ASTER
User's Guide

Part III

3D Ortho Product (L3A01)

(Ver.1.1)

July, 2004

ERSDAC
Earth Remote Sensing Data Analysis Center

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1. Introduction

The Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) is an advanced multispectral imager that was launched on board the Terra spacecraft in December 1999. ASTER covers a wide spectral region with 14 bands from visible to thermal infrared with high spatial, spectral and radiometric resolution. This wide spectral region is covered by three telescopes, three VNIR (Visible and Near Infrared Radiometer) bands with a spatial resolution of 15 m, six SWIR (Short Wave Infrared Radiometer) bands with a spatial resolution of 30 m and five TIR (Thermal Infrared Radiometer) bands with a spatial resolution of 90 m. In addition one more telescope is used to see backward in the near infrared spectral band (band 3B) to give the stereoscopic capability that is the major subject of this User's Guide. The spectral passbands are shown in Table 1-1. The Terra spacecraft is now flying in a circular, near polar orbit at an altitude of 705 km. The orbit is sun-synchronous with equatorial crossing at local time of 10:30 a.m., returning the same orbit every 16 days. The orbit parameters are the same as for Landsat-7 except for the local time.

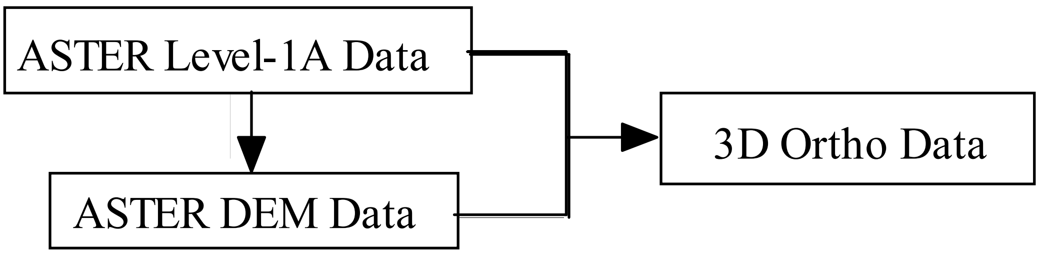
The ASTER instrument has two types of Level-1 data: Level-1A and Level-1B data. Level-1A data are formally defined as reconstructed, unprocessed instrument data at full resolution. According to this definition, the ASTER Level-1A data consist of the image data, the radiometric coefficients, the geometric coefficients and other auxiliary data without applying the coefficients to the image data to maintain the original data values. The Level-1B data are generated applying these coefficients for radiometric calibration and geometric resampling.

The ortho image is the image observed just above the target point. This means the ortho image includes no terrain error. The ortho image can be generated by correcting the terrain error using the elevation data for each pixel and the off-nadir observation angle. The 3D ortho product is the ortho product with the elevation data for each pixel, generated from the Level-1A data. Its formal name is Level-3A01. Figure 1-1 shows the relationship between the 3D ortho data and the source data.

The instrument geometric parameters such as the line of sight (LOS) vectors and the pointing axis vectors were precisely adjusted through avalidation process using numerous GCPs. The DEM data, which is processsed using only these system parameters, has been demonstrated to have extremely good accuracy.

Table 1-1 Spectral Passband

Subsystem	Band No.	Spectral Range	Spatial Resolution
VNIR	1	0.52 – 0.60	15 m
	2	0.63 – 0.69	
	3N	0.78 – 0.86	
	3B	0.78 – 0.86	
SWIR	4	1.600 – 1.700	30 m
	5	2.145 – 2.185	
	6	2.185 – 2.225	
	7	2.235 – 2.285	
	8	2.295 – 2.365	
	9	2.360 – 2.430	
TIR	10	8.125 – 8.475	90 m
	11	8.475 – 8.825	
	12	8.925 – 9.275	
	13	10.25 – 10.95	
	14	10.95 – 11.65	



3 D ortho data are the ortho images with elevation data for each pixel

Figure 3-1 Relationship between the 3D ortho data and the source data

2. System Configuration

The VNIR subsystem has two telescopes: a nadir-viewing telescope and a backward-viewing telescope, as shown in Figure 2-1. This dual-telescope configuration was adopted to give stereoscopic viewing capability in the along-track direction and to enable a large base-to-height ratio of 0.6 with minimum mass. The single telescope design as adopted for JERS/OPS, can feature only a small base-to-height ratio. The combination of the nadir and backward telescopes is a consequence of the trade-off between performance and resources.

