Version 1.2

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 User's Guide
Version 1.2
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Abstract

This document provides a User's Guide for ASTER Level 1 Precision Terrain Correction Registered At-Sensor Radiance (AST_L1T V003 and V031) products. It supplements the JPL ASTER User's Handbook with new information on AST_L1T including an update to the Handbook's section on ASTER Data Search and Order.

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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 aboard the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) flagship Terra spacecraft in December 1999. The mission has generated over 3.8 million ASTER scenes with a wide range of observations that span the visible near-infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR) regions of the electromagnetic spectrum.

ASTER is a high-resolution, pushbroom sensor with 14 spectral bands which include three subsystems that cover the VNIR, SWIR, and TIR regions of the electromagnetic spectrum. Bands 1-3 cover the VNIR region with 15-m spatial resolution, bands 5-10 are in the SWIR region with 30-m spatial resolution, and bands 11-15 cover theTIR region with 90-m spatial resolution. Each subsystem has three nadir-pointing telescopes, and the VNIR subsystem has an additional aft-pointing telescope that duplicates the frequency of nadir Band 3. The cadence of the aft-pointing telescope covers the same scene 55 seconds behind the VNIR nadir Band 3, enabling stereo observations. 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 5 days for the visible and near-infrared bands.

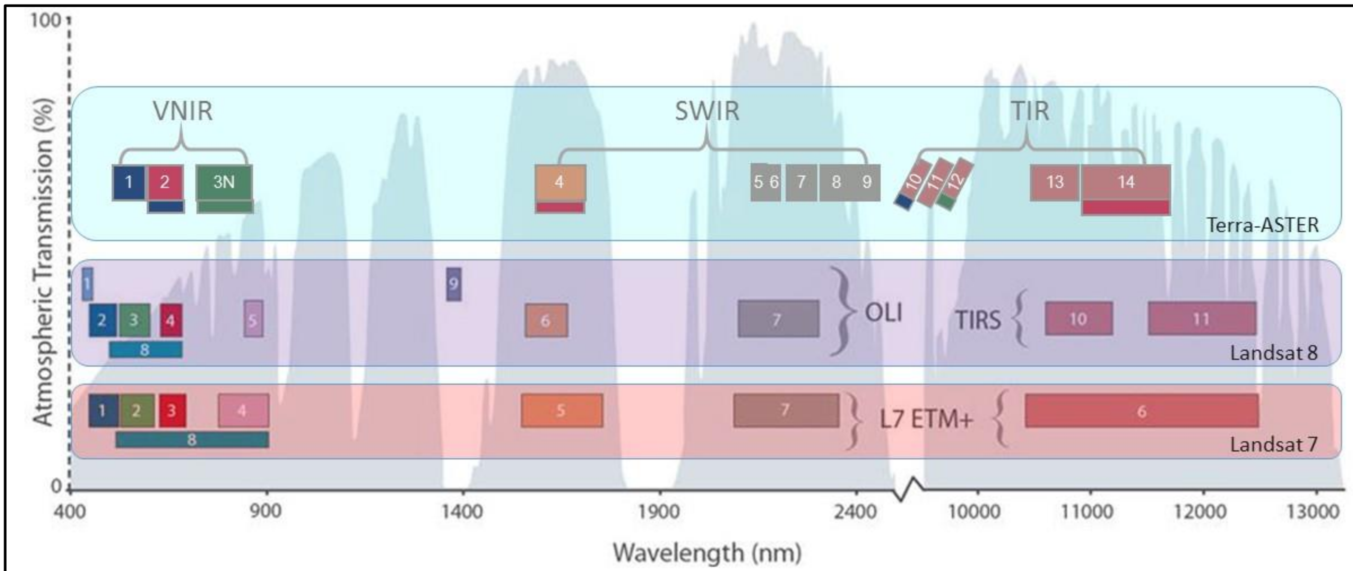
The Department of the Interior (DOI) U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center and NASA partner to establish, develop, and operate the Land Processes (LP) Distributed Active Archive Center (DAAC). The LP DAAC's mission is to process, archive, and distribute NASA's land processes data, such as those derived from ASTER. Raw ASTER data are downlinked from Terra at the White Sands Receiving Station and relayed to NASA Goddard's EOS

*Due to recent Terra activities related to Terra Constellation exit, ASTER will no longer be imaging the Earth surface every 16 days.
**See Section 2.2 on SWIR operationality.

Data and Operations System (EDOS), where it is minimally processed. It is then transmitted to the Ground Data System (GDS) in Japan where it is further processed from Level (L) 0 to 1. ASTER L1A Reconstructed Unprocessed Instrument Data (AST_L1A) are routed from GDS to the LP DAAC for archiving and further processing to higher level data products. The LP DAAC relies on a combination of proprietary software, the NASA-developed processing system called the Science Scalable Scripts-based Processor for Missions (S4PM), and algorithms developed by the ASTER Science Team (Jet Propulsion Laboratory (JPL) and Japan) to generate higher level ASTER data products including ASTER L1B Registered Radiance at the Sensor (AST_1B) product.

The USGS EROS Center also hosts the Landsat Program that processes raw ETM+ data to higher-level products. Landsat data collection characteristics are similar to those of ASTER. Thus, in 2011 when the Terra Senior Review requested L2 products be orthorectified, the LP DAAC took the opportunity to propose the creation of an orthorectified, precision terrain corrected registered at-sensor radiance Level 1 product (AST_L1T) to the ASTER Science Team to be produced 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 new Level 1 product, AST_L1T.

Figure 0-1 illustrates that Landsat and ASTER have similar operational aspects, specifically with respect to spectral observations. Appendix A provides a more detailed comparison between Terra ASTER, Landsat 7, and Landsat 8 at the instrument level.



Approximate bandpass wavelengths for Terra-ASTER (VNIR, SWIR, TIR), Landsat 8 (OLI, TIRS) and Landsat 7 (ETM+) sensors. *The atmospheric transmission graph was generated via MODTRAN for summertime mid-latitude hazy atmosphere (5 km visibility). The blue, red, & green colored bands indicate pseudo colors used in various browse or full resolution images for Landsat and for ASTER VNIR only, VNIR+SWIR, or TIR only.*

Figure 0-1. Terra ASTER and Landsat 7/8 Spectral Bands Compared.

The AST_L1T data product is derived from the L1A data with geometric, cross-talk, and radiometric corrections applied. The AST_L1T algorithm incorporates and modifies Landsat's geometric algorithms, which include systematic correction, resampling correction, precision grid generation, and geometric verification to produce a multi-file product and two associated products. The AST_L1T data product comprises an EOSDIS Hierarchical Data Format (HDF)-EOS2 science data file, an XML metadata file, and a Visible 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 upon 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 products consisting of JPEG low resolution image (visible, thermal, and quality) files.

Originally, AST_L1T was only generated via forward processing, but due to changes with the radiometric calibration coefficients (RCCs) and Product Generation Executables (PGEs), the LP DAAC began to offer on-demand processing for the AST_L1T product in July 2021. The forward processing product retained version (V) 4 of the RCC and maintained one consistent RCC version for the entire ASTER L1T inventory. This inventory is available via Data Pool for historical and time series analysis. The on-demand product is processed with the most recent RCC V5 and is not archived within the LP DAAC's Data Pool.

1.2 Data Access Policy

Access to the ASTER L1T data product was opened to the public in April 2016. All ASTER data products are available at no charge to all users and have no restrictions on reuse, sale, or redistribution. Refer to the Data Citation and Policies web page for the most current policy regarding user access.

1.3 User Benefits

Prior to AST_L1T, users had access to AST_L1B products, which required additional processing and resampling to achieve orthorectification, or orthorectified products. The additional orthorectification relied on processing-intensive, closed-source production code that could not be used in Level 2 processing. This orthorectification required additional effort that increased the complexity and risk to investigator processes including a potential for unnecessary data error due to multiple resampling. Alternatively, the AST_L1T product provides quick turn-around of consistent GIS-ready data.

Previously, for visualization purposes, ASTER users had to create their own images or use the AST_L1A low resolution, non-location-tagged browse images. The AST_L1T product includes two full resolution, orthorectified, location-tagged GeoTIFF image files, as well as a low resolution browse. The GeoTIFF files allow users to overlay location-tagged features and to compare with other ASTER scenes for visually examining the extent of natural disasters or change detection. The full resolution images can be used by non-technical end users without the need for special image analysis software, allowing a reduction in user's cost. A full resolution visible image consists of 3 bands from the VNIR and SWIR telescopes producing a near pseudo color image that can be used when a daytime view is needed. However, in April 2008 ASTER experienced a high temperature anomaly within the SWIR detectors. Data from the SWIR regions have since been deemed unusable. Therefore, post-2008 ASTER images only contain the visible full resolution image created using the 3 bands from the VNIR telescope. The thermal image is created from 3 bands of the TIR telescope, creating a view showing temperatures not only during the day but also at night. It is anticipated, as user client systems advance, that the full resolution images will form a base layer that allows users to zoom in and out of scenes.

1.4 Science Usage

The intended and appropriate user scenarios for the AST_L1T product parallel current scenarios for AST_L1B orthorectified products. These uses include

- Land surface climatology: monitoring land surface parameters such as surface temperature; understanding land surface interaction and energy and moisture fluxes and observing changes in glacial extent
- Vegetation and ecosystem dynamics: investigating vegetation and soil distribution and their changes to estimate biological productivity, understanding land-atmosphere interactions, and detecting ecosystem change
- Volcano monitoring of eruptions and precursor events, such as gas emissions, eruption plumes, development of lava lakes, eruptive history, and eruptive potential
- Hazard monitoring: observing the extent and effects of wildfires, flooding, coastal erosion, earthquake damage, and tsunami damage
- Hydrology: understanding global energy and hydrologic processes and their relationship to global change and observing evapotranspiration from plants
- Geology and soils: observing detailed composition and geomorphologic mapping of surface soils and bedrocks to study land surface processes and Earth's history
- Land surface and land cover change: monitoring desertification, deforestation, and urbanization; providing data for conservation managers to monitor protected areas, national parks, and wilderness areas

But more importantly, because AST_L1T relies on a Landsat geometric algorithm with substantial ground control points and digital elevation models, AST_L1T could harness Landsat's vast data collection without performing geo-registration correction.

Section 2 ASTER Instrument Overview

2.1 Product Chain

Figure 2-1 illustrates the three different processing mechanisms of all ASTER data. For clarity, historical and archival processing is not shown.

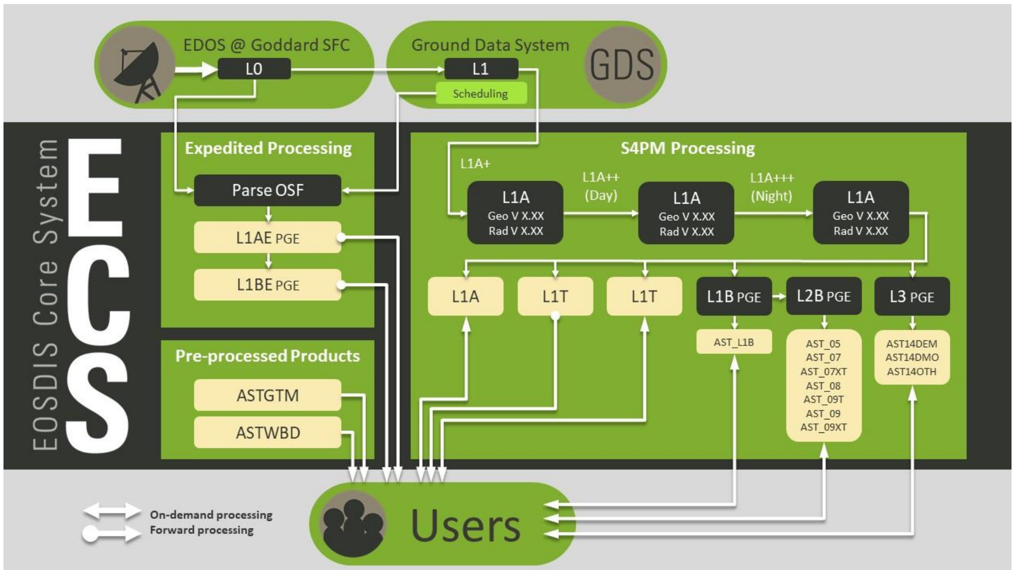


Figure 2-1. ASTER Operations Concept.

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 Appendix B for a discussion on the ASTER data acquisition strategy.

GDS in Japan processes the minimally processed L0 data to L1A, which is then relayed to the LP DAAC and ingested by the EOSDIS Core System (ECS). ASTER L1A is used as a base product to generate Levels 1, 2, and 3 data products. Additional processing and corrections are applied depending on each product.

2.2 Instrument Sensors

Depending on sensor commanding for any given data acquisition, ASTER downlinks may comprise some, or all, of the bands described in Table 2-1. The design of each sensor is discussed in Section 2.0 of the ASTER User Handbook Version 2.

Band	Telescope Pointing	Wavelength (µm)	Description	Resolution (m)
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	Backward	0.760–0.860		
SWIR_Band4	Nadir	1.600–1.700	Shortwave 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	Longwave 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 2-1. ASTER Sensor Characteristics.

VNIR_Band3B is not used in AST-L1T processing or included in the product.

The only significant ASTER instrument-related known issue 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. In August 2012, the SWIR sensor was turned off and invalid data are not 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. The AST_L1T product does not include SWIR band data after April 1, 2008 as well.

2.3 AST_L1A Data[1, 2]

ASTER AST_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 (GCCs) and radiometric calibration coefficients (RCCs), which are referenced in the image header. The GCCs and RCCs database arrive in a separate static file. These coefficients include

- Corrections for SWIR parallax as well as inter- and intra-telescope registration for pre-April 2008 data.
    - 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 updated periodically.
    - 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 supplementary 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.

The AST_L1A is further processed within the Science Scalable Scripts-based Processor for Missions (S4PM) environment at the LP DAAC prior to downstream processing of the higher-level ASTER data products.

The additional processing steps occur in the following order:

1) 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.

[1] This subsection is paraphrased from Section 3.1 of the ASTER User Handbook Version 2 which highlights the processing of ASTER L1A data which is used as an input for the ASTER L1B data product that is further processed to create the ASTER L1T data product.
[2] As of June 2021, this section has been amended to reflect the latest processing changes.

3) AST_L1A+++ Version(V) 2 application of radiometric corrections due to onboard calibration lamps degradation over time causing sensor gain correction variation.

