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 1.1

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AST_L1T Product User's Guide

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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) products. It supplements the JPL ASTER Users Handbook with new information on AST_L1T including an update to the Handbook's section on ASTER Data Search and Order.

Contents

List of Figures

List of Tables

Section 1 Introduction

1.1 Background

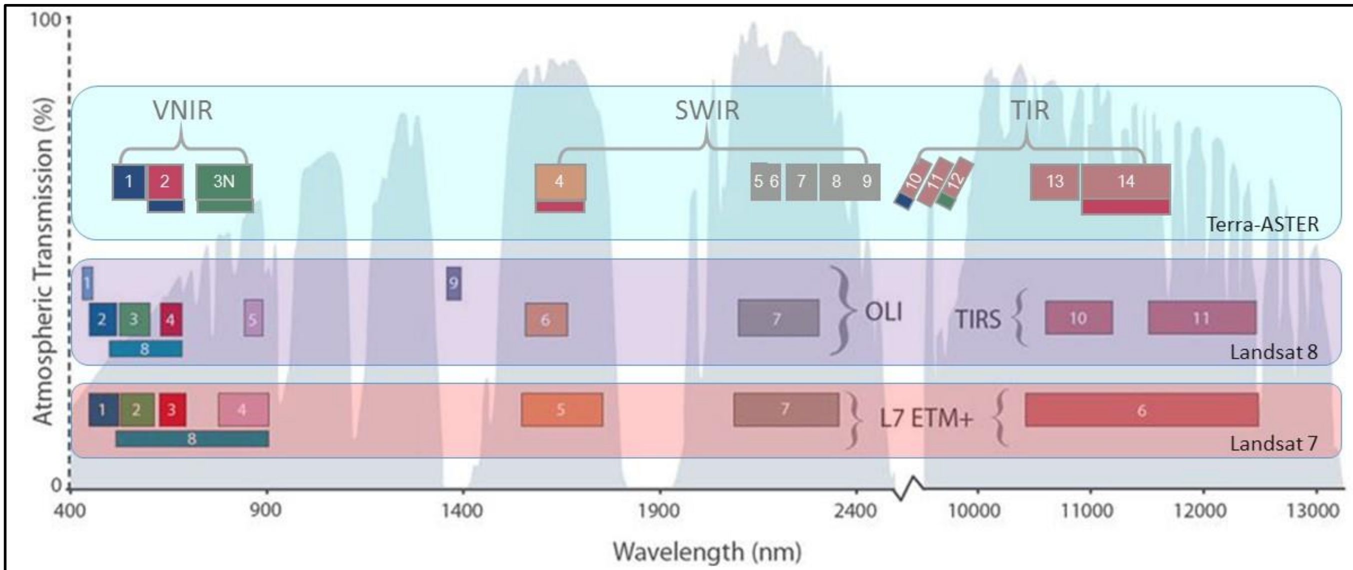
The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a multispectral imager that was provided by the Japanese Ministry of International Trade and Industry (MITI) for launch on board the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Terra spacecraft in December 1999. Since the ASTER instrument's launch, the mission has generated over 3 million ASTER scenes offering a rich range of observations that span the visible infrared, shortwave infrared, and thermal infrared of the observable spectra.

The ASTER instrument is comprised of four telescopes covering 14 frequency bands, three nadir-pointing telescopes, plus an additional aft-pointing telescope duplicating the frequency of nadir Band 3. One nadir-pointing telescope covers visible and near infrared (VNIR) frequencies with 3 bands at 15-meter resolution. Another covers short wave infrared (SWIR) frequencies with 6 bands at 30-meter resolution. The third covers thermal infrared (TIR) wavelength with 5 bands at 90-meter resolution. The aft-pointing telescope using the Band 3 frequency covers the same scene 55 seconds behind the VNIR nadir Band 3, enabling stereo views. 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 acquire, archive, and provide user access to NASA's land processes data, such as those derived from ASTER. Raw ASTER data are downlinked from Terra and forwarded by NASA to Japanese resources for initial processing. AST_L1A data are routed from Japan to the LP DAAC for archiving and further processing. Utilizing a Japanese provided algorithm, the LP DAAC is capable of processing AST_L1A data to AST_L1B at-sensor calibrated radiance. Using AST_L1B as an input, the LP DAAC produces higher level products on-demand using algorithms provided by the Jet Propulsion Laboratory (JPL).

Besides hosting the LP DAAC Program, the EROS Center also hosts the Landsat Program that processes raw ETM+ data to higher-level products. Landsat data collection characteristics are similar to those of ASTER. In response to the 2011 Terra Senior Review requesting Level 2 products be ortho-rectified, the LP DAAC proposed to the ASTER Science Team that an ortho-rectified, precision terrain corrected registered at-sensor radiance Level 1 product (AST_L1T) 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 a new Level 1 product, AST_L1T.

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

The new AST_L1T algorithm uses both Earth and satellite models along with standardized globally distributed ground control points (GCPs) and digital elevation models (DEMs) to produce a multi-file product and two associated products. The AST_L1T data product is comprised of an EOSDIS 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.

1.2 Data Access Policy

Access to ASTER L1T data product available from the LP DAAC 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 ortho-rectification, or to the AST14 product, which relies on processing-intensive, closed-source production code and is unavailable to Level 2 processing. Thus ortho-rectification required additional effort that increased complexity and risk to investigator processes including a potential for unnecessary data error due to multiple resamplings. The AST_L1T product provides quick turn-around of consistent GIS-ready data. AST_L1T features a single resampling from the AST_L1A to be used directly in investigations.

Previously, for visualization, ASTER users also had to create their own images or use AST_L1A low resolution non-location-tagged browse images. The AST_L1T product includes two full resolution ortho-rectified location-tagged GeoTIFF image files as well as low resolution browse. The GeoTIFF files allow users to overlay location-tagged features and also 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 investigator's cost. A full resolution visible image consists of 3 bands from the VNIR and SWIR telescopes producing a near psuedo color image that can be used when a daytime view is needed by the user. In April 2008 the SWIR telescope was determined to be no longer functioning, and the visible full resolution image is created using only 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. The AST_L1T browse JPEG files are generated from the GeoTIFF files providing a thumbnail view of the AST_L1T product.

1.4 Science Usage

The intended and appropriate user scenarios for the AST_L1T product parallel current scenarios for AST_L1B or AST14OTH products. These uses include but are not limited to:

- Land surface climatology: monitoring land surface parameters such as surface temperature; to understand land surface interaction and energy and moisture fluxes; changes in glacial extent
- Vegetation and ecosystem dynamics: investigations of vegetation and soil distribution and their changes to estimate biological productivity, understand land-atmosphere interactions, and detect 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: observation of 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; evapotranspiration from plants

- Geology and soils: the 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

Section 2 ASTER Instrument Overview

2.1 Product Chain

Figure 2-1 illustrates a product-oriented view of the overall ASTER operations concept where forward processing of ASTER data has been augmented for the AST_L1T Product Generation Executable (PGE). ASTER expedited processing is unchanged in the current implementation. Not shown is historical processing, which is a batch process that injects previously ingested AST_L1As into the nominal-processing flow to produce AST_L1T products ranging back to initial ASTER data collection.

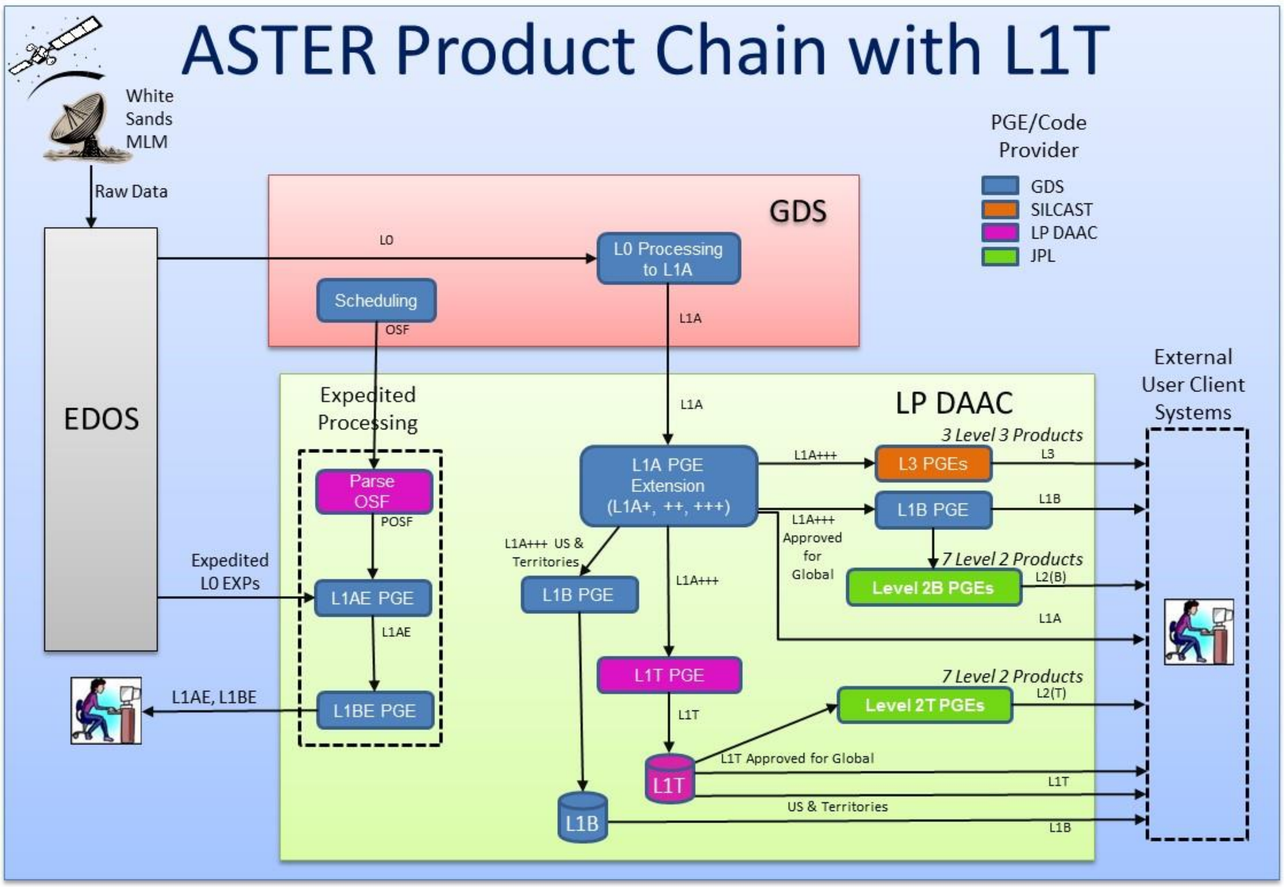


Figure 2-1. ASTER Operations Concept.

