NOAA NESDIS

CENTER FOR SATELLITE APPLICATIONS AND RESEARCH

SOIL MOISTURE OPERATIONAL PRODUCT SYSTEM (SMOPS)

ALGORITHM THEORETICAL BASIS DOCUMENT

Version 4.0

SMOPS ALGORITHM THEORETICAL BASIS DOCUMENT VERSION 4.0

AUTHORS:

Xiwu Zhan (NOAA/NESDIS/STAR)

Jicheng Liu (UMD/ESSIC/CICS)

Limin Zhao (NOAA/NESDIS/OSPO)

SMOPS ALGORITHM THEORETICAL BASIS DOCUMENT
VERSION HISTORY SUMMARY

Version	**Description**	**Revised Sections**	**Date**
1.0	New Document for SMOPS PDR	New Document	05/06/2010
2.0	Revised version for SMOPS CDR	3.5 Merging Function 5.0 Risks and Risks Reduction	10/17/2010
2.1	Revised version for SMOPS CDR	3.5 Merging Function 5.0 Risks and Risks Reduction	1/04/2011
2.2	Revised version for SMOPS SRR	3.5 Merging Function 3.9 Algorithm Validation 5.0 Risks and their Mitigation	8/8/2011
2.3	Revised version for SMOPS ORR	3.9 Algorithm Validation	7/25/2012
3.0	Final version for SMOPS Version 1.0	Added WindSat sensor	9/25/2012
3.1	Final version for SMOPS Version 1.3	Added ASCAT-B	8/04/2015
4.0	Final version for SMOPS Version 2.0	Added NRT SMOS and AMSR2 sensors	9/20/2016

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LIST OF ACRONYMS

AMSR	Advanced Microwave Scanning Radiometer 2
ASCAT	Advanced Scatterometer
ATBD	Algorithm Theoretical Basis Document
AVHRR	Advanced Very High Resolution Radiometer
CDR	Critical Design Review
CM	Configuration Management
DDS	Data Delivery Subsystem
DPP	Development Project Plan
DSA	Data Submission Agreement
EMC	Environmental Modeling Center
EOS	Earth Observing System
EPL	Enterprise Product Lifecycle
ESA	European Space Agency
GAASP	GCOM-W1 AMSR2 Algorithm Software Processor
GCOM-W1	Global Change Observation Mission 1st – Water
GFS	Global Forecast System
GLDAS	Global Land Data Assimilation System
IPD	Information Processing Division
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
IT	Information Technology
MODIS	Moderate Resolution Imaging Spectroradiometer
N/A	Not Applicable
NCDC	National Climate Data Center
NGDC	National Geographic Data Center
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NWP	Numerical Weather Prediction
NRL	Naval Research Laboratory
OCD	Operations Concept Document
PAR	Process Asset Repository
PBR	Project Baseline Report
PDD	Preliminary Design Document
PDR	Preliminary Design Review
PDRR	Preliminary Design Review Report

PRR	Project Requirements Review
PSR	Project Status Report
R&D	Research & Development
RAD	Requirements Allocation Document
SMOPS	Soil Moisture Operational Product System
SMOS	Soil Moisture and Ocean Salinity
SRR	System Readiness Review
STAR	Center for Satellite Applications and Research
SWA	Software Architecture Document
TB	Brightness Temperature
TBD	To Be Determined
TBS	To Be Specified
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
TRR	Test Readiness Review
UTP	Unit Test Plan
UTR	Unit Test Report
VVP	Verification and Validation Plan

ABSTRACT

This document is the Algorithm Theoretical Basis Document (ATBD) for the Soil Moisture Operational Product System (SMOPS) developed by the NOAA/NESDIS Center for Satellite Applications and Research (STAR). The main function of the SMOPS is to retrieve surface soil moisture from currently available low-frequency microwave satellite sensors for applications in numerical weather and seasonal climate prediction models at National Centers for Environmental Prediction (NCEP). The retrieval algorithm used in SMOPS is the Single Channel Retrieval (SCR) algorithm. This document describes the details of the SCR algorithm.

To increase spatial and temporal coverage of the satellite soil moisture observations, SMOPS will import soil moisture retrievals from other satellite sensors and merger them with the output from the SCR algorithm using Global Land Data Assimilation System (GLDAS) modeled output. Currently these satellite sensors include the Advanced Scatterometers (ASCAT) aboard the EUMETSAT METOP-A and METOP-B satellites, the ESA's Soil Moisture and Ocean Salinity (SMOS), and Advanced Microwave Scanning Radiometer 2 (AMSR2) on JAXA's Global Change Observation Mission – Water "SHIZUKU" (GCOM-W1). The algorithm for merging these soil moisture retrievals is described in section 3.

To meet the data needs of NCEP and other potential users, the SMOPS generates two categories of soil moisture data products: the global daily product and the global 6 hour product. Details of these products are presented in Section 2. All of soil moisture retrievals from individual sensors will be contained in both of the SMOPS data products.

1. INTRODUCTION

Land surface soil moisture status controls the sensible and latent heat exchanges between the land surface and atmosphere. These heat exchanges are among the major energy sources for atmospheric motions. Thus, reliable soil moisture data products and techniques for assimilating them into numerical weather prediction models are believed to have significant impacts for weather forecast accuracy.

A number of soil moisture products have been produced from different satellite sensors with different spatial and temporal coverage and quality. To make good use of all available soil moisture products, a Soil Moisture Operational Product System (SMOPS) has been developed at National Oceanic and Atmospheric Administration (NOAA) to produce a one-stop shop for all operational soil moisture products from different satellite sensors. To increase the spatial and temporal coverage of soil moisture product, SMOPS also provides a data layer that merges soil moisture retrievals from multiple satellites in addition to the individual soil moisture retrievals from each of the available satellites.

SMOPS has been operationally running at NOAA NESDIS since 2012. In the first version of SMOPS, soil moisture products from Soil Moisture and Ocean Salinity (SMOS), the Advanced Scatterometer (ASCAT) on EUMETSAT's MetOp-A satellite and WindSat on Coriolis satellite are used to produce the blended product. All soil moisture layers from individual sensors are also gridded and saved in SMOPS final product. SMOPS has a 6-hour product and a daily product both in GRIB2 format. An archive product is also produced in NetCDF-4 format with a 2-day time latency to catch all available swath data from individual sensors.

SMOPS Version 2 improved the SMOPS product in following ways: 1) A new SMOS soil moisture product will be produced using the Single Channel Retrieval (SCR) algorithm in SMOPS to reduce the time latency in using SMOS data; 2) Soil moisture product from ASCAT sensor on MetOp-B satellite will be ingested in the system; 3) Soil moisture product from the Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the GCOM-W satellite will be ingested in the system, and 4) WindSat soil moisture layer will no longer be included.

1.1 Existing products

Several soil moisture data sets have been retrieved from microwave satellite sensors such as the Scanning multichannel Microwave Radiometer (SMRR) on Nimbus-7, the Tropical Rainfall Monitoring Mission (TRMM) Microwave Imager (TMI), the AMSR-E and the WindSat on Navy Coriollis satellite (Owe et al, 2008; Bindlish et al, 2001; Njoku et al, 2003; Li et al, 2008). However, these products are either available for a short time period or unavailable for near real time applications. NASA AMSR-E global soil moisture data product was the first one generated continuously and made constantly available for public users since June 2002. Since then, a number of microwave satellite soil moisture products have been operationally produced from different sensors, including the Soil Moisture and Ocean Salinity (SMOS) from the European Space Agency (ESA), the Advanced Scatterometer (ASCAT) on EUMETSAT's MetOp-A and –B satellites, and the Advanced Microwave Scanning Radiometer 2 (AMSR2) on the GCOM-W1 satellite. Active and passive microwave remote sensing has been shown to be a reliable tool for surface soil moisture retrievals as it is one of the key factors that control the emissive and scattering characteristics of soil surface. These products vary in both data quality and data latency. Some of these products are produced just for research purpose only while some of them are operationally produced for near-real time use. To be able to be used in NOAA Global Forecast Model (GFS) model, a soil moisture product must be produced with data latency within 6 hours. None of these currently available soil moisture products could provide a reasonable spatial coverage with this time latency requirement.

1.2 Purpose

To make effective use of all available microwave-based datasets, Soil Moisture Operational Product System (SMOPS) has been developed at NOAA/NESDIS which has been operational since 2012. This system not only provides global soil moisture data products from individual sensors, such as MetOp-A and –B ASCAT of EUMETSAT, WindSat of Naval Research Laboratory (NRL) and SMOS of ESA, but also provides a blended analysis from all these products. SMOPS produces a 6-hour product with 3 hour latency and a daily product with 6-hour latency for operational use. Since the merged soil moisture product from SMOPS is from all available soil moisture data produced by individual satellite sensors within a given time latency, the more input products, the better the spatial coverage of the blended product will be.

SMOPS Version 2 added near real time SMOS retrievals and GCOM-W1 AMSR2 soil moisture product and dropped WindSat retrievals due to sensor lifetime.

This document describes the SMOPS Version 2.0, its retrieval algorithm and its products.

1.3 Revisions

This is a revised version (Version 4.0) dated September 20, 2016. Dates of the original (Version 1) and previously revised version of this document are listed in a table in Page 2 of this document.

1.4 Document Overview

This DG contains the following sections:

Section 1.0 - Introduction
Section 2.0 - SMOPS Overview
Section 3.0 - Description of Algorithms

2. SMOPS OVERVIEW

2.1 Objectives of Soil Moisture Retrievals

The National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) and North American Mesoscale Model (NAM), and their associated assimilation systems, include a land surface model (LSM) component that requires soil moisture information for accurate weather and seasonal climate predictions. Currently, surface soil moisture is estimated via the background simulation of the LSM of the assimilation system. This simulated soil moisture contains considerable biases and uncertainties. A satellite-based global soil moisture observational data product will provide a substantial constraint that is expected to greatly reduce these uncertainties and thereby improve the global and mesoscale model forecast accuracy.

To meet NCEP's soil moisture data needs, NESDIS is supporting the SMOPS project to develop a blended global soil moisture product by merging soil moisture observations from the Advanced Scatterometer (ASCAT) on EUMETSAT's MetOp satellites, the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) satellite, Advanced Microwave Scanning Radiometer 2 (AMSR2) on JAXA's Global Change Observation Mission – Water "SHIZUKU" (GCOM-W1), and SMOPS own retrievals from Near Real Time (NRT) SMOS Level 1C product.

2.2 Instrument Characteristics

2.2.1 SMOS

Soil Moisture Ocean Salinity (SMOS) mission of European Space Agency (ESA) is the first ever satellite mission designated for soil moisture observation. SMOS was launched on November 2, 2009 and carries the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS). The MIRAS senses L-band microwave emission (1.400-1.427 GHz) that could penetrate soil depth to about 5cm and vegetation cover with vegetation water content up to 5 kg/m^2 (Kerr et al, 2000). The SMOS radiometer exploits the interferometry principle, which by way of 69 small receivers will measure the phase difference of incident radiation. The technique is based on cross-correlation of observations from all possible combinations of receiver pairs. A two-dimensional 'measurement image' is taken every 1.2 seconds. As the satellite moves along its orbital path each observed area is seen under various viewing angles.

From an altitude of around 758 km, the antenna will view an area of almost 3000 km in diameter. However, due to the interferometry principle and the Y-shaped antenna, the field of view is limited to a hexagon-like shape about 1000 km across called the 'alias-free zone'. This area corresponds to observations where there is no ambiguity in the phase-difference. SMOS achieves global coverage every three days. More details of the SMOS mission can be found at http://www.esa.int/esaLP/ESAL3B2VMOC_LPsmos_0.html.

