Soil Moisture Active Passive (SMAP)

Ancillary Data Report

Soil Attributes

Preliminary, v.1
SMAP Science Document no. 044

Narendra Das
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

January 11, 2013
JPL D-53058

Jet Propulsion Laboratory
California Institute of Technology

© 2013 California Institute of Technology. Government sponsorship acknowledged.

Preface

The SMAP Ancillary Data Reports provide descriptions of ancillary data sets used with the science algorithm software in generation of the SMAP science data products. The Ancillary Data Reports may undergo additional updates as new ancillary data sets or processing methods become available. The most recent versions of the ancillary data reports will be made available, along with the Algorithm Theoretical Basis Documents (ATBDs), at the SMAP web site http://smap.jpl.nasa.gov/science/dataproducts/ATBD/.

Table of Contents

1 Overview

1.1 Purpose

The purpose of this report is to describe a soil attributes data set (sand fraction, clay fraction, and bulk density) developed for use in generating SMAP science data products. The soil attributes data are used with a dielectric model in the soil moisture retrieval algorithms to determine the real part of the complex dielectric constant (relative permittivity) of a soil-water mixture. The soil attributes dataset is one of a suite of ancillary datasets required by the SMAP science processing algorithms. The algorithms and ancillary data are described in SMAP algorithm theoretical basis documents (ATBDs) and ancillary data reports. The ATBDs and ancillary data reports are listed in Appendices A and B and are available at the SMAP web site:
http://smap.jpl.nasa.gov/science/dataproducts/ATBD/.

1.2 Requirement

The complex dielectric constant (ε) represents the capacitive and conductive parts of a soil's electrical response. At L-band (1.4 GHz) the real part ε' of the dielectric constant of dry soil is ~4, and for liquid water it is ~80. The dielectric constant of a soil-water mixture (including the solid soil matrix, air, and bound and free water) typically ranges from ~4 (dry soil) to ~20 (wet/saturated soil) depending on the amount of moisture (liquid water) present in the pores of the soil matrix (Dobson et al., 1985; Schmugge, 1985; Ulaby et al., 1986). As the amount of moisture increases the dielectric constant of the soil-water mixture increases and this causes a corresponding decrease in the soil emissivity (~0.9 for dry soil to ~0.6 for wet soil) as determined by the Fresnel reflectivity relations for a bare, smooth surface (Njoku and Kong, 1977).

The moisture in the soil is in the form of both bound water and free water. The relative amounts of bound and free water are influenced by the soil texture (sand, clay and silt fractions) and bulk density, since these influence the pore shape, size and distribution as well as the total available surface area. These physical characteristics of the soil influence the partitioning of the total moisture in the pores into bound water and free water, and thereby affect the soil dielectric constant. The relationship between soil moisture and dielectric constant as influenced by the soil attributes is expressed by a dielectric model. For the SMAP mission, the availability of reliable soil texture and bulk density information to use in the dielectric model of choice will lead to improved estimates of soil dielectric constant and accurate soil moisture retrievals. As discussed in the Algorithm Theoretical Basis Documents (Appendix A) the two dielectric models currently under consideration for SMAP are the Dobson and Mironov models (Dobson et al., 1985; Mironov et al., 2009). The soil attributes used in both these dielectric models are sand fraction, clay fraction, and bulk density [gram/cm^3]. These attributes are the focus of this report.

The soil attributes data are required globally at 3 km, 9 km, and 36 km grid resolutions for the SMAP L2_SM_A, L2_SM_A/P, and L2_SM_P retrieval algorithms, respectively.

2 Selection and Description of Primary Dataset

Thes digital soils databases available for this study, with their spatial resolutions are:

(a) Global:

- Food and Agricultural Organization (FAO) SMW dataset (50 km), compiled in 1974 - 1981 using data collected prior to the 1970s (FAO, 1995).
- Harmonized World Soil Database (HWSD) (10-50 km), an improved version of the FAO SMW dataset which includes regional datasets: SOTER, ESDB, and China Soil (FAO et al., 2009).

(b) Regional:

- STATSGO (1 km) from USDA-NRCS, over the continental U.S. (CONUS) (NRCS, 2010).
- National Soil Database Canada (NSDC) (10 km), over Canada (AAFC, 2010).
- Australian Soil Resources Information System (ASRIS) (3-10 km), over Australia (ASRIS, 2010).

2.1 FAO SMW

The FAO Soil Map of the World (SMW) dataset is the oldest and most widely used soils database. It remains the only worldwide, consistent soil inventory available in digital format (FAO, 1995). The spatial resolution is 50 km and the dataset was created using data collected prior to the 1970s. Recently, a concerted effort was undertaken by the FAO and the International Institute for Applied System Analysis (IIASA) in partnership with the International Soil Reference and Information Centre (ISRIC), European Soil Bureau Network, and Institute of Soil Science, Chinese Academy of Science to improve the FAO digital SMW. The effort resulted in the Harmonized World Soil Database (HWSD).

