Department of the Interior
U.S. Geological Survey

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Level 1 Precision Terrain Corrected Registered At-Sensor Radiance Product (AST_L1T)

AST_L1T Product Specification

Version 1.0

30 July, 2015

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Abstract

This document provides the product specification for ASTER Level 1 precision terrain corrected registered at-sensor radiance (AST_L1T) products. It is intended to supplement the ERSDAC ASTER Level 1 Data Products Specification document with additional information relevant to the AST_L1T product.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Section 1 Introduction

1.1 Background

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a multispectral imager that was provided by the Japanese Ministry of International Trade and Industry (MITI) for launch on board the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Terra spacecraft in December 1999. Since the launch of the Terra satellite and the operation of the ASTER instrument, the mission generated nearly three million ASTER scenes, offering a rich range of observations that span the visible infrared, shortwave infrared, and thermal infrared of the observable spectra.

The ASTER instrument is comprised of four telescopes covering 14 frequency bands, three nadir-pointing telescopes, plus an additional aft-pointing telescope duplicating the frequency of nadir band 3. One nadir-pointing telescope covers visible and near infrared (VNIR) frequencies with three bands at 15-meter resolution. Another covers short-wave infrared (SWIR) frequencies with six bands at 30-meter resolution. The third covers thermal infrared (TIR) wavelength with five bands at 90-meter resolution. The aft-pointing telescope using the band 3 frequency covers the same scene 55 seconds behind the VNIR nadir band 3, enabling stereo views. These telescopes are individually controlled such that various granules may have different combinations of telescopes used. ASTER pointing capabilities are such that any point on the globe can be accessed at least once every 16 days in all 14 bands, and once every five days for the visible / near infrared bands.

The Department of the Interior (DOI) U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center and NASA partner to establish, develop, and operate the Land Processes (LP) Distributed Active Archive Center (DAAC). The LP DAAC's mission is to acquire, archive, and provide user access to NASA's land processes data, such as those derived from ASTER. Raw ASTER data are downlinked from Terra and forwarded by NASA to Japanese resources for initial processing. AST_L1A data are routed from Japan to the LP DAAC for archiving and further processing. Using a Japanese provided algorithm, the LP DAAC is capable of processing AST_L1A data to AST_L1B at-sensor calibrated radiance. Using L1B as an input, the LP DAAC produces higher level products on-demand using algorithms provided by the Jet Propulsion Laboratory (JPL).

Besides hosting the LP DAAC Program, the EROS Center also hosts the Landsat Program that processes raw (or closest to raw available) Landsat 1 through 8 MSS, TM, ETM+, OLI and TIRS data to higher-level products. Landsat data collection characteristics are similar to those of ASTER. In response to the 2011 Terra Senior Review requesting Level 2 products be ortho-rectified, the LP DAAC proposed to the ASTER Science Team that an ASTER ortho-rectified, terrain and precision corrected Level 1 product (AST_L1T) be produced using a single resampling for use as a standard input to Level 2 algorithms. The Earth Science Data and Information System (EOSDIS) Science Operations Office (SOO) serving as a primary sponsor in coordination with USGS, approved the proposal to use existing AST_L1B code enhanced with

USGS Landsat geometric precision and terrain correction techniques to create the ASTER Level 1 precision terrain corrected registered at-sensor radiance (AST_L1T) product. In conjunction with the proposal, JPL has agreed to update its AST_L1B based algorithms to utilize the LP DAAC AST_L1T product as an input to produce Level 2 products.

The AST_L1T algorithm uses both Earth and satellite models, along with standardized globally-distributed ground control points (GCPs) and digital elevation models (DEMs), to produce a multi-file product and two associated products. The AST_L1T product is comprised of an EOSDIS HDF-EOS2 science data file, an XML metadata file, a visual full resolution location-tagged GeoTIFF image file and/or a thermal full resolution location-tagged GeoTIFF image file. The generation of GeoTIFF full resolution images depends on band acquisition settings or sensor environmental conditions for any given satellite observation. The products associated with the AST_L1T multi-file product include a quality assessment (QA) text report product and the BROWSE product consisting of JPEG low resolution browse (visual, thermal, and quality) files.

1.2 Instrument Sensors

Depending on sensor command for any given data acquisition, ASTER downlinks may be comprised of some, or all, of the following bands described in Table 1.2-1. The design of each sensor is discussed in Section 2.0 of the ASTER User Handbook Version 2[1].

Label	Telescope Pointing	Wavelength (μm)	Description	Resolution (meters)
VNIR_Band1	Nadir	0.520–0.600	Visible green/yellow	15 (8-bit)
VNIR_Band2		0.630–0.690	Visible red	
VNIR_Band3N		0.760–0.860	Near infrared	
VNIR_Band3B[2]	Backward	0.760–0.860		
SWIR_Band4	Nadir	1.600–1.700	Short-wave infrared	30 (8-bit)
SWIR_Band5		2.145–2.185		
SWIR_Band6		2.185–2.225		
SWIR_Band7		2.235–2.285		
SWIR_Band8		2.295–2.365		
SWIR_Band9		2.360–2.430		
TIR_Band10	Nadir	8.125–8.475	Long-wave infrared or thermal infrared	90 (12-bit)
TIR_Band11		8.475–8.825		
TIR_Band12		8.925–9.275		
TIR_Band13		10.250–10.950		
TIR_Band14		10.950–11.650		

Table 1.2-1. ASTER Sensor Characteristics

[1] ASTER User Handbook Version 2 is accessible at http://asterweb.jpl.nasa.gov/content/03_data/04_Documents/aster_user_guide_v2.pdf

[2] VNIR_Band3B is not used in the AST_L1T processing or included in the product.

The only major ASTER instrument-related problem to date deals with the SWIR sensor which suffered a setback due to its anomalously high detector temperatures. The anomaly has rendered SWIR data unusable since April 1, 2008. To minimize system impact, SWIR bands are not used after April 2008 even though they may be marked in metadata as having been acquired. Eventually, in August 2012, engineers turned off the SWIR telescope altogether, and dummy data are included in the AST_L1A products after that point. Since the SWIR bands are used in the cloud-coverage calculations in the AST_L1A product headers, the loss of SWIR makes the cloud-coverage percent calculation unreliable.

1.3 ASTER Product Chain

Figure 1.3-1 illustrates a product-oriented view of the overall ASTER operations concept, where forward processing of ASTER data has been augmented for the AST_L1T Product Generation Executable (PGE).

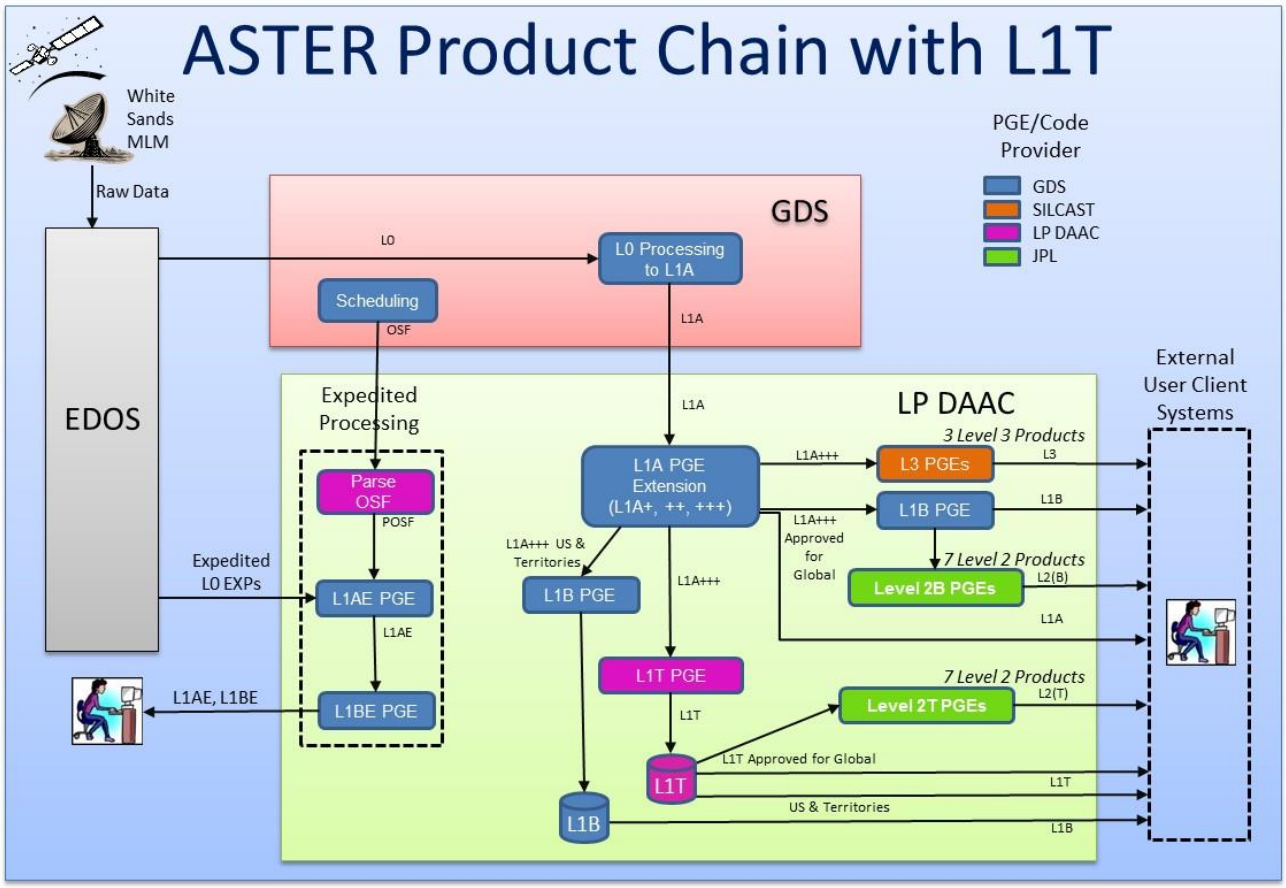


Figure 1.3-1. ASTER Operations Concept

The EOS Operations Center (not shown in the figure) commands the ASTER instrument to collect data per the long-term acquisition plan merged with near-term Data Acquisition Requests (DARs). ASTER raw data are downloaded from the Terra satellite by NASA's EOS Data and Operations System (EDOS) and transferred to Japan's Ground Data System (GDS). Refer to

the next section for a discussion on the overall data acquisition strategy for ASTER, except for the ASTER expedited processing, which remains unchanged in the current implementation.

Upon ingest of AST_L1A products from GDS, granules over the United States (US) and its territories are processed to produce AST_L1B products. These AST_L1B products are saved in the open data pool for direct download or for order/download from client search and order systems. Simultaneously, the LP DAAC associates GDS-provided AST_L1A browse images to the AST_L1B products.

The implementation modifies the legacy operations concept such that AST_L1T granules are routinely produced for all ingested AST_L1A granules. AST_L1T products over the US and its territories are saved in the open data pool for direct download or for order/download from client search and order systems.

All users may order and download AST_L1B and AST_L1T scenes/granules over the US and US Territories, ASTER L1A and L1B Expedited products, and the ASTER Global Digital Elevation Model (GDEM) for no charge. Users approved via an application process, may order any available ASTER product(s) from anywhere on the globe. All AST_L1T products created are archived and searchable in data access clients; however the granules/scenes over international areas of interest are available only to approved ASTER users. More information on the application process is available on the ASTER Policies Page under the heading Data Access for NASA Approved Users. The AST_L1T products are not available through Japan's ERSDAC WWW IMS interface.[3]

ASTER was not designed to continuously acquire data; daily acquisitions are scheduled and prioritized. The ASTER Science Team developed a data acquisition strategy divided into three categories: local observations, regional monitoring, and global map[4].

1.4 AST_L1T Granule and Associated Products

The AST_L1T product is comprised of an Earth Science Data and Information System (EOSDIS) granule and associated support files. Earth Science Data users acquire granules or individual files either through on-line search and order systems provided by NASA (e.g., Reverb) and the USGS (e.g., EarthExplorer or GloVis), or by directly downloading the files using the LP DAAC data pool. Refer to the AST_L1T User's Guide[5] for specifics on acquiring product files.

The AST_L1T granule is a multi-file product, which includes an HDF-EOS2 science data product file, full-resolution images, and a metadata file. Some sensor-specific data may not be present depending upon band acquisition settings or sensor environmental conditions at the time of acquisition:

[3] This subsection is paraphrased from Section 7 of the ASTER User Handbook Version 2.
[4] ASTER Data Collection Categories: http://asterweb.jpl.nasa.gov/categories.asp
[5] AST_L1T User's Guide: https://lpdaac.usgs.gov/dataset_discovery/aster/aster_products_table/ast_l1t.

- HDF: L1T science data comprised of a maximum of 14 bands of calibrated radiance data and embedded Object Description Language (ODL) metadata
- GeoTIFF: Visual Full Resolution Image (FRI) and/or Thermal FRI with embedded GeoKeys
- XML: Individual metadata file corresponding to the HDF science data file

In addition, each AST_L1T granule has a Browse and optionally a Quality Assurance (QA) product associated to it. The Browse product includes a low-resolution VNIR browse corresponding to the Visual FRI, a low-resolution TIR browse corresponding to the Thermal FRI, and a visual quality thumbnail called the QA browse. The QA product is a text report describing the quality of the correction applied to the science data.

- JPEG: Standalone reduced resolution Visual Browse, (VNIR)
- JPEG: Standalone reduced resolution Thermal Browse, (TIR)
- JPEG: Single-band black and white reduced resolution browse overlaid with red, yellow, blue, cyan and green markers indicating the geometric accuracy of the corrected scene (AST_L1T) as compared to a corresponding Global Land Survey (GLS) 2000 (GLS2000) standard scene, (QA)
- HDF: All associated reduced resolution JPEG browse bundled into a single file
- Text: Geometric quality assessment report (QA product)
- XML: Individual metadata files corresponding to bundled browse, and QA product

Section 2 Level 1T Science Data

2.1 Overview

The structure of the AST_L1T HDF-EOS2 science data file maps closely to the legacy AST_L1B product. Each AST_L1T science data file contains complete multi-band single-scene image data generated from the AST_L1A data. All of these data are stored together with metadata, scientific dataset (SDS), Vgroup/Vdata, and Swath Layout.

The AST_L1T product is created by performing the geometric and radiometric corrections on the original AST_L1A image data. The result is projected onto a rotated map (rotated from "path oriented" coordinate to UTM grid north-up) at full-instrument resolutions. The AST_L1T algorithm uses Earth and satellite models, control points, and elevation models. The algorithm ensures all calibrations and corrections historically applied to L1B data are also applied to the AST_L1T data. This includes radiometric calibration based on the most recently available radiometric databases, scene registrations for SWIR and TIR data, geometric processing (with improvements for nighttime TIR geo-location), and corrections for the SWIR cross-talk. For SWIR in particular, the corrections are applied for parallax errors due to the spatial locations of all of its bands. All geometric corrections are applied using a single re-sample.

AST_L1T scene centers are defined as the geodetic center of the scene obtained from SceneCenter found in the HDF-EOS productmetadata.0 attribute. The definition of scene center in AST_L1T is the actual center on the rotated coordinates, which is not the same as in AST_L1A or AST_L1B. Table 2.1-1 outlines the AST_L1T dataset characteristics.

Characteristic	VNIR	SWIR	TIR
Image dimensions in rows x columns	varies by scene (e.g., 5,800 x 6,600)	½ the size of VNIR (e.g., 2,900 x 3,300)	⅓ the size of SWIR (e.g., 960 x 1,100)
Bit-type	8-bit unsigned integer	8-bit unsigned integer	16-bit unsigned integer
Fill Pixel	0	0	0
Digital Number (min)	1	1	1
Digital Number (max)	255 (saturation)	255 (saturation)	4,095 (saturation)
Pixel Size	15-meter	30-meter	90-meter
Area	Varies by scene (typically 60 kilometers by 60 kilometers)		
Projection	Universal Transverse Mercator		
Data format	Hierarchical Data Format – EOS2		

Table 2.1-1. ASTER L1T Dataset Characteristics

2.2 Science Data File Structure

The AST_L1T science data file is comprised of a header including a directory and embedded object definition language (ODL) metadata as well as EOSDIS HDF-EOS2 containers. The hierarchical format includes ancillary information and containers for SWIR, VNIR, TIR image data groups. The SWIR, VNIR, and TIR groups contain science data, geolocation fields (latitude and longitude), and supplementary data. Science data includes image data fields for each band

present. VNIR and SWIR Supplement Data contains temperature and gain status data, calibration data, pointing angles, and other support data carried over from AST_L1A. Likewise, TIR Supplement Data includes containers for temperature, chopper, and encoder parameters. The nominal size (area dimension) of the data collection for an ASTER scene is about 60 kilometers by 60 kilometers.

Day-to-day implementation of the ASTER data acquisition strategy results in various combinations of telescope activation (on/off). Since these variations determine the types of image data available in the AST_L1A base product, they carry over to the associated AST_L1T. However, further variations are possible due to the fact that SWIR was deemed unhealthy past April 2008. Specifically, the AST_L1T algorithm does not produce SWIR L1T images from AST_L1A from April 2008.

For each band present, the science data fields contain reconstructed digital numbers at full resolution, which have been radiometrically calibrated, geometrically co-registered, and terrain and precision corrected using AST_L1T and legacy L1B algorithms. Spacecraft ancillary and instrument engineering supplementary data used by the algorithms are carried forward. This includes radiometric calibration coefficients consisting of offset and sensitivity information originating from a database for all detectors relative to the time-frame of the acquisition. The geometric system correction database is maintained at GDS.

VNIR and SWIR image data are 8-bit and have variable gain settings. TIR image data are significant to 12-bits in a 16-bit field with a single gain. The AST_L1T latitude and longitude geolocation arrays are two 11 x 11 matrices[6] of geodetic latitude and longitude in units of degrees used by the algorithms. The block size of the geolocation array is (number of lines)/10 by (number of samples[7])/10 which, unlike the case for L1B, varies by band because L1T is rotated north-up.[8]

Figure 2.2-1 provides a conceptual view of the physical format of the hierarchical AST_L1T product in full mode (VST) operation. The AST_L1T product structure differs considerably from the AST_L1A, but is structurally similar to the AST_L1B except VNIR band (3B) is not included in the product and the SWIR bands appear before the VNIR bands.

[6] There are 10 x 10 blocks requiring 11 x 11 lat/long pairs to allow for all the corners of each block. Thus for 9 interior block edges, the right-hand corner longitude of a given block is the same as the left-hand corner's longitude of the next right-adjacent block. To complete the grid, two additional longitudes covering the left most and right most block edges are therefore required. A similar approach applies for the upper and lower latitudes of each block.

[7] The terms samples and pixels are interchangeable in this document.

[8] Refer to Standards and Conventions and AST_L1T User's Guide for illustrations of scene rotation.