Figure 2-2 shows the stereo configuration. The relationship between base-to-height (B/H) ratio and α is $B/H = \tan \alpha$, where α is the angle between the nadir and the backward direction at a point on the Earth's surface. The angle α, which corresponds to a B/H ratio of 0.6, is 30.96˚. By taking into account the curvature of the Earth's surface, the setting angle between the nadir and the backward telescope is designed to be 27.60˚.

A pointing function is provided for global coverage in the cross-track direction, since the swath width of ASTER is 60 km and the distance between neighboring orbits is 172 km at the equator. The optical axes of the nadir and backward telescopes can be tilted simultaneously in the cross-track direction to cover a wider range.

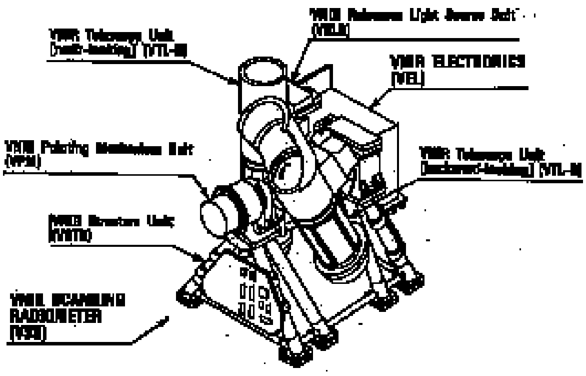


Figure 2-1 VNIR configuration

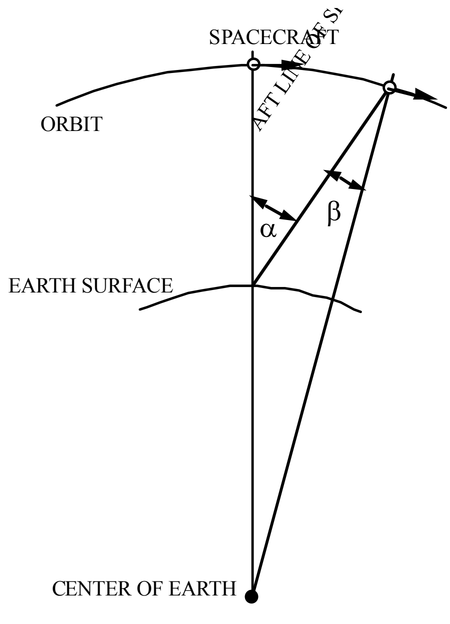


Figure 2-2 Stereo configuration

3. 3D Ortho Generation Algorithm

3.1. Overview

In 3D ortho data processing, the level-1A data is used as input image data. Moreover, the Level-4A01X (DEM XYZ) data is used as geolocation information for providing ortho graphic projection and map coordinate projection features to the Level-1A data. After performing collection to the Level-1A data and the DEM data, a geometric conversion is performed on the image data. At that time, the SWIR parallax erros in the along-track direction due to the detector alignment and in the cross-track direction due to the Earth rotation are also corrected.

The 3D ortho product generated is image data that has been subjected to ortho graphic projection processing and map coordinate projection processing. The DEM Z (elevation) data generated from the Level-4A01X data for geolocation information on the image data, and DEM quality flag data are attached to the 3D ortho product after performing the same transformation of coordinates as for the image data. The DEM data used in the data processing is useful as quality information and, at the same time, may improve users' convenience if the DEM geometrically matching image data is attached.

3.2. Algorithm Flow

Figure 3-1 shows the 3D ortho product generation algorithm flow. This process is carried out as follows

1) to input the Level-1A data and the DEM data.

2) to apply the radiometric correction coefficients, and preprocess the Level-1A data by performing bad pixel interpolation and strip removal. These processing algorithms are based on the processing algorithm from the Level-1A to the Level-1B.