2.2 HWSD

The Harmonized World Soil Database (HWSD) (FAO et al., 2009) is an improvement in terms of spatial resolution over the widely used coarser resolution (50 km) FAO SMW. The HWSD is a composite that includes the following global and regional soils databases

- FAO SMW (50 km)
- The regional Soil and Terrain Database (SOTER) (10-50 km)
- European Soil Database (ESDB) (10 km)
- Soil Map of China (China Soil) (10 km)

Figure 1 illustrates the geographical coverage of the above soil databases as used to develop the HWSD. It is obvious from Figure 1 that the spatial resolution of HWSD varies from 10 km to 50 km in different parts of the world depending upon the type of database used. The SOTER, ESDB, and China Soil have better resolution and quality than FAO because they are based on a large pool of survey data (in situ) and techniques that use high resolution covariates (e.g., DEM, landcover, NDVI) to derive the soil attributes of interest.

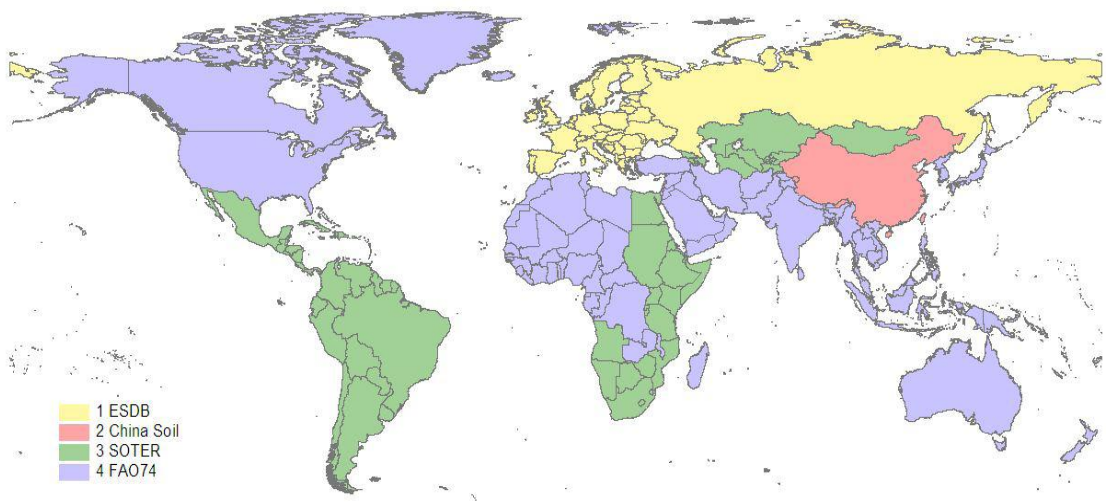

Figure 1: Geographical coverage of FAO, SOTER, European Soil Database (ESDB), and China Soil in HWSD.

The SOTER database (Dobos et al, 2005; FAO/ISRIC 2000) forms a part of ongoing activities of the FAO and ISRIC to update the world soils resources. SOTER (10 km) is intended to replace the FAO (50 km) SMW. The methodology to create SOTER is based on mapping land characteristics, with the idea that land (in which terrain and soil occur) incorporates processes and systems of interrelationships among physical, biological and spatial phenomena evolving through time. This new technique imparts more reliability to the SOTER database than the now obsolete FAO SMW dataset.

The other datasets in HWSD are ESDB (10 km) (ESB, 2004) and China soil (10 km) (Shi et al., 2004). These regional digital soil datasets are recent updates of soil information from Europe and China. The aim of the ESDB is to provide a harmonized set of soil parameters covering Europe, Russia and bordering Mediterranean countries, to be used in agro-meteorological and environmental modeling at regional, national, and/or continental levels. The quality and spatial resolution of ESDC is also superior to the FAO soil dataset. The soil maps of China have been compiled at different scales from information obtained from ground surveys and laboratory analyses. A comprehensive effort coordinated by the Office for the Second National Soil Survey of China resulted in a series of soil maps covering the extent of the country at a scale of 10 km. These map series have been transformed to a digital format to create the China Soil database.

The HWSD dataset is available at the IIASA website
http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html.
The downloadable dataset consists of a band interleaved line (.bil) image file and an attribute database in Microsoft Access format. The image file depicts the geolocated harmonized soil mapping unit identifier (MU_GLOBAL) of HWSD that provides a link to the attributes database.

HWSD in its present form comprises nearly 16000 different soil mapping unit identifiers. The database provides information on the composition of each of the soil mapping unit for top layer (0-30 cm) and subsoil (30-100 cm). A mapping unit can have up to 9 topsoil texture combination records in the database. The soil attributes of topsoil sand fraction, clay fraction and bulk density are available in the HWSD database for SMAP mission purposes. These attributes are those needed for SMAP to compute dielectric constant in the soil moisture retrieval algorithms.