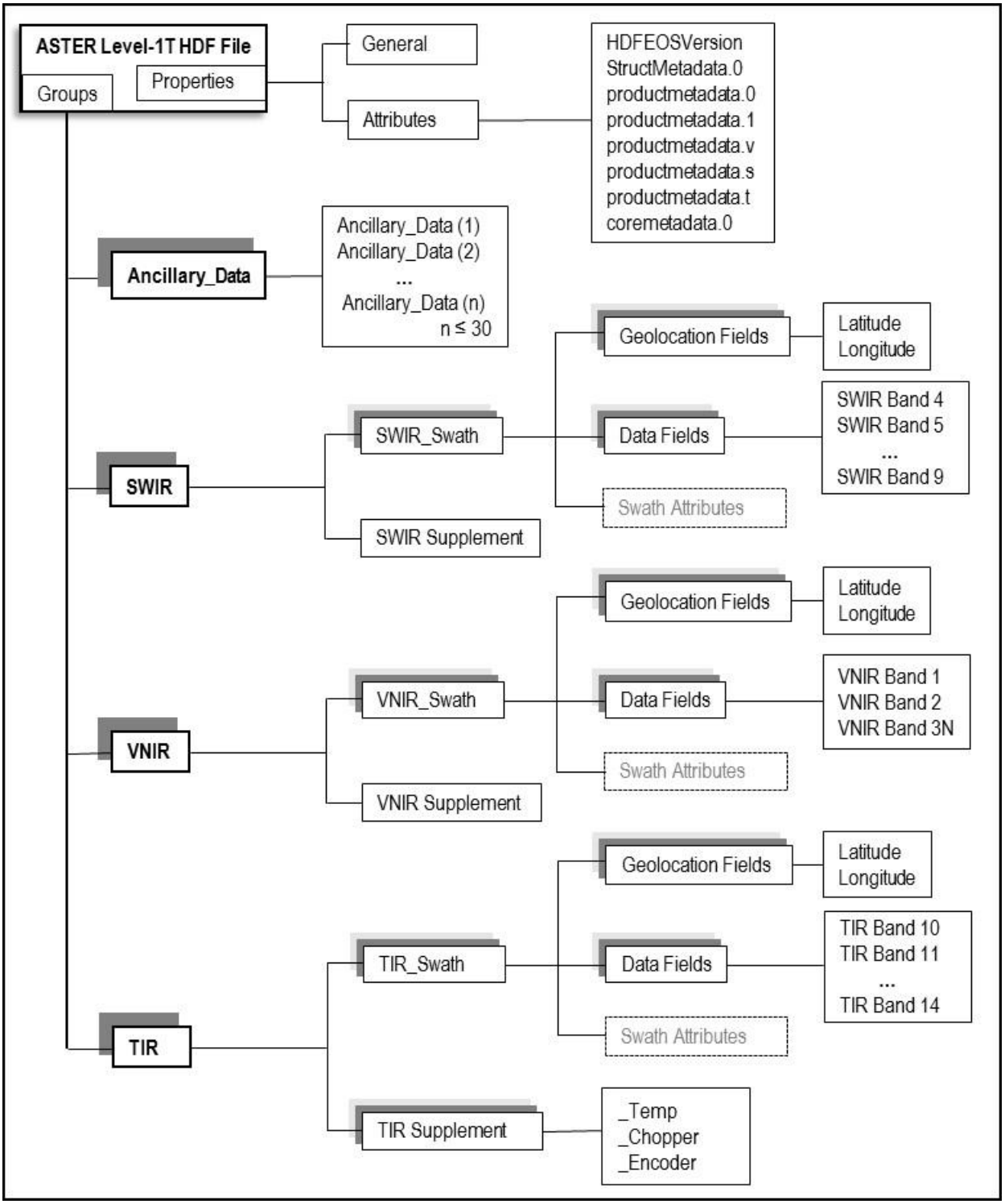


Figure 2.2-1. AST_L1T HDF File Structure

2.3 Science Data Format

2.3.1 Metadata

The science data HDF file header has eight "Attribute" sections that include the following in order of occurrence:

- Attribute #1: "HDFEOSVersion" [HDFEOS Version]
- Attribute #2: "StructMetadata.0" [Swath[9] structure metadata]
- Attribute #3: "productmetadata.0" [ASTER-generic metadata]
- Attribute #4: "productmetadata.1" [Product-generic metadata]
- Attribute #5: "productmetadata.v" [Product-specific VINR metadata]
- Attribute #6: "productmetadata.s" [Product-specific SWIR metadata]
- Attribute #7: "productmetadata.t" [Product-specific TIR metadata]
- Attribute #8:[10] "coremetadata.0" [Inventory-core metadata]

The last seven attributes in the list above are in ODL metadata format.

2.3.1.1 HDF EOS Version

The HDF file attribute named **HDFEOSVersion** is a required field, not in ODL format, indicating the HDF template format for standard data products that support products from EOS missions. The version defines compatibility with specific software suites used to manipulate the data. To-date, values for ASTER products are HDFEOS_V2.6 for L1A and HDFEOS_V2.17 for L1T.

2.3.1.2 Swath Structure Metadata

Table 2.3.1-2 provides the Swath Structure Metadata object list found in the AST_L1T HDF header attribute named "**StructMetadata.0**". Group names are written in **bold** characters. This attribute is used to describe the multi-dimensional structure of sensor geolocation and data fields. The association of telescopes to the SWATH_(n=1,2,3) groups depends on which telescopes are present.

No.				Group/Object Name	Type	Description
				SwathStructure		Master Group
1				**SWATH_1**		SwathName="SWIR_Swath" fixed
	1			**Dimension**		Defines the rows and column values of both the Geolocation and Data fields for the sensor
		1		Dimension_1	String Integer	DimensionName="GeoTrack" fixed[11] Size=11 fixed

[9] Swath usage here is archaic; StructMetadata defines "sensor" structures for each sensor's grouping of bands although the term "swath" is used in the metadata object names. In more current usage, swath is a continuous image strip that can be cut into scenes.

[10] AST_L1A contains a [Bad Pixel Information] Attribute, which is not carried over to L1B or L1T.

[11] "Fixed" implies the text or numerical value is always the same in every AST_L1T file.

No.				Group/Object Name	Type	Description
		2		Dimension_2	String Integer	DimensionName="GeoXtrack" fixed Size=11 fixed
		3		Dimension_3	String Integer	DimensionName="ImageLine" fixed Size=2,485 varies[12]
		4		Dimension_4	String Integer	DimensionName="ImagePixel" fixed Size=2,803 varies
	2			**DimensionMap**		Block size is (Number of lines)/10 * (Number of pixels)/10
		1		DimensionMap_1	String String Integer Integer	GeoDimension="GeoTrack" fixed DataDimension="ImageLine" fixed Offset=0 fixed Increment=248 varies
		2		DimensionMap_2	String String Integer Integer	GeoDimension="GeoXtrack" fixed DataDimension="ImagePixel" fixed Offset=0 fixed Increment=280 varies
	3			**IndexDimensionMap**		Defines the 2D structure of both the Geolocation and Data fields in the scene as well as the Data Type
		1		**GeoField**		geodetic latitude: decimal degree on range [-90.0, 90.0] geodetic longitude: decimal degree on range [-180.0, 180.0)
			1	GeoField_1	String FLOAT64	GeoFieldName="Latitude" fixed DataType=DFNT_FLOAT64 DimList=("GeoTrack","GeoXtrack")
			2	GeoField_2	String FLOAT64	GeoFieldName="Longitude" fixed DimList=("GeoTrack","GeoXtrack")
		2		**DataField**		min: Minimum value (1 < min < 255) max: Maximum value (1 < max < 255)
			1	DataField_1	String UNIT8	DataFieldName="ImageData4" fixed DimList=("ImageLine","ImagePixel")
			2	DataField_2	String UNIT8	DataFieldName="ImageData5" fixed. DimList=("ImageLine","ImagePixel")
			3	DataField_3	String UNIT8	DataFieldName="ImageData6" fixed DimList=("ImageLine","ImagePixel")
			4	DataField_4	String UNIT8	DataFieldName="ImageData7" fixed DimList=("ImageLine","ImagePixel")
			5	DataField_5	String UNIT8	DataFieldName="ImageData8" fixed DimList=("ImageLine","ImagePixel")
			6	DataField_6	String UNIT8	DataFieldName="ImageData9" fixed DimList=("ImageLine","ImagePixel")
		3		**MergedFields**		*Extraneous field not used*
2				**SWATH_2**		SwathName="VNIR_Swath" fixed
	1			**Dimension**		Defines the rows and column values of both the Geolocation and Data fields in the scene

[12] Numerical values given for fields that vary are typical values.

No.				Group/Object Name	Type	Description
		1		Dimension_1	String Integer	DimensionName="GeoTrack" fixed Size=11 fixed
		2		Dimension_2	String Integer	DimensionName="GeoXtrack" fixed Size=11 fixed
		3		Dimension_3	String Integer	DimensionName="ImageLine" fixed Size=4,969 varies
		4		Dimension_4	String Integer	DimensionName="ImagePixel" fixed Size=5,605 varies
		5		*Dimension_5*		*Extraneous field not used* *DimensionName="ImageLine3B"* *Size=4,969*
	2			**DimensionMap**		Block size is (Number of lines)/10 * (Number of pixels)/10
		1		DimensionMap_1	String String Integer Integer	GeoDimension="GeoTrack" fixed DataDimension="ImageLine" fixed Offset=0 fixed. Increment=496 varies.
		2		DimensionMap_2	String String Integer Integer	GeoDimension="GeoXtrack" fixed DataDimension="ImagePixel" fixed Offset=0 fixed Increment=560 varies
		3		*DimensionMap_3*		*Extraneous field not used* *GeoDimension="GeoTrack"* *DataDimension="ImageLine3B"* *Offset=0* *Increment=496*
	3			**IndexDimensionMap**		Defines the 2D structure of both the Geolocation and Data fields in the scene as well as the Data Type
		1		**GeoField**		geodetic latitude: decimal degree on range [-90.0, 90.0] geodetic longitude: decimal degree on range [-180.0, 180.0)
			1	GeoField_1	String FLOAT64	GeoFieldName="Latitude" fixed DimList=("GeoTrack","GeoXtrack")
			2	GeoField_2	String FLOAT64	GeoFieldName="Longitude" fixed DimList=("GeoTrack","GeoXtrack")
		2		**DataField**		min: Minimum value (1 < min < 255) max: Maximum value (1 < max < 255)
			1	DataField_1	String UNIT8	DataFieldName="ImageData1" fixed DimList=("ImageLine","ImagePixel")
			2	DataField_2	String UNIT8	DataFieldName="ImageData2" fixed DimList=("ImageLine","ImagePixel")
			3	DataField_3	String UNIT8	DataFieldName="ImageData3N" DataType=DFNT_UINT8 DimList=("ImageLine","ImagePixel")
		3		**MergedFields**		*Extraneous field not used*
3				**SWATH_3**		SwathName="TIR_Swath" fixed
	1			**Dimension**		Defines the rows and column values of both the Geolocation and Data fields in the scene

No.				Group/Object Name	Type	Description
		1		Dimension_1	String Integer	DimensionName="GeoTrack" fixed Size=11 fixed
		2		Dimension_2	String Integer	DimensionName="GeoXtrack" fixed Size=11 fixed
		3		Dimension_3	String Integer	DimensionName="ImageLine" fixed Size=829 varies
		4		Dimension_4	String Integer	DimensionName="ImagePixel" fixed Size=935 varies
	2			**DimensionMap**		Block size is (Number of lines)/10 * (Number of pixels)/10
		1		DimensionMap_1	String String Integer Integer	GeoDimension="GeoTrack" fixed DataDimension="ImageLine" fixed Offset=0 fixed Increment=82 varies
		2		DimensionMap_2	String String Integer Integer	GeoDimension="GeoXtrack" fixed DataDimension="ImagePixel" fixed Offset=0 fixed Increment=93 varies
	3			**IndexDimensionMap**		Defines the 2D structure of both the Geolocation and Data fields in the scene as well as the Data Type
		1		**GeoField**		geodetic latitude: decimal degree on range [-90.0, 90.0]; geodetic longitude: decimal degree on range [-180.0, 180.0)
			1	GeoField_1	String FLOAT64	GeoFieldName="Latitude" fixed DimList=("GeoTrack","GeoXtrack")
			2	GeoField_2	String FLOAT64	GeoFieldName="Longitude" fixed DimList=("GeoTrack","GeoXtrack")
		2		**DataField**		min: Minimum value (1 < min < 4,095) max: Maximum value (1 < max < 4,095)
			1	DataField_1	String UNIT16	DataFieldName="ImageData10" fixed DimList=("ImageLine","ImagePixel")
			2	DataField_2	String UNIT16	DataFieldName="ImageData11" fixed DimList=("ImageLine","ImagePixel")
			3	DataField_3	String UNIT16	DataFieldName="ImageData12" fixed DimList=("ImageLine","ImagePixel")
			4	DataField_4	String UNIT16	DataFieldName="ImageData13" fixed DimList=("ImageLine","ImagePixel")
			5	DataField_5	String UNIT16	DataFieldName="ImageData14" fixed DimList=("ImageLine","ImagePixel")
	4			**MergedFields**		*Extraneous field not used*
4				**GridStructure**		*Extraneous field not used*
5				**PointStructure**		*Extraneous field not used*

Table 2.3.1-2. List of Objects in AST_L1T Swath Structure Metadata

2.3.1.3 ASTER Generic Metadata[13]

Table 2.3.1-3 provides the ASTER Generic Metadata object list found in the AST_L1T HDF header attribute named "**productmetadata.0**". Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme. Objects which have a class attribute and whose name is followed by (n) may repeat n-times

No.			Group/Object Name	Type	Description
0			**ASTERGenericMetadata**		Master Group
1			InputGranuleID	String	This provides a unique identifier for location of a data granule held in ASTER GDS. Format: "ASTL1A YYMMDDHHMMSSyymmddNNNN" where, YYMMDD:observation date HHMMSS:observation time yymmdd:the data granule generation date NNNN:the data granule sequential No. (per day)
2			ReceivingCenter	String	"EDOS" fixed
3			ProcessingCenter	String	"ASTER_LPDAAC" fixed
4			**PointingAngles**		Specification of the pointing angles of ASTER sensors
	1		PointingAnglesContainer(n)		n = number of sensor
	2		SensorName(n)	String	"VNIR" or "SWIR" or "TIR"
	3		PointingAngle(n)	Double	pointing angle in degrees
	4		SettingTimeofPointing(n)	Datetime	YYYY-MM-DDThh:mm:ss.ddZ
5			**GainInformation**		The information of the gain level
			GainInformationContainer(n)		This container contains the level of the data acquisition gain for VNIR and SWIR
		1	Gain(n)	String	(Band Number, Band Gain) where, Band Number: "01","02","3N","04","05","06","07","08","09" Band Gain: **for VNIR:** "HGH": high gain "NOR": normal gain "LOW": low gain **for SWIR:** "HGH": high gain "NOR": normal gain "LO1": low gain 1 "LO2": low gain 2 when data is not acquired or doesn't exist: "OFF"
6			**CalibrationInformation**		Calibration information used to generate the geometric and radiometric correction tables
	1		GeometricDBVersion	String	The version information of the geometric

[13] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.1.2.

No.			Group/Object Name	Type	Description
					correction data. (Version, Issuance date, Comments) where, Version: Version No. Issuance date: Issuance Date Comments: Comments
	2		RadiometricDBVersion	String	The version information of the radiometric correction data. (Version, Issuance date, Comments) where, Version: Version Number Issuance date: Issuance Date Comments: Comments
	3		CoarseDEMVersion	String	The version information of the Coarse DEM database. (Version, Issuance date, Comments) where, Version: Version Number Issuance date: Issuance Date Comments: Comments Level 1 data product generation software uses GTOPO30 as the source of the ASTER Coarse DEM data
7			**DataQuality**		The information about the quality of this product
	1		**CloudCoverage**		The information about the cloud coverage[14] of the scene carried over from AST_L1A; the most current assessment is in the XML version of the metadata
		1	SceneCloudCoverage	Integer	The percentage of cloud coverage for the whole scene. Carried over from AST_L1A. Unit: %
		2	QuadrantCloudCoverage	Integer	The percentage for four quarters of a scene (qcul, qcur, qcll, qclr) where, qcul: upper left qcur: upper right qcll: lower left qclr: lower right Unit: %
8			SourceDataProduct	String	The information about the input data used for generating this AST_L1T product. (DataID, GenDT, DataTyp) where, DataID: ID of input AST_L1A Data Granule. GenDT: Generation date and time DataTyp: copy of AST_L1A
9			**InstrumentInformation**		The information about sensors used to acquire data
	1		ASTEROperationMode	String	The types of ASTER operation "OBSERVATION" or "CALIBRATION" or "TEST"
	2		**ObservationMode**		This group contains ASTER observation mode
		1	ObservationModeContainer(n)		The container of ASTER observation mode

[14] Due to the degradation of the SWIR telescope images, this value may not indicate a good approximation of cloud coverage for this scene. The XML metadata will have a more accurate cloud coverage value.

No.			Group/Object Name	Type	Description
		2	ASTERObservationMode(n)	String	The observation mode of each sensor group (SGname, Observation) where, SGname: “VNIR1” or “VNIR2” or “SWIR” or “TIR” Observation: “ON” (data is acquired) or “OFF” (data is not acquired, or not existing in the granule)
		3	ProcessedBands	String	The status of all bands during observation carried forward from L1A Format: set of flags described as 2-bytes string. flag = 01,02,3N,3B, ~ ,14 (data of band 01,02,3N, ~ ,14 is used in the granule generation) = XX (data corresponding to the band position marked with XX is not used) Example: Value = “XXXXXXXX040506070809101112131 4”
10			**SceneInformation**		
	1		ASTERSceneID	Integer	The scene identifier defined by path, row and view.(path, row, view) where, path: 1-233 (nominal) row: 1-670 view: 1-7 (-1 for off-nominal pointing)
	2		OrbitNumber	Integer	The orbit number of the satellite, when data is acquired. Copied from the value denoted in the schedule information that AOS provided.
	3		RecurrentCycleNumber	Integer	The satellite recurrent cycle number and the revolution number in the cycle (cycle, revolution) where, cycle: 1-260 (max.) revolution: 1-233 (nominal)
	4		FlyingDirection	String	The satellite flight direction when observation is done “AS”: ascending direction “DE”: descending direction
	5		SolarDirection	Double	The sun direction as seen from the scene center. (az, el) where, az: azimuth angle in degree. 0.0<az<360.0 measured eastward from North el: elevation angle in degree. -90.0<el<90.0
	6		SpatialResolution	Integer	The nominal pixel size of VNIR, SWIR and TIR. Unit: meter
	7		**SceneFourcorners**[15]		This group contains the information for the 4 corner coordinates of the scene

[15] Pixel orientation is critical with respect to the scene’s four corners. For example, in the AST_L1A product the upper left hand corner metadata value of the scene is also the upper left corner of the upper left pixel. However for AST_L1T, the upper left hand corner metadata value of the scene is actually the pixel center of the co-centered upper left pixel(s) in the product. Thus for any given AST_L1T band, the true upper left hand coordinate is offset from the upper left hand corner coordinate by half the band’s pixel size. The same applies for the AST_L1T upper right, lower left, and lower right scene corner coordinates.

No.			Group/Object Name	Type	Description
		1	UpperLeft		The coordinates of the upper-left corner of the scene (lat, long) where, lat: geodetic latitude long: geodetic longitude Unit: degree
		2	UpperRight	Double	The coordinates of the upper-right corner of the scene. (lat, long)
		3	LowerLeft	Double	The coordinates of the lower-left corner of the scene. (lat, long)
		4	LowerRight	Double	The coordinates of the lower-right corner of the scene. (lat, long)
	8		SceneCenter	Double	Longitude and latitude of the scene center. (lat, long) where, lat: geodetic latitude -90.0<lat<90.0 long: East longitude -180.0<long<180.0 Unit: degree
	9		MapOrientationAngle	Double	The angle between the path oriented image and the map oriented image within the range [-180.0, 180.0]. Unit: degree

Table 2.3.1-3. List of Objects in AST_L1T ASTER Generic Metadata

2.3.1.4 Product Generic Metadata

Table 2.3.1-4 provides the GDS Generic Metadata object list found in the AST_L1T HDF header attribute named "**productmetadata.1**". Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme. For AST_L1T, additional objects are provided for bands used in correction, type of correction, scene four corners, as well as an indication of reprocessing.