2.2.2 ASCAT

ASCAT sensors are on board of the MetOp satellites. They are an advanced version of the Scatterometer (called ESCAT) on board of the European Remote Sensing Satellites (ERS). These scatterometers are originally designed for indirectly determining wind stress over oceans by measuring the radar backscattering coefficient (σ_0) from the wind induced water ripples and waves. ASCAT has three radar antenna beams that illuminate a continuous ground swath at three different azimuth angles (45, 90, and 135 degrees sideward from the direction of the satellite motion) on both sides of the track. The result is a triplet of spatially averaged σ_0 values for each location along the swath. The ASCAT measurements have a 50-km spatial resolution along and across the swath, with an additional 25-km resolution product with experimental status. ASCAT also features a symmetrical second swath, which practically increases its temporal sampling capabilities to double that of the ESCAT—this is, on average 0.8 to more than 5 passes per day, depending on latitude (Bartalis et al. 2005; Gelsthorpe et al. 2000). Because of the significant width of the swath, the σ_0 measurements come not only at six different azimuth angles but also at various incidence angles ranging from 25 to 64 degrees. The C-band radar frequency is 5.255 GHz.

The European Organization of Satellite Meteorology (EUMETSAT) MetOp satellites that carries ASCAT is a sun-synchronous polar-orbiting operational satellite with an altitude of about 800 km above the earth's surface and an orbital period of about 100 min.

A more detailed description of the ASCAT instrument is given in Figa-Saldana et al. (2002) and Gelsthorpe et al. (2000). An overview of ASCAT data product can be found in http://oiswww.eumetsat.org/WEBOPS/eps-pg/ASCAT/ASCAT-PG-4ProdOverview.htm#TOC42.

Note that the main purpose of adding ASCAT soil moisture is to increase the spatial and temporal coverage of the SMOPS soil moisture product. Loss of ASCAT soil moisture data may reduce the temporal and spatial coverage of the SMOPS products.

2.2.3 AMSR2

The Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the GCOM-W satellite is a remote sensing instrument for measuring weak microwave emission from the surface and the atmosphere of the Earth. From about 700 km above the Earth, AMSR2 will provide us highly accurate measurements of the intensity of microwave emission and scattering.The antenna of AMSR2 rotates once per 1.5 seconds and obtains data over a 1450 km swath. This conical scan mechanism enables AMSR2 to acquire a set of daytime and nighttime data with more than 99% coverage of the Earth every 2 days. GCOM-W1 is part of the “A-train” constellation along with Aqua. AMSR2 and AMSR-E have the same center frequencies and corresponding bandwidths and is considered as the successor to AMSR-E. AMSR2 has several enhancements: larger main reflector, additional 7.3 GHz channels, an improved calibration system (Imaoka et al., 2010), and improved spatial resolution (Table 2.1).

Table 2.1 – AMSR2 performance characteristics

<table>
<tr><th>Center Freq.</th><th>Band width</th><th>Pol.</th><th>Beam width</th><th>Ground res.</th><th>Sampling interval</th></tr>
<tr><th>GHz</th><th>MHz</th><th></th><th>degree</th><th>km</th><th>km</th></tr>
<tr><td>6.925/7.3</td><td>350</td><td rowspan="6">V/H</td><td>1.8</td><td>35 x 62</td><td rowspan="5">10</td></tr>
<tr><td>10.65</td><td>100</td><td>1.2</td><td>24 x 42</td></tr>
<tr><td>18.7</td><td>200</td><td>0.65</td><td>14 x 22</td></tr>
<tr><td>23.8</td><td>400</td><td>0.75</td><td>15 x 26</td></tr>
<tr><td>36.5</td><td>1000</td><td>0.35</td><td>7 x 12</td></tr>
<tr><td>89.0</td><td>3000</td><td>0.15</td><td>3 x 5</td><td>5</td></tr>
</table>

2.2.4 AVHRR

SMOPS requires the Normalized Difference Vegetation Index (NDVI) data for estimating the vegetation water content (VWC) that is a critical input to the SCR algorithm used to retrieval soil moisture from NRT SMOS observations. The NDVI data will be acquired from the Advanced Very High Resolution Radiometer (AVHRR) onboard all NOAA Polar-orbiting Satellites.

The AVHRR is a six channel scanning radiometer providing three solar channels in the visible-near infrared region and three thermal infrared channels (Table 2.2). More information on AVHRR is provided at

http://www.ncdc.noaa.gov/oa/pod-guide/ncdc/docs/klm/html/c7/sec7-1.htm

Table 2.2 – Summary of AVHRR Spectral Channel Characteristics

Parameter	Ch. 1	Ch. 2	Ch. 3A	Ch. 3B	Ch. 4	Ch. 5
Spectral Range (μm)	0.58-0.68	.725-1.0	1.58-1.64	3.55-3.93	10.3-11.3	11.5-12.5
Resolution (km)	1.09	1.09	1.09	1.09	1.09	1.09

NDVI is basically a calculation of the differences between AVHRR channels 1 (RED) and 2 (NIR) using the equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{2.1}$$

The NDVI data has been generated operationally at NESDIS-OSDPD from current operational NOAA satellite and made available on OSDPD DDS.

2.3 Retrieval Strategy

The basic retrieval strategy of SMOPS is to retrieve soil moisture from a baseline satellite sensor (WindSat for SMOPS Version 1 and NRT SMOS for Version 2), and then to potentially extend spatial and temporal coverage using soil moisture retrievals from other satellite sensors. The baseline satellite sensor may be replaced with a future, more reliable satellite sensor such as NASA's decadal survey mission, Soil Moisture Active/Passive (SMAP). More algorithm details will be described in the next sections.

3.0 ALGORITHM DESCRIPTION

3.1 Processing Outline

SMOPS Version 2 generates two sets of global soil moisture data products: Daily Gridded Product and 6 Hour Gridded Product. Each product contains surface soil moisture retrievals from the baseline satellite sensor, NRT SMOS, and other available satellite sensors (ASCAT-A, ASCAT-B, ESA SMOS and AMSR2), and a combined soil moisture data layer that merges all soil moisture retrievals for each global grid. The daily product contains all soil moisture retrievals and their merged values acquired during the past 24 hours while the 6 Hour product include all soil moisture retrievals and their merged values acquired during the past 6 hours. The processing procedure includes the following stages:

Stage 1: Preprocess the ancillary data required by the SCR algorithm, the baseline satellite sensor swath data, and gridded soil moisture retrievals from other available satellite sensors acquired within the past 6 hours.

Stage 2: Use the SCR algorithm to retrieve soil moisture from the baseline satellite sensor swath data and ancillary data and grid retrieved soil moisture to global 0.25 degree grids.

Stage 3: Combine the baseline satellite sensor soil moisture retrievals and the soil moisture retrievals from other available satellite sensors at the global 0.25 degree grids using a Retrievals Merging algorithm.

Stage 4: Pack the 6 Hour Gridded Global Soil Moisture Product with the soil moisture retrievals from the baseline satellite sensor, the other available satellite sensors, their combination, their quality flags and their metadata acquired or generated within the past 6 hours.

Stage 5: Pack the Daily Gridded Global Soil Moisture Product with the soil moisture retrievals from the baseline satellite sensor, the other available satellite sensors, their combination, their quality flags and their metadata acquired or generated within the past 24 hours if the current processing time is the last of the day.

Stage 6: Deliver the 6 Hour Gridded Global Soil Moisture Product and the Daily Gridded Global Soil Moisture Product (if the current processing time is the last time of the day) to DDS and users.

The SMOPS algorithm consists of the following major functions:

1) A pre-processing function that ingests the required input data and prepares it for processing through formatting and regridding

- Read the process control file
- Read Lat/Long information from the process control file if the validation mode is turned on
- Read soil texture (sand and clay fractions and porosity) maps
- Read land cover map
- Read AVHRR NDVI map
- Read NDVI climatology map
- Read land cover parameter file
- Check validity and QA for the above maps. If any one of them is invalid, stop the process.
- Read one NRT SMOS L1C file name from the file name list
- Open the NRT SMOS L1C file and process it into brightness temperature
- Check the land cover type associated with the footprint and other conditions to proceed on doing SCR soil moisture retrieval

2) The retrieval function that derives soil moisture from microwave brightness temperatures and ancillary data

- Compute the surface emissivity:
  - Correct surface reflectivity for surface roughness effect
  - Estimate vegetation water content from NDVI
  - Compute vegetation optical depth
- Compute soil dielectric constant
- Call the mixing model to calculate soil moisture from the computed soil dielectric constant.
- Grid the all retrieved footprint soil moisture retrievals within the past 6 hours to a global 0.25 degree Lat/Long grid.

3) A merging function that merges soil moisture retrievals into the desired output composite products

- Read ESA SMOS soil moisture data
- Read the Cumulative Distribution Functions (CDFs) for SMOS and GLDAS soil moisture
- Scale SMOS soil moisture retrievals by matching the CDFs
- Read ASCAT-A soil moisture data
- Read the Cumulative Distribution Functions (CDFs) for ASCAT-A and GLDAS soil moisture
- Scale ASCAT-A soil moisture retrievals by matching the CDFs
- Read ASCAT-B soil moisture data
- Read the Cumulative Distribution Functions (CDFs) for ASCAT-B and GLDAS soil moisture
- Scale ASCAT-B soil moisture retrievals by matching the CDFs
- Read AMSR2 soil moisture data
- Read the Cumulative Distribution Functions (CDFs) for AMSR2 and GLDAS soil moisture
- Scale AMSR2 soil moisture retrievals by matching the CDFs
- Composite all soil moisture retrievals from NRT SMOS, ESA SMOS, ASCAT-A, ASCAT-B, and AMSR2 acquired within the previous 6 hour window
- Generate QA layer
- Generate meta data
- Output 6 Hour soil moisture product with QA and meta data
- Generate the status report file for 6 Hour product
- Composite the daily soil moisture product with QA and meta data from previous four 6 Hour products
- Output daily soil moisture product with QA and meta data
- Generate the status report file for daily product
- Output the soil moisture values for the validation sites if the validation mode is turned on

The algorithm processing flow is shown in Figure 3.1. Branches 1 – 3 are corresponding to the about 3 functions. There is a possibility that the delivery of the NRT SMOS L1C, ESA SMOS L2 SM, ASCAT-A L2 SM, ASCAT-B L2 SM or AMSR2 L2 SM data acquired in the past 24 hours is delayed. If these data become available within the next day (i.e. the past 48 hours), another SMOPS archive run will be activated to generate the daily global soil moisture product for archiving. This step is shown as Branch 4 in Figure 3.1.

