Soil Moisture Active Passive (SMAP)

Ancillary Data Report

Digital Elevation Model

Preliminary, v.1
SMAP Science Document no. 043

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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/.

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1 Overview

1.1 Purpose

The purpose of this report is to describe a digital elevation model (DEM) dataset to be used for generating SMAP science data products. The DEM dataset is one of a suite of ancillary datasets used 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

DEM data are used in Level 1 (L1) processing algorithms to perform data ortho-rectification, and in L2 and L3 soil moisture and freeze/thaw algorithms to generate flags indicating mountainous areas. Complex topography introduces geometric and radiometric errors in the radar imagery through layover and shadowing. Ortho-rectification of the L1 radar data using a DEM corrects for most of these geometric and radiometric distortions. For the L2 and L3 soil moisture and freeze/thaw algorithms, a DEM is used to identify highly variable terrain elevation within a sensor footprint or retrieval grid cell, indicating mountainous areas where retrieval quality may be diminished. The DEM evaluation and selection process is based on the quality, spatial resolution and extent of the available regional and global datasets.

A DEM dataset provides elevation (in meters) for any given latitude and longitude. For SMAP, the dataset will be used to ortho-rectify the SMAP L1 radar data and to derive information related to slope, aspect, variance, and elevation, which will be used in the geophysical product algorithms (L2_SM_A, L2_SM_P, L2_SM_AP, and L3_FT) to determine masks and flags.

The DEM spatial resolution needed for ortho-rectification of the L1 radar data is 250 meters, and this resolution is also appropriate for deriving masks or flags at 1 km, 3 km, 9 km, and 36 km for the L2 and L3 products. To ensure consistency across the L1-L3 products we seek a nominal spatial resolution of 250 m.

2 Dataset Description and Selection

2.1 Candidate DEMs

The global and near-global DEMs that were evaluated for use by SMAP are listed in Table 1. The DEMs were examined for meeting the spatial resolution (250 meters) and coverage (global) required by SMAP. The only two datasets meeting these specifications were the ASTER and JPL GDEMs. A comparison of these two datasets and further details about each are listed in Table 2. All other datasets either met the spatial resolution but not the coverage (CGIAR 90m-near global), or met the coverage but not the spatial resolution (GETASSE30, 1km-global).

Table 1. List of global and near global DEM's considered for SMAP

Dataset Name	Description	Spatial Resolution	Coverage
JPL GDEM 30m	A combination of different DEM's all interpolated to 30 m (1 arcsecond) and to a common projection. Sources are: CGIAR void filled SRTM DEM, Alaska DEM, Canada DEM and GTOPO30. Produced by JPL. Released in 2008. http://wetlands.jpl.nasa.gov/data/DEM_Download.html - Content	approx. 30 meters-interpolated (1 arcsecond)	Global
ASTER GDEMv2	Primarily ASTER scenes. External DEM´S used to fill the voids. Produced by Japan's ERSDAC/NASA. Released in 2009. http://asterweb.jpl.nasa.gov/gdem.asp	approx. 30 meters interpolated. Actual resolution: 120m (1 arcsecond)	Global (between 83N and 83S)
SRTM	Voids have not been filled. Produced by JPL and NIMA. Released in 2003. http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/	approx. 90 meters (3 arcseconds)	Near Global 60 degrees north and 56 south
CGIARv4	Void filled SRTM DEM using either real data or through interpolation. Produced by CGIAR. Released in 2008. http://srtm.csi.cgiar.org/	approx. 90 meters (3 arcseconds)	Near Global 60 degrees north and 56 south
SRTM30	SRTM data averaged to 1km. Voids were filled using GTOPO30 data. Produced by JPL and NIMA. Released in 2005. http://dds.cr.usgs.gov/srtm/version2_1/SRTM30/	approx. 1 km (30 arcseconds)	Near Global 60 degrees north and 56 south
GTOPO30	Assembled from different DEM's. Has lots of discontinuities and errors. Produced by USGS. Released in 1996. http://eros.usgs.gov/ - /Find_Data/Products_and_Data_Available/g	approx. 1 km (30 arcseconds)	Global
GLOBE	GLOBE contains data from 11 sources. Produced by NOAA. Released in 1999 (pre-SRTM). http://www.ngdc.noaa.gov/mgg/topo/globe.html	approx. 1 km (30 arcseconds)	Global
GETASSE30	Is a composite of SRTM30, ACE1, Mean Sea Surface (MSS), EGM96 ellipsoid. Produced by ESA/ESRIN. Released in 2008. http://www.array.ca/nest-web/help/visat/GETASSE30ElevationModel.html	approx. 1 km (30 arcseconds)	Global