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.

Upon ingest of an AST_L1A from GDS granules, they are processed to produce AST_L1B products. The LP DAAC links GDS-provided AST_L1A browse images to the AST_L1B products.

The new implementation modifies the legacy operations concept such that AST_L1T granules are routinely produced for all arriving AST_L1A granules. AST_L1T products are saved and archived in the Data Pool for direct download or for download from user client search systems.

All users may download AST_L1T scenes/granules for no charge.

2.2 Instrument Sensors

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

Label	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	Short-wave infrared	30 (8 bit)
SWIR_Band5		2.145–2.185		
SWIR_Band6		2.185–2.225		
SWIR_Band7		2.235–2.285		
SWIR_Band8		2.295–2.365		
SWIR_Band9		2.360–2.430		
TIR_Band10	Nadir	8.125–8.475	Long-wave infrared or thermal infrared	90 (12 bit)
TIR_Band11		8.475–8.825		
TIR_Band12		8.925–9.275		
TIR_Band13		10.250–10.950		
TIR_Band14		10.950–11.650		

Table 2-1. ASTER Sensor Characteristics.

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

The only major ASTER instrument-related problem to date deals with the SWIR sensor, which suffered a setback due to its anomalously high detector temperatures. The anomaly has rendered SWIR data unusable since April 1, 2008. To minimize system impact, SWIR bands are not used after April 2008 even though they may be marked in metadata as having been acquired. Eventually, in August 2012, SWIR was turned off altogether and invalid data are included in the AST_L1A products after that point. Since the SWIR bands are used in the cloud coverage calculations in the AST_L1A product headers, the loss of SWIR makes the cloud coverage percent calculation unreliable. The AST_L1T product does not include SWIR band data after April 1, 2008.

2.3 AST_L1A Data[1]

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 and radiometric calibration coefficients appended **but not applied.** These coefficients include:

- Corrections for SWIR parallax as well as inter- and intra-telescope registration.
  - The parallax error is caused by the offset in detector alignment in the along-track direction and depends on the distance between the spacecraft and the observed earth surface.
  - Parallax corrections are carried out with the image matching technique or the coarse DEM database, depending on cloud cover.
- Spacecraft ancillary and instrument engineering data (coefficients):
  - The radiometric calibration coefficients, consisting of offset and sensitivity information, are generated from a database for all detectors using real temperature values in the instrument supplementary data, and are 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 prior to downstream processing of the ASTER L1B and L1T data products. The additional processing steps occur in the following order:

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

[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.

2.4 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.

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

Band No.	Unit Conversion Coefficient (W/(m²*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[3]

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)[4] 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

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

- 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

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

2.5.3 Geometric System Correction Database

There is an evolving geometric system correction database that is maintained at GDS. This database provides the geometric correction coefficients that are applied in producing the AST_L1T product data. The AST_L1T data like the AST_L1B, has 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). And in addition, for SWIR in particular, the parallax errors due to the spatial locations of all of its bands are corrected. The data are stored together with metadata in the HDF file. The geometric correction reference in an AST_L1T product is provided in metadata embedded in the HDF as well as that provided in the XML metadata file. In the HDF file, this is present as the GeometricDBVersion field in the *productmetadata.0* attribute.

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).

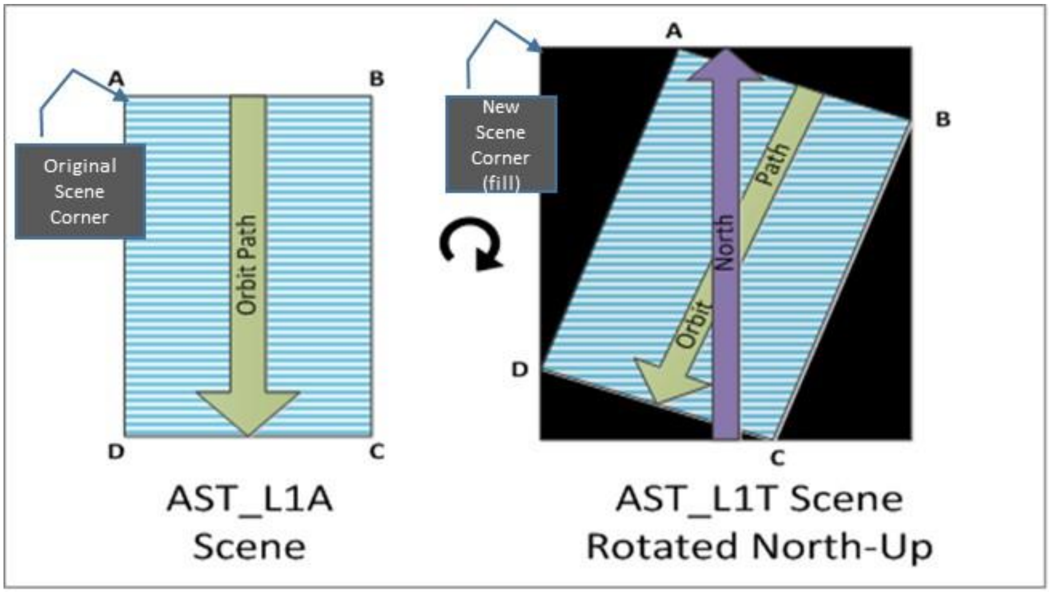


Figure 2-2. AST_L1A Image Rotated North-Up in AST_L1T Product.

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, rather it is the actual center on the rotated coordinates.[5] Table 2-5 provides an example of the embedded metadata listing the four corners[6] 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.

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

Figure 2-3 illustrates that the AST_L1T HDF corner pixels from each instrument are co-centered unlike the case for AST_L1A and AST_L1B. This is done to facilitate the AST_L1T terrain-precision correction process. Because of the pixel dimensions, AST_L1T TIR pixels are co-centered with every third SWIR pixel and every sixth VNIR pixel. Likewise, every SWIR pixel is co-centered with every other VNIR pixel.

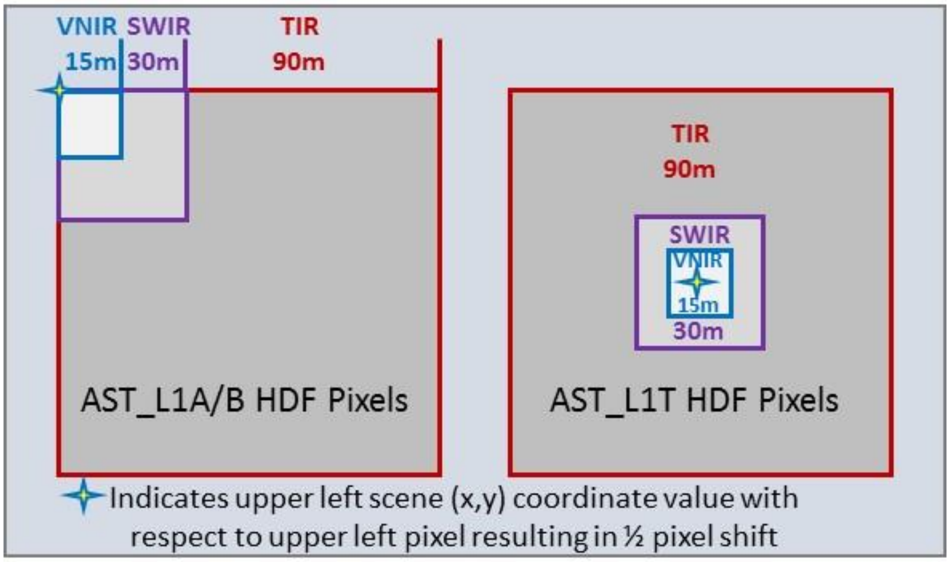


Figure 2-3. Pixel Centering for AST_L1A/B and AST_L1T Bands.

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 as is used by the Landsat Program. This approach is accepted by all the major analysis tools as a slight variation of the Universal Transverse Mercator (UTM) system where the northing coordinates are negative values in the Southern Hemisphere. In this case, the analysis tools recognize a zero false northing with a 500,000 meter false easting as a valid representation of UTM for both hemispheres.

Pixel orientation is critical with respect to the scene's reported four corners. For example, in AST_L1A and AST_L1B HDF products, the upper left hand corner embedded metadata value of the scene is also the upper left corner of the upper left pixel. However for AST_L1T HDF, the upper left hand corner embedded metadata value for the scene is actually the pixel center coordinates of the co-centered upper left pixel(s) in the product. Thus for any given AST_L1T band, the true upper left hand coordinate is offset from the upper left hand corner coordinate by 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 southern hemisphere. Note that the coordinates differ by ½ pixel[7] 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.

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.

[7] 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.

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[8] 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 ortho-rectified 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.

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

Section 4 ASTER L1T Product Architecture

The AST_L1T product is technically comprised of 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, which includes low-resolution browse, 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 4-1 outlines the 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		

Table 4-1. AST_L1T Dataset Characteristics.