The current HWSD version 1.1 does not include the excellent soils databases of the USA, Canada and Australia, namely the State Soil Geographic (STATSGO) database, National Soil database (NSDB), and Australia Soil Resource Information System (ASRIS), respectively. However, a further update of the HWSD is expected in the near future that may include these three soil databases.

2.3 STATSGO

Soil maps for STATSGO (1 km) (NRCS, 2010a) are compiled by generalizing more detailed SSURGO soil survey maps (NRCS, 2010b) that were developed for counties after intensive soil surveys conducted by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS). Where more detailed soil survey maps are not available, data on geology, topography, vegetation, and climate are assembled, together with Land Remote Sensing Satellite (LANDSAT) images. Soils of similar areas are studied, and the probable classification and extent of the soils are determined. STASTGO is the best dataset in terms of spatial resolution and quality as compared to other soils databases considered for developing ancillary datasets for the SMAP mission.

2.4 NSDC

The NSDC (10 km) (AAFC, 2010) was created by the Agriculture and Agri-Food Canada (AAFC) research branch, of the government of Canada. Most of the NSDC database was created by digitizing polygon-based soil survey information. However, this database has several spatial gaps in the northern part of Canada.

2.5 ASRIS

ASRIS (3-10 km) (ASRIS, 2010) is compiled by the Australian Commonwealth Scientific and Research Organization (CSIRO) and was designed to facilitate the Australia contribution to SOTER. ASRIS was officially released in year 2005. The database includes a soil profile database with fully characterized sites that are known to be representative of significant area and environment. The soil attributes of the database were created by combining national and state level land systems polygon maps and intensive soil surveys comprising 50 years of legacy data. The polygon data were then digitized to a continuous raster surface using the soil attribute values calculated for each polygon. The updated digitized dataset was released in year 2005. Figure 2 shows contrasting difference in topsoil sand fraction data between the ASRIS and FAO dataset. This is due to the better quality and volume of survey data used to create ASRIS.

2.6 Discussion

The databases described above vary in spatial resolution, geographical coverage, data quality, and date of creation. For example, the SMW was created by FAO-UNESCO during 1974-1981 using data collected prior to the 1970s. Most of the data and the techniques used for the FAO SMW are now outdated. HWSD is an improvement because it provides a better composite by harmonizing the latest soil databases from a number of different regions (ESDB, NSDC, China Soil) on top of the FAO dataset. Therefore, for the SMAP mission the HWSD is a suitable choice, and can be further improved by compositing only the top soil (0-5 cm) sand fraction, clay fraction and bulk density from the STATSGO, NSDC, and ASRIS datasets. This makes the compositing process of the HWSD, STATSGO, NSDC, and ASRIS datasets relatively simple. Figure 2 shows an example of the significant differences in soil attributes between FAO and regional datasets.

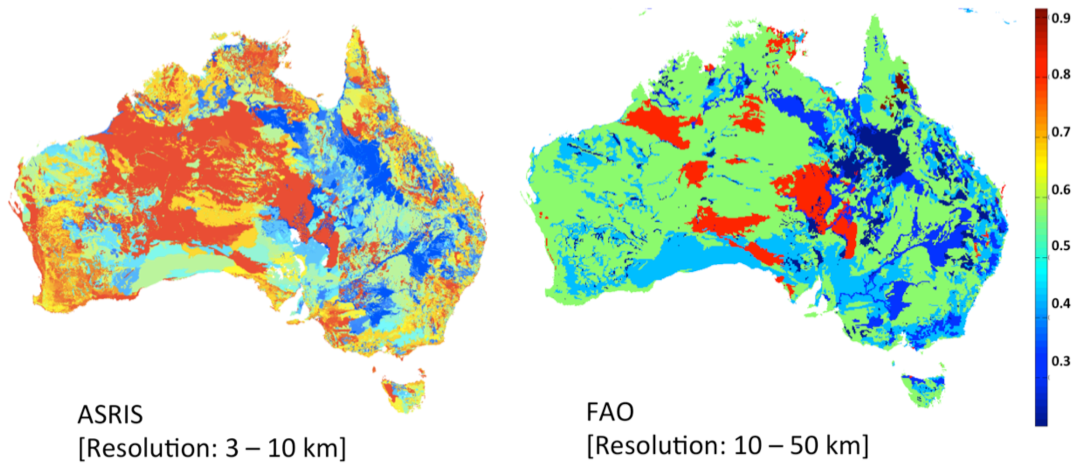

Figure 2: Difference between FAO SMW and ASRIS regional dataset for Australia (sand fraction).