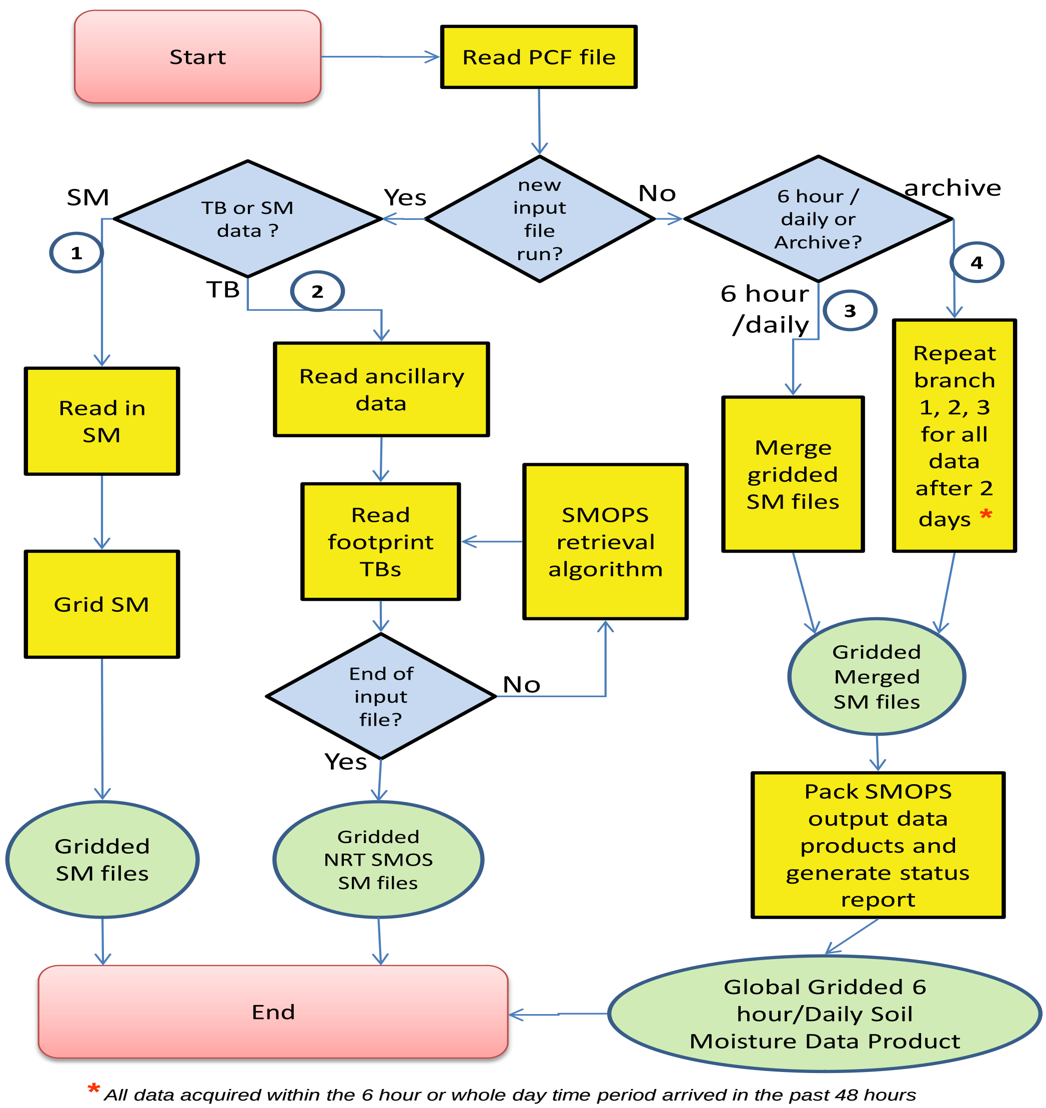


Figure 3.1 – SMOPS Algorithm Process Flow.

3.2 Algorithm Input

3.2.1 SMOS NRT L1C Data

SMOS L1C data product has multi-incidence angle brightness temperature at the top of the atmosphere, geolocated in an equal-area grid system (15km, ISEA 4H9 grid). Separate datasets are available for sea and land pixels. Information is available per pixel and per snapshot. For each Level 1C product there is also a browse product containing the brightness temperatures averaged for an incidence angle of 42.5 degrees. The level 1 Near Real Time (NRT) data product is similar to the L1C product but adjusted to requirements of operational meteorological agencies. The NRT products are generated by the NRT Processor integrated in the Data Processing Ground Segment in BUFR format. NRT data is available from ESA, NRT light is available from EUMETCast Europe and WMO GTS within three hours from sensing time. More detailed information about this data set can be found at https://earth.esa.int/documents/10174/1854456/SMOS_L1c-Data-Processing-Models.

3.2.2 Ancillary Data

The ancillary data for the SCR algorithm include land cover map, AVHRR NDVI, NDVI climatology map, clay map and sand map, and porosity map, and land cover parameters.

3.2.2.1 Land Cover Map

The global land cover map is needed in this algorithm mainly for a land/water mask and to correctly set the Quality Assessment (QA) for areas where the soil moisture retrieval capability of SCR algorithm is weak, such as forested area. To convert the vegetation water content to the vegetation optical depth, an empirical constant, *b*, is needed for different land cover types. In the current implementation of the algorithm, *b* value is simply assumed a universal constant across different land cover types.

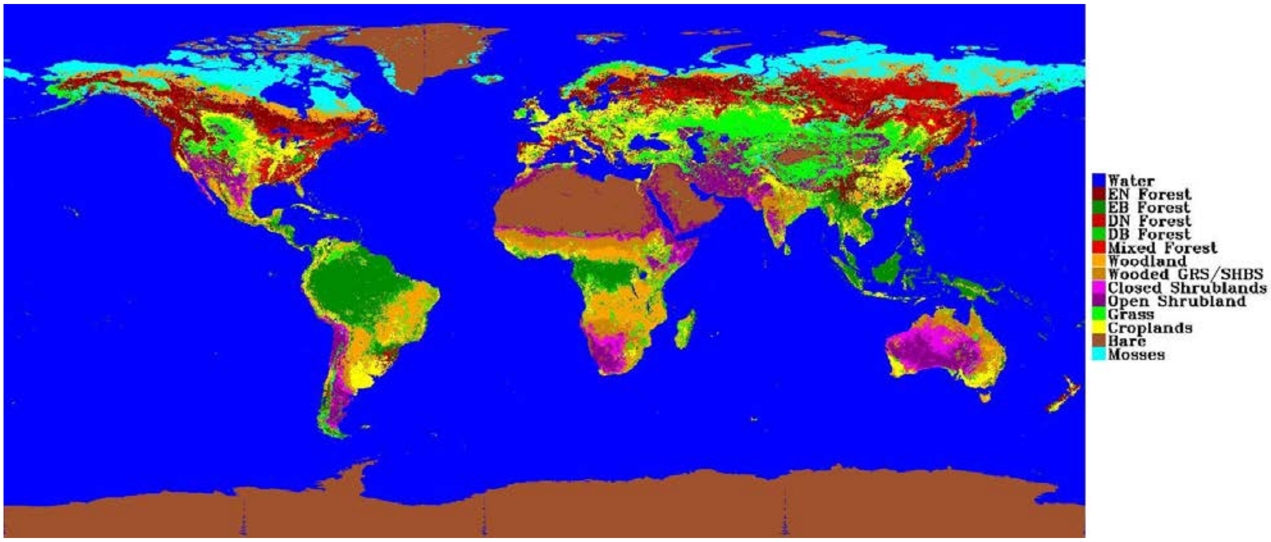


Figure 3.2.1 – Land Cover Map Used by the SCR Algorithm.

The land cover map used in this algorithm is the 8-km land cover map produced by University of Maryland Geography Department (Figure 3.2.1). Land cover type rarely changes at microwave observation footprint size level (usually 20km-50km), therefore, the static land cover map is sufficient. Table 3.1 lists the land cover code in the land cover map and QA configuration.

Table 3.1 – Land Cover Types

Code	Land Cover Type
0	Water
1	Evergreen Needleleaf Forests
2	Evergreen Broadleaf Forests
3	Deciduous Needleleaf Forests
4	Deciduous Broadleaf Forests
5	Mixed Forests
6	Woodlands
7	Wooded Grasslands/Shrubs

8	Closed Bushlands or Shrublands
9	Open Shrublands
10	Grasses
11	Croplands
12	Bare
13	Mosses and Lichens

3.2.2.2 AVHRR NDVI

AVHRR NDVI maps are used to derive the vegetation water content maps, which is further converted to vegetation optical thickness maps using a land cover type-based constant *b* (see Eq. (4)). In case where the AVHRR NDVI data are not available, a multiyear AVHRR NDVI climatology data set is used.

The AVHRR NDVI data to be used have a temporal resolution of 7 days and spatial resolution of 4 km. To aggregate this finer resolution NDVI to SMOPS quarter-degree grids, a simple arithmetic average of NDVI values of all the 4-km grids that fall into a quarter-degree grid is used for this quarter-degree grid. The quarter-degree NDVI value is then used for all the footprints with their center located within this grid. To investigate the effect of this aggregation method on those footprints located on the edge of the grids, another quarter-degree aggregation map is made with the centers of the grids located at the edge of the native quarter-degree map. Figure 3.2.2 shows that the difference of these two NDVI maps is minor. Therefore, using the aggregated quarter-degree NDVI map at the native grid has minor effect on the retrievals of the footprints located on the grid edges.

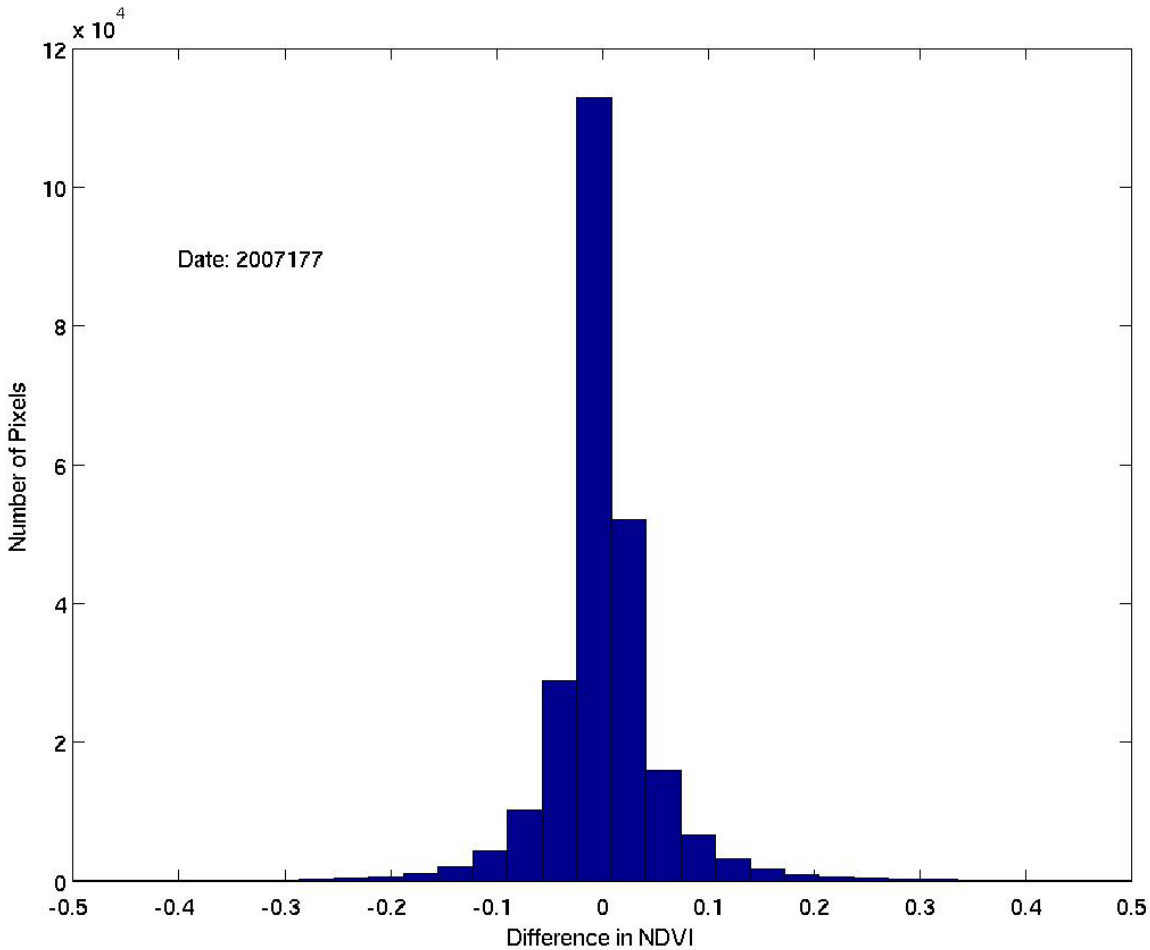


Figure 3.2.2 – NDVI difference histogram from NDVI maps using two different aggregation methods.

