SMAP-ALGMS-SPEC-xxxx

Soil Moisture Active Passive (SMAP) Mission

Radiometer Level 1B_RFICAL Product Specification Document

Initial Version 1.0

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March 18, 2025

National Aeronautics and
Space Administration
Goddard Space Flight Center
Greenbelt, MD

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Product Specification Document

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1 INTRODUCTION

1.1 Identification

This is the Product Specification Document (PSD) for Level 1B RFICAL data for the Science Data System (SDS) of the Soil Moisture Active Passive (SMAP) project. The Level 1B_RFICAL product provides calibrated unaveraged estimates of time-ordered geolocated antenna temperatures, T_A, within the main beam, referenced to the feedhorn. Also included are associated calibration coefficients, radio frequency interference (RFI) flags and kurtosis values. This document applies to any standard Level 1B_RFICAL product acquired by the SMAP radiometer instrument.

1.2 Scope

This Product Specification Document describes the file format of the Radiometer Level 1B_RFICAL Product. Its intent is to elucidate the Radiometer Level 1B_RFICAL data structure and content for external software interfaces. The SMAP Science Data Management and Archive Plan provides a more comprehensive explanation of these data within the complete context of the SMAP instrument, algorithms, and software.

1.3 The SMAP Experiment

The Soil Moisture Active Passive (SMAP) mission has enhanced the accuracy and the resolution of space-based measurements of terrestrial soil moisture and freeze-thaw state. SMAP data products have had a noteworthy impact on multiple relevant and current Earth Science endeavors. These include:

- Understanding of the processes that link the terrestrial water, the energy, and the carbon cycles,
- Estimations of global water and energy fluxes over the land surfaces,
- Quantification of the net carbon flux in boreal landscapes
- Forecast skill of both weather and climate,
- Predictions and monitoring of natural disasters including floods, landslides, and droughts, and
- Predictions of agricultural productivity.

To provide these data, the SMAP mission deployed a satellite observatory in a near polar, sun synchronous orbit. The observatory houses an L-band radiometer that operates at 1.40 GHz and an L-band radar that operates at 1.26 GHz. The instruments share a rotating reflector antenna with a 6-meter aperture that scans over a 1000 km swath.

As the spacecraft flies from north to south on *descending* orbits, the SMAP instruments view Earth locations at approximately 06:00 local time. As the spacecraft flies from south to north, on *ascending* orbits, the SMAP instruments view Earth locations at approximately 18:00 local time. The spacecraft operates in a cycle of 117 repeatable orbits.

Each time that the spacecraft repeats the orbit cycle, the nadir path on the Earth's surface may not vary by more than 20 km. The flight plan enables scientists to collect data over any region of the Earth over seasonal and annual cycles and avoid diurnal variations. The combined flight pattern and viewing design enables the observatory to view almost all the Earth's land mass once every three days.

The SMAP radiometer records microwave emissions from the top 5 cm in the soil with a spatial resolution of about 40 km. Scientific applications based on radiometer measure in the same frequency range have established this approach as an accurate means to detect the presence or water in near surface soil.

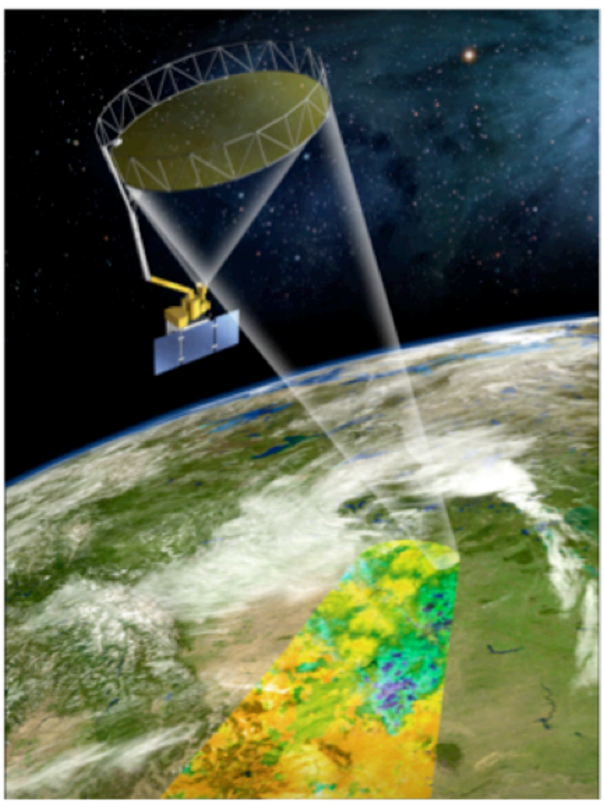

Figure 1: Artist's Concept of SMAP Observatory

The additional information will enable SMAP processors to select appropriate locations for soil moisture retrievals and modeling. In addition, the freeze/thaw data will contribute to models that measure the Net Ecosystem Exchange (NEE) of carbon between the Earth's surface and the atmosphere in Boreal regions.

1.4 SMAP Data Products

The SMAP mission currently generates 15 different distributable data products. The products represent four levels of data processing. Level 1 products contain instrument related data. Level 1 products appear in granules that are based on half orbits of the SMAP satellite. The Northernmost and Southernmost orbit locations demarcate half orbit boundaries. Level 2 products contain output from geophysical retrievals that are based on instrument data. Level 2 products also appear in half orbit granules. Level 3 products contain global output of the Level 2 geophysical retrievals for an entire day. Level 4 products contain output from geophysical models that employ SMAP data. The Radiometer L1B_RFICAL Product is an intermediate product which includes unaveraged antenna temperature data, calibration coefficients and RFI flags from the RFI detection algorithms.

Table 1 lists the distributable SMAP data products. The colors in the table categorize the products by level. The table specifies two sets of short names. The SMAP Mission product short names were adopted by the SMAP mission to identify products. Users will find those short names in SMAP mission documentation, SMAP product file names and in the product metadata. The Data Centers will use short names defined for the Earth Observing System Data and Information System (EOSDIS) Core System (ECS). These short names categorize data products in local databases managed by the ECS. ECS short names will also appear in SMAP product metadata.

SMAP Mission Product Short Name	ECS Short Names	Description
L1A_Radar	SPL1AA	Parsed Radar Instrument Telemetry
L1A_Radiometer	SPL1AP	Parsed Radiometer Instrument Telemetry
L1B_S0_LoRes	SPL1BS0	Low Resolution Radar σ_o in Time Order
L1C_S0_HiRes	SPL1CS0	High Resolution Radar σ_o on Swath Grid
L1B_TB	SPL1BTB	Radiometer T_B in Time Order
L1C_TB	SPL1CTB	Radiometer T_B
L2_SM_A	SPL2SMA	Radar Soil Moisture, includes Freeze/Thaw State
L2_SM_P	SPL2SMP	Radiometer Soil Moisture
L2_SM_AP	SPL2SMAP	Active-Passive Soil Moisture
L3_FT_A	SPL3FTA	Daily Global Composite Freeze/Thaw State
L3_SM_A	SPL3SMA	Daily Global Composite Radar Soil Moisture
L3_SM_P	SPL3SMP	Daily Global Composite Radiometer Soil Moisture
L3_SM_AP	SPL3SMAP	Daily Global Composite Active-Passive Soil Moisture
L4_SM	SPL4TSM	Surface and Root Zone Soil Moisture
L4_C	SPL4C	Carbon Net Ecosystem Exchange

Table 1: SMAP Data Products

1.5 Content Overview

The SMAP Level 1B_RFICAL data product contains a time-ordered geolocated series of unaveraged calibrated antenna temperatures within the main beam referenced to the feedhorn as well as measurements of the third and fourth Stokes parameters. The SMAP mission distributes this data product in half orbit granules. The northernmost and southernmost locations on the SMAP spacecraft path demarcate granule boundaries.

SMAP orbits begin at the southernmost point on the orbit path. The SMAP spacecraft launched into orbit 0. Orbit 1 began as the spacecraft crossed the southernmost location for the first time. The SMAP radiometer instrument gathers instrument data whenever the instrument is on. Based on acquired thermal emissions from the Earth's surface, the radiometer performs sub-channelization, cross-correlation for measurement of the 3rd and 4th Stokes parameters, as well as detection and integration of the first four raw moments of the horizontal and vertical polarization signals. These data are packetized and sent to the ground for calibration and further processing.

Each set of data is associated with a PRI/packet of radiometer counts. For every pulse repetition interval (PRI) of the radar, the radiometer integrates ~300 μs within the receive window. The exact integration time varies based on the radar PRI length and blanking time length chosen by the instrument designers. Radiometer packets are made up of 4 PRIs. Each science data packet includes both fullband data for each of the four PRIs as well as subbanded data, which have been further integrated into 4 PRIs or ~1.2 ms.

The SMAP Level 1B_RFICAL data product is an intermediate product of the Radiometer L1B_TB processing. It contains calibrated unaveraged antenna temperatures (TAs) which are inputs to the radio frequency interference detection and mitigation algorithms. The product includes both the fullband (24-MHz wide) and 16 subband (each 1.5 MHz wide) unaveraged TAs for both polarizations and the 3rd and 4th Stokes parameters. Also included are fullband and subband kurtosis values for both polarizations.

The RFI detection methods implemented on both fullband and subband data include kurtosis detection and polarimetric detection using the 3rd and 4th Stokes parameters. Pulse detection is implemented on the fullband data while cross-frequency is implemented on subband data. RFI flags from the detection algorithms are combined with a logical OR and used to exclude pixels in the time/frequency footprint before averaging. RFI flags from the individual detection algorithms, the combined RFI flag, and calibration coefficients are part of the RFICAL product. Some products from the footprint averaged Radiometer L1B_TB product, are also included such as top of the ionosphere, top of the atmosphere footprints and geolocation. A user can essentially derive the SMAP L1B_TB brightness temperatures with the information in the RFICAL product.

1.6 Related SMAP Project Documents

SMAP L1B_TB Algorithm Theoretical Basis Document, J. Piepmeier, GSFC SMAP-ALGMS-RPT-0026, May 31, 2012.

SMAP Science Data Management and Archive Plan, JPL D-45973, August 29, 2011.

SMAP Pointing, Positioning, Phasing and Coordinate Systems, Volume 0: Definitions and Principle Coordinate Systems, JPL D-46018, Initial Release, May 18, 2010

1.7 Applicable Documents

ISO 19115:2003(E) International Standard – Geographic Information – Metadata, May 1, 2003.

ISO 19115-2:2009 International Standard – Geographic Information – Part 2:Extensions for imagery and gridded data, December 12, 2009.

ISO 19139:2007 International Standard – Geographic Information – Metadata – XML schema implementation, May 14 2009.

Introduction to HDF5, The HDF Group, http://www.hdfgroup.org/HDF5/doc/H5.intro.html.

HDF5: API Specification Reference Manual, The HDF Group http://www.hdfgroup.org/HDF5/doc/RM/RM_H5Front.html

HDF5 User's Guide Release 1.8.9, The HDF Group, http://hdfgroup.com/HDF5/doc/UG, May 2012.

NetCDF Climate and Forecast (CF) Metadata Conventions, Version 1.6, December 5, 2011.

EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets, Brodzik, M.J., et. al., National Snow and Ice Data Center, Cooperative Institute of Environmental Sciences, University of Colorado, ISPRS International Journal of Geo-Information, ISSN 2220-9964, DOI: 10.3390/igji1010032.

2 DATA PRODUCT ORGANIZATION

2.1 File Format

All SMAP standard products are in the Hierarchical Data Format version 5 (HDF5). HDF5 is a general-purpose file format and programming library for storing scientific data. The National Center for Supercomputing Applications (NCSA) at the University of Illinois developed HDF to help scientists share data regardless of the source. Use of the HDF library enables users to read HDF files on multiple platforms regardless of the architecture the platforms use to represent integer and floating-point numbers. HDF files are equally accessible to routines written either in Fortran, C or C++.

A spin-off organization of the NCSA, named The HDF Group, is responsible for development and maintenance of HDF. Users should reference The HDF Group website at http://www.hdfgroup.org to download HDF software and documentation.

2.2 HDF5 Notation

HDF5 represents a significant departure from the conventions of previous versions of HDF. The changes that appear in HDF5 provide flexibility to overcome many of the limitations of previous releases. The basic building blocks have been largely redefined and are more powerful but less numerous. The key concepts of the HDF5 Abstract Data Model are Files, Groups, Datasets, Datatypes, Attributes and Property Lists. The following sections provide a brief description of each of these key HDF5 concepts.