2.4 Radiometry[2]

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 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 pixels not containing data and can be considered transparent
- 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 4094 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 4095 is allocated to saturated pixels for TIR bands

The maximum radiances depend on both the spectral bands and the gain settings as shown in Table 2-2.

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		

Table 2-2. 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

Table 2-3 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	
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}		

Table 2-3. Calculated Unit Conversion Coefficients.

2.5 Geometry[2]

ASTER's geometric system 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 ASTER Level 1 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.

2.5.1 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.

2.5.2 Post-Launch Calibration

Following launch of ASTER, these parameters are being corrected through validation using ASTER Ground Control Points (GCPs)[3] and inter-band image matching techniques. 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 ***Table 2-4***. Where a particular AST_L1A granule does not 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
Pixel Geolocation Knowledge	Relative	< 15 m
	Absolute	< 50 m

[2] This subsection is paraphrased from Section 6 of the ASTER User Handbook Version 2.
[3] Not the same as Global Land Survey 2000 Ground Control Points (GCPs) used for AST_L1T processing.

Table 2-4. Geometric Performance of ASTER Level 1.

2.5.3 Geometric System Correction Database

An evolving geometric system correction database is maintained at GDS. This database provides the geometric correction coefficients that are applied in producing the AST_L1T product data. The AST_L1T data, like the AST_L1B, have the radiometric and geometric coefficients applied to the AST_L1A data. The AST_L1T image is 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). 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.

2.5.4 Geographic Conventions

Figure 2-2 illustrates the actual image after an AST_L1A scene has been rotated north-up. For an AST_L1A image, the location 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).

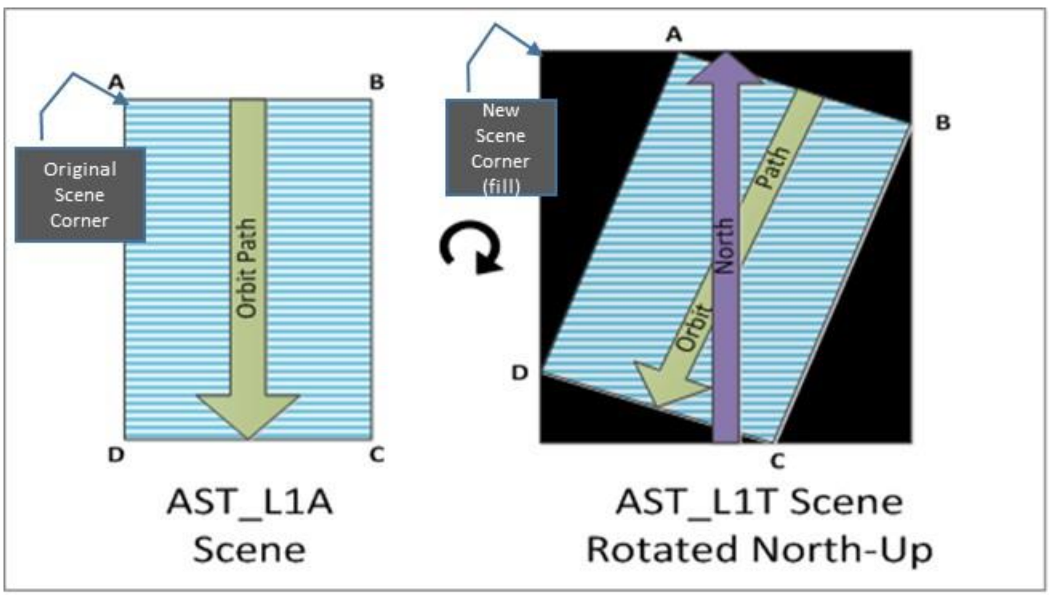


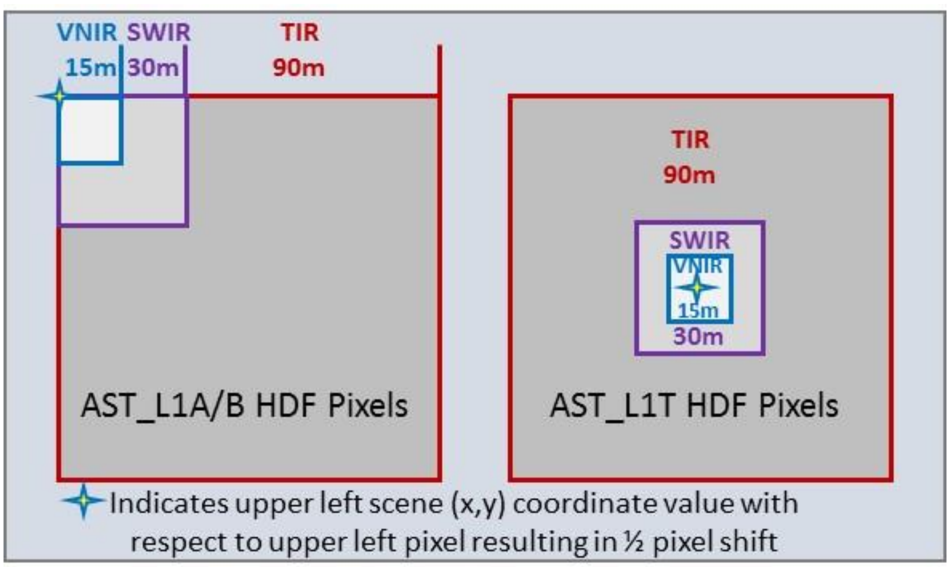
Figure 2-2. AST_L1A Image Rotated North-Up in AST_L1T Product.

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; instead, it is the actual center on the rotated coordinates.[4] Table 2-5 provides an example of the embedded metadata listing the four corners[5] 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***
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)

Table 2-5. Geographic Extent (Degrees) for ASTER Level 1 HDF Products.

Figure 2-3 illustrates that the AST_L1T HDF corner pixels from each instrument are co-centered, unlike 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.



[4] Experience indicates that differences are observed at the sixth significant digit following the decimal in latitude only.
[5] Points are in (y,x) notation where “y” is latitude and “x” is longitude.

Figure 2-3. 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 that 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 ½ 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. Table 2-6 (using _T.tif) and Table 2-7 (using _V.tif) both illustrate the four corners in meters for GeoTIFF/HDF product pairs, one for the northern hemisphere and the other for the southern hemisphere. Note that the coordinates differ by ½ pixel[6] in each example because the HDF pixel grid is defined in a "pixel is point" fashion.

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)

Table 2-6. AST_L1T Northern Hemisphere Corner Points (Meters) TIR.

[6] The LP DAAC GeoTIFF specification calls for the Visible GeoTIFF (_V.tif) to have a ½ pixel resolution of 7.5 meters and separately the Thermal GeoTIFF (_T.tif) to have a ½ pixel resolution of 45 meters.

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)

Table 2-7. AST_L1T Southern Hemisphere Corner Points (Meters) VNIR.

Section 3 ASTER L1T Algorithm Overview

The AST_L1T product is created by performing the geometric and radiometric corrections on the original AST_L1A image data. The AST_L1T algorithm applies Earth and satellite models, control points, and elevation models, ultimately projecting the result onto rotated map (north-up) at full instrument resolutions. The algorithm ensures all calibrations and corrections historically applied to AST_L1B data are also applied to the AST_L1T data, including 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 specifically, corrections are applied for parallax errors due to the spatial locations of its bands. All geometric corrections are applied using a single re-sample. In addition to the HDF-EOS2 product, full resolution location-tagged images are created using a standard three band combination (red, green, and blue), stretched and formatted as GeoTIFF files.

The AST_L1T algorithm was constructed by “wrapping” Landsat functionality within a version of the existing AST_L1B algorithm. This includes:

- Generation of the AST_L1A input product via supplemental algorithms
- Reuse of AST_L1B housekeeping and product formatting code
- Reuse of the AST_L1B algorithms including:
  - Application of radiometric and geometric corrections
  - Application of cross-talk correction coefficients
  - Generation and application of affine transformation coefficients
- Modification and reuse of Landsat’s geometric algorithms[7] including:
  - Systematic – used twice: generates the systematic grid by rotating from image space to Universal Transverse Mercator (UTM) north-up and to make the DEM grid
  - Geometric Pyramid – scale input image to reference image (if necessary)
  - GCP Correlate – computes x/y offsets for GCPs to be used for precision grid generation
  - Precision Refine – generates the precision grid
  - Geodetic Evaluation – checks the results of Precision Refine to see if it is necessary to fall back to systematic processing
  - DMS Retrieve Ancillary – used twice, once to retrieve the DEM data for the scene, and once to retrieve the GCPs for the scene
  - Resampling – only a single resample of input scene
  - Geometric Verification Algorithm – geometric verification determines the relative accuracy of the terrain and precision corrected scene when compared to a corresponding orthorectified GLS2000 standard scene

Refer to Appendix C for a continued overview of the algorithm or consult the ASTER Level 1 Precision Terrain Corrected Registered At-Sensor Radiance Product (AST_L1T) Algorithm Theoretical Basis Document (ATBD) for all specific details.

[7] Selective re-use of Landsat Product Generation System (LPGS) and Image Assessment System (IAS).

Section 4 ASTER L1T Product Architecture

The AST_L1T product comprises an Earth Science Data and Information System (EOSDIS) granule and associated support files. The AST_L1T granule is a multi-file product, which includes an HDF-EOS2 data product file, full-resolution images, and associated metadata files. Some sensor-specific data may not be present depending upon band acquisition settings or sensor environmental conditions at the time of acquisition:

- HDF: AST_L1T Data Product comprised of a maximum of fourteen bands of calibrated radiance data and embedded Object Description Language (ODL) metadata
- GeoTIFF: VNIR/SWIR Visible Full Resolution Image and/or TIR Thermal Full Resolution Image with embedded GeoKey type metadata
- XML: Individual metadata files corresponding to HDF files

In addition, each AST_L1T granule has associated products, including low-resolution browse, Quality Assessment (QA) browse, and a QA text report:

- JPEG: Standalone reduced resolution VNIR and/or TIR browse
- JPEG: Single-band black and white reduced resolution browse overlaid with red, green, and blue (RGB) markers for GCPs used during the geometric verification quality check
- Text: Geometric quality assessment report

4.1 ASTER L1T Granule Components

4.1.1. HDF AST_L1T Data Product

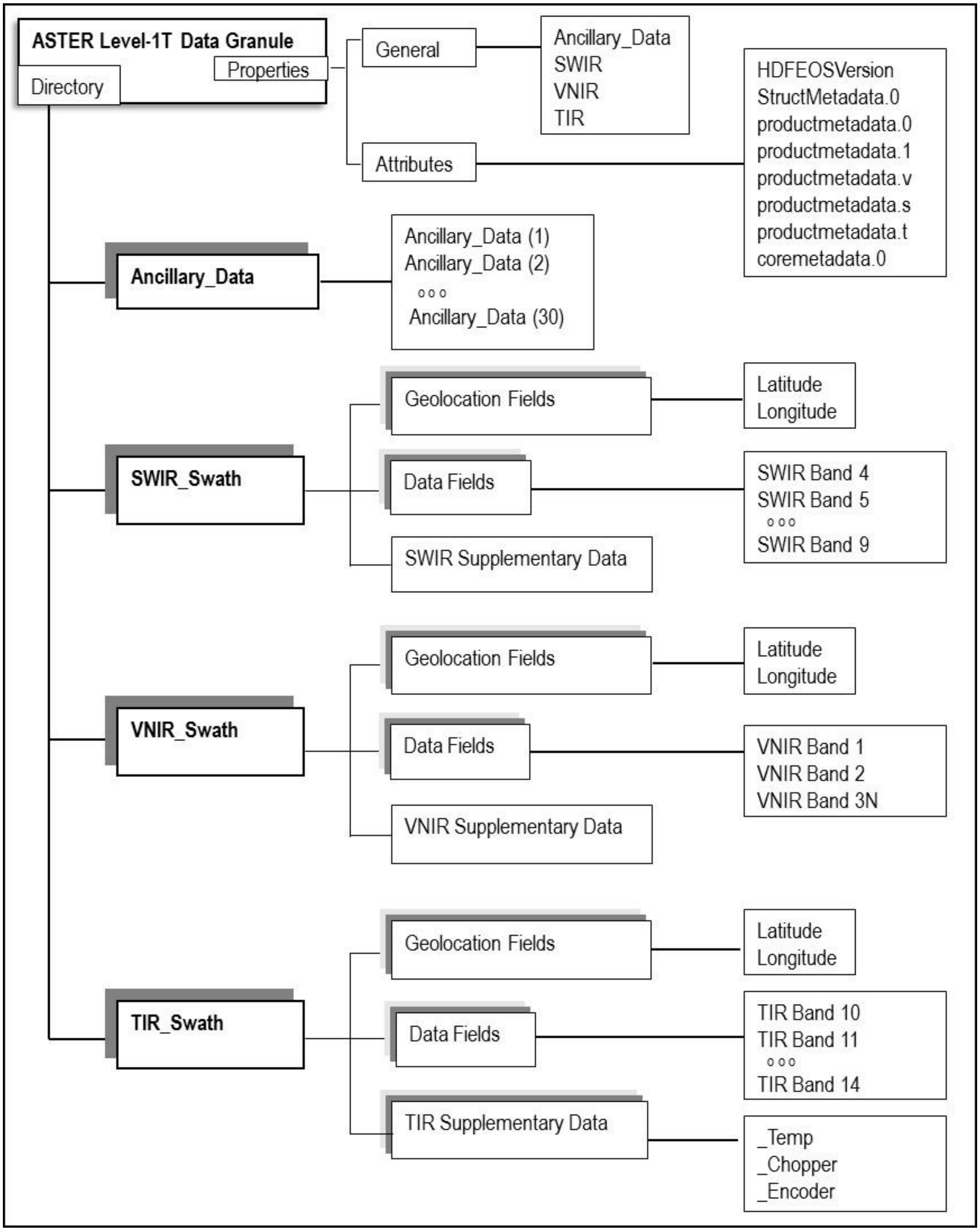
The overall structure of the AST_L1T HDF-EOS2 product maps closely to the legacy AST_L1B product (see the ASTER User Handbook Version 2). The AST_L1T Data Product contains generic and specific embedded metadata, image data, geolocation fields (latitude and longitude), and supplementary data for up to three sensors in a hierarchical format. The nominal size (areal dimension) of an ASTER scene is about 60 km by 60 km. ***Table 3-1*** outlines the AST_L1T dataset characteristics.