An NDVI climatology map is used when the real time NDVI map is not available. The climatology map is generated using all the NDVI data from 1982 to 2010. To investigate the soil moisture retrieval error caused by the use of climatology map, a soil moisture difference map is generated from the soil moisture maps using the real time NDVI map and the multiyear climatology map. Figure 3.2.3 shows that over 95% of the difference is lower than 2% vol/vol. Therefore, the soil moisture map generated using NDVI climatology is comparable with the map generated using the real time NDVI data.

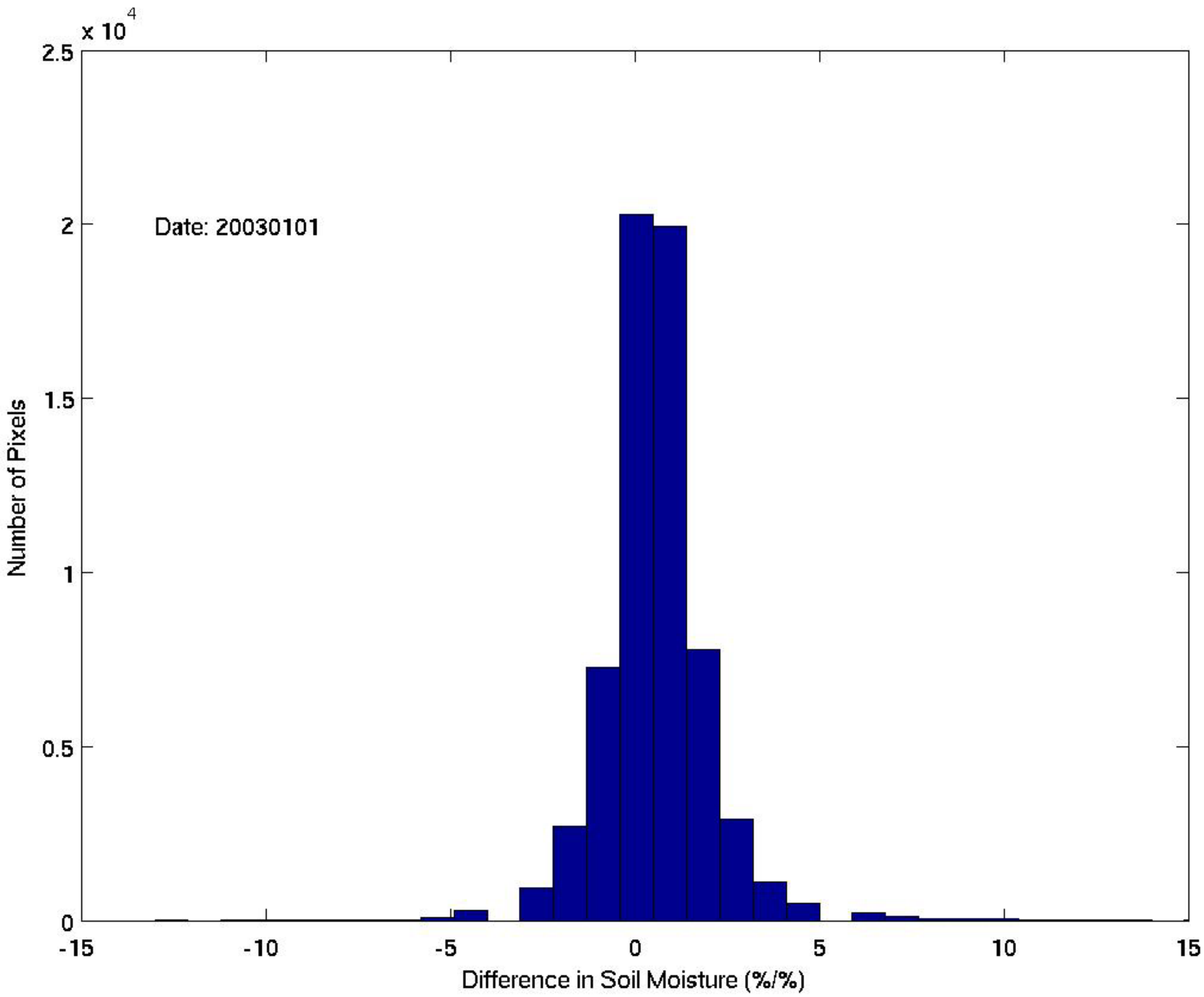


Figure 3.2.3 – Histogram of the difference soil moisture map from two soil moisture maps using NDVI climatology and real time NDVI map.

3.2.2.3 Clay Map

A clay fraction map is used in the SCR algorithm as input of the Dobson mixing model. The clay map (Figure 3.2.4) is from Food and Agriculture Organization (FAO, Reynolds et al. 2000). It has a 5-arcmin spatial resolution, which is equivalent to a 9 km x 9 km cell size at equator.

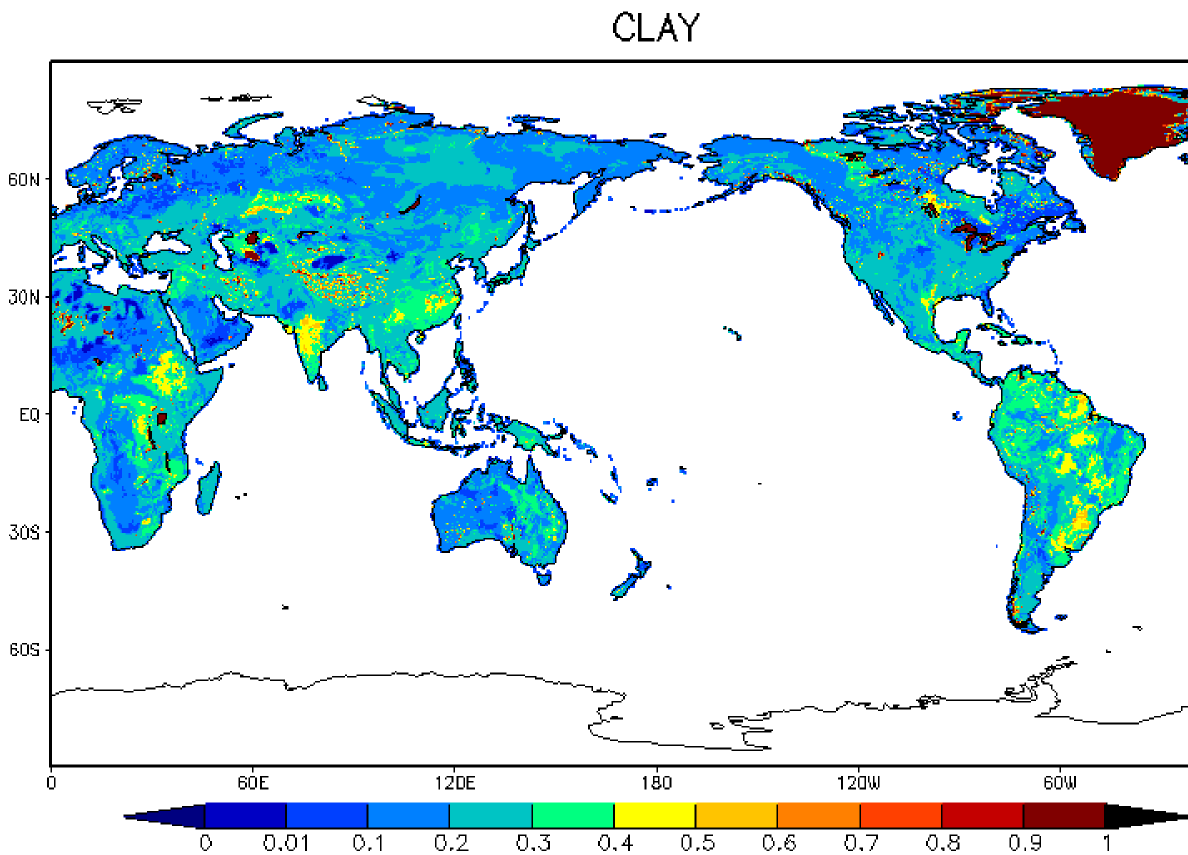


Figure 3.2.4 – Clay Fraction Map Used by the SCR Algorithm

3.2.2.4 Sand Map

A sand fraction map is used in the SCR algorithm as input of the Dobson mixing model. The sand map (Figure 3.2.5) is from FAO (Reynolds et al., 2000) with the same spatial resolution as the clay map.

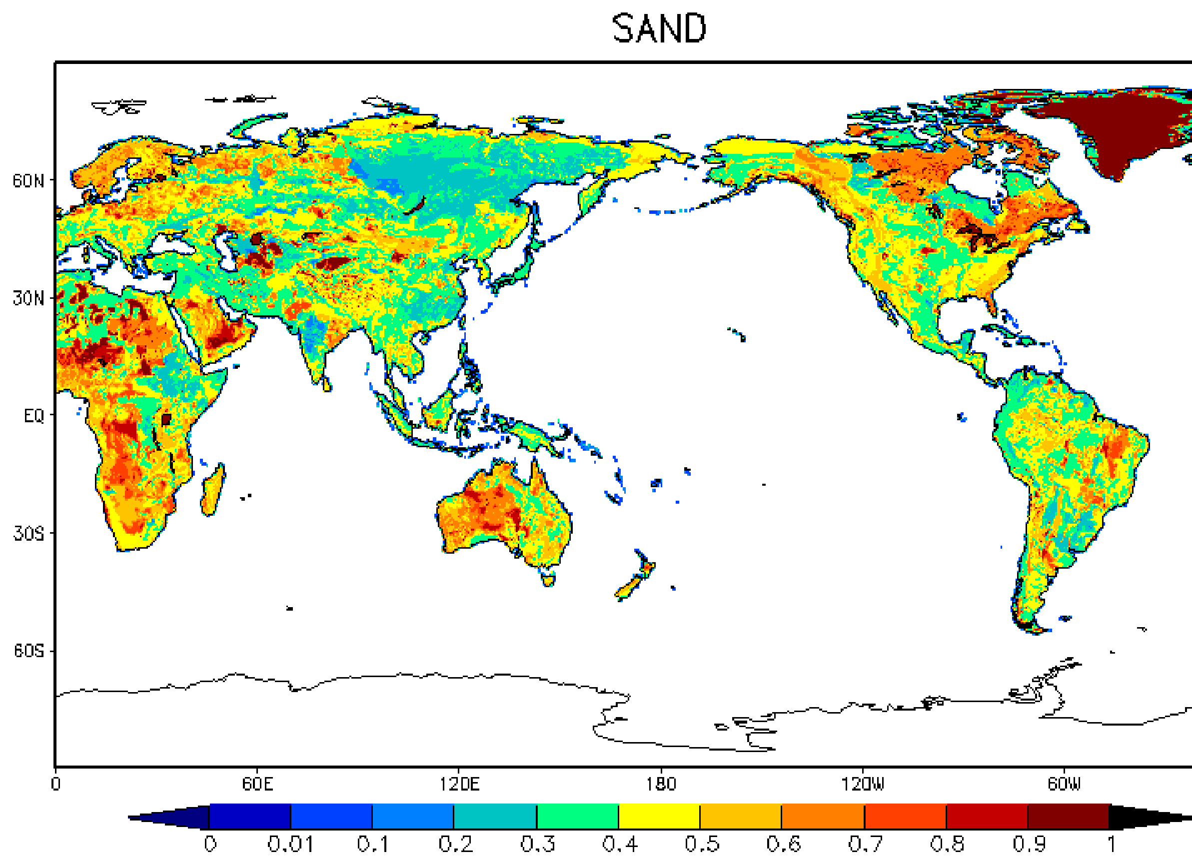


Figure 3.2.5 – Sand Fraction Map Used by the SCR Algorithm

3.2.2.5 Porosity Map

Soil porosity is used in the SCR algorithm as input of the Dobson mixing model. The porosity map (Figure 3.2.6) is from FAO (Reynolds et al., 2000) with the same spatial resolution as the clay map and sand map.