2.2.1 HDF5 File

A File is the abstract representation of a physical data file. Files are containers for HDF5 Objects. These Objects include Groups, Datasets, and Datatypes.

2.2.2 HDF5 Group

Groups provide a means to organize the HDF5 Objects in HDF5 Files. Groups are containers for other Objects, including Datasets, named Datatypes and other Groups. In that sense, groups are analogous to directories that are used to categorize and classify files in standard operating systems.

The notation for files is identical to the notation used for Unix directories. The root Group is “/”. A Group contained in root might be called “/myGroup.” Like Unix directories, Objects appear in Groups through “links”. Thus, the same Object can simultaneously be in multiple Groups.

2.2.3 HDF5 Dataset

The Dataset is the HDF5 component that stores user data. Each Dataset associates with a Dataspace that describes the data dimensions, as well as a Datatype that describes the basic unit of storage element. A Dataset can also have Attributes.

2.2.4 HDF5 Datatype

A Datatype describes a unit of data storage for Datasets and Attributes. Datatypes are subdivided into Atomic and Composite Types.

Atomic Datatypes are analogous to simple basic types in most programming languages. HDF5 Atomic Datatypes include Time, Bitfield, String, Reference, Opaque, Integer, and Float. Each atomic type has a specific set of properties. Examples of the properties associated with Atomic Datatypes are:

- Integers are assigned size, precision, offset, pad byte order, and are designated as signed or unsigned.
- Strings can be fixed or variable length and may or may not be null-terminated.
- References are constructs within HDF5 Files that point to other HDF5 Objects in the same file.

HDF5 provides a large set of predefined Atomic Datatypes. Table 2 lists the Atomic Datatypes that are used in SMAP data products.

Table 2: HDF5 Atomic Datatypes

HDF5 Atomic Datatypes	Description
H5T_STD_U8LE	unsigned, 8-bit, little-endian integer
H5T_STD_U16LE	unsigned, 16-bit, little-endian integer
H5T_STD_U32LE	unsigned, 32-bit, little-endian integer
H5T_STD_U64LE	unsigned, 64-bit, little-endian integer
H5T_STD_I8LE	signed, 8-bit, little-endian integer
H5T_STD_I16LE	signed, 16-bit, little-endian integer

HDF5 Atomic Datatypes	Description
H5T_STD_I32LE	signed, 32-bit, little-endian integer
H5T_STD_I64LE	Signed, 64-bit, little-endian integer
H5T_IEEE_F32LE	32-bit, little-endian, IEEE floating point
H5T_IEEE_F64LE	64-bit, little-endian, IEEE floating point
H5T_C_S1	character string made up of one or more bytes

Composite Datatypes incorporate sets of Atomic datatypes. Composite Datatypes include Array, Enumeration, Variable Length and Compound.

- The Array Datatype defines a multi-dimensional array that can be accessed atomically.
- Variable Length presents a 1-D array element of variable length. Variable Length Datatypes are useful as building blocks of ragged arrays.
- Compound Datatypes are composed of named fields, each of which may be dissimilar Datatypes. Compound Datatypes are conceptually equivalent to structures in the C programming language.

Named Datatypes are explicitly stored as Objects within an HDF5 File. Named Datatypes provide a means to share Datatypes among Objects. Datatypes that are not explicitly stored as Named Datatypes are stored implicitly. They are stored separately for each Dataset or Attribute they describe.

None of the SMAP data products employ Enumeration or Compound data types.

2.2.5 HDF5 Dataspace

A Dataspace describes the rank and dimension of a Dataset or Attribute. For example, a “Scalar” Dataspace has a rank of 1 and a dimension of 1. Thus, all subsequent references to “Scalar” Dataspace in this document imply a single dimensional array with a single element.

Dataspaces provide considerable flexibility to HDF5 products. They incorporate the means to subset associated Datasets along any or all their dimensions. When associated with specific properties, Dataspaces also provide the means for Datasets to expand as the application requires.

2.2.6 HDF5 Attribute

An Attribute is a small aggregate of data that describes Groups or Datasets. Like Datasets, Attributes are also associated with a particular Dataspace and Datatype. Attributes cannot be subsetted or extended. Attributes themselves cannot have Attributes.

2.3 SMAP File Organization

2.3.1 Structure

SMAP data products follow a common convention for all HDF5 Files. Use of this convention provides uniformity of data access and interpretation.

The SMAP Project uses HDF5 Groups to provide an additional level of data organization. All metadata that pertain to the complete data granule are members of the “/Metadata” Group. All other data are organized within Groups that are designed specifically to handle the structure and content of each data product.

2.3.2 Data

All data in HDF5 files are stored in individual Datasets. All the Datasets in an SMAP product are assigned to an HDF5 Group. A standard field name is associated with each Dataset. The field name is a unique string identifier. The field name corresponds to the name of the data element the Dataset stores. This document lists these names with the description of each data element that they identify.

Each Dataset is associated with an HDF5 Dataspace and an HDF5 Datatype. They provide a minimally sufficient set of parameters for reading the data using standard HDF5 tools.

2.3.3 Element Types

SMAP HDF5 employs the Data Attribute “Type” to classify every data field as a specific data type. The “Type” is an embellishment upon the standard HDF5 Datatypes that is designed specifically to configure SMAP data products.

Table 3 lists all the “Type” strings that appear in the SMAP data products. The table maps each SMAP “Type” to a specific HDF5 Datatype in both the HDF5 file and in the data buffer. The table also specifies the common conceptual data type that corresponds to the “Type” in SMAP executable code.

Table 3: Element Type Definitions

Type	HDF5 Datatype (File)	HDF5 Datatype (Buffer)	Conceptual Type
Unsigned8	H5T_STD_U8LE	H5T_NATIVE_UCHAR	unsigned integer
Unsigned16	H5T_STD_U16LE	H5T_NATIVE_USHORT	unsigned integer
Unsigned24	H5T_STD_U16LE, with precision set to 24 bits, and size set to 3 bytes.	H5T_NATIVE_INT	unsigned integer
Unsigned32	H5T_STD_U32LE	H5T_NATIVE_UINT	unsigned integer
Unsigned64	H5T_STD_U64LE	H5T_NATIVE_ULLONG	unsigned integer
Signed8	H5T_STD_I8LE	H5T_NATIVE_SCHAR	signed integer
Signed16	H5T_STD_I16LE	H5T_NATIVE_SHORT	signed integer
Signed32	H5T_STD_I32LE	H5T_NATIVE_INT	signed integer
Signed64	H5T_STD_I64LE	H5T_NATIVE_LLONG	signed integer
Float32	H5T_IEEE_F32LE	H5T_NATIVE_FLOAT	floating point
Float64	H5T_IEEE_F64LE	H5T_NATIVE_DOUBLE	floating point
FixLenStr	H5T_C_S1	H5T_NATIVE_CHAR	character string
VarLenStr	H5T_C_S1, where	H5T_NATIVE_CHAR	character

Type	HDF5 Datatype (File)	HDF5 Datatype (Buffer)	Conceptual Type
	the length is set to H5T_VARIABLE		string

SMAP HDF5 files employ two different types of string representation. “VarLenStr” are strings of variable length. “VarLenStr” provides greater flexibility to represent character strings. To make SMAP HDF5 more friendly to users who wish to use netCDF software, SMAP products restrict the use of “VarLenStr”. “FixLenStr” are strings with a prescribed fixed-length. “FixLenStr” are useful for fixed length strings that are stored in large multi-dimension array. UTC time stamps are an excellent example of the type of data that store well in a “FixLenStr”.

2.3.4 File Level Metadata

All metadata that describe the full content of each granule of the SMAP data product are stored within the explicitly named “/Metadata” Group. SMAP metadata are handled using the same procedures as those that are used to handle SMAP data. The contents of each Attribute that stores metadata conform to one of the SMAP Types. Like data, each metadata element is also assigned a shape. Most metadata elements are stored as scalars. A few metadata elements are stored as arrays.

SMAP data products represent file level metadata in two forms. One form appears in one or more Attributes within the Metadata Group. Combined, those Attributes contain a complete representation of the product metadata. The content conforms to the ISO 19115-2 models in ISO 19139 compliant XML.

The second form of the metadata appears in a set of HDF5 Groups under the “/Metadata” Group. Each of these HDF5 Groups represents one of the major classes in the ISO 19115-2 model. These HDF5 Groups contain a set of HDF5 Attributes. Each HDF5 Attributes represents a specific ISO attribute of the associated ISO class. Although this representation inherits design from the ISO model, it does not completely conform to the model. In many cases, the names of the HDF5 Attributes match those used in the ISO model. In some situations, names were changed to provide greater clarity to SMAP users who are not familiar with the ISO model. Furthermore, to ease metadata searches, the structure of Groups within Groups was limited to four levels.

2.3.5 Local Metadata

SMAP standards incorporate additional metadata that describe each HDF5 Dataset within the HDF5 file. Each of these metadata elements appear in an HDF5 Attribute that is directly associated with the HDF5 Dataset. Wherever possible, these HDF5 Attributes employ names that conform to the Climate and Forecast (CF) conventions. Table 4 lists the CF names for the HDF5 Attributes that SMAP products typically employ.

Table 4: SMAP Specific Local Attributes

CF Compliant Attribute Name	Description	Required?
Units	Units of measure. Appendix E lists applicable units for various data elements in this product.	Yes
valid_max	The largest valid value for any element in the Dataset. The data type in valid_max matches the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding valid_max will also be float32.	No
valid_min	The smallest valid value for any element in the Dataset. The data type in valid_min matches the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding valid_min will also be float32.	No
_FillValue	Specification of the value that will appear in the Dataset when an element is missing or undefined. The data type of _FillValue matches the type of the associated Dataset. Thus, if the associated Dataset stores float32 values, the corresponding _FillValue will also be float32.	Yes for all numeric data types
long_name	A descriptive name that clearly describes the content of the associated Dataset.	Yes
coordinates	Identifies auxiliary coordinate variables in the data product.	No

CF Compliant Attribute Name	Description	Required?
flag_values	Provides a list of flag values that appear in bit flag variables. Should be used in conjunction with local HDF5 attribute *flag_meanings*. Only appears with bit flag variables.	No
flag_masks	Provides a list of bit fields that express Boolean or enumerated flags. Only appears with bit flag variables or enumerated data types.	No
flag_meanings	Provides descriptive words or phrases for each potential bit flag value. Should be used in conjunction with local HDF5 attribute *flag_values*.	No

2.4 Data Definition Standards

Section 4.6 of this document specifies the characteristics and definitions of every data element stored in this SMAP data product. Table 5 defines each of the specific characteristics that are listed in that section of this document. Some of these characteristics correspond with the SMAP HDF5 Attributes that are associated with each Dataset. Data element characteristics that correspond to SMAP HDF5 Attributes bear the same name. The remaining characteristics are descriptive data that help users better understand the data product content.

In some situations, a standard characteristic may not apply to a data element. In those cases, the field contains the character string 'n/a'. Hexadecimal representation sometimes indicates data content more clearly. Numbers represented in hexadecimal begin with the character string '0x'.

Table 5: Data Element Characteristic Definitions

Characteristic	Definition
Type	The data representation of the element within the storage medium. The storage class specification must conform to a valid SMAP type. The first column in table 3 lists all of the valid values that correspond to this characteristic.

Characteristic	Definition
Shape	The name of the shape data element that specifies the rank and dimension of a particular data set. Appendix C lists all of the valid shapes that appear in this data product.
Valid_max	The expected minimum value for a data element. In most instances, data element values never fall below this limit. However, some data elements, particularly when they do not reflect normal geophysical conditions, may contain values that fall below this limit.
Valid_min	The expected maximum value for a data element. In most instances, data element values never exceed this limit. However, some data elements, particularly when they do not reflect normal geophysical conditions, may contain values that exceed this limit.
Valid Values	Some data elements may store a restricted set of values. In those instances, this listing specifies the values that the data element may store.
Nominal Value	Some data elements have an expected value. In those instances, this listing provides that expected value. Nominal values are particularly common among a subset of the metadata elements.
String Length	This characteristic specifies the length of the data string that represents a single instance of the data element. This characteristic appears exclusively for data elements of FixLenStr type.
Units	Units of measure. Typical values include “deg”, “degC”, “Kelvins”, “m/s”, “m”, “m**2”, “s” and “counts”. Appendix A and Appendix E include references to important data measurement unit symbols.

2.4.1 Double Precision Time Variables

SMAP double precision time variables contain measurements relative to the J2000 epoch. Thus, these variables represent a real number of Standard International (SI) compatible seconds since 11:58:55.816 on January 1, 2000 UTC.

