Abstract—The SMOS data product steps from raw data to brightness temperature maps are described. Originally ordered in the sequence of snapshots, the data are rearranged for the Level 1c Brightness Temperature maps according to their location in a Discrete Global Grid (DGG). A number of candidate DGGs are introduced and their suitability is evaluated.

Keywords—SMOS, Level 1 Processing, Discrete Global Grids

I. INTRODUCTION

The SMOS mission, which is scheduled for launch in early 2007 as part of ESA’s Living Planet Program, aims to advance the development of climatological, meteorological and hydrological models by observing two key variables of the Earth System, namely soil moisture over land and salinity over oceans.

In order to retrieve these geophysical variables on a global scale the SMOS mission is adopting a completely new approach in the field of spaceborne remote sensing. With its two-dimensional Microwave Imaging Radiometer with Aperture Synthesis (MIRAS) SMOS will acquire the polarimetric brightness temperature of the earth at L-band (1.404 - 1423 GHz). In each snapshot, which corresponds to an integration period of 1.2 sec, the MIRAS instrument measures the complex visibility function of the complete observed scene.

With this data the level 1 processor is able to form simultaneously a number of measurement beams in azimuth as well as in elevation. The MIRAS instrument is tilted forward towards flight direction and the various beams intersect with the earth surface at different ground positions along the ground track. As the satellite flies over the scene the brightness temperature of the same area on the ground is measured at a number of different incidence angles in subsequent snapshots. The geophysical parameter retrieval can therefore be based on a set of polarimetric brightness temperature observations measured at a number of different incidence angles.

In the following the processing steps required to obtain the brightness temperature maps are described; further a trade-off between different global geodesic grids to represent SMOS products is performed.

II. SMOS MISSION DATA PRODUCT DEFINITION

The SMOS Mission Data Product definition illustrated here are based on the CEOS conventions which have been specifically tailored to the SMOS Mission’s requirements. The definitions describe the current baseline in the ongoing discussion with the data users.

The task of the SMOS level 1 processing is to generate swath based brightness temperature maps of the earth from the correlations measured by the MIRAS instrument. This is performed in a number of processing steps where intermediate products are created.

The brightness temperature maps produced by the level 1 processor plus a number of auxiliary data are then the input to the Level 2 processing which aims to produce swath based Soil Moisture as well as Ocean Salinity maps.

A. SMOS Level 0 Data

The Level 0 data contain the unprocessed SMOS Payload data with the received SMOS Raw data packets decoded, quality checked and furnished with an Earth Explorer product header. The Level 0 data product indicates different types of source packets: Observation and calibration data; Satellite Housekeeping data (SC-HKTM) with on-board time, satellite position and attitude parameters; Instrument Housekeeping data (I-HKTM) with mode, health status and engineering parameters like temperatures, voltages etc. and NIR measurements (the Noise Injection Radiometers, used to measure the total...
received power within the observed bandwidth). The Level 0 data are ordered in chronological sequence.

B. SMOS Level 1a Data

The first step of the Level 1 processing is the generation of the Calibrated Visibilities (Level 1a) from the Raw Data (Level 0). This calibration of the observation data is based on contemporary internal calibration measurements and pre-launch instrument characterizations. Further the Housekeeping data are converted into engineering units. The Level 1a data arranged in chronological order as snapshots i.e. referred to a single integration time and for each polarization. Internal and external calibration data are subject to a special processing in order to feed back calibration information to Level 1a and Level 1b processing.

C. SMOS Level 1b Data

The Level 1b data product is a series of brightness temperature image snapshots of a specific polarization. They are obtained through the SMOS image reconstruction from the Calibrated Visibilities. The exact image reconstruction algorithm to be used here is not yet selected. A number of algorithms are currently being assessed with respect to a set of performance criteria. One class of algorithms is based on an iterative approximation [1],[2] while a second class of algorithms is based on the so called G-matrix reconstruction [3],[4],[5] with similarities to the one described in [6]. The snapshots obtained this way contain brightness temperatures at the top of the atmosphere in a vector which represents a fixed set of directions in the natural hexagonal grid in the antenna polarization reference frame of the instrument. This natural hexagonal grid is defined by the Y-shape of the aperture synthesis radiometer, the number of baselines measured and the maximum baseline length processed [7]. Based on this grid the Level 1b product contains the Brightness Temperature Spectrum of the whole snapshot as well as the alias free field of view plus the area of the sky alias filtered with the two dimensional Blackman apodisation window. Furthermore it contains all auxiliary information needed to allow geometrical geo-location. The only effects that are compensated for in the Level 1b product is the direct or alias sun and the alias of the galactic background in the area outside the alias free field of view. Like in the Level 1a the Level 1b data are arranged in a chronological sequence of snapshots.

