Soil Moisture Active Passive (SMAP)

Ancillary Data Report

Soil Attributes

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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/ and on the NSIDC SMAP Technical References page https://nsidc.org/data/smap/technical-references .

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1 Overview

1.1 Purpose

The purpose of this report is to describe a soil attributes dataset (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 currently used dielectric model for SMAP is the Mironov model (Mironov et al., 2009). The soil attribute used in this dielectric model is the clay fraction.

The soil attributes data are required globally at 36 km, 9 km, 3 km and 1 km grid resolutions for the SMAP L2_SM_P, L2_SM_P_E, and L2_SM_SP Science Algorithm Software (SAS), respectively.

2 Description of New Soil Attributes Dataset

A new resource is recommended as a third version of soil attribute ancillary data input for the SMAP Level-2 SAS. This new 250 m resolution soil attribute data (SoilGrid250m) is available at https://openlandmap.org. The web portal has all the high-resolution soil attributes (clay fraction, sand fraction, bulk density, and organic carbon content) required for the SMAP SAS. More details about the characteristics of this dataset are available in Hengl et al., 2017.

SoilGrids250m provides data for the following list of standard soil properties at global extent:

· *Soil organic carbon content in(g kg-1)*
· *Soil pH*
· *Sand, silt and clay (weight %)*
· *Bulk density (kg m-3)*
· *Cation-exchange capacity (cmol + /kg)*
· *Coarse fragments (volumetric %)*
· *Depth to bedrock (cm)*
· *USDA Soil Taxonomy classes*

SoilGrid250m is created through a data-driven statistical framework on Open Source Geospatial Foundation (OSGeo) software tools. The inputs to this framework are primarily based on publicly released soil profile compilations and many covariates derived from remotely sensed products of NASA's MODIS and SRTM data missions. The soil profile data (Figure 1) come from around the world and are at seven standard depths (0 cm, 5 cm, 15 cm, 30 cm, 60 cm, 100 cm, and 200 cm) for all numeric soil properties.

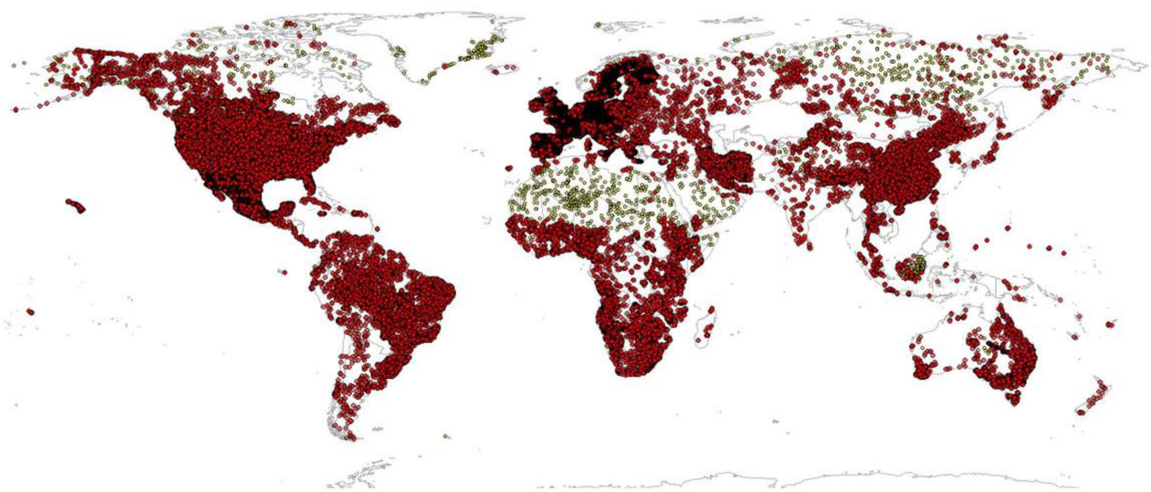


Figure 1: Soil profile data, about 150,000 points shown on the map. Available from the ISRIC's World Soil Information Service (WoSIS) at http://wfs.isric.org/geoserver/wosis/wfs. (Plot courtesy, Hengl et al., 2017)

The remotely sensed covariates primarily from the NASA's MODIS and SRTM data missions are:

