Aquarius L2 Swath Single Orbit Soil Moisture, Version 5

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Bindlish, R. and T. Jackson. 2018. *Aquarius L2 Swath Single Orbit Soil Moisture, Version 5*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/GB6FZ0UPCOGP. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/AQ2_SM

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

Aquarius LeveL-2 Soil Moisture products are produced by the NASA Goddard Space Flight Center's Aquarius Data Processing Segment (ADPS).

1.1 Format

Data are provided in Hierarchical Data Format 5 (HDF5) files. Each data file is paired with an associated XML file. XML files contain file level metadata and location, platform, and campaign information.

1.2 File and Directory Structure

Data are available at:

https://n5eil01u.ecs.nsidc.org/AQUARIUS/AQ2_SM.005/

Data files are organized in directories by date in YYYY.MM.DD format, for example:

```
/2013.09.28/
/2013.09.29/
/2013.09.30/
/2013.10.01/
```

1.3 File Naming Convention

All files are named according to the convention shown in the following example. File name variables are defined in Table 1.

Example

`Q2014271210000.L2_SOILM_V5.0`

Naming Convention

`Qyyyydddhhmmss.L2_SOILM_V5.0`

Table 1. File Naming Convention

Variable	Description
Q	Indicates Aquarius instrument
YYYYDDD	Start date (4-digit year, 3-digit day)
yyyyddd	End date (4-digit year, 3-digit day)

Variable	Description
hhmmss	UTC hours, minutes, and seconds of the first sample block in the product where a sample block is defined as the first set of observations from the three Aquarius beams
SOILM	Parameter (SOILM: soil moisture)
V5.0	Data version number (V5.0)

1.4 Volume

The total data volume for all Aquarius L2 soil moisture files is approximately 21 GB.

1.5 Spatial Coverage

Coverage spans from 180°W to 180°E, and from approximately 90°N to 90°S. The swath width is approximately 390 km, enabling nearly global coverage every seven days. Figure 1 shows the spatial coverage of the Aquarius radiometer for one orbit, which comprises one file/granule of this data set.