Table 3-1. AST_L1T Dataset Characteristics

Characteristic	VNIR	SWIR	TIR
Image dimensions (rows x columns)	varies by scene (e.g., 5800 x 6600)	½ VNIR (e.g. 2900 x 3300)	⅓ SWIR (e.g., 960 x 1100)
Bit-type	8-bit unsigned integer	8-bit unsigned integer	16-bit unsigned integer
Pixel Size	15 m	30 m	90 m
Area	Varies by scene		
Projection	Universal Transverse Mercator		
Data format	Hierarchical Data Format – EOS2		

Figure 3-1 illustrates the hierarchical AST_L1T product structure which differs considerably from the AST_L1A product structure. The AST_L1T is the same as the AST_L1B structure except VNIR Band 3B is not included in the product.

Figure 3-1. AST_L1T HDF Product Structure



The HDF file header has eight Attribute sections. The last seven attributes are in ODL metadata format. Refer to AST_L1T Product Specification for a detailed review of embedded metadata for the following attribute sections.

- Attribute #1: "*HDFEOSVersion*" [HDFEOS Version]
- Attribute #2: "*StructMetadata.0*" [Swath[8] 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:[9] "*coremetadata.0*" [Inventory-core metadata]

Spacecraft ancillary and instrument engineering supplementary data used by the algorithms are included.

For each scene, the latitude and longitude geolocation arrays are two 11 x 11[10] matrices 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[11])/10 which, unlike the case for L1B, varies by scene because L1T is rotated north-up.

For each band present, the scene data fields contain reconstructed digital numbers at full resolution which have been radiometrically calibrated, geometrically co-registered, and terrain and precision corrected. The VNIR and SWIR data are 8-bit and have variable gain settings. The TIR data are significant to 12-bits in a 16-bit field with a single gain.

VNIR and SWIR supplementary data containers are empty; TIR supplementary data contains temperature, chopper, and encoder data carried over from AST_L1T for information purposes.

4.1.2 Full Resolution Images

Using the GDAL geographic imaging package, the AST_L1T algorithm produces full resolution GeoTIFF image files from AST_L1T HDF (simultaneously with the reduced

[8] Swath usage here is archaic; StructMetadata defines "scene" structures for each band although the term "swath" is used in the metadata object names for scene. In more current usage, scenes are actually cutouts of image strips for each band from a continuous acquisition (a.k.a., swaths) when the acquisition has more than one scene.

[9] ASTER L1A contains a [Bad Pixel Information] Attribute which is not carried over to AST_L1B or AST_L1T.

[10] 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.

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

resolution browse JPEG). The Visible and Thermal full resolution images are provided for users who prefer GeoTIFF over HDF. The GeoTIFF files may ultimately be part of a multi-level browse capability. Full resolution image 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 not useable after April 2008 and was eventually turned off August 2012). Pixels are sized at 8-bits and retain DNs in each of the bands; the TIR bands were scaled down from 16-bits to 8-bits per the GeoTIFF specification.

Table 3-2 defines full resolution image pseudo color composite images generated from a subset of bands as determined by availability within each specific AST_L1T product.

Table 3-2. GeoTIFF (and Browse) Band Characteristics

Bands Available	Red	Green	Blue	Pixel Size	GeoTIFF DN Units
VNIR/SWIR	B4[12]	B3N	B2	15 meter	Changed from Reflectance to Radiance
VNIR only	B2	B3N	B1	15 meter	Changed from Reflectance to Radiance
TIR	B14	B12	B10	90 meter	Changed from Radiance to Degrees Kelvin scaled from 16-bit to 8-bit

4.1.3. XML Metadata

The 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 an update.** Some metadata do not become available until after the algorithm has been run; therefore, 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 ODL, such as full resolution image 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 postproduction.

Several distribution scenarios provide either the granule XML file or a similar XML 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 standard process 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, QA flags, 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 postproduction. 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 GeoTIFF files, database

[12] SWIR is resampled from 30 meter to 15 meter to align with VNIR bands.

pointers to reduced resolution browse, and essential system data useful for problem triage (such as checksum and core system database IDs).

The ODL and XML metadata often have different parameter names. Table 3-3 illustrates both the 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.

Table 3-3. Comparing ODL to XML Scene Boundary Coordinates (Degrees)

L1T_00303262005171548_20141222114612_66074	
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 VALUE = (44.8471098271548, -92.3070515243552)*	<PointLongitude>-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*

Table 3-4 illustrates ODL and XML cloud cover parameter values. Note that in this case the XML values have been updated since AST_L1A acquisition.

Table 3-4. Comparing ODL to XML Cloud Cover

L1T_00303262005171548_20141222114612_66074	
ODL (copied from AST_L1A ODL)	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* *(Rounded up to integer for value of 12)*

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 Data Pool which contains a full set of fields, while the other is from the Earthdata Search download process, which contains a subset of fields that were sent to the Common

Metadata Repository (CMR) 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.

4.2. ASTER L1T Associated Products

4.2.3. Reduced Resolution and Quality Assessment Browse

Reduced resolution browse (a.k.a., thumbnail) images assume the same band combination as their associated full resolution images because they are generated simultaneously from the same virtual raster files. Both are created from the AST_L1T HDF using GDAL tools. Reduced resolution browse has 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[13]-combination full resolution image, it is necessary to reduce these 15-meter pixels by 84% in order to correspond to nominal browse pixel dimensions.

The geometric verification process is used to generate a grayscale QA browse JPEG file having color-coded displacement rankings of standard scene ground control points overlaid on a reference band (B4 if SWIR available or B2 if only VNIR). The JPEG files are overlaid with color-coded displacement rankings. 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 ½ pixel). The scene must be comparable to a GLS2000 standard scene, be a daytime scene, and have VNIR or SWIR telescopes on in order to generate a QA browse file. The QA browse file is not generated for TIR only HDF files.

The standalone JPEG browse files are made available for download in the Data Pool. Note that the Visible browse is only produced if VNIR is on, the Thermal browse is only produced if TIR is on, and the QA browse is only produced when a QA report is generated.

4.2.4. 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. This file contains a listing of the GCPs that were used to assess the geometric location of the pixels. The report provides an independent geometric verification of the corrected pixels by using the GLS2000 Standard Scene to create a grid of 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 mean, median, and standard deviation in RMSE by quadrant and full scene. This is only produced if the precision correction is attempted, VNIR or SWIR ON, and for Day only scenes.

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

4.3. File Naming Conventions

The AST_L1T data product consists of an HDF science data file and a full resolution image GeoTIFF file; supplementary products consist of browse image JPEG files (a Visible browse, a Thermal browse, and/or a QA browse) 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. At least one full resolution image and one browse file will be present.

File names are constructed as "L1T Short Name"_"Collection Version" "Start Date-Time-Group "_"Production Date-Time-Group"_"Processing Random Number". ***Table 3-5*** provides example values for fields.

Table 3-5. Example File Name Fields

File Name Field	Format	Example Value (Forward Processing)	Example Value (On-demand Processing)
L1T Short Name	AST_L1T	AST_L1T	AST_L1T
Collection Version	Integer 3	003*	031*
Start Date-Time-Group	DDMMYYYYhhmmss	01112010002054	01112010002054
Production Date-Time-Group	YYYYDDMMhhmmss	20140423133114	20140423133114
Processing Random Number	Integer 5	12345	12345

*The file naming conventions for forward and on-demand processing have not changed; the only difference is the collection version number to differentiate the two processing methods.

The short name, AST_L1T, is used in file naming conventions for forward and on-demand processing terrain and precision corrected products. The inaugural collection version is 003. In response to recent changes with the radiometric calibration coefficients during the L1A+++ processing, LP DAAC generated a second processing option known as on-demand processing to support the new PGEs that will be applied to L1As. The radiometric calibration coefficient corrections are due to degradation of onboard calibration lamps over time causing sensor gain correction variation. Hence, on-demand processing will be labelled with version 031 while forward processing will retain the original version label, 003. Both versions 031 and 003 will have a unique processing number associated with each granule.

Table 3-6. Example Output File Name Type Extensions

File Name Type	Extension Code	ESDT
Science data file	.hdf	L1T
Visible full resolution image for VNIR/SWIR bands (GeoTIFF)	_V.tif	L1T
Thermal full resolution image for TIR bands (GeoTIFF)	_T.tif	L1T
Line, sample locations of the control points that correlated and comprehensive set of information regarding the verification	_QA.txt	QA
XML metadata file	hdf.xml	N/A
Individual browse files	_BR.{2,3,4}.{VNIR, TIR,QA}.jpg	N/A

Browse files may include up to three JPEG images: (1) Visible browse, (2) Thermal browse, and (3) single-band black and white browse overlaid with red, green, and blue (RGB) markers indicating GCPs used during the geometric verification quality check. ***Table 3-7*** illustrates the file names that would be constructed for AST_L1T files based on an AST_L1A file named: AST_L1A_00301112010002054_20140423133114_12345.hdf.

Table 3-7. Example ASTER Output File Names

Example file names	Dissemination Method
HDF: AST_L1T Data Product AST_L1T_00301112010002054_20140423133114_12345.**hdf**	Earthdata Search, Data Pool, EarthExplorer
GeoTIFF: Visible Image AST_L1T_00301112010002054_20140423133114_12345_**V.tif**	Earthdata Search, Data Pool, EarthExplorer
GeoTIFF: Thermal Image AST_L1T_00301112010002054_20140423133114_12345_**T.tif**	Earthdata Search, Data Pool, EarthExplorer
XML: Metadata AST_L1T Data Product AST_L1T_00301112010002054_20140423133114_12345.**hdf.xml**	Data Pool, EarthExplorer
JPEG: Standalone Reduced Resolution VNIR, TIR, and QA Browse 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*	Data Pool
Text: Geometric Quality Verification Report AST_L1T_00301112010002054_20140423133114_12345_**QA.txt**	Data Pool, EarthExplorer

Different granule file options are offered depending on the dissemination method (Earthdata Search, Data Pool, EarthExplorer) selected.

4.4. Telescope Combinations

Day-to-day implementation of the ASTER data acquisition strategy results in various combinations of telescope activation. Variations in telescope commanding determines the types of image data available in the AST_L1A dataset collection. By default, these variations in the AST_L1A are replicated in the associated AST_L1T file. Further variations are possible because SWIR was deemed not usable after April 2008. Specifically, the AST_L1T algorithm does not produce SWIR AST_L1T images from AST_L1A (where SWIR is present) for the time period ranging from April 1, 2008, through August 2012. SWIR was turned off August 2012, eliminating the inconsistency between AST_L1A and AST_L1T SWIR. Table 2-1 illustrates the various combinations of image data observed in AST_L1A HDF files and potentially associated AST_L1T granules.

Table 3-8. Potential Mapping of AST_L1A Bands to AST_L1T

L1A Telescopes Available	L1T Telescopes Available	L1T _T.tif	L1T _V.tif
VNIR + SWIR+ TIR	VNIR + SWIR+ TIR	Yes	Yes
VNIR + SWIR+ TIR	VNIR + TIR	Yes	Yes*
VNIR + SWIR	VNIR + SWIR	No	Yes
VNIR + SWIR	VNIR	No	Yes*

L1A Telescopes Available	L1T Telescopes Available	L1T _T.tif	L1T _V.tif
SWIR + TIR	SWIR + TIR	Yes	No
SWIR + TIR	TIR	Yes	No
VNIR + TIR	VNIR + TIR	Yes	Yes*
VNIR only	VNIR	No	Yes*
TIR only	TIR	Yes	No

**Note: GeoTIFF band selection differs because SWIR B4 is not available; no size impact.*

4.5. Download Expectations

LP DAAC offers different interfaces to download AST_L1T forward and on-demand processing products. Forward processing provides five different avenues (Data Pool, NASA Earthdata Search, USGS EarthExplorer, Data Prep Script, and DAAC2Disk utility) to download the data. Appendixes D, E, and F provide additional information on different interfaces to download AST_L1T products. On-demand processing products are limited to the NASA Earthdata Search, and users will receive an email once their order has been processed. A download link will be provided for immediate download. Download experience can differ depending on the user's system.

Table 3-9 provides estimated AST_L1T file and granule sizes for various AST_L1A telescope combinations based on current LP DAAC holdings.[14] LP DAAC historical holdings prior to April 2008 are weighted heavily on the top four rows of the table.

Table 3-9. Estimated Output File Sizes

L1A Telescopes Available	Typical L1A HDF File Size	L1T Telescopes Used	Estimated L1T HDF File Size
VNIR + SWIR+ TIR	117 MB	VNIR + SWIR+ TIR	140 MB
VNIR + SWIR+ TIR	117 MB	VNIR + TIR	98 MB
VNIR + SWIR	107 MB	VNIR + SWIR	129 MB
VNIR + SWIR	107 MB	VNIR	86 MB
SWIR + TIR	35 MB	SWIR + TIR	47 MB
SWIR + TIR	35 MB	TIR	9 MB
VNIR + TIR	85 MB	VNIR + TIR	94 MB
VNIR only	80 MB	VNIR	86 MB
TIR only	6 MB	TIR	9 MB
		Visible **GeoTIFF**	85 MB
		Thermal **GeoTIFF**	2 MB

Ultimately, transfer of files from the HTTPS server to user resources depends upon how fast the user's remote system can take data. GeoTIFF downloads will be somewhat faster than downloading their associated HDF files. Additionally, forward and on-demand processing have a minimal impact on the file size.