3) to carry out the following three interpolations for abnormal DEM data as a DEM preprocessing. The quality flag is used to evaluate the abnormal data

   a) 3.1. to replace abnormal values with linearly interpolated values using neighboring normal values. This interpolation is carried out in both directions: in the pixel direction and the line direction in turn (CROSS-WIZE INTERPOLATION).

   b) 3.2. to replace any abnormal value for sea area with the geoid data (EGM96, 0.25° mesh).

   c) 3.3. to carry out smoothing for any data with a radically different value compared with the surrounding values . This smoothing is repeated a number of times. The default repeating time is 50.

4) to calculate the SWIR parallax error due to detector alignment on the focal plane (see Figure 3-2). The following two kinds of the parallax exist. The elevation data and the off-nadir observation angle are used to calculate the parallax error. Real execution is carried out during the next geometric correction stage simultaneously with other corrections.

   a) Parallax error in the along-track direction due to detector alignment gap.

   b) Parallax error in the cross-track direction due to the Earth rotation during observation of all SWIR bands. The observation time difference between band 6 and band 7 is 1.8 seconds.

5) to carry out the following geometric correction processing.

a) to transform the band 3N image to the selected map projection coordinates using the geolocation information for the DEM-xyz data product

b) to calculate the relative geolocation between band 3N and other bands using the geometric correction table (GCT).

c) to transform VNIR and TIR images besides band 3N to the selected map projection coordinates using the previously calculated relative geolocation values.

d) to transform the SWIR images to the selected map projection coordinates, simultaneously applying the previously calculated the terrain errors and the relative geolocation values.

e) to generate elevation data for VNIR, SWIR and TIR.

f) to transform the elevation data and the quality data to the selected map projection coordinates.

6) to output the 3D ortho (Level-3A01) data.