ESA's SMOS mission is using the GETASSE30 DEM, which is a composite of three DEMs. It uses the SRTM30 DEM, ACE DEM, and Mean Sea Surface (MSS) data as sources. The resulting DEM represents the earth topography and sea surface elevation with respect to the WGS84 ellipsoid at 1 km resolution (30 arcseconds). The spatial resolution of this DEM is coarser than required for SMAP and was therefore not considered for SMAP use.

Table 2. Comparison of ASTER GDEM and JPL GDEM

Dataset	Spatial Resolution	Availability	Issues
JPL GDEM	A collection of different DEM's interpolated to 30 meters (1 arcsecond) and having a common projection.	Free	Areas (those covered by GTOPO30) interpolated from 1km to 30 meters have low level of detail.
ASTER GDEM	1 arcsecond posting (30m). Actual resolution: 100-120 meters (3-4 arcseconds)	Free	- Cloud filter algorithm leaves residual anomalies, such as crater like features. - Artifacts related to linear and curvilinear boundaries between different stacks, appearing as straight lines, pits, bumps, mole runs, and other geometric shapes. Elevations associated with these artifacts range from 1-2 m to more than 100 m. - The existence of most water bodies is not indicated. - METI and NASA acknowledge that Version 1 of the ASTER GDEM should be viewed as experimental or research grade.

A global DEM of 250 meters resolution is needed for generating SMAP L1, L2 and L3 products. At the present time the best available global DEM that meets or exceeds this requirement is the JPL Global DEM or GDEM. The JPL GDEM is considered superior to the ASTER GDEM because it has fewer artifacts and water bodies are identified. In addition, METI and NASA acknowledge that the ASTER GDEM v1 is still considered experimental while the SRTM DEM (which covers the majority of the landmass on the JPL GDEM) is widely used by the scientific community and is considered the "standard" DEM.

2.2 JPL GDEM Description and Processing

2.2.1 Input DEMs and Data Assembly

The JPL GDEM was developed by a team at JPL and released on August 2009 in support of a NASA MEaSUREs project to monitor wetlands (PI: Kyle McDonald). The DEM can be freely downloaded through the following website:
http://wetlands.jpl.nasa.gov/data/DEM_Download.html

The approach used for the JPL GDEM was to assemble a global DEM consisting of the best available and freely accessible DEMs. SRTM was used as the primary DEM, covering latitudes 60N to 56S. Areas outside of this domain were covered by the Alaska DEM, Canada DEM, and GTOPO30. Table 3 lists the DEMs used to assemble the JPL GDEM. The void issue inherent in the original SRTM DEM was addressed by using the void-filled (through interpolation and real data) SRTM DEM generated by the Consultative Group on International Agricultural Research (CGIAR).

Table 3. Input DEMs.