2.4.2 Array Representation

This document employs array notation to demonstrate and clarify the correspondence among data elements in different product data elements. The array notation adopted in this document is similar to the standards of the Fortran programming language. Indices are one based. Thus, the first index in each dimension is one. This convention is unlike C or C++, where the initial index in each dimension is zero. In multidimensional arrays, the leftmost subscript index changes most rapidly. Thus, in this document, array elements ARRAY (15,1,5) and ARRAY (16,1,5) are stored contiguously.

HDF5 is designed to read data seamlessly regardless of the computer language used to write an application. Thus, elements that are contiguous using the dimension notation in this document will appear in contiguous locations in arrays for reading applications in any language with an HDF5 interface.

This document differentiates among array indices based on relative contiguity of storage of elements referenced with consecutive numbers in that index position. A faster or fastest moving index implies that the elements with consecutive numbers in that index position are stored in relative proximity in memory. A slower or slowest moving index implies that the elements referenced with consecutive indices are stored more remotely in memory. For instance, given array element ARRAY (15,1,5) in Fortran, the first index is the fastest moving index, and the third index is the slowest moving index. On the other hand, given array element array [4][0][14] in C, the first index is the slowest moving index, and the third index is the fastest moving index.

3 INTERFACE CHARACTERISTICS

3.1 Coordinate Systems

The SMAP mission will use the Science Orbit Reference Frame (SRF) and the Earth Centered Rotating (ECR) coordinate systems to represent spacecraft attitude, position, and relative motion.

The Science Orbit Reference Frame (SRF) is a right-handed coordinate system with its three axes mutually orthogonal. The SRF is defined such that the origin is at the spacecraft center of mass (CM). The +Z axis points toward Geodetic Nadir. Due to the oblateness of the Earth, the vector from the spacecraft to the geometric center of the Earth (Geocentric Nadir) is different from the vector from the spacecraft to the local WGS84 ellipsoid normal (Geodetic Nadir). The +X axis is coplanar with both the +Z axis and the spacecraft inertial velocity vector. The +X axis closely adheres to the direction of the spacecraft inertial velocity vector. The +Y axis completes the right-handed, orthogonal coordinate system. The +Y axis is normal to the orbit plane with positive sense in the direction opposite the orbit angular momentum vector.

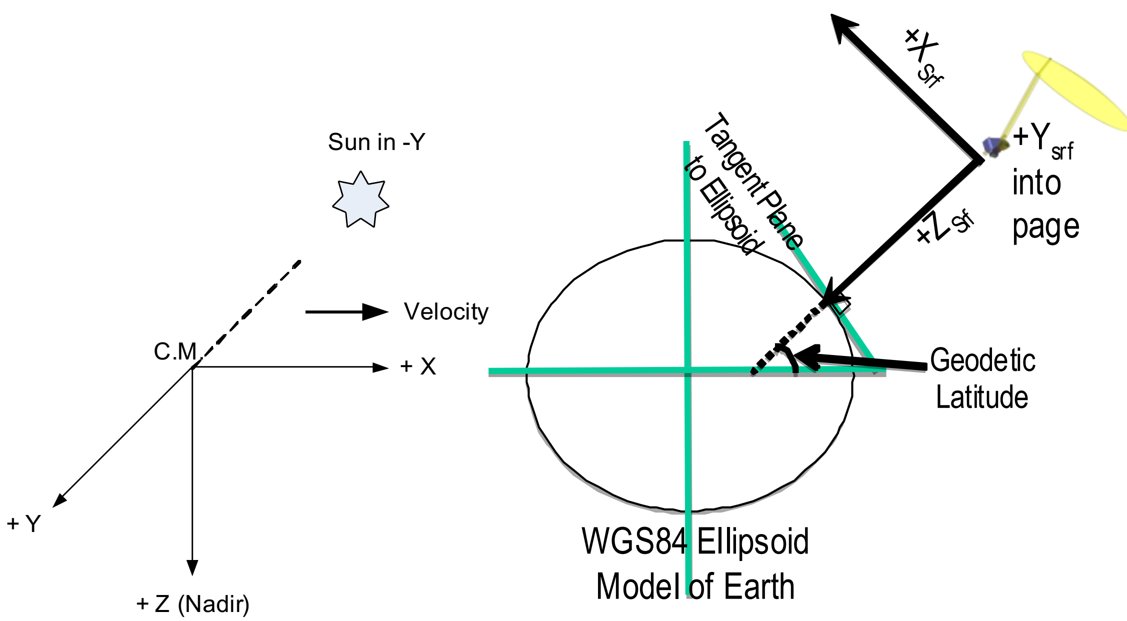

Figure 2: The Science Reference Frame Coordinate System

The Earth Centered Rotating (ECR) or Earth Centered Fixed coordinate system is a right-handed coordinate system with three mutually orthogonal axes. The origin of the system is the Earth's center of mass. The positive x-axis extends from the origin through the intersection of the Equator at 0° latitude and the Greenwich Meridian at 0° longitude. The positive z-axis extends directly North from the origin of the ECR system. Due to a slight wobbling of the Earth, the z-axis does not coincide exactly with the instantaneous rotation axis of the Earth. The y-axis completes the right- handed coordinate system as a vector from the origin to the intersection of the Equator and 90° East longitude.

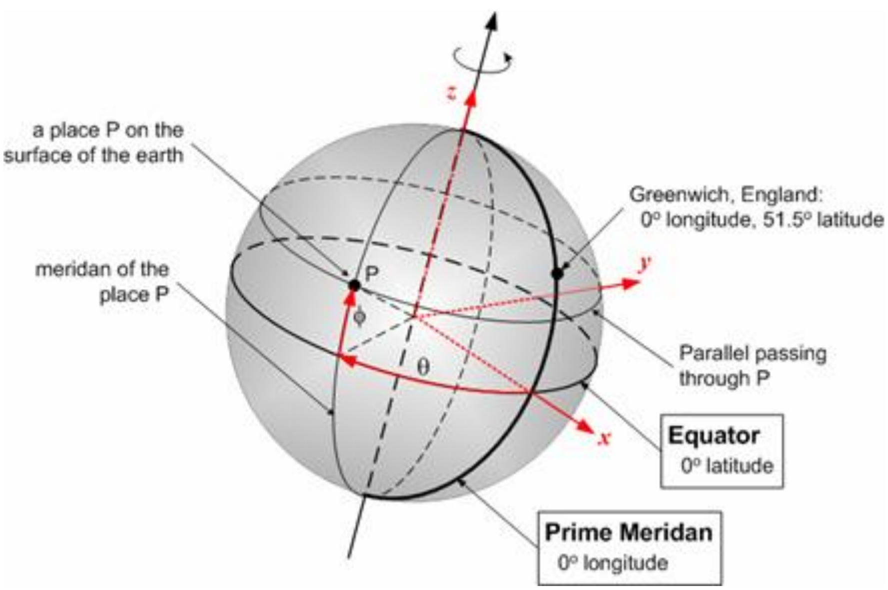

Figure 3: Earth Centered Rotating Coordinate System

The SMAP mission adopted the World Reference System WGS84 ellipsoid to define the horizontal Earth reference coordinates. The WGS84 geoid was adopted as the vertical Earth reference coordinates. Geodetic measure is used to define both the spacecraft location and the instrument target location relative to the Earth's surface.

3.2 Spacecraft Attitude

The SMAP SDS receives spacecraft attitude data on a regular basis from the Navigation and Ancillary Information Facility (NAIF) at JPL. Upon arrival from NAIF, these data specify the orientation of the Spacecraft Coordinate System with respect to J2000 coordinates. The NAIF data are represented in quaternions.

The attitude angles (pitch, roll and yaw) of the spacecraft are referred to the Science Orbit Reference Frame (SRF). They are measured in a counterclockwise direction and should be depicted as the angles between the

SRF and the INSF. A slight offset (measured before launch) between the INSF and the Spacecraft Coordinate system (SC) is included in the values of pitch, roll and yaw. The SC is equivalent to the SRF defined above, except that the SRF's +Z axis points toward Nadir (the SC's points toward Zenith) and the +/- Y axes are switched.

The attitude angles are measured in a counterclockwise direction (as seen from the origin of the axes looking toward the positive ends) around the rotation axis. Because of the unfortunate choice of definitions for the INSF and SRF, the common definition of euler angles would yield large values for pitch and for roll (about 180 deg). The angles are therefore defined to be the angle, measured counterclockwise from each one of the SRF axis, to the corresponding INSF axis AFTER THE SRF HAS BEEN ROTATED 180 deg AROUND THE SRF's +X AXIS.

- The pitch angle is the rotation around the +Y axis, with positive values indicating that the +X axis moves toward the +Z direction. The pitch angle is 0 when the +X axis of the INSF is aligned with the tangent to the orbit path and the nominal velocity vector. For +90 deg pitch, +X and +Z change place, and +Z and –X change place. A passenger standing on the SMAP would experience a positive pitch angle as a raising of the SMAP 'nose'.
- The roll angle is the rotation around the +X axis, with positive values indicating that the +Z axis moves toward the +Y direction. The roll angle is 0 when the Y axis of the INSF is perpendicular to the plane of the orbit and the +Z axis points to zenith. For +90 deg roll, +Z and +Y change place, and +Y and –Z change place. A passenger standing on the SMAP would experience a positive roll angle as a tilting of the SMAP to port.
- The yaw angle is the rotation around the +Z axis, with positive values indicating that the +Y axis moves toward the +X direction. The yaw angle is 0 when the +X axis of the INSF is pointed along the nominal velocity vector. For +90 deg yaw, +Y and +X change place, and +X and –Y change place. A passenger standing on the SMAP would experience a positive yaw angle as a pointing of the SMAP to the right of the orbital track.

The Science Orbit Reference Frame (SRF) and the Instrument Fixed Frame (INSF) and the Spacecraft Coordinate (SC) systems are defined and fully described in the SMAP Pointing, Positioning, Phasing and Coordinate System Volume 0, Revision B, April 15, 2014

During nominal operations, the pitch, yaw and roll angles will be very small. Indeed, to retain anticipated incidence angles for radar and radiometer measure, these angles will almost always be less than 1 degree. The order of rotation that users should employ is pitch, followed by roll and then yaw.

3.3 Fill and Gap Values

SMAP data products employ fill and gap values to indicate when no valid data appear in a particular data element. Fill values ensure that data elements retain the correct shape. Gap values locate portions of a data stream that do not appear in the output data file.

The total number of science packets or PRIs per scan varies depending on the antenna rotation rate and integration time of the instrument. Each science packet contains data in one of 5 radiometric states and the data is parsed and stored in this manner. To preserve the shape of the stored data elements, the size of certain dimensions is assigned a maximum value. Thus, fill values appear in the SMAP L1A Radiometer Product when data in a particular radiometric state does not call for the maximum number of packets or PRIs per antenna rotation. Those elements with indices that do not contain recorded data contain fill values.

SMAP data products employ a specific set of data values to connote that an element is fill. The selected values that represent fill are dependent on the data type. Table 6 lists the values that represent fill in SMAP products based on data type:

Table 6: SMAP Product Fill Values

Type	Value	Pattern
Float32, Float64	-999999	Large, negative number
Signed8, NormSigned8	-127	Type minimum + 1
Signed16, NormSigned16	-32767	Type minimum + 1
Signed24	-8388607	Type minimum + 1
Signed32	-2147483647	Type minimum + 1
Signed64	-9223372036854775807	Type minimum + 1
Unsigned8	254	Type maximum - 1
Unsigned16	65534	Type maximum - 1

Type	Value	Pattern
Unsigned24	16777214	Type maximum - 1
Unsigned32	4294967294	Type maximum - 1
Unsigned64	18446744073709551614	Type maximum - 1
FixedLenString, VarLenString	NA	Not available

No valid value in the L1B_RFICAL product is equal to the values that represent fill. If any exceptions should exist in the future, the L1B_RFICAL content will provide a means for users to discern between elements that contain fill and elements that contain genuine data values. This document will also contain a description of the method used to ascertain which elements are fill and which elements are genuine.

3.4 Flexible Data Design

HDF5 format gives the SMAP Level Products a high degree of flexibility. This flexibility in turn gives SMAP end-product users the capability to write software that does not need to be modified to accommodate unforeseeable changes in the SMAP products. Since changes to the products are certain to take place over the life of the SMAP mission, users are encouraged to use software techniques that take advantage of some of the features in HDF5.

For example, users can write a product reader that selects only those product data elements they wish to read from an SMAP Level Product file. With the appropriate design, this software will not need to change, regardless of the number, the size, or the order of the current data product entries. Indeed, the only changes users need to implement would take place if they should choose to read a newly defined data element after a product upgrade.

