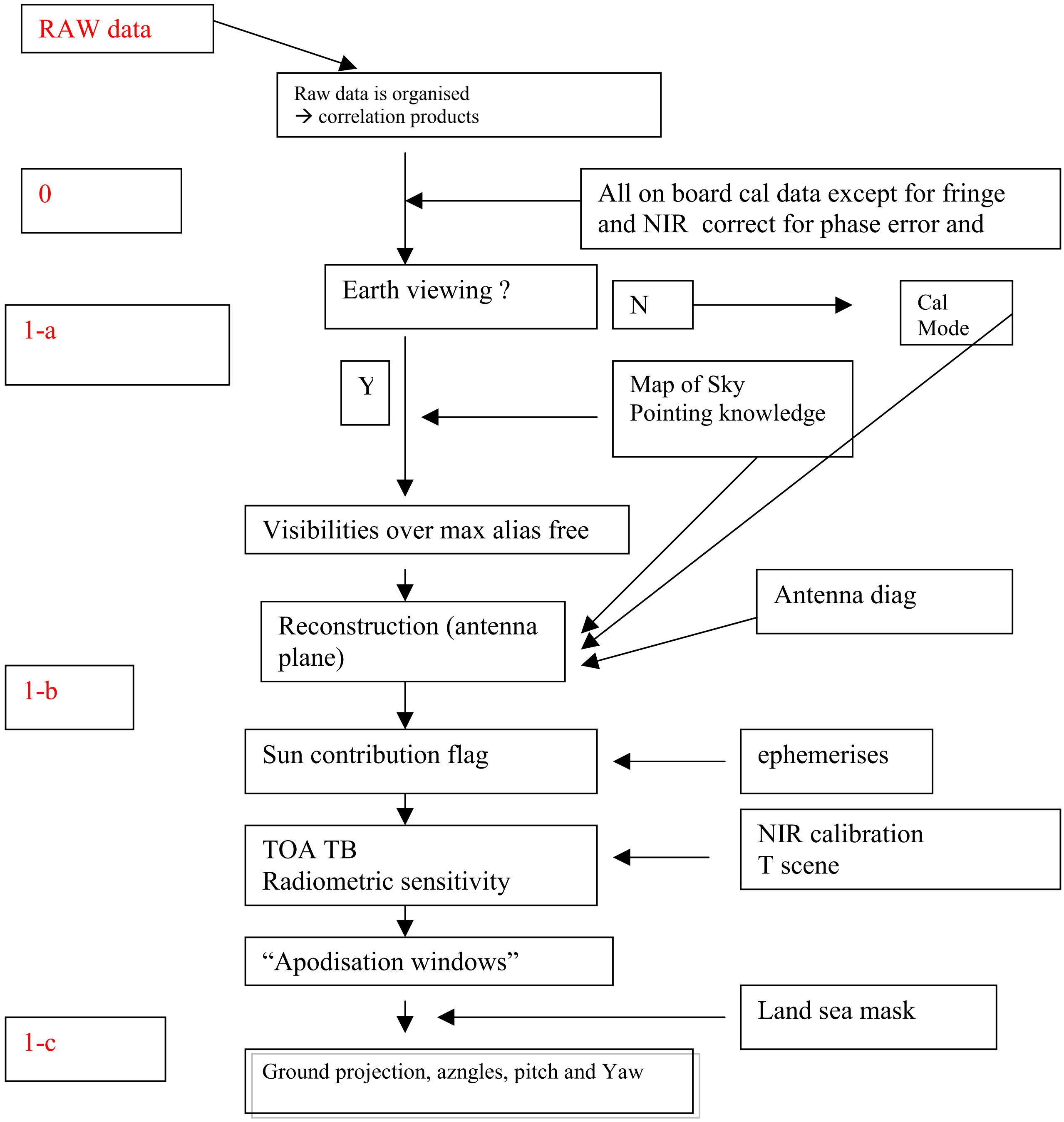


Figure 3: basic scheme

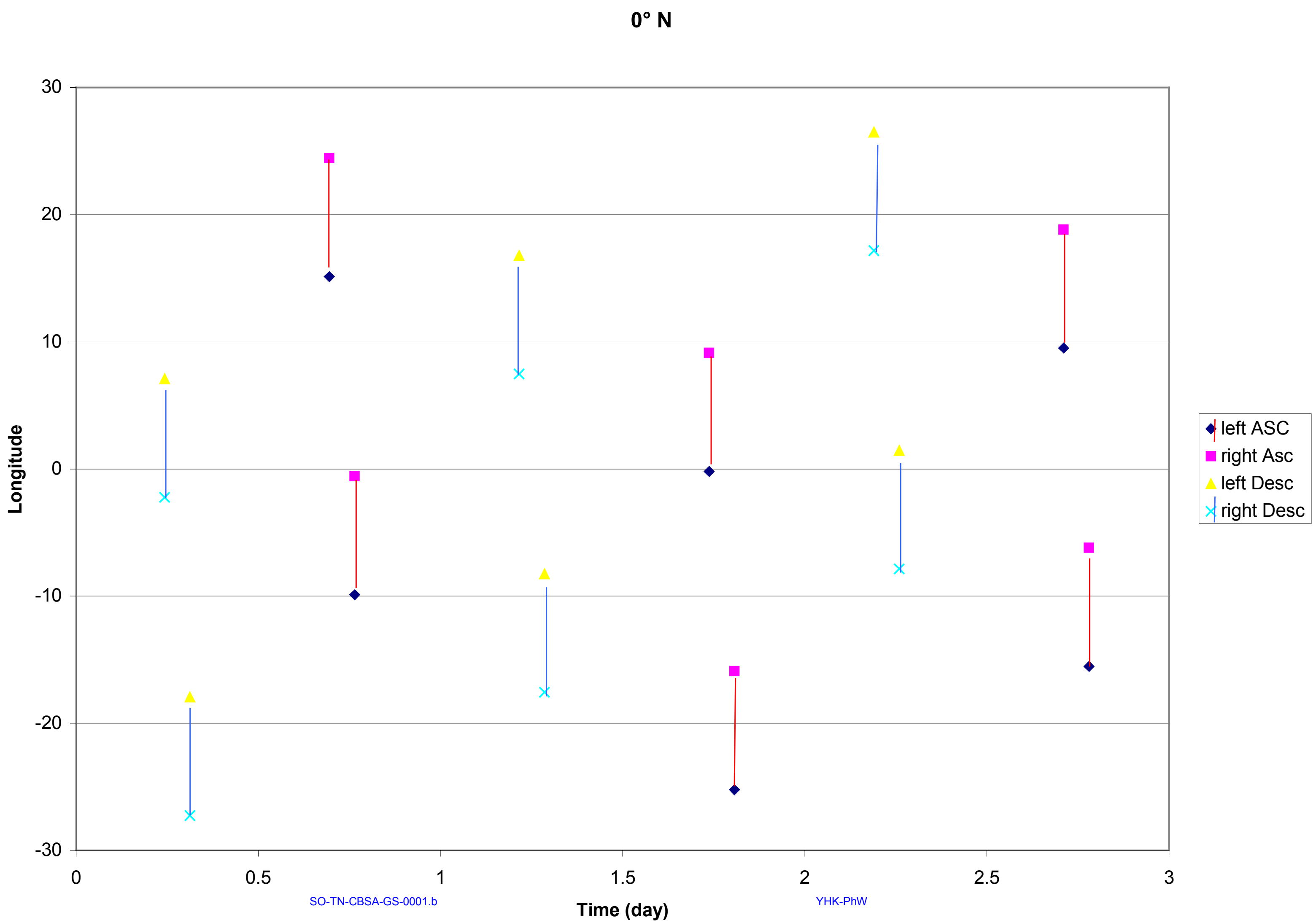
7. ANNEX 1: SMOS COVERAGE

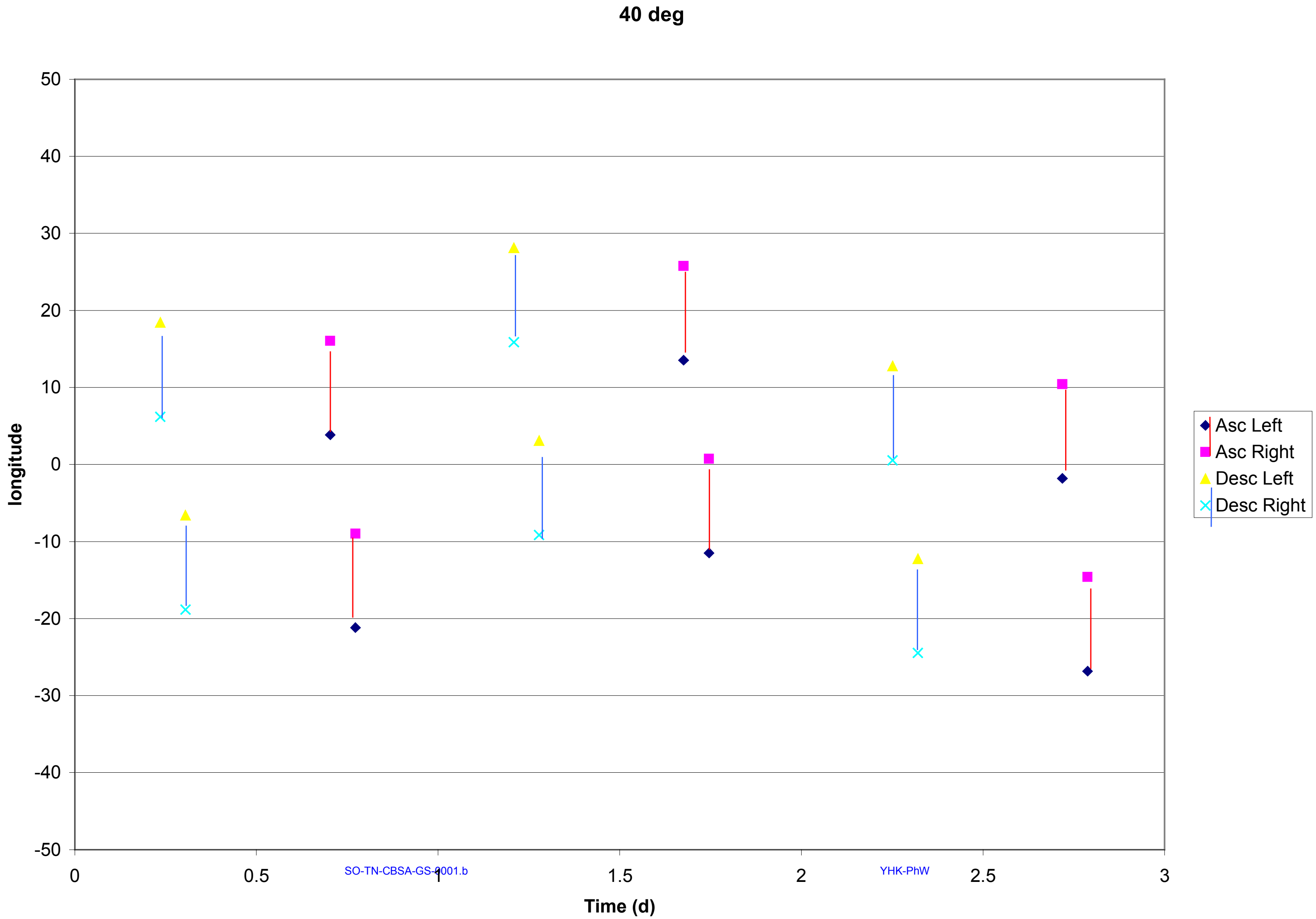
So as to get a better picture of the SMOS coverage, you will find in this annex the swaths obtained at different latitudes (0; 40 and 80°N) with both ascending ands descending passes.