3 Processing

3.1 Compositing

The SMAP mission plans to provide global soil moisture products at 3, 9, and 36 km resolutions. This necessitates having soil attribute ancillary data that match the highest resolution of 3 km. The currently available soil datasets do not meet the requirement of 3 km resolution except in the CONUS domain and to some extent in the Australian continent. However, an optimized global composite can be generated by using the best available information from the FAO, HWSD, STATSGO, NSDC, and ASRIS datasets. Figure 3 illustrates the decision tree used to make global composites of sand and clay fractions, and bulk density. The decision tree ensures that soil attributes are populated over the global landmass using the highest resolution available global and regional digital datasets. An example of a sand fraction composite created at 0.01 degree is shown in Figure 4. The base maps of FAO, HWSD, STATSGO, NSDC, and ASRIS datasets were first resampled to 0.01 degree before applying the decision tree. Resampling to 0.01 degree was performed to bring all datasets to same grid resolution.

The accuracy of soil attributes datasets depends on the digital soil mapping technique used to create them. The regional databases have considerably better accuracy and credibility than the now obsolete FAO data due to the state-of-the-art digital soil mapping techniques implemented to create them. Digital soil mapping techniques consist of essentially three basic steps: 1) Collection of relevant data inputs, starting with collection of all legacy *in situ* data, production of base maps, and assembling and calibrating spatially contiguous covariates (DEM, NVDI, landcover, landuse, and geologic variables relating to soil parent materials); 2) development of pedotransfer functions derived using relationships between *in situ* soil measurements and spatially continuous covariates; and 3) application of the pedotransfer functions to estimate soil properties based on spatially continuous covariates. Additionally, some unused *in situ* measurements are used for validation and fine-tuning of the digital soil maps.

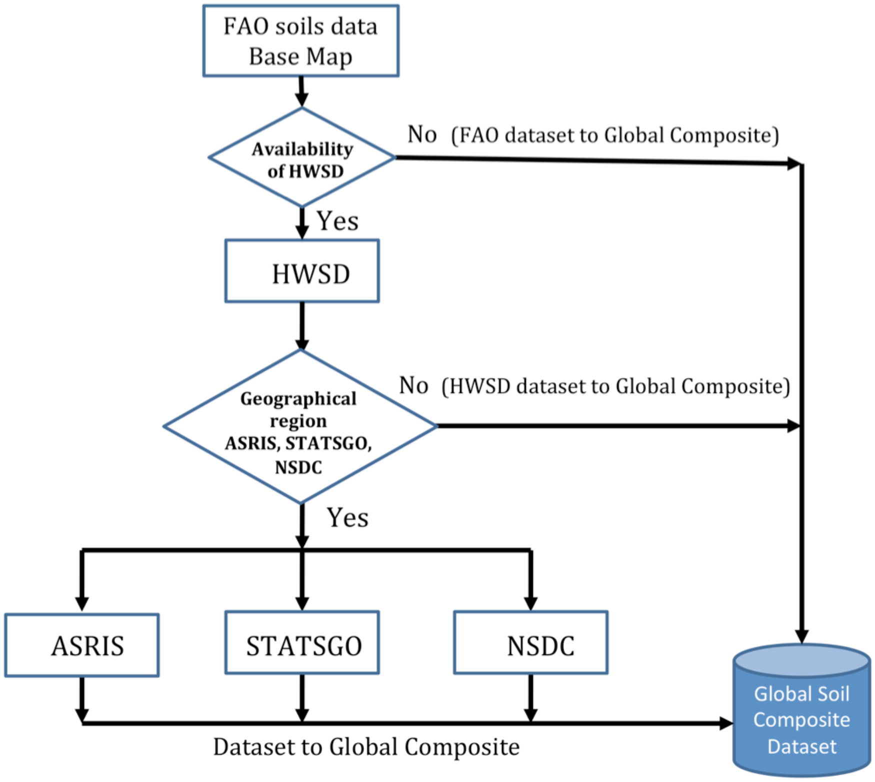

Figure 3: Decision tree for soil attributes global composite.