Figure 4-1 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.

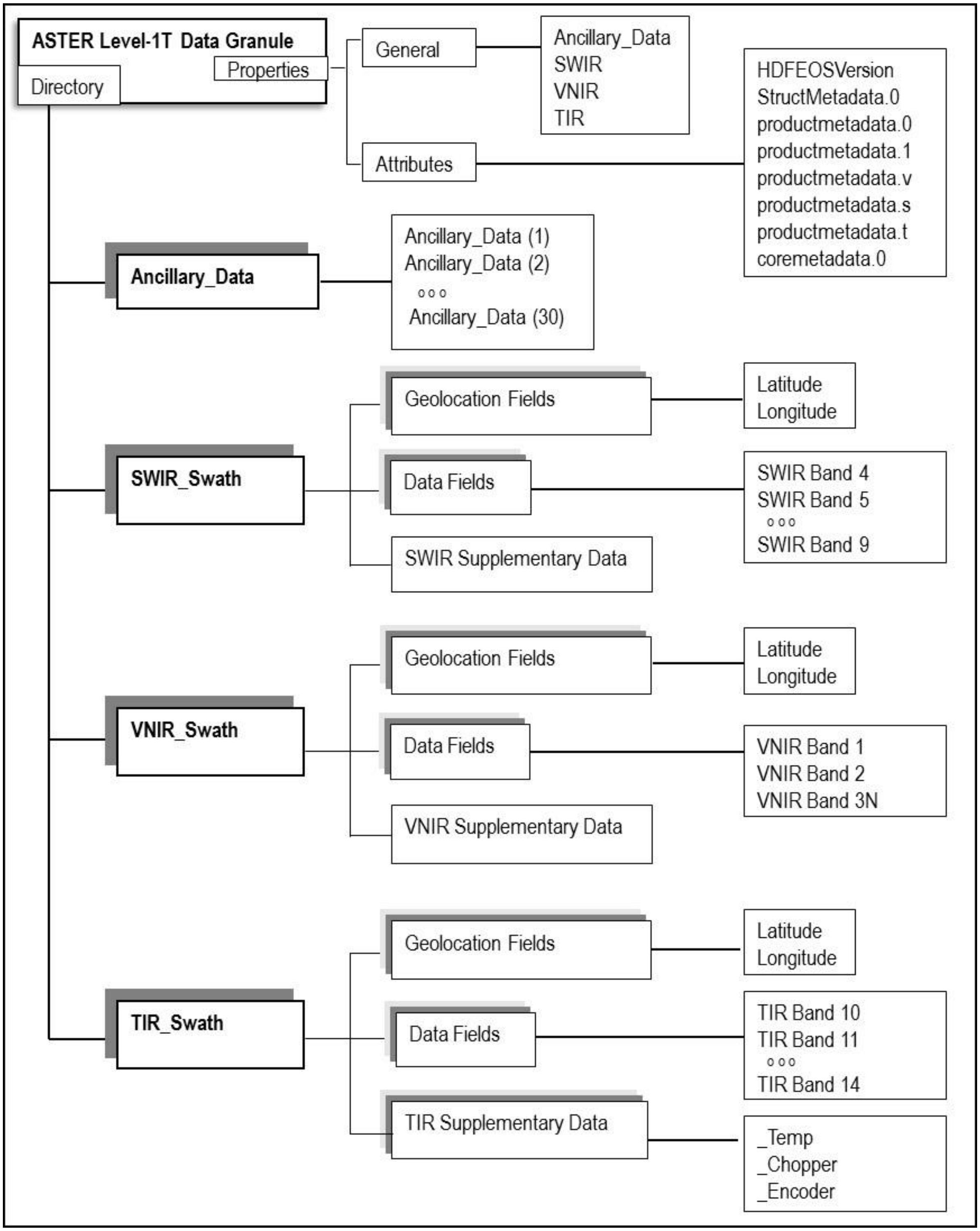


Figure 4-1. AST_L1T HDF Product Structure.

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

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[11] 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[12])/10 which, unlike the case for L1B, varies by scene due to the fact 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 resolution browse JPEG). The Visible and Thermal full resolution images are provided

[9] 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 cut outs of image strips for each band from a continuous acquisition (a.k.a., swaths) when the acquisition has more than one scene.

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

[11] 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.

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

for users who prefer GeoTIFF over HDF. The GeoTIFF files may ultimately be part 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 unhealthy past April 2008, and SWIR was 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 4-2 defines full resolution image pseudo color composite images generated from a subset of bands as determined by availability within each specific AST_L1T product.

Bands Available	Red	Green	Blue	Pixel Size	GeoTIFF DN Units
VNIR/SWIR	B4[13]	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

Table 4-2. GeoTIFF (and Browse) Band Characteristics.

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 update.** Because some metadata do not become available until after the algorithm was run, 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 post production.

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 general rule of thumb is to start with the embedded metadata and then override it with like fields from the XML metadata.

Examples of repeated metadata include source data (L1A) and production date-time groups, reference databases, Digital Object Identifier (DOI), spatial extent, map projection, 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 post-production. Cloud cover is set to the most current value available at XML creation; cloud cover is always the most current value available for user client search and order systems. Metadata found in XML files and not the HDF header includes the names of associated GeoTIFF files, database pointers to reduced resolution browse, and essential system data useful for problem triage (such as checksum and core system database IDs).

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

The ODL and XML metadata often have different parameter names. Table 4-3 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.

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 4-3. Comparing ODL to XML Scene Boundary Coordinates (Degrees).

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

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)*

Table 4-4. Comparing ODL to XML Cloud Cover.

XML files related to product HDF files have two sources depending on the users' distribution approach. One source is from the core system made available from the 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

4.2.1 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 the either the VNIR-only or the VNIR/SWIR[14]-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 Quality Assessment (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 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.

4.2.2 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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[14] 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 data file and full resolution image GeoTIFF files. The associated products produced 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 4-5 provides example values for fields.

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

Table 4-5. Example File Name Fields.

The short name, AST_L1T, is used in file naming conventions for the terrain and precision corrected products. The inaugural collection version is 003. If a change in the AST_L1T or AST_L1A algorithms necessitates the reprocessing of AST_L1Ts or AST_L1As, then processing will increase the version of the collection for both AST_L1A and AST_L1T. If only the AST_L1T algorithm changes, then only the AST_L1T and its associated products will change. In either case, reprocessing would be required for all AST_L1T in the archive. For each granule, a unique processing number is assigned to the files associated with the granule. File name type extensions are identified in Table 4-6.

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

Table 4-6. Example Output File Name Type Extensions.

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 4-7 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.

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

Table 4-7. Example ASTER Output File Names.

The user should note that 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 associated AST_L1T. Further variations are possible due to the fact that SWIR was deemed unhealthy past April 2008. Specifically, the AST_L1T algorithm does not produce SWIR AST_L1T images from AST_L1A (where SWIR is present) for the time period ranging from April 1, 2008 SWIR 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.

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*
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.*

Table 4-8. Potential Mapping of AST_L1A Bands to AST_L1T.

4.5 Download Expectations

Based on current experience with existing ASTER browse, it is reasonable to expect that the Visible, Thermal, or QA browse files to upload and display in under one second. However, users may experience AST_L1T granule downloads to average slightly longer than that experienced for AST_L1A downloads.

Table 4-9 provides estimated AST_L1T file and granule sizes for various AST_L1A telescope combinations based on current LP DAAC holdings.[15] LP DAAC historical holdings prior to April 2008 are weighted heavily on the top four rows of the table.

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

Table 4-9. Estimated Output File Sizes.

Ultimately, file moves 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 what it takes to download their associated HDF files.

[15] 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

ASTER AST_L1T products 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. In addition, users who are very familiar with the ASTER dataset collection may choose to directly download AST_L1T from the public LP DAAC Data Pool by using HTTPS access. For this document, the user can acquire AST_L1T granules from NASA Earthdata Search, USGS EROS EarthExplorer, and the LP DAAC Data Pool using Earthdata Login credentials. New users will need to register for an Earthdata Login Profile. USGS EarthExplorer will require registering for EROS Registration System (ERS) user credentials.

5.1.1 NASA Common Metadata Repository/Earthdata Search

NASA provides the Common Metadata Repository (CMR) system to serve its Earthdata Search user client. 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 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 user enters the characters “AST_L1T” in the “Search Terms” field. Also it is recommended that users plot an area of interest on the map and consider entering “Temporal Search” for start and end of data acquisition. 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 provides an executable shell script to retrieve files.

The URL used to start an Earthdata Search session is:

https://search.earthdata.nasa.gov/

Refer to **Error! Reference source not found.** for screen-shots illustrating a typical Earthdata Search session.

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 granule elements from an on-line service referred to as the "public Data Pool".

Unlike user clients, the public Data Pool does not help to 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 the 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.

The URL used to start a public Data Pool session is:

https://e4ftl01.cr.usgs.gov/

Refer to Appendix E for screen shots 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. For AST_L1T, 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 much more land science datasets. EE has the capability of displaying browse overlay images which is a feature not offered by Earthdata Search. In addition to NASA Earthdata Login credentials, EarthExplorer requires the use of 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 screen shots 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.