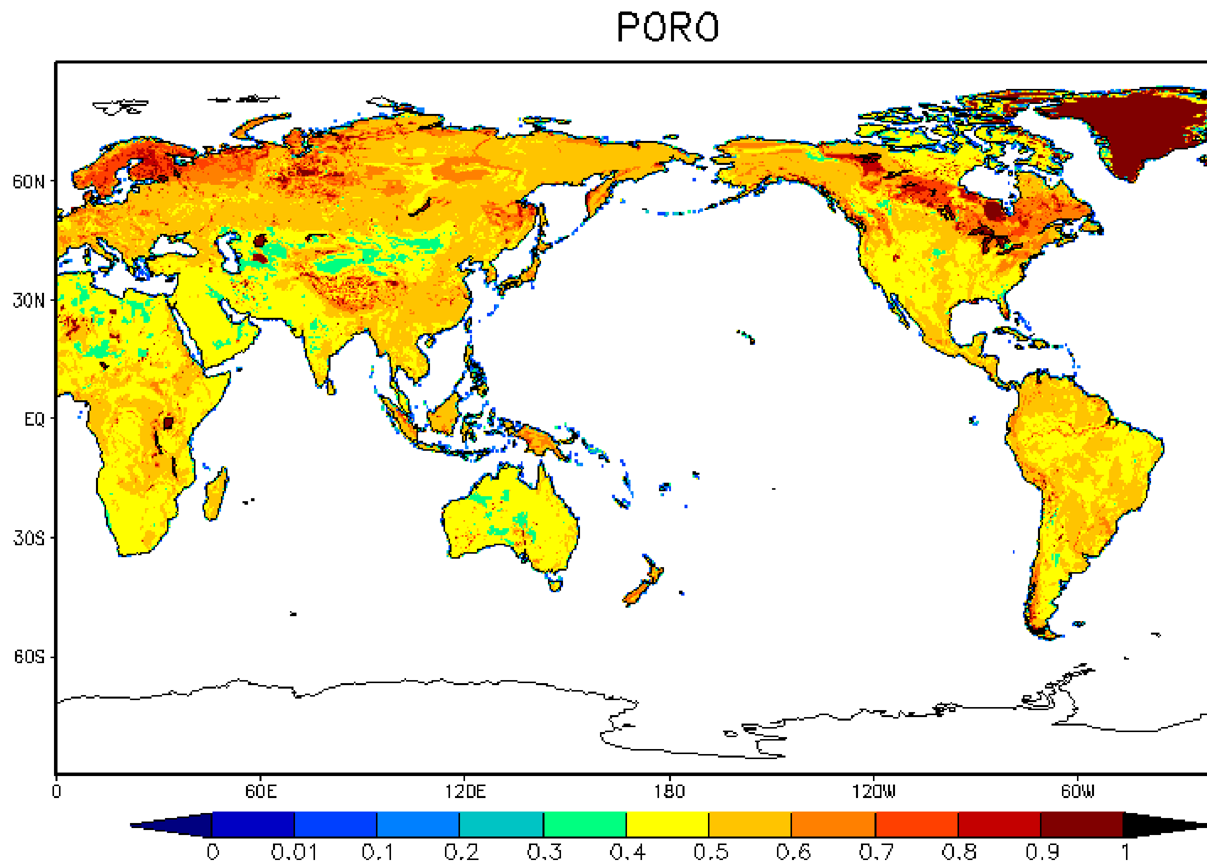


Figure 3.2.6 – Porosity Map Used by the SCR Algorithm

3.2.3 ASCAT-A, ASCAT-B, ESA SMOS and AMSR2 Soil Moisture

To increase the spatial and temporal coverage of the soil moisture data product, soil moisture retrievals from ESA SMOS, ASCAT-A, ASCAT-B and AMSR2 are imported to the merging function of the algorithm (see Section 3.5).

3.2.3.1 ASCAT (A and B) Soil Moisture

The ASCAT Level 2 Soil Moisture product is generated and distributed in near real-time. The main geophysical parameter is relative land surface soil moisture, based on the swath-based grid. The expected average RMS error of the ASCAT soil moisture index is about 25%, which corresponds to about 0.03-0.07 [vol/vol], depending on soil type. ASCAT soil moisture data is available at 25km global grids. With two 500km subswath widths, ASCAT revisit time for a specific location is about 6 days.

More details about the ASCAT soil moisture product can be found in the Soil Moisture Product Guide (Bartalis et al, 2005).

3.2.3.2 SMOS Soil Moisture

SMOS soil moisture retrievals are available at 40km global grids with a 4% accuracy expectation. SMOS revisit time is 2-3 days for each grid. Details of the SMOS soil moisture data will be determined by an agreement with ESA and described in a future version of this ATBD (http://www.cesbio.ups-tlse.fr/us/smos/ smos_atbd.html).

3.2.3.3 AMSR2 Soil Moisture

The NOAA Operational GCOM-W1 AMSR-2 Products System (NOGAPS) is developed to process GCOM data and generate NOAA unique operational products for users. Soil moisture product is one of its major level 2 products. Detailed description can be found on their Website (http://www.ospo.noaa.gov/Products/atmosphere/gpds/).

3.3 Pre-processing Function

The pre-processing function is to ingest the required input data and prepares it for processing through formatting and regridding.

NRT SMOS L1C data will be extracted from BUFR files and reformatted to SMOPS plain binary files. ASCAT, SMOS and AMSR2 soil moisture data will be extracted from their original formats, formatted to SMOPS plain binary format, and regridded to SMOPS 0.25-degree lat/long grids. Ancillary data (AVHRR NDVI, FAO soil texture maps, land cover types) are read from plain binary files.

3.4 Theoretical description of soil moisture retrieval (SCR) algorithm

The SCR method used in SMOPS is mainly based on an algorithm developed by Jackson (1993). In this approach, brightness temperature from a single microwave channel is converted to emissivity that is further corrected for vegetation and surface roughness effect. The Fresnel equation is then used to determine the dielectric constant and a dielectric mixing model is used to obtain the soil moisture.

3.4.1 Brightness Temperature / Emissivity Relation

The major input for this algorithm is the 10.7 GHz H-pol brightness temperature, Tb, from a satellite sensor, which includes contributions from the land surface, the atmosphere, and reflected sky radiation. Considering the latter two are negligible at the frequency we are using, the relationship between land surface emissivity, e_s, and Tb for pure soil can be expressed as

$$T_b = eT_s \tag{3.1}$$

where T_s is the soil effective temperature. If T_s is estimated independently, emissivity can then be determined.

In the case where there is vegetation above the soil, the above forward microwave emission model can be expressed as

$$T_{Bp} = T_s e_{r,p} \exp(-\tau_p / \cos\theta) + T_c(1-\omega_p)$$

$$[1-\exp(-\tau_p / \cos\theta)][1+R_{r,p}\exp(-\tau_p / \cos\theta)] \tag{3.2}$$

where, the subscript p refers to polarization (H or V) and subscript *r* stands for rough surface, T_s is the soil skin temperature, T_c is the vegetation temperature, τ_p is the nadir vegetation opacity, ω_p is the vegetation single scattering albedo, and $R_{r,p}$ is the soil reflectivity. The rough surface soil reflectivity is related to the soil emissivity by $e_{r,p} = (1 - R_{r,p})$, and ω_p, $R_{r,p}$ and $e_{r,p}$ are values at an assumed radiometer incident angle of $\theta=55°$. $R_{r,p}$ is related to smooth surface soil reflectivity R_s through the soil roughness parameter *h* so that $R_s = R_r \exp(h \cos 2\theta)$ without notification for polarization. While Eq. (3.2) and these parameterizations of τ and R_s represent simplifications of the actual microwave emission process, they are widely utilized for low-frequency (L-band) microwave emission and retrieval modeling of the land surface – especially within lightly to moderately vegetated regions.

In SCR algorithm, with the assumptions of $T_c = T_s$ and $\omega_p = 0$ (Jackson, 1993), Eq. (3.2) can be simplified as

$$T_B = T_S[1 - R_r \exp(\frac{-2\tau}{\cos\theta})] \tag{3.3}$$

Note that SCR algorithm only uses the H-pol T_b observations, polarization indications in Eq. (3.3) has been dropped.

The vegetation optical depth, τ, is dependent upon vegetation water content (*W*). A simple linear relationship is employed to calculate τ from *W*:

$$\tau = bW \tag{3.4}$$

where *b* is an empirical parameter associated with different land cover types defined with the land cover parameters file. Vegetation water content, *W*, is estimated using AVHRR NDVI and the method described in this document: https://smap-archive.jpl.nasa.gov/files/smap2/L2&3_SM_P_RevA_web.pdf.

3.4.2 Emissivity / Dielectric Constant Relation

The Fresnel reflection equations are used to predict the surface microwave emissivity as a function of dielectric constant (ε_r) and the viewing angle (θ) based on the polarization of the sensor (Ulaby, 1986). Since the imaginary part of the complex dielectric constant is relatively small and thus is often ignored, the Fresnel equation can be simplified by including only the real part of the complex dielectric constant (only H-pol is presented):

$$e_H = 1 - \left| \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \right|^2 \tag{3.5}$$

The real part (ε_r) of the dielectric constant of the soil can be solved given the calculated emissivity and known sensor viewing angle.

3.4.3 Dielectric Constant / Volumetric Soil Moisture Relation

Both components of wet soil, soil and water, contribute to its dielectric constant. The fundamental principle of this algorithm is the large contrast in dielectric properties of water and soil. Water has a complex dielectric constant of about 80 for the real part as compared to about 3.5 for dry soil. Thus, the real part of dielectric constant for wet soil can be 3.5 - 80. This large dielectric constant difference between wet and dry soil correspondingly impacts the soil emissivity that can be related to the brightness temperature measured by the satellite sensor as showing in above section. Since the dielectric constant is a volume property, the volumetric fraction of each component must be considered.