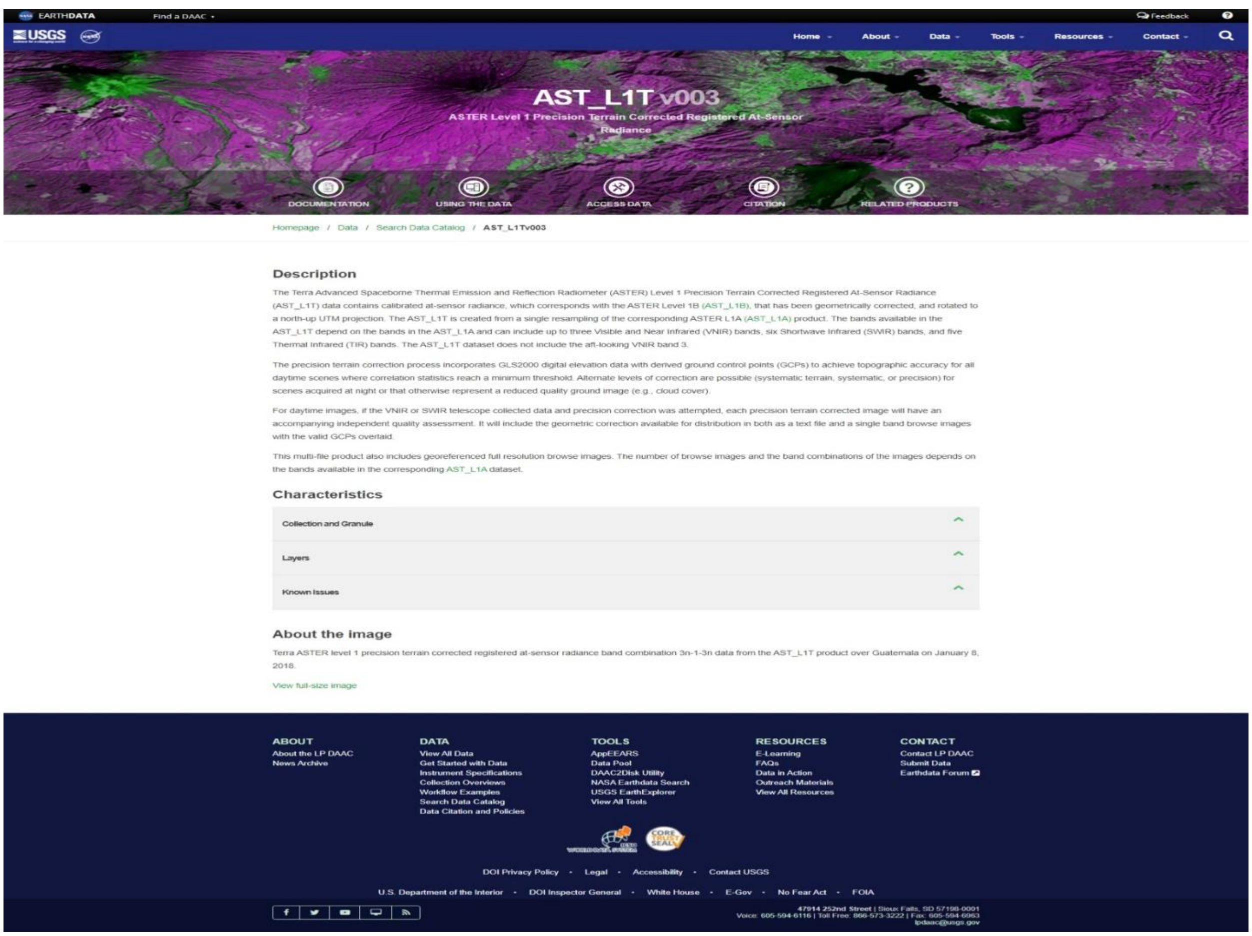
[14] File sizes given in the table were estimated using "pigeonhole" ranging; actual file sizes may differ considerably about the average depending on how much rotation of the scene was required.

Section 5 Search, Order and User Tools

5.1 Search and Dissemination Approaches

Both ASTER L1T products, forward- and on-demand processing, are made available to the user community through online interfaces provided by both NASA and USGS. The LP DAAC pushes AST_L1T metadata to external systems that support search engines accessed through user client tools. The primary option to search and order all AST_L1T (V003 and V031) data products is through NASA's Earthdata Search. Earthdata Search is a web application interface developed by EOSDIS to search, compare, visualize, and publicly access all NASA DAAC archives for current and past missions, projects, and campaigns. In addition, users who are very familiar with the ASTER dataset collection may choose to directly download AST_L1T V003 data from the public LP DAAC Data Pool by using HTTPS access. A NASA Earthdata Login is required to access and download all LP DAAC data products including AST_L1T V003 and V031. The account is free to create and is open to everyone. Users can also reach the Earthdata Search page or access the data by visiting each ASTER data Digital Object Identifier (DOI) landing page. Figure 1 shows the AST_L1T V003 DOI landing page.

Figure 5.1. AST_L1T DOI Landing Page



5.1.1. NASA Common Metadata Repository/Earthdata Search

NASA's EOSDIS generates, archives, and distributes petabytes of Earth Science data through various DAACs to a diverse user community. EOSDIS develops, maintains, and utilizes a centralized system to catalogue, search, access, and interpret its massive data holdings. NASA provides the Common Metadata Repository (CMR) system to serve its Earthdata Search user client. The objective of CMR is to ensure elements follow the standards established by the Unified Metadata Model (UMM). Earthdata Search supports many EOS data products, so the user generally down selects to specific collections and datasets in order to quickly locate science granules of interest. Science granules from the dataset are placed in a project (shopping cart), which is used to provide options for allowing access to the entire granule or its elements.

To fast track to AST_L1T granules, it is recommended that users enter the characters "AST_L1T" in the "Search for collections or topics" field. Also, it is recommended that users plot an area of interest on the map via the spatial feature (crop icon) and consider searching temporally for start and end of data acquisition (calendar icon). These steps lead to an offering of datasets for selection and finally to a granule list. Granules can be inspected using browse and information buttons before being selected for inclusion in the download list.

The download capability allows users to select HDF or GeoTIFF data products from individual granule(s) listed in the returned results. Upon selection of a list of matching granules, the user has the option to View/Download Data Links that allow retrieval of individual granule elements or to utilize the Download Access Script which provide an executable shell script to retrieve files.

The URL used to start an Earthdata Search session is https://search.earthdata.nasa.gov/.

5.1.2. NASA LP DAAC Data Pool

NASA provides computer resources deployed at, and managed by, the LP DAAC to allow direct download of data granules from an online service referred to as the "public Data Pool."

Unlike user clients, the public Data Pool does not help guide users to specific collections via search parameters. Rather, users navigate using HTTPS access by selecting from directories within a hierarchy. Thus, users who choose to download from public Data Pool collections are expected to be very familiar with the ASTER acquisition and processing history in order to navigate to their desired granules. This is because directories are named for collections, datasets, and granule acquisition date. Users of the public Data Pool must interrogate the metadata elements of each granule in order to determine location and inspect browse elements to determine scene quality or cloud coverage.

Users can download AST_L1T V003 directly from https://e4ftl01.cr.usgs.gov/.

Refer to Appendix E for screenshots illustrating a typical Data Pool download session.

5.1.3. USGS EarthExplorer

USGS EROS provides the EarthExplorer (EE) user client to access certain land process granules exported by the LP DAAC such as AST_L1T V003. For AST_L1T V003, EE provides LP DAAC options for download only. EE is very similar to Earthdata Search in its functionality but provides a slightly different look and feel for selection of search criteria. EE is strictly land processes orientated, so it offers less in the way of interdisciplinary datasets than Earthdata Search but offers more land science datasets. EE can display browse overlay images for certain Terra ASTER data, which is a feature not available for all Terra ASTER data by Earthdata Search. In addition to NASA Earthdata Login credentials, EarthExplorer requires the use of its own EROS Registration System (ERS) user credentials. New users will need to complete the ERS User Registration Form.

To search, discover, and download AST_L1T granules, EE users select search criteria such as an area of interest polygon on a map along with other fundamental criteria used to select granules from NASA LP DAAC collections. Granules meeting the criteria will be listed on the search results tab. Download options for each granule include the Standard HDF product, Thermal full resolution image (GeoTIFF), Visible full resolution image (GeoTIFF), Metadata, Quality Assurance browse image, and Quality Assurance Metadata.

The URL used to start an EarthExplorer session is https://earthexplorer.usgs.gov/.

Refer to Appendix F for screenshots illustrating a typical EarthExplorer search and download session.

5.1.4. DAAC2Disk and Script Options

The DAAC2Disk download manager allows users to simplify the search and HTTPS download process of the LP DAAC's Data Pool holdings. The DAAC2Disk utility is available as a script that can be downloaded and executed from the command line.

LP DAAC offers a collection of R and Python scripts that can be used to download data and perform basic data processing functions such as georeferencing, reprojecting, converting, and reformatting data. Scripts are available in Python and/or R and each have a README that provides additional information.

Bulk download options are available at two URLs:

- DAAC2Disk Utility: https://lpdaac.usgs.gov/tools/daac2diskscripts/
- Access Data Pool with R or Python: https://lpdaac.usgs.gov/tools/data-prep-scripts/

Section 6 Processing Irregularities

Several irregularities were observed while processing 3 million AST_L1A historical source files to create associated AST_L1T products. In one case, visible full resolution images, having a SWIR band, were found to have color stripes on the east and west edges. In these cases, striping is a normal condition resulting from an attempt to preserve all available data available in the bands. Two other cases observed are due to rare anomalies in support information embedded in the original AST_L1A HDF. One anomaly, associated with bad mapping data, causes clipped corners in the rotated AST_L1T image. The other anomaly, due to bad affine coefficients, causes warping in the image. If errors other than the ones pointed out in this section are observed, users are encouraged to notify the LP DAAC using the contact information found on the web page: https://lpdaac.usgs.gov/lpdaac-contact-us/.

6.1 Edge Striping on Visible GeoTIFF Having SWIR Band

AST_L1T visible full resolution images having SWIR Band 4[15] exhibit a red stripe on the west (left) side and a green stripe on the east (right) side of the image. The image RGB bands consist of SWIR Band 4 (red), VNIR Band 3N (green), and VNIR Band 2 (blue). As illustrated in Figure 0-1, the L1A data for these bands have different ground "footprints," most likely due to slightly differing telescope ground views. The bands used in the color images are not trimmed to the common ground coverage because data in the trimmed regions may be of interest to some users.

AST_L1T_00306032001190608_20150429152117_4161_V.tiff

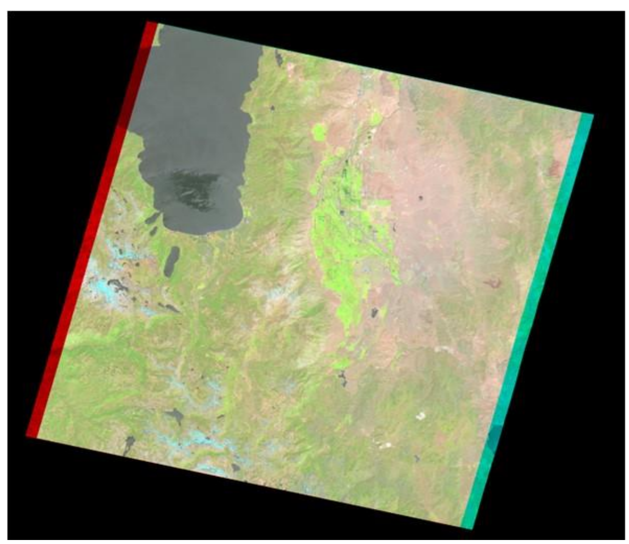


Figure 0-1. Edge Striping in Visible GeoTIFF having SWIR Band.

[15] In the Visual GeoTIFF having a SWIR band, SWIR Band 4 is resampled from 30-meter resolution to be compatible with 15-meter VNIR bands.

6.2 Clipped Corners on VNIR-Only HDF

For some AST_L1T VNIR only scenes, the information used for mapping from L1A to L1B space contains errors. The AST_L1T PGE uses L1A to L1B mapping parameters for systematic corrections such as band offsets, so these errors are inherited by the AST_L1T. Figure 0-2 illustrates what happens when the PGE projects the left and right boundary data outside the scene frame, which in this case is the lower left corner. The clipped corners are also noticeable on the Visible GeoTIFF.

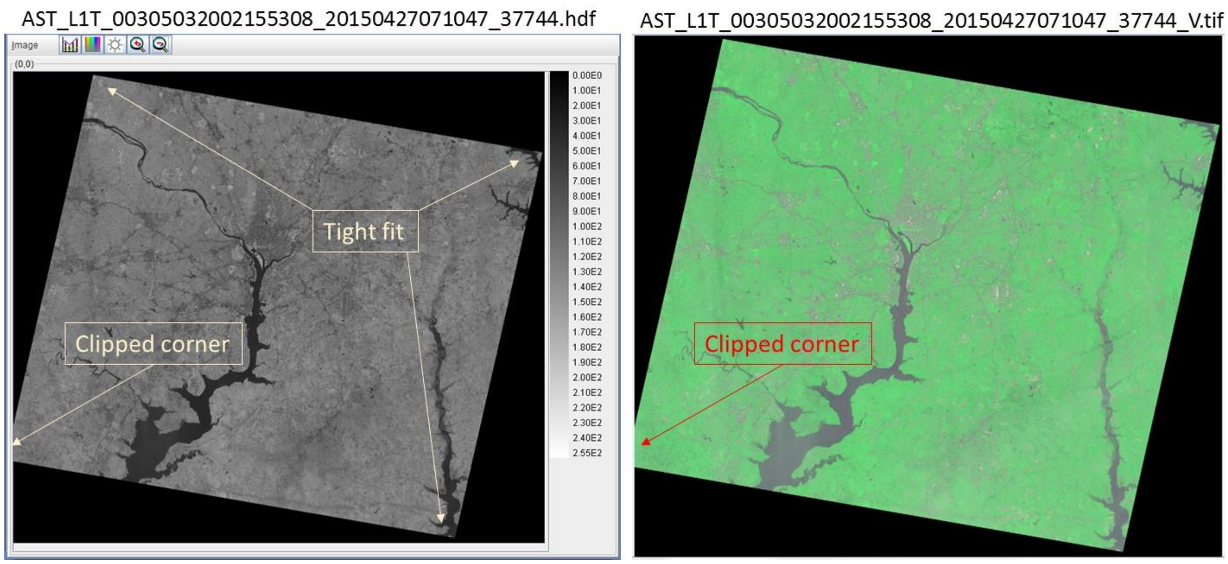


Figure 0-2. Clipped Corner for VNIR-only AST_L1T HDF and _V.TIF.

6.3 Warping Due to Bad Affine Coefficients

Under certain conditions, a few AST_L1A products will not process up to the AST_L1T level or they may process but result in a warped image. To date the main failure has been due to bad affine coefficients that cause AST_L1T resampling to fail. Under AST_L1T production rules, the entire product fails if any band in the file fails to process. This is unlike AST_L1B production which only fails if all bands to fail to process. Both Figure 0-3 and Figure 0-4 provide examples of failures seen in AST_L1A files that have succeeded to process to AST_L1B but **failed** in AST_L1T production.