For those users who wish to extract a specific subset of the data from an SMAP Product, the HDF5 routines H5Dopen and H5Dread (h5dopen_f and h5dread_f in FORTRAN) are very useful. H5Dopen requires two input parameters, the first is an HDF5 file/group identifier, the second is a character string that contains the name of a Dataset. H5Dopen returns the identifier for the specified Dataset in the product file. HDF5 routine H5Dread then uses the Dataset identifier to fetch the contents. H5Dread places the contents of the Dataset in a specified output variable.

Once the data element is located and read, users can generate standardized code that reads the metadata associated with each element. Users of the SMAP Level Products should employ the same methods to read metadata and standard data elements.

3.5 Access to Product Element Dimensions

Each data element in every SMAP data product is assigned a specific shape. Elements with the same shape have the same number of dimensions, and each of those dimensions have the same extent and meaning. Thus, if two data elements have the same shape, then their constituent array elements with identical indices correspond.

The SMAP L1B_RFICAL Product employs a naming convention for shapes. The convention specifies the component dimensions. The final word in all shape names is always “Array”. The text that precedes the word “Array” provides the order of dimensions. The word that just precedes “Array” represents the dimension with the “fastest moving” index. In other words, consecutive indices in this dimension, provided the other dimension indices are identical, represent contiguous storage. For example, the Shape name AntennaScan_AntPRI_Array implies that the dimension where consecutive indices imply contiguous storage represents antenna PRIs. The other, slower moving, dimension represents antenna scans. Appendix C provides the nominal rank and dimension sizes for each shape that appears in the L1B_RFICAL Product.

Appendix D provides the nominal or expected maximum product dimensions.

Appendix F contains an example of code that reads dimensions for a particular data element directly from the L1B_RFICAL Radiometer product.

4 DATA DEFINITION

4.1 Product Overview

4.1.1 Level 1B_RFICAL Product

Each Level 1B_RFICAL product granule incorporates all the radiometer data that were downlinked from the SMAP spacecraft for one specific half orbit. The SMAP project delineates half orbits at the northernmost and southernmost point of each orbit path.

The major contents of the Level 1B_RFICAL product include:

- Fullband and subband calibration gains and offsets.
- Fullband and subband antenna temperatures (TAs) and 3rd and 4th Stokes parameters calibrated to the feedhorn before RFI detection and mitigation.
- RFI flags for both fullband and subband detection algorithms including the logical OR of all flags.
- Fullband and subband kurtosis values.
- Geolocation for each footprint brightness temperature and for each unaveraged pixel for both fullband and subband data.

Elements in the Level 1B_RFICAL product appear in time order.

4.1.2 Level 1B_RFICAL Metadata

The SMAP Radiometer Level 1B_RFICAL metadata are representative of the entire contents of the file. The metadata appear in two forms. One form of the metadata appears in single HDF5 Attribute. That Attribute contains a subset of the product metadata that conforms to the ISO 19115-2 model in ISO 19139 compliant XML. The second form of the metadata appears in a set of HDF5 groups. Each HDF5 group contains a set of HDF5 attributes. The arrangement and names of the groups and their attribute components approximate major contents of the ISO model.

Metadata in ISO 19139 conformant XML enables users who are familiar with the ISO metadata standards to extract the metadata they need using software that operates with the ISO 19115-2 model and its formal representation. The set of groups and attributes enable users who are not as familiar with the ISO standard to find the metadata elements they need to better comprehend product content and format.

4.1.3 Radiometer Level 1B_RFICAL Data

All product elements in the Level 1B_RFICAL Product are stored as HDF5 Datasets. Each of these datasets belongs to one of three distinct HDF5 Groups. The data design employs HDF5 Groups to categorize datasets that have corresponding array elements and that relate to a common application.

The HDF5 Groups in the Level 1B_RFICAL product include the Fullband_MaxPD_Cal Group, the Fullband_RFI_Cal Group, the Geolocation Group, the Intermediary_Temperature_Data Group, the Subband_Footprint Group, the Subband_RFI_Cal Group and Metadata. Section 4.5 of this document includes more detailed descriptions of each of the HDF5 Groups in the data product.

All the Level 1B_RFICAL HDF5 Groups are organized relative to the SMAP antenna scan. All array elements with the same antenna scan index fall in the same antenna scan. Within each data granule, the time the spacecraft flew over any given antenna scan is a monotonically increasing function of the antenna scan index. Thus, a smaller antenna scan index represents an antenna scan that took place earlier during flight. A larger antenna scan index represents an antenna scan that took place later during flight.

4.2 Data Volume Estimates

L-band anthropogenic Radio Frequency Interference (RFI), from ground-based surveillance radars and many other ground-based transmitters, can contaminate radiometer measurements. Early measurements and results from the SMOS mission indicated that in some regions, RFI is present and detectable. The SMAP radiometer electronics and algorithms were designed to include features to mitigate the effects of RFI. To combat the RFI problem, the SMAP radiometer implements a combination of time and frequency diversity, kurtosis detection, and the use of 3rd and 4th Stokes parameter thresholds to detect and where possible filter RFI. Data elements associated with subbands are used to track and enable RFI detection and filtering. Since RFI was expected to be significantly less over the ocean, the algorithm did not initially require frequency diversity over this region. The radiometer was originally meant to operate in high-rate mode over land thereby including both fullband and subband data and low-rate mode over the ocean (except for a select region over the tropical Pacific for data calibration and validation) where only fullband data would be collected. However, soon after the radar failed on July 7, 2015, the radiometer began to operate in high-rate mode globally.

Table 7 provides users with an estimated average uncompressed volume of L1B_RFICAL products for high-rate mode globally. The volumetric estimate assumes an entire half orbit of high-rate data. The table specifies the contribution of each of the HDF5 data Groups to the total data volume of the product. The final row in each table provides an estimate of the volume of an average data granule.

Table 7: Data Volume Estimates for Data Acquired at 06:00 Local Time

Group	Number of Entries	Bytes Per Entry	Expected Total Volume (MBytes)
Level 1B_RFICAL Metadata	1	1000	0.001
XML Version of ISO Metadata	1	124000	0.124
Fullband_MaxPD_Cal	779	7724	6.017
Fullband_RFI_Cal	779	169884	132.340
Geolocation	779	3856	3.004
Intermediary_Temperature_Data	779	7712	6.008
Subband_Footprint	779	3856	3.004
Subband_RFI_Cal	779	1405784	1095.106
Level TB_RFICAL Product			1245.604

4.3 SMAP Level 1A_Radiometer Product File Names

Distributable SMAP L1B_RFICAL data product file names are 56 characters in length. The first 5 characters in the name of all mission distributable products are 'SMAP_'. These characters identify all products generated by the SMAP mission. The following 14 characters are always 'L1B_TB_RFICAL_'. These characters identify the Level 1B_RFICAL Data Product. The following 34 characters uniquely identify the data stored in the file. The final 3 characters of each SMAP Product file name are '.h5'. These characters specify the format of the data in the file.

More specifically, all SMAP L1B_RFICAL data product file names must conform to the following convention:

SMAP_L1B_TB_RFICAL_[Orbit Number]_[A|D]_[First Date/Time Stamp]_[Composite Release ID]_[Product Counter].[extension]

The outline below describes the content of each field in the file naming convention:

Orbit Number – The sequential number of the orbit that the SMAP spacecraft flew when the data in the associated product were acquired. Orbit 0 will begin at launch. The orbit number must occupy five digits. Orbit numbers that are smaller than 10000 will appear with leading zeroes.

The Half Orbit Designator - SMAP divides orbits into two distinct parts. Division of half orbits takes place at the northernmost and southernmost point on the spacecraft path. Half orbits where the spacecraft moves from North to South are *descending* half orbits. Local time for measurements acquired during a *descending* half orbit is approximately 6 AM. The character "D" appears as the Half Orbit Designator in the file names of products that contain data representing *descending* half orbits. Half orbits where the spacecraft moves from South to North are classified as *ascending* half orbits. Local time for measurements acquired during an *ascending* half orbit is approximately 6 PM. The character "A" appears as the Half Orbit Designator in the file names of products that contain data represent *ascending* half orbits.

First Date/Time Stamp – The date/time stamp of the first data element that appears in the product. Date/time stamps in SMAP file names are always recorded in Universal Coordinated Time (UTC). Date/time stamps conform to the following convention:

YYYYMMDD**T**hhmmss

where:

YYYY is the calendar year. The full calendar year must appear in the file name.

MM designates the month of the year. The month designator always occupies two digits. Months that can be represented with fewer than two digits must employ a leading zero.

DD designates the day of the month. The day designator always occupies two digits. Days of the month that can be represented with fewer than two digits must employ a leading zero.

T delineates the date from the time and is a required character in all time stamps in product names.

hh designates the hour of the day on a 24-hour clock in UTC. The hour designator always occupies two digits. Hours that can be represented with fewer than two digits must employ a leading zero.

mm designates the minute of the hour in UTC. The minute designator always occupies two digits. Minutes that can be represented with fewer than two digits must employ leading zeroes.

ss designates the truncated second of the minute in UTC. Fractional second specification is not necessary in file names. The second designator always occupies two digits. Seconds that can be represented with fewer than two digits must employ leading zeroes.

Composite Release ID – The Composite Release ID incorporates changes to any processing condition that might impact product results. The format of the Composite Release ID is as follows:

"R"	The character "R" always precedes this identifier
Launch indicator	Distinguishes between pre-launch or pre-instrument commissioned data and data generated under mission operation conditions. A launch indicator of "0" implies the data are simulated or acquired under early mission conditions that exempt the content from mission requirements. A launch indicator of "1" implies the data are acquired by the instrument at or after the time of instrument commissioning and must therefore meet mission requirements.
Major ID	One digit indicates major releases. Major changes in algorithm or processing approach will generate an update to this identifier.
Minor ID	Three digits indicate minor releases. Any change to any component that impacts data processing, such as algorithm, software or parameters will lead to a change in this identifier.

Product Counter – Files that represent the same half orbit of any product type may be generated multiple times over the life of the mission. This counter tracks the number of times that a particular product type for a specific half orbit was generated. The system assigns the first instance of a file that represents a half orbit of a particular product type with a Product Counter of 001. The system assigns each subsequent instance of the same half orbit and same product type with the next consecutive integer. The Product Counter always occupies three digits. Product Counters that do not require three digits contain leading zeroes.

Extension – The extension for all SMAP LB_RFICAL data products is "h5". That extension indicates that the product contents are in HDF5 format.

Example File Names – Based on the above standard, the following name describes a simulated data product from pre-launch release 4 of the Radiometer Level 1A data product that is labeled to cover the ascending half of orbit 934. The first data point acquired 7:49:51 UTC on December 25, 2014. The file represents the second time an L1A Radiometer product was generated for the ascending half of orbit 924:

`SMAP_ L1B_TB_RFICAL_00934_A_20141225T074951_R04000_002.h5`

4.4 L1B_RFICAL Product Metadata

As mentioned in section 4.1.2, the metadata elements in the Level 1B_RFICAL product appear in two forms. One form appears in one or more Attributes within the Metadata Group. Combined, those Attributes contain a complete representation of the product metadata. The content conforms to the ISO 19115-2 models in ISO 19139 compliant XML.

The second form of the metadata appears in a set of HDF5 groups under the Metadata Group. Each of these HDF5 Groups represents one of the major classes in the ISO structure. These groups contain a set of HDF5 attributes. Each HDF5 Attribute represents a specific ISO attribute of the associated ISO class. Although this representation inherits design from the ISO model, it does not completely conform to the model. In many cases, the names of the HDF5 Attributes match those used in the ISO model. In some situations, names were changed to provide greater clarity to SMAP users who are not familiar with the ISO model. Furthermore, to ease metadata searches, the structure of Groups within Groups was limited to four levels.

Table 8 describes the subgroups of the Metadata group, and the attributes within each group. The first column of Table 8 specifies a major class in the ISO 19115 metadata model. The second column provides the name of the HDF5 Group under “/Metadata” where attributes associated with the corresponding class will appear. The third column lists the names of the subgroups and attributes where specific metadata values appear. The fourth column provides valid values for each element. Constant values appear with no diacritical marks. Variable values are encapsulated by carats <>. All the metadata elements that appear in Table 8 should also appear in every Level 1B_RFICAL Product file.