No.			Group/Object Name	Type	Description
1			**ProductGenericMetadata**		Master Group
	1		SensorShortName		The redundant array of short name for all sensors using in generating the product as per the string observation mode: "ASTER_VNIR", "ASTER_SWIR", "ASTER_TIR", "ASTER_STEREO"
		1	BandsUsed	String	The status of all bands during observation carried forward from L1A Format: set of flags described as 2-bytes string. flag = 01,02,3N,3B, ~ ,14 (data of band 01,02,3N, ~ ,14 is used in the granule generation) = XX (data corresponding to the band position marked with XX is not used) Example: Value = "XXXXXXXX040506070809101112131 4"
		2	CorrectionAchieved	String	Possible level of correction achieved: "Terrain+Precision", "Terrain+Systematic", "Systematic", "Precision"

No.			Group/Object Name	Type	Description
		3	NumberGCPChipsCorrelated	Integer	This is how many chips correlated during correlation statistics creation
		4	SpheroidCode	String	"WGS84" fixed
		5	UTMZoneNumber	Integer	Zone code for UTM projection. If southern zone is intended then use negative values.
	2		**SceneFourCornersMeters**[16]		Relative to the UTM Zone number in meters
		1	UpperLeftM	Double	Upper left corner relative to the UTM zone
		2	UpperRightM	Double	Upper right corner relative to the UTM Zone number
		3	LowerLeftM	Double	Lower left corner relative to the UTM zone
		4	LowerRightM	Double	Lower right corner relative to the UTM zone
		5	SceneCenterMeters	Double	Scene center in meters relative to the UTM zone
		6	L1TReprocessingActual	String	The stating what reprocessing has been performed on this granule. (possible entries are “not reprocessed”, “reprocessed once”, “reprocessed twice”, “reprocessing n times”)

Table 2.3.1-4. List of Objects in AST_L1T GDS Generic Metadata

2.3.1.5 Product Specific Metadata (VNIR)[17]

Table 2.3.1-5 provides the VNIR Product Specific Metadata object list found in the AST_L1T HDF header attribute named “**productmetadata.v**”. The metadata structure for the VNIR backward looking band (3B) is carried forward in the product although the values are null. Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme.

No.			Group/Object Name	Type	Description
1			**ProductSpecificMetadataVNIR**		Master Group
	1		**VNIRBand1Data**		The information about VNIR band 1 of AST_L1T.
		1	ImageDataInformation1	Integer	The information of VNIR band 1 image data. (npx, nln, bpp) where, npx: Number of pixels per line (4,969: typical) nln: Number of lines in frame (5,606: typical) bpp: Bytes per pixel (1: fixed)
	2		**ImageStatistics1**		The statistical information about the quality of AST_L1T VNIR band 1 data

[16] UTM corner and scene center values in meters were introduced for the first time in AST-L1T. The upper left hand corner metadata value of the scene for AST_L1T is actually the pixel center of the co-centered upper left pixel(s) in the product. Thus for any given AST_L1T band, the true upper left hand coordinate is offset from the upper left hand corner coordinate by half the band’s pixel size. The same applies for the AST_L1T upper right, lower left, and lower right scene corner coordinates.

[17] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.1.4

No.			Group/Object Name	Type	Description
		1	MinandMax1	Integer	Minimum and Maximum value in this band of AST_L1T VNIR image data. (min, max) where, min: Minimum value (1 < min < 255) max: Maximum value (1 < max < 255)
		2	MeanandStd1	Double	Mean and Standard deviation value in this band of AST_L1T VNIR image data. (mean, sd) where, mean: Mean value (1.0 < mean < 255.0) sd: Standard deviation value
		3	ModeandMedian1	Integer	Mode and Median value in this band of AST_L1T VNIR image data. (mode, med) where, mode: Mode value (1 < mode < 255) med: Median value (1 < med < 255)
	3		**DataQuality1**		This group contains the information about the quality of AST_L1T band 1 VNIR data
		1	NumberofBadPixels1	Integer	The number of bad pixels in the L-1T VNIR band 1 image. (nbp, ncg) where, nbp: number of bad pixels ncg: number of elements of the list of bad pixels. The information concerning the list of bad pixels is maintained **only** in the AST_L1A file to the separated AST_L1A attribute named “badpixelinformation”
	4		**ProcessingParameters1**		This group contains the parameters used by AST_L1T generation processing
		1	CorIntel1	String	Correction of the intertelescope error of SWIR and TIR: “N/A” fixed
		2	Corpara1	String	Correction of the SWIR parallax error: “N/A” fixed
		3	ResMethod1	String	Resampling Method: “BL” or “NN” or “CC”
		4	MPMethod1	String	Map Projection Method: “UTM”, “PS”, “LAMCC”, “SOM”, or “EQRECT”
		5	ProjectionParameters1	Double	Parameters used in GCTP Map projection. (When parameters that are not used are filled with the value “0.0”.) AST_L1T image is projected onto map using GCTP map projection tools through SCF Toolkit. For the parameters used in GCTP, see Appendix G of SCF Toolkit Users Guide.
		6	UTMZoneCode1	Integer	Zone code for UTM projection. If southern zone is intended then use negative values.
	5		**UnitConversionCoeff1**		This group contains the coefficients used for radiance conversion, from the pixel value of the band 1 image.
		1	Incl1	Double	Inclination Value
		2	Offset1	Double	Offset Value
		3	ConUnit1	String	Converted Unit ‘W/m2/sr/mm’ fixed
For next **VNIRBand2Data**, repeat the above items (1 through 1.5.3).					
For next **VNIRBand3NData**, repeat the above items (1 through 1.5.3).					

No.			Group/Object Name	Type	Description
For next **VNIRBand3BData**, repeat the above items (1 through 1.5.3); although metadata syntax is present in AST_L1T, the values are set to null since AST_L1T does not contain a Band 3B.					

Table 2.3.1-5. List of Objects in AST_L1T Product Specific Metadata (VNIR)

2.3.1.6 Product Specific Metadata (SWIR)[18]

Table 2.3.1-6 provides the SWIR Product Specific Metadata object list found in the AST_L1T HDF header attribute named "**productmetadata.s**". Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme.

No.				Group/Object Name	Type	Description
1				**ProductSpecificMetadataSWIR**		Master Group
	1			**SwirBand4Data**		The information about SWIR band 4 of AST_L1T.
		1		ImageDataInformation4	Integer	The information of SWIR band 4 image data. (npx, nln, bpp) where, npx: Number of pixels per line (2485: typical) nln: Number of lines in frame (2803: typical) bpp: Bytes per pixel (1: fixed)
	2			**ImageStatistics4**		The statistical information about the quality of AST_L1T SWIR band 4 data
		1		MinandMax4	Integer	Minimum and Maximum value in this band of AST_L1T SWIR image data. (min, max) where, min: Minimum value (1 < min < 255) max: Maximum value (1 < max < 255)
		2		MeanandStd4	Double	Mean and Standard deviation value in this band of AST_L1T SWIR image data. (mean, sd) where, mean: Mean value (1.0 < mean < 255.0) sd: Standard deviation value
		3		ModeandMedian4	Integer	Mode and Median value in this band of AST_L1T SWIR image data. (mode, med) where, mode: Mode value (1 < mode < 255) med: Median value (1 < med < 255)
	3			**DataQuality4**		This group contains the information about the quality of AST_L1T band 4 SWIR data.
		1		NumberofBadPixels4	Integer	The number of bad pixels in the L-1T SWIR band 4 image. (nbp, ncg) where, nbp: number of bad pixels. ncg: number of elements of the list of bad pixels. The information concerning the list of bad pixels is maintained **only** in the

[18] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.1.5

No.				Group/Object Name	Type	Description
						AST_L1A file to the separated AST_L1A attribute named “badpixelinformation”.
		2		**SWIRRegistrationQuality4**		The registration information of SWIR based on VNIR.
			1	ProcessingFlag4	Integer	Processing flag: 0: no output, because processing is impossible 1: output is the result computed 2: output is extracted from registration file 4: output obtained by other method
			2	NumberofMeasurements4	Integer	The number of measurements
			3	MeasurementPointNumber4	Integer	The number of measurement points
			4	AverageOffset4	Double	Average offset value. (LAOset, PAOset) where, LAOset: average offset in along track direction PAOset: average offset in cross track direction
			5	StandardDeviationOffset4	Double	Standard deviation offset value (LSDOset, PSDOset) where, LSDOset: SD offset in along track direction PSDOset: SD offset in cross track direction
			6	Threshold4	Double	Threshold value. (CThld, LOThld, POThld, VOThld) where, CThld: Correction threshold LOThld: offset threshold in along track direction POThld: offset threshold in cross track direction VOThld: Vector offset threshold
		3		**ParallaxCorrectionQuality4**		The information of SWIR parallax correction
			1	PCTIMageMatch4	Integer	The percentage of image matching used in the SWIR parallax correction processing. Unit: %
			2	AvgCorrelCoef4	Double	The Average Correlation Coefficient
			3	Cthld4	Double	The Correlation Threshold value
	4			**ProcessingParameters4**		This group contains the parameters used by AST_L1T generation processing
		1		CorIntel4	String	Correction of the intertelescope error of SWIR and TIR: “N/A” fixed
		2		CorPara4	String	Correction of the SWIR parallax error: “N/A” fixed
		3		ResMethod4	String	Resampling Method: “BL” or “NN” or “CC”
		4		MPMethod4	String	Map Projection Method: “UTM”, “PS”, “LAMCC”, “SOM”, or “EQRECT”
		5		ProjectionParameters4	Double	Parameters used in GCTP Map projection (When parameters that are not used are

No.				Group/Object Name	Type	Description
						filled with the value “0.0”.) AST_L1T image is projected onto map using GCTP map projection tools through SCF Toolkit. For the parameters used in GCTP, see Appendix G of SCF Toolkit Users Guide.
		6		UTMZoneCode4	Integer	Zone code for UTM projection If southern zone is intended, then use negative values.
	5			**UnitConversionCoeff4**		This group contains the coefficients used for radiance conversion, from the pixel value of the band 4 image.
		1		Incl4	Double	Inclination Value
		2		Offset4	Double	Offset Value
		3		ConUnit4	String	Converted Unit “W/m2/sr/mm” fixed
For next **SWIRBand5Data**, repeat the above items (1 through 1.5.3)						
For next **SWIRBand6Data**, repeat the above items (1 through 1.5.3)						
For next **SWIRBand7Data**, repeat the above items (1 through 1.5.3)						
For next **SWIRBand8Data**, repeat the above items (1 through 1.5.3)						
For next **SWIRBand9Data**, repeat the above items (1 through 1.5.3)						

Table 2.3.1-6. List of Objects in AST_L1T Product Specific Metadata (SWIR)

2.3.1.7 Product Specific Metadata (TIR)[19]

Table 2.3.1-7 provides the TIR Product Specific Metadata object list found in the AST_L1T HDF header attribute named “**productmetadata.t**”. Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme.

No.	G2	Ob	Group/Object Name	Type	Description
1			**ProductSpecificMetadataTIR**		Master Group
	1		**TIRBand10Data**		The information about TIR band 10 of AST_L1T
		1	ImageDataInformation10	Integer	The information of TIR band 10 image data. (npx, nln, bpp) where, npx: Number of pixels per line (829: typical) nln: Number of lines in frame (935: typical) bpp: Bytes per pixel (2: fixed)
	2		**ImageStatistics10**		The statistical information about the quality of AST_L1T TIR band 10 data
		1	MinandMax10	Integer	Minimum and Maximum value in this band of AST_L1T TIR image data. (min, max) where, min: Minimum value (1 < min < 4,095) max: Maximum value (1 < max < 4,095)
		2	MeanandStd10	Double	Mean and Standard deviation value in this band of AST_L1T TIR image data (mean, sd) where,

[19] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.1.6

					mean: Mean value (1.0 < mean < 4,095.0) sd: Standard deviation value
		3	ModeandMedian10	Integer	Mode and Median value in this band of AST_L1T TIR image data. (mode, med) where, mode: Mode value (1 < mode < 4,095) med: Median value (1 < med < 4,095)
	3		**DataQuality10**		This group contains the information about the quality of AST_L1T band 10 TIR data.
		1	NumberofproductmetadataPixels10	Integer	The number of bad pixels in the L-1T TIR band 10 image. (nbp, ncg) where, nbp: number of bad pixels. ncg: number of elements of the list of bad pixels. The information concerning the list of bad pixels is maintained **only** in the AST_L1A file to the separated AST_L1A attribute named “badpixelinformation”
	4		**TIRRegistrationQuality10**		The registration information of TIR Is based on VNIR.
		1	ProcessingFlag10	Integer	Processing flag: 0: no output, because processing is impossible 1: output is the result computed 2: output is extracted from registration file 4: output obtained by other method
		2	NumberofMeasurements10	Integer	The number of measurements
		3	MeasurementPointNumber10	Integer	The number of measurement points
		4	AverageOffset10	Double	Average offset value. (LAOset, PAOset) where, LAOset: average offset in along track direction PAOset: average offset in cross track direction
		5	StandardDeviationOffset10	Double	Standard deviation offset value (LSDOset, PSDOset) where, LSDOset: SD offset in along track direction PSDOset: SD offset in cross track direction
		6	Threshold10	Double	Threshold value (CThld, LOThld, POThld, VOThld) where, CThld: Correction threshold LOThld: offset threshold in along track direction POThld: offset threshold in cross track direction VOThld: Vector offset threshold
	5		**ProcessingParameters10**		This group contains the parameters used by AST_L1T generation processing.
		1	CorIntel10	String	Correction of the intertelescope error of SWIR and TIR: “Corrected Intertelescope Error” or “Uncorrected Intertelescope Error”
		2	CorPara10	String	Correction of the SWIR parallax error:

					"N/A" fixed
		3	ResMethod10	String	Resampling Method: "BL" or "NN" or "CC"
1			MPMethod10	String	Map Projection Method: "UTM", "PS", "LAMCC", "SOM", or "EQRECT"
	1		ProjectionParameters10	Double	Parameters used in GCTP Map projection (When parameters that are not used are filled with the value "0.0".) AST_L1T image is projected onto map using GCTP map projection tools through SCF Toolkit. For the parameters used in GCTP, see Appendix G of SCF Toolkit Users Guide.
		1	UTMZoneCode10	Integer	Zone code for UTM projection If southern zone is intended then use negative values.
	2		**UnitConversionCoeff10**		This group contains the coefficients used for radiance conversion, from the pixel value of the band 10 image.
		1	Incl10	Double	Inclination Value
		2	Offset10	Double	Offset Value
		3	ConUnit10	String	Converted Unit "W/m2/sr/mm" fixed
For next **TIRBand11Data**, repeat the above items (1 through 1.5.3)					
For next **TIRBand12Data**, repeat the above items (1 through 1.5.3)					
For next **TIRBand13Data**, repeat the above items (1 through 1.5.3)					
For next **TIRBand14Data**, repeat the above items (1 through 1.5.3)					

Table 2.3.1-7. List of Objects in AST_L1T Product Specific Metadata (TIR)

2.3.1.8 Inventory (Core) Metadata[20]

Table 2.3.1-8 provides the ASTER Generic Metadata object list found in the AST_L1T HDF header attribute named "**StructMetadata.0**". Group names are written in **bold** characters. A group contains a set of objects that all have a similar theme.

The Inventory Metadata attributes apply to the whole HDF file-attribute named **coremetadata.0**. Group names are written in **bold** characters

No.	Ob	Group/Object Name	Type	Description
0		**InventoryMetadata**		Master Group
1		ShortName	String	The short name for information that identifies a dataset: "AST_L1T"
2		SizeMBDataGranule	Double	The estimated volume of data contained in the granule (does not include T.tif or V.tif file size). Unit: Mbytes (estimate runs high at around 0.6MB above actual)
3		ProductionDateTime	Datetime	Generation date and time of this AST_L1T product
4		PlatformShortName	String	"Terra" fixed
5		InstrumentShortName	String	"ASTER" fixed

[20] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.1.1

6		**BoundingRectangle**[21]		This block contains area coverage for a granule
	1	WestBoundingCoordinate	Double	Western-most coordinate of the scene expressed in longitude
	2	NorthBoundingCoordinate	Double	Northern-most coordinate of the scene expressed in geodetic latitude
	3	EastBoundingCoordinate	Double	Eastern-most coordinate of the scene expressed in longitude
	4	SouthBoundingCoordinate	Double	Southern-most coordinate of the scene expressed in geodetic latitude
7		**SingleDatetime**		This contains the time of day and calendar date, at which the center of the scene is observed.
	1	TimeofDay	String	format: hhmmss d→dZ
	2	CalendarDate	String	format: YYYYMMDD
8		**Review**		This block provides for dates and status as applicable for collection that are active.
	1	FutureReviewDate	String	The date of the nearest planned QA peer review in future. format: YYYYMMDD
	2	ScienceReviewDate	String	The date of the last QA peer review. format: YYYYMMDD
9		**QAStats**		This block contains measures of quality for a granule.
	1	QAPercentMissingData	Double	The percentage of missing data in the scene. Unit: %
	2	QAPercentOutofBoundsData	Double	The percentage of out of bounds data in the scene. Unit: %
	3	QAPercentInterpolatedData	Double	The percentage of interpolated data in the scene. Unit: %
10		ReprocessingActual	String	The stating what reprocessing has been performed on this granule. (“not reprocessed”, “reprocessed once”, “reprocessed twice”, “reprocessing n times”)
11		PGEVersion	String	The version of PGE. Format “n.n”
12		ProcessingLevelID	String	The classification of the science data processing level: “1T”
13		MapProjectionName	String	The name of the mapping method for AST_L1T: “Universal Transverse Mercator” fixed.
14		Identifier_Product_Doi_Authority	String	http://dx.doi.org fixed
15		Identifier_Product_Doi	String	“10.5067/ASTER/AST_L1T.003” fixed

Table 2.3.1-8. List of Objects in AST_L1T Inventory (Core) Metadata

[21] For AST_L1T, the west bounding coordinate metadata value of the scene is actually the west most pixel center value of the co-centered west most pixel(s) in the product. Thus for any given AST_L1T band, the true west coordinate is offset by half the band’s pixel size. The same applies for the AST_L1T north, east, and south scene corner coordinates.

2.3.2 Ancillary Data[22]

Ancillary Data includes the satellite's orbit/attitude data, and their time tags. Ancillary data, appended to onboard instrument data, are updated once per major cycle time (1.024 sec). To ensure the conformity with instrument data, UTC time data are assigned to the leading ancillary data. Time tag data are used as control data for extracted Image Data.