Input Data Set:	US SRTM	CGIAR-SRTM	GTOPO30	Alaska DEM	Canada DEM
Coverage:	United States	56 °S to 60 °N	Global	Alaska	Canada
Source:	NASA-JPL	NASA-JPL	USGS	USGS	GeoBase
Resolution:	1 arc-second	3 arc-seconds	30 arc-seconds	2 arc-seconds	3x6 arc-seconds
Horizontal Datum:	WGS84	WGS84	WGS84	NAD27	NAD83
Vertical Datum:	EGM96	EGM96	EGM96	NAVD29	CVGD28
Projection:	Geographic	Geographic	Geographic	Geographic	Geographic
Acquisition Date:	February 2000	February 2000	Late 1996	1925 - 1999	-

Issues related to the JPL GDEM arise from interpolating the GTOPO30 DEM from 1km to 30 meters, causing topographical details to appear washed out. There are plans to improve this product by using the ASTER GDEM (which has a 30 meter resolution) instead of GTOPO30. However, it is still unknown when development of this improved product will begin.

To generate the JPL GDEM the input DEM datasets were interpolated to 1 arcsecond, saved into 1x1 degree tiles, and formatted to a common resolution and format as described below:

Dimensions: 3600 x 3600 pixels
Resolution: 1 arc-second
Pixel spacing: 0.0000277778 deg.
Elevation Units: Meters
Bytes per Pixel: 4 bytes
Format: Geotiff and Binary with header file
Tiles: 1 degree x 1 degree
Naming convention: South west corner (following SRTM naming convention)
Vertical Datum: EGM96
Horizontal Datum: WGS84
Projection: Geographic

2.2.2 Data Voids

The original SRTM data contained a total of 3,436,585 voids accounting for about 0.2% of the available data. CGIAR-V3 corrected this problem with a void-filling algorithm that established a void-free DEM by using real data and interpolation. This 3-arcsecond void-filled SRTM DEM was interpolated at JPL to 1-arcsecond and used to fill the voids of the US 1-arcsecond SRTM DEM.

2.2.3 Value Replacement

Different input data sets used different numerical values to represent water. For consistency, all water regions were replaced with the number 0.

2.2.4 Interpolation

An interpolation algorithm developed at JPL (by S. Hensley) was used to interpolate all the DEMs (see example in Figure 1 below).

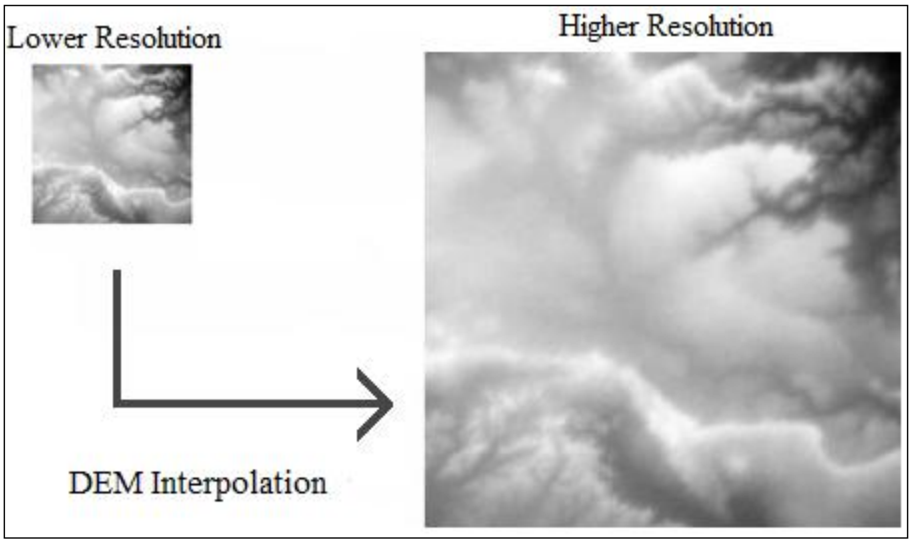

Figure 1. Example of interpolated data.