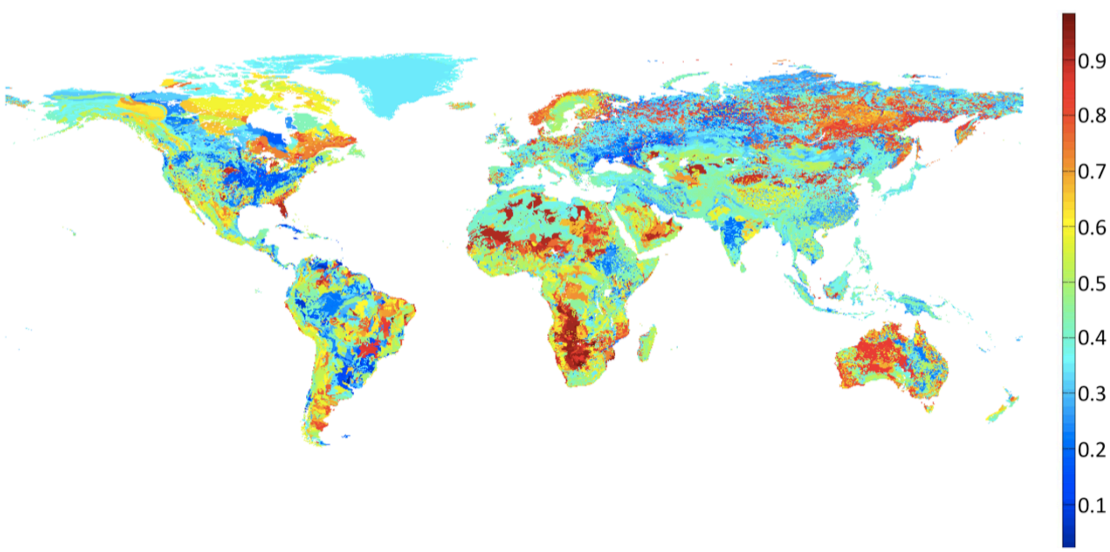

Figure 4: Global sand fraction composite at 0.01 degree.

Having better regional datasets for making global composites introduces some inconsistencies at regional boundaries. For example, using the STATSGO and NSDC regional datasets makes the political boundary between the USA and Canada clearly noticeable in the maps. This is an undesirable artifact that persists primarily due to: (a) difference in the spatial resolution of the datasets (STATSGO is 1 km and NSDC is 10 km), (b) difference in the intensity of the soil survey data used to create them, (c) the number of covariates used in digitizing, and (d) differences in land use across the international boundary that affect the composition of the top layer soil texture. However, inclusion of other regional data like the ASRIS database in the global soil composites has no such undesirable affects because the data of the base map from the whole Australian continent is replaced by ASRIS (see Figure 3).

For the SMAP mission the soil attributes composite dataset will be used for the soil moisture retrieval algorithms until further updates of global digital soil maps become available. Currently, there are at least two separate and parallel projects underway that share a vision to produce new soil information on a global basis. The *GlobalSoilMap.net* project has a commitment to produce digital maps of continuous variation at 90 m grid resolution globally for a selected number of soil properties that include sand fraction, clay fraction and bulk density. The *e-SOTER* project has an ambition to apply newly demonstrated methods to produce more conventional area-class soil maps, in polygon format, for entire continents and, eventually, the entire world at a nominal resolution of 10 km. Both of these projects are being coordinated by ISRIC. However, none of these soil mapping projects are expected to be completed before 2015 (personal communication with Dr. Bob MacMillan from ISRIC).

3.2 Source Dataset Characteristics

The global and regional digital soil datasets used in this processing are all available online. The datasets were downloaded and stored on the SMAP science data system testbed. The projections of the datasets are mostly in a Geographical Coordinate System using the datum of WGS1984. The spatial extent and native resolution of the datasets are described in Section 2 and are summarized in Table 1.

Table 1: Characteristics of source global and regional soil databases.

Name of Database	Extent	Spatial Resolution	Version	Date of creation	No data values
FAO	Global	50 km		Updated 1995	-9999
HWSD	Global	10-50 km	1.1	2008	0
STATSGO	CONUS	1 km	1	2005	-9999
NSDC	Canada	10 km	3.1.1	2007	-9999
ASRIS	Australia	3-10 km	1.5	2005	-9999

The global composites of sand fraction (Fig. 4), clay fraction and bulk density created from the above regional and global databases are in 0.01-degree resolution binary files. The binary files have 18000 rows and 36000 columns. The water bodies and 'no data' values are assigned -9999. The extent of latitude and longitude covered by the global composite database is 90˚ to -90˚ and -180˚ to 180˚, respectively. The Antarctica continent is excluded from the composite database.

3.3 Re-Gridded Data

The global composites of sand fraction, clay fraction, and bulk density processed as described in Section 3.1 are further re-gridded to the Equal-Area Scalable Earth (EASE) Grids (NSIDC) of 1, 3, 9, and 36 km grid resolutions. The gridding process is simple linear averaging (drop-in-the-bucket technique) where the 'no data' values are ignored. Linear averaging is used because sand fraction, clay fraction, and bulk density are physical quantities and do not need any spatial scaling while averaging. Examples of the sand fraction, clay fraction, and bulk density at the 9-km EASE grid resolution are shown in Figures 5-6.