In the SCR algorithm, the Dobson mixing model is used to calculate the volumetric soil moisture from the computed dielectric (Dobson et al., 1985). This model is based upon the index of refraction, and yields an excellent fit to the measured data at frequencies above 1.4 GHz and should be adequate for most applications requiring estimated soil dielectric properties for use in emission and scattering calculations. This model requires soil textural composition as input, such as proportions of clay and sand. The following equations are used for the Dobson mixing model:

m_v = (eps_r**alpha-fv*(eps_solid_r**alpha-1.0)-1.0)/(eps_water_r**alpha-1.0)**(1.0/betar)
por = 0.505-0.142*sf-0.037*cf
fv = 1.0-por
ew0 = 88.045 - 0.4147*tt + 6.295e-04*tt**2 + 1.075e-05*tt**3
rt = (1.1109e-10 - 3.824e-12*tt + 6.938e-14*tt**2 -5.096e-16*tt**3)*fi
eps_water_r = 4.9 + (ew0-4.9)/(1+rt**2)
betar = 1.2748-0.519*sf-0.152*cf (3.6)

where m_v is the soil moisture retrieval, eps_r, eps_water_r and eps_solid_r are dielectric constants for the soil, pure water and solid rock (4.7). Symbol alpha is a shape parameter and equals 0.65. Symbol fi is the microwave frequency in Hz. cf & sf are clay & sand fraction and tt is surface temperature in degree Celsius, Other variables (fv, betar, ew0, tt, and rt) are intermediate symbols and used for programming convenience.

3.5 Merging Function

3.5.1 Objectives of Merging Soil Moisture Retrievals from Different Satellites

All microwave soil moisture remote sensing satellites, currently in space or to be launched in near future, do not have a full global coverage for every day. Each of these satellite sensors may not have observations or soil moisture retrievals for the day.

To increase the spatial coverage of 6 hour and daily soil moisture retrievals, SMOPS provides a soil moisture data layer that merges all available satellite soil moisture retrievals in addition to the individual soil moisture retrievals from each of the available satellites.

3.5.2 Merging Approach

To generate a merged global soil moisture data product, the soil moisture retrievals from NRT SMOS footprints, ESA SMOS, ASCAT-A, ASCAT-B and AMSR2 will need to be combined into one value for each grid. Retrievals from different satellite sensors have their own climatology. The soil moisture retrievals from different satellite sensors should have been gridded to the same grid and have the same climatology. For this purpose, three steps are taken to merge them into one value for each grid: Grid NRT SMOS footprint retrievals, scale NRTSMOS, ESA SMOS, ASCAT-A, ASCAT-B and AMSR-2 retrievals to GLDAS climatology, and finally merge them to a single value.

3.5.2.1 Grid NRT SMOS Footprint Retrievals

Each 0.25 degree lat/lon grid may be represented by multiple NRT SMOS footprints. Observation times of these footprints may be very different from each other when they belong to different overpass swaths. To represent the most current situation of the grid, the retrieval based on the latest observation covering the grid is selected as soil moisture value of the grid. The latest observation time together with the soil moisture value are recorded for the grid.

3.5.2.2 Scale NRT SMOS, SMOS, ASCAT-A, ASCAT-B and AMSR-2 Retrievals

For each 0.25 degree lat/lon grid, there may be soil moisture retrievals from NRT SMOS, ESA SMOS, ASCAT-A, ASCAT-B and AMSR2. Each of them may have different climatology. Before merging them together, retrievals from all these products are scaled to GLDAS model output climatology using the CDF-matching method (Reichle & Koster, 2005). The CDF-matching method is to match the cumulative distribution function of two variables. For a single grid x, assume that GLDAS soil moisture values are a_1, a_2, …, a_n and their daily corresponding AMSR-2 retrievals are b_1, b_2, …, b_n. Rearrange a_1, a_2, …, a_n from their minimum A_1 gradually to their maximum A_n and the new GLDAS soil moisture values are A_1, A_2, …, A_n. Similarly, AMSR-2 retrievals can be rearranged from their minimum B_1 to maximum B_n. If a new SMOS retrieval for the grid is c and $B_{j-1} <= c <= B_{j+1}$, then its CDF-matched value will be A_j. Fig 3.5.5 demonstrates the CDF-match process. A Look-Up Table A = F(c) will be used to represent this CDF-matching process. F(x) represents the value of A corresponding to the value of B based on at least one year of SMOS and AMSR-E data.

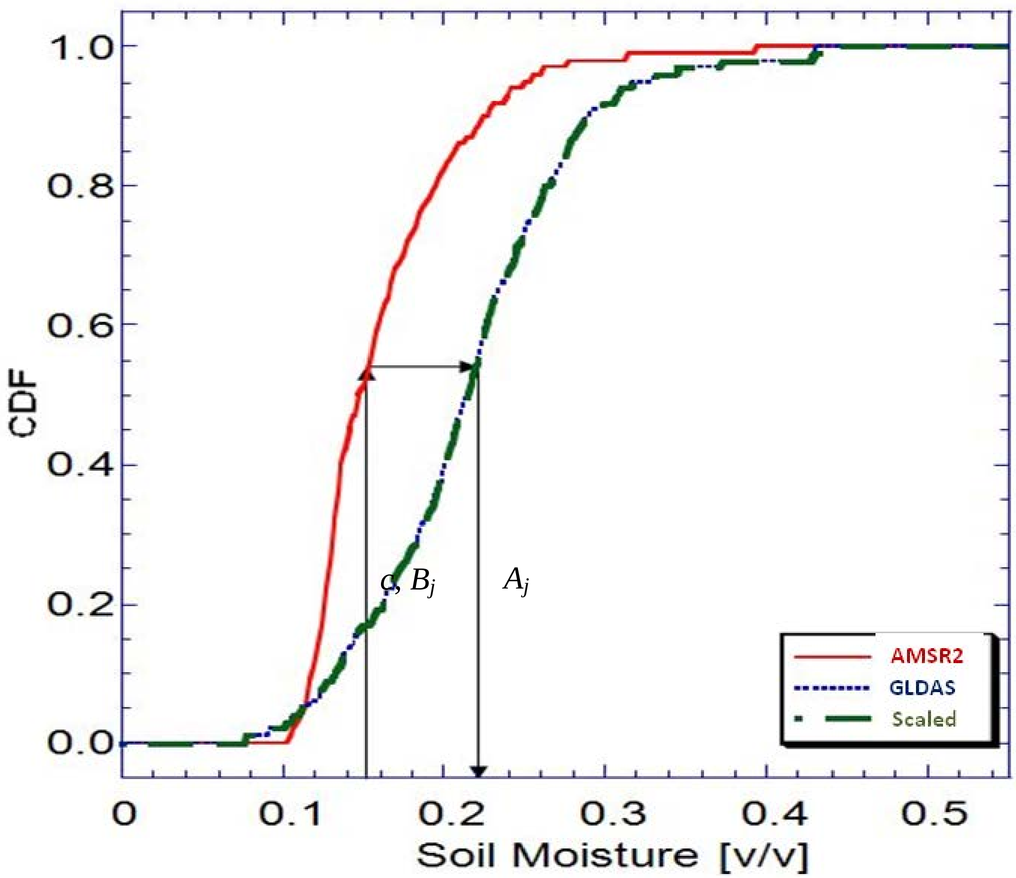


Figure 3.5.1 – Scaling AMSR2 Soil Moisture Retrievals to GLDAS Climatology Using the CDF-matching Method

3.5.2.3 Merge Gridded Soil Moisture Retrievals

Once the soil moisture retrievals of the day are obtained from the available satellite sensors and are scaled to the climatology of GLDAS, the latest retrieval will be selected to represent the soil moisture observation for the day.

3.6 Algorithm Output

The pre-processing, retrieval, and merging functions of the algorithm result in an output soil moisture map on a global Lat/Lon 0.25 degree grid. For each grid point of the map, the output includes soil moisture values (%vol/vol) of the surface (top 1-5 cm) soil layer with associated quality information and metadata. These soil moisture values are the retrieval from NRT SMOS L1C data using the SCR algorithm, the imported ASCAT soil moisture, the imported SMOS soil moisture, the imported AMSR2 soil moisture and their merged value. The merged soil moisture value is expected to have better accuracy and coverage, but users can choose any of these data layers.

The SMOPS product files also contain a quality assessment (QA) data layer for each of the soil moisture data layers. Details of the QA data layer are provided in the following tables.

Table 3.6.1 – SMOPS soil moisture product Quality Assessment (QA) bits.

(a) Blended Soil Moisture Layer QA

Byte	Bit	Description
1	0	0 = questionable; 1 = good retrievals
	1	0 = no NRT SMOS; 1 = NRT SMOS included
	2	0 = no ESA SMOS; 1 = ESA SMOS included
	3	0 = no ASCAT-A; 1 = ASCAT-A included
	4	0 = no ASCAT-B; 1 = ASCAT-B included
	5	0 = no AMSR2; 1 = AMSR2 included
	6	0 = no open water; 1 = open water
	7	0 = not frozen ground; 1 = frozen ground
2	0	0 ≤ GVF < 0.1
	1	0.1 ≤ GVF < 0.2
	2	0.2 ≤ GVF < 0.3
	3	0.3 ≤ GVF < 0.4
	4	0.4 ≤ GVF < 0.5
	5	0.5 ≤ GVF
	6	Spare
	7	Spare

(b) NRT SMOS Soil Moisture Layer QA

Byte	Bit	Description
1	0	0 = overall quality is not good; 1 = overall quality is good
	1	1 = retrieval attempted but quality is not good; 0 = otherwise
	2	1 = retrieval attempted but unsuccessful due to input brightness temperature data quality; 0 = otherwise
	3	1 = retrieval attempted but unsuccessful due to the quality of other input data; 0 = otherwise
	4	1 = retrieval not attempted; 0 = retrieval attempted
	5	0 = not cold desert; 1 = cold desert
	6	0 = not snow or rain; 1 = snow or rain
	7	0 = not frozen ground; 1 = frozen ground
2	0	1: 0 ≤ GVF < 0.1; 0: otherwise
	1	1: 0.1 ≤ GVF < 0.2; 0: otherwise
	2	1: 0.2 ≤ GVF < 0.3; 0: otherwise

	3	1: 0.3 ≤ GVF < 0.4; 0: otherwise
	4	1: 0.4 ≤ GVF < 0.5; 0: otherwise
	5	1: 0.5 ≤ GVF; 0: otherwise
	6	1: overall input TB quality is good; 0 overall input TB quality is not good
	7	1 = real time NDVI; 0 = NDVI climate

(c) SMOS Soil Moisture Product QA

Byte	Bit	Description
1	0	Spare bit
	1	1 = RFI for H pol above threshold, 0 = otherwise
	2	1 = RFI for V pol above threshold, 0 = otherwise
	3	Spare bit
	4	1 = No products are generated, 0 = otherwise
	5	1 = Retrieval values outside range, 0 = otherwise
	6	1 = High retrieval DQX, 0 = otherwise
	7	1 = Poor fit quality, 0 = otherwise
2	0	1 = Presence of other than nominal soil; 0 = otherwise
	1	1 = Rocks; 0 = not rocks
	2	1 = Moderate or strong topography; 0 = otherwise
	3	1 = Open water; 0 = not open water
	4	1 = Snow; 0 = not snow
	5	1 = Forest; 0 = not forest
	6	1 = Flood risk; 0 = no flood risk
	7	1 = Urban area; 0 = not urban area

(d) ASCAT Soil Moisture Product QA

Byte	Description
0	Estimated Error in Soil Moisture. (Integer. Scale factor: 0.01)
1	Soil Moisture Quality (Integer, Scale factor: 0.01)

(e) AMSR2 Soil Moisture Layer QA

Byte	Bit	Description
1	0	0 = overall quality is not good; 1 = overall quality is good
	1	1 = retrieval attempted but quality is not good; 0 = otherwise
	2	1 = retrieval attempted but unsuccessful due to input brightness temperature data quality; 0 = otherwise
	3	1 = retrieval attempted but unsuccessful due to the quality of other input data; 0 = otherwise
	4	1 = retrieval not attempted; 0 = retrieval attempted
	5	0 = not cold desert; 1 = cold desert
	6	0 = not snow or rain; 1 = snow or rain
	7	0 = not frozen ground; 1 = frozen ground

2	0	1: 0 ≤ GVF < 0.1; 0: otherwise
	1	1: 0.1 ≤ GVF < 0.2; 0: otherwise
	2	1: 0.2 ≤ GVF < 0.3; 0: otherwise
	3	1: 0.3 ≤ GVF < 0.4; 0: otherwise
	4	1: 0.4 ≤ GVF < 0.5; 0: otherwise
	5	1: 0.5 ≤ GVF; 0: otherwise
	6	1: overall input TB quality is good; 0 overall input TB quality is not good
	7	1 = real time NDVI; 0 = NDVI climate

Each SMOPS 6 hour soil moisture product data file also comes with a Metadata file that carries some overall information on the generation of this product. Table 3.6.2 shows the fields carried in the metadata file.