Ancillary Data Group contains a series of Ancillary Data Records through the use of Vgroup API as per the HDF User's Guide.

vgroup name: **Ancillary_Data**
class: **Ancillary**

Each record of Ancillary Data features the following characteristics.
a) Data model: Vdata
b) Object Name: **Ancillary_Data**
c) Class Name: Anci_Record.*n* (*n*: Record count number – from 12 to 29 records)

Field Name	Dimension	Variable Size	Description
Time_Tag	4	UINT16	Time Tag (UTC): Spacecraft Time Format
Primary_Header	6	UINT8	CCSDS Primary Packet Header for downlink, used for ground routing and processing
Secondary_Header	8	UINT8	This field is part of the secondary header of the packet for downlink. Bit 0: Secondary Header ID Flag (always a data zero) Bit 1-63: Time Stamp -- Epoch of the data in the ancillary data message. Spacecraft clock time in CCSDS Day-Segmented Format. The code epoch is January 1, 1958.
Flag_Byte	1	UINT8	Flag Byte -- Flags for ground data processing control. First (most significant) bit is the "quick look" bit. Other bits are reserved and will contain data zero. This field is part of the secondary header of the packet for downlink.
Time_Conversion	3	INT8	Time conversion -- Estimated difference between UTC and the Spacecraft Clock. This may be added to the Spacecraft Clock time to derive UTC time.
Position	3	NT32	Spacecraft Position (x, y, z) -- Estimated position of the spacecraft, expressed in Earth Centered Inertial frame (mean Equator and Equinox of J2000)
Velocity	3	INT32	Spacecraft Velocity (x, y, z) -- Estimated velocity of the spacecraft, expressed in Earth Centered Inertial frame (mean Equator and Equinox of J2000)
Attitude_Angle	3	INT16	Attitude Angle (Roll, Pitch, Yaw) -- The estimated attitude of the spacecraft, expressed in the Orbital Reference frame
Attitude_Rate	3	INT16	Attitude Rate (Roll, Pitch, Yaw) -- The estimated attitude rate of the spacecraft, expressed in the Orbital Reference

[22] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 2.3.3

			frame
Magnetic_Coil	3	INT8	Magnetic Coil Current (x, y, z) -- Currents flowing in each of the magnetic torque coils used for Spacecraft momentum unloading
Solar_Array	1	UINT8	Solar Array Current -- Current flowing from the Spacecraft solar array
Solar_Position	3	INT8	Solar Position (x, y, z) -- Components of unit vector, expressed in the Spacecraft Reference frame, pointing in the direction of the Sun
Mon_Position	3	INT8	Moon Position (x, y, z) -- Components of the unit vector, expressed in the Spacecraft Reference frame, pointing in the direction of the Moon

Table 2.3.2-9. Format of AST_L1T Ancillary Data.

Note 1: Resolution and Range are shown as follows:

Ancillary Data	**Resolution**	**Range**
Primary Header	N/A	N/A
Secondary Header	N/A	N/A
Time Stamp	1μsec	1958-2047
Flag Byte	N/A	N/A
Time Conversion	1μsec	$\pm 8.3*10^{6}$μsec
Spacecraft Position	0.125 m	$\pm 268*10^{6}$ m
Spacecraft Velocity	$244*10^{-6}$ m/s	$\pm 524*10^{3}$ m/s
Attitude Angle	1.0 arcsec	+2,048 arcsec
Attitude Rate	0.5 arcsec/sec	±1,024 arcsec/sec
Magnetic Coil	Current $15.6*10^{-3}$ A	±2.0 A
Solar Array Current	1.0 A	0-256 A
Solar Position	$7.8*10^{-3}$	±1
Moon Position	$7.8*10^{-3}$	±1

2.3.3 SWIR Group[23]

2.3.3.1 Overview

SWIR Group contains an SDS and a Swath Object through the use of the Vgroup API. Vgroup name that establishes access to a Vgroup is as follows.

vgroup name: SWIR
class: 1T

Map projection method: Universal Transverse Mercator (UTM)

Resampling methods: Cubic Convolution (CC)

For further details on projection parameters (Projection Codes, Zone Codes, etc.), please refer to the HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 1: Overview and Examples (EOSDIS, 2014a), HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 2: Function Reference Guide (EOSDIS, 2014b), and the Release 8 SDP Toolkit Users Guide (EOSDIS, 2014c).

2.3.3.2 SWIR Swath

(1) Structure

The AST_L1T SWIR swath structure contains a single geolocation table and six SWIR band image data multidimensional arrays. The swath structure contains a single geolocation component which pertains to all six bands. The first point in the 2-dimensional geolocation array is the most north west pixel center in the UTM projection. Each row has a constant northing and each column has a constant easting since the scene is rotated to north up in the UTM projection.

For the AST_L1T product, all science data in the same sensor (telescope) are stored per band as 2-dimensional arrays in the swath structure. Therefore the SWIR swath structure contains band data in 2-dimensional arrays for bands 4, 5, 6, 7, 8 and 9.

(2) Characteristics

Table 2.3.3-10 shows the list of data items in SWIR Swath (sensor data for SWIR).
a) Data model: Swath
b) Object Name: SWIR_Swath
c) Format: Table 2.3.3-10 shows the contents of the Swath Object. Table 2.3.3-11 shows the format of the Swath Object.

No.	Field Name	Type	Unit	Comments
1.	Latitude	Geolocation Array	degree	**geodetic**[24] latitude: decimal degree on range [-90.0, 90.0]
2.	Longitude	Geolocation Array	degree	geodetic longitude: decimal degree on range [-180.0, 180.0)

[23] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.4
[24] This field is geocentric in L1A and L1B but is **geodetic** in L1T for all scenes. In addition, unlike L1A and L1B, the pixels for each sensor in L1T are co-centered so the scene center values are identical for each sensor.

No.	Field Name	Type	Unit	Comments
3.	ImageData4	2D Data Array	N/A	AST_L1T spectral band 4 image data – DNs
4.	ImageData5	2D Data Array	N/A	AST_L1T spectral band 5 image data – DNs
5.	ImageData6	2D Data Array	N/A	AST_L1T spectral band 6 image data – DNs
6.	ImageData7	2D Data Array	N/A	AST_L1T spectral band 7 image data – DNs
7.	ImageData8	2D Data Array	N/A	AST_L1T spectral band 8 image data – DNs
8.	ImageData9	2D Data Array	N/A	AST_L1T spectral band 9 image data– DNs

Table 2.3.3-10. List of data items in AST_L1T SWIR Swath

Field Name	Dimension Size	Variable Type	Remarks
Latitude	[11][11]	DOUBLE	geolocation field (array)
Longitude	[11][11]	DOUBLE	geolocation field (array)
ImageData4	{2570}{2880}[25]	UINT8	mapping to geolocation array
ImageData5	{2570}{2880}	UINT8	mapping to geolocation array
ImageData6	{2570}{2880}	UINT8	mapping to geolocation array
ImageData7	{2570}{2880}	UINT8	mapping to geolocation array
ImageData8	{2570}{2880}	UINT8	mapping to geolocation array
ImageData9	{2570}{2880}	UINT8	mapping to geolocation array

Table 2.3.3-11. Format of data items in AST_L1T SWIR Swath

(3) Block Size

Block size is shown as follows.

Type	Block size
Geolocation Array	(Number of lines)/10 * (Number of pixels per line)/10

2.3.3.3 SWIR Supplement Data

(1) Description

SWIR Supplement Data contains SWIR status data, calibration data, pointing angles, sensor temperatures, voltages and currents.

(2) Characteristics

a) Data Model: SDS (2-Dimensional Array)

b) Object Name: **SWIR_Supplement**

c) Format: Dimension size and variable type are as follows. Since SWIR Supplement Data are updated once per cycle time (4.398 msec), Increment of frame number is attended on this update. Table 2.3.3-12 shows the contents of each entry. Table 2.3.3-13 shows the contents of Supplement Data with relation to each column of the last dimension. Table 2.3.3-14, Table 2.3.3-15, Table 2.3.3-16, and Table 2.3.3-17 show the contents of Supplement Data at the bit-structure level for certain words.

[25] Items in braces { } indicate typical values.

Dimension Size	Variable Type
[n][49]	UINT8

Where [n] is revised to accommodate a record count number (2,510: nominal).

Frame Number	Contents of the Entries
0	Repeat time tag, synchronous code, frame number, and reserved fields as described in following table. Major Frame 0 and 1 descriptions apply from WORD#38 to WORD#53.
1	Repeat time tag, synchronous code, frame number, and reserved fields as described in following table. Major Frame 2 and 3 descriptions apply from WORD#38 to WORD#53.
2	Repeat time tag, synchronous code, frame number, and reserved fields as described in following table. Major Frame 4 and 5 descriptions apply from WORD#38 to WORD#53.
3	Repeat time tag, synchronous code, frame number, and reserved fields as described in following table. Major Frame 6 and 7 descriptions apply from WORD#38 to WORD#53.
4 and continuous	Repeat pattern of above four frames incrementally for all rows in the SWIR HDF supplement container.

Table 2.3.3-12. Content of data items in AST_L1T SWIR Supplement

Number	Description
0	Time Tag: Spacecraft Time Format
1	
2	
3	
4	
5	
6	
7	
8	Synchronous Code (6DE2B846)
9	
10	
11	
12	Frame Number (sequential number from 0 to 2^{24}-1)
13	
14	
15	WORD#38 MF-0: Optics monitor voltage A MF-2: Optics monitor voltage A MF-4: Optics monitor voltage A MF-6: Optics monitor voltage A
16	WORD#38 MF-1: Cooler current 3 MF-3: Cooler current 3 MF-5: Cooler current 3 MF-7: Cooler current 3

Number	Description
17	WORD#39 MF-0: Spare MF-2: Spare MF-4: Spare MF-6: Spare
18	WORD#39 MF-1: Cooler current 4 MF-3: Cooler current 4 MF-5: Cooler current 4 MF-7: Cooler current 4
19	WORD#40 MF-0: Optics monitor voltage B MF-2: Optics monitor voltage B MF-4: Optics monitor voltage B MF-6: Optics monitor voltage B
20	WORD#40 MF-1: Detector temperature (NARROW) MF-3: Detector temperature (NARROW) MF-5: Detector temperature (NARROW) MF-7: Detector temperature (NARROW)
21	WORD#41 MF-0: Spare MF-2: Spare MF-4: Spare MF-6: Spare
22	WORD#41 MF-1: TLM/CMD circuit reference voltage 1 MF-3: TLM/CMD circuit reference voltage 1 MF-5: TLM/CMD circuit reference voltage 1 MF-7: TLM/CMD circuit reference voltage 1
23	WORD#42 MF-0: Cooler current 1 MF-2: Cooler current 1 MF-4: Cooler current 1 MF-6: Cooler current 1
24	WORD#42 MF-1: TLM/CMD circuit reference voltage 2 MF-3: TLM/CMD circuit reference voltage 2 MF-5: TLM/CMD circuit reference voltage 2 MF-7: TLM/CMD circuit reference voltage 2
25	WORD#43 MF-0: Cooler current 2 MF-2: Cooler current 2 MF-4: Cooler current 2 MF-6: Cooler current 2
26	WORD#43 MF-1: TLM/CMD circuit reference voltage 3 MF-3: TLM/CMD circuit reference voltage 3 MF-5: TLM/CMD circuit reference voltage 3 MF-7: TLM/CMD circuit reference voltage 3

Number	Description
27	WORD#44 See Table 2.3.3-14 (MF-0, 2, 4, 6)
28	WORD#44 See Table 2.3.3-14 (MF-1, 3, 5, 7)
29	WORD#45 MF-0: See Table 2.3.3-15 MF-2: See Table 2.3.3-15 MF-4: See Table 2.3.3-15 MF-6: See Table 2.3.3-15
30	WORD#45 MF-1: Drive plus width MF-3: Drive plus width MF-5: Drive plus width MF-7: Drive plus width
31	WORD#46 MF-0: A/D reference voltage (Band 4) MF-2: Detector Dewar temperature MF-4: Collector module temperature 1 MF-6: Spare
32	WORD#46 MF-1: Calibration lamp voltage A MF-3: Barrel STR temperature MF-5: Electrical circuit temperature 1 (DRV) MF-7: Spare
33	WORD#47 MF-0: A/D reference voltage (Band 5) MF-2: Radiator temperature (Inner) MF-4: Collector module temperature 2 MF-6: Spare
34	WORD#47 MF-1: Calibration lamp voltage B MF-3: INE Mount temperature MF-5: Electrical circuit temperature 2 (PRO) MF-7: Spare
35	WORD#48 MF-0: A/D reference voltage (Band 6) MF-2: Radiator temperature A MF-4: Detector preamp/dewar temperature A MF-6: Spare
36	WORD#48 MF-1: Detector temperature (Wide) MF-3: Electrical circuit 1 temperature MF-5: Electrical circuit temperature 3A (CT) MF-7: Spare
37	WORD#49 MF-0: A/D reference voltage (Band 7) MF-2: Cover temperature 2A (-X) MF-4: Pointing mechanism temperature MF-6: Spare

Number	Description
38	WORD#49 MF-1: Motor amplitude MF-3: Electrical circuit 2 temperature MF-5: Electrical circuit temperature 4 (CAL) MF-7: Spare
39	WORD#50 MF-0: A/D reference voltage (Band 8) MF-2: Cover temperature 1A (+X) MF-4: Cooler temperature 1A (COMP) MF-6: Spare
40	WORD#50 MF-1: Spare MF-3: Pointing mechanism temperature 1 (MTR) MF-5: Optics monitor temperature A MF-7: Spare
41	WORD#51 MF-0: A/D reference voltage (Band 9) MF-2: Cover temperature 3A (+Z) MF-4: Cooler temperature 2A (C-FNG) MF-6: Spare
42	WORD#51 MF-1: Spare MF-3: Calibration lamp temperature MF-5: Optics monitor temperature B MF-7: Spare
43	WORD#52 MF-0: Drive plus number 1 MF-2: See Table 2.3.3-16 MF-4: See Table 2.3.3-16 MF-6: Spare
44	WORD#52 MF-1: See Table 2.3.3-16 MF-3: See Table 2.3.3-16 MF-5: Spare MF-7: Spare
45	WORD#53 MF-0: Drive plus number 2 MF-2: See Table 2.3.3-17 MF-4: See Table 2.3.3-17 MF-6: Spare
46	WORD#53 MF-1: See Table 2.3.3-17 MF-3: See Table 2.3.3-17 MF-5: Spare MF-7: Spare
47	reserved
48	reserved

Table 2.3.3-13. Format of data items in AST_L1T SWIR Supplement

Major Frame	Contents
0, 2, 4, 6	Bit-0: Pointing mirror encoder 1
	Bit-1: Pointing mirror encoder 1
	Bit-2: Pointing mirror encoder 1
	Bit-3: Pointing mirror encoder 1
	Bit-4: Pointing mirror encoder 1
	Bit-5: Pointing mirror encoder 1
	Bit-6: Pointing mirror encoder 1
	Bit-7: Pointing mirror encoder 1
1, 3, 5, 7	Bit-0: Pointing mirror encoder 3
	Bit-1: Mirror position status
	Bit-2: Mirror position status
	Bit-3: Mirror position limit status
	Bit-4: Limit ENA/DISA
	Bit-5: Pointing motor ENA/DISA
	Bit-6: Encoder on/off
	Bit-7: Motor rotation CW/CCW

Table 2.3.3-14. Bit structure of Word#44 in AST_L1T SWIR Supplement

Major Frame	Contents
0, 2, 4, 6	Bit-0: Pointing mirror encoder 2
	Bit-1: Pointing mirror encoder 2
	Bit-2: Pointing mirror encoder 2
	Bit-3: Pointing mirror encoder 2
	Bit-4: Pointing mirror encoder 2
	Bit-5: Pointing mirror encoder 2
	Bit-6: Pointing mirror encoder 2
	Bit-7: Pointing mirror encoder 2

Table 2.3.3-15. Bit structure of Word#45 in AST_L1T SWIR Supplement

Major Frame	Contents
1	Bit-0: Band 4 gain status
	Bit-1: Band 4 gain status
	Bit-2: Band 5 gain status
	Bit-3: Band 5 gain status
	Bit-4: Band 6 gain status
	Bit-5: Band 6 gain status
	Bit-6: Spare
	Bit-7: Spare
2	Bit-0: DIG SIG PROC PWR
	Bit-1: TML/CMD PWR on/off
	Bit-2: Analog circuit power on/off
	Bit-3: Spare
	Bit-4: Spare
	Bit-5: Spare

Major Frame	Contents
	Bit-6: Pointing CIR PWR
	Bit-7: Spare
3	Bit-0: THER CIR PWR
	Bit-1: Spare
	Bit-2: Spare
	Bit-3: Heater 3 on/off
	Bit-4: Heater 4 on/off
	Bit-5: Heater 5 on/off
	Bit-6: Spare
	Bit-7: Spare
4	Bit-0: Party flag status
	Bit-1: ERR CMD DIS status
	Bit-2: ERR CMD DIS status
	Bit-3: ERR CMD DIS status
	Bit-4: ERR CMD DIS status
	Bit-5: ERR CMD DIS status
	Bit-6: Spare
	Bit-7: Spare

Table 2.3.3-16. Bit structure of Word#52 in AST_L1T SWIR Supplement

Major Frame	Contents
1	Bit-0: Band 7 gain status
	Bit-1: Band 7 gain status
	Bit-2: Band 8 gain status
	Bit-3: Band 8 gain status
	Bit-4: Band 9 gain status
	Bit-5: Band 9 gain status
	Bit-6: Spare
	Bit-7: Spare
2	Bit-0: Calibration lamp power on/off
	Bit-1: Calibration lamp A/B selection
	Bit-2: Spare
	Bit-3: Spare
	Bit-4: Spare
	Bit-5: Spare
	Bit-6: Spare
	Bit-7: Spare
3	Bit-0: CLR motor amplitude status
	Bit-1: CLR motor amplitude status
	Bit-2: Spare
	Bit-3: Spare
	Bit-4: Detector temperature set status
	Bit-5: Detector temperature set status
	Bit-6: Spare
	Bit-7: Spare

Major Frame	Contents
4	Bit-0: Motor position status
	Bit-1: Motor position status
	Bit-2: Spare
	Bit-3: Spare
	Bit-4: Spare
	Bit-5: Spare
	Bit-6: Spare
	Bit-7: Spare

Table 2.3.3-17. Bit structure of Word#53 in AST_L1T SWIR Supplement

2.3.4 VNIR Group[26]

2.3.4.1 Overview

The VNIR Group contains an SDS and a Swath Object through the use of the Vgroup API. Vgroup name that establishes access to a Vgroup is as follows:

vgroup name: VNIR
class: 1T

Map projection method: Universal Transverse Mercator (UTM)

Resampling methods: Cubic Convolution (CC)

For further details on projection parameters (e.g., Projection Codes, Zone Codes, etc.), please refer to the HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 1: Overview and Examples (EOSDIS, 2014a), HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 2: Function Reference Guide (EOSDIS, 2014b), and the Release 8 SDP Toolkit Users Guide (EOSDIS, 2014c).

2.3.4.2 VNIR Swath

(1) Structure

The AST_L1T VNIR swath structure contains a single geolocation table and three VNIR band image data multidimensional arrays. The VNIR swath structure's geolocation information pertains to all three bands of VNIR data. The first point in the geolocation 2-dimensional array is the most north west pixel center in the UTM projection. Each row has a constant northing and each column has a constant easting since the scene is rotated to north up in the UTM projection.

For the AST_L1T product, all science data in the same sensor (telescope) are stored per band as 2-dimensional arrays in the swath structure. Therefore the VNIR swath structure contains band data in 2-dimensional arrays for bands 1, 2, and 3N. Band 3B is not included in the AST_L1T product.

(2) Characteristics

Table 2.3.4-18 shows the list of data items in VNIR Swath (sensor data for VNIR).
a) Data model: Swath
b) Object Name: VNIR_Swath
c) Format: Table 2.3.4-18 shows the contents of the Swath Object. Table 2.3.4-19 shows the format of the Swath Object.

No.	Field Name	Type	Unit	Comments
1.	Latitude	Geolocation Array	degree	**geodetic** latitude: decimal degree on range [-90.0, 90.0]
2.	Longitude	Geolocation Array	degree	geodetic longitude: decimal degree on range [-

[26] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.3

				180.0, 180.0)
3.	ImageData1	2D Data Array	N/A	AST_L1T spectral band 1 image data – DNs
4.	ImageData2	2D Data Array	N/A	AST_L1T spectral band 2 image data – DNs
5.	ImageData3N	2D Data Array	N/A	AST_L1T spectral band 3N image data– DNs

Table 2.3.4-18. List of data items in AST_L1T VNIR Swath

The VNIR backward looking band (3B) is not included in the AST_L1T product. Items in braces { } indicate typical values.