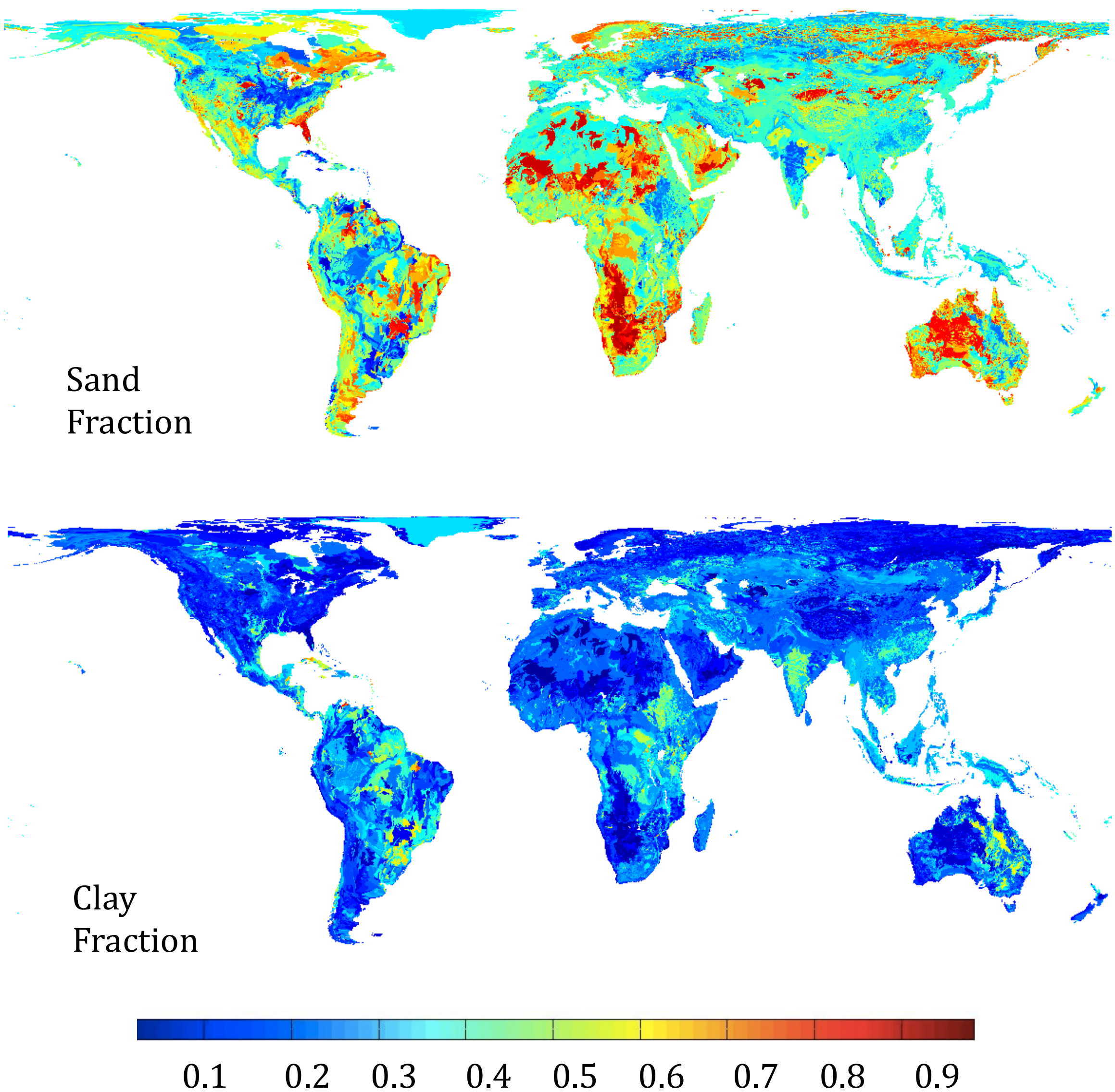

Figure 5: Global sand and clay fractions of top soil layer at EASE grid resolution of 9 km.