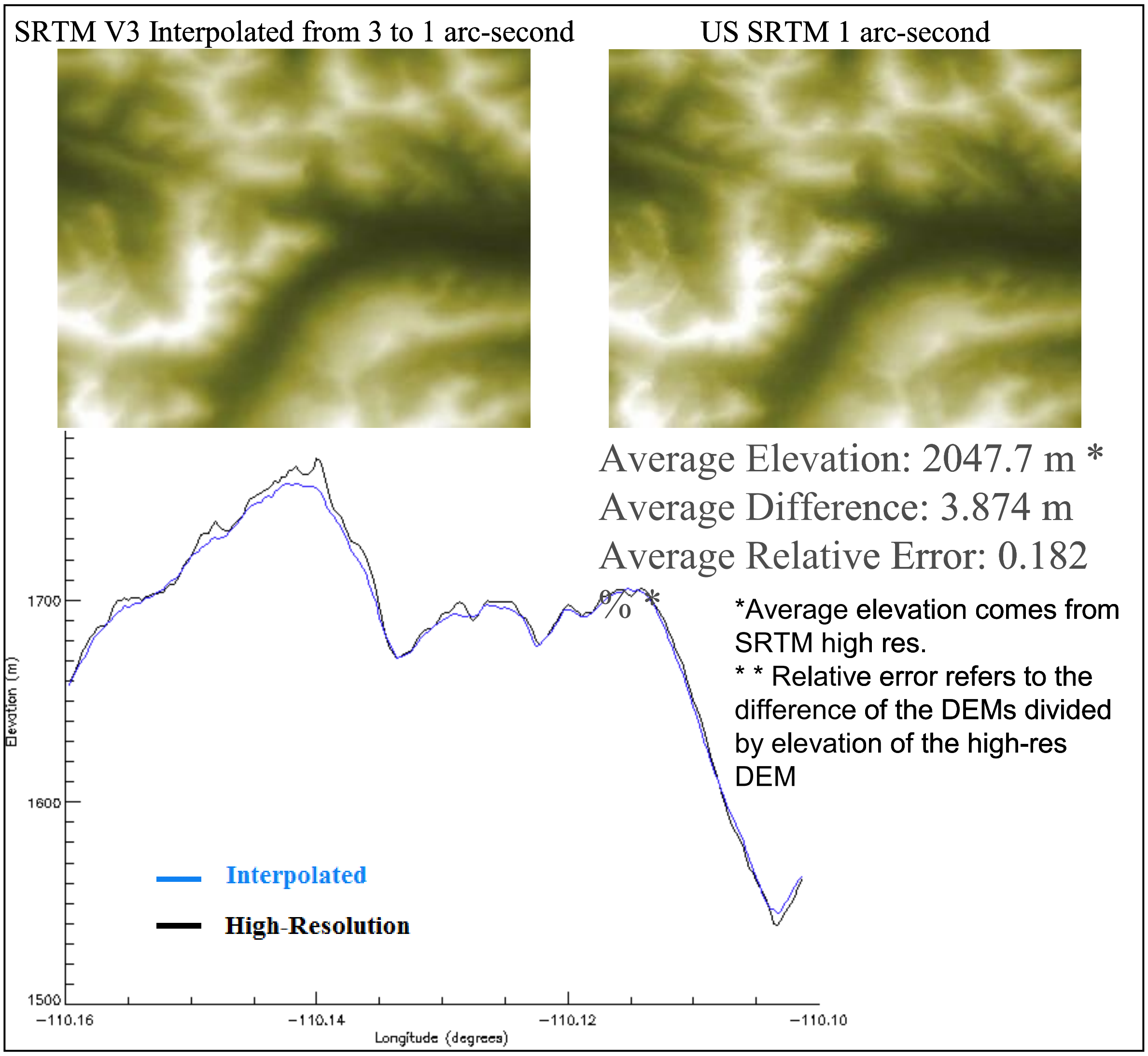

Figure 2. Interpolated SRTM V3 compared to US SRTM (N45W111)

2.2.5 Comparison of DEMs

Comparisons were performed between interpolated and non-interpolated DEMs in overlapping regions. Figure 2 is an example comparison of the interpolated (30 meter, 1 arcsecond) SRTM DEM to the original 30 meter (1 arcsecond) SRTM DEM over a region in the U.S.