The URLs for the bulk download options are:

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

5.2 Data Manipulation Tools

The majority of the proprietary as well as public domain image processing and GIS software packages that currently support HDF-EOS format are expected to handle the ASTER L1T product given that an AST_L1T scene is reprojected north-up in UTM space. Several tools are available to allow users to manipulate the data through a number of capabilities including the following:

- Reformatting, reprojecting, and mosaicking
- Data quality assessment
- GIS and image processing
- Multispectral data analysis

Table 5-1 is a list of some of the publicly available tools that support ASTER data manipulation. An updated list, with current URLs, can found on the current LP DAAC web page:

ASTER Overview : https://lpdaac.usgs.gov/data/get-started-data/collection-overview/missions/aster-overview/#aster-tools-and-services

Tool	Description
LP DAAC Tools	Maintained by LP DAAC
ASTER DAR Tool	Schedule ASTER data tasking requests
ASTER Overpass Predictor	Estimate future ASTER imaging locations
Public Domain Tools	Maintained by external provider
HEG	HDF-EOS to GeoTIFF Conversion
MultiSpec	Multispectral Image Data Analysis

HDFView	Data Visualization
Cube Visualization (CV)	Data Visualization
HDFLook	Data Visualization/Processing
WebWinds	Data Visualization/Processing
WinVicar	Windows-Based Image Processing
HDF Explorer Lite	Data Visualization
hdf2bin	HDF-to-Binary Conversion
hdf2asc	HDF-to-ASCII Conversion
NCSA HDF Tools	HDF Utilities
GDALInfo	Visualize HDF embedded ODL metadata and select GeoTIFF GeoKeys
GeoTIFF_GUI	Visualize select GeoTIFF GeoKeys

Table 5-1. ASTER Data Manipulation Tools.

There is also a sizable selection of tools available to the science user community for performing operations on ASTER HDF files. ENVI by RSI and ERDAS Imagine by Leica Geosystems are examples of two popular commercial off the shelf (COTS) tools in wide use. Like HDFView, another popular public domain tool is the HDF-EOS to GeoTIFF (HEG) conversion tool.

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 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[16] exhibit a red stripe on the west (right) side and a green stripe on the east (left) 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 6-1, the L1A data for these bands have different ground "foot prints", 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.

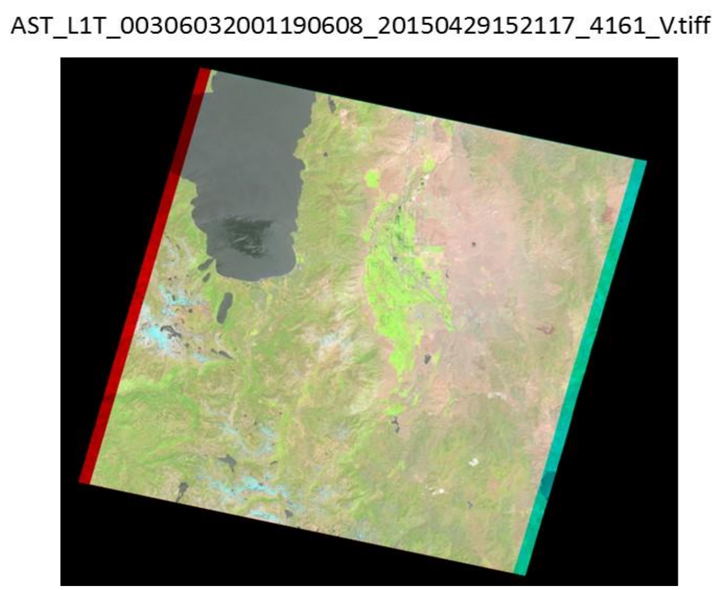


Figure 6-1. Edge Striping in Visible GeoTIFF having SWIR Band.

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 6-2 illustrates what happens when the PGE projects the left and right

[16] 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.

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.

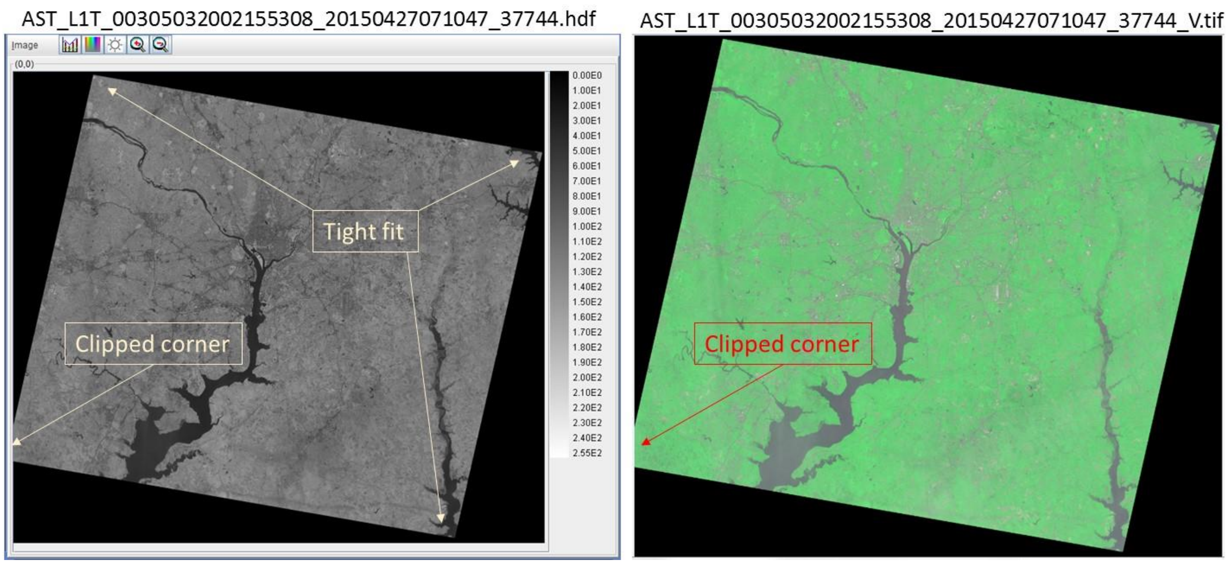


Figure 6-2. Clipped Corner for VNIR-only AST_L1T HDF and _V.TIF.

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 6-3 and Figure 6-4 provide examples of failures seen in AST_L1A files that have succeeded to process to AST_L1B but **failed** in AST_L1T production.

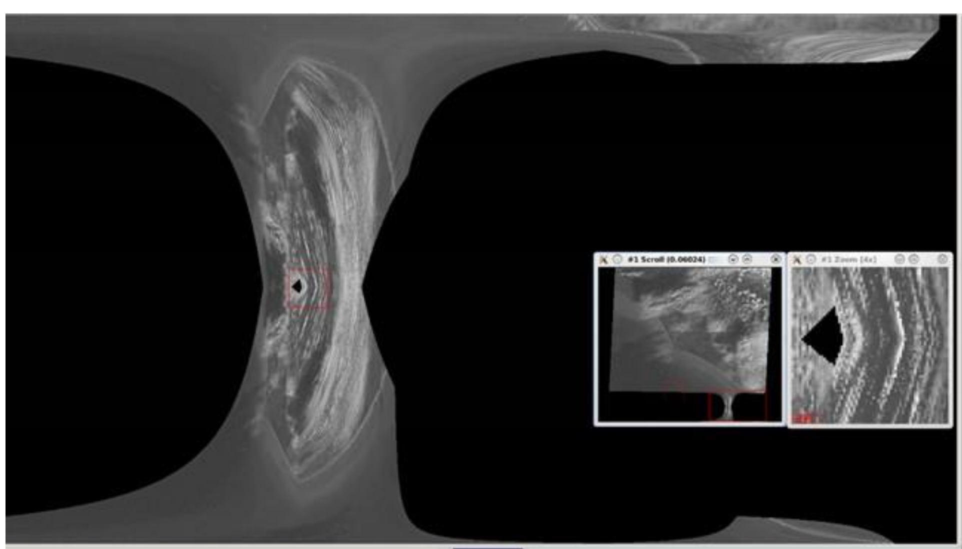


Figure 6-3. Bottom Warping AST_L1B Which Fails AST_L1T PGE.

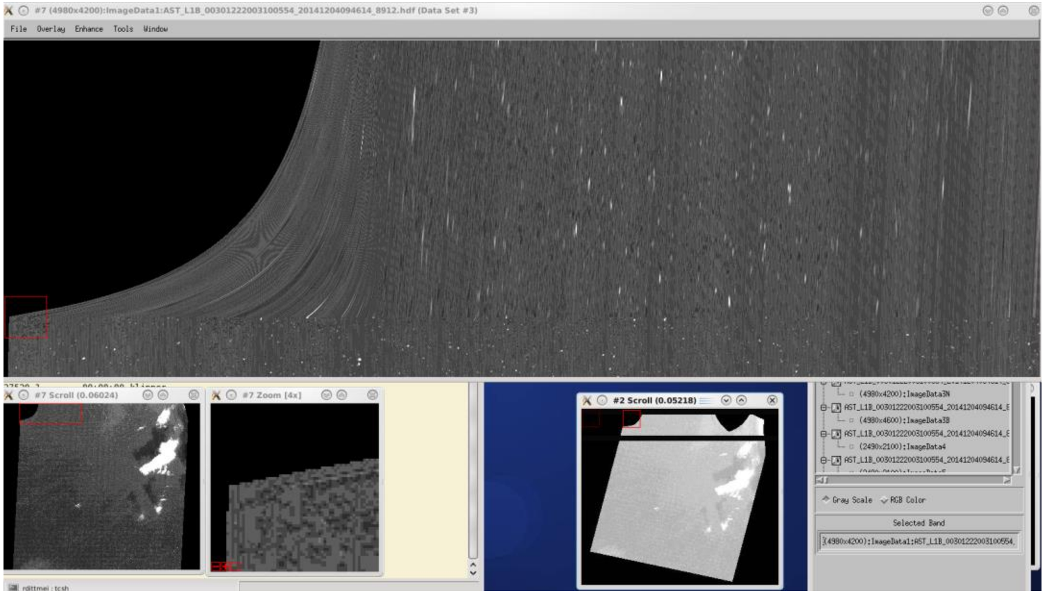


Figure 6-4. Top Warping AST_L1B Which Fails AST_L1T PGE.

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 6-5 illustrates a production run involving bad affine coefficients which resulted in an AST_L1T having anomalous artifacts near the bottom of the scene.

