

# ACCURACY OF ASTER GEOLOCATION AND DEM AND THEIR APPLICATION

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## ABSTRACT:

Since the launch in December of 1999, ASTER (Advanced Thermal Emission and Reflection Radiometer) has collected more than 1,100,000 scenes of data and generated more than 11,000 DEM and ortho-rectified images (Level 3A) from them, covering 20% of the whole land. The relative and absolute accuracy of geolocation and DEM will be discussed by comparing GCPs (Ground Control Point), GIS (Geographic Information System) and other existing topographic map. ASTER has shown very high geometric accuracy even if any GCP is not available. Contributing factors to this high accuracy are the stability and knowledge of the space craft orbit and attitude, ASTER sensors geometry, information on the Earth movement, algorithm to calculate the line of site vectors, and so on. Discussion will also cover the applicability of the DEM and ortho-rectified image data, based on the accuracy, and the discussion on further improvement.

## 1. INTRODUCTION TO ASTER

Since the launch of ASTER in December 1999, ASTER has been stably acquiring earth observation data for more than 6 years with the cooperation of NASA. As of early April 2006, the number of acquired scenes has exceeded 1.1 million scenes, and has covered most of the land area of the earth twenty-two times in average. The observation data are uploaded to the NASA's Tracking and Data Relay Satellite System (TDRSS) and transferred immediately to the Ground Data System of the Earth Remote Sensing Data Analysis Center (ERSDAC) in Tokyo, Japan via APAN (Asia-Pacific Advanced Network). The Level 0 data transferred are basically all processed to Level 1A data, and offered to the users to search for the data. Level 1A is generated by applying reversible corrections to the Level 0 data, and geometric correction coefficient and radiometric calibration coefficient are appended to the data. At this point, the data cannot be superimposed onto the map. However, Level 1B data, generated by applying radiometric and geometric corrections to the L1A data, can be superimposed onto the existing map except for the geometric distortion caused by the terrain height. The number of processed scenes for Level 1A has counted approximately 950 thousand scenes, and approximately 250 thousand scenes have been processed up to Level 1B. The number of observed scenes and the number of processed scenes for Level 1A and Level 1B are shown in the Figure 1.

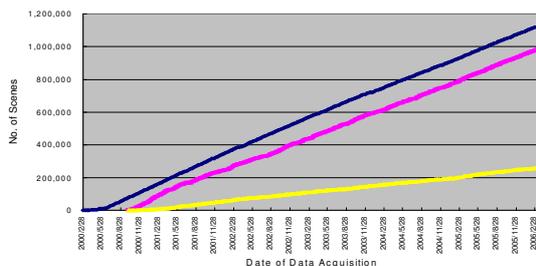


Figure 1. Acquired Scenes and L1A/B Production

ASTER GDS also provides DEM (Digital Terrain Model, Level 4) and Level 3A data containing both orthogonally projected data and DEM, with geometric correction applied to the Level 1A data, and the data with atmospheric correction and radiometric correction such as reflectance, emissivity, temperature correction applied to the Level 1B data, as higher-level products offered to the users. DEM related data (Level 3A, Level 4) have also been generated nearly 10 thousand scenes, covering 20% of the whole land area of the earth, and the data have been archived.

## 2. BRIEF EXPLANATION OF THE ALGORITHM

The ASTER system, in addition to the nadir looking 14 data, has a backward looking data in the same wavelength as the band 3N. It is called the band 3B. A set of band 3N and band 3B is used to calculate the horizontal location as well as the height. Schematic diagram is shown in Figure 2.

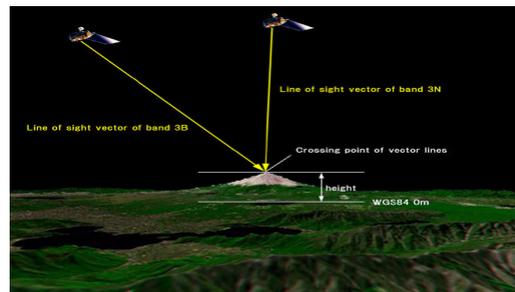


Figure 2. Schematic Diagram of DEM Extraction from ASTER Data

The band 3B data is not only rotated backward direction by 27.6 degrees around the pitch axis but also 1.33 degrees by roll axis to compensate the Earth Rotation during approximately 55 seconds. This configuration is kept when there is a cross track pointing. In the Band 3B sensor, there are 5,000 CCD's, and when the data is downloaded from the Terra, 4,100 pixel data are selected in function of the latitude to compensate the Earth

