EVALUATION OF THE GEOMETRIC ACCURACY OF TERRASAR-X

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KEY WORDS: validation, geometric accuracy, synthetic aperture radar, basic product

ABSTRACT:

The TerraSAR-X launched on June 15, 2007 is one of the most state of the art satellite sensors. Its sophisticated feature is in demand for the application for map generation and monitoring purposes. One of the basic products of TerraSAR-X is the Enhanced Ellipsoid Corrected (EEC) orthorectified image. The product is projected to map geometry and terrain induced distortions are corrected using a digital elevation model (DEM). The geometric accuracy of this product depends on the referred DEM. In this study, we evaluated the pixel location accuracy of the product by two methods. The method using corner reflectors shows that the pixel location accuracy of SSC product was better than 1 meter, and that of EEC product was better than 5 meter in the flat area. On the contrast, the pixel location accuracy of the mountain areas evaluated by comparison with digital maps was reduced. It reveals that the enhancement of the orthorectified product is necessary for considering the creation of the topographic maps using TerraSAR-X data.

1. INTRODUCTION

TerraSAR-X is the latest German radar satellite that has been launched on June 15, 2007. The objective of the mission was to develop an operational spaceborne X-band synthetic aperture radar (SAR) system in order to produce various products for commercial and scientific use (Werninghaus *et al*., 2004).

The applications of TerraSAR-X include environment planning, land cover mapping, natural resource exploration, regional and urban development, crisis response, security intelligence and so on (Schmidt and Janoth, 2007). Especially for the DEM, TanDEM-X will make it possible to generate the high-quality DEMs of any area on the globe (Krieger, *et al*., 2005).

In order to evaluate the usefulness of TerraSAR-X data for the generation of topographic maps, the geometric accuracy of the SAR data should be analysed. The calibration and validation concept was planned before launching, and one of the subjects is geometric calibration (Schwerdt *et al*., 2005). In previous study, individual error budgets, such as orbit accuracy, DEM accuracy, atmospheric refraction, were calculated by the simulation (Frei *et al*., 2004). This simulation revealed that the geometric accuracy was mainly restricted by the quality of DEM.

The present study evaluated the geometric accuracy of the EEC basic product of TerraSAR-X. Our existing processing system uses the SRTM DEM with 90 m spatial resolution for generating orthorectified products (EEC) because DEMs of better quality are not available on a global scale (Hiramatsu *et al*., 2008). The study site was mountain area as well as flat ground to evaluate the effects of used DEM.

2. FEATURES OF TERRASAR-X

2.1 Specifications and Features

TerraSAR-X is a side-looking X-band synthetic aperture radar (SAR) based on active phased array antenna technology (Roth and Werninghaus, 2006). It is the first satellite to be built in a Public Private Partnership (PPP) in Germany: The German Aerospace Center (DLR) and Europe's leading satellite system specialist, EADS Astrium. DLR holds the rights for the scientific exploitation of the data, while Infoterra GmbH holds the exclusive rights for the commercial exploitation of the data product.

The operational lifetime is 5 years. The TerraSAR-X satellite flies in a sun-synchronous dawn-dusk 11 days repeat orbit at an altitude of 514 km at the equator. Table 1 shows the specification of the satellite (German Aerospace Center).

Repeat Cycle	11 days
Orbit per day	15 2/11
Local time at ascending node equator crossing	18:00+/- 15 minutes
Altitude at equator	514.8 km
Inclination angle	97.44 °
Ground track repeatability	+/- 500 m per cycle for mapping

Table 1. TerraSAR-X key orbit parameters.

The instrument timing and pointing of the electric antenna can be programmed allowing numerous combinations. From the many technical possibilities, four imaging modes have been designed to support a variety of applications ranging from medium resolution polarimetric imaging to high resolution mapping. The active beam steering of the SAR antenna allows for high resolution imagery. The following imaging modes are defined for the generation of basic products.

-High resolution SpotLight Mode HS in single or dual polarization
-SpotLight mode SL in single or dual polarization
-StripMap mode SM in single or dual polarization
-ScanSAR mode SC in single polarization

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Table 2 shows the specification of the each acquisition mode (German Aerospace Center).