Table 3.6.2 – SMOPS SMOPS metadata file fields

(a) Common metadata

Elements	Data Type	Content
Satellite	char	Multi-Satellites
Instrument	char	AMSR-E, ASCAT, SMOS, WindSat
Projection	char	Cylindrical
Latitude at lower left corner	16-bit integer	
Longitude at lower left corner	16-bit integer	
Latitude at upper right corner	16-bit integer	
Longitude at upper right corner	16-bit integer	
Date & Time	16-bit integer	
Product Resolution (at nadir)	16-bit integer	0.5x0.5 degree
RowNumbers	16-bit integer	
ColumnNumbers	16-bit integer	
ByteOrderInfo (leftmost/rightmost)	16-bit integer	
Product Units	char	vol/vol
Product Version Number	16-bit integer	1.0
Data Compression Type	char	0=none
Scaling Factor	16-bit	10000.0

	integer	
Offset	16-bit integer	0
Missing value	16-bit integer	
Production Location	char	NOAA/NESDIS/OSPO at Camp Springs, MD
Contact Information	char	Science Lead : Xiwu Zhan, NOAA/NESDIS/STAR, xinwu.zhan@noaa.gov Operation Lead: Limin Zhao, NOAA/NESDIS/OSPO, limin.zhao@noaa.gov

(b) Specific metadata

Category	Elements	Type
Input Data Quality	Percentage of valid NRT SMOS retrievals over land	16-bit integer
	Percentage of valid SMOS retrievals over land	16-bit integer
	Percentage of valid ASCAT-A retrievals over land	
	Percentage of valid ASCAT-B retrievals over land	16-bit integer
	Percentage of valid AMSR2 retrievals over land	16-bit integer
	Percentage of valid retrievals in the blended product over land	16-bit integer
	Percentage of valid NRT SMOS retrievals in the blended product	16-bit integer
	Percentage of valid SMOS retrievals in the blended product	16-bit integer
	Percentage of valid ASCAT-A retrievals in the blended product	
	Percentage of valid ASCAT-B retrievals in the blended product	16-bit integer
	Percentage of valid AMSR2 retrievals in the blended product	16-bit integer
Retrieval Statistics	Minimum Value	16-bit integer
	Maximum Value	16-bit integer
	Mean	16-bit integer
	Standard Deviation	16-bit integer
Retrieval Quality	Total number of pixels with valid observations over land	16-bit integer
	Total number of pixels with valid retrievals	16-bit integer
	Total number of pixels with good retrievals	16-bit integer

3.7 Performance Estimates

To evaluate the algorithm performance under certain circumstances, sensitivity analysis is performed. Overall, this algorithm can retrieve reasonable soil moisture values in most cases where the input data are meaningful while the sensitivity to the input variable does vary for different soil types. Figure 3.7.1, for example, shows the retrieved soil moisture from SCR as a function of brightness temperature for three different soil types with all other inputs fixed. The SCR algorithm is most sensitive in the brightness temperature range from around 150 K to 200 K, which is the typical range for real soil brightness temperature. In this brightness temperature range, the retrieved soil moisture could differ up to ten percent for different soil type, meaning that reliable soil texture maps are necessary as the inputs for the SCR.

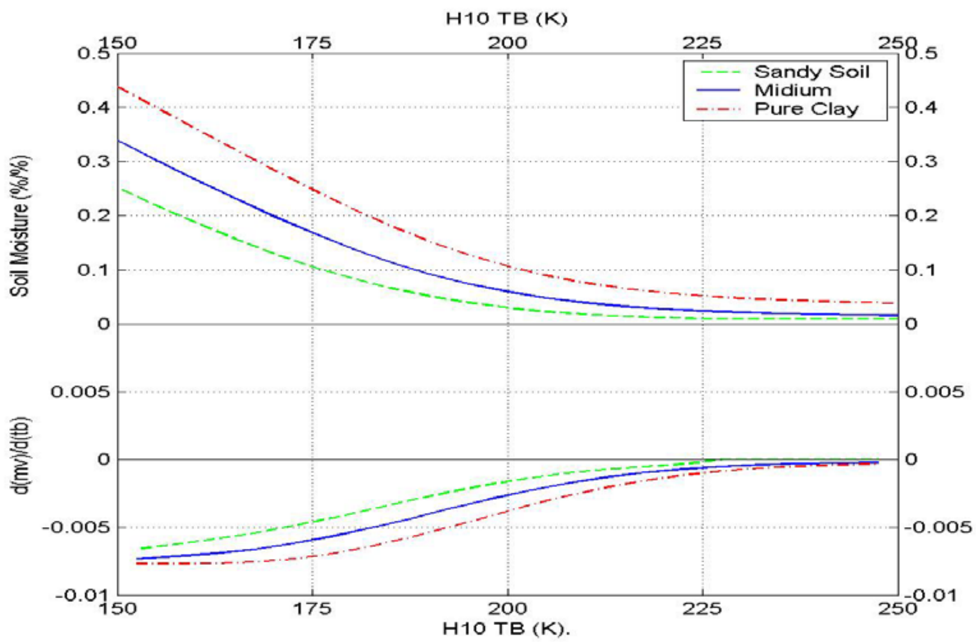


Figure 3.7.1 – Retrieved soil moisture from SCR Algorithm

To produce the soil moisture maps from different satellite sensors using the same algorithm, one needs to know if the calibration of the brightness temperature between these sensors is necessary. Figure 3.7.1 shows the SCR retrieval as a function of 10 brightness temperatures for three different types of soils. The lower part of this figure shows the changing rate of retrieved soil moisture as a function of brightness temperature. In the “sensitive” range (150 – 200 K), the changing rate can go as high as 0.007 (i.e., 0.7%/K). With soil moisture accuracy requirement of 0.10 (10%), this translates to a maximum brightness temperature difference of approximately 14 K. This places an upper limit on the acceptable brightness temperature accuracy. Because there are other sources of accuracy error (e.g. soil condition and vegetation condition), the acceptable accuracy will be less than 14 K.

ASCAT soil moisture validation (http://oiswww.eumetsat.org/WEBOPS/eps-pg/ASCAT/ASCAT-PG-4ProdOverview.htm) shows that ASCAT soil moisture retrievals have 3-7%[v/v] RMSE.

SMOS soil moisture retrievals are expected to have smaller than 4% [v/v] RMSE according to their ATBD (http://www.cesbio.ups-tlse.fr/data_all/SMOS-doc/SM_ATBD_v05a_CDR.pdf).

Soil roughness is an input variable to the SCR algorithm, thus error in the specified roughness parameter may cause error in the soil moisture retrieval. A roughness parameter sensitivity analysis shows that doubling or halving the roughness parameter does not change soil moisture retrieval more than 5%[v/v] (Zhan et al, 2009). However, the soil moisture retrievals from the SCR algorithm are strongly impacted by the vegetation cover.

3.8 Practical Considerations

3.8.1 Numerical Computation Considerations

The whole algorithm is composed of many straightforward calculations, thus, it is light computationally.

3.8.2 Programming and Procedural Considerations

SMOPS code is run every 6 hours with all the available input data for the previous 6 hours to produce the 6 Hour product. In the case that the input data come in late, the operational procedure will run without the later swath(s). The daily product is produced once every day using 4 6 Hour products on that day.

3.8.3 Quality Assessment and Diagnostics.

Quality assessment with historical in situ observations will be presented in later sections.

3.8.4 Exception Handling

The expected exceptions, and a description of how they are identified, trapped, and handled, will be provided in a future version.

3.9 Algorithm Validation

3.9.1 Sample Results

Figure 3.9.1 shows examples of SMOPS daily product. The retrieved NRT SMOS soil moisture (top-right panel) values generally exhibit a good dynamic range, indicating that this algorithm is capable of retrieving the required range of soil moisture values given different vegetation type and brightness temperature inputs from satellite sensors. The spatial patterns shown in the maps are also consistent with global dry/wet patterns of climate regimes.

Figure 3.9.1 also shows much better spatial coverage of SMOPS blended product (top-left panel) than any of the products from individual satellite sensors. Because of the CDF matching approach used to merge all the individual soil moisture products into this blended product, the overall magnitude of this merged product is different from all other sensors.