Rotation. And to keep the pixel size of the Band 3B as that of the band 3N, the instantaneous field of view is designed slightly smaller than that of band 3N. (21.3 and 18.6 micro radian respectively.) The band 3B looks at the same location of the Earth approximately 55 seconds after the data take by the band 3N. A set of bands 3N and 3B constitutes a stereo pair, from which the user can see ASTER data stereoscopically, even in Level 1B data set, with the Base to Height Ratio ( B/H )= 0.6 calculating as follows ( Fujisada et.al., 1998):

$$\tan(\arcsin((R_E + H)/ R_E * \sin(27.6)))$$

where  $R_E$  and  $H$  denote the radius of the Earth and the Altitude of the Spacecraft ( 6378 km and 705 km at the Equator, respectively). Therefore, note this value of  $B/H$  is not necessarily equal to 0.6, but slightly changing depending on the relative location of the pair pixel. And also please note the overlap of the Bands 3N and 3B does not cover the completely the same location, the coverage of the stereo pair is usually slightly less than the coverage of nadir looking data, 60 km.

From ASTER GDS, two kinds of data set, Level 4 and Level 3A are available. The former is just a data set of the Digital Terrain Model with the same horizontal interval defined by a map projection selected by the user (default value 30 m in case of UTM), and the latter is composed of three data sets of VNIR, SWIR and TIR with the same horizontal interval (default value in VNIR is 15 m in case of UTM, and 30 m and 90 m), together with the ortho-rectified VNIR, SWIR and TIR data set with the same spatial distances in each telescope. In the Level 3A data set, there is a data set of "Band 3B. In this data set, the geometric distortion in cross track direction is corrected. But, the parallax in along track direction still remains. As a result, the user can see a stereo pair even in case of the Level 3A data set.

The algorithm to extract the location and the DEM is essentially the same as the case of the Level 1 product. In this case, the target location is not calculated by the location of the crossing point of the two Line of Sight Vectors (LOS vectors) with the Earth Ellipsoid, but by the crossing point of the two LOS vectors for the corresponding pixels. The corresponding pixels are calculated by taking a spatial correlation between two corresponding location with a fixed window size. In this calculation process, matching location is estimated by fitting to the two-dimensional quadratic polynomial to achieve sub pixel accuracy. In general, two LOS vectors do not cross in strict mathematical sense. So, the crossing point is defined as a mid point of the line connecting two LOS vectors with minimal distance. This calculation is performed every two pixels. This crossing point is calculated in the Earth Inertial Coordinate, then, converted to the Earth Fixed Coordinate, assuming the Earth motion in the space. This values of (x, y, z) in the Earth Fixed Coordinate is a intermediate product ( DEM XYZ) to the Level 3A and the Level 4 data. As a next step, the relative height against the Earth Ellipsoid is calculated for each XYZ value. Please note the horizontal location is also calculated at the same time. Since the XYZ value can be easily correlated to the original pixel, the ortho-rectification is possible. And the final data set is generated by interpolation to provide a data set with equal data interval. Therefore, the height value is the height against the Earth Ellipsoid and not against the geoid value. So, for the sea area, in the level 3A data, the geoid value is given for each pixel. In order to convert this height against the geoid, the user should subtract the geoid value of the target location from the height in the ASTER products (The geoid

value can be obtained in various Web sites. But the values of the geoid height vary in general within +/- 40m.).

The above process is a general description of the algorithm. Therefore, the discussion of the accuracy and spatial resolution of DEM should be based on this background. But, essential point of this algorithm is that this process of the DEM generation does not refer to any Ground Control Point (GCP). In this sense, this product is called "relative". But, the result shows this relative DEM and Ortho-rectified product provides a good accuracy even compared with the case of using GCP's to estimate the Spacecraft location and the attitude. Thus, by this method, the geometric distortion caused by the altitude can be corrected.

### 3. EVALUATION OF THE ACCURACY OF GEOLOCATION AND DEM

As described above, this method does not employ orientation by GCP (Ground Control Point), and the calculation depends on the accuracy of each data described above such as the position and attitude of the satellite. The accuracy obtained as a result is shown in the Table 1.

	delta lon	delta lat	delta h
	(m)	(m)	(m)
Results for all the 90 data			
mean	40.75	-11.82	-19.81
std	44.67	11.43	7.65
Results for each scenes			
mean	42.86	-10.56	-19.19
std	6.86	5.48	4.12

Table 1. Error Evaluation by GCPs for the data of 2003

This table was compiled for the data acquired in 2003, and the position accuracy in the horizontal direction is within 50m in longitude direction, within 15 m in latitude direction and the altitude is approximately 10-15m. However, after the checking, it was found that the error in the horizontal direction has been increasing in the longitude direction. After the investigation why the error is more significant in longitude, it was found that it was caused by not adequately calculating the nutation of the earth and by correcting the calculation, the position can be obtained to be as accurate as that of a year ago. The error due to nutation of the earth is shown in the Figure 3.