Field Name	Dimension Size	Variable Type	Remarks
Latitude	[11][11]	DOUBLE	geolocation field (array)
Longitude	[11][11]	DOUBLE	geolocation field (array)
ImageData1	{5140}{5750}	UINT8	mapping to geolocation array
ImageData2	{5140}{5750}	UINT8	mapping to geolocation array
ImageData3N	{5140}{5750}	UINT8	mapping to geolocation array

Table 2.3.4-19. Format of data items in AST_L1T VNIR Swath

(3) Block Size
Block size is shown as follows.

Type	Block size
Geolocation Array	(Number of lines)/10 * (Number of pixels per line)/10

2.3.4.3 VNIR Supplement Data[27]

(1) Description
VNIR Supplement Data contains VNIR status data, calibration data, pointing angles, temperatures and voltages.

(2) Characteristics
a) Data model: SDS (2 dimensional array)
b) Object Name: **VNIR_Supplement**
c) Format: Dimension size and variable type are as follows. Table 2.3.4-20 shows the contents of Supplement Data with relation to each column of the last dimension.

Dimension Size	Variable Type
[n][58]	UINT8

Where [n] is revised to accommodate a record count number (9,600: nominal).

Number	Description
0	Time Tag (UTC): Spacecraft Time Format (Time Tag is assigned to the leading supplement data to ensure the conformity with instrument data.)
1	
2	
3	

[27] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 2.3.4.6

Number	Description
4	
5	
6	
7	
8	Band 1 Detector Temperature
9	Band 2 Detector Temperature
10	Band 3N Detector Temperature
11	Band 3B Detector Temperature
12	Calibration Lamp A Temperature
13	Calibration Lamp B Temperature
14	Monitor Amp. Temperature
15	Photodiode 1 Temperature
16	Photodiode 2A Temperature
17	Photodiode 2B Temperature
18	VSP 1 Temperature
19	VSP 2 Temperature
20	VEL Base Plate Temperature
21	Nadir Telescope Temperature 1
22	Nadir Telescope Temperature 2
23	Nadir Telescope Temperature 3
24	Preamp 2 Temperature
25	Backward Telescope Temperature 2
26	Backward Telescope Temperature 3
27	VPS Lamp Power Supply Voltage
28	Photodiode 1A Output
29	Photodiode 1B Output
30	Photodiode 2A Output
31	Photodiode 2B Output
32	Electric Calibration Voltage.1
33	Electric Calibration Voltage.2
34	Electric Calibration Voltage.3
35	Electric Calibration Voltage.4
36	VSP1 APS Vol. +10V
37	VSP1 APS Vol. -10V
38	Pointing Angle 1
39	Pointing Angle 2
40	Initial Extract Address 1
41	Initial Extract Address 2
42	Spare
43	Spare
44	Bit-0: OPE, Optical/Electric Calibration Bit-1: Band 3 A/B Selection Bit-2,3: Band 3 Gain Selection (Bit-3, Bit-2) Low=(0,1), Normal=(0,0), High=(1,0) Bit-4,5: Band 2 Gain Selection (Bit-5, Bit-4) Low=(0,1), Normal=(0,0), High=(1,0) Bit-6,7: Band 1 Gain Selection (Bit-7, Bit-6) Low=(0,1), Normal=(0,0), High=(1,0)

Number	Description
45	Bit-0: Calibration Lamp A/B Selection Bit-1: PS1 On/Off Bit-2: PS3 On/Off Bit-3: Table Cancel On/Off Bit-4: PS4 On/Off Bit-5: Spare Bit-6: Spare Bit-7: Spare
46	Spare
47	Spare
48	Spare
49	Spare
50	Spare
51	Spare
52	Spare
53	Spare
54	Spare
55	Spare
56	Spare
57	Spare

Table 2.3.4-20. Format of data items in AST_L1T VNIR Supplement

2.3.5 TIR Group[28]

2.3.5.1 Overview

TIR Group contains a Vgroup and a Swath Object through the use of the Vgroup API. Vgroup name that establishes access to a Vgroup is as follows:

vgroup name: TIR
class: 1T

Map projection method: Universal Transverse Mercator (UTM)

Resampling methods: Cubic Convolution (CC)

For further details on projection parameters (Projection Codes, Zone Codes, etc.), please refer to the HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 1: Overview and Examples (EOSDIS, 2014a), HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 2: Function Reference Guide (EOSDIS, 2014b), and the Release 8 SDP Toolkit Users Guide (EOSDIS, 2014c).

2.3.5.2 TIR Swath

(1) Structure

The AST_L1T TIR swath structure contains a single geolocation table and five TIR band image data multidimensional arrays. The swath structure for this sensor contains a single geolocation component which pertains to all five TIR bands. The first point in the 2-dimensional geolocation array is the most north west pixel center in the UTM projection. Each row has a constant northing and each column has a constant easting since the scene is rotated to north up in the UTM projection.

For the AST_L1T product, all science data in the same telescope (or sensor) are stored per band as 2-dimensional arrays in the swath structure. Therefore the TIR swath structure contains band data for bands 10, 11, 12, 13, and 14.

(2) Characteristics

Table 2.3.5-21 shows the list of data items in TIR Swath (sensor data for TIR).
a) Data model: Swath
b) Object Name: TIR_Swath
c) Format: Table 2.3.5-21 shows the contents of the Swath Object. Table 2.3.5-22 shows the format of the Swath Object.

No.	Field Name	Type	Unit	Comments
1.	Latitude	Geolocation Array	degree	Geodetic latitude: decimal degree on range [-90.0, 90.0]
2.	Longitude	Geolocation Array	deg.	Geodetic longitude: decimal degree on range [-180.0, 180.0)

[28] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 3.3.5.

3.	ImageData10	2D Data Array	N/A	AST_L1T spectral band 10 image data– DNs
4.	ImageData11	2D Data Array	N/A	AST_L1T spectral band 11 image data– DNs
5.	ImageData12	2D Data Array	N/A	AST_L1T spectral band 12 image data– DNs
6.	ImageData13	2D Data Array	N/A	AST_L1T spectral band 13 image data– DNs
7.	ImageData14	2D Data Array	N/A	AST_L1T spectral band 14 image data– DNs

Table 2.3.5-21 List of data items in AST_L1T TIR Swath

Field Name	Dimension Size	Variable Type	Remarks
Latitude	[11][11]	DOUBLE	geolocation field (array)
Longitude	[11][11]	DOUBLE	geolocation field (array)
ImageData10	{860}{960}	UINT16	mapping to geolocation array
ImageData11	{860}{960}	UINT16	mapping to geolocation array
ImageData12	{860}{960}	UINT16	mapping to geolocation array
ImageData13	{860}{960}	UINT16	mapping to geolocation array
ImageData14	{860}{960}	UINT16	mapping to geolocation array

Table 2.3.5-22 Format of data items in AST_L1T TIR Swath

Items in braces { } indicate typical values.

(3) Block Size
Block size is shown as follows:

Type	Block size
Geolocation Array	(Number of lines)/10 * (Number of pixels per line)/10

2.3.5.3 TIR Supplement Data

(1) Description
TIR Supplement Data contains TIR status data, calibration data, pointing angles, etc. TIR Supplement Data contains a series of SDS (Temperature, Chopper, and Encoder) through the use of the Vgroup API. Vgroup name that establishes access to a Vgroup is as follows:

vgroup name: **TIR_Supplement**
class: **Supplement**

(2) Characteristics
Three categories in Vgroup object are shown as follows:

Supplement Data about Temperature

a) Data Object: SDS (2-Dimensional Array)
b) Object Name: **TIR_Supplement_Temp**
c) Format: Table 2.3.5-23 shows the dimension size and variable type. Table 2.3.5-24 shows the contents of Supplement Data about temperatures with relation to each column of the last dimension.

Dimension Size	Variable Type
[n][100][13]	UINT32
n: revised to accommodate a record count number (71: nominal).	

Table 2.3.5-23. Dimension Size and Variable Type of TIR Supplement Data (Temperature)

No.[1]	Description
0	Time Tag: Spacecraft Time Format
1	
2	Detector Temperature[2]
3	Temperature of Black-Body[2]
4	
5	
6	
7	
8	Temperature of Chopper[2]
9	
10	
11	Temperature of Telescope[2]
12	Temperature of Lens[2]

Table 2.3.5-24. Format of TIR Supplement Data (Temperature)

NOTES:
(1) 'No.' expresses the relative position in the last dimension. The dimension is entered in C order ('0' origin).
(2) Temperature data consists of two samplings within the each column. Each column is segmented as follows:

Segment Width	Temperature	Spare	Temperature	Spare
(bits)	12	4	12	4

Supplement Data about Chopper

a) Data Object: SDS (4-Dimensional Array)
b) Object Name: **TIR_Supplement_Chopper**
c) Format: Table 2.3.5-25 shows the format and contents of Supplement Data about chopper images.

Dimension Size	Variable Type
[n][100][10][8][1]	UINT8
n: revised to accommodate a processing scene. (71: nominal)	

Table 2.3.5-25. Format of TIR Supplement Data (Chopper[2])

NOTES:
(1) Chopper image is stored as ‘record * sampling * detector * component.’
(2) Each chopper image represents as follows:

Component	[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Band 10	Band 11		Band 12	Band 13		Band 14	Spare
Segment Width (bits)	12	12		12	12		12	4

Supplement Data about Encoder

a) Data Object: SDS (2-Dimensional Array)
b) Object Name: TIR_Supplement_Encoder
c) Format: Table 2.3.5-26 shows the format and contents of Supplement Data about encoder data.

Dimension Size	Variable Type
[n][935]	UINT16
n: revised to accommodate a processing scene (71: nominal).	

Table 2.3.5-26. Format of TIR Supplement Data (Encoder)

Section 3 Level 1T GeoTIFF Full Resolution Images

3.1 Overview

"GeoTIFF" refers to Tiff files which have geographic (or cartographic) data embedded as tags. The geographic data can then be used to position the image in the correct location and geometry on the screen of a geographic information display. GeoTIFF makes use of a public tag structure which is platform interoperable between any and all GeoTIFF-savvy readers. Any GIS, CAD, Image Processing, Desktop Mapping and any other types of systems using geographic images can read any GeoTIFF files created on any system to the GeoTIFF specification.

The AST_L1T algorithm produces full resolution GeoTIFF image files from AST_L1T science data (simultaneously with the reduced resolution browse JPEG). Full Resolution Images[29] (FRI) are provided for users who don't require all the science data bands for analysis and prefer GeoTIFF over HDF. FRI generation is sensitive to scenarios where one or more sensors have been turned off or have health issues (e.g., only TIR is on at night, SWIR was deemed unhealthy past April 1, 2008, and SWIR was turned off August 2012). Pixels are sized at 8-bits and remain DNs in each of the bands; the TIR bands were therefore scaled down from 12-bits to 8-bits, thus losing resolution.

Table 3.1-1 defines FRI pseudo color composite images generated from a subset of bands as determined by availability within each specific AST_L1T product.

Bands Available	Red	Green	Blue	Pixel Size	GeoTIFF Units
VNIR/SWIR	B4[30]	B3N	B2	15-meter	Changed from Radiance to Reflectance
VNIR only	B2	B3N	B1	15-meter	Changed from Radiance to Reflectance
TIR	B14	B12	B10	90-meter	Changed from Radiance to temperature factor scaled from 12-bit to 8-bit pixels

Table 3.1-1. GeoTIFF Full Resolution Image (FRI) Bands Characteristics.

[29] Paraphrased from section 4.1 ASTER Level 1T User's Guide.
[30] SWIR is resampled from 30 meter to 15 meter to align with VNIR bands.

3.2 GeoTIFF Specification

Table 3.2-2 defines key AST_L1T FRI GeoTIFF file characteristics that were extracted and combined from ArcMap, ENVI, and GDAL header dumps. A mapping of characteristics to GeoKey is provided for known GeoKeys (represented in blue text).

File Characteristic	Type[31]	Description
---- Data Source ----		
Folder	*Implied*	*Variable: "Source File System Directory"*
File	*Implied*	*Variable: "Source HDF file name" replacing file extension with _V.tif for Visual Tiff or ._T.tif for Thermal Tiff* *Example:* *AST_L1T_00307102000015506_20150324143949_25623_V.tif*
---- Raster Properties ----		
Uncompressed Size		Variable: Approximately _V.tif 85MB ._T.tif approximately 2MB
Raster Type		Fixed: (File System Raster) TIFF
Columns	Integer	Variable: Same value as DimensionName="ImagePixel" in HDF header StructMetadata.0 for VNIR also first dimension in IMAGEDATAINFORMATIONn (n=1,2, 3N) HDF header productmetadata.v **OR** Same value as DimensionName="ImagePixel" in HDF header StructMetadata.0 for TIR also first dimension in IMAGEDATAINFORMATIONn (n=10, 11,12, 13, or 14)) HDF header productmetadata.t Example: 5,533 (.v) or 935 (.t) PixelIsArea first coordinate
Rows	Integer	Variable: Same value as DimensionName="ImageLine" in HDF header StructMetadata.0 for VNIR also second dimension in IMAGEDATAINFORMATIONn (n=1,2, 3N) HDF header productmetadata.v **OR** Same value as DimensionName="ImageLine" in HDF header StructMetadata.0 for TIR also second dimension in IMAGEDATAINFORMATIONn (n=10, 11,12, 13, or 14)) HDF header productmetadata.t Example: 4873 (.v) or 829 (.t) PixelIsArea second coordinate
Raster Type	Short	Fixed: RasterPixelIsArea indicates that the pixel represents an area rather than a point on the map. GTRasterTypeGeoKey

[31] Users should consult the GeoTIFF Format Specification for the appropriate GeoKey to Reference Name mapping definitions to verify the "TYPE" listed in this table; where the mapping is clear, the key is given in the Description column.

File Characteristic	Type[31]	Description
Raster to Model Tie Points	Double 6	Variable 2 three-dimensional arrays: (I, J, K) and (X, Y, Z) where (I,J) represents the upper left pixel (raster) tie point and (X,Y) represent upper left map (model) tie point. K and Z are not used. Example: (0, 0, 0) (516142.500, 5166997.500, 0) ModelTiepointTag
Pixel Resolution	Double 3	Variable three-dimensional array: Three dimensional scale of the raster pixel = (ScaleX, ScaleY, ScaleZ). One of (15, 15, 0) for _V.tif or (90, 90, 0) for _T.tif. ModelPixelScaleTag
Number of Bands	*[32]	Fixed: 3
Interleave Type	*	Fixed: BIP ("INTERLEAVE=PIXEL")
Data Type	*	Fixed: Byte (TIR was rescaled from 0-4095 down to 0-255)
Pixel Depth	*	Fixed: 8-Bit
No Data Value	*	Fixed: 0
Colormap	*	Fixed Band 1: ColorInterp=Red Fixed Band 2: ColorInterp=Green Fixed Band 3: ColorInterp=Blue
Pyrmids	*	Absent
Compression	*	Fixed: None
---- Map Info Properties ----		
Projection Type	Short	Fixed: ModelTypeProjected GTModelTypeGeoKey
Pixel Tie Point X	Double	Fixed: 0.0 (For any given pixel, West most pixel edge in meters)
Pixel Tie Point Y	Double	Fixed: 0.0 (For any given pixel, North most pixel edge in meters)
Map Tie Point X	Double	Variable: West most scene pixel in UTM meters Same value as second dimension in UPPERLEFTM in HDF header productmetadata.1 less ½ pixel (½ pixel is 7.5 meters for _V.tif, 45 meters for _T.tif) Example: 635122.5 ModelTiepointTag (2,1) in 2x3 array
Map Tie Point Y	Double	Variable: North most scene pixel in UTM meters Same value as first dimension in UPPERLEFTM in HDF header productmetadata.1 plus ½ pixel (half pixel is 7.5 meters for _V.tif, 45 meters for _T.tif) Example: 3896737.5 ModelTiepointTag (2,2) in 2x3 array
Pixel Size X	Double	Fixed: 15.0 for _V.tif or 90.0 for _T.tif ModelPizelScaleTag
Pixel Size Y	Double	Fixed: 15.0 for _V.tif or 90.0 for _T.tif ModelPizelScaleTag
Units	Short	Fixed: Linear_Meter ProjLinearUnitsGeoKey
Rotation	Double	Fixed: 0.0
---- Coordinate System Properties ----		

[32] Several tools report on this characteristic but it is not found in the GeoTIFF Format Specification.

File Characteristic	Type[31]	Description
Projected Coordinate System	Short	Variable: "PCS_WGS84_UTM_zone_zzN" where “zz” ranges between 1 and 60. “N” for Northern hemisphere is used exclusively. (“S” for Southern hemisphere is not used in this product rather negative values are used) ProjectedCSTypeGeoKey
GeoTIFF Configuration	String	Variable: "UTM Zone zz, Northern Hemisphere" where zz is zone number. Provided to give an ASCII reference to published documentation on the overall configuration of the GeoTIFF file GTCitationGeoKey
Geographic Coordinate System	Short	Fixed: "GCS_WGS_1984" GeographicTypeGeoKey
	String	"WGS 84" GeogCitationGeoKey
Geodetic Datum	Short	Fixed: Datum_WGS84 World Geodetic System 1984 GeogGeodeticDatumGeoKey
Ellipsoid (Spheroid)	Short	Fixed: Ellipse_WGS_84 Translates to "WGS 1984, 6378137.0, 298.257223563 GeogEllipsoidGeoKey
Prime Meridian	Short	Fixed: PM_Greenwich GeogPrimeMeridianGeoKey
Angular Unit	Short	Fixed: Angular_Degree Translates to “Degree”, 0.0174532925199433 GeogAngularUnitsGeoKey
Coordinate Transformation Code (Projection Method)	Short	Fixed: CT_TransverseMercator ProjCoordTransGeoKey
False Easting	Double	Fixed: 500000.0 ProjFalseEastingGeoKey
False Northing	Double	Fixed: 0.0 ProjFalseNorthingGeoKey
Longitude of Origin (Central Meridian)	Double	Variable: Longitude center of UTM Zone (One of 60 possible values pegged to the UTM zone for this product. Zones are 6 degrees wide.) Examples: 135.0, -117.0 ProjNatOriginLongGeoKey
Latitude of Origin	Double	Fixed: 0.0 ProjNatOriginLatGeoKey
Scale Factor	Double	Fixed: 0.9996 ProjScaleAtNatOriginGeoKey
Unit	Short	Fixed: Linear_Meter ProjLinearUnitsGeoKey
---- Extents Properties ----		
Extent Left	*	Variable: West most scene pixel in meters Same value as second dimension in UPPERLEFTM or LOWERLEFTM in HDF header productmetadata.1 less half pixel (7.5 meters for _V.tif, 45 meters for _T.tif) Example: 635122.5

File Characteristic	Type[31]	Description
Extent Top	*	Variable: North most scene pixel in meters Same value as first dimension in UPPERLEFTM or UPPERRIGHT in HDF header productmetadata.1 plus half pixel (7.5 meter , 45 meters for _T.tif) Example: 3896737.5
Extent Right	*	Variable: East most scene pixel in meters Same value as second dimension in UPPERRIGHTM or LOWERRIGHTM in HDF header productmetadata.1 plus half pixel (7.5 meters for _V.tif, 45 meters for _T.tif) Example: 718117.5
Extent Bottom	*	Variable: South most scene pixel in meters Same value as first dimension in LOWERLEFTM or LOWETRIGHTM in HDF header productmetadata.1 less half pixel (7.5 meter , 45 meters for _T.tif) Example: 3823642.5
---- Spectral Properties ----		
Band Names 1	*	Fixed: Band 1
Band Names 2	*	Fixed: Band 2
Band Names 3	*	Fixed: Band 3
---- Statistics ----		
For All Bands	*	Statistics have not been calculated
---- Time Properties ----		
Acquisition Time	*	Unknown (Acquisition and production times are found in the file name)

Table 3.2-2. List of GeoKeys in AST_L1T GeoTIFF.