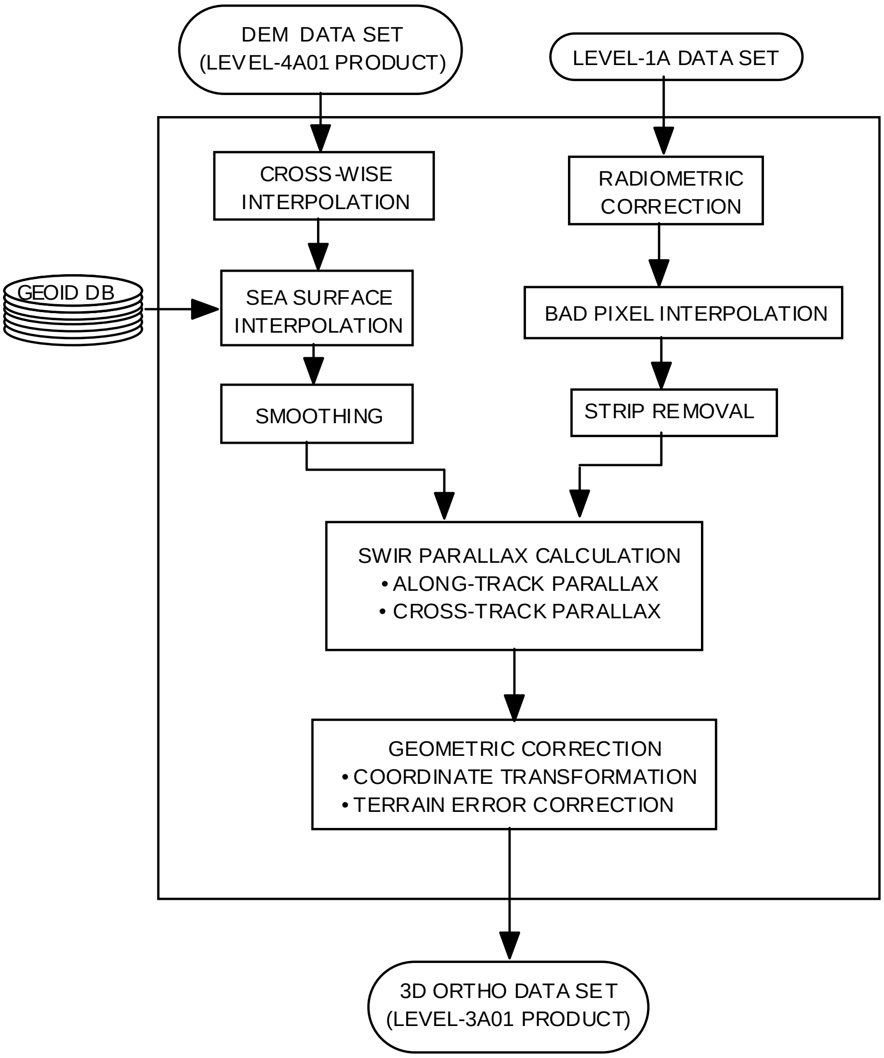


Figure 3-1 3D ortho product generation algorithm flow

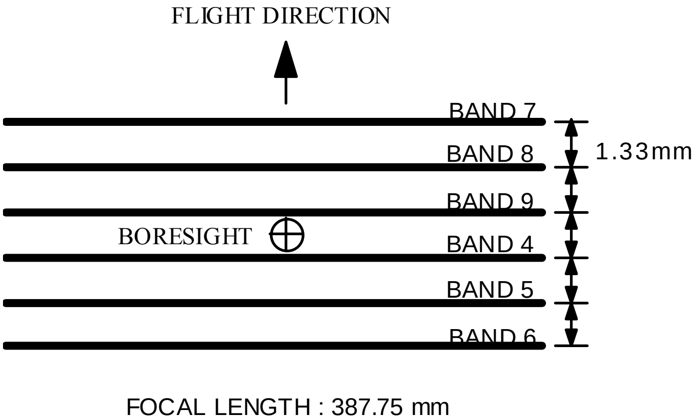


Figure 3-2 SWI R detector array alignment

4. Product Description

4.1. Outline of Contents

Figure 4-1 shows the outline of the 3D ortho (Level-3A01) data products.