2.2 Basic Product

The raw TerraSAR-X data are processed to create basic image products and then to Level 1B format. The Level 1B contains the following geometric projections and data representations;

Single Look Slant Range Complex (SSC), with amplitude and phase information in slant range geometry,

Multilook Ground Range Detected (MGD), is corrected from slant range to ground range projection,

Geocoded Ellipsoid Corrected (GEC), corrected to Universal Transversal Mercator (UTM) and Uniform Polar Stereographic (UPS) projection using the WGS84 ellipsoid with an average terrain height,

Enhanced Ellipsoid Corrected (EEC), corrected to UTM or UPS projection with a digital elevation model (DEM), e.g. the SRTM elevation models, which are available with a mesh width of 1 and 3 arc seconds, respectively.

Orbit type	Required accuracy	Purpose
Predicted	700 m along track	Processing near real time products
Rapid	2 m (3D, 1σ)	Standard processing of basic products
Science	20 cm (3D, 1σ)	Processing for high accuracy purposes (e.g., interferometry)

Table 3. Orbit types used for basic product processing.

The pixel localization accuracy defines how accurate a pixel in TheTerraSAR-X basic product can be transformed to a ground position. An error contribution comes from the GPS orbit determination, to some extent. Table 3 shows three types of orbits used for the processing of basic products (Roth *et al*., 2004). For SSC products, the pixel location accuracy is given in slant range coordinates.

3. PIXEL LOCATION ACCURACY

Several reports published by DLR regarding the results of the commissioning phase activities state that the achieved absolute geometric accuracy is much better than formerly specified due to the reliable orbit accuracy (Yoon *et al*., submitted). The specified accuracy is satisfied with 1 m absolute geometric accuracy and is now valid for nominal imaging conditions.

The geometric accuracy is evaluated by several methods is mentioned in this section. First, the simulation result is reviewed by the previous study. Then the pixel location is evaluated by two methods, by using corner reflectors (landmark of the image) in Tokyo and Tsukuba cities, and by the comparison with the digital map in Toya and Kagawa cities. The latter one was used for the evaluation of the accuracy in the mountain area.

3.1 Simulation

It is assumed that the main contributions to the pixel localization accuracy are the orbit determination and the height accuracy of the DEM. When the elevation accuracy of DEM varies locally, the effect on the pixel location accuracy can be estimated. Table 4 shows the simulation results of the pixel displacement in range that is caused by DEM elevation errors (Fritz and Eineder, 2008). In table 4 the elevation errors range from 2 to 100 m, and the incidence angle from 20 to 50 degrees. The cotangent of the incidence angle is the factor that converts a height error into a location error.

DEM elevation error (m)	Incidence angle (degree)					
	20	26	32	38	44	50
	Resulting location error (m)					
2	5.5	4.1	3.2	2.6	2.1	1.7
6	16.5	12.3	9.6	7.7	6.2	4.9
16	44	33	25	21	17	13
30	82	61	48	38	31	25
100	275	205	160	128	103	83

Table 4. Pixel localization error resulting from DEM errors at different incidence angles .

	High-resolution SpotLight	SpotLight	StripMap	ScanSAR
Swath width	/	/	30 km	100 km
Scene extension	5 km (Az)×10 km (R)	10 km (Az)×10 km (R)	/	/
Acquisition length	/	/	Max. 1650 km	Max. 1650 km
Incidence angle	20-55°	20-55°	20-45°	20-45°
Azimuth resolution	1 m	2 m	3 m	16 m
Ground range resolution	1.5-3.5 m	1.5-3.5 m	1.7-3.5 m	1.7-3.5 m

Table 2. Main characteristics of the each acquisition mode.

3.2 Evaluation using corner reflector

The accuracy of the pixel location in the flat area was evaluated using several corner reflectors. Corner reflectors were placed in the large park for the simultaneous observations when TerraSAR-X observed the ground. The study sites are Tokyo and Tsukuba.