1.5.1 Spatial Coverage Map

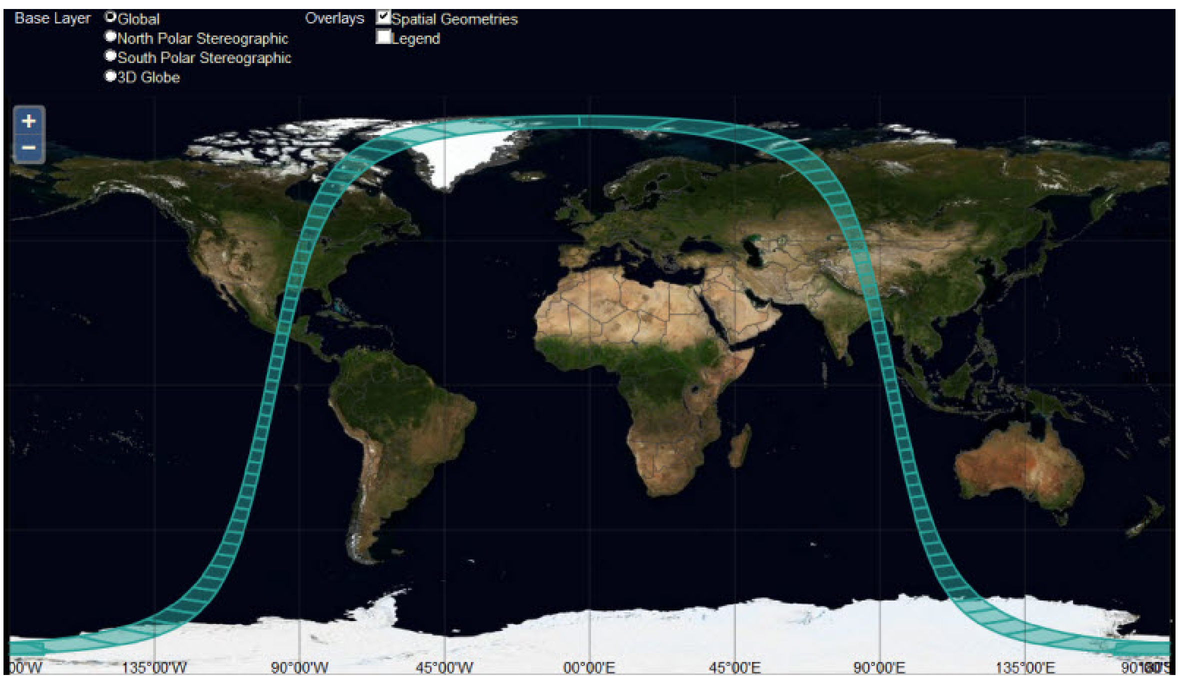

Figure 1. This spatial coverage map displaying one orbit of the Aquarius Radiometer. The map was created using Reverb | ECHO.

1.5.2 Spatial Resolution

The Aquarius radiometer consists of three beams of varying sizes that result in a total swath width of approximately 390 km. The beam sizes are: 76 x 94 km (inner beam), 84 x 120 km (middle beam), and 96 x 156 km (outer beam).

Soil moisture is estimated for each individual radiometer beam footprint. The exact spatial resolution of the Level-2 (L2) product varies depending on the beam position: inner, middle, or outer beam. Figure 2 shows the position of the Aquarius beams.