- DEM-derived surfaces - slope, profile curvature, Multiresolution Index of Valley Bottom Flatness (VBF), deviation from Mean Value, valley depth, negative and positive Topographic Openness, and SAGA Wetness Index based on the global merge of SRTMGL3 DEM and GMTED2010.
- Long-term averaged monthly mean and standard deviation of the MODIS Enhanced Vegetation Index (EVI).
- Long-term averaged mean monthly surface reflectance for MODIS bands 4 (NIR) and 7(MIR).
- Long-term averaged monthly mean and standard deviation of the MODIS land surface temperature (daytime and nighttime).
- Long-term averaged mean monthly hours under snow cover based on a stack of MOD10A2 8-day snow occurrence images

- Land cover classes (cultivated land, forests, grasslands, shrublands, wetlands, tundra, artificial surfaces and bare-land cover) for the year 2010 based on the GlobCover30.
- Monthly precipitation images derived as the weighted average between the WorldClim monthly precipitation and GPCP.
- Long-term averaged mean monthly hours under snow cover derived from MOD10A2 8-day snow occurrence images.
- Lithologic units based on Global Lithological Map.
- Landform classes based on the USGS's Map of Global Ecological Land Units.
- Global Water Table Depth in meters.
- Long-term averaged mean monthly MODIS Flood Water based on the NRT Global MODIS Mapping Flood Water product,.
- Landsat-based estimated distribution of Mangroves,.
- Average soil and sedimentary-deposit thickness in meters.

The soil physical attributes at resolution 250 m were created using the spatial prediction method that involves fitting of models and generation of maps that consists of four main steps:

- Overlay points and covariates and prepare the regression matrix.
- Fit spatial prediction models.
- Apply spatial prediction models using tiled raster stacks (covariates).
- Assess accuracy using cross-validation.

Examples of clay fraction and bulk density from the SoilGrid250m are shown in the subsequent figures.

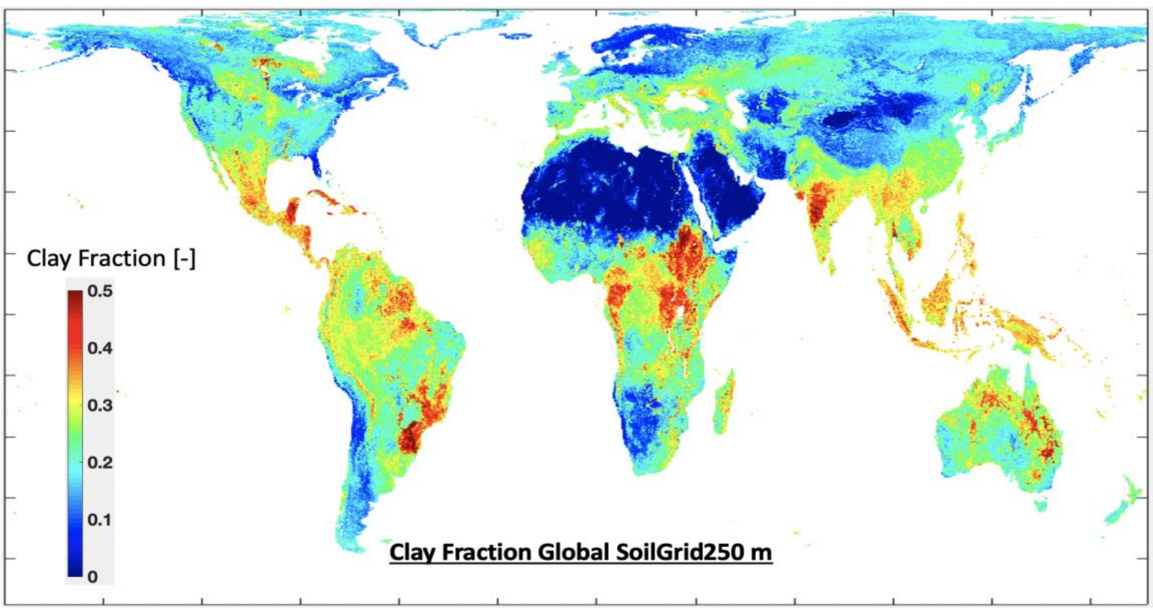


Figure 2: Clay fraction map of top 5 cm at 3 km resolution EASE2 grid projection created from the SoilGrid250m database obtained from www.OpenLandMap.org.