3.3 GeoTIFF Header Report

The Geospatial Data Abstraction Library, found at http://www.gdal.org, makes available (under User Oriented Documentation, Raster utility programs) a number of GeoTIFF tools which includes a GeoTIFF Information report generator (GDALinfo). GDALinfo calculates scene-center-Northing as the Extent-Top plus Extent-Bottom divided by two and scene-center-Easting as the Extent-Left plus Extent-Right divided by two. GDALinfo also converts UTM coordinates to latitude and longitude degrees, minutes and seconds using well-established conversion tools. The following is an example of a GDALinfo report for a sample AST_L1T GeoTIFF product in the southern hemisphere:

```
Driver: GTiff/GeoTIFF
Files: AST_L1T_00303262010005617_20150407085647_114813_T.tif
```

```
Size is 924, 814
Coordinate System is:
PROJCS["WGS 84 / UTM zone 54N",
    GEOGCS["WGS 84",
        DATUM["WGS_1984",
            SPHEROID["WGS 84",6378137,298.257223563,
                AUTHORITY["EPSG","7030"]],
            AUTHORITY["EPSG","6326"]],
        PRIMEM["Greenwich",0],
        UNIT["degree",0.0174532925199433],
        AUTHORITY["EPSG","4326"]],
    PROJECTION["Transverse Mercator"][33],
    PARAMETER["latitude_of_origin",0],
    PARAMETER["central_meridian",141],
    PARAMETER["scale_factor",0.9996],
    PARAMETER["false_easting",500000],
    PARAMETER["false_northing",0],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]],
    AUTHORITY["EPSG","32654"]]
Origin = (325485.000000000000000,-3409515.000000000000000)
Pixel Size = (90.000000000000000,-90.000000000000000)
Metadata:
  AREA_OR_POINT=Area
Image Structure Metadata:
  INTERLEAVE=PIXEL
Corner Coordinates:
Upper Left  (  325485.000,-3409515.000) (139d10'32.88"E, 30d48'21.27"S)
Lower Left  (  325485.000,-3482775.000) (139d 9'47.18"E, 31d27'59.75"S)
Upper Right (  408645.000,-3409515.000) (140d 2'41.72"E, 30d48'54.82"S)
Lower Right (  408645.000,-3482775.000) (140d 2'17.78"E, 31d28'34.18"S)
Center      (  367065.000,-3446145.000) (139d36'19.85"E, 31d 8'30.19"S)
Band 1 Block=924x2 Type=Byte, ColorInterp=Red
Band 2 Block=924x2 Type=Byte, ColorInterp=Green
Band 3 Block=924x2 Type=Byte, ColorInterp=Blue
```

[33] Universal Transverse Mercator (UTM) is a more specific variation of the Transverse Mercator (TM) system; for AST_L1T, the northing coordinates are negative values in the Southern Hemisphere which GDALinfo interprets as going to the more general case. Current analysis tools recognize a zero false northing with a 500,000-meter false easting as a valid representation of UTM for both hemispheres. A Southern Hemisphere GeoTIFF was selected for this example to show the variation from standard UTM.

References and Information

EOSDIS	170-EED-001, Revision 02, 2014a, HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 1: Overview and Examples, available at: http://newsroom.gsfc.nasa.gov/sdptoolkit/docs/2.19/HDF-EOS_UG.pdf
EOSDIS	170-EED-002, Revision 02, 2014b, HDF-EOS Library User's Guide for EOSDIS Evolution and Development (EED) Contract, Volume 2: Function Reference Guide, available at: http://newsroom.gsfc.nasa.gov/sdptoolkit/docs/2.19/HDF-EOS_REF.pdf
EOSDIS	333-EED-001, 2014c, Release 8 SDP Toolkit Users Guide, available at: http://newsroom.gsfc.nasa.gov/sdptoolkit/docs/333eed001.html
ERSDAC	AG-E-E-2209-R03, 2001, ASTER Level 1 Data Products Specification (GDS Version) Version 1.3
ERSDAC	Level 1 Data Working Group, ASTER Science Team,1996, Level 1 Algorithm Theoretical Basis Document for ASTER Level 1 Data Processing Version 3
USGS/LP DAAC	Meyer, Siemonsma, Johnson, Brooks, 2015, Algorithm Theoretical Basis Document (ATBD) for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Level 1 Terrain and Precision Corrected Product (AST_L1T)
JPL	Abrams, Hook, Ramachandran, 2002, ASTER User Handbook Version 2
JPL, Spot	Ritter, Ruth, 28 December, 2000, GeoTIFF Format Specification, GeoTIFF Revision 1.0, Specification Version: 1.8.2 available at: ftp://ftp.remotesensing.org/pub/geotiff/spec/
USGS/LP DAAC	Duda, Daucsavage, 2015, ASTER Level 1T User's Guide
NASA/ECS	WBS-WP-003-001, HDF-EOS User's Guide for ECS Project
NASA/ECS	333-CD-004-001, SDP Toolkit Users Guide for the ECS Project

Glossary

ASTER – The Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument provides 14 multispectral bands from visible through thermal infrared.

AST_L1T PGE – The AST_L1T product generation executable (PGE) specifically is the software executable that implements the L1T algorithms to create the AST_L1T product. Used generically throughout this document to represent all the software used in creating the AST_L1T product that includes the AST_L1T executable.

EarthExplorer – A USGS EROS Earth Science metadata and service discovery tool linked to the USGS inventory. The EE user client allows users to query collections for granules, view reduced resolution (thumbnail) browse, view collection or granule metadata, view QA information, view granule extents on a map, and select individual granules for direct download from the LP DAAC.

Earth Science Data Type – A product definition used to convey relationships between product attributes and their characteristics and to enable EOSDIS Core System interfaces for a product.

ECHO – The EOS Clearing HOuse (ECHO) is an Earth Science metadata and service registry populated with metadata and browse imagery from data partners, such as the LP DAAC. ECHO is an open system providing Application Program Interfaces (APIs) to the Earth science communities, which are used to build client systems. The LP DAAC exports metadata information to ECHO, which provides product inventory to the Reverb user client. ECHO serves as an order broker for user client systems.

Global Visualization Viewer (GloVis) – A USGS EROS Earth Science data discovery tool linked to the USGS inventory. GloVis provides a graphic map display from which a user can select any area of interest and immediately view all available browse images within the USGS inventory for the specified location.

Granule – Used to represent a collection of files that aggregate together to make up a whole instance of a given level of a product (science data, browse and QA).

Historical Processing – The operation executed to process lower-level products to replace higher-level products is generally referred to as reprocessing in the earth science community. Reprocessing implies that an older version of the higher-level product will be supplanted with a newer version. A special case of reprocessing occurs when there is no older version to replace. This special case is referred to as historical processing because it is needed to initialize the collection usually going back through an archive from the point where forward processing of the new product eventually started.

Product – Often used in the context as the output of a process that converts an input to a new science level. Product is the preferred term but use often becomes unwieldy in sentences containing several derivations of the word so scene or granule may be substituted.

Reverb – A NASA-provided Earth Science metadata and service discovery tool linked to the ECHO inventory. The Reverb user client allows users to create accounts, view collection summary information, filter product collections using keywords, save queries as bookmarks, query collections for granules, view reduced resolution (thumbnail) browse, view collection or granule metadata, view QA information, view granule extents on a map, select individual granules for direct download, or place orders to data providers, such as the LP DAAC.

Scene – A single granule or science data product. Most often used in a visual context or as an index in a database.

Scientific Datasets (SDS) – An SDS is a multidimensional array filled by data.

Swath – A swath is a continuous acquisition image strip which can be cut up into scenes. The Swath StructMetadata technically defines sensor (telescope) structures for each band although the term “swath” is used in the metadata object names for these sensor containers.

Vdata – Vdata, or vertex data, are data structures in HDF that consist of a collection of records whose values are stored in fixed-length fields.

Vgroup – A Vgroup, or vertex group, is a structure in HDF designed to associate related data objects.

Acronyms

Acronym	Description
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer – an instrument on the Terra satellite
ATBD	Algorithm Theoretical Basis Document
CAL/VAL	Calibration / Validation
DEM	Digital Elevation Model
DN	Digital Numbers
ECHO	EOS Clearing HOuse
ECS	EOSDIS Core System
EDOS	EOS Data and Operations System
EDS	Expedited Dataset
EE	EarthExplorer – Search system for direct download of ASTER products
EOS	Earth Observing System
EROS	Earth Resources Observation and Science
ESDIS	Earth Science Data and Information System
ESDT	Earth Science Data Type
ETM+	Enhanced Thematic Mapper Plus (a Landsat instrument)
EXP	Expedited
FRI	AST_L1T Full Resolution Image (GeoTIFF)
GDS	Ground Data System (Japan)
GloVis	USGS Global Visualization Viewer – Search system for direct download and/or order of ASTER products
GUI	Graphical User Interface
HDF	Hierarchical Data Format
HTTP	HyperText Transfer Protocol
JPL	Jet Propulsion Laboratory
L1A	ASTER Level 1 Reconstructed, Unprocessed Instrument Data
L1B	ASTER Level 1 Registered Radiance at the Sensor
L1T	AST Level 1 Terrain and Precision Corrected at Sensor Radiance
LP DAAC	Land Processing Distributed Active Archive Center
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
ODL	Object Description Language
OLI	Operational Land Imager (a Landsat Instrument)
PGE	Product Generation Executable
Reverb	NASA system for direct download and/or order of ASTER products via ECHO inventory
SDS	Scientific Dataset
SILC	Sensor Information Laboratory Corporation (for ASTER)
SIPS	Science Investigator-led Processing Systems
SWIR	Short Wave Infrared
TIR	Thermal Infrared (Long Wave)
TIRS	Thermal Infrared Sensor (a Landsat Instrument)
TM	Thematic Mapper (a Landsat Instrument)
USGS	United States Geological Survey
VNIR	Visible Near Infrared

Standards and Conventions

Primary Reference Document

The remainder of this section is paraphrased from Section 1 of the ERSDAC AST_L1 Data Products Specification (GDS) Version 1.3. Sections 2 and 3 of that document provide specifications on AST_L1A and AST_L1B products respectively. Section 4 of this document conforms to the format of the ERSDAC document and serves as a supplement providing specifications on the AST_L1T product.

Coordinates Systems[34]

The following coordinates systems used in this specification:

- Spacecraft Reference Frame
- Orbital Reference Frame
- Earth-Centered Inertial Coordinates System
- Earth Greenwich Coordinates System

All coordinates systems are right-handed Cartesian coordinates systems.

(1) Spacecraft Reference Frame - Attitude reference frame of spacecraft bus

[Origin]	Spacecraft Center of Mass	
[Reference Direction]	X-axis	Roll axis
	Y-axis	Pitch axis
	Z-axis	Yaw axis

(2) Orbital Reference Frame- reference frame of flight attitude on orbit

[Origin]	Spacecraft Center of Mass	
[Reference Plane]	X-Y Plane	Normal to the position vector
	Z-axis	Directed toward geocentric nadir
[Reference Direction]	X-axis	Vector cross product between Z-axis and Y-axis that is normal to the orbit, anti-parallel to the angular momentum

(3) Earth-Centered Inertial Coordinates System (Mean Equator and Equinox of J2000) - Geocentric-Equatorial Inertial (GEI_{2000}) Coordinate System

[Origin]	Center of the Earth	
[Reference Plane]	X-Y Plane	Plane of Earth's mean equator
	Z-axis	Along Earth's rotational axis, with north positive
[Reference Direction]	X-axis	Directed toward the vernal equinox

[34] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 1.2.

(4) Earth Greenwich (Earth-Centered Rotating: ECR) Coordinates System – Geographic (GEO)

[Origin]	Center of the Earth	
[Reference Plane]	X-Y Plane	Plane of Earth's equator
	Z-axis	Along Earth's rotational axis, with north positive
[Reference Direction]	X-axis	Directed toward the prime (Greenwich) meridian

When coordinates are expressed in spherical form, the latitude component is termed *geocentric latitude* by astronomers and geographers. However, note that this is different to the system of *geodetic latitude* used in normal map-making. The *geodetic latitude* at any location is the angle between the equatorial plane and the local normal to the Earth's surface. In general, the local normal is NOT parallel to a radius vector because the shape of the Earth is an oblate spheroid and not a sphere.[35]

Time Code Formats[36]

Time and date described in AST_L1T data products are expressed in two formats; CCSDS ASCII Time Code (A format) and Spacecraft Time Format (CCSDS Day Segmented Time Code: CDS). Tables in this document indicate which format is in use. The time code formats can be represented as a combination of a preamble (P) field and a time (T) field. But the P-field is implied and not actually transmitted (e.g., this information is not included in these products).

Both time-code formats are defined in CCSDS 301.0-B-2, Blue Book Issue 2: Time Code Formats published by the Consultative Committee for Space Data Systems (NASA Code-OS, NASA, Washington DC 20546), April 1990.

CCSDS ASCII Calendar Segmented Time Code (ASCII)

CCSDS ASCII segmented time code is composed of a variable number of ASCII characters forming the T-field. ASCII time code variations are UTC (Universal Time Coordinated) based and leap second corrections are made.
The format for ASCII Time Code A as used in AST_L1 Data Processing Subsystem:

YYYY-MM-DDThh:mm:ssZ
or
YYYY-MM-DDThh:mm:ss.d→dZ

Where:

YYYY	Four character subfield for year, with value in range 1970 ~ 2038
MM	Two character subfield for month with values 01 ~ 12, leading zeros
DD	Two character subfield for day with values in the range 01 ~ end of month (where end of month is 28, 29, 30, or 31 according to the)
T	Time separator
hh	Two character subfield for hours, with values 00 ~ 23

[35] http://www.mssl.ucl.ac.uk/grid/iau/extra/local_copy/SP_coords/geo_sys.htm
[36] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 1.3.

mm Two character subfield for minutes, with values 00 ~ 59

ss Two character subfield for seconds, with values 00 ~ 59
(00 ~ 60 in a positive leap second interval, 00 ~ 58 in the case of negative leap second)

d→d N-character subfield, (n < 6), for decimal fraction of a second, with each digit in range 0 ~ 9 (optional)

Z a terminator (UTC is sometimes known as Zulu time)

Spacecraft Time Format (CDS)

Spacecraft Time Format contains the 64-bit CCSDS Day Segmented Time Code (DST) T-field as defined in the following table. Spacecraft Time Code consists of a selected number of continuous time segments. Each segment represents the state of a binary counter cascaded with the adjacent counters, which roll over at a module specified for each counter.

Width (bits)	Description	Units
16	Days since 1958 January 1. The first bit is always "0".	Days
32	Millisecond of Day (number milliseconds since beginning of current day)	msec
16	Microsecond of Millisecond (number microseconds in current millisecond)	µsec

Format of CCSDS Day Segmented Time Code (DST) T-field

Data Type Definitions[37]

The following table provides data types used in field definitions.

Definition	Name Description
DATETIME	CCSDS ASCII Time Code (A format)
FLOAT	IEEE single-precision (32-bit) format float type
DOUBLE	IEEE double-precision (64-bit) format float type (6 digits after the decimal-point character).
STRING	A text string value consists of a text string lexical elements
INT8	8-bit integer type
UINT8	8-bit unsigned integer type
INT16	16-bit integer type
UINT16	16-bit unsigned integer type
INT32	32-bit integer type
UINT32	32-bit unsigned integer type
INTEGER	Same as INT32
SHORT	Reserved integer defining GeoKey codes

Data Type Definitions

Strip Observation Mode[38]

The following table defines the strip observation modes of operation.

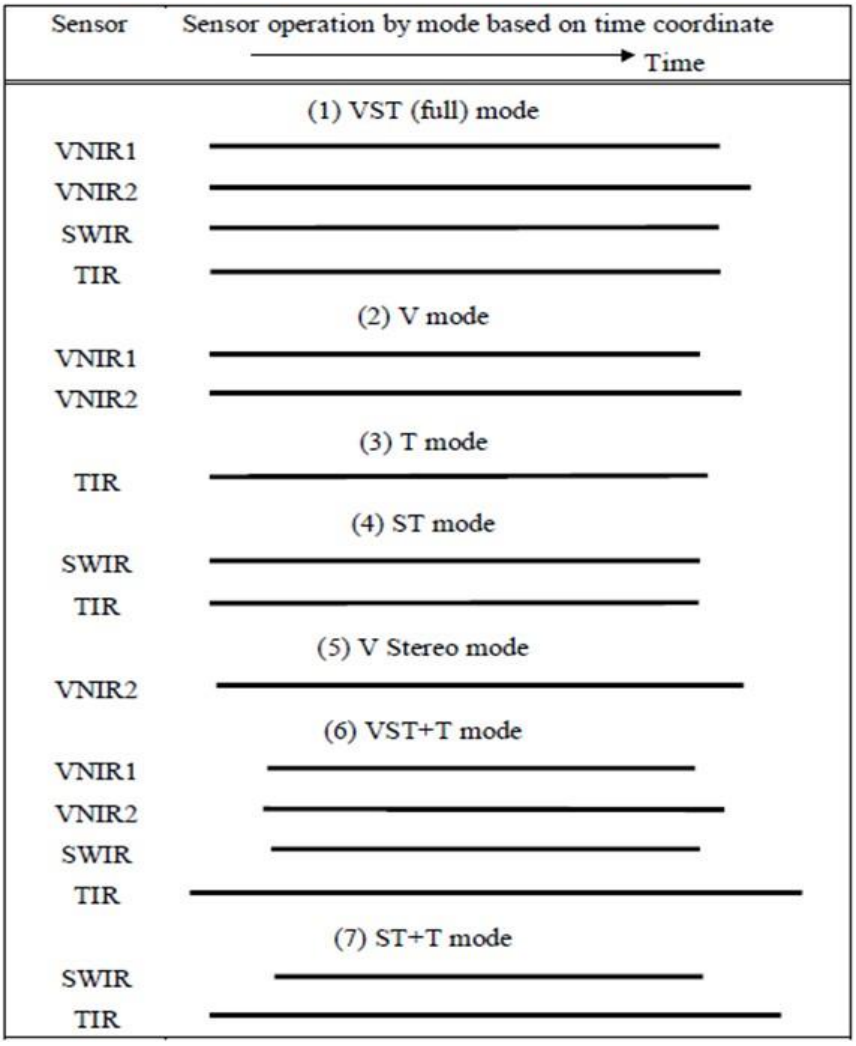
[37] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 1.4.

[38] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 1.5.

ASTER OBS Mode				Processed Bands	Sensor Short Name	Strip Mode
VNIR1	VNIR2	SWIR	TIR	ProcessedBands	SensorShortName	Mode **(fig)**
ON	ON	ON	ON	01023N3B040506070809101112131 4	ASTER_VNIR ASTER_SWIR ASTER_TIR	VST (1) VST+T (6)
ON	ON	OFF	OFF	01023N3BXXXXXXXXXXXXXXXXXXXXX	ASTER_VNIR	V (2)
OFF	OFF	OFF	ON	XXXXXXXXXXXXXXXXXX1011121314	ASTER_TIR	T (3)
OFF	OFF	ON	ON	XXXXXXXX040506070809101112131 4	ASTER_SWIR ASTER_TIR	ST (4) ST+T (7)
OFF	ON	OFF	OFF	XXXX3N3BXXXXXXXXXXXXXXXXXXX	ASTER_STEREO	V-Stereo (5)
ON	ON	ON	ON	XXXXXXXXXXXXXXXXXX1011121314	ASTER_TIR	VST+T (6)
OFF	OFF	ON	ON	XXXXXXXXXXXXXXXXXX1011121314	ASTER_TIR	ST+T (7)

Strip Observation Mode Defined

The following figure provides a conceptual view of the strip (observation) mode.