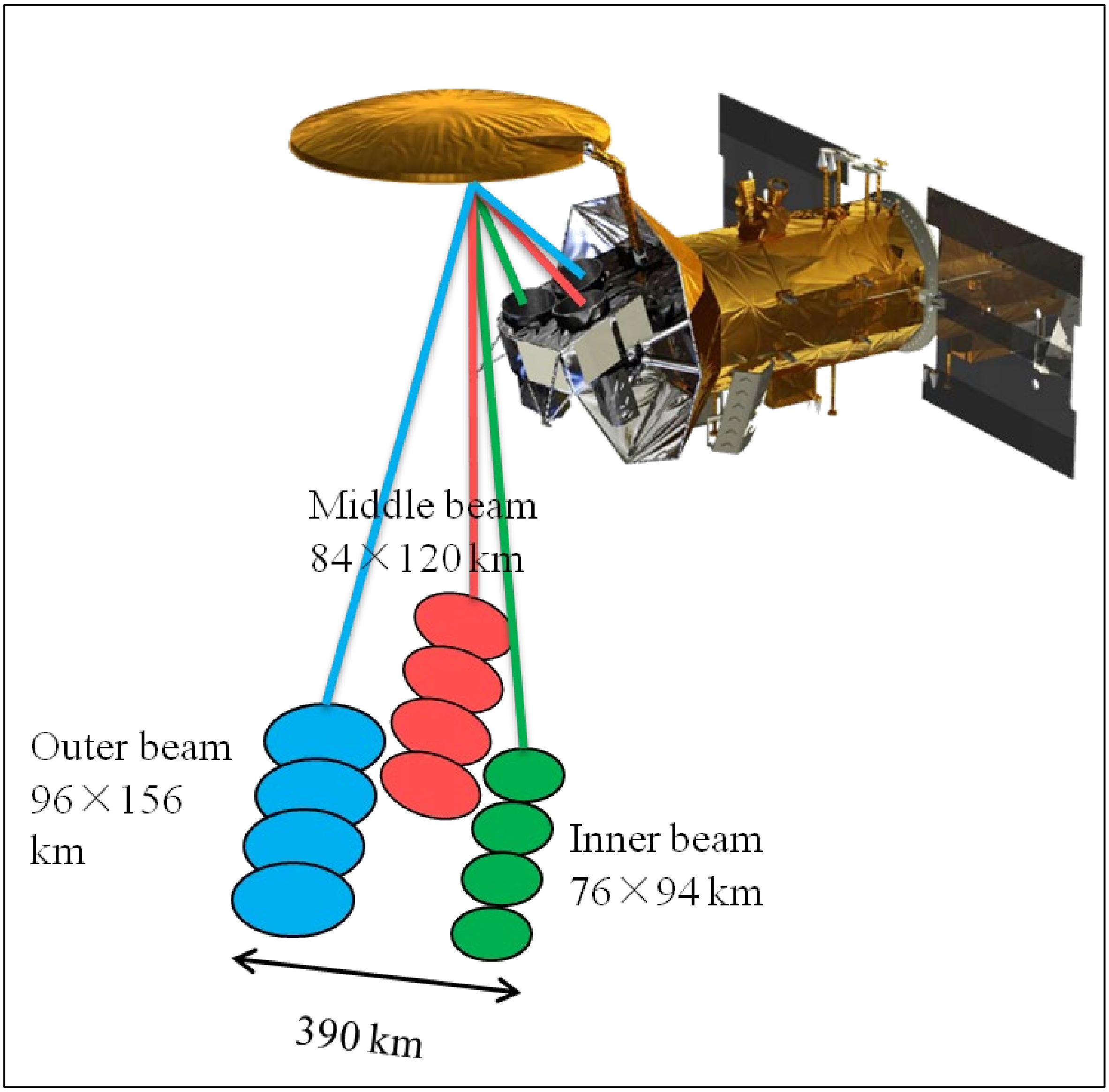

Figure 2. The above image shows the location and 3 dB size of the three Aquarius beams

1.6 Temporal Coverage

The temporal coverage for this data set spans from 25 August 2011 through 07 June 2015.

Due to a power failure on the Satélite de Aplicaciones Científicas (SAC)-D spacecraft on 08 June 2015, data from the NASA Aquarius instrument are no longer being produced. For more information on this event, refer to the official NASA announcement, International Spacecraft Carrying NASA's Aquarius Instrument Ends Operations. The NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC) will continue to distribute Aquarius soil moisture and polar-gridded data sets for the full duration of the mission, 25 August 2011 through 07 June 2015.

1.6.1 Temporal Resolution

Each Level-2 file spans approximately 98 minutes.

1.7 Parameter or Variable

The Single Channel Algorithm (SCA) is used to estimate soil moisture using Aquarius brightness temperature observations. The SCA is applied to the individual Aquarius footprint brightness temperature observations (L2) to produce a swath-based. time-ordered product. Each swath is stored in a separate file. Files are organized by the groups shown in Figure 3.

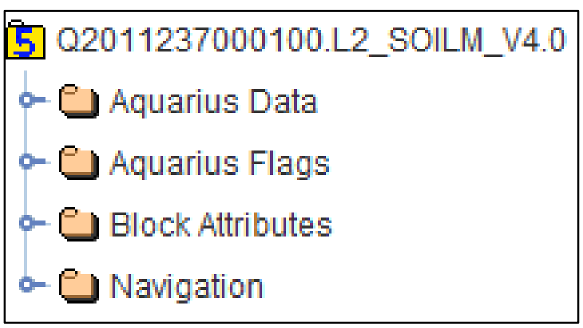

Figure 3. This figure shows the data groups in each Aquarius L2 soil moisture file

1.7.1 Parameter Description

The four data groups—`Aquarius Data`, `Aquarius Flags`, `Block Attributes`, and `Navigation`—contain data stored as HDF5 data blocks. Each data array in the `Aquarius Data` group is 4083 rows x 3 columns (coinciding with the number of Aquarius beams). Parameters contained in the `Block Attributes` group are 4083 rows x 1 column. With one exception, parameters contained in the `Navigation` group are 4083 rows x 3 columns; the `zang parameter` is 4083 rows x 1 column.

Metadata are included as global attributes within each data file and have been adapted for Version 5 to more closely align with Climate and Forecast (CF) metadata conventions. A total of 36 metadata fields are provided, such as minimum and maximum data values, units, and platform and projection information. Values for some data fields may vary from granule to granule.

Figure 4 shows the Aquarius soil moisture estimates using all three beams for 07 June 2015.