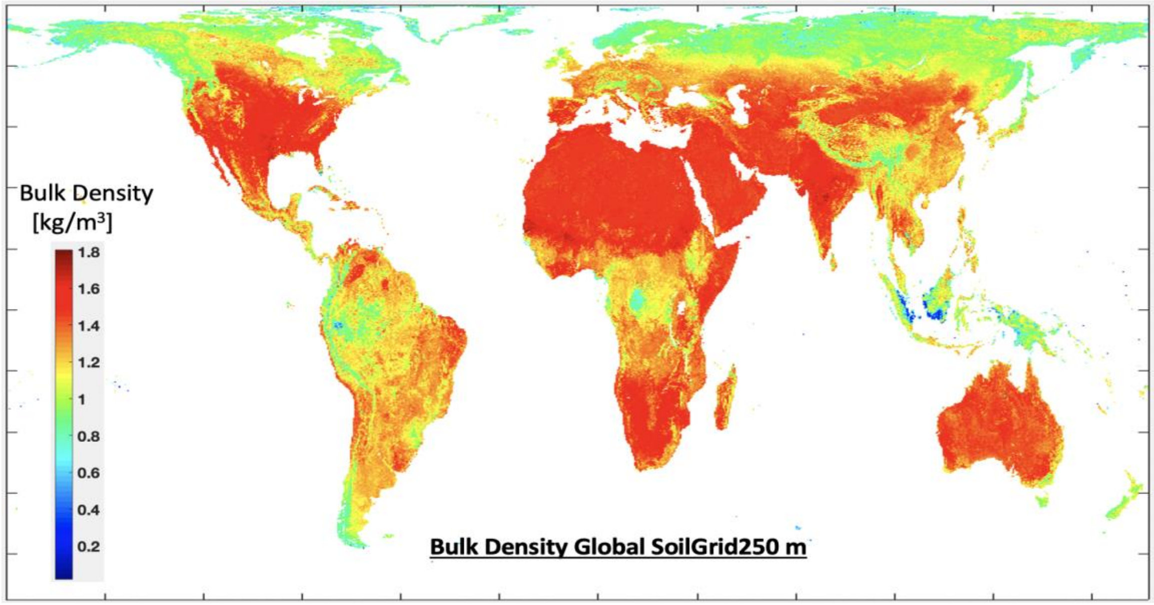


Figure 3: Bulk density map of top 5 cm at 3 km resolution EASE2 grid projection created from the SoilGrid250m database obtained from www.OpenLandMap.org.

2.1 Discussion

The previous version of soil attribute data used in the SMAP SAS processing was created from best available resources of soil databases in the year 2012 (three years prior to SMAP's launch in 2015). These soil data primarily came from the Food and Agricultural Organization (FAO), the Harmonized World Soil Database (HWSD), the State Soil Geographic (STATSGO) database, the National Soil Data Canada (NSDC), and the Australia Soil Resources Information System (ASRIS). The soil attributes were composited with the FAO as a base map overlay with HWSD, and then replacing the HWSD domain over the United States with STATSGO, NSDC over Canada, and ASRIS over Australia. The approach of making the composite has its advantage and limitations. The prominent advantage was to get the best data wherever available; for example, the HWSD over the United States at a resolution of ~10 km was replaced by STATSGO at 1 km resolution. The limitation of this approach was the possibility of stark unnatural physical boundaries (discontinuities) because of the patchwork nature of the composite. However, the composite soil database was the best available at the time of the SMAP launch and was successfully used in many versions of the SMAP Level-2 SAS processing to produce soil moisture products.

Over the period after the SMAP launch in 2015, many advances were made in the field of soil sciences, data acquisition (*in situ* and remote sensing), statistical techniques, computing hardware, and free software. These advances led to the creation of high-resolution soil attribute databases, such as the global SoilGrid250m (Hengl et al., 2017). Dai et al., 2019 evaluated the quality and accuracy of the SoilGrid250m data against other available global resources (such as HWSD), and they reported that the SoilGrid250m database has the most accurate estimate of soil properties when compared against the *in situ* soil profile data from the World Soil Information Service (WoSIS). Table 1 illustrates the comparison statistics of most of the relevant and available global soil attribute databases. However, the comparison shown in Table 1 is not completely independent because quite a number of sites used for the compilation of these products are also used in computing the statistics.

Table 1: Evaluation statistics of soil datasets using soil profiles from the World Soil Information Service (WoSIS). The table is sourced verbatim from Dai et al., 2019. Highlighted rows are for SoilGrid250m.