D. SMOS Level 1c Data

In the Level 1c product the brightness temperature data are projected onto a fixed DGG on the earth reference ellipsoid (Figure 1) with the polarization vectors transformed according to the local coordinates and corrected for the effect of Faraday Rotation. In the following paragraph a number of different DGG is introduced and investigated for their suitability to represent SMOS data.

Based on the Brightness Temperature Spectrum \(\hat{T}(u,v)\) in the Level 1b data the exact Brightness Temperature value in the direction of the DGG points \(\hat{T}(\xi',\eta')\) is determined by calculating the inverse Discrete Fourier Transform (DFT) in order to avoid interpolation errors.

\[
T(\xi',\eta') = \sum_{u,v} \hat{W}(u,v) \cdot \hat{T}(u,v) e^{-j2\pi(\xi' u + \eta' v)}
\]  

The chronological order in snapshots used up to here is replaced by a geographical order according to the earth fixed grid. Data corresponding to one grid point are collected from the different snapshots and provided together with their corresponding incidence angles and other geometric information. It is planned to produce two different Level 1c products, one for Land and one for Sea applications. The difference is in the specific optimized apodisation window \(\hat{W}(u,v)\) applied for each product with which geometric resolution can be traded against main beam efficiency.

III. STRIP-ADAPTIVE PROCESSING

The concept of strip-adaptive processing, which was first proposed in [8] and is further described in [9], aims at equalizing not only the centre but also the size and the shape of the SMOS beam footprints. This can be achieved by adaptation of the 2D apodisation window at the expense of geometric resolution. In order to optimize the geometric resolution for the worse case beam, the main beam efficiency of the 2D Blackman window is set as reference. Increased main beam efficiency in one direction can then be traded for an improved resolution in another direction.

The advantage of strip-adaptive processing specifically for the Soil Moisture retrieval is that it ensures that each measurement value originates from the same contributing area on the ground.

It is still to be decided whether strip-adaptive processing is going to be implemented in SMOS Level 1c processing.

IV. DISCRETE GLOBAL GRIDS

Level 2 processing aims to use values of brightness temperature for each ground pixel taken at different incidence angles to retrieve Soil Moisture and Ocean Salinity; it is however clear that due to geometry the level 1b grid points when projected on the ground will not coincide for subsequent snapshots and that some lossy interpolation is used unless a global grid is defined and used directly in producing level 1c. The problem is also exacerbated by the different target grids that different user communities need.

The issue arises then of which discrete global grid (DGG) best satisfies the following SMOS requirements:

a) maintain the full information content of the measured SMOS samples (which corresponds to a maximum instrument resolution of approximately 30 km)

b) minimise interpolation error due to regridding to arbitrary user defined ground grid.

SMOS measurements are performed uniformly along the orbit with no knowledge of latitude and with the natural geometry of the instrument based on a hexagonal level 1b grid. Requirement a) translates therefore in a uniformly spaced global and isotropic grid at twice the instrument resolution.

Requirement b), i.e. minimisation of user interpolation can be achieved by having a uniform intercell spacing.

Of these characteristics, uniform intercell spacing is, ideally, a consequence of the grid being conformal, adjacent and equi-area at the same time.
A number of grids have been therefore analysed with respect to conformality (shape invariance), isotropy, global coverage and adjacency with the ultimate criteria being however quantitative minimisation of intercell distance variation. These characteristics are also very well suited for the description of products where strip adaptive techniques are used.

An exhaustive description of global grids can be found in [10], however broadly speaking grids are obtained by three main techniques:

a) Partition of the globe in lat-long coordinate systems (e.g. Lat-long and UTM),

b) Tiling of the globe once in a specific projection with a square lattice (e.g. EASE)

c) Regular subdivision of a platonic solid inscribed in the globe with triangles, hexagons or diamonds (e.g. QTM, ISEA).

A special case is GRIB2 from WMO and EUMETSAT that contains a number of templates belonging to all three types mentioned above.