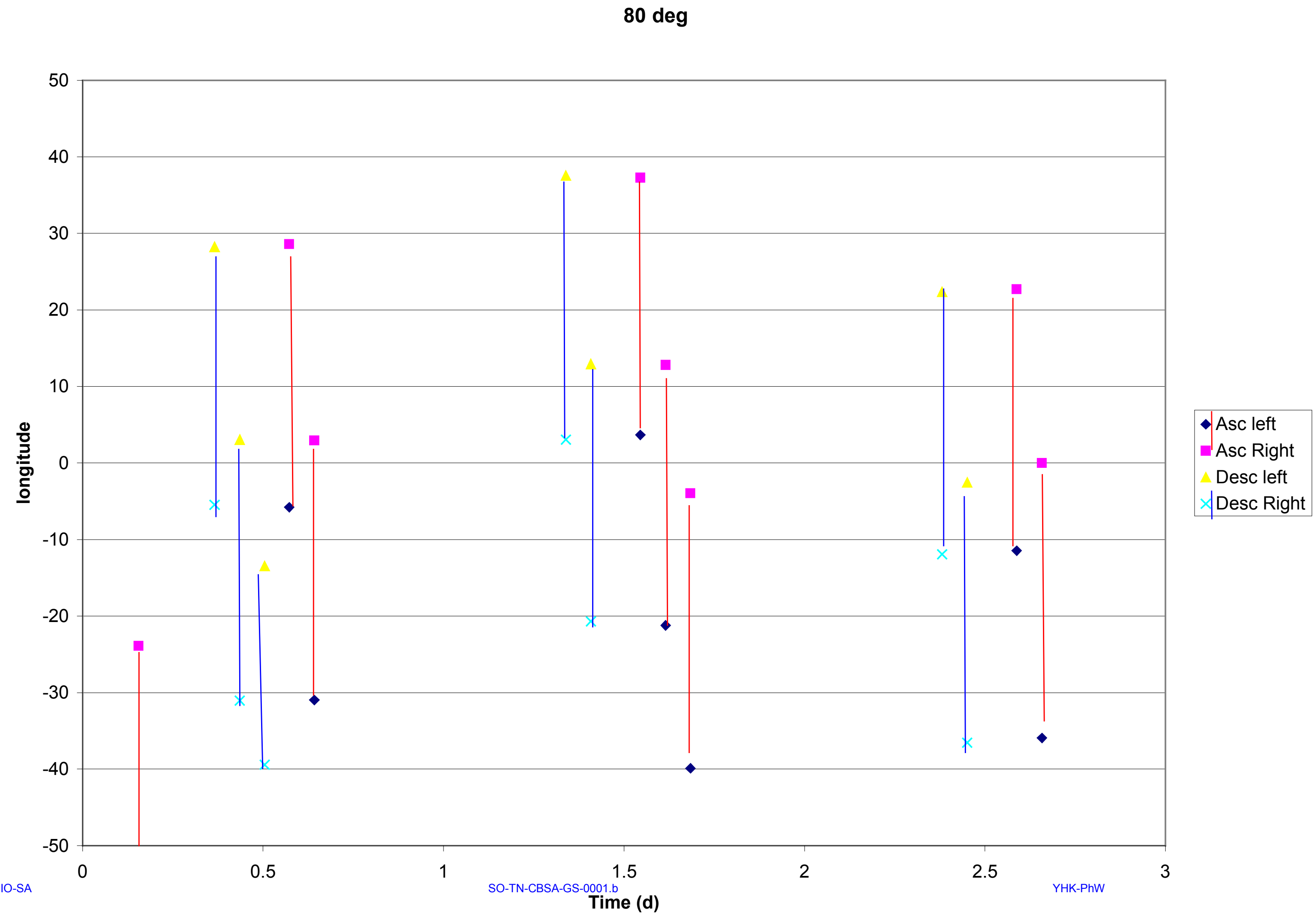
The plots show for each latitude and as a function of time (X-axis) the swath (blue and red lines) expressed as longitudes. This is computed for the baseline SMOS characteristics.