Soil property	Dataset	Topsoil (0–30 cm)*				Subsoil (30–100 cm)			
		ME	RMSE	CV	R^2	ME	RMSE	CV	R^2
Sand content (% in weight)	SoilGrids	−0.906	18.6	0.457	0.518	−0.27	19.1	0.501	0.492
	GSDE	−0.443	23.2	0.571	0.247	−1.31	23.8	0.625	0.211
	HWSD	6.64	27.4	0.673	0.014	2.08	27.6	0.725	−0.058
	IGBP	3.74	26.3	0.647	0.051	4.06	26.3	0.691	0.055
Clay content (% in weight)	SoilGrids	1.34	12.5	0.554	0.339	0.39	13.6	0.485	0.382
	GSDE	−0.949	14.6	0.643	0.104	−0.79	16.4	0.584	0.105
	HWSD	0.77	16.2	0.718	−0.119	1.42	18.9	0.672	−0.182
	IGBP	3.27	15.4	0.678	0.044	2.44	16.8	0.597	0.084
Bulk density ($kg\,m^{-3}$)	SoilGrids	−79.7	237	0.164	0.338	−33.5	212	0.136	0.327
	GSDE	−68.4	279	0.193	0.030	−65.5	269	0.173	−0.043
	HWSD	−105	298	0.206	−0.033	−168	317	0.204	−0.107
	IGBP	−55.6	273	0.189	0.050	−112	294	0.189	−0.130
Coarse fragment (% in volume)	SoilGrids	1.53	10.1	1.68	0.319	1.23	12.8	1.47	0.335
	GSDE	3.2	13.5	2.24	−0.165	3.18	16.8	1.93	−0.115
	HWSD	1.8	13.2	2.2	−0.164	−0.40	16.2	1.87	−0.081
Organic carbon ($g\,kg^{-1}$)	SoilGrids	6.21	29.8	1.69	0.218	0.99	23.5	3.32	0.134
	GSDE	−0.354	34.5	1.95	−0.095	0.45	27.4	3.87	−0.174
	HWSD	−3.67	36.2	2.05	−0.194	−1.38	27.4	3.87	−0.172
	IGBP	0.61	33.4	1.89	−0.026	1.67	28.5	4.02	−0.268

* Quite a number of WoSIS soil profiles were considered in the compilation of the four products. ME is the mean error. RMSE is the root mean squared error. CV is the coefficient of variation. R^2 is the coefficient of determination.

The SMAP mission took notice of the high-resolution soil database (SoilGrid250m) because of the soil moisture product resolution enhancement activities for the L2_SM_P_E and the L2_SM_SP products. The resolutions of L2_SM_SP product data fields are 3 km and 1 km, and therefore, it is better to have ancillary information and data more compatible with these spatial resolutions. As mentioned in Section 1.2, the SMAP SAS needs clay fraction data to compute the dielectric constant of the soil that is needed to invert brightness temperature into soil moisture. Before ingesting the SoilGrid250m data in the SMAP SAS processing, analysis was conducted by the project to evaluate the SoilGrid250m database. Some of the results are highlighted in the subsequent discussion.

Figure 4 illustrates the old clay fraction map that was used to produce the older versions of SMAP soil moisture data. The difference map between the new clay fraction (Fig. 2) and old clay fraction (Fig. 4) is shown in Fig. 5. It is obvious from Fig. 5 that there are significant differences in the amount of soil clay fraction in many parts of the world (except for the U.S. and most of Europe, where most differences are very small). These differences (Fig. 5) in clay fraction will lead to alterations in the volumetric soil moisture retrievals, and the magnitude of volumetric soil moisture retrieval differences between the older versions and the newer version will depend on the % differences in the clay fraction. Studies conducted in JPL show that clay fraction has a second-order impact on the soil moisture retrieval using the Tau-Omega model. Figure 6 illustrates the impacts of changing the clay fraction on volumetric soil moisture retrievals. The plots in Fig. 6 highlight the positive increase in soil moisture difference with increasing soil moisture content and increasing clay fraction, and vice-versa. A difference of ~0.02 m_3/m_3 is visible at the very wet end with very high clay fraction having a 25% change in the clay fraction. From this analysis, it is very clear that change in volumetric soil moisture retrievals of any particular location overall mean will be within +/- 0.02 m_3/m_3, and most changes will be smaller.