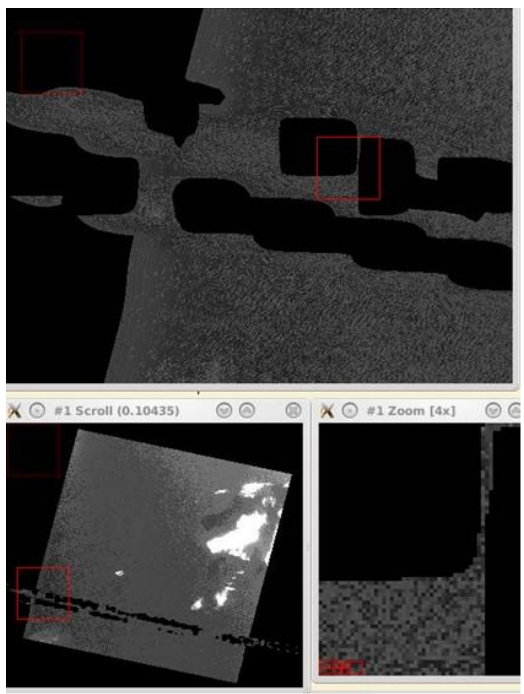


Figure 6-5. Bottom Warping Which Succeeds in AST_L1T Production.

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, L1Core which is part of Landsat's precision and terrain correction production executable modified to handle ASTER data, GDAL to generate GeoTIFF full-resolution browse as well as JPEG reduced-resolution browse, and ASTER Gverify (geometric verification) to generate geometric Quality Assessment data.

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.

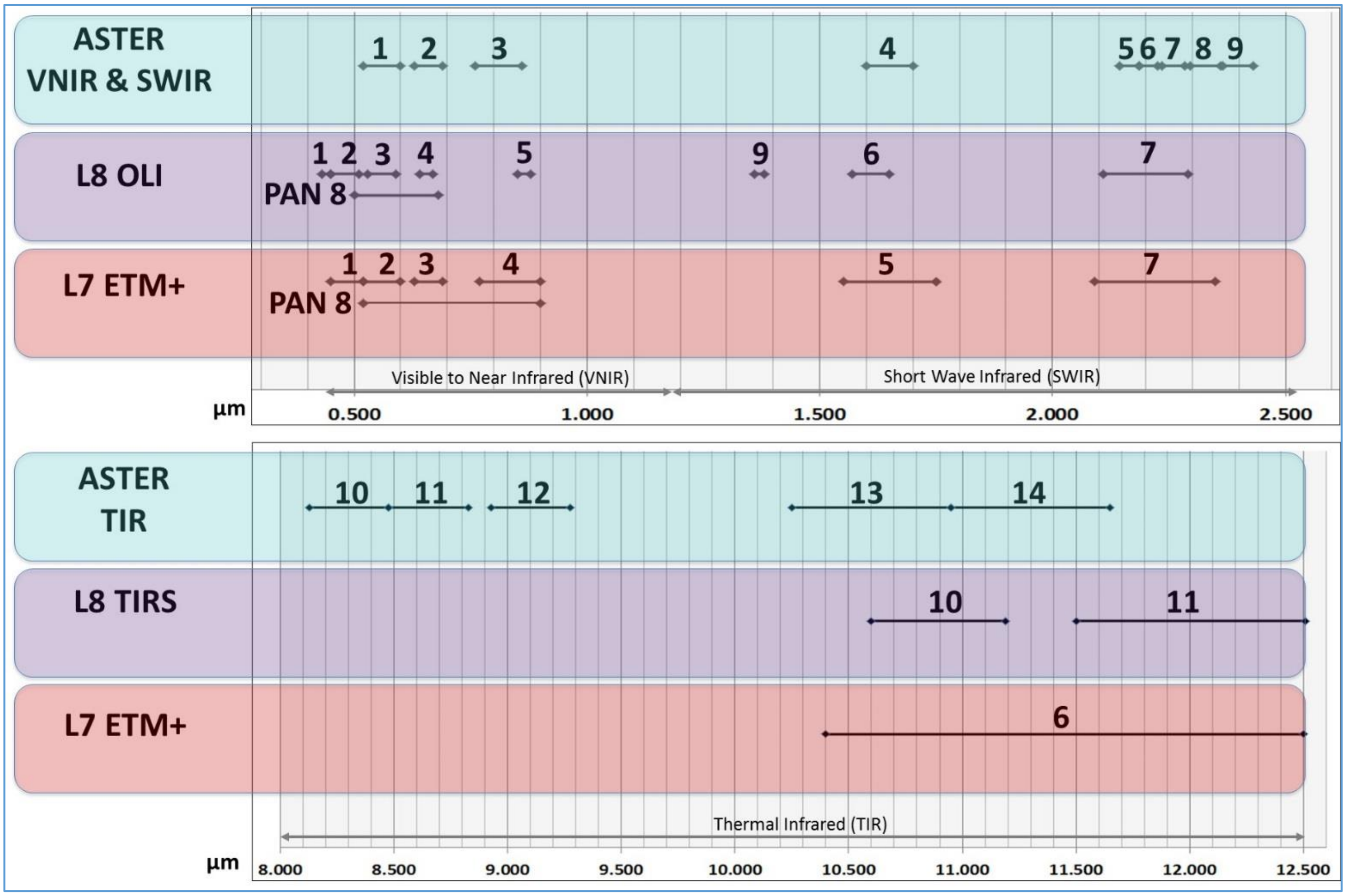
Scene – Most often used in a visible context or as an index in a database.

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
SILC	Sensor Information Laboratory Corporation (for ASTER)
SIPS	Science Investigator-led Processing Systems
SWIR	Short Wave 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; 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.[17]

Local Observations

Local observations are made in response to DARs submitted by authorized ASTER users include, 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 for 25% high priority areas, 50% for medium priority areas, and 25% for low priority areas.

[17] 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

Processing is initiated immediately upon the arrival of new AST_L1A from Japan but can also be scheduled should reprocessing be necessary. The LP DAAC used a version of the reprocessing capability in early 2015 to initialize the AST_L1T collection from the historical AST_L1A archive which goes back to the year 2000.[18]

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 actually processed to a systematic or precision level without the benefit of terrain correction.

The input AST_L1A is comprised of reconstructed unprocessed instrument data that contains depacketized, demultiplexed, and realigned instrument image data with geometric correction coefficients and radiometric calibration coefficients calculated and appended **but not applied**. 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_L1T science data. Also 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. The two main logic paths for correction levels are:

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

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

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 on-board 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+++ supplemental algorithm utilizes radiometric database version 4.13.

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) for 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. These two levels of correction are:

1) <u>Terrain+Systematic</u> 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) <u>Terrain+Precision</u> correction: applicable to all daytime AST_L1A scenes where correlation statistics reach a minimum threshold

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

The table below summarizes four possible results that are allowed by the flexible AST_L1T algorithm. To determine the correction levels applied to a specific product, the user must examine 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. Then the resampling of the AST_L1A input scene will use both the terrain dataset and the precision grid.

Systematic Correction

ASTER Terrain Systematic correction compensates for distortion in AST_L1A data resulting from topographical variations and image data with off-nadir cross-track pointing angles. It includes determining the output map-projected image space, creating the systematic grid, mosaicking the GLS2000 DEM data, clipping the GLS2000 mosaic to match the scene boundaries, and resampling the DEM to match the final 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 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, with the terrain dataset (if available) and the precision grid to create a terrain-precision corrected image. If Band 4 is unavailable, Band 2 is used in its place. In any case, no matter which correction level is achieved, only one resampling is done to produce the final product.

Geometric Verification

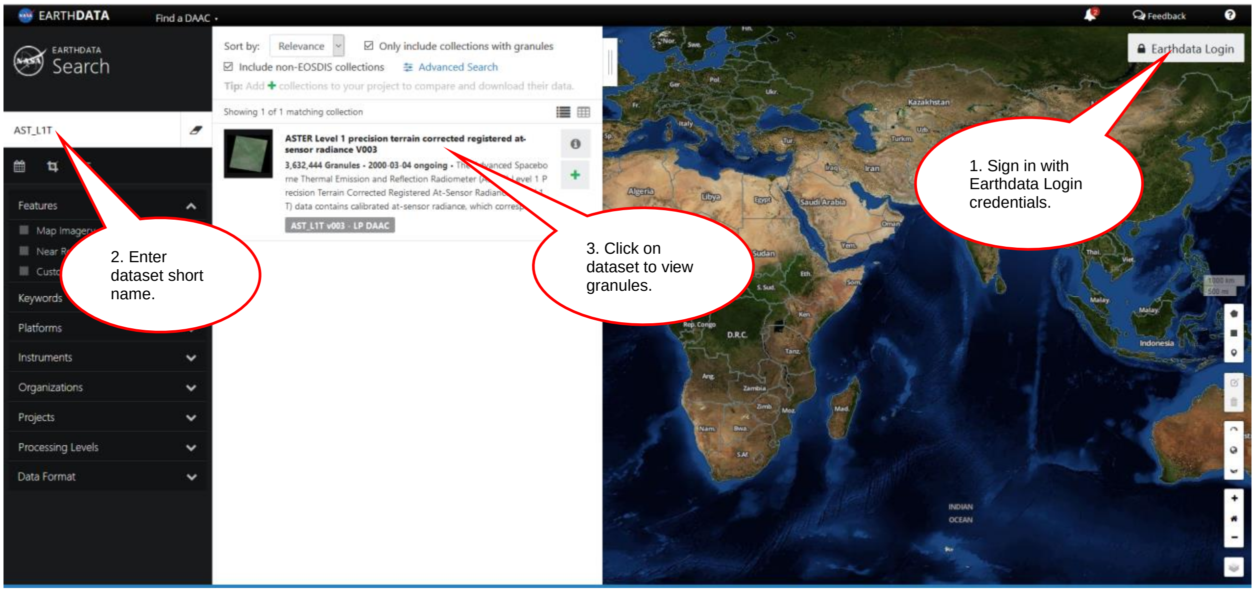
The geometric verification algorithm (Gverify) determines the relative accuracy of the terrain and precision corrected scene when compared to the corresponding ortho-rectified GLS2000 scene. The algorithm uses a cross-correlation procedure along with a simple outlier detection algorithm to determine 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.