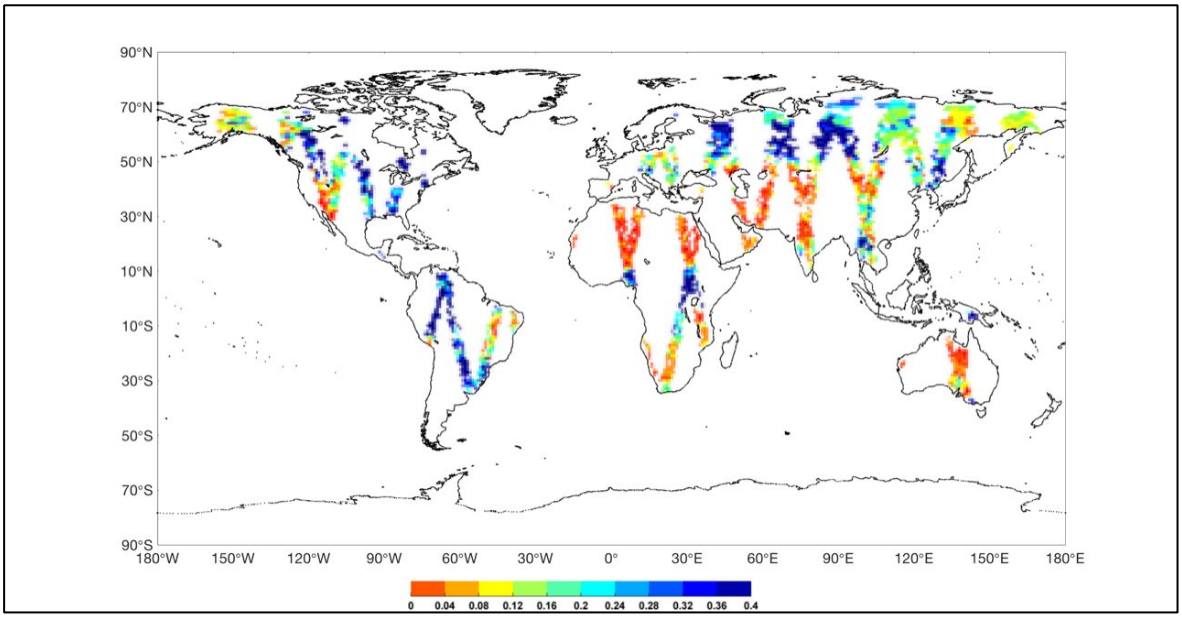

Figure 4. This figure shows Aquarius soil moisture estimates using all three beams for 06 June 2018

2 SOFTWARE AND TOOLS

The following resources provide access to software for reading and viewing HDF5 data files:

- HDFView — Visual tool for browsing and editing HDF4 and HDF5 files; additional tools are available on the HDF5 Tools and Software website.
- Panoply, NetCDF, HDF, and GRIB Data Viewer — Cross-platform application that plots geo-gridded arrays from NetCDF, HDF, and GRIB data sets.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

The Aquarius Single Channel Algorithm (SCA) uses the L-band horizontally polarized (h-pol) brightness temperature observations due to the higher sensitivity of this channel to soil moisture. The Aquarius SCA approach is based on the simplified radiative transfer model developed under the assumption that the canopy and soil temperatures are the same (Jackson 1993). The SCA is applied to the individual Aquarius footprint Level-2 brightness temperature observations to produce a swath-based, time-ordered product. (Bindlish and Jackson 2013, Bindlish et al. 2013). Details on these steps are provided in Section 3.3.

3.2 Data Acquisition Methods

This Version 5 Aquarius L2 soil moisture data set is generated from brightness temperature measurements included in the NASA Aquarius Level-2 Sea Surface Salinity & Wind Speed Data V5.0 product. This soil moisture data set contains measurements at the observed surface locations, along with coordinates of viewed locations and navigation data, and is stored as one physical HDF5 file. Each product contains data from one orbit of Aquarius data. An orbit begins and ends as the SAC-D spacecraft crosses the South Pole. The best quality data are selected for each orbit during Level-0 (L0) to Level-1A (L1A) data processing and are then used to create the L1A file that is input to the L2 science file (Pratt 2013).

3.3 Derivation Techniques and Algorithms

The derivation techniques and algorithms in this section are from the Aquarius Soil Moisture Algorithm Theroretical Basis Document (ATBD) Users Guide (Bindlish and Jackson 2013, Meissner et al. 2014).