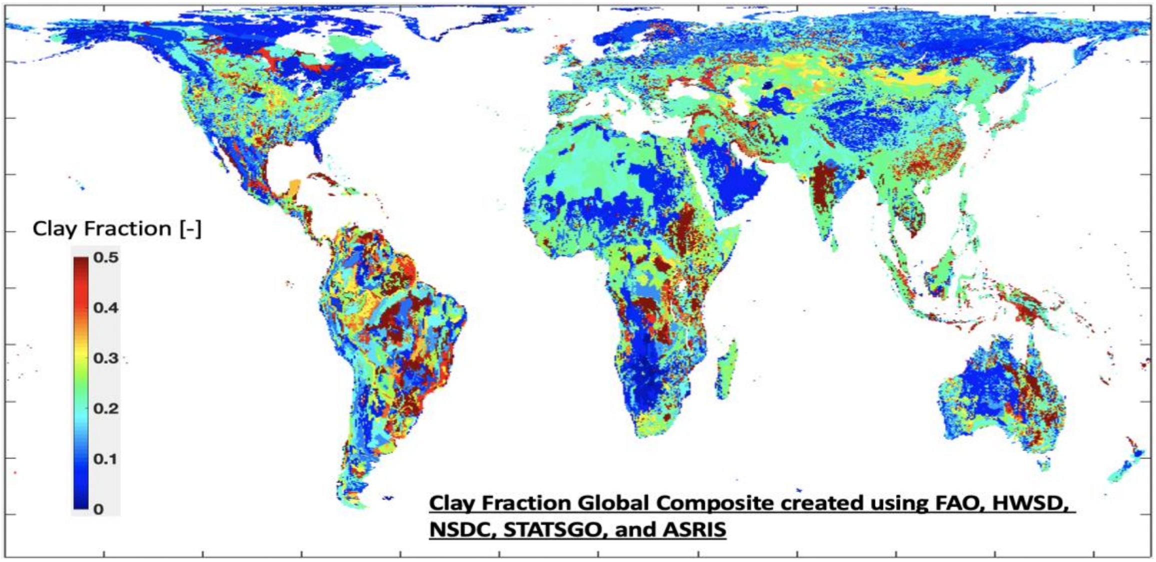


Figure 4: Composite clay fraction map of top 5 cm at 3 km resolution EASE2 grid projection created from FAO, HWSD, NSDC, STATSGO, and ASRIS.

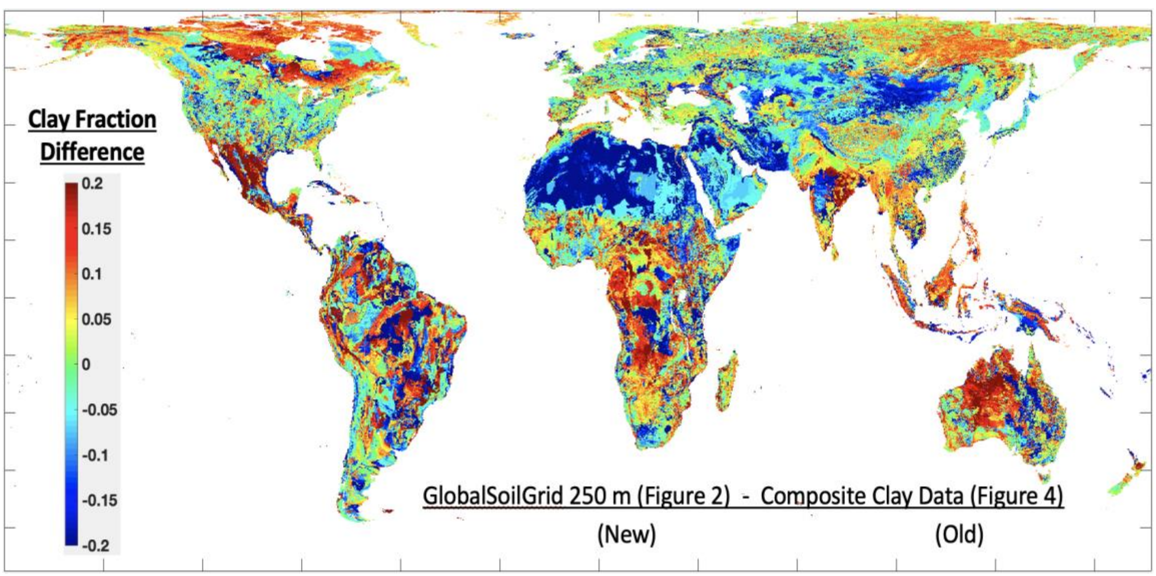


Figure 5: Clay fraction difference between GlobalSoilGrid250m (New) and the Composite Clay fraction (Old) created using the FAO, HWSD, STATSGO, NSDC, and ASRIS.