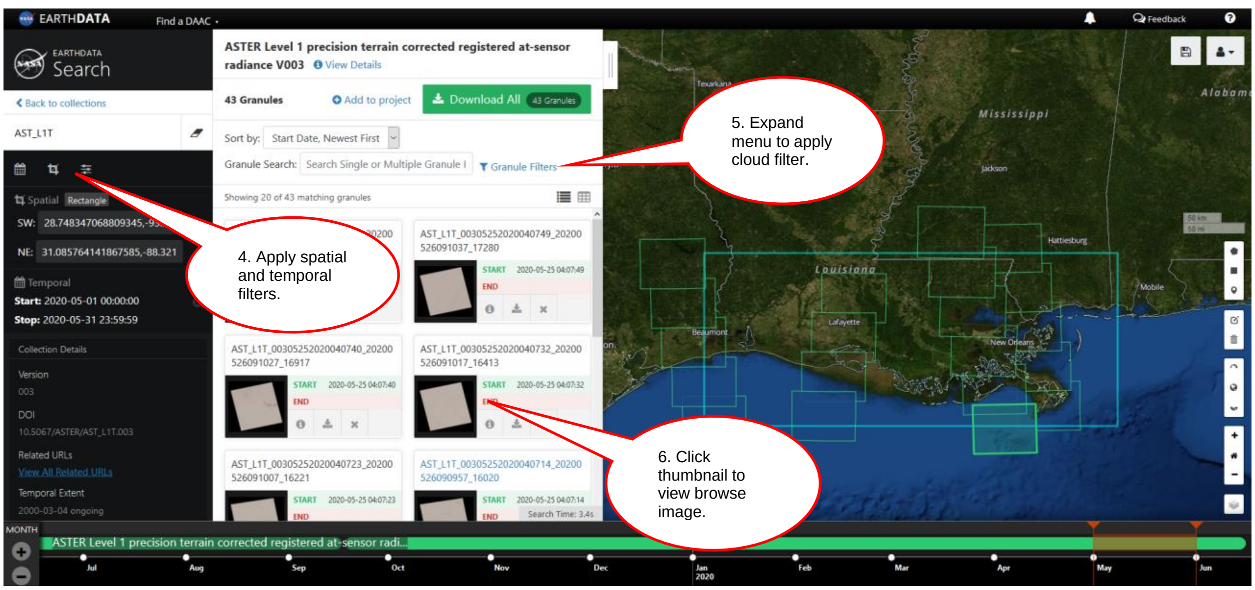
Quality Assurance

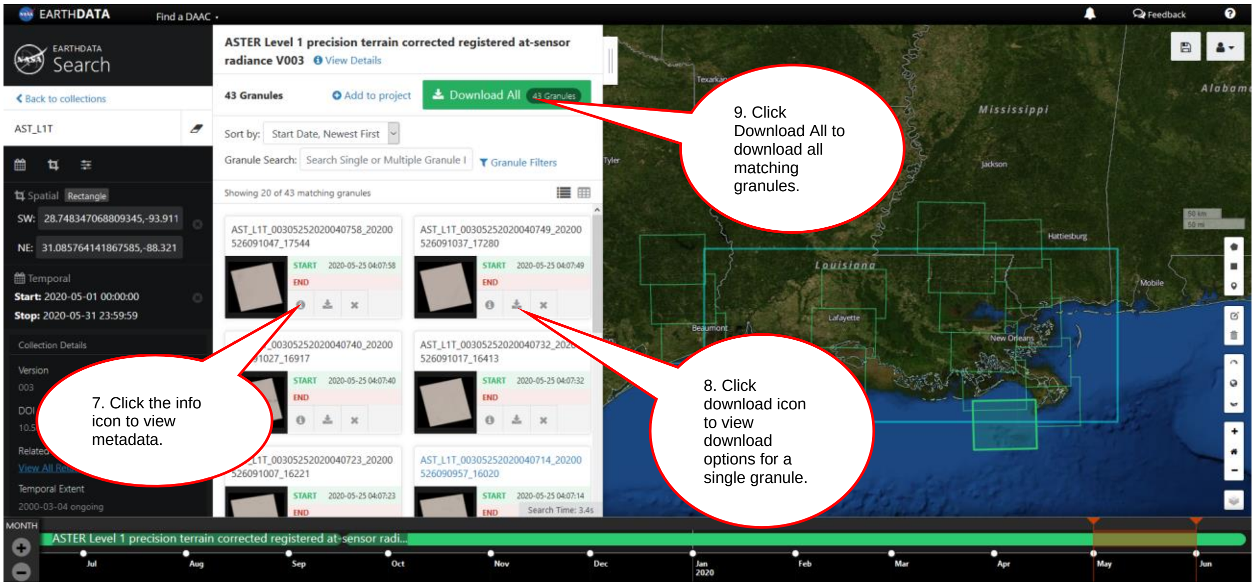
Simple statistics, such as mean, median, standard deviation, and RMSE for the good GCPs[19], are calculated for the entire scene by dividing the scene into four regions. The set of good GCP points are color-coded based on their ranks and overlaid on the terrain corrected product, then a browse image is generated. The quadrant RMSE and full scene RMSE are provided in the AST_L1T metadata files for the end user.

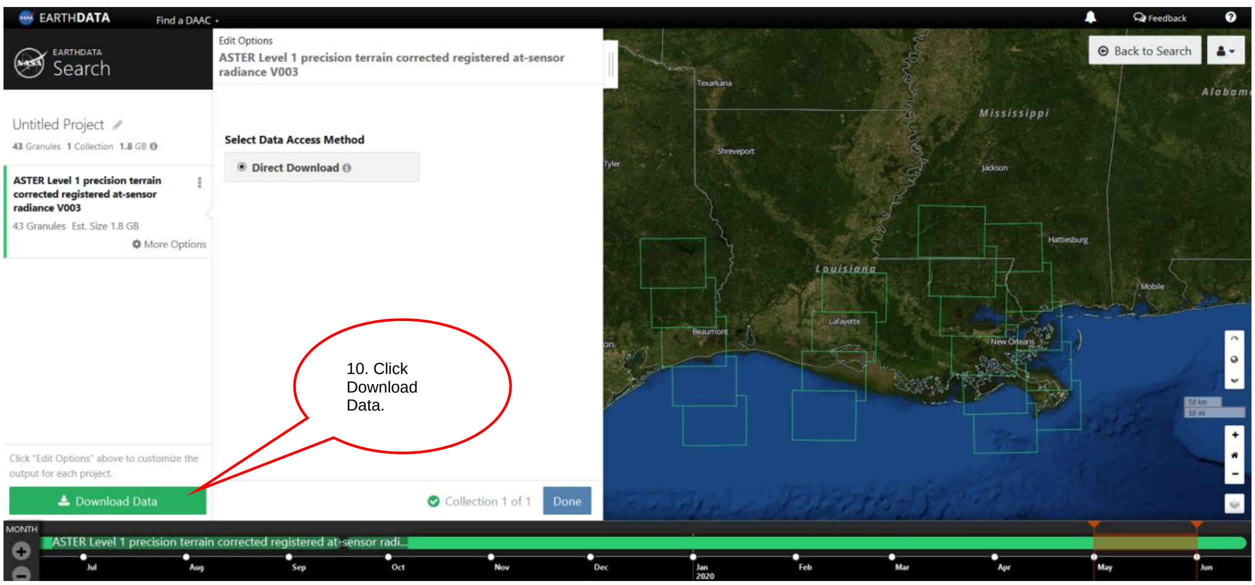
[19] The Gverify ground control points (GCPs) are not the same as those used for precision registration (in GCPCorrelate). The points used in Gverify are defined by a relatively high-density uniform grid across the GLS2000 Standard scene space, for the standard scene over the ASTER L1T scene center.

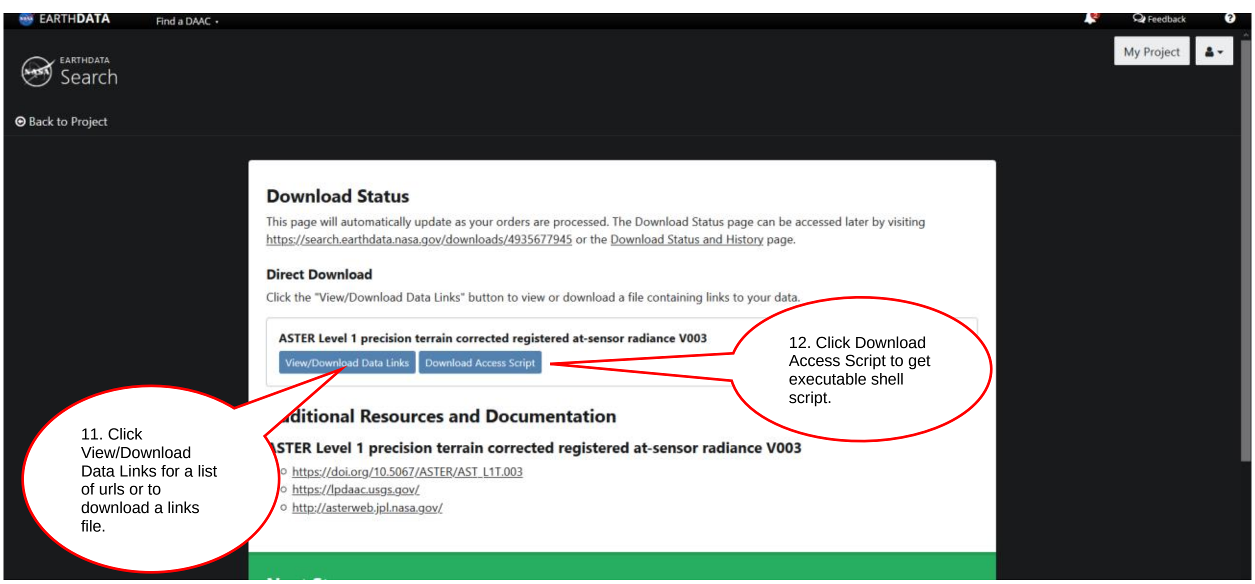
Appendix D Earthdata Search Download Session