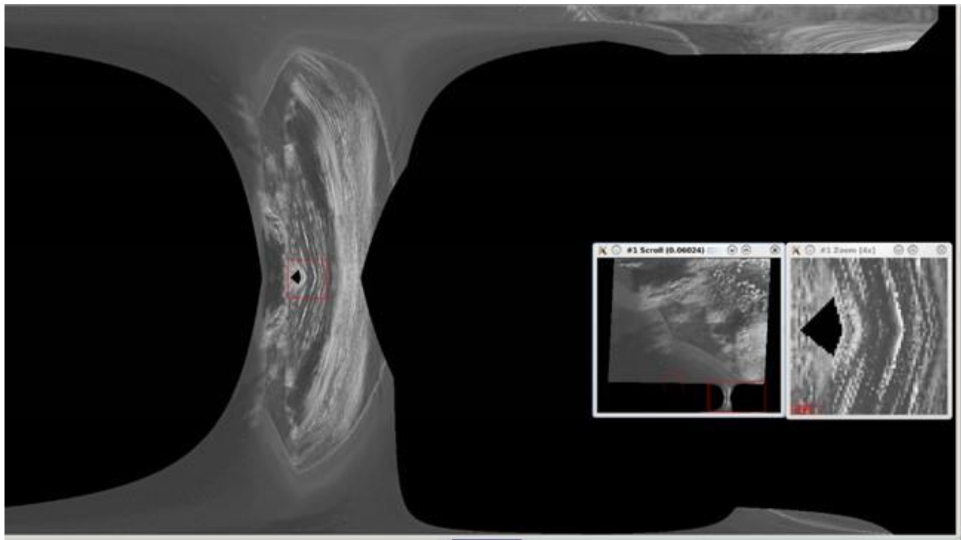


Figure 0-3. Bottom Warping AST_L1B Which Fails AST_L1T PGE.

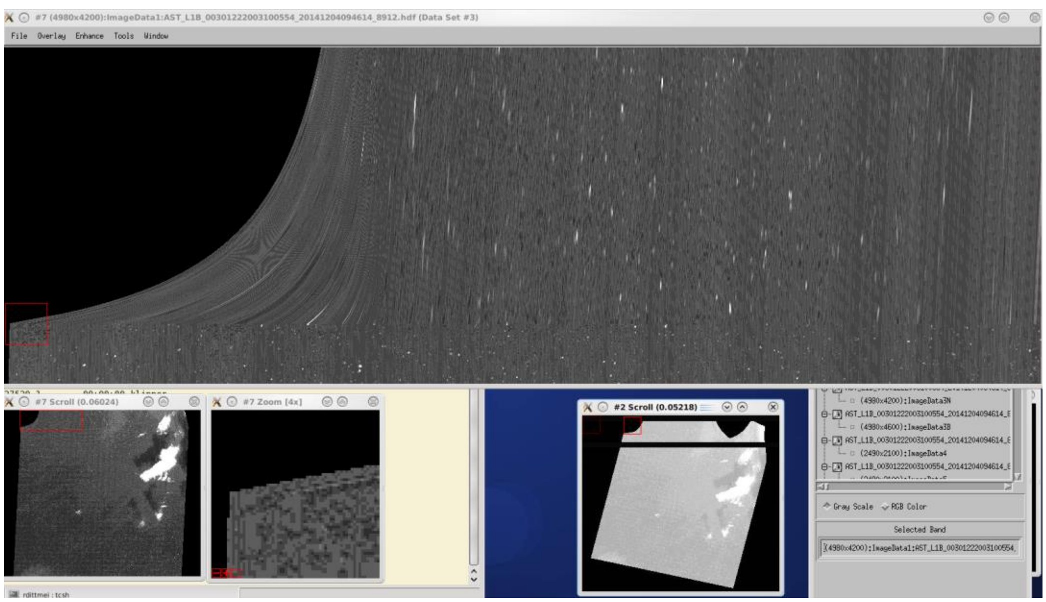


Figure 0-4. Top Warping AST_L1B Which Fails AST_L1T PGE.

A subset of production runs involving bad affine coefficients **may succeed** in producing an AST_L1T product. In these rare cases, production results in an image with some warped areas. Figure 0-5 illustrates a production run involving bad affine coefficients which resulted in an AST_L1T having anomalous artifacts near the bottom of the scene.

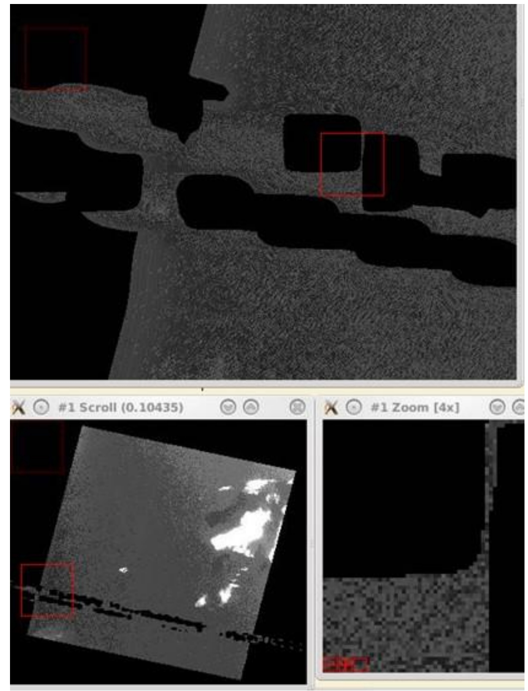


Figure 0-5. Bottom Warping Which Succeeds in AST_L1T Production.

References and Information

ERSDAC	Level-1 Data Working Group, ASTER Science Team,1996, Level-1 Algorithm Theoretical Basis Document for ASTER Level-1 Data Processing Version 3
JPL	Abrams, Hook, Ramachandran, 2002, ASTER User Handbook Version 2
NASA/ESDIS	Behnke, DATA Templates *[for Product Developers, DAAC and ESDIS-SOO, and Science Community Participants]* – Modified with 2012 LP DAAC proposal for AST_L1T
USGS/LP DAAC	Daucsavage, March 2015, AST_L1T Product Specification
USGS/LP DAAC	Meyer, Siemonsma, February 2015, Algorithm Theoretical Basis Document (ATBD) for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Level 1 Precision Terrain Corrected Registered At-sensor Radiance Product (AST_L1T)

Glossary

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

ASTER L1T PGE – Used generically throughout this document to represent product generation software that includes the AST_L1T executable utilizing the systematic L1B correction.

CMR – The Common Metadata Repository (CMR) is an Earth Science metadata and service registry populated with metadata and browse imagery from data partners, such as the LP DAAC. CMR is an open system providing Application Program Interfaces (APIs) to the Earth science community, which are used to build client systems. The LP DAAC exports metadata information to CMR, which provides product inventory to the Earthdata Search user client.

Earthdata Search – A NASA-provided Earth Science metadata and service discovery tool linked to the CMR inventory. The Earthdata Search 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, or select individual granules for direct download.

EarthExplorer (EE) – 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 –Used to convey relationships between product attributes and their characteristics and to enable EOSDIS Core System interfaces for a product.

Granule – Used to represent a collection of files that aggregate together to make up a whole instance of a given level of a product.

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 usage often becomes unwieldy in sentences containing several derivations of the word.

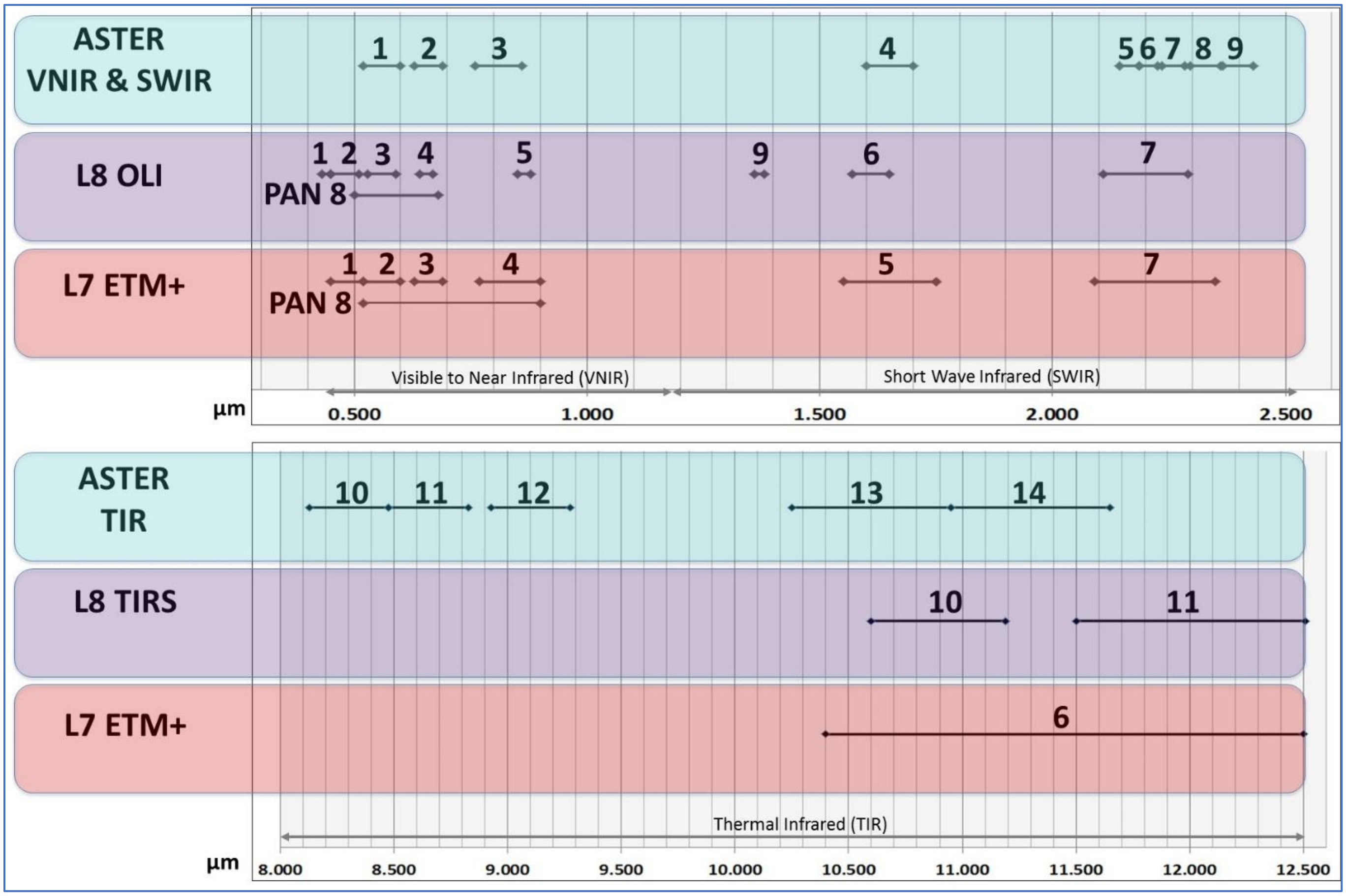
Scene – Most often used in a visible context or as an index in a database.

Acronyms

Acronym	Description
ASTER	Advanced Spaceborne Thermal Emission and Reflectance Radiometer – an instrument on the Terra satellite
ATBD	Algorithm Theoretical Basis Document
CMR	Common Metadata Repository
DEM	Digital Elevation Model
DN	Digital Numbers
ECS	EOSDIS Core System
EDOS	EOS Data and Operations System
EDS	Expedited Dataset
EE	EarthExplorer – *Search client for download of ASTER products*
EOS	Earth Observing System
EROS	Earth Resource Observation Sciences
ESDIS	Earth Science Data and Information System
ESDT	Earth Science Data Type
EXP	Expedited
GDS	Ground Data System (Japan)
GUI	Graphical User Interface
HDF	Hierarchical Data Format
HTTPS	HyperText Transfer Protocol Secure
JPL	Jet Propulsion Laboratory
L(n)	Science Product Level (n = 1, 2, or 3)
L1A	ASTER Level 1 Reconstructed, Unprocessed Instrument Digital Numbers
L1AE	ASTER Level 1A Expedited via DAR process
L1B	ASTER Level 1 Radiometrically Calibrated, Geometrically Co-registered
L1BE	ASTER Level 1B Expedited via DAR process
L1T	ASTER Level 1 Precision Terrain Corrected Registered At-Sensor Radiance
LP DAAC	Land Processing Distributed Active Archive Center
NASA	National Aeronautics and Space Administration
OSF	Orbit Schedule File
PGE	Product Generation Executable
POSF	Parsed OSF
QA	Quality Assessment
SILC	Sensor Information Laboratory Corporation (for ASTER)
SIPS	Science Investigator-led Processing Systems
SWIR	Shortwave Infrared
TIR	Thermal Infrared (Long Wave)
USGS	United States Geological Survey
VNIR	Visible Near Infrared

Appendix A ASTER and Landsat Spectral Comparisons

The following figure compares the Terra ASTER and Landsat spacecraft, instruments, and bands within the observable spectrum.



Similar to the Terra satellite, the Landsat spacecraft are flying in a circular, near-polar orbit at an altitude of 705 km. The orbit is sun-synchronous with the Terra equatorial crossing at local time of 10:30 a.m. This renders daytime orbits to be descending passes while nighttime orbits are ascending passes. Terra returns to the same orbit every 16 days completing over 14 orbits per day. The orbit parameters are the same as those of Landsat, with an equatorial crossing time between 10:00 am and 10:15 am (local time). Terra and Landsat 7 are in the same orbit with Terra crossing the equator 15 minutes later than Landsat 7. Landsat 8 is offset from the other two satellites by 8 days.

The following table compares the Terra ASTER and Landsat spacecraft, instruments, and bands for pixel size, band numbering scheme, and spectral wavelength collected.

Spacecraft	Instrument	Pixel size (m)	Band	Wavelength (µm)	
				From	*To*
Terra	ASTER VNIR	15	1	0.52	0.60
	ASTER VNIR	15	2	0.63	0.69
	ASTER VNIR	15	3	0.76	0.86
	ASTER SWIR	30	4	1.600	1.700
	ASTER SWIR	30	5	2.145	2.185
	ASTER SWIR	30	6	2.185	2.225
	ASTER SWIR	30	7	2.235	2.285
	ASTER SWIR	30	8	2.295	2.365
	ASTER SWIR	30	9	2.360	2.430
	ASTER TIR	90	10	8.125	8.475
	ASTER TIR	90	11	8.475	8.825
	ASTER TIR	90	12	8.925	9.275
	ASTER TIR	90	13	10.25	10.95
	ASTER TIR	90	14	10.95	11.65
Landsat 8	OLI	30	1	0.43	0.45
	OLI	30	2	0.45	0.51
	OLI	30	3	0.53	0.59
	OLI	30	4	0.64	0.67
	OLI	30	5	0.85	0.88
	OLI	30	6	1.57	1.65
	OLI	30	7	2.11	2.29
	OLI PAN	15	8	0.50	0.68
	OLI	30	9	1.36	1.38
	TIRS	100* (30)	10	10.60	11.19
	TIRS	100* (30)	11	11.50	12.51
Landsat 7	ETM+	30	1	0.45	0.52
	ETM+	30	2	0.52	0.60
	ETM+	30	3	0.63	0.69
	ETM+	30	4	0.77	0.90
	ETM+	30	5	1.55	1.75
	ETM+	60** (30)	6	10.40	12.50
	ETM+	30	7	2.09	2.35
	ETM+ PAN	15	8	0.52	0.90

* Landsat 8 TIRS Bands 10 and 11 acquired at 100 m, resampled to 30 m.