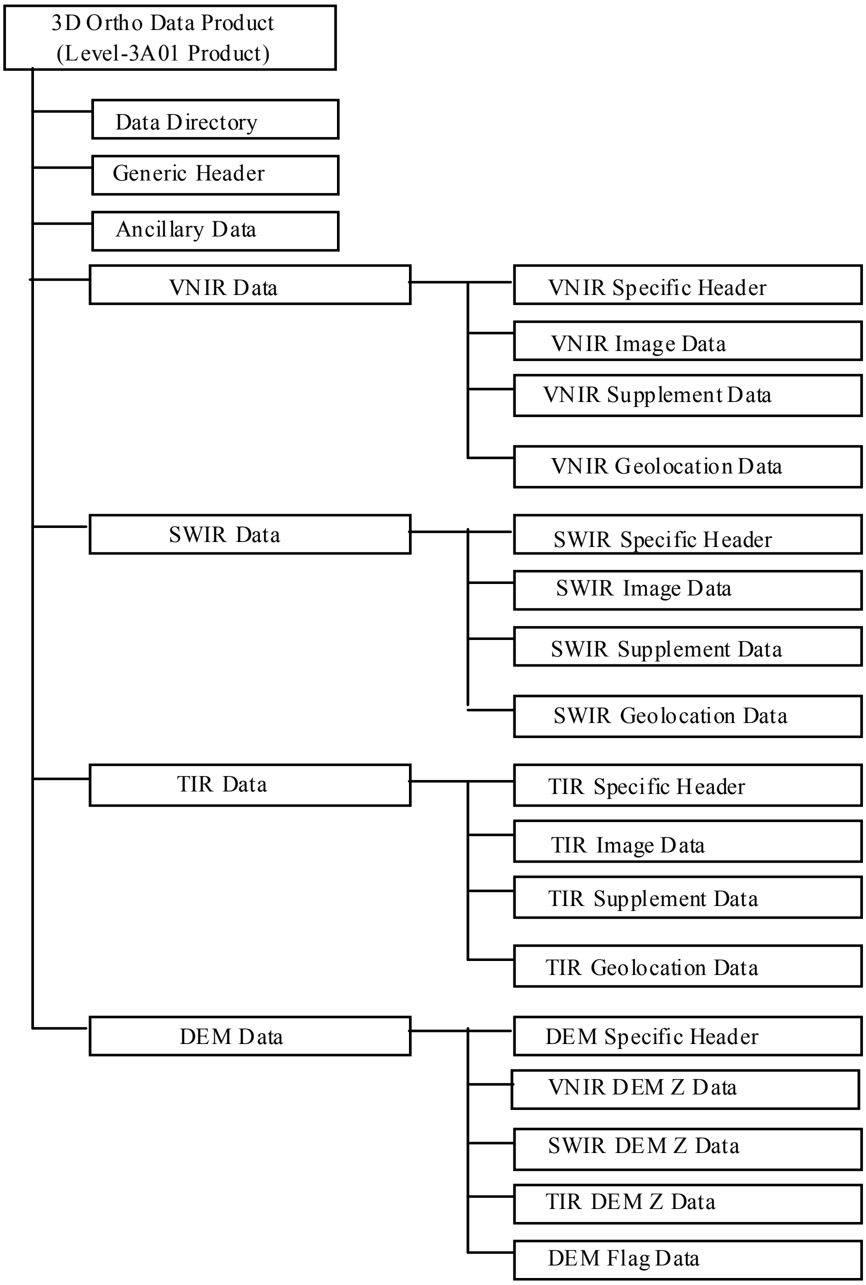


Figure 4-1 3D ortho data products outline

The 3D ortho product is basically the same as the Level-1B product except for the terrain error corrected and the map oriented image. The data size is variable. The typical size of the product is shown in Table 4-1.

Table 4-1 Typical Size of 3D Ortho Product

No.	Item	Data Size(bytes)
1	Data Directory	4,0960
2	Generic Header	about 3,000
3	Specific Header	about 8,000
4	Ancillary Data	about 1,728
5	Supplement Data	about 1,379,550
6	VNIR Image Data	about 100,000,000
7	SWIR Image Data	about 35,000,000
8	TIR Image Data	about 7,000,000
9	VNIR Geolocation Data	about 3,000
10	SWIR Geolocation Data	about 3,000
11	TIR Geolocation Data	about 3,000
12	DEM ZV Data	about 50,000,000
13	DEM ZS Data	about 12,500,000
14	DEM ZT Data	about 1,400,000
15	DEM Flag Data	about 25,000,000
	Total	about 260MB

4.2. User Assignable Parameters

Table 4-2 shows the user-assignable parameters when ordering the 3D ortho product.

Table 4-2 User Assignable Parameters

Parameter	Value
Data	Arbitrary (Default:WGS-84)
Map Projection	・UTM(Default) ・LCC ・PS ・Uniform Lat., Lon
Interpolation	・Nearest Neighbor ・Bi-linear ・Cubic Convolution (Default)

4.3. Image Data

(1) Definition of DN Value
Unit conversion coefficients, which are defined as radiance per 1DN, are used to convert from DN to radiance. Radiance (spectral radiance) is expressed in unit of W/(m^2•sr•μm). It is a basic policy that the unit conversion coefficient will be kept in the same values throughout the mission life. The relationship between DN value and radiance is shown below and illustrated in Figure 4-2.

(i) A DN value of zero is allocated to dummy pixels.

(ii) A DN value of 1 is allocated to zero radiance.

(iii) A DN value of 254 is allocated to the maximum radiance in the VNIR and SWIR bands.

(iv) A DN value of 4094 is allocated to the maximum radiance in the TIR bands.

(v) A DN value of 255 is allocated to saturated pixels in the VNIR and SWIR bands.

(vi) A DN value of 4095 is allocated to saturated pixels in the TIR bands.