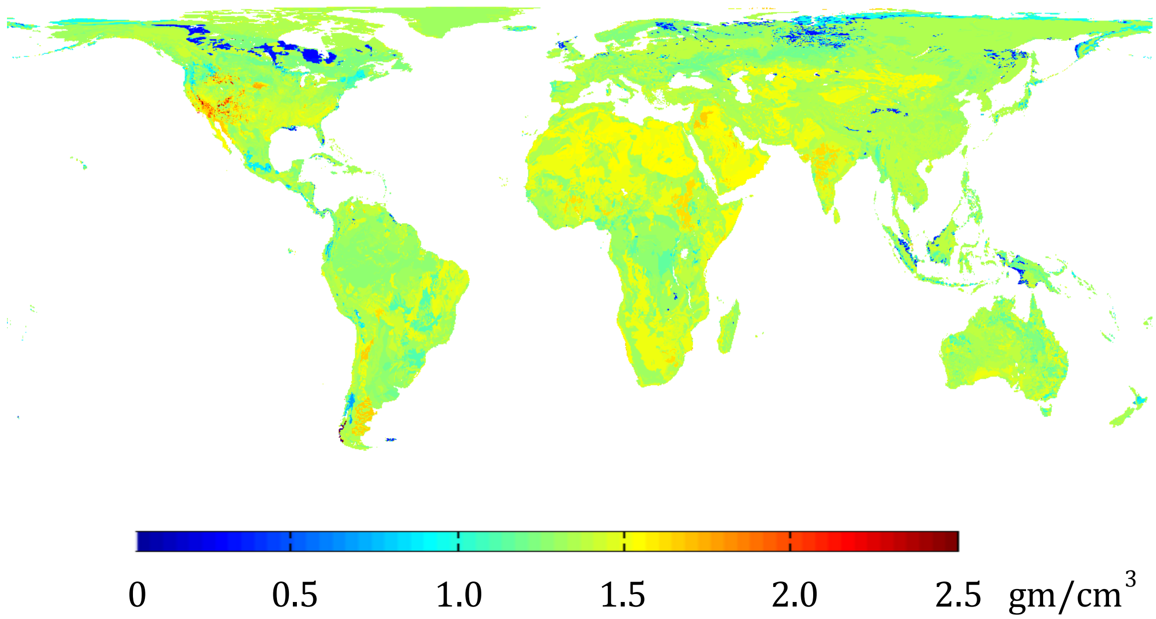

Figure 6: Global bulk density of top soil layer at EASE grid resolution of 9 km

The re-gridded data at 1, 3, 9, and 36 km were also checked against permanent water body maps. Very few inconsistencies were observed, mostly at the coastal regions.

4 Data Availability

A current version of the re-gridded (EASE-grid) dataset of sand fraction, clay fraction, and bulk density at 1, 3, 9, and 36 km is available from the author, and will eventually be available via the National Snow and Ice Data Center (NSIDC) along with the SMAP data products. A readme file is provided that contains details on the array dimensions at different grid resolutions. A description of the dataset is provided in Appendix C. Modifications and further processing of this dataset may occur. The world consortiums (ISRIC and SOTER) for soils are expected to publish a new global soil database at high resolution by 2015.

5 Acknowledgment

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

6 References

AAFC (2010): *Soil Landscapes of Canada version 3.2 (digital map and database at 1:1 million scale)*, Soil Landscapes of Canada Working Group, Agriculture and Agri-Food Canada .

ASRIS (2010): *Australian Soil Resource Information System,* http://www.asris.csiro.au. Accessed [03/20/2010].

Dobos, E., J. Daroussin, and L. Montanarella (2005): *An SRTM-based procedure to delineate SOTER terrain units on 1:1 and 1:5 million scales. EUR 21571 EN*, 55 pp. Office for Official Publications of the European Communities, Luxembourg.

Dobson, M. C., F. T. Ulaby, M. T. Hallikainen, and M. A. El-Rayes (1985): Microwave dielectric behavior of wet soil - part II: dielectric mixing models, *IEEE Trans. Geosci. Remote Sens*., GE-23, 35-46.

ESB (2004): *European Soil Database (vs 2.0)*. European Commission-JRC-Institute for Environment and Sustainability, European Soil Bureau. Ispra, Italy.

FAO (1995): Digital Soil Map of the World and derived soil properties, *Food and Agricultural Organization of the United Nations*, FAO.

FAO/IIASA/ISRIC/ISSCAS/JRC (2009): *Harmonized World Soil Database (version 1.1)*. *FAO and IIASA*, Laxenburg, Austria.

FAO/ISRIC (2000): *Soil and Terrain Database, Land Degradation Status and Soil Vulnerability Assessment for Central and Eastern Europe Version 1.0 (1:2.5 million scale)*. Land and Water Digital Media Series # 10, FAO, Rome.

Mironov, V. L., L. G. Kosolapova, and S. V. Fomin (2009): Physically and mineralogically based spectroscopic dielectric model for moist soils, *IEEE Trans. Geosci. Remote Sens.*, *47(7),* 2059–2070.

Njoku, E. G. and J. A. Kong, J. A. (1977): Theory for passive microwave remote sensing of near-surface soil moisture, *J. Geophys. Res.*, 82, 3108-3118.

NRCS (2010a): *U. S. General Soil Map (STATSGO2),* Natural Resources Conservation Service, U. S. Department of Agriculture. Available online at http://soildatamart.nrcs.usda.gov. Accessed [03/20/2010].

NRCS (2010b): *U.S. General Soil Map (SSURGO).* Natural Resources Conservation Service, U. S. Department of Agriculture. Available online at http://soildatamart.nrcs.usda.gov. Accessed [03/20/2010].

NSIDC, “EASE-Grid Data,” [Online] Available: http://nsidc.org/data/ease/index.html.

Schmugge, T. J. (1985): *Remote sensing of soil moisture*, pp. 101-124. John Wiley, New York.

Shi, X. Z., D. S. Yu, E. D. Warner, X. Z. Pan, G. W. Petersen, Z. G. Gong, and D. C. Weindorf (2004): Soil Database of 1:1,000,000 Digital Soil Survey and Reference System of the Chinese Genetic Soil Classification System, *Soil Survey Horizons, 45,* 129-136.

Ulaby, F. T., R. K. Moore, and A. K. Fung (1986): *Microwave Remote Sensing, Active and Passive, vol.III: From Theory to Applications*, Boston, MA: Artech House.

Appendix A: SMAP Science Data Products and ATBDs

The SMAP Algorithm Theoretical Basis Documents are available at the SMAP web site http://smap.jpl.nasa.gov/science/dataproducts/ATBD/.