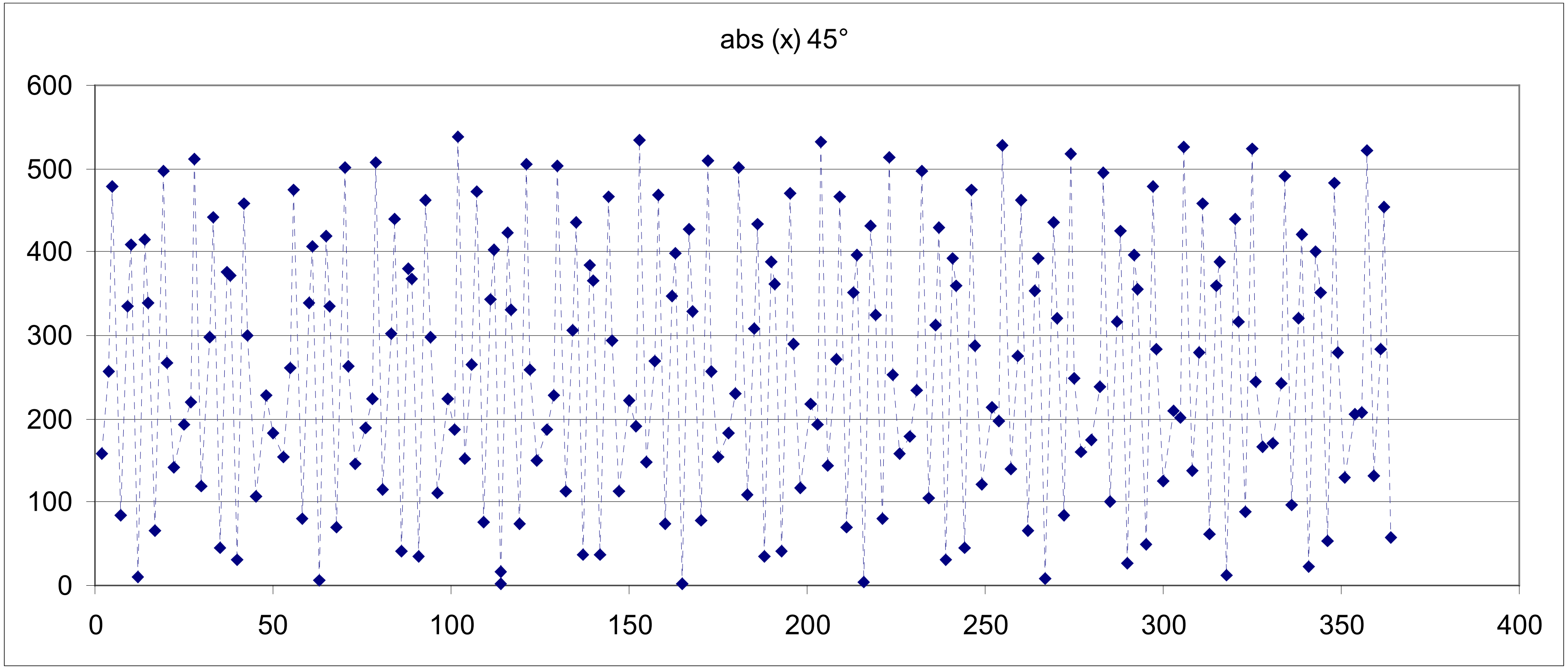
I have made this with coarse tools and it is only indicative of course, but it should give an idea and one conclusion might be that daily maps make sense.

The next page shows the temporal evolution of any pixel located at 45° N with respect to the centre of the swath (ascending passes only). It can be seen that the point flips from close to centre to near the border showing that the two step approach is perfectly feasible.


0° N
30
20
10
0
-10
-20
-30
Longitude
0
0.5
1
1.5
2
2.5
3
Time (day)
left ASC
right Asc
left Desc
right Desc


40 deg
longitude
Time (d)
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
0.5
1
1.5
2
2.5
3
Asc Left
Asc Right
Desc Left
Desc Right


80 deg
longitude
Time (d)
50
40
30
20
10
0
-10
-20
-30
-40
-50
0
0.5
1
1.5
2
2.5
3
Asc left
Asc Right
Desc left
Desc Right



Example of position of a point located 45°N within the FOV as a function of time (DOY)

x-axis =DOY,

y-axis = absolute value of the distance to subtrack in km(FOV extends to about +/-530 km)

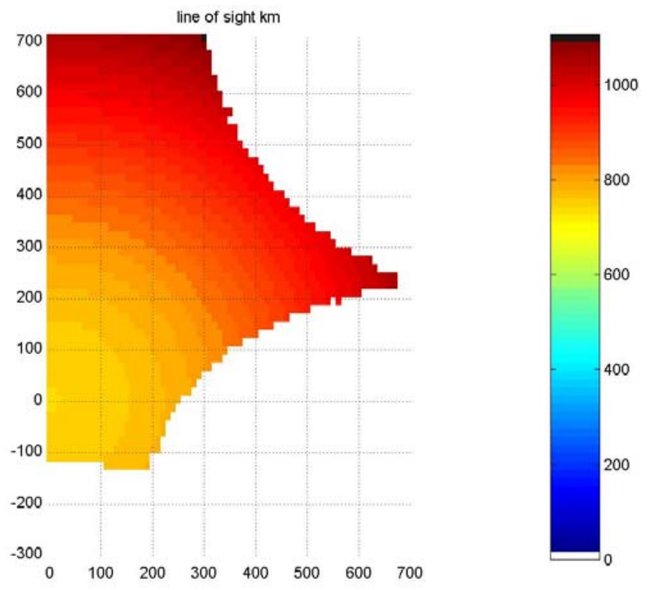
8. ANNEX 2: CHARACTERISTICS OF SMOS FIELD OF VIEW