Brightness temperatures are converted to emissivity using a surrogate for the effective physical temperature (T) of the emitting layer. The observed emissivity (e_{obs}) is corrected for vegetation and surface roughness to obtain the smooth soil emissivity (e_{soil}). The Fresnel equation is then used to determine the dielectric constant of the soil-water mixture (k). Finally, a dielectric mixing model is used to obtain the soil moisture (SM).

Brightness temperature of the land surface is equivalent to its emissivity (e_{obs}, where e_{obs} = 1 - r) (r = Reflectivity) multiplied by its physical temperature (T). It is assumed that the temperatures of the soil and the vegetation are the same.

Based upon the above, the complete radiative transfer model can be simplified yielding the following expression for the observed brightness temperature (TB) in Equation 1:

$$TB = Te_{obs}$$ **(Equation 1)**

Ancillary surface temperature data from the Numerical Weather Prediction model of the National Centers for Environmental Prediction Global Forecast System (NCEP GFS) is used as the effective physical temperature of the emitting medium.

The emissivity retrieved above is that of the soil as modified by any overlying vegetation and surface roughness. In the presence of vegetation, the observed emissivity is a composite of the soil and vegetation. To retrieve soil water content, it is necessary to isolate the soil surface emissivity (e_{surf}). First, the correction for the presence of vegetation is completed based on Jackson and Schmugge (1991), as in Equation 2:

$$e_{obs} = [1 - \omega][1 - \gamma]\left[1 + (1 - e_{surf})\gamma\right] + e_{surf}\gamma$$ **(Equation 2)**

Where:

Table 2. Emissivity - Correction For Presence of Vegetation

Variable	Description
ω	single-scattering albedo
γ	one-way transmissivity of the canopy
e_{surf}	soil surface emissivity

Both the single-scattering albedo (ω) and the one-way transmissivity of the canopy (γ) are dependent upon the vegetation structure, polarization, and frequency. The transmissivity is a function of the optical depth (τ) of the vegetation canopy:

$$\gamma = \exp[-\tau \sec\theta]$$ **(Equation 3)**

Where:

Table 3. One-way Transmissivity of Canopy

Variable	Description
τ	optical depth of vegetation canopy
θ	system incidence angle

A constant value of the single-scattering albedo is used in the Aquarius formulation (ω=0.05). Rearranging Equation 2 yields:

$$e_{surf} = \frac{e_{obs} - 1 + \gamma^2 + \omega - \omega\gamma^2}{\gamma^2 + \omega\gamma - \omega\gamma^2}$$ **(Equation 4)**

The vegetation optical depth is a function of the Vegetation Water Content (VWC). In studies reported in Jackson and Schmugge (1991), it was found that the following functional relationship between the optical depth and vegetation water content could be applied:

$$\tau = (b \times VWC) / \cos\theta$$ **(Equation 5)**

Where:

Table 4. Relation Between Optical Depth and Vegetation Water Content

Variable	Description
b	Proportionality value; depends on vegetation structure and microwave frequency
VWC	Vegetation Water Content

The algorithm uses a default global constant value of *b* = 0.8 for all vegetation classes. The vegetation water content can be estimated using several ancillary data sources. The baseline approach utilizes a set of land cover-based equations to estimate VWC from values of the Moderate Resolution Imaging Spectroradiometer (MODIS) derived Normalized Difference Vegetation Index (NDVI), an index derived from visible near-infrared reflectance data. The approach uses a MODIS NDVI climatology that was derived based on observations from 2001-2010.

The emissivity that results from the vegetation correction is that of the soil surface, including any effects of surface roughness. These effects are removed in order to determine the smooth surface soil emissivity (e_{soil}), which is required for the Fresnel equation inversion. One approach to removing this effect is a model described in Choudhury et al. (1979) that yields the bare smooth soil emissivity:

$$e_{soil} = 1 - \left[1 - e_{surf}\right] \exp[h \cos^2\theta]$$ **(Equation 6)**

Where:

Table 5. Bare Smooth Soil Emissivity

Variable	Description
h	*h* is dependent on the polarization, frequency, and geometric properties of the soil surface; a constant roughness parameter of *h* = 0.1 is used in the formulation

The $\cos^2 \Theta$ term is often dropped to avoid overcorrecting for roughness. The Aquarius soil moisture algorithm does not drop this term.