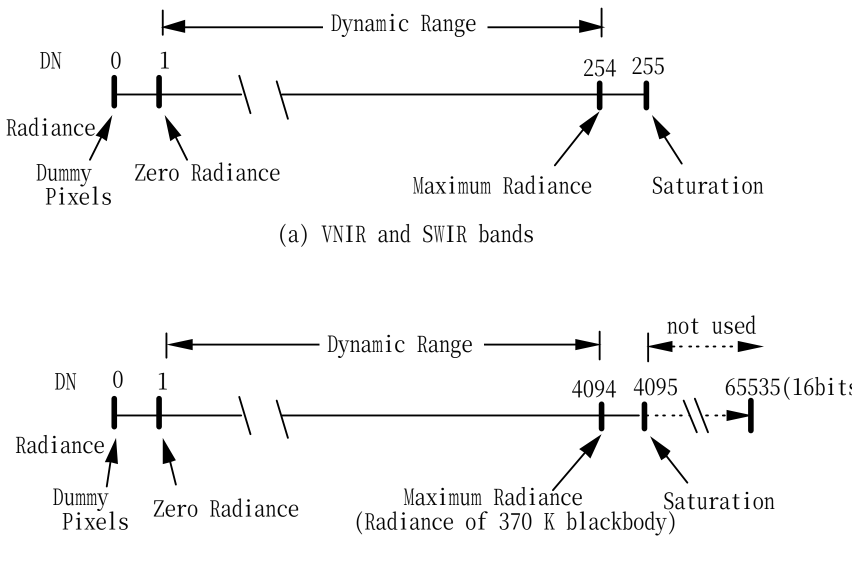


Figure 4-2 Relationship between DN and radiances

Table 4-3 shows the unit conversion coefficients for each band. The unit conversion coefficients are also included in the specific header and are the same as those for Level-1B data.

Table 4-3 Unit conversion Coefficients

Band No.	Coefficient (W/(m^2•sr•µm)/DN)			
	High gain	Normal gain	Low gain 1	Low gain 2
1	0.676	1.688	2.25	N/A
2	0.708	1.415	1.89	
3N	0.423	0.862	1.15	
3B	0.423	0.862	1.15	
4	0.1087	0.2174	0.290	0.290
5	0.0348	0.0696	0.0925	0.409
6	0.0313	0.0625	0.0830	0.390
7	0.0299	0.0597	0.0795	0.332
8	0.0209	0.0417	0.0556	0.245
9	0.0159	0.0318	0.0424	0.265
10	N/A	6.882×10^{-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}		

From the relationship described above, the radiance value can be obtained from the DN values as follows.

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

(2) Pixel Sixe
The pixel size for each subsystem is as follows.

VNIR : 15 m
SWIR : 30 m
TIR : 90 m

(3) Image Data Size
The image data size (pixels and line numbers) is variable depending on the processing parameters.

4.4. DEM-Z (Elevation) Data

The elevation data plane for each subsystem (VNIR, SWIR and TIR) is attached to the 3D ortho product. The 16 bits are allocated to the elevation data with a resolution of 1 m (1 m/DN). The elevation data is based on WGS-84 ellipsoid. The formal geoid base elevation can be calculated by subtracting the geoid heights from the WGS-84 ellipsoid base values.

A DN value of –9999 is allocated to the dummy area. The pixel with an interpolated value can be identified from the quality flag data. Table 4-4 shows a summary of the elevation data.

Table 4-4 Elevation Data Summary

Item	Description
Data Size	Variable (value in each product is described in DEM Specific Metadata)
Pixel Spacing	VNIR: 15 m SWIR: 30 m TIR: 90 m
Data Type	2 dimensional data array 16 bits integer (signed)
Unit Conversion Factor	1 m/DN
Reference Elevation	WGS-84 ellipsoid
Dummy Area Data	-9999

4.5. DEM-Z Flag Data

The DEM-Z flag data is generated from 2nd QA data of the DEM product projected to the 3D ortho product coordinates. The QA flag data are bit flag data which show the state of each pixel of DEM data using 8 bit flags. The lower-ranking of 5 bits show the states of the band 3N image that is used for generation of DEM. The 3 higher-ranking bits how the states of DEM states.