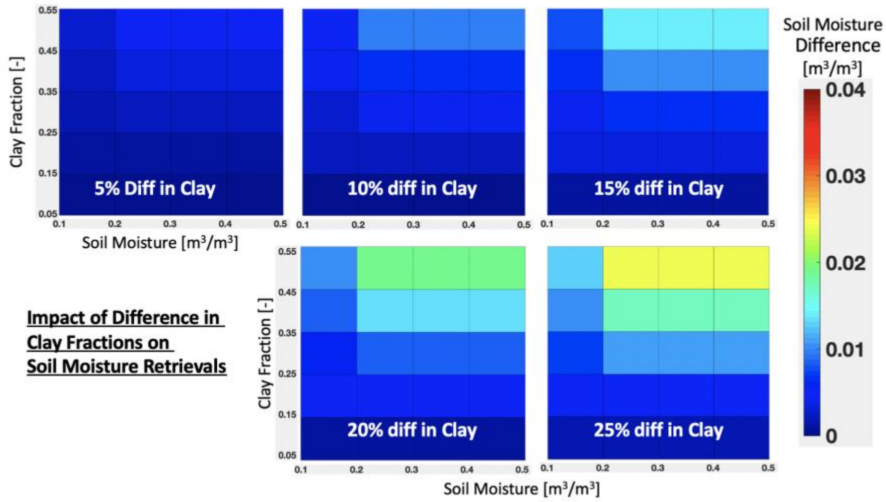


Figure 6: Impact of changing the clay fraction on SMAP soil moisture retrievals.

We also evaluated the gridded clay fraction data for the SMAP project created using the new SoilGrid250m base maps. The gridded (at 36 km, 9 km, 3 km, and 1 km) clay fraction data were compared against the *in situ* WoSIS database. Figure 7 illustrates the scatter plots along with the comparison statistics of gridded clay fraction data. The plots in Fig. 7 clearly show that the new clay fraction gridded data have better RMSDs and correlations than the old clay fraction gridded data. This analysis is one of the primary factors that initiated the decision for the SMAP project to switch to the use of clay fraction data derived from SoilGrid250m for the SMAP SAS processing to produce the latest version of soil moisture products.

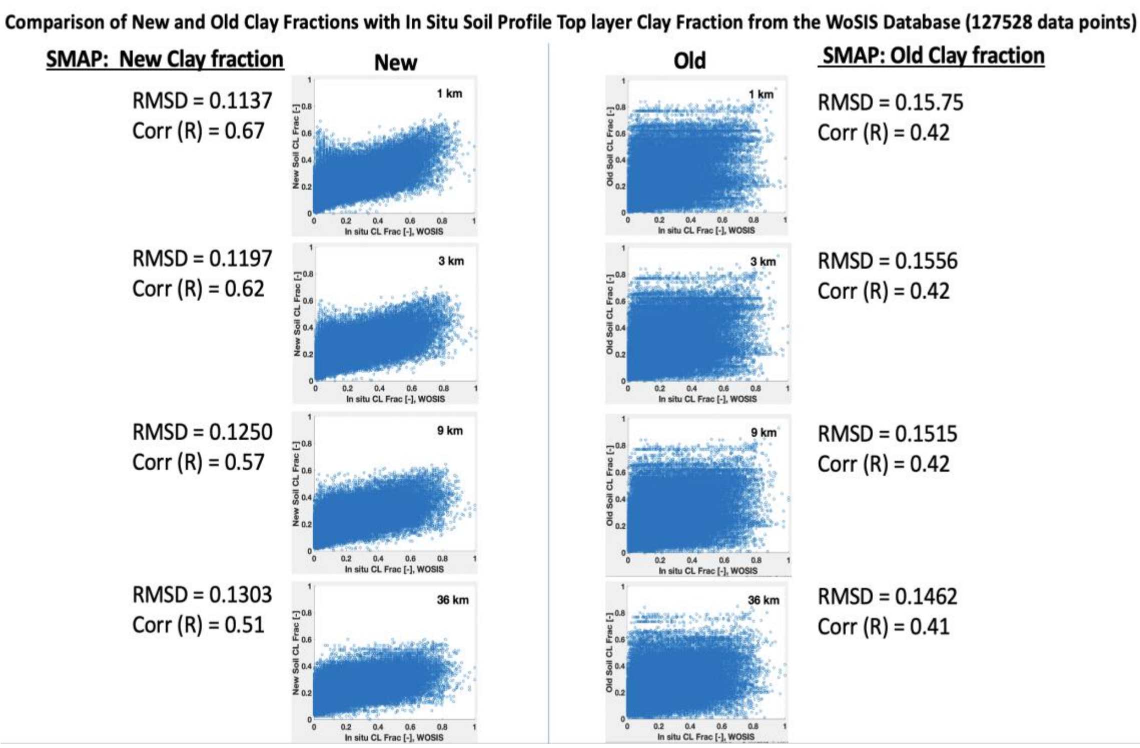
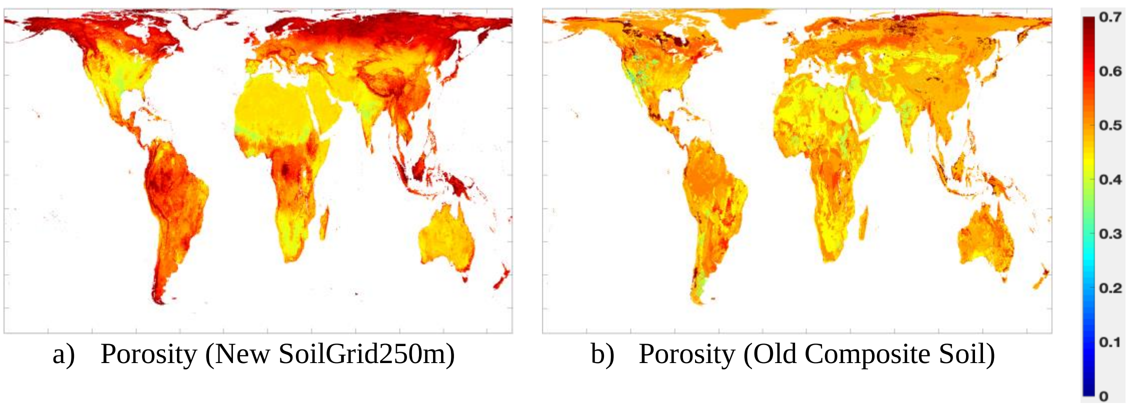