The profile plot shows elevation variations along a cross-section of both DEMs and an overall very good correlation between both DEM's, averaging 3.8 meters in difference.

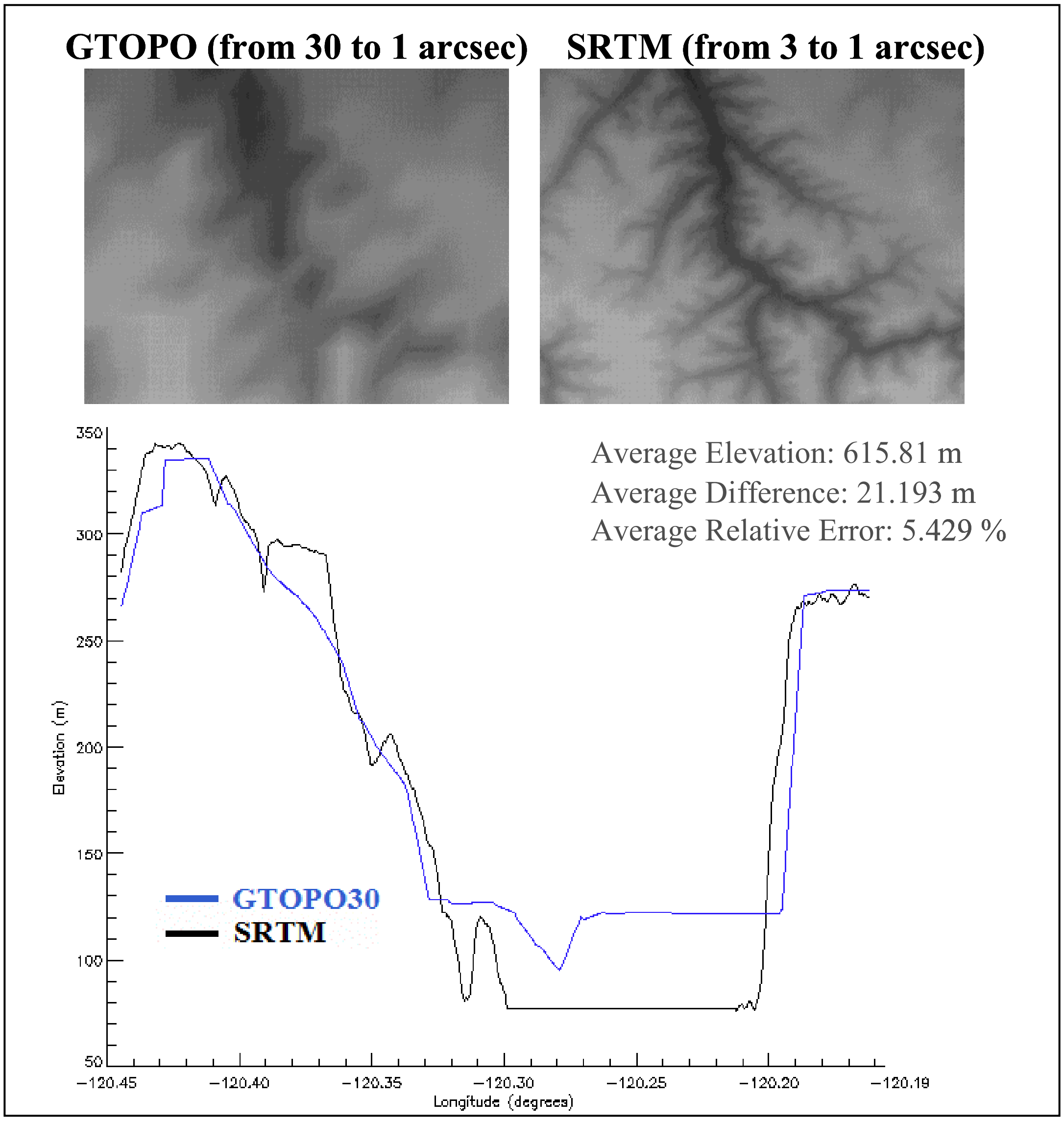

Figure 3. Interpolated GTOPO30 compared to SRTM (N45W121).