Table 5 shows the specification of utilized data. Figure 1 shows the TerraSAR-X EEC product of Tokyo and an enhanced

portion of the corner reflectors. The reflection from the corner reflector is much stronger than neighbourhood.
Figure 2 shows the corner reflector (CR) used in this study. The reflector consists of 3 sides of rectangular aluminium panels with 50 cm length. The panels are attached perpendicular to each other by bolts. We measured the coordinates of the CRs using GPS (accuracy is better than several centimeters). From the comparison of the coordinates derived from TerraSAR-X and CRs, pixel location accuracy of TerraSAR-X was evaluated.

	Tokyo1	Tokyo2	Tsukuba
Acquisition Date	16th Feb. 2008	29th Nov. 2007	23th Oct. 2007
Mode	HS	HS	HS
Incidence Angle	39.4	42.2	52.7
Orbit	Ascending	Descending	Descending
Scene Center	35.7 N, 139.8 E	35.6 N, 139.8 E	36.1 N, 140.1 E

Table 5. Specification of used TerraSAR-X data.

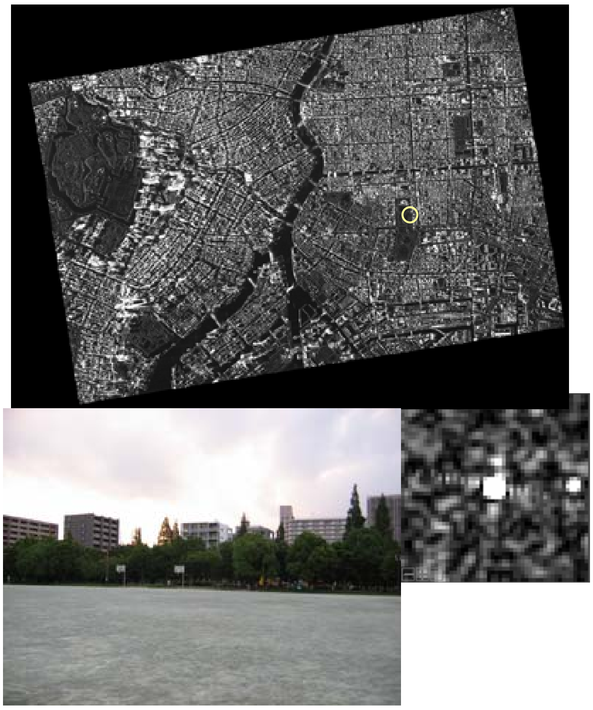


Figure 1. TerraSAR-X EEC product of Tokyo on 29th Nov., 2007 and an enhanced portion of the corner reflectors.

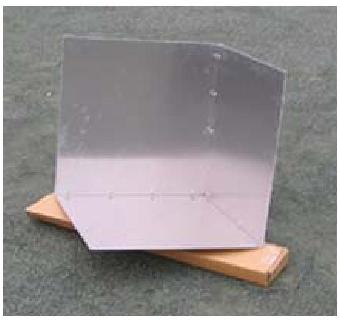


Figure 2. Corner reflector used in this study.

3.2.1 Pixel location accuracy using science orbit: Table 6 shows the comparison of location accuracy of both SSC and EEC product when science orbit information was used. This analysis was done using the image of Tokyo of 29th Nov. The latest supplied processing system was applied to generate the level 1B product.

The radar signal is subject to path delay due to the different refractive indices of vacuum, ionosphere and troposphere. This results in slant range error of the order of 2-3 m that depends on the actual conditions in the passed media and on the length of the signal path hence the incidence angle. This value is annotated in the meta data annotation file.

The pixel location accuracy of the SSC product for slant range and azimuth was estimated using the projected spacing value for slant range and azimuth, respectively. Errors of slant range are 0.4 m, and azimuth is -0.5 m. Therefore the result of the pixel location accuracy is better than 1 m. Almost the same results were obtained for Tsukuba site.

The pixel location accuracy for the northing (Y) direction was 1 m, though easting (X) direction of the EEC product was not better than 1 m,. It is assumed that the vertical errors of DEM affect the pixel location accuracy of the EEC product.

(a) SSC

	TSX	GPS	Difference
Slant Range (pixel)	2781.46	2781.03	0.43
Azimuth (pixel)	2727.04	2727.62	-0.58

(b) EEC

	TSX	GPS	Difference
X (m)	392133.5	392137.1	-3.6 m
Y (m)	3948968.6	3948967.6	1.0 m

Table 6. The location accuracy of the SSC and EEC product calculated using the image of 29th Nov.