Data Product	Description	ATBD
L1A_Radar	Radar raw data in time order	(Joint with L1C_S0_HiRes)
L1A_Radiometer	Radiometer raw data in time order	(Joint with L1B_TB)
L1B_S0_LoRes	Low resolution radar σ_o in time order	(Joint with L1C_S0_HiRes)
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	West, R., L1B & L1C radar products, JPL D-53052, JPL, Pasadena, CA.
L1B_TB	Radiometer T_B in time order	Piepmeier, J. et al., L1B radiometer product, GSFC SMAP-006, GSFC, Greenbelt, MD.
L1C_TB	Radiometer T_B (half orbit, gridded)	Chan, S. et al., L1C radiometer product, JPL D-53053, JPL, Pasadena, CA.
L2_SM_A	Soil moisture (radar, half orbit)	Kim, S. et al., L2 & L3 radar soil moisture (active) product, JPL D-66479, JPL, Pasadena, CA.
L2_SM_P	Soil moisture (radiometer, half orbit)	O'Neill, P. et al., L2 & L3 radiometer soil moisture (passive) product, JPL D-66480, JPL, Pasadena, CA.
L2_SM_AP	Soil moisture (radar/radiometer, half orbit)	Entekhabi, D. et al., L2 & L3 radar/radiometer soil moisture (active/passive) products, JPL D-66481, JPL, Pasadena, CA.
L3_FT_A	Freeze/thaw state (radar, daily composite)	McDonald, K. et al., L3 radar freeze/thaw (active) product, JPL D-66482, JPL, Pasadena, CA.
L3_SM_A	Soil moisture (radar, daily composite)	(Joint with L2_SM_A)
L3_SM_P	Soil moisture (radiometer, daily composite)	(Joint with L2_SM_P)
L3_SM_AP	Soil moisture (radar/radiometer, daily composite)	(Joint with L2_SM_AP)
L4_SM	Soil moisture (surface & root zone)	Reichle, R. et al., L4 surface and root-zone soil moisture product, JPL D-66483, JPL, Pasadena, CA.
L4_C	Carbon net ecosystem exchange (NEE)	Kimball, J. et al., L4 carbon product, JPL D-66484, JPL, Pasadena, CA.

Appendix B: SMAP Ancillary Data Reports

The SMAP Ancillary Data Reports are available with the ATBDs at the SMAP web site http://smap.jpl.nasa.gov/science/dataproducts/ATBD/.

Data/Parameter	Ancillary Data Report
Crop Type	Kim, S., Crop Type, JPL D-53054, Pasadena, CA
Digital Elevation Model	Podest, E. et al., Digital Elevation Model, JPL D-53056, Pasadena, CA
Landcover Classification	Kim, S., Landcover Classification, JPL D-53057, Pasadena, CA
Soil Attributes	Das, N. et al., Soil Attributes, JPL D-53058, Pasadena, CA
Static Water Fraction	Chan, S. et al., Static Water Fraction, JPL D-53059, Pasadena, CA
Urban Area	Das, N., Urban Area, JPL D-53060, Pasadena, CA
Vegetation Water Content	Chan, S. et al., Vegetation Water Content, JPL D-53061, Pasadena, CA
Permanent Ice	McDonald, K., Permanent Ice & Snow, JPL D-53062, Pasadena, CA
Precipitation	Dunbar, S., Precipitation, JPL D-53063, Pasadena, CA
Snow	Kim, E. et al., Snow, GSFC SMAP-007, Greenbelt, MD
Surface Temperature	Fisher, J. et al., Surface Temperature, JPL D-53064 Pasadena, CA
Vegetation and Roughness Parameters	Colliander, A., Vegetation & Roughness Parameters, JPL D-53065, Pasadena, CA

Appendix C: Soil Attributes Dataset Description

The global soil attributes dataset files (bulk density, sand fraction and clay fraction) are available in four grid resolutions: 1 km, 3 km, 9 km, and 36 km. Following are the file names and respective characteristics:

File_Name	Format	Rows	Cols	Projection	Resolution	NoData	Precision
bulk01km_EZ2.14616x34704.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
bulk03km_EZ2.4872x11568.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
bulk09km_EZ2.1624x3856.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
bulk36km_EZ2.406x964.float32	Binary	406	964	EASE2	36 km	-9999	real*4
sand01km_EZ2.14616x34704.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
sand03km_EZ2.4872x11568.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
sand09km_EZ2.1624x3856.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
sand36km_EZ2.406x964.float32	Binary	406	964	EASE2	36 km	-9999	real*4
clay01km_EZ2.14616x34704.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
clay03km_EZ2.4872x11568.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
clay09km_EZ2.1624x3856.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
clay36km_EZ2.406x964.float32	Binary	406	964	EASE2	36 km	-9999	real*4

The binary files are written in column major order.

For georeferencing, the above binary files use the EASE2 grid lat-lon files, available via the National Snow and Ice Data Center (NSIDC), Boulder, CO.

Contact email: Narendra.N.Das@jpl.nasa.gov