**Lat-long:** Commonly used square based equal angle grid. Not equi-spaced, associated with increasing distortion towards the poles in both area and shapes and presenting privileged directions along meridian and parallels. Considered unsuitable for SMOS. A variation of this grid trying to overcome their limitation is the Gaussian (which is using irregular latitude spacing). Still its adjacency and intercell spacing make it unsuitable.

**Universal Transverse Mercator (UTM):** Popular Square-based grid with lat-long symmetry, non-uniform adjacency and with considerable distortion. Considered unsuitable for SMOS.

**Quaternary Triangular Mesh (QTM):** Widely used grid obtained by the triangular partitioning of an inscribed octahedron. It is global and regular behaving better than UTM or lat-long, but due to the use of triangles it does not exhibits uniform adjacency (which is desirable to map circular pixels) and presents a moderate intercell spacing variation with a range of up to 7 km for mean intercell distance of 17 km (Aperture 4 resolution 8), correspondingly cells area in bigger pixels is 1.8 times the smallest [11].

**Icosahedron Snyder Equal Area (ISEA):** A recently developed equal-area grid with minimal distortion obtained by regular partition of inscribed icosahedron with triangles, diamonds or hexagons using Snyder projection. Snyder projection can also be successfully applied to an octahedron, however here only the icosahedron has been considered since the larger the number of solid faces, the better the adjustment to earth’s spheroid.
Equal Area Scalable Earth (EASE): Popular square based grid used in a number of NASA missions. EASE is built as a regular lat-long grid once the globe is represented in one of three projections: Northern, Southern or Global (Lambert azimuthal equal-area north and south, Cylindrical equal-area). EASE is not a global grid in the sense that grid points need to be selected on one of three different projection types, in fact each latitude range is better represented only in one of the three projections. EASE equal area feature is moreover not accompanied by uniform adjacency (which hinders regular intercell spacing) and presents a high degree of distortion. As an example, EASE Global grid exhibits an aspect ratio up to 11.2 at 75 degrees latitude as shown in the figure below.

A specific intercell spacing analysis has been performed for EASE and resulted in standard deviations of up to 5.3 km even when constrained to cylindrical below 60 degrees latitude for mean intercell spacing of 25 km which is quite high. EASE main advantages consist in flexibility of resolutions, ease by which grid point position can be calculated by knowing row and column numbers, full congruence and by the fact that locally it displays uniformly on digital output devices due to its square lattice; furthermore EASE can be scaled very easily to any other resolution, this latter feature is however not important for SMOS since the grid needs to be calculated only once at fixed resolution.

**GRID TRADE OFF**

Following the analysis performed for the family of regular partitioned grids the ISEA/Snyder family seems to be the best option to suit SMOS requirements. In general grids based on partition of an inscribed platonic solid present isotropy, regularity, less distortion, global coverage and a better adjacency than grids having square lattices resulting at the end in lower intercell spacing variance and spatial uniformity. A direct comparison between EASE and ISEA was also performed and confirmed that EASE is less suited as a global grid to represent products consolidated from pole to pole, due to its lack of global coverage, marked distortion and less favourable intercell spacing variation. The grid that behaves better in this respect is the ISEA4H9 shown in Figure 1 superimposed to a SMOS snapshot measurement and whose parameters are presented in Table I.

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Resolution</th>
<th>Max. distance (km)</th>
<th>Min. distance (km)</th>
<th>Range (km)</th>
<th>Mean (km)</th>
<th>Standard deviation</th>
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</thead>
<tbody>
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<td>16.654</td>
<td>12.952</td>
<td>3.702</td>
<td>15.072</td>
<td>0.954</td>
</tr>
</tbody>
</table>

TABLE I. ISEA APERTURE 4 RESOLUTION 9 PARAMETERS.

VI. CONCLUSION

The comparison of a number of Discrete Global Grids shows that ISEA Snyder grid with hexagonal partitions Aperture 4 resolution 9 is technically the best-suited global grid to be used in mapping L1c and L2 SMOS products. Its behaviour closely matches the instrument measuring symmetry, exhibits a minimal cell spacing variations, is suited to support strip-adaptive processing and insures best data for subsequent re-gridding.

The final decision on the grid to be used in representing the L1c and L2 SMOS data products is still pending at this moment.

REFERENCES