Table 8: Granule Level Metadata in the Radiometer L1B_RFICAL Product

ISO Major Class	SMAP HDF5 Metadata SubGroup	Subgroup/Attribute in SMAP HDF5	Valid Values
EX_Extent	Extent	rangeBeginningDateTime	<Time stamp that indicates the initial time element in the product>
DS_Dataset/MD_DataIdentification	DataSetIdentification	fileName	<Name of the L1B_RFICAL output data file.>
		SMAPShortName	L1B_TB_RFICAL
SD_OrbitMeasuredLocation	OrbitMeasuredLocation	orbitDirection	<SMAP Level 1 and Level 2 products appear in half orbit granules. This element provides direction of orbital path relative to equatorial plane. Values are “ascending” or “descending”:>
		revNumber	<The count of orbits from beginning of mission to the orbit that the spacecraft flew when the data in the file were acquired. Orbit zero begins at launch and extends until the spacecraft crosses the southernmost point in its path for the first time. Orbit one commences at that instant.>

[1] The metadata will allocate a group for each input data set that requires provenance tracking. The most critical ones listed in this document are those that are likely to vary from one orbit granule to the next. The metadata will track and list additional files for user information.

4.5 Data Structure

4.5.1 Subband RFI Cal Group

The Subband RFI Cal Group provides the time ordered unaveraged brightness temperatures (TAs) for 16 subbands referenced to the feedhorn without error sources removed and before radio frequency interference filtering. The 3rd and 4th Stokes parameters of the two polarizations are also included for each of the 16 subbands. In addition, the group contains geolocation information, RFI flags, kurtosis values, and gain and offset values used in TA calibration.

The Subband RFI Cal Group includes the RFI flags for the reference and reference plus noise diode counts. To prevent radio frequency interference from impacting calibration, the RFI detection and removal algorithms are implemented on the reference and reference plus noise diode counts. The cross frequency and kurtosis subband RFI detection algorithms operates on 16 spectral subbands with integration time of ~1.2 ms or 4 pulse repetition intervals (PRIs) of reference and reference plus noise diode second moments data. The logical OR operation uses only subband RFI flags to produce a composite subband RFI flag. In the flag arrays, data flagged as RFI is indicated by 1 and data without RFI or data fillers such as -9999.0 are indicated as 0. The RFI flags provide both vertical and horizontal polarizations and are separately expressed in terms of the in-phase (real) and quadrature (imaginary) components of the signals. All the fullband and subband RFI detection algorithms use the unaveraged TAs of the fullband and subband data respectively to flag RFI. The fullband and subband RFI flags are combined in a logical OR to create a combined flag for the time/frequency footprint. The Subband RFI Cal Group contains these RFI flags for the unaveraged TAs.

All the product elements in the Subband RFI Cal Group are stored in a single HDF5 Group named “/Subband_RFI_Cal”. A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Radiometer data include science data packets that are generated once every 4 PRIs. Table 9 lists the elements in the Subband RFI Cal Group.

The data elements in the Subband RFI Cal Group have varying shapes depending on the information stored. For example, the AntennaScan_AntPacket_Subband_Polarization_Array shape describes a 4-dimensional array. The slowest moving dimension represents a particular antenna scan. The second dimension represents the maximum number of antenna packets. The third dimension represents the 16 subbands. The fastest moving dimension represents one of two polarizations: the order of storage v, h. Elements with different second dimensions are associated with different radiometric states, and thus different maximum array sizes. Appendix B and Appendix C provide more detail about the shapes and dimension sizes used in the Radiometer L1B_TB RFICAL product.

Table 9: Subband RFI Cal Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
RFI_ref_flag	Bit flag	AntennaScan_RefPacket_Subband_Array	n/a	n/a	n/a
RFI_refnd_flag	Bit flag	AntennaScan_RefNdPacket_Subband_Array	n/a	n/a	n/a
kurt16_h	Float32	AntennaScan_AntPacket_Subband_Array	1	$1x10^{6}$	unitless
kurt16_v	Float32	AntennaScan_AntPacket_Subband_Array	1	$1x10^{6}$	unitless
subband_RFI_flag	Bit flag	AntennaScan_AntPacket_Subband_Array	n/a	n/a	n/a
subband_calibration_gain16	Float32	AntennaScan_AntPacket_Subband_Polarization_Array	0	$5.88x10^{18}$	Counts/Kelvin
subband_calibration_offset16	Float32	AntennaScan_AntPacket_Subband_Polarization_Array	0	$5.88x10^{18}$	Counts
subband_latitude	Float32	AntennaScan_AntPacket_Array	-90	90	Degrees
subband_longitude	Float32	AntennaScan_AntPacket_Array	-180	180	Degrees
ta16_3	Float32	AntennaScan_AntPacket_Subband_Array	-50	50	Kelvin
ta16_4	Float32	AntennaScan_AntPacket_Subband_Array	-50	50	Kelvin
ta16_h	Float32	AntennaScan_AntPacket_Subband_Array	0	310	Kelvin
ta16_v	Float32	AntennaScan_AntPacket_Subband_Array	0	310	Kelvin

4.5.2 Subband Footprint Group

The Subband Footprint Group provides the RFI flag from the cross-frequency algorithm that uses antenna temperatures averaged to 9.6 ms. The flag provides bits for both horizontal and vertical polarizations in that order. All the product elements in the Subband Footprint Group are stored in a single HDF5 Group named "/Subband_Footprint". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 10 lists the elements in the Subband Footprint Group.

The AntennaScan_Footprint_Subband_Array shape describes a 3-dimensional array. The slowest moving dimension represents a particular antenna scan. The second dimension represents the resolution of integrated data to 9.6 ms while the fastest moving dimension represents the subbands. Appendix B and Appendix C provide more detail about the shapes and dimension sizes used in the Level 1B_RFICAL product.

Table 10: Subband Footprint Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
subband_footprint_flag	Uint8	AntennaScan_Footprint_Subband_Array	n/a	n/a	n/a

4.5.3 Fullband RFI Cal Group

The Fullband RFI Cal Group contains similar information to that in the Subband RFI Cal Group except for the fullband signal which is data obtained for the entire 24 MHz radiometer bandwidth. All of the product elements in the Fullband RFI Cal Group are stored in a single HDF5 Group named “/Fullband_RFI_Cal”. A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 11 lists the elements in the Fullband RFI Cal Group.

The data elements in the Fullband RFI Cal Group have varying shapes depending on the type of data being stored. The data elements in the Fullband RFI Cal Group have varying shapes depending on the information stored. For example, the AntennaScan_AntPRI_Polarization_Array shape describes a 3-dimensional array. The slowest moving dimension represents a particular antenna scan. The second dimension represents the maximum number of antenna PRIs which are data averaged to ~300μs. The fastest moving dimension represents one of two polarizations: the order of storage v, h. See Table 11 for a detailed list of the Fullband RFI Cal Group.

Table 11: Fullband RFI Cal Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
RFI_ref_flag	Bit flag	AntennaScan_RefPRI_Array	n/a	n/a	n/a
RFI_refnd_flag	Bit flag	AntennaScan_RefNdPRI_Array	n/a	n/a	n/a
fullband_RFI_flag	Bit flag	AntennaScan_AntPRI_Array	n/a	n/a	n/a
fullband_calibration_gain	Float32	AntennaScan_AntPRI_Polarization_Array	0	5.88×10^{18}	Counts/Kelvin
fullband_calibration_offset	Float32	AntennaScan_AntPRI_Polarization_Array	0	5.88×10^{18}	Counts

fullband_kurt_h	Float32	AntennaScan_AntPRI_Array	1	$1x10^6$	unitless
fullband_kurt_v	Float32	AntennaScan_AntPRI_Array	1	$1x10^6$	unitless
fullband_latitude	Float32	AntennaScan_AntPRI_Array	-90	90	Degrees
fullband_longitude	Float32	AntennaScan_AntPRI_Array	-180	180	Degrees
fullband_ta_3	Float32	AntennaScan_AntPRI_Array	-50	50	Kelvin
fullband_ta_4	Float32	AntennaScan_AntPRI_Array	-50	50	Kelvin
fullband_ta_h	Float32	AntennaScan_AntPRI_Array	0	310	Kelvin
fullband_ta_v	Float32	AntennaScan_AntPRI_Array	0	310	Kelvin

4.5.4 Fullband MaxPD Cal Group

The Fullband MaxPD Cal Group contains a 3-bit RFI flag which is a logical OR of all the fullband RFI flags when subband data is not present. Before the radar failed, the radiometer operated in a high-rate mode where both fullband and subband data streams were obtained over land and only fullband data over the ocean. Once the radar failed, the radiometer data began to operate in high-rate mode globally. All the product elements in the Fullband RFI Cal Group are stored in a single HDF5 Group named “/Fullband_MaxPD_Cal”. A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 12 lists the elements in the Fullband MaxPD Cal Group. The AntennaScan_AntPRI_Array shape describes a 2-dimensional array. The slowest moving dimension represents a particular antenna scan. The second dimension represents the maximum number of antenna PRIs.

Table 12: Fullband RFI Cal Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
fullband_MaxPD_flag	Bit flag	AntennaScan_AntPRI_Array	n/a	n/a	n/a

4.5.5 Intermediary Temperature Data Group

The Intermediary Temperature Data Group provides the time ordered footprint averaged antenna temperatures (TAs) referenced to the feedhorn after RFI detection and filtering without error sources removed.

All the product elements in the Brightness Temperature Group are stored in a single HDF5 Group named "/Intermediary_Temperature_Data". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 13 lists the elements in the Intermediary Temperature Data Group.

All the data elements in the Intermediary Temperature Data Group have the AntennaScan_Tb_Array shape. The AntennaScan_Tb_Array shape describes a 2-dimensional array. The slowest moving dimension represents a particular antenna scan, and the second dimension represents the footprint.

Table 13: Intermediary Temperature Data Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
tap_toa_3	Float32	AntennaScan_Tb_Array	-50	50	Kelvin
tap_toa_4	Float32	AntennaScan_Tb_Array	-50	50	Kelvin
tap_toa_h	Float32	AntennaScan_Tb_Array	0	310	Kelvin

tap_toa_v	Float32	AntennaScan_Tb_Array	0	310	Kelvin
tap_toi_3	Float32	AntennaScan_Tb_Array	-50	50	Kelvin
tap_toi_4	Float32	AntennaScan_Tb_Array	-50	50	Kelvin
tap_toi_h	Float32	AntennaScan_Tb_Array	0	310	Kelvin
tap_toi_v	Float32	AntennaScan_Tb_Array	0	310	Kelvin

4.5.6 Geolocation Group

The Geolocation Group provides latitude and longitude for the time ordered footprints and the antenna azimuth and scan angles. All the product elements in the Geolocation Group are stored in a single HDF5 Group named "/Geolocation". A distinct HDF5 Dataset stores each data element. The name of each Dataset object matches the data element that it stores. Table 14 lists the elements in the Geolocation Group.

All the data elements in the Geolocation Group have the AntennaScan_Tb_Array shape which describes a 2-dimensional array. The slowest moving dimension represents a particular antenna scan, and the second dimension represents the footprint.

Table 14: Geolocation Group

Element Name	Type	Shape	Valid_Min	Valid_Max	Units
antenna_azimuth_angle	Float32	AntennaScan_Tb_Array	0	359.999	degrees
antenna_scan_angle	Float32	AntennaScan_Tb_Array	0	359.999	degrees

tb_lat	Float32	AntennaScan_Tb_Array	-90	90	degrees
tb_lon	Float32	AntennaScan_Tb_Array	-180	179.999	degrees

4.6 Element Definitions

4.6.1 RFI_ref_flag (Subband_RFI_Cal)

RFI flags indicate which pixels have been flagged by the cross frequency and subband kurtosis RFI detection algorithms for the subband reference counts. Table 15 specifies the meaning of individual bits in the *RFI_ref_flag*.

Table 15: RFI_ref_flag

Bits	Value	Interpretation
0		**V-pol in phase cross-frequency detection**
	0	RFI not detected
	1	RFI detected
1		**V-pol quadrature cross-frequency detection**
	0	RFI not detected
	1	RFI detected
2-5		**Undefined**
6		**H-pol in phase cross-frequency detection**
	0	RFI not detected
	1	RFI detected
7		**H-pol quadrature cross-frequency detection**
	0	RFI not detected
	1	RFI detected
8		**V-pol subband kurtosis detection**
	0	RFI not detected
	1	RFI detected

Bits	Value	Interpretation
9		**H-pol subband kurtosis detection**
	0	RFI not detected
	1	RFI detected.
10-15		**Undefined**

RFI_ref_flag is a three-dimensional array. The slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets in the reference radiometric state in the antenna scan and the third index represents the 16 subbands.