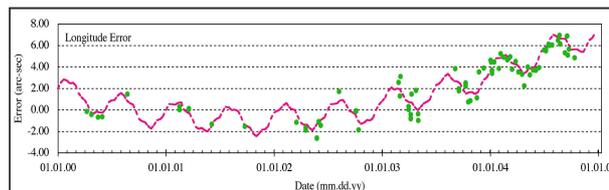


Figure 3. Change in errors due to earth nutation (Fujisada)

This revision was implemented at the version up of the Level 1 algorithm conducted on May 23, 2005, (Version 6.0) but the equation for making correction for older data is also posted on

the web, so the older data can also be correct by the equation (Watanabe, 2005):  
[http://www.gds.aster.ersdac.or.jp/gds\\_www2002/service\\_e/release\\_e/set\\_release\\_e16.html](http://www.gds.aster.ersdac.or.jp/gds_www2002/service_e/release_e/set_release_e16.html)  
 This error is shown in Figure 4.

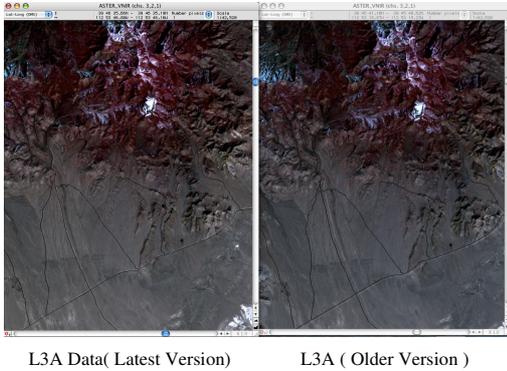


Figure 4. Error caused by the nutation

Left image is a newly processed L3A data, while Right image is L3A data processed by the older version, including the earth nutation error. In Right image, a road is shifted eastward from the road of GIS.

Thus, ASTER data can be corrected for the Earth nutation and other predictable geometric errors. However, for the high altitude area, if the pointing angle is large, there is a geometric distortion caused by the elevation. If the altitude is  $h$  meters high and pointing angle is  $\theta$ , the geometric distortion caused by elevation and pointing can be calculated by:

$$h \cdot \tan(\theta)$$

If  $h$  is 2000 m and  $\theta$  is 8.55 deg, the geometric distortion is approximately 300 m. In ASTER data, L1B should include this error. But, this error is corrected for L3A. This is shown in Figures 5 and 6.

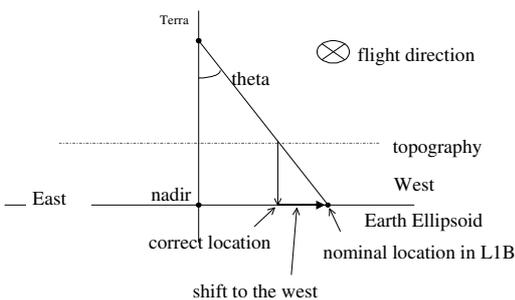


Figure 5. Geometric Configuration to explain error caused by Elevation and Pointing

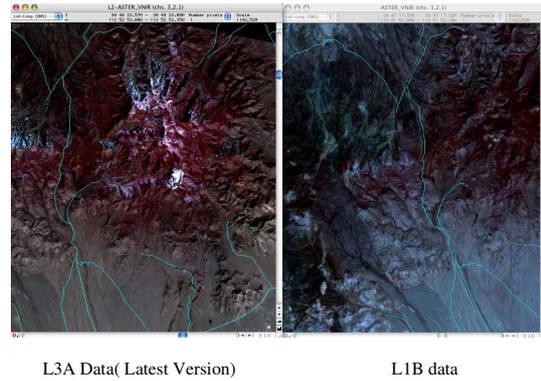


Figure 6. Error caused by Elevation

In this data set, average height of this image is about 1550 m and the pointing angle is  $-5.721$  degrees (minus indicates right hand side of the satellite direction). Left image shows a geometrically correct, newly processed L3A data, while right image shows L1B image including a shift caused by the elevation and the pointing. In the right image, a road is shifted westward from the road of the GIS.

#### 4. ISSUES AND SOLUTIONS

In ASTER data, there still remain some errors caused by the current algorithm.