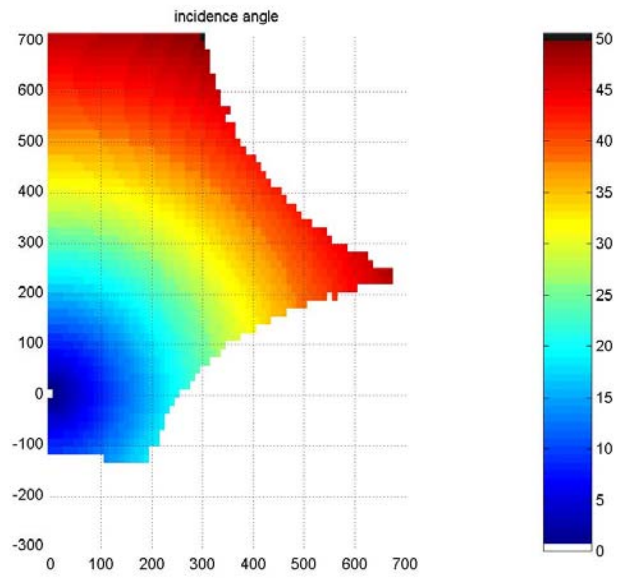
From the simulator developed by P. Waldteufel (NOPT) here are selected diagrams showing the characteristics of the FOV in terms of angles, aspect ratio etc….

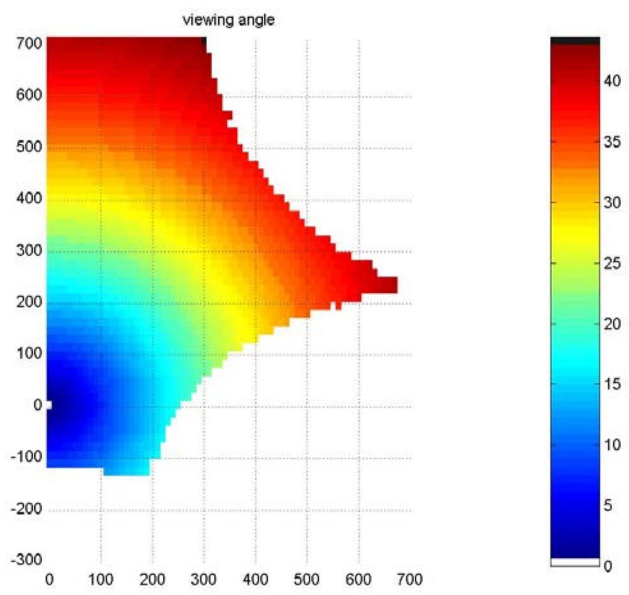
Graph characteristics for eventual replication
NOPT71 : D=2002 1 9 T=14 59 55 chi=0 dia=0,2 nly,lly,min=99 1 1 jst0=1 0 jan0=0 0 jva0=0 0 jfr0=0 0
OPTIONS1 : dx,dy=10 16 dc=0.0077 Rter=6378 vsat=6.6667 (e=.89: 3dBW=32.5,Glin= 8.70) orb=14.3;D+D;DX,Dt=200,10
OPTIONS2 : mdB=0.0 sky,sys=3.5 180 com=2 bw=19.0 cbit,frd=1.81 0.820 fwi/ma=0.720 0.80 alf/w=1.00 0.452
OPTIONS3 : jdot=1 jnoi=0

UPDATES____: GRID O= 0.07 PIX O= 0.01 MSK N= 8.01 D=10.92 T= 0.52 DIAG DIR N= 0.71 INV=DIR t= 0.01
*CONFIG. : **H=755km e,n,L=0.880 21 4.02m tilt,st=32.0 30°** Dtet=32.9 Ym,M,d=-304 704 16km dt=2.4s sc=1e+000*
BORESIGHT : y,z=483 773 SP= 912 arc=484 hor=63.4°(ce=1) - TB DIR N= 1.84

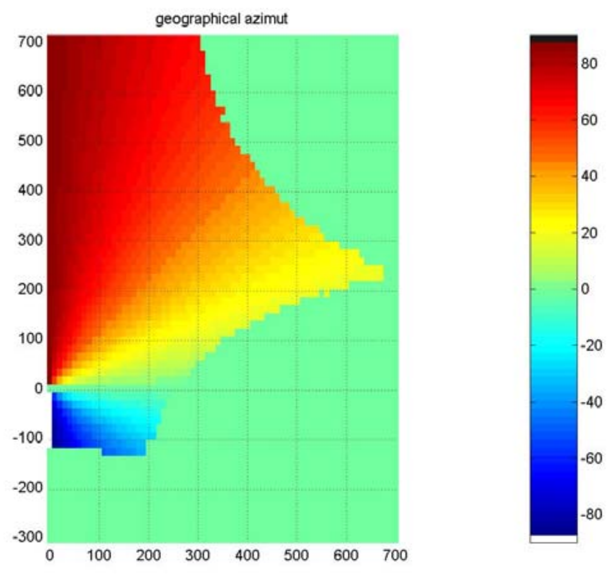
*LOOP sws2 : (1-1); n=1; sws2,4=40 40 dTBax=11510+ 64xT bTB= 0+ 0xT jsta= 1 Tscene=**243** 243 14 14*
TARGET : LAND Ts=293(2.0, bias=0.0) SS,W=35 8(2.00) Ws,Wv=0.10 3.5(0.00) bias2=0.00
*RESO LOOPS : jres=1,resm=**100**; jlrx=1,lrx=3(meanax): resM=1.0 x100; jrem=1,elongM=**2.00** - NX LOOP*


line of sight km
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
1000
800
600
400
200
0