Emissivity is related to the dielectric properties (ε) of the soil and the viewing or incidence angle. For ease of computational inversion, it is assumed that the real component (ε_r) of the dielectric constant provides a good approximation of the complex dielectric constant. However, this assumption can be modified if additional evidence is found to support the use of this more complex formulation. The Fresnel equations link the dielectric constant to emissivity. For horizontal polarization:

$$e_{surf} = 1 - \left| \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \right|^2$$ **(Equation 7)**

Where:

Table 6. Surface Emissivity - Horizontal Polarization

Variable	Description
ε_r	Real component of the dielectric constant

The dielectric constant of soil is a composite of the values of its components air, soil, and water, which have greatly different values. A dielectric mixing model is used to relate the estimated dielectric constant to the amount of soil moisture. The Aquarius SCA uses Wang and Schmugge (1980) dielectric mixing model to estimate soil moisture.

3.3.1 Version History

The following table outlines the version history for this product.

Table 7. Version History Details

Version	Description
V5	Changes to this version include: Updated Version 5 Aquarius brightness temperature data were used as input File-level metadata were modified to more closely align with Climate and Forecast (CF) metadata conventions
V4	Updated Version 4 Aquarius brightness temperature data were used as input

Version	Description
V3	Changes to this version include: Updated Version 3 Aquarius brightness temperature data were used as input Aquarius brightness temperatures are no longer re-calibrated before soil moisture retrievals as was done for Version 2 data Soil moisture observations are valid over a wider range of brightness temperatures compared to Version 2 data Updates to the soil moisture model parameters (b and ω).
V2	First public data release

3.4 Sensor or Instrument Description

Aquarius/SAC-D is a collaboration between NASA and the Argentinean space agency, Comisión Nacional de Actividades Espaciales (CONAE), with participation from Brazil, Canada, France, and Italy. The Aquarius instrument was built jointly by the NASA Jet Propulsion Laboratory and NASA Goddard Space Flight Center.

The Aquarius instrument includes three radiometers and one scatterometer. The soil moisture data are collected by the radiometers. The radiometers measure brightness temperature at 1.414 GHz in the horizontal and vertical polarizations (T_H and T_V). The scatterometer is a microwave radar sensor that measures backscatter for surface roughness corrections. The following table summarizes instrument characteristics.

Table 8. Aquarius Instrument Characteristics

Instrument	Characteristics
3 radiometers in push-broom alignment	Frequency: 1.413 GHz Band width: less than or equal to 26 MHz Swath width: 390 km Science data block period: 1.44 sec Footprints for beams: 74 km along track x 94 km cross track, 84 x 120 km, and 96 x 156 km, yielding a total cross track of 390 km. Beam incidence angles of 29.36, 38.49, and 46.29 degrees incident to the surface; beams point away from the sun
Scatterometer	Frequency: 1.26 GHz Band width: 4 MHz Swath width: 390 km Science data block period: 1.44 sec

SAC-D spacecraft Orbit Parameters:

- 98 minute sun-synchronous
- 6 p.m. ascending orbit, 6 a.m. descending orbit

- 657 km equatorial altitude (655 km minimum, 685 km maximum over the orbit)
- Ground-track repeat interval: Weekly, 103 orbits

4 REFERENCES AND RELATED PUBLICATIONS

Bindlish, Rajat, Thomas Jackson, Michael Cosh, Tianjie Zhao and Peggy O'Neill. 2014. Global Soil Moisture from the Aquarius/SAC-D Satellite: Description and Initial Assessment. *IEEE Geosciences and Remote Sensing Letters* (in print). doi 10.1109/LGRS.2014.2364151.

Bindlish, Rajat, and Thomas J. Jackson. 2013. *Aquarius Soil Moisture ATBD Users Guide, Version 2.0*. Beltsville, Maryland USA: USDA Hydrology and Remote Sensing Lab. (https://nsidc.org/sites/nsidc.org/files/files/data/aquarius/Aquarius-VSM-ATBD-UsersGuide.pdf, 315 KB).