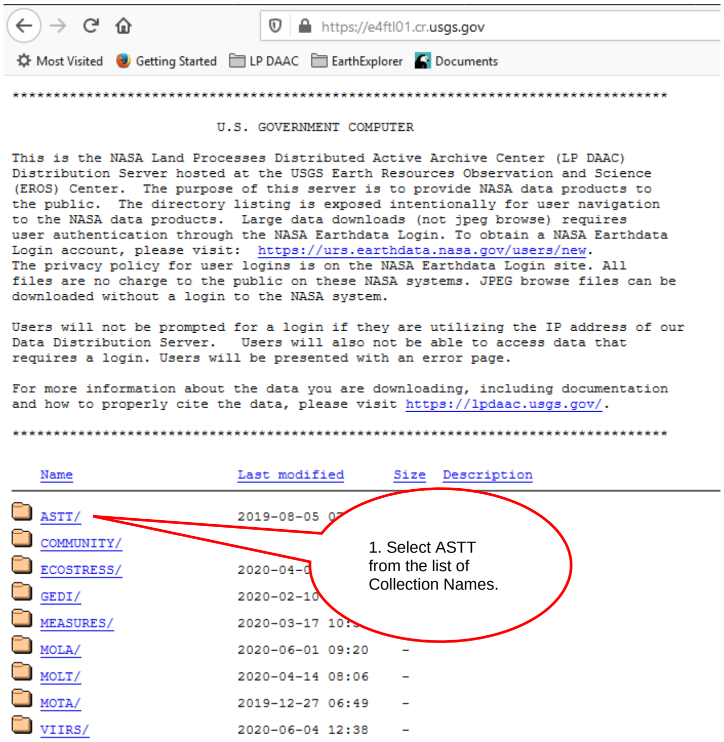



EARTHDATA
Find a DAAC
Feedback
EARTHDATA Search
Back to collections
AST_L1T
ASTER Level 1 precision terrain corrected registered at-sensor radiance V003
View Details
43 Granules
Add to project
Download All
43 Granules
Sort by: Start Date, Newest First
Granule Search: Search Single or Multiple Granule I
Granule Filters
Showing 20 of 43 matching granules
Spatial Rectangle
SW: 28.748347068809345,-93.911
NE: 31.085764141867585,-88.321
Temporal
Start: 2020-05-01 00:00:00
Stop: 2020-05-31 23:59:59
Collection Details
AST_L1T_00305252020040758_20200526091047_17544
AST_L1T_00305252020040749_20200526091037_17280
START 2020-05-25 04:07:58
START 2020-05-25 04:07:49
END
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.
Search Time: 3.4s
ASTER Level 1 precision terrain corrected registered at-sensor radi...
Mississippi
Louisiana
Jackson
Hattiesburg
Lafayette
New Orleans
Mobile
Beaumont
Jul
Aug
Sep
Oct
Nov
Dec
Jan 2020
Feb
Mar
Apr
May
Jun


EARTHDATA
Find a DAAC
Feedback
EARTHDATA Search
Edit Options
ASTER Level 1 precision terrain corrected registered at-sensor radiance V003
Back to Search
Untitled Project
43 Granules 1 Collection 1.8 GB
ASTER Level 1 precision terrain corrected registered at-sensor radiance V003
43 Granules Est. Size 1.8 GB
More Options
Select Data Access Method
Direct Download
10. Click Download Data.
Click "Edit Options" above to customize the output for each project.
Download Data
Collection 1 of 1
Done
ASTER Level 1 precision terrain corrected registered at-sensor radi...
Mississippi
Louisiana
Shreveport
Jackson
Hattiesburg
Lafayette
New Orleans
Mobile
Beaumont


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.
...ditional Resources and Documentation
...STER 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



****

Name	Last modified	Size	Description
Parent Directory		-	
2000.03.04/	2017-03-08 04:27	-	
2000.03.05/	2017-08-11 12:24	-	
2000.03.06/	2017-03-07 23:38	-	
2000.03.07/	2017-08-11 12:32	-	
2000.03.08/	2017-03-06 03:19	-	
2000.03.09/	2017-03-06 03:38	-	
2000.03.10/	2017-03-07 23:32	-	
2000.03.12/	2017-03-07 23:32	-	
2000.03.13/	2017-03-06 03:48	-	
2000.03.14/	2017-03-07 23:32	-	
2000.03.16/	2017-03-07 23:32	-	
2000.03.17/	201[illegible]	[illegible]	
2000.03.18/	20[illegible]	[illegible]	
2000.03.19/	[illegible]	[illegible]	
2000.03.20/	2017-03-07 23:32	-	
2000.03.28/	2017-03-07 23:32	-	
2000.03.29/	2017-03-07 23:32	-	
2000.03.30/	2017-03-08 03:05	-	

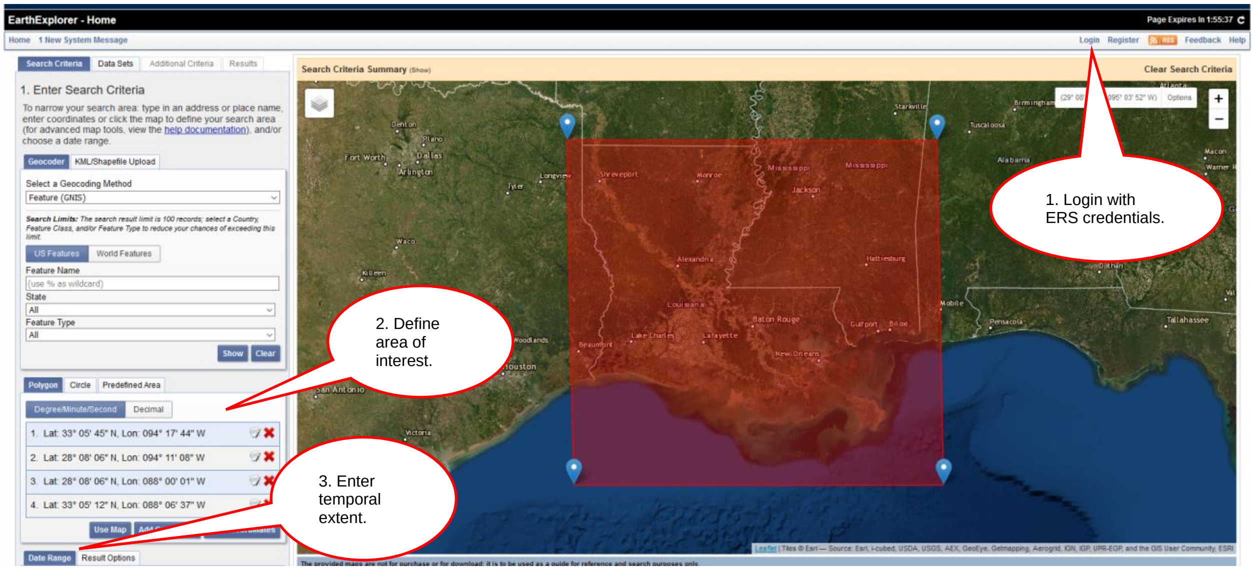
3. Select Date.