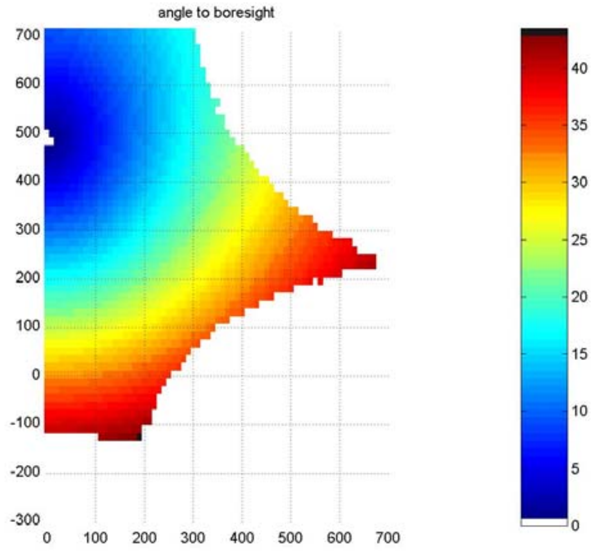

incidence angle
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
50
45
40
35
30
25
20
15
10
5
0



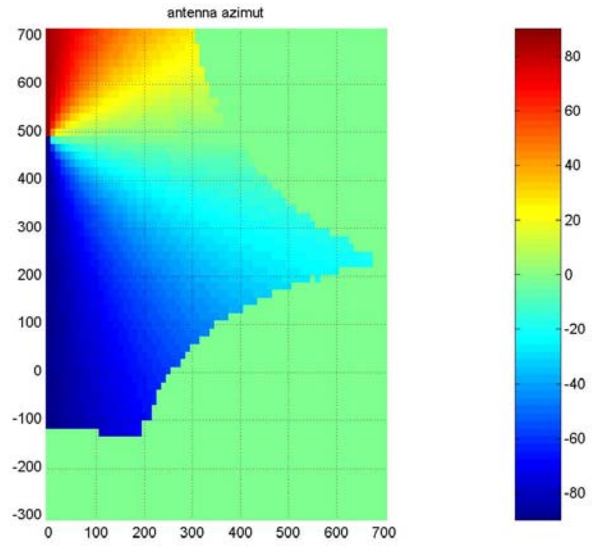
viewing angle
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
40
35
30
25
20
15
10
5
0



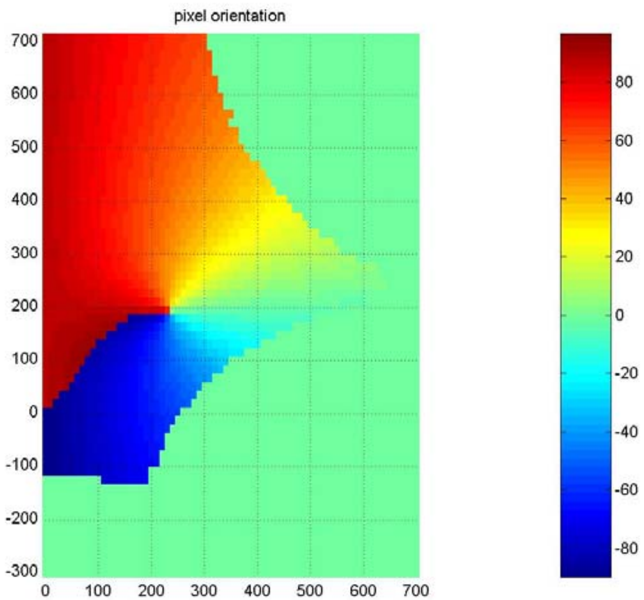
geographical azimut
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
80
60
40
20
0
-20
-40
-60
-80



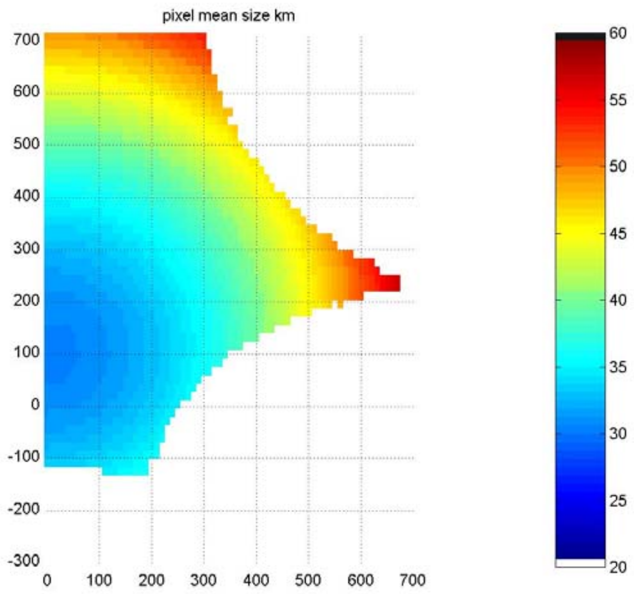
angle to boresight
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
40
35
30
25
20
15
10
5
0



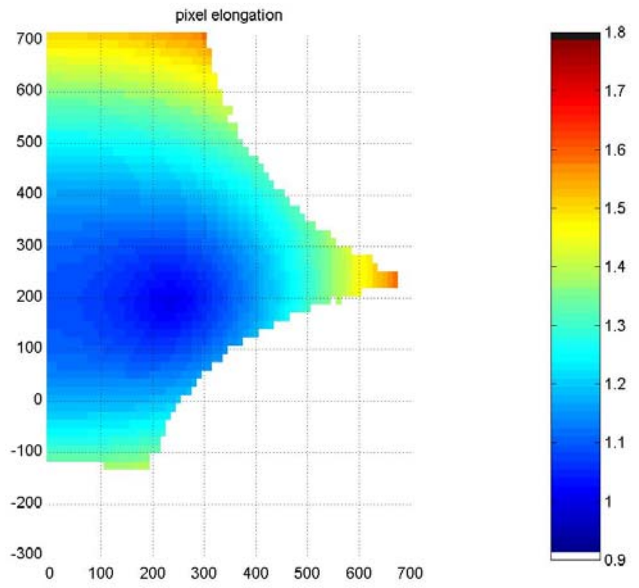
antenna azimut
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
80
60
40
20
0
-20
-40
-60
-80