Conceptual View of the Strip Observation Mode

Map Projection Parameters[39]

The following table defines map projection parameters used in AST_L1T processing. The software uses the Geo-Coordinate Transformation (GCT) tools, based on the commonly available packages General Cartographic Transformation Package (GCTP) contained in the SDP Toolkit routines.

	Array Element[40]							
Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
UTM[41]	SMajor	SMinor	Factor		CentMer	OriginLat	FE	FN
LAMCC	SMajor	SMinor	STDPR1	STDPR2	CentMer	OriginLat	FE	FN
PS	SMajor	SMinor		LongPol	LTrueScale	FE	FN	
EQRECT	Sphere			CentMer	LTrueScale	FE	FN	
SOM	SMajor	SMinor		IncAng	AscLong		FE	FN

Name	**9**	**10**	**11**	**12**	**13**
UTM					
LAMCC					
PS					
EQRECT					
SOM	PSRev	LRat	PFlag		zero

Projection Transformation Package Projection Parameters Elements

Where:

SMajor	**Semi-major axis of the ellipsoid**
SMinor	Semi-minor axis of the ellipsoid
Sphere	Radius of reference sphere
STDPR1	Latitude of the first standard parallel
STDPR2	Latitude of the second standard parallel
CentMer	Longitude of the central meridian
OriginLat	Latitude of the projection origin
FE	False easting in the same units as the semi-major axis
FN	False northing in the same units as the semi-major axis
LTrueScale	Latitude of true scale
LongPol	Longitude down below pole of map
Factor	Scale factor at central meridian
CentLat	Latitude of center of projection
IncAng	Inclination of orbit at ascending node, counter-clockwise from equator
AscLong	Longitude of ascending orbit at equator
PSRev	Period of satellite revolution in minutes
LRat	Landsat ratio to compare for confusion at northern end of orbit (ASTER: 0.5201613)
PFlag	End of path flag for Landsat: 0 = start of path, 1 = end of path (ASTER: 0)
zero	0.0

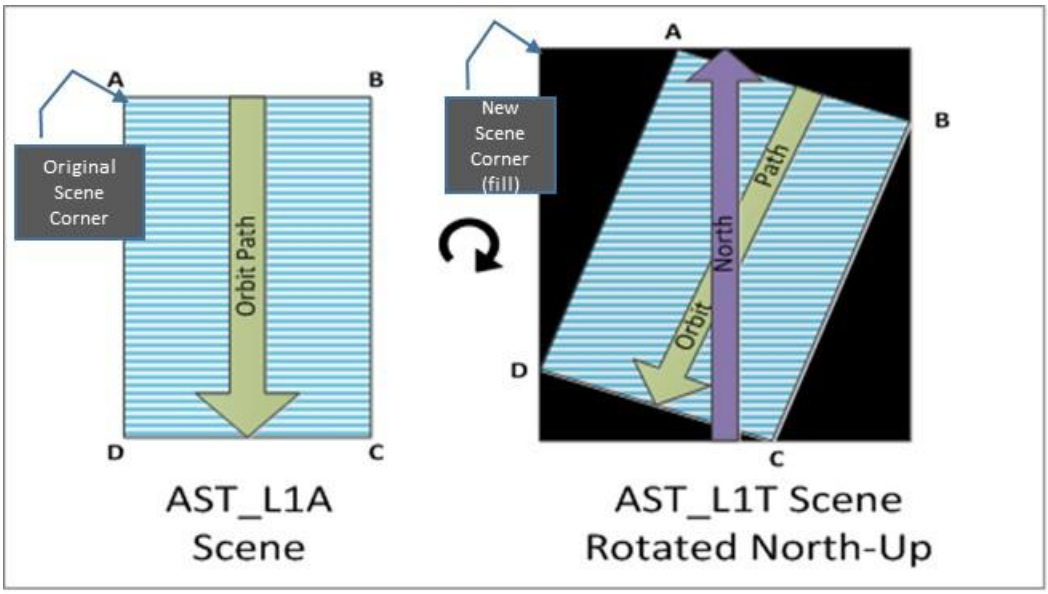
Geographic Conventions

[39] Paraphrased from ERSDAC ASTER Level 1 Data Products Specification (GDS Version) Section 1.6.

[40] All array elements with blank fields are set to zero. All angles are in radians.

[41] The ASTER Level 1 Data Processing Subsystem software uses TM for the treatments of the scene across the zone boundary. Longitude is negative west of Greenwich and latitude is negative south of the equator. False northing is not used.

The following figure illustrates the actual image after AST_L1A scene has been rotated north-up. For an AST_L1A image, the locations of the four corners correspond to the area of the actual image. In the case of AST-L1B and AST_L1T images, these locations correspond to the corners of the entire scene (the four corners include the fill or no-data area).



AST_L1A Image Rotated North-Up in AST_L1T Product

AST_L1B data define a scene center as the geodetic center of the scene obtained from the AST_L1A attribute named "SceneCenter" from the HDF-EOS2 *productmetadata.0* attribute. SceneCenter in AST_L1T is not exactly the same as in AST_L1A, rather it is the actual center on the rotated coordinates.[42] The following table provides an example of the embedded metadata listing the four corners[43] and scene center for AST_L1A, AST_L1B, and AST_L1T products in degrees.

Example: AST_L1T_00303022001180031		
AST_L1A (y,x)	**AST_L1B (y,x)**	**AST_L1T (y,x)**
OBJECT = UPPERLEFT	***OBJECT = UPPERLEFT***	***OBJECT=UPPERLEFT***
VALUE = (38.371925, -104.985303)	VALUE = (38.38275034471, -105.063365793084)	VALUE=(38.3824888283457, -105.18193394103)
OBJECT = UPPERRIGHT	**OBJECT = UPPERRIGHT**	**OBJECT=UPPERRIGHT**
VALUE = (38.276098, -104.268059)	VALUE = (38.2696062382925, -104.220911313396)	VALUE=(38.3800318673019, -104.219513324943)
OBJECT = LOWERLEFT	***OBJECT = LOWERLEFT***	***OBJECT=LOWERLEFT***
VALUE = (37.817597, -105.139441)	VALUE = (37.8225375573003, -105.180457655311)	VALUE=(37.7108562381888, -105.180279399827)
OBJECT = LOWERRIGHT	***OBJECT = LOWERRIGHT***	***OBJECT=LOWERRIGHT***

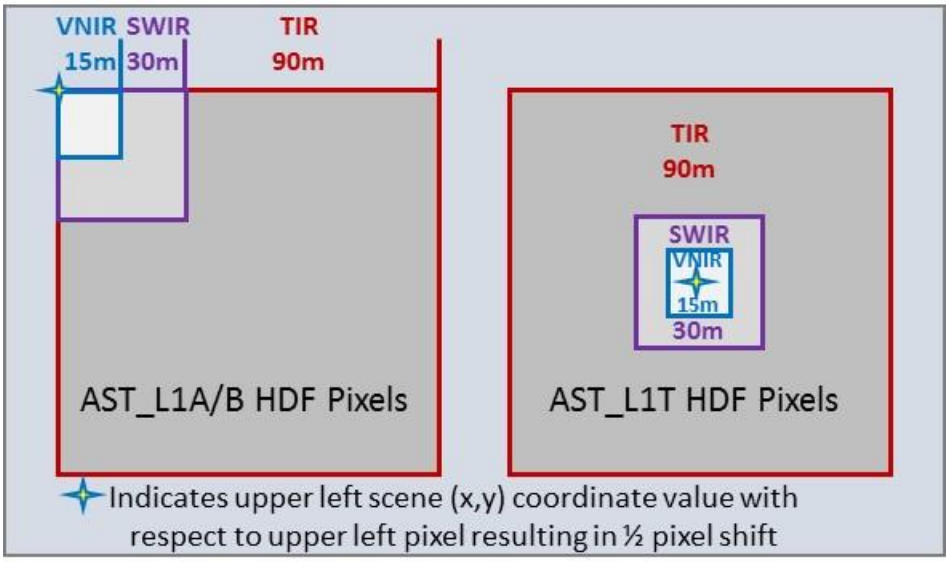
[42] Experience indicates that differences are observed at the sixth significant digit following the decimal in latitude only.

[43] Points are in (y,x) notation where "y" latitude and "x" is longitude.

VALUE = (37.722386, -104.427565)	VALUE = (37.7102666494694, -104.344198661)	VALUE=(37.7084575408995, -104.226610397362)
OBJECT = SCENECENTER	***OBJECT = SCENECENTER***	***OBJECT=SCENECENTER***
VALUE = (38.047135, -104.702209)	VALUE = (38.047135, -104.702209)	VALUE=(38.0471370921037, -104.702209)

Geographic Extent (Degrees) for ASTER Level 1 HDF Products

The following figure illustrates that the AST_L1T HDF corner pixels from each instrument are co-centered unlike the case for AST_L1A and AST_L1B. This is done to facilitate the AST_L1T terrain-precision correction process. Because of the pixel dimensions, AST_L1T TIR pixels are co-centered with every third SWIR pixel and every sixth VNIR pixel. Likewise, every SWIR pixel is co-centered with every other VNIR pixel.



Pixel Centering for AST_L1A/B and AST_L1T Bands

The LP DAAC introduced new metadata fields in the AST_L1T embedded *productmetadata.1* group to include spheroid code, UTM zone number, scene four corners, and scene center. These fields complement the map projection method (a fixed value of "UTM") found in embedded metadata fields of the *productmetadata.{v, s, or t}* groups carried forward from AST_L1B to AST_L1T for each band. This allows LP DAAC to employ the same Transverse Mercator (TM) map projection approach for AST_L1T as is used by the Landsat Program. This approach is accepted by all the major analysis tools as a slight variation of the Universal Transverse Mercator (UTM) system where the northing coordinates are negative values in the Southern Hemisphere. In this case, the analysis tools recognize a zero false northing with a 500,000-meter false easting as a valid representation of UTM for both hemispheres.

Pixel orientation is critical with respect to the scene's reported four corners. For example, in AST_L1A and AST_L1B HDF products, the upper left hand corner embedded metadata value of the scene is also the upper-left corner of the upper-left pixel. However for AST_L1T HDF, the upper left hand corner embedded metadata value for the scene is actually the pixel center coordinates of the co-centered upper left pixel(s) in the product. Thus, for any given AST_L1T band, the true upper left hand coordinate is offset from the upper left hand corner coordinate by half the band's pixel size. The same applies for the AST_L1T upper right, lower left, and lower right scene corner coordinates. Note that all AST_L1T scene corners are fill pixels.

The co-centered pixel approach does not work well with analysis tools on GeoTIFF products. Therefore the LP DAAC specifies the GeoTIFFKey "RasterPixelIsArea" rather than "RasterPixelIsPoint" to characterize the pixel locations in building the GeoTIFF files. This causes the four-corner pixel to move back to the edges. The following tables illustrate the four corners in meters for GeoTIFF/HDF product pairs showing the half pixel offset. The first table compares a northern hemisphere HDF to a _T.tif file showing a 45-meter difference and the other table compares the HDF to a _V.tif file in the southern hemisphere for a 7.5-meter difference. Note that the "y" axis for the four corners in the southern hemisphere are negative values.

Example: AST_L1T_00303122000173206 (Northern Hemisphere)			
Corner	**GeoTIFF_T (x,y)**	**HDF (x,y)**	**Diff (x,y)**
Upper Left	(229905, 4662765)	(229950, 4662720)	(-45, 45)
Lower Left	(229905, 4585365)	(229950, 4585410)	(-45, -45)
Upper Right	(316305, 4662765)	(316260, 4662720)	(45, 45)
Lower Right	(316305, 4585365)	(316260, 4585410)	(45, -45)

AST_L1T Northern Hemisphere Corner Points (Meters) TIR.

Example: AST_L1T_00305122010131728 (Southern Hemisphere)			
Corner	**GeoTIFF_V (x,y)**	**HDF (x,y)**	**Diff (x,y)**
Upper Left	(649252.5, -788032.5)	(649260, -788040)	(-7.5, 7.5)
Lower Left	(649252.5, -861487.5)	(649260, -861480)	(-7.5, -7.5)
Upper Right	(732517.5, -788032.5)	(732510, -788040)	(7.5, 7.5)
Lower Right	(732517.5, -861487.5)	(732510, -861480)	(7.5, -7.5)

AST_L1T Southern Hemisphere Corner Points (Meters) VNIR.

Appendix A AST_L1A and AST_L1B Processing

Level 1A Data[44]

ASTER L1A raw data are reconstructed from Level 0 analog values referred to as unprocessed instrument digital numbers (DN). This product contains depacketized, demultiplexed, and realigned instrument image data with geometric correction coefficients and radiometric calibration coefficients appended **but not applied.** These coefficients include:

- Corrections for SWIR parallax as well as inter- and intra-telescope registration.
    - The parallax error is caused by the offset in detector alignment in the along-track direction and depends on the distance between the spacecraft and the observed Earth surface.
    - Parallax corrections are carried out with the image matching technique or the coarse DEM database, depending on cloud cover.
- Spacecraft ancillary and instrument engineering data (coefficients):
    - The radiometric calibration coefficients, consisting of offset and sensitivity information, are generated from a database for all detectors using real temperature values in the instrument supplementary data, and are periodically updated.
    - The geometric correction is the coordinate transformation for band-to-band co-registration. The coordinate transformation of the line-of-sight vector uses ancillary information from instrument supplement data and spacecraft ancillary data to identify the observation points in latitude/longitude coordinates on the Earth's surface defined by the WGS84 Earth model.

The VNIR and SWIR data are 8-bit and have variable gain settings. The TIR data are 12-bit with a single gain.

Raw AST_L1A is further processed on-demand before it is made available directly to users or as an input to downstream processing. The additional processing steps occur in the following order:

1) AST_L1A+ application of geometric correction of errors accounting for Earth rotation angle and Earth nutation
2) AST_L1A++ application of geometric database correction to address cross-track geolocation errors associated with night-time TIR scenes
3) AST_L1A+++ application of radiometric corrections due to on-board VNIR calibration lamps degradation over time causing sensor gain correction variation

Radiometry[45]

As has been the case for AST_L1B, AST_L1T data are offered in terms of scaled radiance. To convert from Digital Numbers (DN) to radiance at the sensor, the unit conversion coefficients (defined as radiance per 1 DN) are used. Spectral radiance is expressed in units of watts divided

[44] This subsection is paraphrased from Section 3.1 of the ASTER User Handbook Version 2
[45] This subsection is paraphrased from Section 5 of the ASTER User Handbook Version 2

by meters squared times steradian times micrometer [W/(m^2*sr*µm)] per DN. The relation between DN values and radiances is shown below:

- a DN value of zero is allocated to fill pixels
- a DN value of 1 is allocated to zero radiance
- a DN value of 254 is allocated to the maximum radiance for VNIR and SWIR bands
- a DN value of 4,094 is allocated to the maximum radiance for TIR bands
- a DN value of 255 is allocated to saturated pixels for VNIR and SWIR bands
- a DN value of 4,095 is allocated to saturated pixels for TIR bands

The maximum radiance depends on both the spectral bands and the gain settings as shown in the following table.

Band No.	**Maximum radiance (W/(m2*sr*µm)**			
	High Gain	**Normal Gain**	**Low Gain 1**	**Low Gain 2**
1	170.8	427	569	N/A
2	179.0	358	477	
3N	106.8	218	290	
3B	106.8	218	290	
4	27.5	55.0	73.3	73.3
5	8.8	17.6	23.4	103.5
6	7.9	15.8	21.0	98.7
7	7.55	15.1	20.1	83.8
8	5.27	10.55	14.06	62.0
9	4.02	8.04	10.72	67.0
10	N/A	28.17	N/A	N/A
11		27.75		
12		26.97		
13		23.30		
14		21.38		

Maximum Radiance Values for all ASTER Bands and all Gains

The radiance can be obtained from DN values as follows:

Radiance at-sensor = (DN value – 1) x Unit conversion coefficient

The following table shows the unit conversion coefficients of each band

Band No.	**Unit Conversion Coefficient (W/(m^2*sr*µm)/DN)**			
	High Gain	**Normal Gain**	**Low Gain 1**	**Low Gain 2**
1	0.676	1.688	2.25	N/A
2	0.708	1.415	1.89	
3N	0.423	0.862	1.15	
3B	0.423	0.862	1.15	

Band No.	Unit Conversion Coefficient (W/(m^2*sr*µm)/DN)			
	High Gain	Normal Gain	Low Gain 1	Low Gain 2
4	0.1087	0.2174	0.290	0.290
5	0.0348	0.0696	0.0925	0.409
6	0.0313	0.0625	0.0830	0.390
7	0.0299	0.0597	0.0795	0.332
8	0.0209	0.0417	0.0556	0.245
9	0.0159	0.0318	0.0424	0.265
10	N/A	6.822×10^{-3}	N/A	N/A
11		6.780×10^{-3}		
12		6.590×10^{-3}		
13		5.693×10^{-3}		
14		5.225×10^{-3}		

Calculated Unit Conversion Coefficients

Geometry[46]

ASTER's geometric systematic correction primarily involves the rotation and the coordinate transformation of the line of sight vectors (geocentric) of the detectors to the coordinate system of the Earth (geodetic). This is done as part of AST_L1 processing at GDS using engineering data from the instrument (called supplementary data) and similar data from the spacecraft platform (called ancillary data). The geometric correction of ASTER data has evolved through elaborate processes of both pre-flight and post-launch calibration.

Pre-Flight Calibration

Pre-flight calibration is an off-line process to generate geometric parameters. Parameters such as detector Line of Sight (LOS) vectors and pointing axes information are evaluated toward the Navigation Base Reference (NBR) of the spacecraft to determine instrument accuracy and stability. These data are stored in the geometric system correction database.

Post-Launch Calibration

Following launch of Terra, these parameters are being corrected through standard calibration and validation techniques which are put into a geometric correction database. Geometric system correction in the post-launch phase entails the following processes:

- Pointing correction
- Coordinate transformation from spacecraft coordinates to the orbital
- Coordinate transformation from orbital coordinates to the Earth's inertial
- Coordinate transformation from Earth's inertial coordinates to Greenwich
- Improving band-to-band registration accuracy through image-matching involving SWIR parallax correction and Inter-telescope registration

Based on V2.1 of the Geometric Correction Database, the geometric performance parameters of ASTER are summarized in the following table. Where a particular AST_L1A granule does not

[46] This subsection is paraphrased from Section 6 of the ASTER User Handbook Version 2

meet these performance maximums, the AST_L1T may not be able to meet these maximums either.

Parameter		Version 2.1 Geometric Db
Intra-Telescope Registration	VNIR	< 0.1 pixel
	SWIR	< 0.1 pixel
	TIR	< 0.1 pixel
Inter-Telescope Registration	SWIR/VNIR	< 0.2 pixel
	TIR/VNIR	< 0.2 pixel
Stereo Pair System Error	Band 3B/3N	< 10 m
Pixel Geolocation Knowledge*	Relative	< 15 m
	Absolute	< 50 m

* Not Terrain Corrected

Geometric Performance of ASTER Level 1

Geometric System Correction Database

There is an evolving geometric system correction database that is maintained at GDS. This database provides the geometric correction coefficients that are applied to produce both the AST_L1B science data and the AST_L1T science data. The AST_L1T science data like the AST_L1B, has the radiometric and geometric coefficients applied to the AST_L1A science data. The AST_L1T image is also projected onto a rotated map (rotated to “north-up”) at full instrument resolutions. The AST_L1T data generation also includes co-registration of the SWIR and TIR data to the VNIR data (resulting in the affine grid coefficients). And in addition, for SWIR in particular, the parallax errors due to the spatial locations of all of its bands are corrected. The data are stored together with metadata in the HDF file. The geometric correction reference in an AST_L1T product is provided in metadata embedded in the HDF as well as that provided in the XML metadata file. In the HDF file, this is present as the GeometricDBVersion field in the productmetadata.0 attribute.