Bindlish, Rajat, Thomas Jackson, Michael Cosh, Tianjie Zhao and Peggy O'Neill. 2015. Global Soil Moisture from the Aquarius Satellite: Description and Initial Assessment. *IEEE Geosciences and Remote Sensing Letters* 12(5):923-927.

Bindlish, Rajat, Thomas Jackson, Ruijing Sun, Michael Cosh, Simon Yueh, and Steve Dinardo. 2009. Combined Passive and Active Microwave Observations of Soil Moisture During CLASIC. *IEEE Geoscience and Remote Sensing Letters* 6(4).

Choudhury, B. J., T. J. Schmugge, A. Chang, and R. W Newton. 1979. Effect of Surface Roughness on the Microwave Emission from Soils, *Journal Geophysical Research* 84:5699–5706.

Jackson, Thomas J., et al. 2010. Validation of Advanced Microwave Scanning Radiometer Soil Moisture Products. *IEEE Transactions on Geoscience and Remote Sensing* 48(12).

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Jackson, T. J., and T. J Schmugge. 1991. Vegetation Effects on the Microwave Emission of Soils, *Remote Sensing of Environment* 36(3): 203–212.

Meissner, T., F. Wentz, D. LeVine and J. Scott. 2014. Addendum III to ATBD Version 3.0, Beltsville, Maryland USA: USDA Hydrology and Remote Sensing Lab.

Pratt, Frederick S. 2013. Aquarius Level-2 Soil Moisture Data Product. NASA Goddard Space Flight Center Aquarius Project Document AQ-014-PS-0021, Version 2.0.

Piepmeier, Jeffrey, Shannon Brown, Joel Gales, Liang Hong, Gary Lagerloef, David Le Vine, Paolo de Matthaeis, Thomas Meissner, Rajat Bindlish, and Thomas Jackson. 2013. *Aquarius Radiometer Post-Launch Calibration for Product Version 2.0*, Aquarius Project Document: AQ-014-PS-0015. ftp://podaac-ftp.jpl.nasa.gov/allData/aquarius/docs/v2/AQ-014-PS-0015_AquariusInstrumentCalibratrionDescriptionDocument.pdf.

Wang, J. R., and T. J. Schmugge. 1980. An Empirical Model for the Complex Dielectric Permittivity of Soils as a Function of Water Content, *IEEE Transactions on Geoscience and Remote Sensing* 18(4):288–295.

4.1 Related Data Collections

Aquarius Level-1 and Level-2 Sea Surface Salinity Data
SMAP Data Sets at NSIDC
AMSR-E/Aqua L2B Surface Soil Moisture, Ancillary Parms, & QC EASE-Grids, Version 2
AMSR-E/Aqua Daily L3 Surface Soil Moisture, Interpretive Parameters, & QC EASE-Grids, Version 2
AMSR-E Validation Soil Moisture Data
Aquarius L3 Gridded 1-Degree Soil Moisture Data
ESA Soil Moisture and Ocean Salinity (SMOS)
NASA Aquarius Level-2 Sea Surface Salinity & Wind Speed Data V4.0
Soil Moisture Product Using Aquarius/SAC-D Observations

4.2 Related Websites

Aquarius Web site at NASA Goddard Space Flight Center
Aquarius Data Web Site at NSIDC
Aquarius Web Site at PODAAC
SMAP Web Site at NSIDC
SMOS Website at ESA

5 CONTACTS AND ACKNOWLEDGMENTS

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Acknowledgments:

This work was funded by NASA under the Interagency agreement NNH10AN10I. Tianjie Zhao helped with development of the soil moisture algorithm. The support provided by Michael Cosh, Peggy O'Neill, Thomas Holmes and Wade Crow is acknowledged. We acknowledge the support provided by Gary Lagerloef, David Le Vine, Gene Feldman and the Aquarius Data Processing Segment (ADPS) group in the implementation of the Aquarius Soil moisture algorithm.

6 DOCUMENT INFORMATION

6.1 Publication Date

December 2013

6.2 Date Last Updated

September 2018