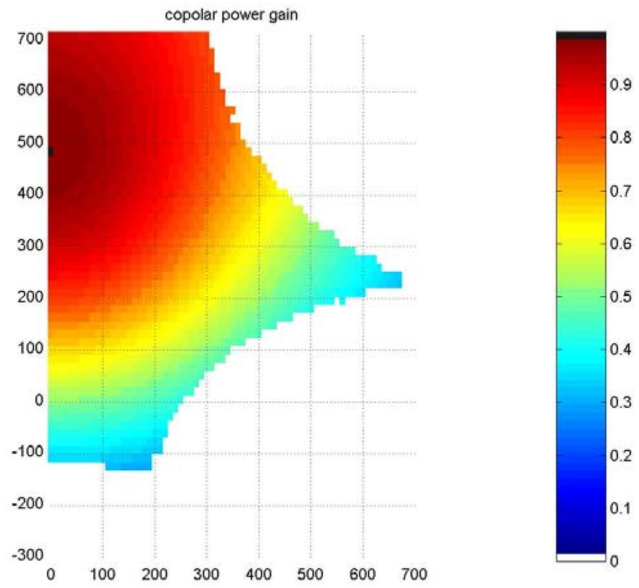
pixel orientation
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
80
60
40
20
0
-20
-40
-60
-80



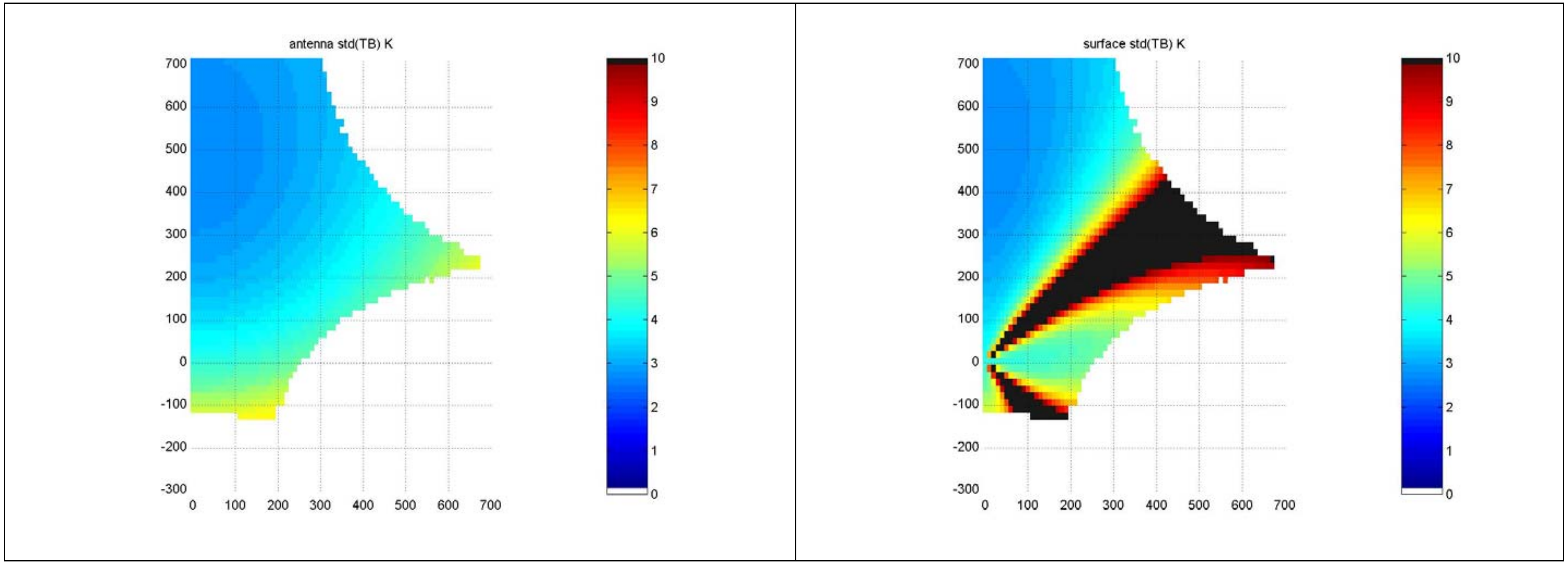
pixel mean size km
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
60
55
50
45
40
35
30
25
20



pixel elongation
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9



copolar power gain
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


antenna std(TB) K
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
10
9
8
7
6
5
4
3
2
1
0
surface std(TB) K
700
600
500
400
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
10
9
8
7
6
5
4
3
2
1
0

9. ANNEX 3 PROCESSING ORGA CHART

The two charts below were prepared (phw) to give some details on potential organisation for the product levels with two options: the extended clean and resolvant matrix approaches .