Appendix B AST_L1T XML Metadata File

XML Metadata

The AST_L1T ODL metadata embedded in the HDF file header provides field values available at algorithm execution time. **Once the HDF data product is produced, it is never re-opened for update.** Because some metadata does not become available until after the algorithm runs, the granule also includes a separate XML metadata file. The XML file contains key metadata replicated from the HDF file as well as other metadata not found in the embedded ODL metadata, such as FRI file names, browse file names, and other fields related to core system processing. Also the XML file allows for data management updates that may impact metadata field values post production such as for cloud-cover recalculations.

Several distribution scenarios provide either the granule XML file or an ODL-formatted file to the user as an option to accompany the HDF data product. Because some embedded metadata fields are also found in the XML files, they may have been updated in the external XML files. The general rule of thumb is to start with the embedded metadata and then override it with like fields from the XML metadata.

Examples of repeated metadata include source data (L1A) and production date-time groups, reference databases, Digital Object Identifier (DOI), spatial extent, map projection, on/off status of sensors, sensor-pointing angles, gain settings, descending/ascending, and type of correction achieved. The repeated metadata generally identifies the data product. An example of updated metadata is cloud cover since cloud cover is provided a number of days post-production. Cloud cover is set to the most current value available at XML creation; cloud cover is always the most current value available for user-client search and order systems. Metadata found in XML files and not the HDF header includes the names of associated FRI files, database pointers to reduced resolution browse, and essential system data useful for problem triage (such as checksum and core system database IDs).

The embedded metadata and XML metadata often have different parameter names. The table below illustrates both the embedded ODL SCENEFOURCORNERS and XML GPolygon metadata values for an example AST_L1T file. (Redundant ODL/XML syntax removed to aid readability.) Note that the values agree in both metadata types.

AST_L1T_00303262005171548_20141222114612_66074	
Embedded ODL	**XML**
GROUP = SCENEFOURCORNERS	<GPolygon>
OBJECT = UPPERLEFT VALUE = (45.5419899574936, -93.4018255912307)	<PointLongitude>-93.4018255912307 <PointLatitude>45.5419899574936
OBJECT = UPPERRIGHT VALUE = (45.5405432330736, -92.2985842710224)	<PointLongitude>-92.2985842710224 <PointLatitude>45.5405432330736
OBJECT = LOWERRIGHT	<PointLongitude>-92.3070515243552

VALUE = (44.8471098271548, -92.3070515243552)*	<PointLatitude>44.8471098271548
OBJECT = LOWERLEFT VALUE = (44.8485221806005, -93.3969745689327)*	<PointLongitude>-93.3969745689327 <PointLatitude>44.8485221806005
OBJECT = SCENECENTER VALUE = (45.1968464839957, -92.852588)	No equivalent XML
* Two scene corner objects swapped from original ODL flow to simplify comparison of values	

Comparing ODL to XML Scene Boundary Coordinates (Degrees).

The table below illustrates ODL and XML cloud cover parameter values. Note that in this case the XML values have been updated since creation of the AST_L1A product.

AST_L1T_00303262005171548_20141222114612_66074	
Embedded ODL (copied from AST_L1A header)	**XML (revised with more current values)**
OBJECT = SCENECLOUDCOVERAGE VALUE = 5	QAPercentCloudCover 12 SceneCloudCoverage 12
OBJECT = QUADRANTCLOUDCOVERAGE VALUE = (12, 2, 4, 2)	UpperLeftQuadCloudCoverage 10 UpperRightQuadCloudCoverage 21 LowerLeftQuadCloudCoverage 9 LowerRightQuadCloudCoverage 7
Computed CC Average: (12+2+4+2)/4 = 5	Computed CC Average: (10+21+9+7)/4 = 11.5 (Round up to integer for value of 12)

Comparing ODL to XML Cloud Cover.

XML files related to product HDF files have two sources depending on the users' distribution approach. One source is from the core system made available from the *order* process which contains a full set of fields, while the other is from the Reverb *download* process, which contains a subset of fields that were sent to the ECHO server by the core system. XML from either source should be adequate for science data processing support but the full core system XML is needed for problem triage.

Users who order data from client systems may also receive small XML metadata files for bundled browse and QA text reports. These XML files provide production date-time groups and essential system data useful for problem triage.

Appendix C AST_L1T Associated Browse and QA Products

Reduced Resolution VNIR, TIR and QA Browse Product

Each AST_L1T product has an associated Browse product. The Browse product can have 1 to 3 browse images which are in JPEG format. If the VNIR telescope is on, the VNIR browse image is created. If the TIR telescope is on, the TIR browse image is created. If the precision correction for the AST_L1T product is attempted and the geometric verification is run, the quality assurance (QA) browse image is created.

The VNIR and TIR reduced resolution browse (a.k.a., thumbnail) images assume the same band combination as their associated full resolution images because both are generated simultaneously from the same virtual raster files. Both are created from the AST_L1T HDF science data using GDAL tools. Reduced resolution browse have the same size in pixel dimensions relative to nominal AST_L1A reduced resolution browse. It is only necessary to reduce TIR by 4% because its 90-meter pixel dimensions are already very near to nominal browse size. Given that TIR has 1/36th the pixels of either the VNIR-only or the VNIR/SWIR[47]-combination FRI, it is necessary to reduce these 15-meter pixel dimensions by 84% to correspond to nominal browse pixel dimensions.

The geometric verification process is used to generate a grayscale Quality Assessment browse JPEG file having color-coded displacement rankings of standard scene ground control points overlaid on a grayscale reference band image (B4 if SWIR available or B2 if only VNIR available). Rankings indicate number of pixels off nominal (red greater than 3 pixels, yellow between 3 and 2 pixels, blue between 2 and 1 pixel, cyan between 1 and 0.5, or green for less than half pixel). The scene must be comparable to a GLS2000 standard scene, be a daytime scene, and have VNIR or SWIR telescopes on to generate a QA browse file. The QA browse file is not generated for TIR-only science data.

The algorithm bundles the browse files in a single HDF file which is eventually split into the various JPEG browse images for downstream access by user client search and order systems. The bundled browse HDF files are distributed in user orders while standalone JPEG browse are made available for download scenarios.

QA Report

The geometric verification algorithm produces logs that are used to populate a text report providing quality assessment of geometric corrections for the AST_L1T Product. Part 1 of the report has the correlation GCPs used to create the precision grid, if the product is precision corrected. Part 2 has the GLS2000 standard scene gridded GCPs used to assess the geometric location of the reference band pixels and a list of simple statistics. The listing of the GCPs used for assessment has an indication as to how far off each geolocation point is from the

[47] SWIR 30 meter pixels are sub-sampled to align with the VNIR in the combination FRI so that combination pixel size is 15 meter.

corresponding point in the reference band science data. The report provides an independent geometric verification of the precision terrain corrected pixels by using the GLS2000 standard scene to create a grid of assessment GCPs (not the same as the correction GCPs) and those are compared to the corrected AST_L1T reference band. The report summarizes the total correlated GCPs; mean, median and standard deviation in pixel offset; and means, medians, and standard deviations in RMSE by quadrant and full scene.

Appendix D File Naming Conventions

The AST_L1T product and the associated Browse and QA products consist of an HDF science data file, Full Resolution Image (FRI) GeoTIFF files, browse image JPEG files, and a QA text file. The AST_L1T may contain either all or some TIR, VNIR, and SWIR bands depending on instrument scheduling and health and this will determine which FRIs and browse files are present. At least one FRI and one browse file will be present. The browse product can be delivered as three separate JPEG files or as an HDF file containing the three JPEG images. All of these files follow the following described format.

File names are constructed as "L1T Short Name"_"Collection Version""Start Date-Time-Group "_"Production Date-Time-Group"_"Processing Random Number." The table below provides example values for these fields.

File Name Field	Format	Example Value
L1T Short Name	AST_L1T	AST_L1T
Collection Version	Integer 3	003
Start Date-Time-Group	DDMMYYYYhhmmss	01112010002054
Production Date-Time-Group	YYYYDDMMhhmmss	20140423133114
Processing Random Number	Integer 5	12345

Example File Name Fields

The short name, AST_L1T, is used in file naming conventions for the level 1 precision terrain corrected registered at-sensor radiance products and the associated browse and QA products. The inaugural collection version is 003. If a change in the AST_L1A algorithm necessitates the reprocessing of AST_L1Ts, then processing will increase the version of the collection for both AST_L1A and AST_L1T. If only the AST_L1T algorithm changes, then only the AST_L1T and its associated products will change. In either case, reprocessing would be required for all AST_L1T in the archive. For each granule, a unique processing number is assigned to the files associated with the granule. File name type extensions are identified in the following table.

File Name Type	Extension Code	ESDT
Science data file	.hdf	L1T
Visual FRI for VNIR/SWIR bands *(GeoTIFF)*	_V.tif	L1T
Thermal FRI for TIR bands *(GeoTIFF)*	_T.tif	L1T
Browse bundled in a single HDF file	_BR.hdf	BROWSE
Line, sample locations of the control points that correlated and comprehensive set of information regarding the verification	_QA.txt	QA
XML metadata file (three file types: hdf.xml, _BR.hdf.xml, and _QA.txt.xml)	.xml	N/A
Individual browse files extracted from a _BR.hdf file	_BR.{2,3,4}.{VNIR,TIR,QA}.jpg	N/A

Example Output File Name Type Extensions

The HDF bundled browse contain JPEG images that include a QA browse single-band black-and-white image overlaid with red, yellow, blue, cyan, and green markers indicating the reference scene alignment with the GLS2000 standard scene created during the geometric verification quality check. The table below illustrates the file names that would be constructed for AST_L1T files based on an AST_L1A file named:
AST_L1A_00301112010002054_xxxxxxxxxxxxx_yyyyyy.hdf.

Example file names	Dissemination Method
HDF: AST_L1T Data Product AST_L1T_00301112010002054_20140423133114_12345.**hdf**	Client download, Client order, HTTP download
GeoTIFF: Visual FRI AST_L1T_00301112010002054_20140423133114_12345**_V.tif**	Client download, Client order, HTTP download
GeoTIFF: Thermal FRI AST_L1T_00301112010002054_20140423133114_12345**_T.tif**	Client download, Client order, HTTP download
XML: Metadata AST_L1T Data Product G1000067890-LPDAAC	(Reverb only) Client download
XML: Metadata AST_L1T Data Product AST_L1T_00301112010002054_20140423133114_12345.**hdf.xml**	Client order, HTTP download
XML: Metadata Browse AST_L1T_00301112010002054_20140423133114_12345_BR.hdf.xml	Client order
XML:QA Report AST_L1T_00301112010002054_20140423133114_12345_QA.txt.xml	Client order
JPEG: Stand Alone Reduced Resolution Browse and single-band black and white image overlaid with color markers indicating geometric verification quality AST_L1T_00301112010002054_20140423133114_12345_BR.**2.VNIR.jpg** AST_L1T_00301112010002054_20140423133114_12345_BR.{2,**3}.TIR.jpg** AST_L1T_00301112010002054_20140423133114_12345_BR.{3,**4}.QA.jpg** *{ } Number in extension depends upon VNIR and/or TIR ON*	Client download, HTTP download
HDF: Bundled Browse AST_L1T_00301112010002054_20140423133114_12345**_BR.hdf**	Client order
Text: Geometric Quality Verification Report AST_L1T_00301112010002054_20140423133114_12345**_QA.tx**t	Client order, HTTP download

Example ASTER Output File Names

The user should note that different granule file combinations are offered depending on the dissemination method (client order, client download, HTTP download) selected.

Appendix E Terrain Correction Defined

Where sufficient elevation data exists, the AST_L1T product may exhibit one of two different levels of terrain correction due to variations in the AST_L1A input scenes. These two levels of correction are:

1) Terrain+Systematic correction: applied to AST_L1A input data for which the precision correction is not possible, usually because of poor ground imaging (e.g., heavily-clouded scenes, night scenes, TIR only scenes) or where ground control is not available

2) Terrain+Precision correction: applicable to all daytime AST_L1A scenes where correlation statistics reach a minimum threshold

In addition to the two primary levels of terrain correction listed above, two less frequent scenarios may occur for scenes with no corresponding terrain elevation data (such as scenes over water). The two correction types are referred to as precision and systematic having no reference to the term "terrain." These production scenarios follow the respective processes of the primary levels, except the elevation-related components are skipped.

The table below summarizes four possible results that are allowed by the flexible AST_L1T algorithm. To determine the correction levels applied to a specific product, the user must examine the metadata (CorrectionAchieved) associated to the product.

Correction Level	Condition	Likelihood
Terrain+Systematic	Poor ground imaging, or where ground control is not available	Frequent
Terrain+Precision	Correlation statistics that achieve a minimum threshold	Frequent
Systematic	Uncorrelated scenes with no corresponding terrain data	Rare
Precision	Correlated scenes with no corresponding terrain data	Rare

Possible Correction Levels Summarized

Because ASTER SWIR band 4 has a similar spatial and spectral resolution to Landsat's band 5 and the GLS2000 GCPs, DEMs and standard scenes were created from Landsat band 5 data, it is the preferred band for use in the geometric algorithm. However if band 4 is not available, (or for SWIR acquired after April 2008 when the data became saturated) then VNIR band 2 is used. Use of the geometric algorithm begins with the creation of the systematic grid where the Level 1 input scene is rotated from the satellite path orientation to Universal Transverse Mercator (UTM) north-up orientation. The points in the rotated image are then mapped back to those of the initial AST_L1A input image space.

Global Land Survey (GLS) 2000 (GLS2000) DEM tiles are mosaicked to create an intermediary terrain dataset spanning the geometric extents of the systematic grid. At this point, the algorithm must determine the level of correction that may be achieved.

- If the scene contains only TIR bands or it is a night scene, the intermediary terrain dataset is resampled and clipped to the systematic reference image to create a matching pixel-for-pixel terrain dataset. The AST_L1A input scene will ultimately be resampled using both the terrain dataset and the systematic grid.

- If the scene contains bands other than TIR bands, the algorithm passes the systematic grid and the intermediary terrain dataset to the terrain-precision correction process, which begins with generating a precision grid. The precision grid is created by updating the systematic grid GCP offsets computed by correlating the GCP image chips to points in the systematic band. If the number of correlation chips and precision fit statistics are within the specified tolerances, the precision grid is then used to resample the terrain dataset. Then the resampling of the AST_L1A input scene will use both the terrain dataset and the precision grid.

Systematic Correction

ASTER Terrain+Systematic correction compensates for distortion in AST_L1A data resulting from topographical variations and image data with off-nadir cross-track pointing angles. It includes determining the output map-projected image space, creating the systematic grid, mosaicking the GLS2000 DEM data, clipping the GLS2000 mosaic to match the scene boundaries, and resampling the DEM to match the final ASTER L1T image space. The AST_L1A input image is then resampled using both the systematic grid and the matching DEM to create the terrain-systematic image. This comprises the default level of correction for TIR-only scenes, night scenes, scenes that contain high cloud-cover, and scenes that fail to create the precision grid necessary for the precision correction process.

Precision Correction

Precision correction is performed for datasets where the number of correlation chips and precision fit statistics are within the specified tolerances. In this process, the previously generated systematic image is correlated with GLS2000 ground control points (GCP). When the 30-meter resolution SWIR reference band 4 is not available, the 15-meter VNIR band 2 is used for correlation. The 15-meter band is down-sampled to match the GLS2000 30-meter resolution GCP chips using the GPYRAMID algorithm. GPYRAMID creates a 30-meter resolution equivalent to that of the 15-meter resolution VNIR band 2 to use the 30-meter resolution GCP chips. In general, the GPYRAMID algorithm creates under-sampled images using the Gaussian resampling technique at multiple resolutions.

The GCPCorrelate algorithm then correlates the ground control points, and generates line and sample offsets used to update the systematic grid and ultimately creates the precision grid. The GLS2000 GCPs used are small image chips (64x64 pixels) with geographic information that have been extracted from the reference image using the Modified Moravec Interest Operator (MMIO) algorithm developed to identify well-defined interest points from the reference scene (USGS/EROS 2008). Using these interest points increases the success of correlation with the search image and provides accurate offsets. By choosing chips that are well-distributed

throughout the imagery, nonlinear differences between the image sources can be found. For AST_L1T processing, the GLS2000 dataset is used as reference image for the precision correction process. The USGS-validated GLS2000 reference dataset has an expected Root Mean Squared Error (RMSE) of 25-meters or less.

The REFINE algorithm generates the precision grid from the systematic grid using the registration information, such as GCP residuals. The REFINE algorithm starts by using the GCPs x and y offset generated with the GCPCorrelate algorithm. Each of the GCPs is adjusted for relief displacement in the input image (AST_L1A) using the systematic grid. The adjusted GCPs in the input image are projected back to the output grid space using the same systematic grid. The systematic image location of each GCP and its relief-adjusted correlated locations are used to fit the polynomial of either first or second order using the least squares fit method. Outliers are removed by comparing the residuals in the fit to the weighted standard deviation. The systematic grid is adjusted with the polynomial coefficients to generate a precision grid, which relates the output projection location to the input line and sample location from the AST_L1A image. The geometric resampling algorithm uses the precision grid to create a precision terrain corrected product. By default, the second order polynomial fit is used for precision correction. If significant warping occurs from the second order polynomial fit, then a first order polynomial fit is used for precision correction. To determine warping on the precision corrected image, REFINE checks if the set of points along each edge of the precision corrected image lies in a straight line to within certain specified tolerance.

Resampling For Geometric Correction

ASTER images that have only systematic correction are resampled using both the terrain dataset (if available) and the systematic grid to create a terrain-systematic corrected image. ASTER images that have precision correction, are resampled using SWIR band 4 when it is available, with the terrain dataset (if available) and the precision grid to create a terrain-precision corrected image. If band 4 is unavailable, band 2 is used in its place. In any case, no matter which correction level is achieved, only one resampling is done to produce the final product.

Geometric Verification

The geometric verification algorithm (Gverify) determines the relative accuracy of the terrain and precision corrected scene when compared to the corresponding ortho-rectified GLS2000 standard scene. The algorithm uses a cross-correlation procedure along with a simple outlier detection algorithm to determine the relative offsets of the terrain corrected scene to the reference GLS2000 standard scene, which are accurate to 25-meters. The result is a relative error estimate for four quadrants of the scene, overall relative error estimate of the full scene, and a color-coded greyscale browse image showing the relative offsets at different geographic locations within the scene. Due to the variability of the ASTER scene location, the reference GLS2000 standard scene selected is the one with the closest scene center. The GLS2000 standard scene may not completely cover the ASTER scene.

Quality Assurance

Along with the AST_L1T product, an associated QA product will be created when precision correction is attempted. The QA product contains a list of the GLS2000 GCPs used for precision correction, a list of GCPs[48] used in performing the geometric verification and some simple statistics for the scene created during geometric verification. The statistics created during geometric verification, mean, median, standard deviation, and RMSE for the assessment GCPs[49], are calculated for the entire scene and the scene quadrants. The set of good assessment GCP points are also used to create a browse image for the associated browse product. The set of good assessment GCP points are color-coded based on their ranks and overlaid on the corrected reference band, then a browse image is generated.

[48] The Gverify ground control points (GCPs) are not the same as those used for precision registration (in GCPCorrelate). The points used in Gverify are defined by a relatively high-density uniform grid across the intersection of the L1T scene space and the reference GLS2000 standard scene used space.

[49] The Gverify assessment ground control points (GCPs) are not the same as those used for precision registration (in GCPCorrelate). The points used in Gverify are defined by a relatively high-density uniform grid across the GLS2000 standard scene space where it overlaps the AST_L1T reference band space.