** Landsat 7 ETM+ Band 6 acquired at 60 m, resampled to 30 m.

References

ASTER: https://asterweb.jpl.nasa.gov/characteristics.asp

Landsat: https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites?qt-news_science_products=0#qt-news_science_products

Appendix B ASTER Data Acquisition Strategy

ASTER was not designed to continuously acquire data; therefore, daily acquisitions are scheduled and prioritized. The ASTER Science Team has developed a data acquisition strategy divided into three categories: local observations, regional monitoring, and global map.[16]

Local Observations
Local observations are made in response to Data Acquisition Requests (DAR) submitted by authorized ASTER users including, for example, scenes for analyzing land use, surface energy balance, or local geologic features. Local observations are often referred to as targets of opportunity such as volcanoes, floods, or fires. Requests for urgent observations of such phenomena must be fulfilled in short time periods (a few days) so they receive special handling.

Regional Monitoring Data
Regional datasets contain the data necessary for analysis of a large region or a region requiring multi-temporal analysis. Local Observation and Regional Monitoring requests are distinguished by the amount of viewing resources required. A number of Regional Monitoring tasks have been pre-designated by the ASTER Science Team, which include repetitive imaging of:

- The world's mountain glaciers
- The world's active and dormant volcanoes
- The Long-Term Ecological Research (LTER) field sites

Global Map
The Global Map dataset is available to investigators of every discipline to complement lower resolution data acquired more frequently by other EOS instruments. Each region of the Earth has been prioritized by the ASTER Science Team for observation using the following strategy:

- Minimum of one-time coverage
- High sun angle
- Optimum gain for the local land surface
- Minimum snow and ice cover
- Minimum vegetation cover, and
- No more than 20% cloud cover (perhaps more for special sub-regions).

Allocation of Science Data
The general strategy to allocate observations to the three categories is that approximately 25% of ASTER resources will be allocated to Local Observations, 50% to Regional Monitoring, and 25% to the Global Map. Global Map data is further sub-divided to 25% for high priority areas, 50% for medium priority areas, and 25% for low priority areas.

[16] This subsection is paraphrased from Section 7 of the ASTER User Handbook Version 2.

Regional Monitoring and the Global Map will be acquired by ASTER in response to acquisition requests submitted by the ASTER Science Team acting on behalf of the science community via Science Team Acquisition Requests (STARs) directly to the ASTER Ground Data System in Japan. Under limited circumstances, STARs for Local Observations may also be submitted by the Science Team.

STARs for Regional Monitoring data are subject to a proposal that is evaluated by ASTER's science working groups before being formally submitted to the Science Team.

Appendix C ASTER Processing Flow

Depending on the ASTER Product, processing is initiated immediately upon the arrival of new AST_L1A from GDS or EDOS while reprocessing relies on the collaborative effort between Japan and the LP DAAC. In early 2015, The LP DAAC reprocessed the entire L1A archive to generate the AST_L1T collection.[17]

Figure 2.1 from Section 2 shows a detailed processing flow for all ASTER products. Processing is triggered when a user orders a product from different interfaces as described in Section 5 of this Product Guide. The initial AST_L1T relied on the historical AST_L1A archive, which dates back to 2000. There have been a number of radiometric and geometric updates implemented as part of the ASTER processing mechanism since 2000; therefore, the inventory contains different radiometric and geometric calibration coefficient versions. The most recent L1A PGE updates gave LP DAAC the opportunity to reprocess the entire L1A inventory with one consistent radiometric version (RCC V4), thereby providing a homogenous radiometric traceability to perform time series analysis by the user community.

The forward processing AST_L1T V003 product provides one consistent radiometric version for the entire inventory, while on-demand processing (AST_L1T V031) includes the most recent application of new L1A PGEs and radiometric calibration coefficients (V5) with improved degradation curves for bands 1 and 2.

This discussion assumes the AST_L1A has sufficient content to allow processing; otherwise, the algorithm would exit without producing a product. Also, to enhance readability, the discussion ignores checks for rare technical conditions that prohibit the use of digital elevation data for terrain correction. Therefore, it is possible that some AST_L1T may be processed to a systematic or precision level without the benefit of terrain correction.

The input AST_L1A comprises reconstructed, unprocessed instrument data that contains depacketized, demultiplexed, and realigned instrument image data with geometric correction coefficients and radiometric calibration coefficients referenced in the image header, but not applied when it’s ingested by the ECS. AST_L1A also includes the SWIR parallax corrections, and intra- and inter-telescope registration information. These calculated and appended correction coefficients are applied to all AST_L1A science data, which is used to create AST_L1T science data. Additionally, the science data are rotated from the satellite path orientation to a north-up orientation in UTM coordinate space.

The ASTER Level 1 precision terrain corrected registered at-sensor radiance product can result from one of two different levels of potential correction because of variations among the AST_L1A input scenes. There are two main logic paths for correction levels:

[17] This subsection is paraphrased from Section 2 of the ASTER L1T ATBD and Section 3 of the ASTER L1A/B ATBD.

a) Terrain+Precision correction:
   Applicable to all daytime AST_L1A scenes where correlation statistics reach a minimum threshold
b) Terrain+Systematic correction:
   Applied to all AST_L1A input data for which the precision correction is not possible

Two less frequent corrections may occur for scenes with no corresponding terrain data such as ocean scenes: precision correction and systematic correction. Each band is only resampled once in the flow. A Quality Assessment process occurs after the AST_L1T product has been generated. Also, a process is executed to generate full resolution images for users preferring GeoTIFF over HDF-EOS2 file formats.

Earth Rotation and Nutation

The AST_L1A+ supplemental algorithm was implemented on May 25, 2005, to address geolocation discrepancies caused by an incorrect calculation of the Earth's rotation angle and a longitudinal error resulting from an omission of compensation for nutation in the Earth's rotation.

An incorrect calculation of the Earth's rotation angle produced a geolocation error of up to 300 meters near the poles for daytime scenes and less than 100 meters below 70 degrees latitude. The longitude error for nighttime scenes is largest at the equator and decreases to ~100 meters at the poles.

Between September 2003 and April 2005 an Earth nutation-related longitudinal error can be corrected by post-processing AST_L1A data using an equation defined in the AST_L1T ATBD. The longitudinal error is dependent on the date of ASTER data acquisition. In general, the magnitude of error is less than 50 meters before July 2003 and increased to approximately 200 meters through the end of 2004. All ASTER Level 1 data distributed after April 2005 was produced with the AST_L1A+ supplemental algorithm incorporating geometric database version 3.0 or later, which corrects for nutation error.

TIR Bore Sight

The AST_L1A++ supplemental algorithm implemented on May 9, 2012, uses geometric database version 3.02 or greater to address geolocation discrepancies in the TIR bands for nighttime acquisitions of approximately 100–400 meters toward the cross-track direction. This cross-track error contributes to both latitudinal and longitudinal errors because ASTER's orbit, in relation to geographic north, varies with latitude. The AST_L1T ATBD provides several equations that are a function of the pointing angle and scene orientation angle to correct latitudinal and longitudinal errors.

VNIR Lamp Calibration

The AST_L1A+++ supplemental algorithm implemented in late 2014 addresses degradation of the VNIR onboard calibrator (OBC) affected by the dimming of the OBC halogen lamps over time. The VNIR lamp-based calibration method, selected over alternate methods based on real-estate limitations aboard the Terra platform, consists of two redundant onboard calibration halogen lamps. Data collected from these lamps every 33 days are used to generate radiometric calibration coefficients (RCC) that are normalized using pre-flight data providing for a precise and repeatable means to monitor temporal trends in the radiometric response of the sensor. When the new RCC values deviate from the existing trend by 2% or more, ASTER implements a new version of the RCC values. Since launch, the average change in response is 23% for Band 1, 16% for Band 2, and 10% for Band 3. Currently, the AST_L1A+++V2 supplemental algorithm utilizes radiometric database version 5.0, which has improved degradation curves for bands 1 and 2.

Appended Corrections Applied
The AST_L1T uses the AST_L1B algorithm to apply the aforementioned radiometric calibration coefficients that were calculated and appended but not applied to the original AST_L1A data product. Refer to the Level-1 Algorithm Theoretical Basis Document for ASTER Level-1 Data Processing (ERSDAC 1996) and a more detailed description of AST_L1B processing.

The appended coefficients also include original corrections for the TIR DC Clamp phenomenon, and inter- and intra-telescope bore alignment. Bad pixel values are evaluated and corrected. Radiance is converted to DN values, taking into account both the acquisition gain settings and the gain calibration included within the radiometric database. DN values of the bad pixels are evaluated by the linear interpolation from the adjacent pixels, followed by the de-striping correction for the DN values of the image data.

SWIR Cross-talk Correction
The cross-talk correction algorithm is a supplementary algorithm developed to address a SWIR optical leak from Band 4 resulting in a superimposed ghost image on bands 5−9. The leak occurs when Band 4 incident light is reflected by the detector’s aluminum-coated parts and is projected onto the other detectors. The cross-talk effect also depends upon band-to-band parallax error and the distance between array pairs. Bands 9 and 5 display the most dominant effects because of their locational proximity to the Band 4 detectors. The original algorithm for cross-talk correction generates a cross-talk image by convolution between a Band 4 image and the two-dimensional Gaussian function. However, the kernel function for convolution is not always symmetrical in the cross-track direction. The new kernel function considers all cross-talk components with sensitivity correction coefficients that are statistically determined from a sample scene.

Pseudo-affine Transformation Coefficients
According to the well-established usual procedure, logic from the AST_L1B algorithm transforms the path-oriented coordinates to UTM coordinates, which are then linked back to the original AST_L1A input image coordinates using a set of eight pseudo-affine transformation coefficients per block, expressed by the pixel size units of each band.

Terrain Correction

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.

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 these two primary levels of terrain correction, two less frequent scenarios may occur for scenes with no corresponding terrain elevation data. 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, but 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 metadata 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, it is the preferred band for use in the modified Landsat geometric algorithm. However, if Band 5 is not available, (or for SWIR acquired after April 2008 when the data became saturated) then VNIR Band 2 is used. Use of the modified Landsat geometric algorithm begins with the creation of the systematic grid where the AST_L1A input scene is rotated from the satellite path orientation to 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, 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. The resampling of the AST_L1A input scene will then 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 AST_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 terrain 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 Landsat Modified Moravec Interest Operator (MMIO) ground control points. When the 30-meter 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 VNIR Band 2 to the 30-meter 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 GCPs used are small image chips (64x64 pixels) with geographic information that have been extracted from the reference image using the 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 a 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 (ASTER 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, 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 orthorectified GLS2000 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, 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.

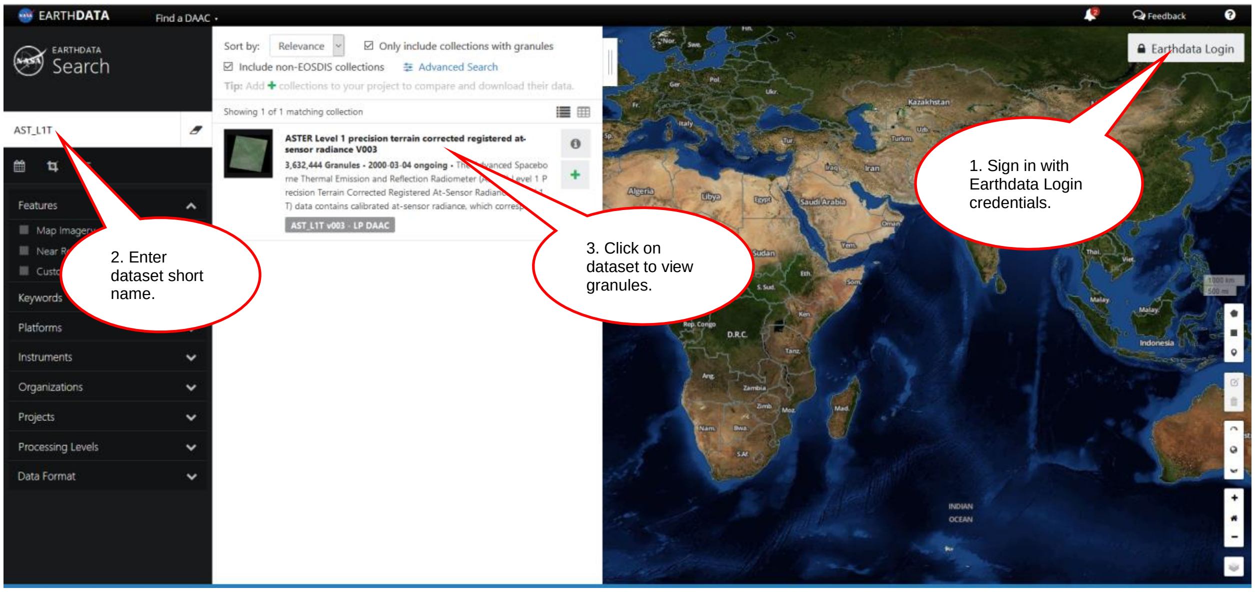
Quality Assurance

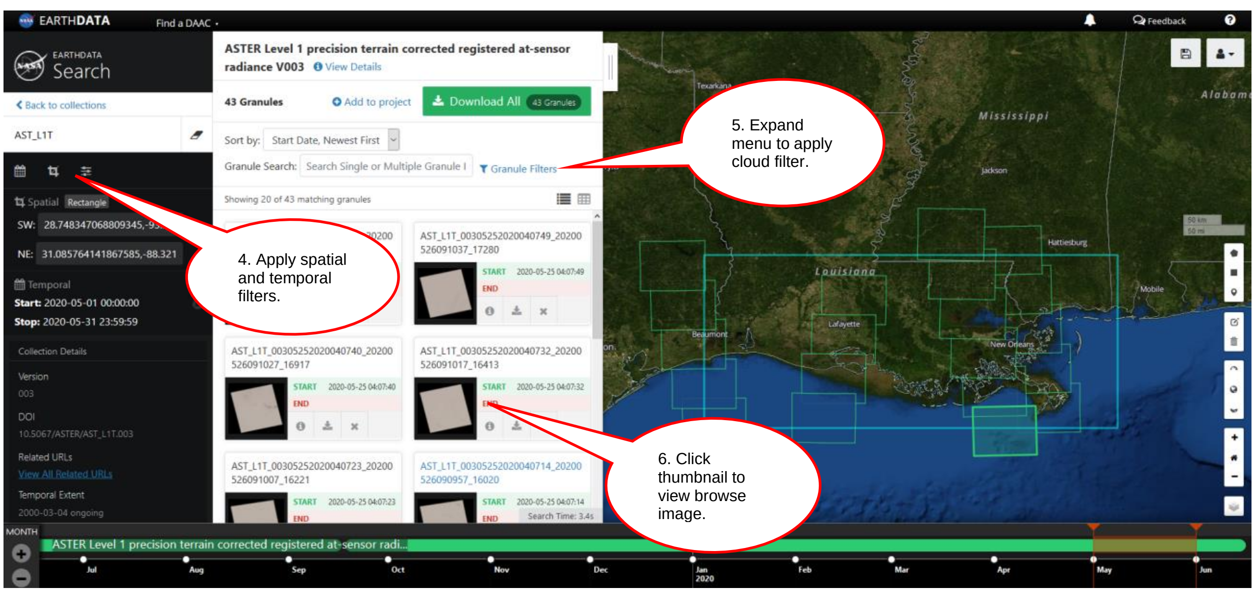
Simple statistics, such as mean, median, standard deviation, and RMSE for the good GCPs[18], are calculated for the entire scene by dividing the scene into four regions. The