Figure 7: Statistics of comparison of statistics of new clay fraction data (from SoilGrid250m) and old clay fraction data (from Soil Composite created from FAO, HWSD, STATSGO, NSDC, and ASRIS) for different SMAP grid resolutions against the *in situ* 127528 data points from the WoSIS

database. (RMSD and Corr are abbreviations of Root-Mean-Square-Difference and Correlation, respectively).

Another soil attribute that is used in the SMAP SAS processing is the bulk density (BD). However, it is not directly ingested as a parameter in the Tau-Omega model or the Mironov model. Instead, the bulk density is used to compute the threshold, i.e., the upper limit (~equal to the porosity of the soil), of soil moisture content that would trigger a quality flag. The porosity based on bulk density is computed using Eq. 1.

Soil Porosity (Saturated Soil Moisture Content) = 1 – (BD / 2.65) (1where 2.65 g/cm3 is the average particle density for mineral soils. Porosity and bulk density vary inversely with each other. Figures 8a-8b show the soil porosity map created using the new SoilGrid250m database and the old composite soil database, respectively. It is clear from Fig. 8 that the BD from SoilGrid250m is lower in value (porosity is higher) for the top 5 cm of the soil profile, especially over the northern latitudes, the boreal forests (in Eurasia), and the rain forests (Amazon, Congo, and Southeast Asia). This is possibly due to the litter and undecomposed organic material mixed up in the top 5 cm soil layer. Figure 9 displays the difference (new – old) of the porosities from the new (SoilGrid250m) and the old (soil composite) database.



a) Porosity (New SoilGrid250m)   b) Porosity (Old Composite Soil)

Figure 8: Porosity maps at 3 km resolution EASE grid project, a) from new SoilGrid250m, and; b) from old composite soil.

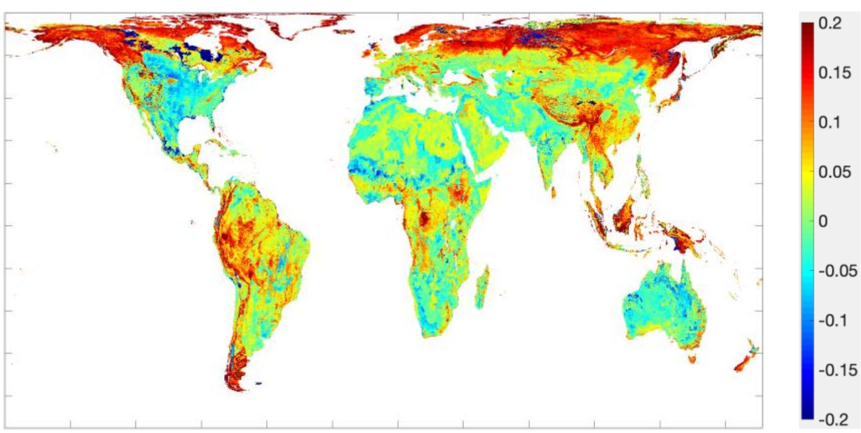


Figure 9: Difference of porosities between the new (SoilGrid250m) and the old (soil composite) database

It is obvious from Fig. 9 that in most parts of the world the upper threshold of soil moisture retrievals will not be impacted substantially, with porosity mainly increasing/decreasing within +/- 0.05 m^3/m^3. However, stronger impacts will occur in the northern latitudes and heavily forested regions, with porosity increasing/decreasing within +/- 0.20 m^3/m^3. Further analysis of the SMAP Level-2 products will reveal the overall impact of new BD thresholding for QC and flagging activities.