The comparison in Figure 3 was performed between the 30 meter (1 arcsecond) interpolated GTOPO30 and SRTM. The relative lack of detail present in GTOPO30 is expected since the input DEM was interpolated from 1km to 30 meters (30 to 1 arcsecond). Compared to SRTM V3, GTOPO30 is very coarse indicating that its interpolation was only useful in establishing a consistent global resolution DEM of 30 meters (1 arcsecond). Despite its relative low quality, GTOPO30 serves as a useful supplementary DEM in regions not covered by higher quality DEM's.

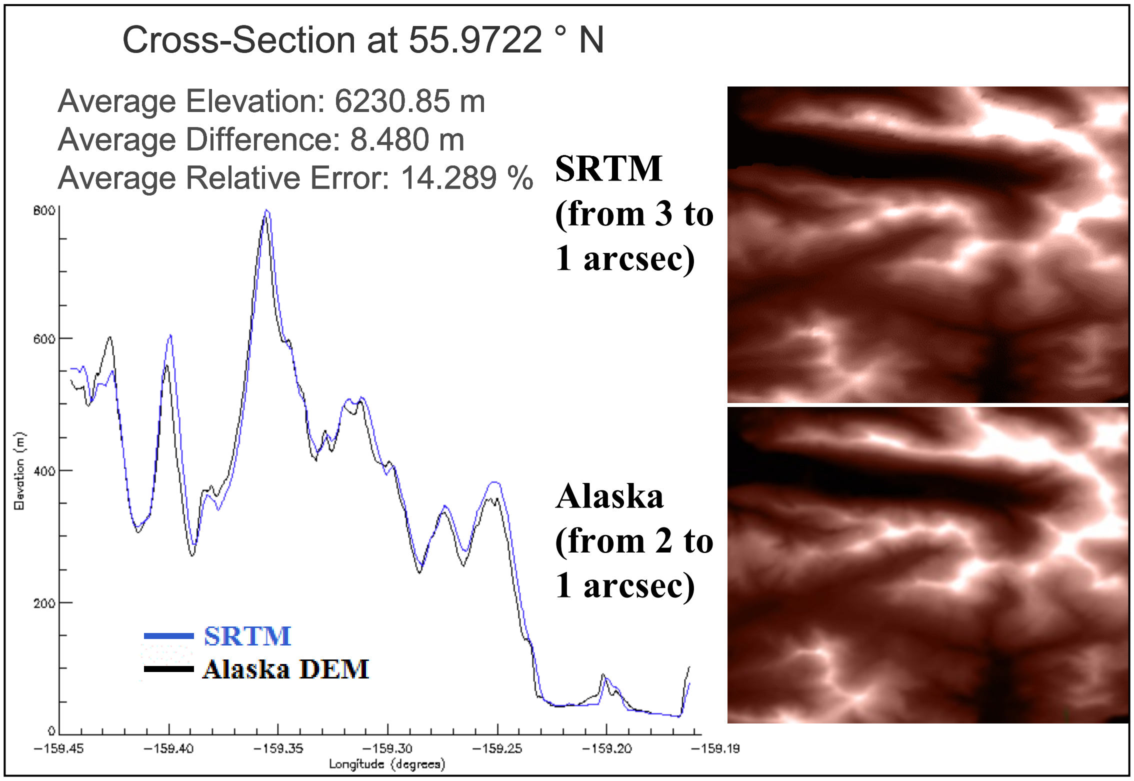

Figure 4. Comparison between interpolated Alaska and SRTM DEMs (N55W160).