Table 4-5 DEM-Z Flag Data Format

Item	Description
Data Size	Variable (same as VNIR image data) (value in each product is described in DEM Specific Metadata)
Data Type	2 dimensional data array 8 bits integer (unsigned)

Table 4-6 DEM-Z Flag Data Structure

DEM Status			VNIR Status				
8	7	6	5	4	3	2	1

1: Bad / Suspect
2: Overflow / Underflow
3: Sea
4: Lake / Pond
5: Cloud
6: Abnormal Value
7: Blank Pixel
8: Interpolated Pixel

4.6. Geolocation Data

Geolocation data are image coordinate values and latitude/longitude coordinate values stored at each of lattice points set at a certain interval on image data. Table 4-7 and Table 4-8 show the interval of lattice points in each subsystem and the contents, respectively.

Table 4-7 Intervals of Lattice Points in Geolocation Data

No.	Subsystem	Interval of lattice points
1	VNIR	498 x 420
2	SWIR	249 x 210
3	TIR	83 x 70

Table 4-8 Contents of Geolocation Data

No.	Type	Description	Unit
1	double	Geocentric latitude	deg.
2	double	Geocentric longitude	deg.
3	int	Pixel coordinates	pixel
4	int	Line coordinates	line

Taking the interchangeability with Level 1B data products into consideration, the geolocation data format is the same for both. Level-1B data is different from 3D ortho data in that the former has a fixed number of lattice points in the geolocation data, since the size of the image data is fixed; while in the latter, the number of lattice points is variable due to the variable size of the image data.

4.7. Metadata

The 3D ortho meta data consists of following eight groups.

(1) Inventory Metadata
(2) ASTER Generic Metadata
(3) GDS Generic Metadata
(4) Product Specific Metadata VNIR
(5) Product Specific Metadata SWIR
(6) Product Specific Metadata TIR
(7) Bad Pixel Information
(8) Product Specific Metadata DEM

The term “metadata” relates to all information of a descriptive nature that is associated with a product or dataset. This includes information that identifies a dataset, giving characteristics such as its origin, contents, quality, and condition. Metadata can also provide information needed to decode, process and interpret the data, and can include items such as the software that was used to create the data. Metadata entries are described in Object Description Language (ODL) and CLASS system (for two-dimensional arrays). Details are provided in “ASTER Level-3A01 Data Products Specification”. The relationship between the metadata and the HDF attribute name is shown in Table 4-9.

Table 4-9 Relationship between Metadata and HDF Attribute Name

Metadata	HDF Attribute Name
Inventory Metadata	coremetadata.0
ASTER Generic Metadata	productmetadata.0
GDS Generic Metadata	productmetadata.1
Product Specific Metadata	VNIR: productmetadata.v SWIR: productmetadata.s TIR; productmetadata.t
Bad Pixel Information	badpixelinformation
DEM Specific Metadata DEM	productmetadata.d

4.8. Supplement Data

Each subsystem instrument (VNIR, SWIR and TIR) status is described in supplement data. In details, refer “ASTER Level-3A01 Data Products Specification”.

5. Quality Information

The geometric accuracy of the 3D ortho data is defined on the basis of VNIR-3N data. Absolute geolocation accuracy is defined by the Level 4A01X (DEM-xyz) data, and the relative geolocation accuracy for intra- and inter-telescopes is determined by the geometric collection table (GCT) of the Level-1A data. Table 5-1 lists the target images used in the validation process.

Geometric accuracies of Level 3A01 data obtained during initial verification work are shown below. Table 3.5 shows a list of target images used for verification

Table 5-1 List of 3D Ortho Product Verification Images

Target Area	Observation Date	Pointing Angle
Tsukuba (107,100,4)	June 4, 2001	0.027°
Kiso-koma (109,99,7)	May 30, 2000	8.59°
Saga (113,106,4)	April 8, 2000	0.022°

5-1. Absolute Accuracy

Table 5-2 and Table 5-3 show two examples of absolute accuracies calculated by comparing high-accuracy GCP (required accuracy : 1.5m in a horizontal and 0.5m in an altitudinal direction) with the 3D ortho data and its comparison with errors of the Level-4A01X data used to locate 3D ortho data.