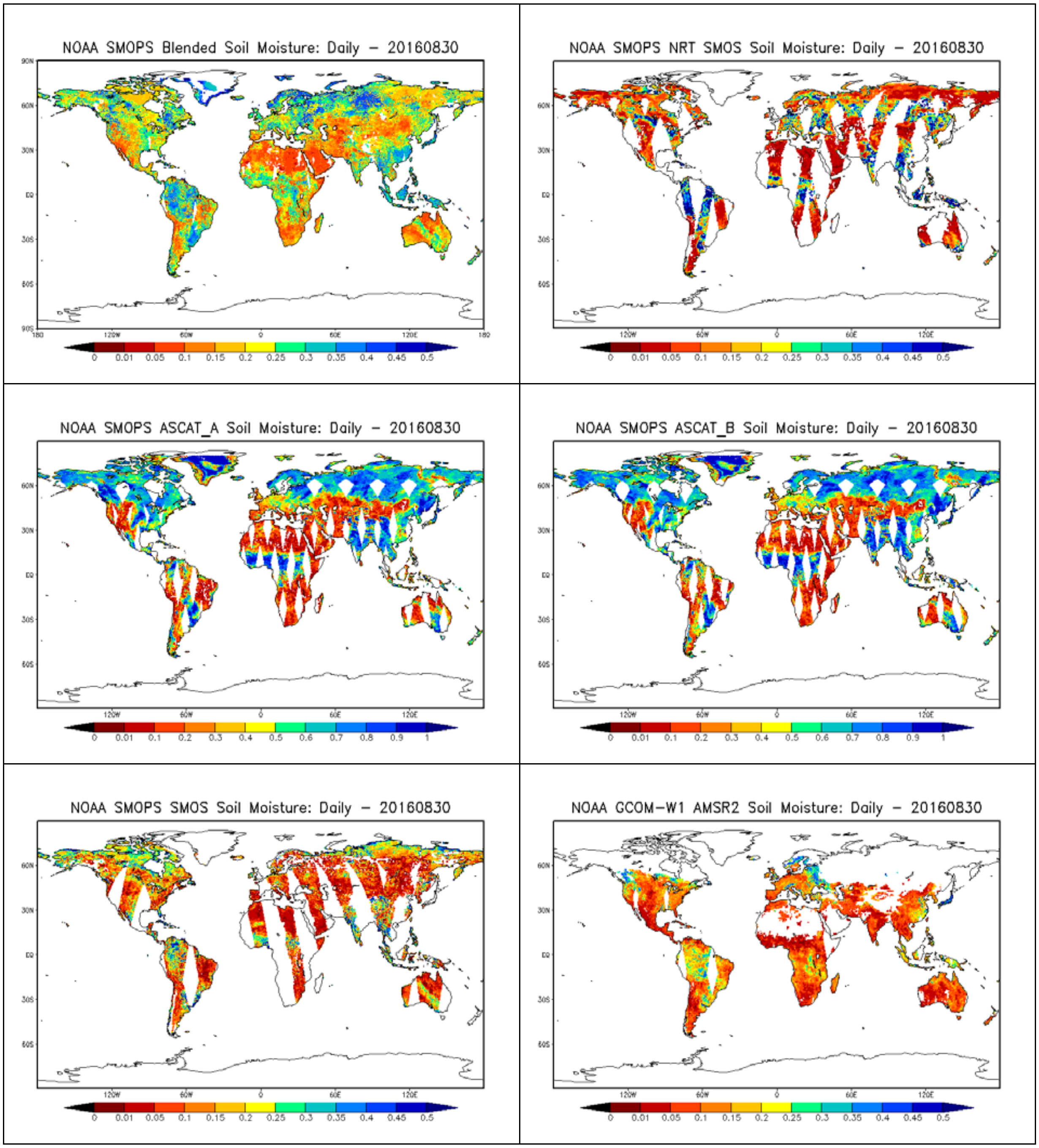
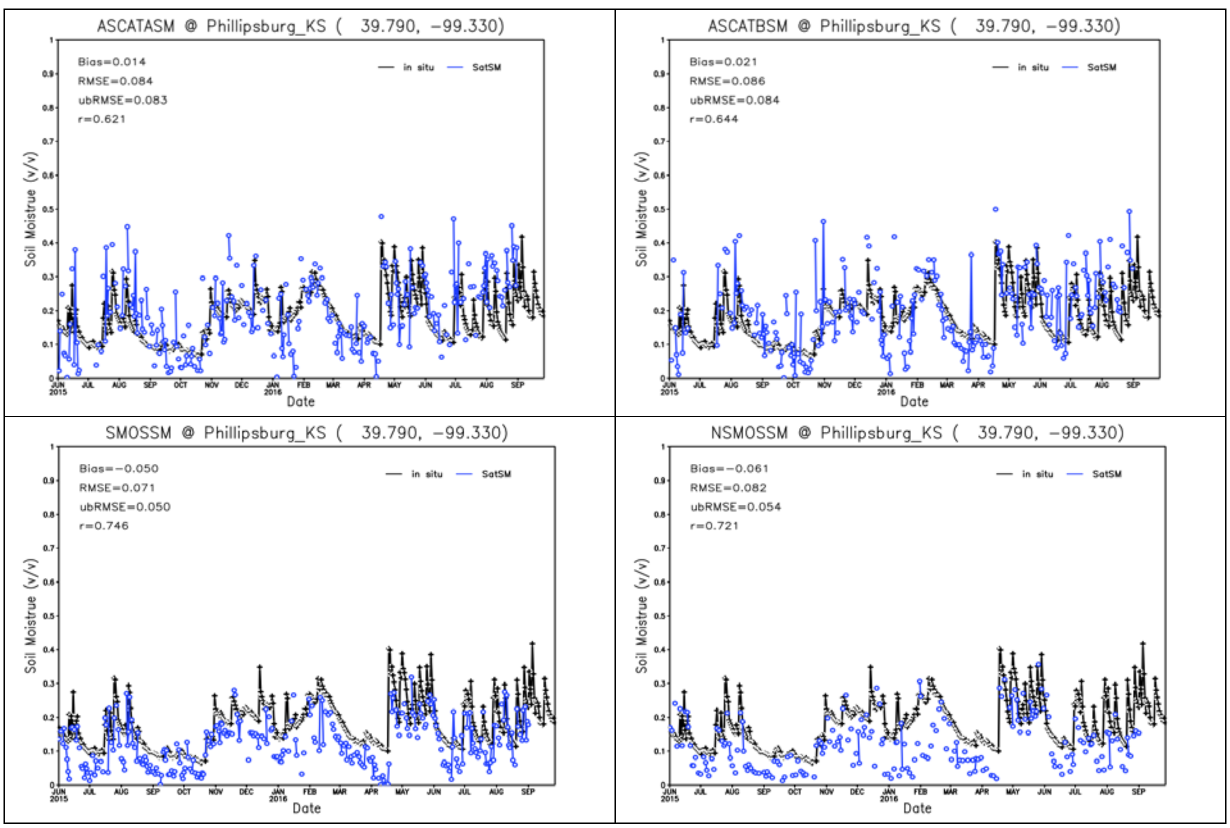


Figure 3.9.1 – Soil moisture maps produced by the SMOPS Version 2.0.

3.9.2 Validation Efforts

3.9.2.1 Validation of SCR algorithm with science data

In the efforts to quantitatively assess SMOPS soil moisture product quality, in-situ soil moisture measurements from a number of in-situ measurement sites are used to evaluate the overall performance of each product from SMOPS. Although this is still an on-going effort, the preliminary validation results show fairly good agreement between the satellite retrievals and in-situ data. Figure 3.9.2 shows a sample validation result using in-situ ground observation data from a Soil Climate Analysis Network (SCAN) station. Almost all SMOPS soil moisture layers show very good dynamics following the precipitation events with correlation coefficient above 0.5. Because SMOPS daily blended product has almost full land coverage, it has data available for this site for almost every single day.



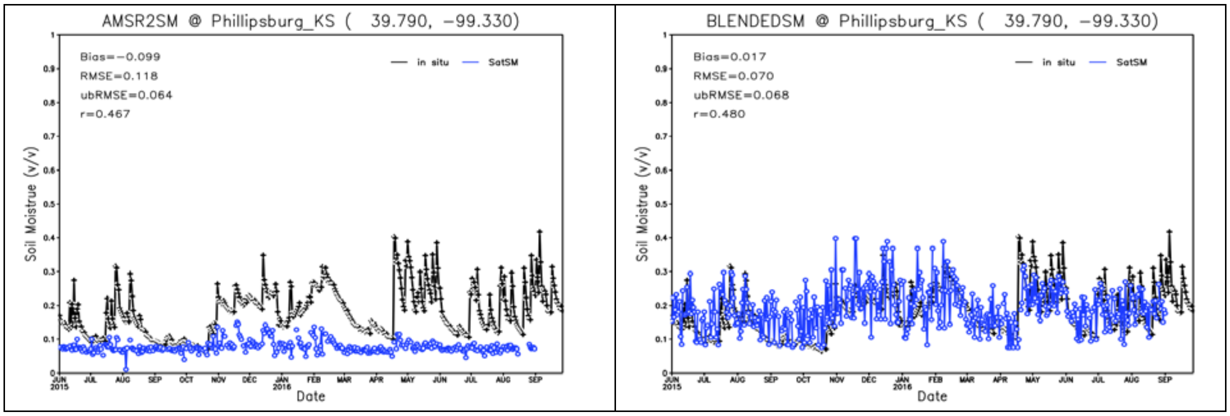


Figure 3.9.2 – Time series of SMOPS soil moisture products vs. a SCAN site in Phillipsburg, GA. Top-left (ASCATASM): ASCAT-A soil moisture; top-right (ASCATBSM): ASCAT-B soil moisture; middle-left (SMOSSM): ESA SMOS soil moisture; middle-right (NSMOSSM): NRT SMOS soil moisture; bottom-left (AMSR2SM): AMSR2 soil moisture; bottom-right (BLENDEDSM): SMOPS blended soil moisture.

More validation work will be carried out as more SMOPS Version 2 data becomes available. The future validation plan is described in next section.

3.9.2.2 Validation plan for SMOPS products

To further validate the soil moisture retrievals from SMOPS, we plan to use the following in situ in dependent soil moisture measurements. These continuous soil moisture measurements are available from either websites or ftp servers.

USCRN: The United States Climate Reference Network (USCRN) was created by NOAA National Climate Data Center. In situ soil moisture measurement sensors have been installed gradually to most of the more than 100 stations spreading over all US 50 states. More than 40 stations have been equipped with the soil moisture and soil temperature sensors currently (October 2010). Some of these soil moisture measurements are currently available from the USCRN website (http://www.ncdc.noaa.gov/crn/products.html).

SCAN: The Soil Climate Analysis Network (SCAN) was established by US Department of Agriculture (USDA). The network has been measuring soil moisture at more than 120 stations around US since late 1990s. These soil moisture measurements are mostly available from the SCAN website (http://www.wcc.nrcs.usda.gov/scan/).

COSMOS: National Science Foundation (NSF) has funded University of Arizona to establish a COSmic-ray Soil Moisture Observing System (COSMOS) to measure surface soil moisture over an about 300m sampling area surrounding a cosmic-ray sensor. About a dozen of this kind of soil moisture sensors have been installed around the US since later 2009. Soil moisture data from these sites have been available from the project website (http://cosmos.hwr.arizona.edu).

OZNet: Several small ground networks of soil moisture observation have been setup in Australia. The data are generally measured by Stevens Hydro Probes and are periodically available from OZNET website (http://www.oznet.org.au).

ChinaNet: There are several soil moisture measurement networks in China. They are managed by either China Meteorological Administration (CMA) or Chinese Academy of Science (CAS). Parts of their observational data are obtained through collaborative projects to validate SMOPS retrieval algorithms.

4.0 ASSUMPTIONS AND LIMITATIONS

4.1 Assumptions

The assumptions that were made in producing soil moisture product using SMOPS include:

1. The assumptions that were made in SCR for producing NRT SMOS soil moisture include:
   a. Soil texture, namely sand, clay and porosity, does not change in time at 1/12 degree spatial resolution.
   b. Land cover classification does not change in time at the 1/16 degree spatial resolution. This could be a risk as the land cover type may change slowly. Resolution to this problem could be updating the input land cover map every several years.
   c. NDVI does not change within a week. This would not be a risk as the change of NDVI within one week is usually very small and, thus, only has marginal impact on soil moisture retrievals.
2. The time latency of NRT SMOS L1C brightness temperature is within 2.5 hours.
3. The 6 Hour soil moisture product can be produced by SCR Unit within 0.5 hour. This would not be a risk based on the experimental runs of the R&D code.
4. The time latency of Level 2 AMSR2 soil moisture data is about hours.
5. The time latency of daily ASCAT soil moisture data is within 5.0 hours.
6. At least one of soil moisture products from NRT SMOS, SMOS, ASCAT-A, ASCAT-B and AMSR2 is available at the time when the algorithm is doing composites.
7. The daily soil moisture product can be produced by SMA Unit within 1.0 hour after all data arrive.

4.2 Limitations

1) The SCR will not retrieve soil moisture in densely vegetated areas.
2) The SCR will not retrieve soil moisture in the cold desert area.

5.0 RISKS AND RISK REDUCTION EFFORTS

5.1 Unavailability of NDVI Weekly Composite

Weekly composite of NDVI is required for estimating vegetation water content and optical depth. If the current week NDVI data is not available, the previous week data will be used. If both weeks are not available, a static NDVI climatology data for the current week will be used. The accuracy of retrieved soil moisture based on the climatology NDVI data could be compromised to a certain degree, depending on the difference of the climatological NDVI value from the current week real situation. If NDVI difference is 0.10, it may cause 5-10%[v/v] soil moisture difference. Further assessment of the NDVI impact will be provided by the unit test or system test.

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