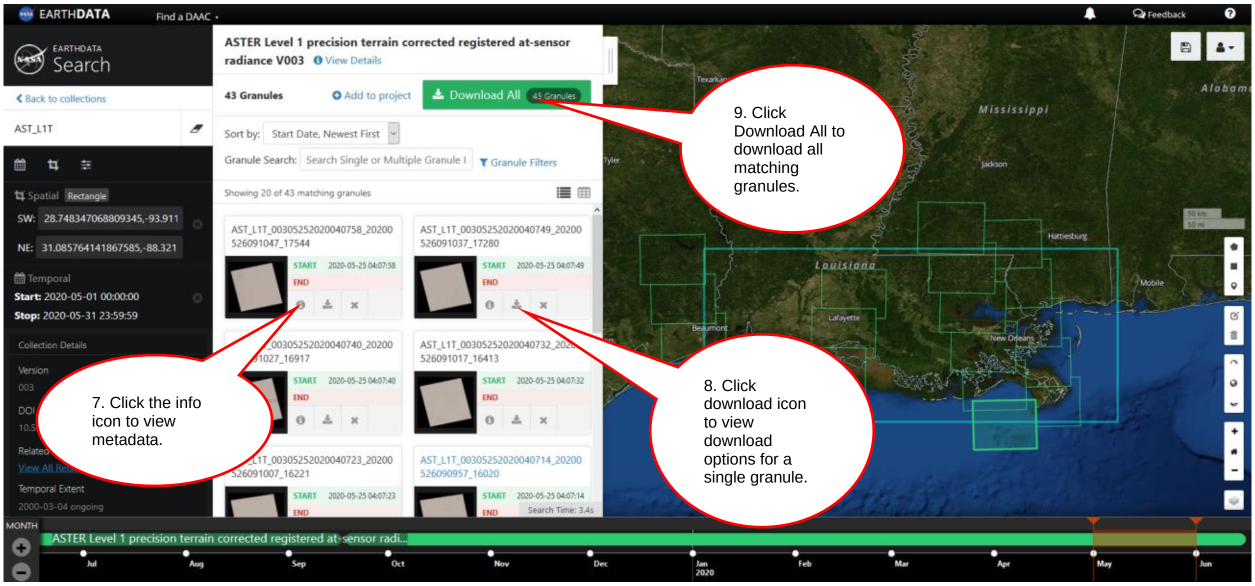
[18] The Gverify ground control points (GCPs) are not the same as those used for precision registration (in GCPCorrelate). The points used in Gverify are defined by a relatively high-density uniform grid across the GLS2000 Standard scene space for the standard scene over the ASTER L1T scene center.

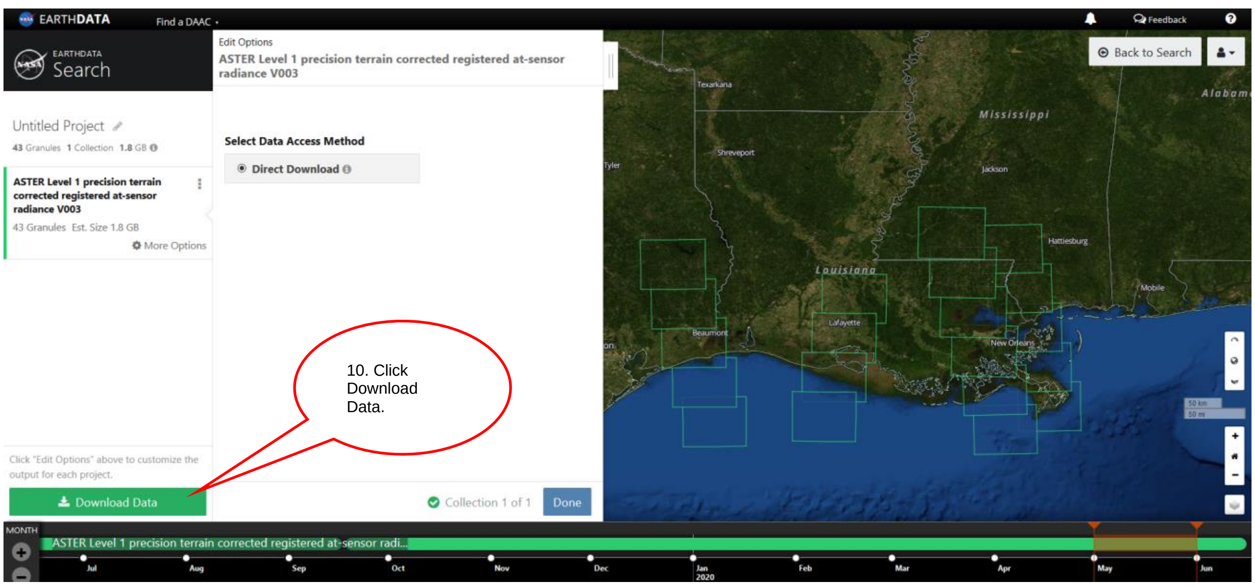
set of good GCP points are color-coded based on their ranks and overlaid on the terrain corrected product; then a browse image is generated. The quadrant RMSE and full scene RMSE are provided in the AST_L1T metadata files for the end user.

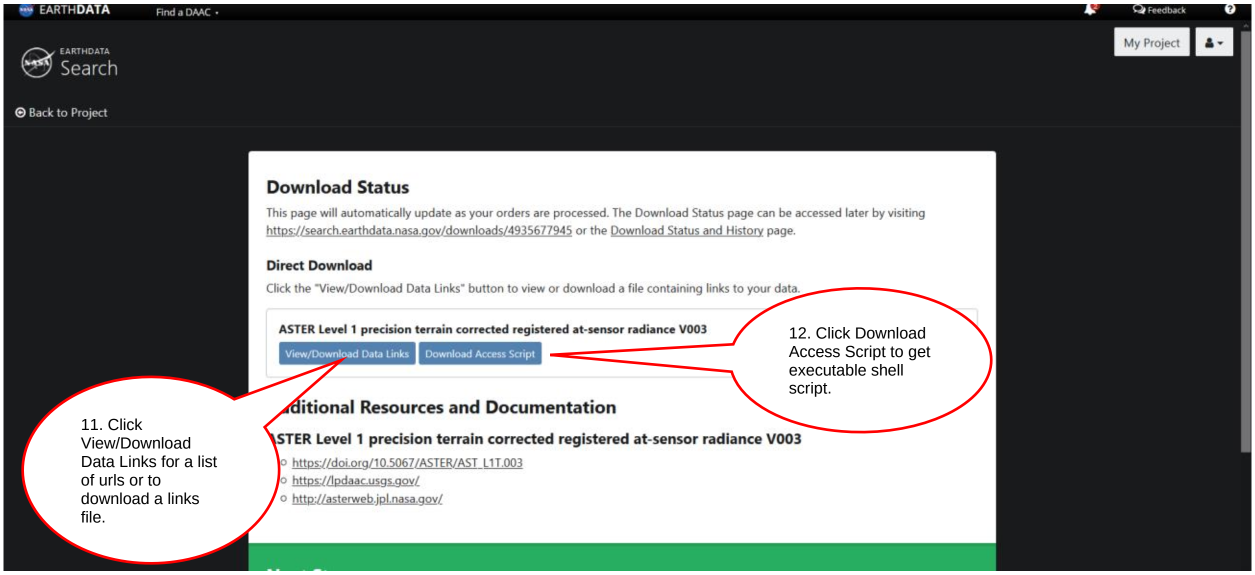
Appendix D Earthdata Search Download Session



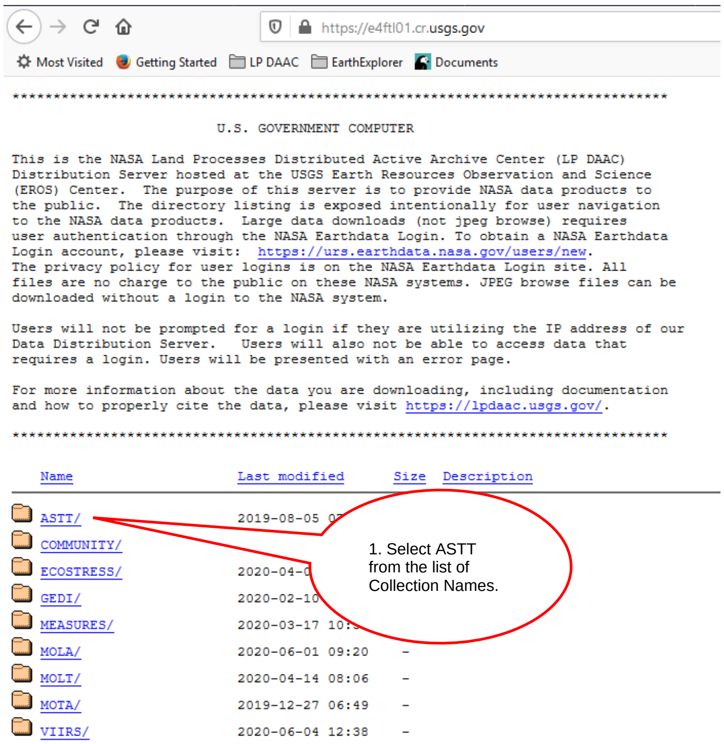



9. Click Download All to download all matching granules.
7. Click the info icon to view metadata.
8. Click download icon to view download options for a single granule.


10. Click Download Data.


EARTHDATA
Find a DAAC
Feedback
EARTHDATA Search
My Project
Back to Project
Download Status
This page will automatically update as your orders are processed. The Download Status page can be accessed later by visiting https://search.earthdata.nasa.gov/downloads/4935677945 or the Download Status and History page.
Direct Download
Click the "View/Download Data Links" button to view or download a file containing links to your data.
ASTER Level 1 precision terrain corrected registered at-sensor radiance V003
View/Download Data Links
Download Access Script
12. Click Download Access Script to get executable shell script.
11. Click View/Download Data Links for a list of urls or to download a links file.
ASTER Level 1 precision terrain corrected registered at-sensor radiance V003
https://doi.org/10.5067/ASTER/AST_L1T.003
https://lpdaac.usgs.gov/
http://asterweb.jpl.nasa.gov/

Appendix E Data Pool Download Session



https://e4ftl01.cr.usgs.gov

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This is the NASA Land Processes Distributed Active Archive Center (LP DAAC) Distribution Server hosted at the USGS Earth Resources Observation and Science (EROS) Center. The purpose of this server is to provide NASA data products to the public. The directory listing is exposed intentionally for user navigation to the NASA data products. Large data downloads (not jpeg browse) requires user authentication through the NASA Earthdata Login. To obtain a NASA Earthdata Login account, please visit: https://urs.earthdata.nasa.gov/users/new. The privacy policy for user logins is on the NASA Earthdata Login site. All files are no charge to the public on these NASA systems. JPEG browse files can be downloaded without a login to the NASA system.