Type: Uint16

Group: Subband RFI Cal

Shape: AntennaScan_RefPacket_Subband_Array

Units: n/a

4.6.2 RFI_refnd_flag (Subband_RFI_Cal)

RFI flags indicate which subband packets have been flagged by the cross frequency and the subband kurtosis RFI detection algorithms for the subband reference plus noise diode counts. Table 16 specifies the meaning of individual bits in the *RFI_refnd_flag*.

Table 16: RFI_refnd_flag

Bits	Value	Interpretation
0		**V-pol in phase cross-frequency detection**
	0	RFI not detected
	1	RFI detected
1		**V-pol quadrature cross-frequency detection**
	0	RFI not detected

Bits	Value	Interpretation
	1	RFI detected
2-5		**Undefined**
6		**H-pol in phase cross-frequency detection**
	0	RFI not detected
	1	RFI detected
7		**H-pol quadrature cross-frequency detection**
	0	RFI not detected
	1	RFI detected
8		**V-pol subband kurtosis detection**
	0	RFI not detected
	1	RFI detected
9		**H-pol subband kurtosis detection**
	0	RFI not detected
	1	RFI detected.
10-15		**Undefined**

RFI_refnd_flag is a three-dimensional array. The slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets in the reference plus noise diode radiometric state in the antenna scan and the third index represents the 16 subbands.

Type: Uint16

Group: Subband RFI Cal

Shape: AntennaScan_RefNdPacket_Subband_Array

Units: n/a

4.6.3 kurt16_h

k*urt16_h* is a three-dimensional array of the subband kurtosis values for the horizontal polarization. The slowest moving dimension index represents the antenna scan, the second-dimension index represents the number of packets in the antenna radiometric state in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: 1

Valid_max: ∞

Units: n/a

4.6.4 kurt16_v

k*urt16_v* is a three-dimensional array of the subband kurtosis values for the vertical polarization. The slowest moving dimension index represents the antenna scan, the second-dimension index represents the number of packets in the antenna radiometric state in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: 1

Valid_max: ∞

Units: n/a

4.6.5 subband_RFI_flag

The RFI flags indicate which subband packets have been flagged by the RFI detection algorithms for the subband antenna temperatures. Table 17 specifies the meaning of individual bits in the *subband_RFI_flag*.

Table 17: subband_RFI_flag

Bits	Value	Interpretation
0		**V-pol cross frequency detection**
	0	RFI not detected
	1	RFI detected
1		**H-pol cross frequency detection**
	0	RFI not detected
	1	RFI detected
2		**V-pol kurtosis subband detection**
	0	RFI not detected
	1	RFI detected
3		**H-pol kurtosis subband detection**
	0	RFI not detected
	1	RFI detected
4		**T3 subband detection**
	0	RFI not detected
	1	RFI detected
5		**T4 subband detection**
	0	RFI not detected
	1	RFI detected
6		**V-pol MAXPD subband**
	0	RFI not detected
	1	RFI detected

Bits	Value	Interpretation
7		**H-pol MAXPD subband**
		RFI not detected
		RFI detected
8-15		**Undefined**

subband_RFI_flag is a three-dimensional array. The slowest moving dimension index represents the antenna scan, the second-dimension index represents the number of antenna temperature packets in the antenna scan and the third index represents the 16 subbands.

Type: Uint8

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Units: n/a

4.6.6 subband_calibration_gain16

This is the subband calibration gain is used to derive antenna temperature values. s*ubband_calibration_gain16* is a four-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of antenna temperature packets in the antenna scan. The third index represents the 16 subbands and the fourth index is the polarization with the order of storage being v, h.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Polarization_Array

Valid_min: -1.41×10^{16}

Valid_max: 1.41×10^{16}

Units: Counts/Kelvin

4.6.7 subband_calibration_offset16

This is the subband calibration offset is used to derive antenna temperature values. s*ubband_calibration_offset16* is a four-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of antenna temperature packets in the antenna scan. The third index represents the 16 subbands and the fourth index is the polarization with the order of storage being v, h.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Polarization_Array

Valid_min: -4.49×10^{18}

Valid_max: 7.37×10^{18}

Units: Counts

4.6.8 subband_latitude

This is the latitude of the antenna look packet on the surface of the Earth.

subband_latitude is a two-dimensional array. The slower moving dimension index represents the antenna scan. The faster moving dimension index represents the number of packets in the antenna state in the scan.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Array

Valid_min: -90

Valid_max: 90

Units: degrees

4.6.9 subband_longitude

This is the longitude of the antenna look packet on the surface of the Earth.

subband_longitude is a two-dimensional array. The slower moving dimension index represents the antenna scan. The faster moving dimension index represents the number of packets in the antenna state in the scan.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Array

Valid_min: -180

Valid_max: 180

Units: degrees

4.6.10 ta16_3

This is the subband 3rd Stokes parameter with a resolution of 4 pulse repetition intervals (PRIs) or ~1.2 ms. *ta16_3* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets with data in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: -50

Valid_max: 50

Units: Kelvin

4.6.11 ta16_4

This is the subband 4th Stokes parameter with a resolution of 4 pulse repetition intervals (PRIs) or ~1.2 ms. *ta16_4* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets with data in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: -50

Valid_max: 50

Units: Kelvin

4.6.12 ta16_h

The subband horizontal antenna temperature with a resolution of 4 pulse repetition intervals (PRIs) or ~1.2 ms. *ta16_h* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets with data in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.13 ta16_v

This is the subband vertical antenna temperature with a resolution of 4 pulse repetition intervals (PRIs) or ~1.2 ms. *ta16_v* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of packets with data in the antenna scan and the third index represents the 16 subbands.

Type: Float32

Group: Subband RFI Cal

Shape: AntennaScan_AntPacket_Subband_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.14 subband_footprint_flag

The RFI flags indicate which pixels have been flagged by the cross frequency RFI detection algorithm for the subband antenna temperatures averaged to 9.6 ms. Table 18 specifies the meaning of individual bits in the *subband_footprint_flag*.

Table 18: subband_footprint_flag

Bits	Value	Interpretation
0		**V-pol cross-frequency detection**
	0	RFI not detected

Bits	Value	Interpretation
	1	RFI detected
1		**H-pol cross-frequency detection**
	0	RFI not detected
	1	RFI detected
2-15		**Undefined**

Type: Uint8
Group: Subband Footprint
Shape: AntennaScan_Footprint_Subband_Array
Units: n/a

4.6.15 RFI_ref_flag (Fullband_RFI_Cal)

The RFI flags indicate which pixels have been flagged by the time domain and the fullband kurtosis RFI detection algorithms for the fullband reference counts. Table 19 specifies the meaning of individual bits in the *RFI_ref_flag*.

Table 19: RFI_ref_flag

Bits	Value	Interpretation
0		**V-pol in phase time domain detection**
	0	RFI not detected
	1	RFI detected
1		**V-pol quadrature time domain detection**
	0	RFI not detected
	1	RFI detected
2		**H-pol in phase time domain detection**
	0	RFI not detected

Bits	Value	Interpretation
	1	RFI detected
3		**H-pol quadrature time domain detection**
	0	RFI not detected
	1	RFI detected
4		**V-pol fullband kurtosis detection**
	0	RFI not detected
	1	RFI detected
5		**H-pol fullband kurtosis detection**
	0	RFI not detected
	1	RFI detected.
6-15		**Undefined**

RFI_ref_flag is a two-dimensional array. The slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of PRIs in the reference radiometric state in the antenna scan.

Type: Uint16

Group: Fullband RFI Cal

Shape: AntennaScan_RefPRI_Array

Units: n/a

4.6.16 RFI_refnd_flag (Fullband_RFI_Cal)

The RFI flags indicate which pixels have been flagged by the tie domain and the fullband kurtosis RFI detection algorithms for the fullband reference plus noise diode counts. Table 20 specifies the meaning of individual bits in the *RFI_refnd_flag*.

Table 20: RFI_refnd_flag

Bits	Value	Interpretation
0		**V-pol in phase time domain detection**
	0	RFI not detected
	1	RFI detected
1		**V-pol quadrature time domain detection**
	0	RFI not detected
	1	RFI detected
2		**H-pol in phase time domain detection**
	0	RFI not detected
	1	RFI detected
3		**H-pol quadrature time domain detection**
	0	RFI not detected
	1	RFI detected
4		**V-pol fullband kurtosis detection**
	0	RFI not detected
	1	RFI detected
5		**H-pol fullband kurtosis detection**
	0	RFI not detected
	1	RFI detected.
6-15		**Undefined**

RFI_refnd_flag is a two-dimensional array. The slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of PRIs in the reference plus noise diode radiometric state in the antenna scan.

Type: Uint16

Group: Fullband RFI Cal

Shape: AntennaScan_RefNdPRI_Array

Units: n/a

4.6.17 fullband_RFI_flag

The RFI flags indicate which fullband antenna temperatures have been flagged by the fullband RFI detection algorithms. Table 21 specifies the meaning of individual bits in the *fullband_RFI_flag*.

Table 21: fullband_RFI_flag

Bits	Value	Interpretation
0		**V-pol time domain detection**
	0	RFI not detected
	1	RFI detected
1		**H-pol time domain detection**
	0	RFI not detected
	1	RFI detected
2		**V-pol kurtosis fullband detection**
	0	RFI not detected
	1	RFI detected
3		**H-pol kurtosis fullband detection**
	0	RFI not detected
	1	RFI detected
4		**T3 fullband detection**
	0	RFI not detected

Bits	Value	Interpretation
	1	RFI detected
5		**T4 fullband detection**
	0	RFI not detected
	1	RFI detected
6-15		**Undefined**

fullband_RFI_flag is a two-dimensional array. The slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of antenna temperature PRIs in the antenna scan.

Type: Uint8

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Units: n/a

4.6.18 fullband_calibration_gain

The fullband calibration gain is used to derive fullband antenna temperature values. *fullband_calibration_gain* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of antenna temperature PRIs in the antenna scan and the third index is the polarization. The order of storage is v, h.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Polarization_Array

Valid_min: -5.99×10^{16}

Valid_max: 5.99×10^{16}

Units: Counts/Kelvin

4.6.19 fullband_calibration_offset

The fullband calibration offset is used to derive fullband antenna temperature values. *fullband_calibration_offset* is a three-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan. The second-dimension index represents the number of antenna temperature PRIs in the antenna scan and the third index is the polarization. The order of storage is v, h.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Polarization_Array

Valid_min: -1.88×10^{19}

Valid_max: 3.06×10^{19}

Units: Counts

4.6.20 fullband_kurt_h

This is the fullband kurtosis values for the horizontal polarization. *fullband_kurt_h* is a two-dimensional array. The slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs in the antenna radiometric state in the antenna scan.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Valid_min: 1

Valid_max: ∞

Units: n/a

4.6.21 fullband_kurt_v

This is the fullband kurtosis values for vertical the polarization. *fullband_kurt_v* is a two-dimensional array. The slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs in the antenna radiometric state in the antenna scan.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Valid_min: 1

Valid_max: ∞

Units: n/a

4.6.22 fullband_latitude

This is the latitude of the antenna-look PRI on the surface of the Earth. *fullband_latitude* is a two-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents the number of PRIs in the antenna state in the scan.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Valid_min: -90

Valid_max: 90

Units: degrees

4.6.23 fullband_longitude

This is the longitude of the antenna-look PRI on the surface of the Earth. *fullband_longitude* is a two-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents the number of PRIs in the antenna state in the scan.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Valid_min: -180

Valid_max: 180

Units: degrees

4.6.24 fullband_ta_3

This is the fullband 3rd Stokes parameter of radiometer data with a resolution of ~300 μs or one pulse repetition interval (PRI). *fullband_ta_3* is a two-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs with data in the antenna scan.

Type:	Float32
Group:	Fullband RFI Cal
Shape:	AntennaScan_AntPRI_Array
Valid_min:	-50
Valid_max:	50
Units:	Kelvin

4.6.25 fullband_ta_4

This is the fullband 4th Stokes parameter with a resolution of ~300 μs or one pulse repetition interval (PRI). f*ullband_ta_4* is a two-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs with data in the antenna scan.

Type:	Float32
Group:	Fullband RFI Cal
Shape:	AntennaScan_AntPRI_Array
Valid_min:	-50
Valid_max:	50
Units:	Kelvin

4.6.26 fullband_ta_h

This is the fullband horizontal antenna temperatures with a resolution of ~300 μs or one pulse repetition interval (PRI). *fullband_ta_h* is a two-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs in the antenna scan.