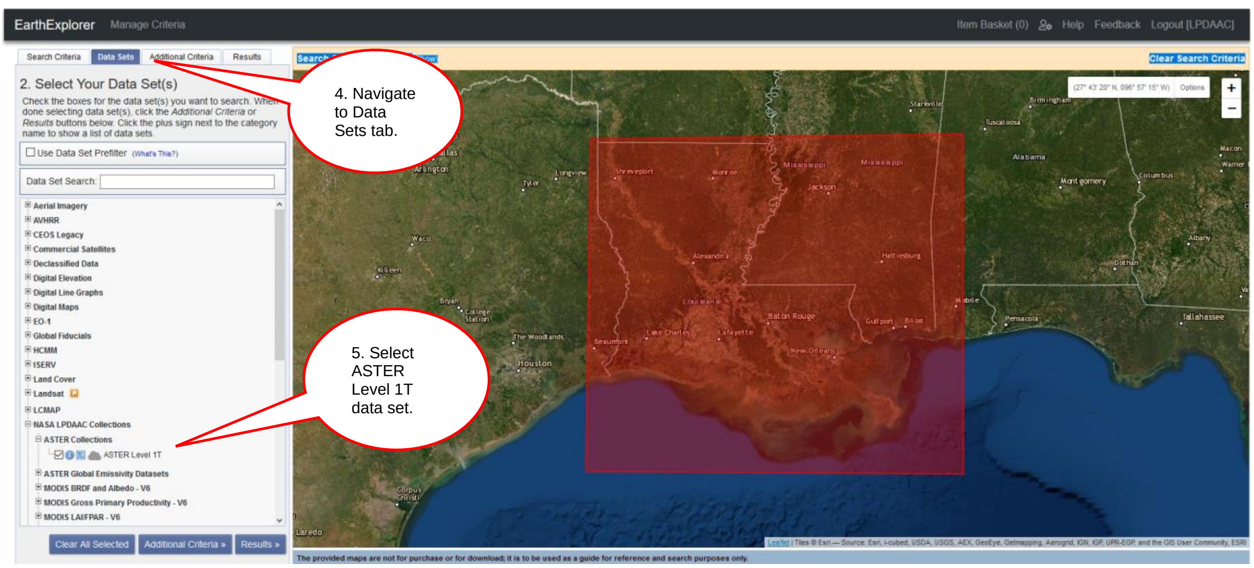
****

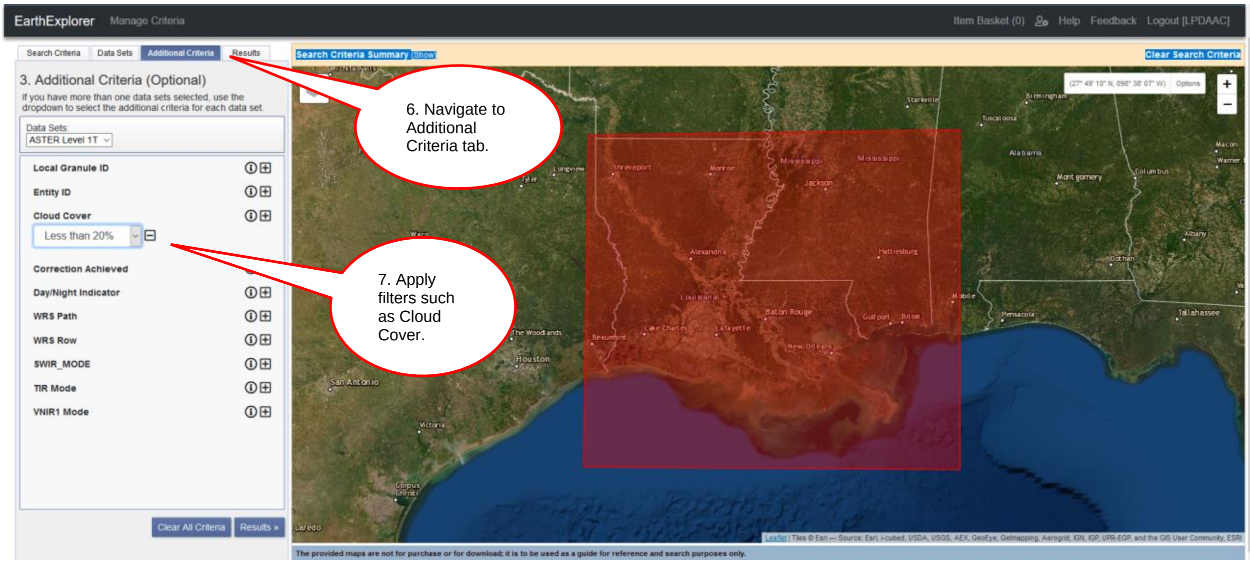
Name	Last modified	Size
Parent Directory		-
AST_L1T_00306082020000556_20200609093019_8002.hdf	2020-06-09 09:34	86M
AST_L1T_00306082020000556_20200609093019_8002.hdf.xml	2020-06-10 23:11	12K
AST_L1T_00306082020000556_20200609093019_8002_BR.2.VNIR.jpg	2020-06-09 [illegible]	[illegible]
AST_L1T_00306082020000556_20200609093019_8002_BR.3.TIR.jpg	2020-[illegible]	[illegible]
AST_L1T_00306082020000556_20200609093019_8002_BR.4.QA.jpg	202[illegible]	[illegible]
AST_L1T_00306082020000556_20200609093019_8002_QA.txt	202[illegible]	[illegible]
AST_L1T_00306082020000556_20200609093019_8002_T.tif	[illegible]	[illegible]
AST_L1T_00306082020000556_20200609093019_8002_V.tif	2020-06-0[illegible]	[illegible]
AST_L1T_00306082020000604_20200609093029_8377.hdf	2020-06-09 09:34	86M
AST_L1T_00306082020000604_20200609093029_8377.hdf.xml	2020-06-10 23:11	12K
AST_L1T_00306082020000604_20200609093029_8377_BR.2.VNIR.jpg	2020-06-09 09:34	46K
AST_L1T_00306082020000604_20200609093029_8377_BR.3.TIR.jpg	2020-06-09 09:34	28K
AST_L1T_00306082020000604_20200609093029_8377_BR.4.QA.jpg	2020-06-09 09:34	98K
AST_L1T_00306082020000604_20200609093029_8377_QA.txt	2020-06-09 09:34	7.7K
AST_L1T_00306082020000604_20200609093029_8377_T.tif	2020-06-09 09:34	2.2M
AST_L1T_00306082020000604_20200609093029_8377_V.tif	2020-06-09 09:34	78M
AST_L1T_00306082020000613_20200609093039_8682.hdf	2020-06-09 09:34	86M
AST_L1T_00306082020000613_20200609093039_8682.hdf.xml	2020-06-10 23:11	12K

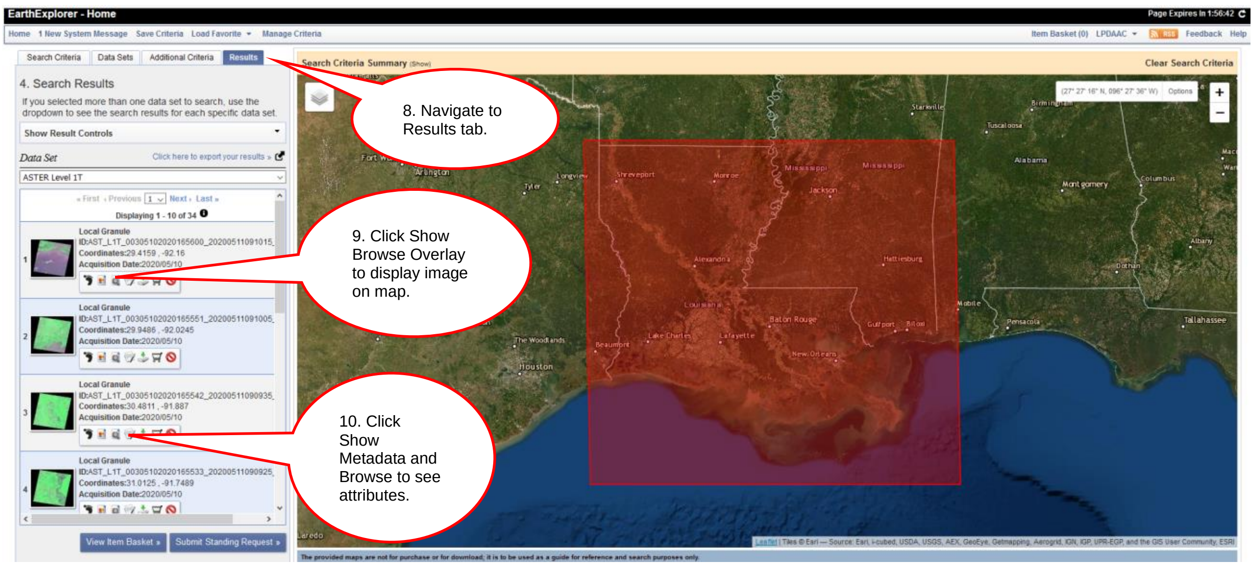
4. Select file and click url to download.

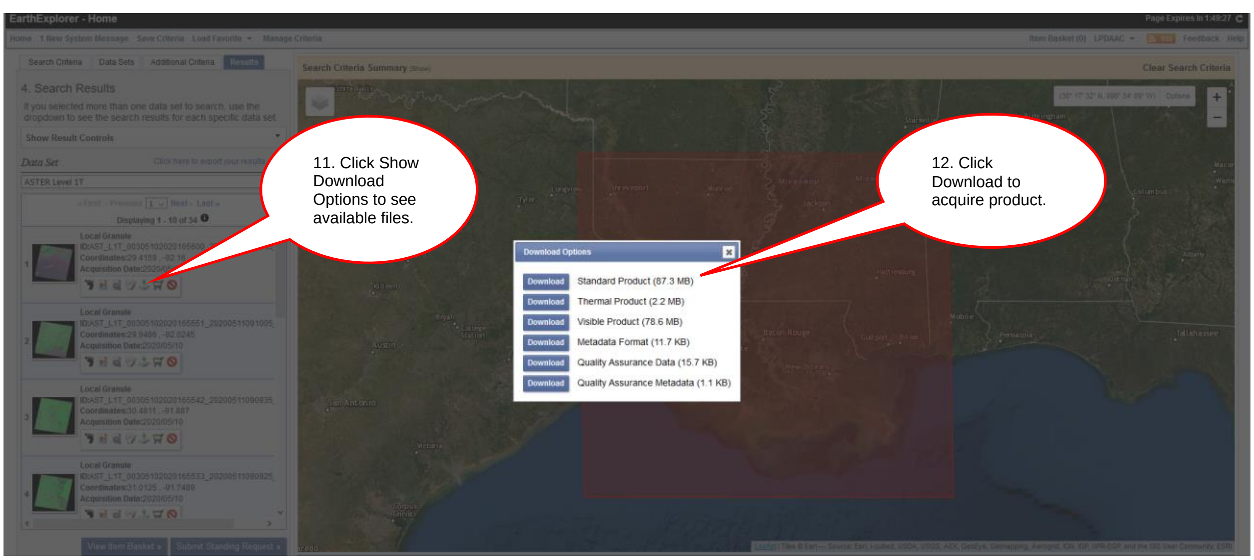
Appendix F EarthExplorer Download Session






6. Navigate to Additional Criteria tab.
7. Apply filters such as Cloud Cover.


8. Navigate to Results tab.
9. Click Show Browse Overlay to display image on map.
10. Click Show Metadata and Browse to see attributes.


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)
Download Metadata Format (11.7 KB)
Download Quality Assurance Data (15.7 KB)
Download Quality Assurance Metadata (1.1 KB)