9.1 EXTENDED CLEAN

	A	B	C	D	E	F	G	H	I	J	K	L
1	**input level**			**CLEAN processing**	**output**	**rever-sible**	**arch.**	**grain, frame**		**comments**	**output Level**	
2		**ext static**	**ancillary**									**name**
3	**O**			mode recognition		yes						
4				conv engin. units		yes						
5			basic geoloc	generic geoloc (LOS, orbit)								
6				unpack reformat	unpacked,formatted : raw correl. products	yes	no or yes	scene	antenna SFD		**1A**	
7	**1A**		visibility cal data	apply calibration to RCP	2 or 4 "**normalized**" V (=1 for null baseline)	yes	yes or no	scene	antenna SFD	use for deep sky view ?	**1B**	snap shot
8	**1B**		calibrated **NIR**	calibrate V	V in Kelvin in SFD Scene temperature	yes				2628 (+PMS) complex numbers		
9		instrument model sky Tb map	instrument model more geoloc	compute **sky** visibilities Vs	Vs in Kelvin							
10				compute average Earth temp TE	Vs in Kelvin					from 20310 Eqn (33)		
11				substract sky & mean Earth	sky free (-mean Earth ?) V	yes						
12		window file	more geoloc ?	apply N windows (to visibilities)	N x M tapered V	no				Probably does not work for equipixel		
13				update G matrix ?								
14		alias map		remove alias apply margins	select alias free zone	no						
15				reconstruction	N x M **Tmod** in cosdir	no			antenna cosdir	16384 cmplx numbers average redundant V		
16		antenna pattern file		compute Tb from Tmod	N x M **Tb** in cosdir	yes			antenna cosdir	assume average pattern		
17			geoloc ?	detect wild points (**sun**)						***discuss later use***		
18					N x M **Tb** reference fields cosdir frame		yes	scene	antenna cosdir		**1C**	scene
19		geo grid coastline	accurate geoloc H/V shift	tranlate geo grid into cosdir frame idem coastline mask						excluding sky		
20				interpolate Tb to grid nodes correct H/V shift	N x M **Tb** in cosdir at grid nodes	yes				circa 2000 points		
21		eqp window file		convolute eqp windows remove alias, apply margins	equipixel case	no				heavy, discuss		
22				merge Tb(N) maps	M **Tb** in cosdir at grid nodes	no				***discuss***		
23		antenna pattern file		compute : angles, pixel sizes & orientation dTB & *covariance matrix*	ancillary results for grid nodes							
24				transform TB to surface	surface Tb (Faraday **uncorrected)**	yes						
25					gridded set of Tb at surface level	no	yes	orbit	surface grid	only M maps	**1D**	pixels
26												
27		no TEC removal				M=2 or 4 according to dual/full pol						
28		additional data only mentioned when **necessary** for present & further steps				eqp = equipixel						
29		SFD=spatial frequencies domain				**Tmod** = modified temperatures = Tb x gain pattern/oblicity factor						

9.2 RESOLVANT MATRIX

	A	B	C	D	E	F	G	H	I	J	K	L
1	**input level**			**RESOLVANT processing**	**output**	**rever-sible**	**arch.**	**grain**	**frame**	**comments**	**output Level**	
2		**ext static**	**ancillary**									**name**
3	**O**			mode recognition		yes						
4				conv engin. units		yes						
5			basic geoloc	generic geoloc (LOS, orbit)								
6				unpack reformat	unpacked,formatted : raw correl. products	yes	no or yes	scene	antenna SFD		**1 A**	
7	**1 A**		visibility cal data	apply calibration to RCP	2 or 4 **"normalized"** V (=1 for null baseline)	yes	yes or no	scene	antenna SFD	use for deep sky view ?	**1 B**	snap shot
8	**1 B**		calibrated **NIR**	calibrate V	V in Kelvin Scene temperature	yes				2628 (+PMS) complex numbers		
9		instrument model sky Tb map	instrument model more geoloc	compute **sky** visibilities Vs	Vs in Kelvin							
10				compute average Earth temp ?	Vs in Kelvin					from 20310 Eqn (33)		
11				substract sky (& mean Earth ?)	sky free (-mean Earth ?) V	yes						
12				update resolvant matrix ?								
13				reconstruction / **resolvant**	projected **T^** in SFD	no			antenna SFD	**1394 + 1** **complex numbers**	**1B'**	
14				reconstruction / **Fourier step** **(no window)**	M **Tb** in cosdir **regular grid**	**yes** **TBC**			antenna cosdir	1395 points		
15			geoloc ?	detect wild points (**sun**)						***discuss later use***		
16		alias map		**flag** alias and margins	flagged alias free zone	yes						
17					M **Tb** reference fields		yes	scene		M **Tb (eg** for sky)	**1 C**	scene
18	**1B'**	windows file	more geoloc ?	apply N windows	N x M tapered **T^**	no			antenna SFD	Probably does not work for equipixel		
19		geo grid coastline	accurate geoloc H/V shift	tranlate geo grid into cosdir frame idem coastline mask						excluding sky views		
20				interpolate Tb in **Fourier step** to grid nodes, correct H/V shift	N x M **Tb** in cosdir at grid nodes	no			antenna cosdir	circa 2000 points; except equipixel		
21	**1 B'**	eqp window file		reconstruction / **Fourier step** convolute eqp windows	equipixel case	no			antenna cosdir	**heavy**, discuss		
22				merge Tb(N) maps	M **Tb** in cosdir at grid nodes	no				***discuss***		
23		alias map		remove alias apply margins	alias free zone	no						
24		antenna pattern file		compute : angles, pixel sizes & orientation dTB & *covariance matrix*	ancillary results for grid nodes							
25				transform TB to surface	surface Tb (Faraday **uncorrected)**	yes			Surface grid			
26				accupulate	gridded sets of Tb		yes	orbit		only M maps	**1 D**	pixels
27												
28		no TEC removal				M=2 or 4 according to dual/full pol						
29		additional data only mentioned when **necessary** for present & further steps				eqp = equipixel						
30		SFD=spatial frequencies (baselines) domain										