The comparison in Figure 4 of the interpolated Alaska DEM to SRTM V3 demonstrates the slightly better quality of the Alaska DEM in its level of detail. The average difference between both DEMs over areas of moderate to complex topography was 8.5 meters.

Comparisons between the interpolated Canada and SRTM DEMs showed an average difference of 8 meters between both.

3 Future DEM Development

Upcoming enhanced global DEMs to be released in the near future are listed in Table 4. An assessment will be performed of the GMTED2010 and the ASTER GDEM version 2 upon their release. Based on the assessment results, replacement of the JPL GDEM will be considered.

4 Re-Gridding and Mask/Flag Generation

The base resolution, 30 meter JPL GDEM will be resampled to 250 meters to be used by the SMAP L1 processing algorithm to perform radar data ortho-rectification. It will match the swath-grid projection of the L1 data.

Table 4. Upcoming DEMs.

	Agency	**Availability**	**Release Date**	**Spatial Resolution**	**Coverage**
GMTED2010 http://pubs.usgs.gov/of/2011/1073/	USGS	Free	At any moment	250m, 500m, 1km	Global
ASTER-GDEM2 http://www.grss-ieee.org/presentations/characteristics-of-aster-gdem-version-2/	Japan/NASA	Free	At any moment	30m	Global
Tandem-X http://www.infoterra.de/tandem-x_dem	Astrium Geo (a European based company)	At a cost	2014	12 m	Global

In addition, the original 30 meter JPL GDEM will be used to generate slope and aspect at 3, 9, and 36 km EASE grid projections. Elevation will be re-gridded to 3, 9, and 36 km EASE grid projections through averaging. The variance of the slope, aspect, and elevation will also be calculated at each resolution. Values representing no data will be excluded from averaging and variance calculations. The SMAP geophysical algorithm leads will coordinate the re-gridding using an agreed processing approach to be used at 3, 9, and 36 kilometers.

The re-gridded data will be used to determine topographic complexity thresholds (based on elevation, elevation variance, slope, slope variance, or aspect) in order to generate masks that will exclude retrievals over such areas (in areas of high topographic complexity) or flags to associate retrieval quality (in areas of low to moderate topographic complexity).

5 Acknowledgment

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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: List of Acronyms

ACE2 GDEM	Altimeter Corrected Elevation v2 Global Digital Elevation Model
ASTER	Advanced Spaceborne Thermal Emission and Reflection
CGIAR	Consultative Group on International Agricultural Research
DEM	Digital Elevation Model
EASE	Equal-Area Scalable Earth Grid
ERSDAC	Earth Remote Sensing Data Analysis Center
GDEM	Global Digital Elevation Model
GETASSE30	Global Earth Topography and Sea Surface Elevation at 30 arcseconds res.
GLOBE	The Global Land 1km-Base Elevation project
GMTED2010	Global Multi-Resolution Terrain Elevation Data 2010
GTOPO30	Global Topographic Data at 30 arcseconds
JPL	Jet Propulsion Laboratory
L2_SM_A	Level 2 Soil Moisture Active (data product)
L2_SM_AP	Level 2 Soil Moisture Active/Passive (data product)
L2_SM_P	Level 2 Soil Moisture Passive (data product)
L3_FT_A	Level 3 Freeze/Thaw Active (data product)
MEaSUREs	Making Earth Science Data Records for Use in Research Environments
METI	Japan's Ministry of Economy, Trade and Industry
MSS	Mean Sea Surface
NASA	National Aeronautics and Space Administration
NIMA	National Geospatial Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
SMAP	Soil Moisture Active Passive Mission
SMOS	Soil Moisture and Ocean Salinity
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
WGS84	World Geodetic System 198