Type:	Float32
Group:	Fullband RFI Cal
Shape:	AntennaScan_AntPRI_Array
Valid_min:	0

Valid_max: 310

Units: Kelvin

4.6.27 fullband_ta_v

This is the fullband vertical antenna temperature with a resolution of ~300 µs or one pulse repetition interval (PRI). *fullband_ta_v* is a two-dimensional array. The first dimension or the slowest moving dimension index represents the antenna scan and the second-dimension index represents the number of PRIs with data in the antenna scan.

Type: Float32

Group: Fullband RFI Cal

Shape: AntennaScan_AntPRI_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.28 fullband_MaxPD_flag

The RFI flags indicate which pixels have been flagged by the fullband RFI detection algorithms for the fullband antenna temperatures. This is a composite flag which is a logical OR of all the bits in **fullband_RFI_flag**. Table 22 specifies the meaning of individual bits in the *fullband_MaxPD_flag*. These flags are only enabled when the antenna scan is in low resolution mode.

Table 22: subband_footprint_flag

Bits	Value	Interpretation
0		**V-pol fullband MaxPD flag**
	0	RFI not detected
	1	RFI detected
1		**H-pol fullband MaxPD flag**
	0	RFI not detected
	1	RFI detected

Bits	Value	Interpretation
3		**High resolution bit**
	0	Antenna scan is not in high resolution (low resolution)
	1	Antenna scan is in high resolution
4-15		**Not defined**

Type: Uint8

Group: Fullband MaxPD Cal

Shape: AntennaScan_AntPRI_Array

Units: n/a

4.6.29 tap_toa_3

This is the apparent 3rd Stokes parameter at the top of the atmosphere after RFI detection and filtering. The top of atmosphere is equivalent to the bottom of the ionosphere.

The Faraday Rotation Correction algorithm in the L1B_TB executable sets the 3rd Stokes to zero and then recalculates the apparent top of atmosphere temperature vector with non-zero vertical and horizontal brightness temperatures. Thus, this element always displays a value of 0. Users who are interested in 3rd Stokes measure derived from instrument data should inspect either the antenna temperatures or the top of ionosphere temperatures. Details of the Faraday Rotation Correction algorithm appear in the Algorithm Theoretical Basis Document for the SMAP Level 1B Radiometer Data Product.

tap_toa_3 is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: -50

Valid_max: 50

Units: Kelvin

4.6.30 tap_toa_4

This is the apparent 4th Stokes parameter at the top of the atmosphere after RFI detection and filtering. The top of atmosphere is equivalent to the bottom of the ionosphere.

tap_toa_4 is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Intermediary Temperature Data
Shape:	AntennaScan_Tb_Array
Valid_min:	-50
Valid_max:	50
Units:	Kelvin

4.6.31 tap_toa_h

This is the horizontally polarized apparent brightness temperature at the top of the atmosphere after RFI detection and filtering. The top of atmosphere is equivalent to the bottom of the ionosphere.

tap_toa_h is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Intermediary Temperature Data
Shape:	AntennaScan_Tb_Array
Valid_min:	0
Valid_max:	310
Units:	Kelvin

4.6.32 tap_toa_v

This is the vertically polarized apparent brightness temperature at the top of the atmosphere after RFI detection and filtering. The top of atmosphere is equivalent to the bottom of the ionosphere.

tap_toa_v is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.33 tap_toi_3

This is the apparent 3rd Stokes parameter at the top of the ionosphere after RFI detection and filtering.

tap_toi_3 is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: -50

Valid_max: 50

Units: Kelvin

4.6.34 tap_toi_4

This is the apparent 4th Stokes parameter at the top of the ionosphere after RFI detection and filtering.

tap_toi_4 is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: -50

Valid_max: 50

Units: Kelvin

4.6.35 tap_toi_h

This is the horizontally polarized apparent brightness temperature at the top of the ionosphere after RFI detection and filtering.

tap_toi_h is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.36 tap_toi_v

This is the vertically polarized apparent brightness temperature at the top of the ionosphere after RFI detection and filtering.

tap_toi_v is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type: Float32

Group: Intermediary Temperature Data

Shape: AntennaScan_Tb_Array

Valid_min: 0

Valid_max: 310

Units: Kelvin

4.6.37 antenna_azimuth_angle

The antenna_azimuth_angle records the clockwise rotation from the projection of the Earth's North polar axis onto the XY plane of the SMAP Spacecraft Coordinate System to the projection of the antenna boresight vector onto the XY plane of the SMAP spacecraft coordinate system. The vertex of the angle is at the origin of the Spacecraft Coordinate System.

antenna_azimuth_angle is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Geolocation
Shape:	AntennaScan_Tb_Array
Valid_min:	0
Valid_max:	359.999
Units:	degrees

4.6.38 antenna_scan_angle

The angular position of the antenna boresight projected onto the X-Y plane of the spacecraft coordinate system. The antenna_scan_angle is zero when the antenna boresight aligns with the X axis of the spacecraft coordinate system. Angular measure increases as the antenna rotates counterclockwise.

antenna_scan_angle is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Geolocation
Shape:	AntennaScan_Tb_Array
Valid_min:	0
Valid_max:	359.999
Units:	degrees

4.6.39 tb_lat

This is the geodetic latitude of the intersection of the antenna boresight vector and the Earth’s surface.

tb_lat is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Geolocation
Shape:	AntennaScan_Tb_Array
Valid_min:	-90
Valid_max:	90
Units:	degrees

4.6.40 tb_lon

This is the longitude of the intersection of the antenna boresight vector and the Earth's surface.

tb_lon is a 2-dimensional array. The slower moving dimension index represents the antenna scan and the faster moving dimension index represents each of the footprints in the scan.

Type:	Float32
Group:	Geolocation
Shape:	AntennaScan_Tb_Array
Valid_min:	-180
Valid_max:	179.999
Units:	degrees

5 APPENDIX A – ACRONYMS AND ABBREVIATIONS

This is the standard Soil Moisture Active Passive (SMAP) Science Data System (SDS) list of acronyms and abbreviations. Not all these acronyms and abbreviations appear in every SMAP SDS document.

ADT	Algorithm Development Team
AMSR	Advanced Microwave Scanning Radiometer
ANSI	American National Standards Institute
AOS	Acquisition of Signal
APF	Algorithm Parameter File

ARS	Agricultural Research Service
ASF	Alaska Satellite Facility
ATBD	Algorithm Theoretical Basis Document
ATLO	Assembly Test Launch and Operations
BFPQ	Block Floating Point Quantization
BIC	Beam Index Crossing
CARA	Criticality and Risk Assessment
CBE	Current Best Estimate
CCB	Configuration Control Board
CCSDS	Consultative Committee on Space Data Systems
CDR	Critical Design Review
CEOS	Committee on Earth Observing Systems
CF	Climate and Forecast (metadata convention)
CM	Configuration Management
CM	Center of Mass
CONUS	Continental United States
COTS	Commercial Off the Shelf
CR	Change Request
DAAC	Distributed Active Archive Center
DB	Database
DBA	Database Administrator
dB	decibels
deg	degrees
deg/sec	degrees per second
deg C	degrees Celsius
DEM	Digital Elevation Model
DFM	Design File Memorandum
DIU	Digital Interface Unit
DN	Data Number
DOORS	Dynamic Object-Oriented Requirements
DQC	Data Quality Control

DSK	Digital Skin Kernel
DVD	Digital Versatile Disc
EASE	Equal Area Scalable Earth
ECMWF	European Centre for Medium Range Weather Forecasts
ECHO	EOS Clearing House
ECI	Earth Centered Inertial Coordinate System
ECR	Earth Centered Rotating Coordinate System
ECR	Engineering Change Request
ECS	EOSDIS Core System
EDOS	EOS Data Operations System
EM	Engineering Model
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPO	Education and Public Outreach
ESDIS	Earth Science Data and Information System Project
ESDT	Earth Science Data Type
ESH	EDOS Service Header
ESSP	Earth Science System Pathfinder
ET	Ephemeris Time
EU	Engineering Units
FOV	Field of View
FRB	Functional Requirements Baseline
FS	Flight System
FSW	Flight Software
F/T	Freeze/Thaw
FTP	File Transfer Protocol
GByte	gigabyte
GDS	Ground Data System
GHA	Greenwich Hour Angle

GHz	gigahertz
GLOSIM	Global Simulation
GMAO	Global Modeling and Assimilation Office
GMT	Greenwich Mean Time
GN	Ground Network
GPMC	Governing Program Management Council
GPP	Gross Primary Production
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HK	Housekeeping (telemetry)
Hz	Hertz
HSD	Health and Status Data
ICE	Integrated Control Electronics
ICESat	Ice, Cloud and Land Elevation Satellite
IDL	Interactive Data Language
I&T	Integration and Test
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IFOV	Instantaneous Field of View
I/O	Input/Output
IOC	In-Orbit Checkout
IRU	Inertial Reference Unit
ISO	International Organization for Standardization
IV&V	Independent Verification and Validation
ITAR	International Traffic in Arms Regulations
I&T	Integration and Test
JPL	Jet Propulsion Laboratory
KHz	kilohertz
km	kilometers

LAN	Local Area Network
LBT	Loopback Trap
LEO	Low Earth Orbit
LEOP	Launch and Early Operations
LOE	Level Of Effort
LOM	Life Of Mission
LOS	Loss of Signal
LSK	Leap Seconds Kernel
LZPF	Level Zero Processing Facility
m	meters
MHz	megahertz
MIT	Massachusetts Institute of Technology
MMR	Monthly Management Review
MOA	Memorandum of Agreement
MOC	Mission Operations Center
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Mission Operations System
m/s	meters per second
ms	milliseconds
MS	Mission System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Protection
NCP	North Celestial Pole
NCSA	National Center for Supercomputing Applications
NEDT	Noise Equivalent Diode Temperature
NEE	Net Ecosystem Exchange
NEN	Near Earth Network
netCDF	Network Common Data Form
NFS	Network File System/Server
NISN	NASA Integrated Services Network

NRT	Near Real Time
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
NVM	Non-Volatile Memory
NWP	Numerical Weather Product
n/a	not applicable
OCO	Orbiting Carbon Observatory
OEF	Orbit Events File
ORBNUM	Orbit Number File
OODT	Object Oriented Data Technology
ORR	Operational Readiness Review
ORT	Operational Readiness Test
OSSE	Observing System Simulation Experiment
OSTC	One Second Time Command
PALS	Passive and Active L-Band System
PALSAR	Phased Array L-Band Synthetic Aperture Radar
PcK	Planetary Constants Kernel
PDR	Preliminary Design Review
PPPCS	Pointing, Position, Phasing and Coordinate System
PR	Problem Report
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PROM	Programmable Read Only Memory
PSD	Product Specification Document
QA	Quality Assurance
rad	radians
RAM	Random Access Memory
RBA	Reflector Boom Assembly
RBD	Rate Buffered Data
RBE	Radiometer Back End
RDD	Release Description Document

RDE	Radiometer Digital Electronics
RF	Radio Frequency
RFA	Request For Action
RFE	Radiometer Front End
RFI	Radio Frequency Interference
RMS	root mean square
RSS	root sum square
ROM	Read Only Memory
RPM	revolutions per minute
RVI	Radar Vegetation Index
SA	System Administrator
SAR	Synthetic Aperture Radar
S/C	Spacecraft
SCE	Spin Control Electronics
SCLK	Spacecraft Clock
SDP	Software Development Plan
SDS	Science Data System
SDT	Science Definition Team
SI	International System
SITP	System Integration and Test Plan
SMAP	Soil Moisture Active Passive
SMEX	Soil Moisture Experiment
SMOS	Soil Moisture and Ocean Salinity Mission
SMP	Software Management Plan
SNR	signal to noise ratio
SOC	Soil Organic Carbon
SOM	Software Operators Manual
SQA	Software Quality Assurance
SPDM	Science Process and Data Management
SPG	Standards Process Group
SPK	Spacecraft Kernel

SQA	Software Quality Assurance
SPS	Science Production Software
SRF	Science Orbit Reference Frame
SRR	System Requirements Review
SRTM	Shuttle Radar Topography Mission
SSM/I	Special Sensor Microwave/Imager
STP	Software Test Plan
sec	seconds
TAI	International Atomic Time
T_b	Brightness Temperature
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Resolved
TBS	To Be Specified
TCP/IP	Transmission Control Protocol/Internet Protocol
TEC	Total Electron Content
TM	Trademark
TOA	Time of Arrival
TPS	Third Party Software
UML	Unified Modeling Language
U-MT	University of Montana
USDA	United States Department of Agriculture
UTC	Coordinated Universal Time
V&V	Verification and Validation
VWC	Vegetation Water Content

6 APPENDIX B - SMAP Data Product Specification Documents

SMAP Level 1A Radar Product Specification Document, JPL D-72543, March 21, 2016.