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Name	Last modified	Size	Description
ASTT/	2019-08-05 0		
COMMUNITY/			
ECOSTRESS/	2020-04-0		
GEDI/	2020-02-10		
MEASURES/	2020-03-17 10:		
MOLA/	2020-06-01 09:20	-	
MOLT/	2020-04-14 08:06	-	
MOTA/	2019-12-27 06:49	-	
VIIRS/	2020-06-04 12:38	-	

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Name	Last modified	Size	Description
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AG1km.003/	2014-04-02 13:10	-	
AG5KMMOH.041/	2016-11-30 15:41	-	
ASTGTM.003/	2019-08-05 07:31	-	
ASTGTM_NC.003/	2019-08-05 07:35	-	
ASTGTM_NUMNC.003/	2019-08-05 07:38	-	
ASTWBD.001/	2019-08-05 07:43		
ASTWBD_ATTNC.001/	2019-08-0		
ASTWBD_NC.001/	2019-0		
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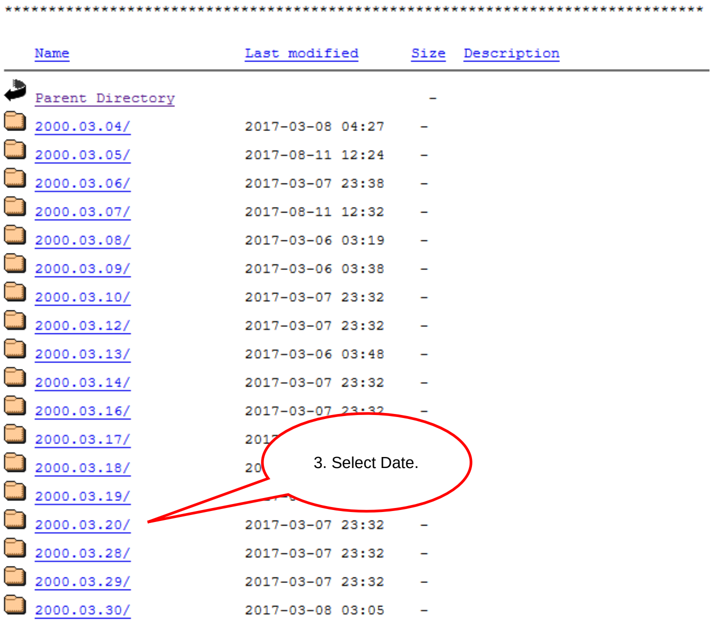
AST_L1T.003/	2020-06-12 09:20	-	



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2000.03.09/	2017-03-06 03:38	-	
2000.03.10/	2017-03-07 23:32	-	
2000.03.12/	2017-03-07 23:32	-	
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2000.03.14/	2017-03-07 23:32	-	
2000.03.16/	2017-03-07 23:32	-	
2000.03.17/	201		
2000.03.18/	20		
2000.03.19/			
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Name	Last modified	Size
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AST_L1T_00306082020000556_20200609093019_8002_BR.4.QA.jpg	202	
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AST_L1T_00306082020000556_20200609093019_8002_V.tif	2020-06-0	
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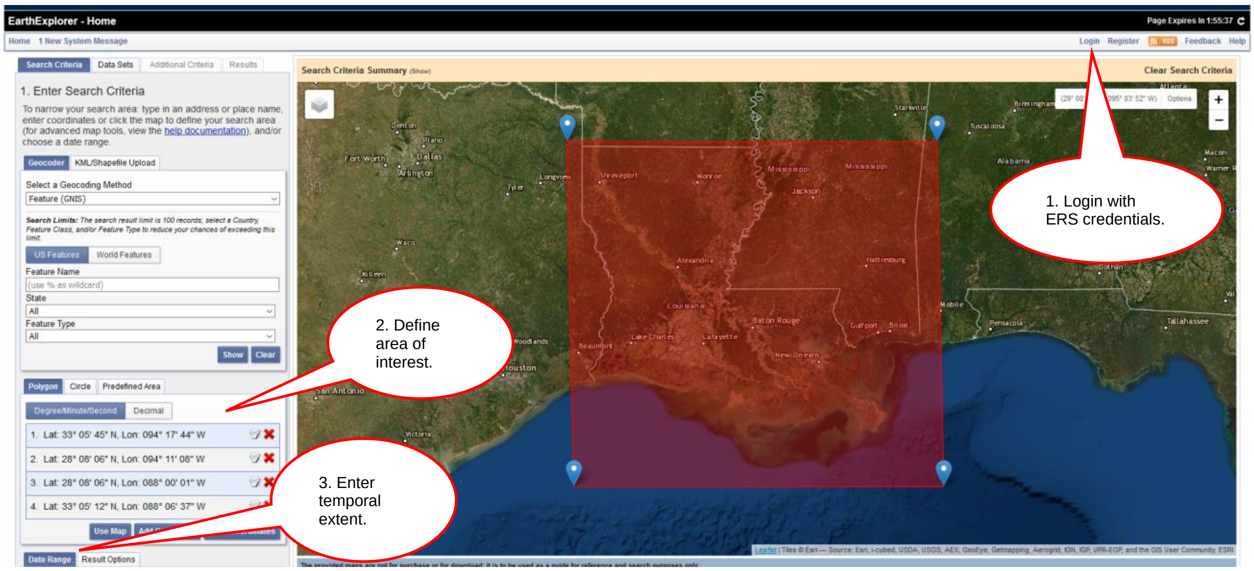
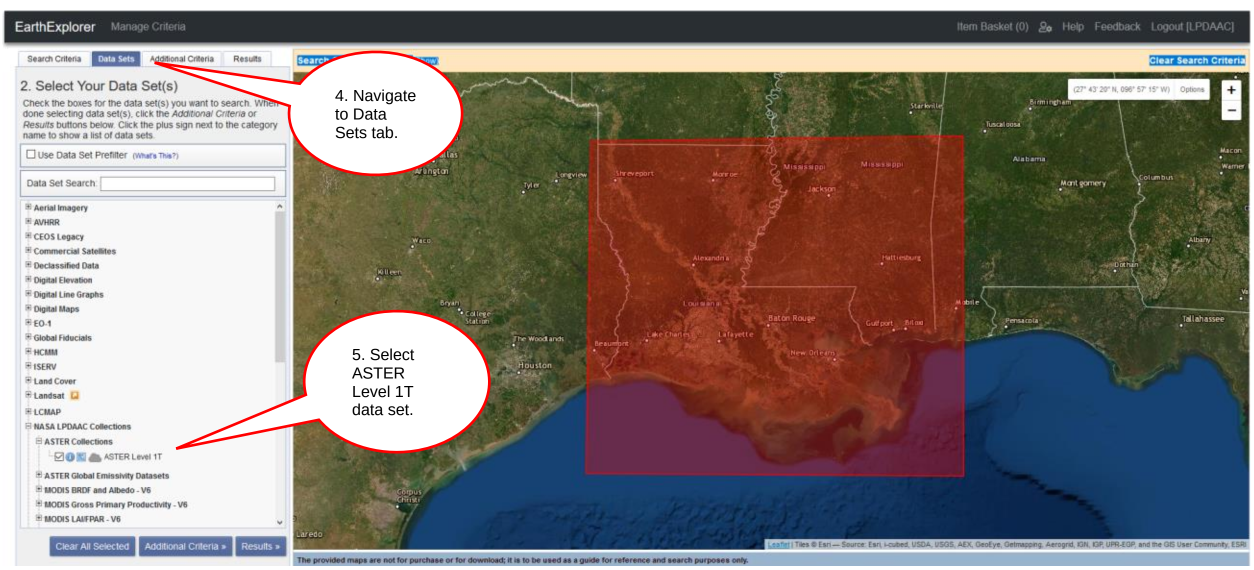
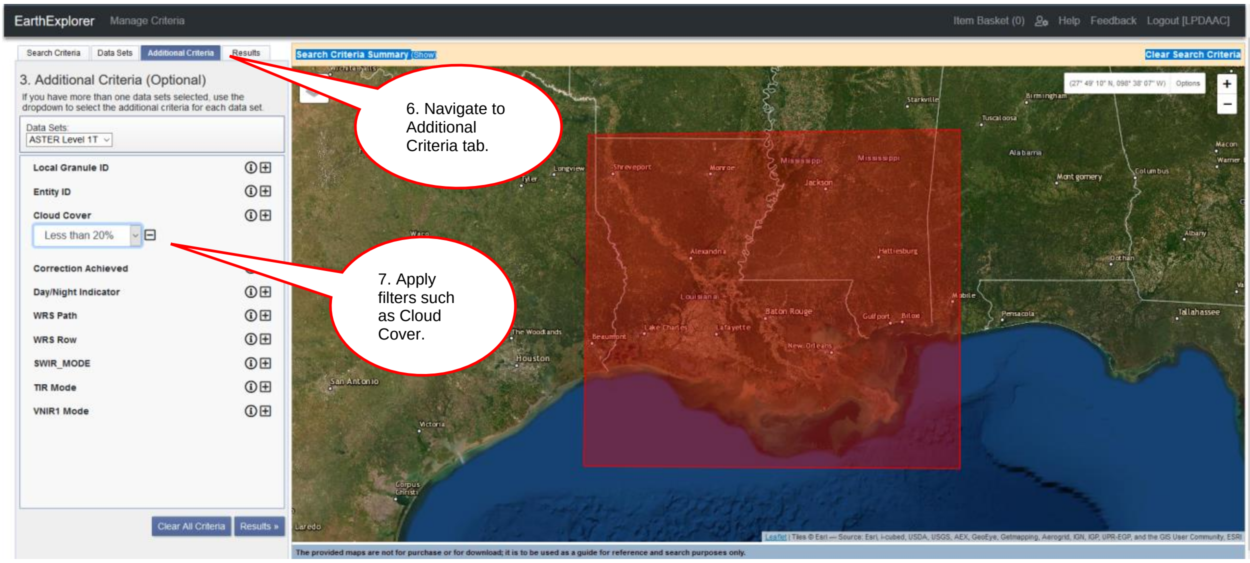
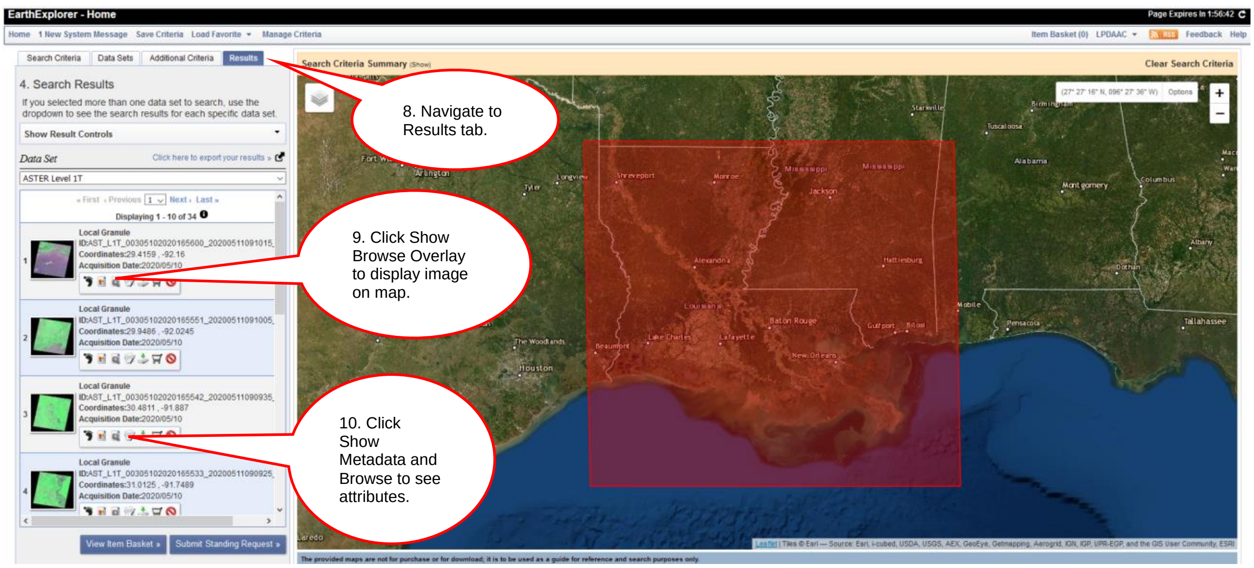
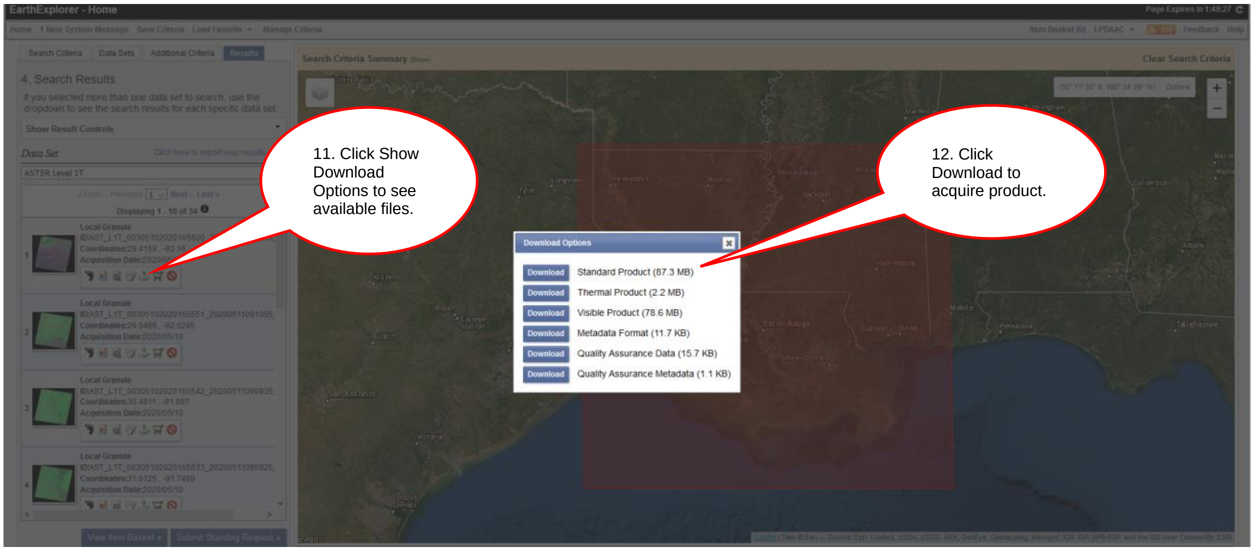
Appendix F EarthExplorer Download Session






EarthExplorer
Manage Criteria
Item Basket (0)
Help
Feedback
Logout [LPDAAC]
Search Criteria
Data Sets
Additional Criteria
Results
3. Additional Criteria (Optional)
If you have more than one data sets selected, use the dropdown to select the additional criteria for each data set.
Data Sets:
ASTER Level 1T
Local Granule ID
Entity ID
Cloud Cover
Less than 20%
Correction Achieved
Day/Night Indicator
WRS Path
WRS Row
SWIR_MODE
TIR Mode
VNIR1 Mode
Clear All Criteria
Results »
Search Criteria Summary
Clear Search Criteria
6. Navigate to Additional Criteria tab.
7. Apply filters such as Cloud Cover.
The provided maps are not for purchase or for download; it is to be used as a guide for reference and search purposes only.


EarthExplorer - Home
Home
Save Criteria
Load Favorite
Manage Criteria
Item Basket (0)
LPDAAC
Feedback
Help
Search Criteria
Data Sets
Additional Criteria
Results
4. Search Results
If you selected more than one data set to search, use the dropdown to see the search results for each specific data set.
Show Result Controls
Data Set
Click here to export your results »
ASTER Level 1T
Displaying 1 - 10 of 34
View Item Basket »
Submit Standing Request »
Search Criteria Summary
Clear Search Criteria
8. Navigate to Results tab.
9. Click Show Browse Overlay to display image on map.
10. Click Show Metadata and Browse to see attributes.
The provided maps are not for purchase or for download; it is to be used as a guide for reference and search purposes only.


11. Click Show Download Options to see available files.
12. Click Download to acquire product.
Download Options
Download Standard Product (87.3 MB)
Download Thermal Product (2.2 MB)
Download Visible Product (78.6 MB)
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