1) Sometimes, sharp edge of the cliff looks smoother than actual one. Also sometimes the river runs on the flank of the adjacent cliff. Such problems are caused by the algorithm using fixed size of matching window in the calculation of the spatial correlation. This situation can be at least partly improved by introducing other algorithm such as flexible changing window size. As for the height of the river, there have been some efforts to correct the strange height sequence of the river. These efforts show higher possibility of ASTER data. But, at the ASTER GDS, the DEM data is data is provided by the fixed parameters, considering the productivity.

2) Matching sometimes does not work in the homogeneous areas such as sea, lake, playa, etc. This kind of errors is detected by calculating the changing rate of the height. In such cases, error flag will be set in the error plane in the data set. In case of the sea, geoids value will replace. In the case of the lake and homogeneous areas, estimated values from the surrounding more reliable data.

3) In case of the cloud, error flag will be also set. Estimated height is also calculated from the surrounding area which have reliable values as the case of the lake.

4) In case of the night time data, VNIR data are missing and intertelescope band to band registration between SWIR and TIR cannot be properly conducted. Therefore, the geolocation data is provided only by using system parameters. Therefore, the geolocation accuracy has some limitation.

#### 5. ADDITION TO RADIOMETRY

As described above, observation by On Board Calibration is

performed once every 33 days (number of days of revolution plus one), and the result is reflected to the database (RCC) as a coefficient for radiometric correction as needed. For VNIR and SWIR, the sensitivity gradually deteriorates over time, but the extent of deterioration is smaller as the wavelength becomes longer (See Figure 7).

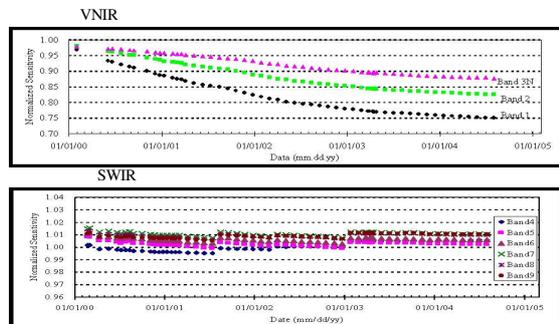
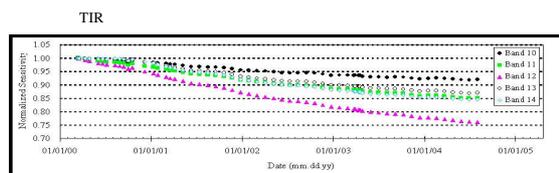


Figure 7. Radiometric Performance --Sensitivity Trend Data--

For TIR, this change is relatively greater, and therefore, the RCC is changed once every three months (See Figure 8).



• The radiometric performance will be kept within the required accuracy by the database update.

Figure 8. Radiometric Performance --Sensitivity Trend Data--

However, since the change can be predicted to a certain extent, so the equation will be adopted for the revision of the RCC in the future. The change will be reflected to the correction coefficient of the Level 1A. And for Level 1B, DN value corrected for the change in sensitivity of the detector will be given, and can be converted from DN value to the radiance by a certain conversion coefficient.

Recently, there has been a problem of the change in offset value of SWIR along with the rise in detector temperature about 1.4K, and that is producing some error in the radiance value of SWIR. However, this problem will be dealt with in the near future.

## 6. CONCLUSION AND COUNTER MEASURE

In general, ASTER data shows good geolocation accuracy in Level 1B or Level 2 data for the area with low elevation. There was a degradation of the accuracy caused by the Earth nutation. But it was corrected by the latest version up of the Level 1 software. Currently, the geolocation accuracy is almost 15 m in standard deviation. This accuracy is equivalent to that of Landsat ETM+. But, both ASTER Level 1B data and Landsat ETM+ data have a geometric distortion caused by the elevation and pointing angle. The Level 3A (Ortho-rectified data) and Level 4 data (DEM data) are corrected for this geometric distortion. As a result, the geolocation accuracy for high elevation area is as good as in the area with low elevation. The

accuracy of the ASTER DEM is about 15 m in standard deviation. But, there is a limitation of the DEM accuracy derived from the current algorithm of DEM extraction. But, it should be emphasized that ASTER achieved the high geolocation and DEM accuracy without use the GCP.

As such, the level 1 Software and geometric and radiometric database has been updated sometimes. And the degradation of the detector is periodically conducted, and the measured degradation of the sensitivity of each detector is reflected in the radiometric database.

As noticed, the version up conducted in May of 2005 (Version 6.0R00) provided best quality in geometry. And, the latest version up in February of 2006 (Version 6.2 R00) provided best quality in radiometry by estimating the degradation of the detectors by the use of the function. However, the older data remains uncorrected. Therefore, ASTER GDS started "On Demand Processing" to apply the latest version of Level 1 Software even for older data to provide best quality.

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