SMAP Level 1B Radar (L1B_S0_LoRes) Product Specification Document, JPL D-72544, March 21, 2016.

SMAP Level 1C Radar (L1C_S0_HiRes) Product Specification Document, JPL D-72554, March 21, 2016

SMAP Level 1A Radiometer Product Specification Document, Document JPL D-92340, July 20, 2015.

SMAP Level 1B Radiometer (L1B_TB) Product Specification Document, JPL D-92339, March 31, 2016.

SMAP Level 1C Radiometer (L1C_TB) Product Specification Document, JPL D-72545, April 31, 2020.

SMAP Level 2 Active Soil Moisture (L2_SM_A) Product Specification Document, JPL D-72546, April 14, 2016.

SMAP Level 2 Passive Soil Moisture (L2_SM_P) Product Specification Document, JPL D-72547, August 31, 2020.

SMAP Level 3 Freeze-Thaw (L3_FT_A) Product Specification Document, JPL D-72549, October 12, 2015.

SMAP Level 3 Active Soil Moisture (L3_SM_A) Product Specification Document, JPL D-72550, April 14, 2016.

SMAP Level 3 Passive Soil Moisture (L3_SM_P) Product Specification Document, JPL D-72551, August 31, 2020.

SMAP Level 3 Active/Passive Soil Moisture (L3_SM_AP) Product Specification Document, JPL D-72552, September 30, 2015.

SMAP Level 4 Carbon (L4_C) Product Specification Document, GMAO Office Note No. 11 (Version 2.2), November 15, 2022.

SMAP Level 4 Soil Moisture (L4_SM) Product Specification Document, GMAO Office Note No. 10 (Version 1.6), November 14, 2022.

7 APPENDIX C – SHAPES IN THE RADIOMETER L1B_RFICAL PRODUCT

Table 23 lists all the shapes that appear in the RADIOMETER L1B_RFICAL Product. The table also lists the rank, the nominal dimensions, and the maximum dimensions for each shape in the RADIOMETER L1B_RFICAL Product.

The naming convention for shape names places the dimension where consecutive indices represent contiguous storage positions last. The naming convention thus conforms to index representation in the C language.

On the other hand, since a large contingent of the SMAP science community programs are in Fortran, index order of arrays in this document conforms to the Fortran standard. Thus, in array dimension representation, the dimension where consecutive indices represent contiguous storage appears first.

Table 23: Shapes in the SMAP Radiometer L1B_RFICAL Data Product

Shape	Rank	Nominal Product Dimensions	Maximum Product Dimensions
AntennaScan_AntPacket_Array	2	(779,1931)	(779,3619)
AntennaScan_AntPRI_Array	2	(779,7724)	(779,14476)
AntennaScan_Tb_Array	2	(779,241)	(779,452)
AntennaScan_RefPRI_Array	2	(779,1920)	(779,3608)
AntennaScan_RefNdPRI_Array	2	(779,1920)	(779,3608)
AntennaScan_AntPRI_Polarization_Array	3	(779,7729,2)	(779, 14476,2)
AntennaScan_AntPacket_Subband_Array	3	(779,1931,16)	(779, 3619,16)
AntennaScan_RefPacket_Subband_Array	3	(779,480,16)	(779,902,16)
AntennaScan_RefNdPacket_Subband_Array	3	(779,480,16)	(779,902,16)
AntennaScan_AntPacket_Subband_Polarization_Array	4	(779,1931,16,2)	(779, 3619,16,2)

8 APPENDIX D – Radiometer L1B_RFICAL DIMENSIONS

Table 23 lists all the dimensions that are used by data elements in the Radiometer L1B_RFICAL. The name of each dimension matches the name given in the Dimension column below. The table also lists the anticipated nominal value and the maximum value for each dimension that appears in the Radiometer L1B_RFICAL product.

Some of the dimension sizes of the Radiometer L1B_RFICAL product are based on the radiometer switching scheme. The existing radiometer states are antenna (Ant), antenna plus external noise diode (AntXnd), antenna plus noise diode (AntNd), reference (Ref) and reference plus noise diode (RefNd). The switching sequence is described below.

- Each antenna scan contains several footprints. The maximum number of footprints possible based on the antenna rotation rate and PRI time is 302.
  Minimum rotation rate = 13 RPM
  Minimum PRI time = 318.4 μs
  Max number of footprints per scan = (Rotation time (sec)*Number of PRIs per second)/32 PRIs per footprint
  = (60 seconds/13 RPM)*(1/318.4 μs)/32 = 452.
- Each footprint contains 8 packets of science data. Radiometer packets are each made up of 4 PRIs. Each science data packet therefore includes fullband or time domain data for each of the 4 PRIs and subbanded data which have been further integrated over 4 PRIs.

The following holds true except for the last 2 footprints in each scan:

- The radiometer is in the antenna state for packet 1-4 and 7-10 of each footprint.
- The 5th and 11th packet of each footprint contains reference data.
- The 6th and 12th packet of each footprint contains reference plus noise diode data. The maximum number of reference and reference plus noise diode data packets is 902 each.

The following holds true for only the last 2 footprints in each scan:

- The radiometer is in the antenna state for all 12 packets in the penultimate footprint of each scan.
- The correlated noise source (CNS) or external noise diode is turned on during the last 2 footprints of each scan for the odd numbered packets. Therefore, the number of packets in the AntXnd state is always 12.
- The radiometer is in the antenna state for the 1st 11 packets of the last footprint of each scan.
- The 12th packet of the last footprint contains antenna plus noise diode data. Therefore, the number of packets in the AntNd state is always 1.

See Tables 24 and 25 explicitly define the radiometric state of the data as they appear in the instrument telemetry packets.

The maximum number of antenna packets is 3619.

Table 24: Switching scheme except for last 2 footprints in each scan.

Packet	State
1	ANT
2	ANT
3	ANT
4	ANT
5	REF
6	REF+ND
7	ANT
8	ANT
9	ANT
10	ANT
11	REF
12	REF+ND

Table 25: Switching scheme for last 2 footprints in each scan.

Packet	State	CNS
1	ANT	ON
2	ANT	
3	ANT	ON

4	ANT	
5	ANT	ON
6	ANT	
7	ANT	ON
8	ANT	
9	ANT	ON
10	ANT	
11	ANT	ON
12	ANT	
13	ANT	ON
14	ANT	
15	ANT	ON
16	ANT	
17	ANT	ON
18	ANT	
19	ANT	ON
20	ANT	
21	ANT	ON
22	ANT	
23	ANT	ON
24	ANT+ND	

Table 26: Dimensions in the SMAP Radiometer L1B_RFICAL Product

Dimension	Nominal Size	Maximum Size
AntennaScan	779	779
AntPacket	1931	3619
AntXndPacket	12	12
AntNdPacket	1	1
RefPacket	480	902
RefNdPacket	480	902
Subband	16	16
Polarization	4	4
AntPRI	7724	14476
AntXndPRI	48	48
AntNdPRI	4	4
RefPRI	1920	3608
RefNdPRI	1920	3608

9 APPENDIX E – RADIOMETER L1B_RFICAL UNITS

Table 27 lists the units that are used by the Radiometer L1B_RFICAL product elements. The SMAP implementation of HDF5 stores unit information for each data element in the local metadata. The first column in the Table 27 identifies units that apply to data in Radiometer L1B_RFICAL Product. The second column lists the Common Symbol used to represent the unit. The third column lists the matching label that appears in the local metadata in the Radiometer L1B_RFICAL Product.

Table 27: Units in the SMAP Radiometer L1B_RFICAL Product

Unit	Common Symbol	Radiometer L1B_RFICAL	Typical Use
counts	Counts	counts	number of elements in a set
counts/Kelvin	counts/Kelvin	counts/Kelvin	radiometer gain
degrees	degrees	degrees	angular measure
dimensionless	n/a		dimensionless quantity
kelvin	K	Kelvin	brightness temperature measure
megabytes	MBytes	MBytes	computer storage units
ratio	n/a		dimensionless quantity

10 APPENDIX F – Code Examples that Read HDF5

```
% Written by Priscilla N. Mohammed-Tano, Priscilla.N.Mohammed@nasa.gov

%Code written with Matlab R2013b

%This code reads SMAP hdf5 data files which are either L1A, L1B or the
%special cal/val product

%%
%Open HDF file
%Used h5info, h5read functions instead of hdf5info, hdf5read. Latter set will
be removed in future versions of Matlab

%Obtain info on file structure
%FF is data location, fn is filename

fileinfo = h5info([FF fn]);
nGroups = length(fileinfo.Groups);%number of groups in the file

for i1 = 1:nGroups
    numGroupDatasets = length(fileinfo.Groups(i1).Datasets);%number of data
elements in each group
    GroupName = fileinfo.Groups(i1).Name(2:end);%Get the name of the group
without the forward slash

    %Reads all the groups except the metadata
    if numGroupDatasets > 0
        for i2 = 1:numGroupDatasets
            dsname = fileinfo.Groups(i1).Datasets(i2).Name;%dataset element
name eg. z_vel
            dsnamestruct = ([GroupName '.' dsname]);%data set structure name
eg. Spacecraft_Data.z_vel
            fname =([fileinfo.Groups(i1).Name '/'
fileinfo.Groups(i1).Datasets(i2).Name]);%name of path to read the data eg.
/Spacecraft_Data/z_vel
            eval([dsnamestruct ' = h5read([FF fn],fname);']);%read each data
set
            d = size(eval(dsnamestruct));%determine size of the dataset array
            if length(d) == 2 && d(2) > 1
                eval([dsnamestruct ' = transpose(eval(dsnamestruct));']);%re-
order the data to the dimensions described in the product spec
            elseif length(d) == 3
                eval([dsnamestruct ' =
permute(eval(dsnamestruct),[3,2,1]);']);%re-order the data to the dimensions
described in the product spec
            elseif length(d) == 4
```

```
                eval([dsnamestruct ' = 
permute(eval(dsnamestruct),[4,3,2,1]);']);%re-order the data to the dimensions 
described in the product spec
            end
        end
    end

end

%%
%Read the Metadata
for i1 = 1:nGroups
    numGrpGrp = length(fileinfo.Groups(i1).Groups);
    
    if numGrpGrp > 0
        for i2 = 1:numGrpGrp
            nAttributes = length(fileinfo.Groups(i1).Groups(i2).Attributes);
            if nAttributes > 0
                for k = 1:nAttributes
                    GName = 
strrep(fileinfo.Groups(i1).Groups(i2).Name(2:end),'/','.');
                    AttrName = 
fileinfo.Groups(i1).Groups(i2).Attributes(k).Name;
                    Attrstruct = ([GName '.' AttrName]);
                    if 
iscell(fileinfo.Groups(i1).Groups(i2).Attributes(k).Value)
                        eval([Attrstruct ' = 
cell2mat(fileinfo.Groups(i1).Groups(i2).Attributes(k).Value);']);
                    else
                        eval([Attrstruct ' = 
(fileinfo.Groups(i1).Groups(i2).Attributes(k).Value);']);
                    end
                end
            end
            numGrpGrpGrp = length(fileinfo.Groups(i1).Groups(i2).Groups);
            if numGrpGrpGrp > 0
                for i3 = 1:numGrpGrpGrp
                    numAttributes = 
length(fileinfo.Groups(i1).Groups(i2).Groups(i3).Attributes);
                    for i4 = 1:numAttributes
                        GroupName = 
fileinfo.Groups(i1).Groups(i2).Groups(i3).Name(2:end);
                        GrpName = strrep(GroupName,'/','.');
                        AttributeName = 
fileinfo.Groups(i1).Groups(i2).Groups(i3).Attributes(i4).Name;
                        dsnamestruct = ([GrpName '.' AttributeName]);
                        if 
iscell(fileinfo.Groups(i1).Groups(i2).Groups(i3).Attributes(i4).Value)
                            eval([dsnamestruct ' = 
cell2mat(fileinfo.Groups(i1).Groups(i2).Groups(i3).Attributes(i4).Value);']);
                        else
```

```
                            eval([dsnamestruct ' =
(fileinfo.Groups(i1).Groups(i2).Groups(i3).Attributes(i4).Value);']);
                        end
                    end
                end
            end
        end
    end
end

clear AttrName AttributeName Attrstruct GName GroupName d dsname fname i1 i2
i3 i4 k nAttributes nGroups numAttributes ...
    numGroupDatasets numGrpGrp numGrpGrpGrp dsnamestruct GrpName
```