3 Processing and Gridding

The SMAP mission provides global soil moisture products at 1, 3, 9, and 36 km grid resolutions. This necessitates having soil attribute ancillary data that match the highest resolution of 1 km if possible. The latest SoilGrid250m data were downloaded from the www.openlandmap.org web portal. The downloaded soil attributes were sand fraction, clay fraction, bulk density, and organic carbon content. These attributes were available for six standard depths (0 cm, 10 cm, 30 cm, 60 cm, 100 cm, and 200 cm). For the purpose of SMAP Level-2 processing, soil attribute data are required for the top ~5 cm. Therefore, the top two layers were downloaded for all the required soil attributes data. The data are in Geotiff format at 250 m resolution with geographic projection at global extent. A total of 8 data layers were downloaded.

3.1 Re-Gridded Data

First, the average of soil attributes at 0 cm and 10 cm was computed to obtain soil attribute data at 5 cm depth. The validity of this averaging step was confirmed by the author (Dr. Tomislav Hengl) of the dataset. The resulting ~5 cm depth global Geotiff file at 250 m resolution was then subjected to regridding to the SMAP EASE2 projections at 1 km, 3 km, 9 km ,and 36 km. A simple drop-in-the-bucket averaging was conduct to compute the value of the soil attribute during the regridding process. For example, the drop-in-the-bucket scheme means that all of the data at 250 m resolution that fall with the 1 km grid cell (based on their lat-lon center) were first accumulated and then linearly averaged. In this process 'no data' values were ignored. Although the use of the Mirinov dielectric model in SAS processing does not require sand fraction and organic carbon content data, these data are made available keeping in mind possible future needs if a different dielectric model selection is made for SAS processing. For example, the SMAP project plans to investigate the use of organic carbon content as an input to the dielectric model to compute the dielectric constant of a top soil layer with high organic content to improve soil moisture retrievals in higher latitudes and dense forests.

4 Data Availability

A current version of the re-gridded dataset of sand fraction, clay fraction, and bulk density on the 1, 3, 9, and 36 km EASE2 grids 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 in the future and will be noted in updates to this document.

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. The SMAP project greatly thanks and acknowledge the help and guidance extended by Dr. Tomislav Hengl to produce the gridded soil attributes from the SoilGrid250m data available through www.openlandmap.org.

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Appendix A: SMAP Science Data Product 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_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_P_E	Enhanced Soil moisture (radiometer, half orbit)	Chan, S. et al., Enhanced Level 2 Passive Soil Moisture Product, JPL D-56291, JPL, Pasadena, CA.
L2_SM_SP	Soil moisture (radar/radiometer, half orbit)	Das, N. N. et al., L2 SMAP-Sentinel (active/passive) products, JPL D-104870, JPL, Pasadena, CA.
L3_FT_P/_E	Freeze-Thaw (radiometer, daily composite)	Dunbar, S., et al., Level 3 RadiometerFreeze/Thaw Data Products(L3_FT_Pand L3_FT_P_E, Pasadena, CA.
L3_SM_P	Soil moisture (radiometer, daily composite)	(Joint with L2_SM_P)
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 Data Set Description

The global soil attributes data set 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
bulk_M01_006.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
bulk_M03_006.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
bulk_M09_006.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
bulk_M36_006.float32	Binary	406	964	EASE2	36 km	-9999	real*4
clay_M01_006.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
clay_M03_006.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
clay_M09_006.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
clay_M36_006.float32	Binary	406	964	EASE2	36 km	-9999	real*4
sand_M01_006.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
sand_M03_006.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
sand_M09_006.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
sand_M36_006.float32	Binary	406	964	EASE2	36 km	-9999	real*4
OC_M01_006.float32	Binary	14616	34704	EASE2	1 km	-9999	real*4
OC_M03_006.float32	Binary	4872	11568	EASE2	3 km	-9999	real*4
OC_M09_006.float32	Binary	1624	3856	EASE2	9 km	-9999	real*4
OC_M36_006.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.

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