Table 5-2 Absolute Accuracy of 3D Ortho Data (Tsukuba)

	3D ortho		DEM	
	Δlon(m)	Δlat(m)	Δlon(m)	Δlat(m)
Average	-15.7	-1.6	-19.8	3.4
Standard Deviation	6.4	6.2	5.3	6.6
RMSE	16.9	6.4	20.5	7.4

Table 5-3 Absolute Accuracy of 3D Ortho Data (Yatsugatake)

	3D ortho		DEM	
	Δlon(m)	Δlat(m)	Δlon(m)	Δlat(m)
Average	-27	11.6	-24.5	12.0
Standard Deviation	8.7	11.7	12.2	9.2
RMSE	28.4	16.5	27.4	15.2

A large geolocation errors are due to an imperfect Earth nutation correction in Level-1 processing are reported. See User’s Guide ‘ASTER Level-1 product’ (section for ‘Quality Information’) for details.

5-2. Inter-telescope Band-to-band Registration Accuracy

Table 5-4 shows the iner-telescope band-to-band registration accuracy of three 3D ortho data sets.

Table 5-4 Inter-telescope Band-to-band Registration Accuracy

Band		Tsukuba		Yatsugatake		Saga	
		Δx	Δy	Δx	Δy	Δx	Δy
V2-S6	Average	-0.10	-0.04	-0.06	0.01	0.03	0.01
	Standard Deviation	0.12	0.10	0.16	0.11	0.11	0.10
	RMSE	0.16	0.11	0.17	0.11	0.12	0.10
V2-T11	Average	0.03	0.00	0.03	0.01	0.01	0.00
	Standard Deviation	0.13	0.09	0.14	0.10	0.05	0.04
	RMSE	0.14	0.09	0.15	0.10	0.05	0.04

Note 1--- V2: VNIR Band 2, S6: SWIR Band 6, T11: TIR Band 11
Note 2----Units are pixels of coarser resolution.

5-3 Intra-telescope Band-to-band Registration Accuracy

Tables 5-5 through Table 5-7 show the intra-telescope band-to-band registration accuracy for VNIR, SWIR and TIR, respectively.

Table 5-5 VNIR Intra-telescope Band-to-band Registration Accuracy

Band		Yatsugatake	
		Δx	Δy
V3N-V1	Average	0.06	0.02
	Standard Deviation	0.17	0.12
	RMSE	0.18	0.12
V3N-V2	Average	0.04	0.02
	Standard Deviation	0.22	0.16
	RMSE	0.22	0.16
V2-V1	Average	0.03	0.02
	Standard Deviation	0.08	0.07
	RMSE	0.09	0.08

(Unit: VNIR pixel)

Table 5-6 SWIR Intra-telescope Band-to-band Registration Accuracy

Bamd		Yatsugatake	
		Δx	Δy
S6-S4	Average	0.03	-0.01
	Standard Deviation	0.16	0.12
	RMSE	0.16	0.12
S6-S5	Average	0.01	0.01
	Standard Deviation	0.18	0.10
	RMSE	0.18	0.10
S6-7	Average	-0.01	-0.09
	Standard Deviation	0.12	0.12
	RMSE	0.12	0.15
S6-S8	Average	0.00	-0.04
	Standard Deviation	0.14	0.11
	RMSE	0.14	0.11
S6-S9	Average	-0.01	-0.03
	Standard Deviation	0.12	0.11
	RMSE	0.12	0.11

(Unit: SWIR pixel)

Table 5-7 TIR Intra-telescope Band-to-band Registration Accuracy

Band		Yatsugatake	
		Δx	Δy
T11-T10	Average	0.00	-0.03
	Standard Deviation	0.05	0.04
	RMSE	0.06	0.05
T11-T12	Average	0.03	0.02
	Standard Deviation	0.06	0.04
	RMSE	0.06	0.04
T11-T13	Average	0.06	0.02
	Standard Deviation	0.10	0.04
	RMSE	0.11	0.05
T11-T14	Average	0.05	0.06
	Standard Deviation	0.12	0.05
	RMSE	0.12	0.08

(Unit: TIR pixel)