3.2.2 Pixel location accuracy comparison using another orbit type: Table 7 shows the comparison of location accuracy of EEC product by different orbit type. Even if smaller X deviations for the predicted orbit observed, that doesn't mean it is more accurate because the errors of Y is much greater.

It reveals that in this case the pixel location accuracy is almost same when using rapid and science orbit. This demonstrates that JPL real-time GPS products used for the generation of the rapid orbit product already provides high accuracies (Yoon et al., submitted).

	Predicted	Rapid	Science
X (m)	0.3	-3.6	-3.6
Y (m)	11.7	1.0	1.0

Table 7. Comparison of the location accuracy of the EEC product by different orbit types. The acquisition date is 29th Nov.

3.2.3 Pixel location accuracy comparison using different looking direction:

Table 8 shows the comparison of location accuracy of EEC product by different looking direction (orbit). The incidence angle is almost same, and the rapid orbit is descending for 29th Nov and ascending for 16th Feb. The two CRs were set with 30 m distance for range direction on 16th Feb.

The difference of the accuracy for both X and Y direction is about 1 m between these acquisitions. It seems that the looking direction does not affect the pixel location accuracy of the EEC product. The deviation of the accuracy of 2 reflectors is also small.

(a) 29th November

	TSX	GPS	Difference
X (m)	392133.5	392137.1	-3.6 m
Y (m)	3948968.6	3948967.6	1.0 m

(b) 16th February

Corner reflector 1

	TSX	GPS	Difference
X (m)	392130.3	392136.2	-5.9
Y (m)	3948962.3	3948962.2	0.1

Corner reflector 2

	TSX	GPS	Difference
X (m)	392146.3	392151.1	-4.8
Y (m)	3948963.3	3948963.2	0.1

Table 8. Comparison of the location accuracy of the EEC product by different looking direction.

3.2.4 Pixel location accuracy comparison for Tsukuba site:

The validation of the pixel location accuracy for some points is effective to evaluate the deviation of the errors spatially. Table 9 shows the comparison of location accuracy of EEC product in Tsukuba site. Four corner reflectors were set at the flat park or parking lots (Fig. 3). The used orbit type was science orbit.

The pixel location accuracy is better than 1 m for both X and Y except the X of point 1. The deviation for the points is found to be small.

Point 1

	Difference
X (m)	1.7
Y (m)	0.0

Point 2

	Difference
X (m)	-0.1
Y (m)	-0.2

Point 3

	Difference
X (m)	0.5
Y (m)	-0.3

Point 4

	Difference
X (m)	0.3
Y (m)	0.1

Table 9. Comparison of the location accuracy of 4 points in Tsukuba site.

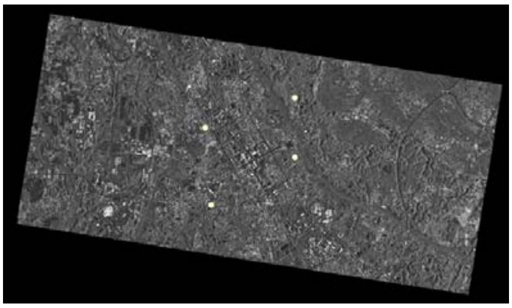


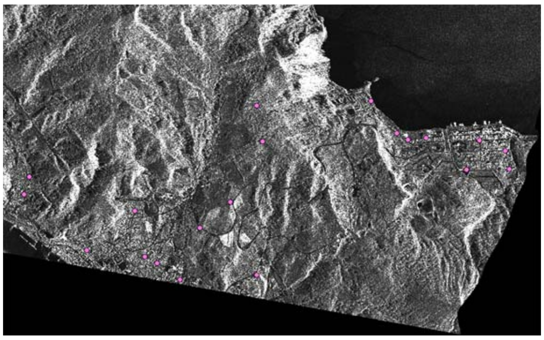
Figure3. Four validation points of Tsukuba site.

3.3 Evaluation using the digital map

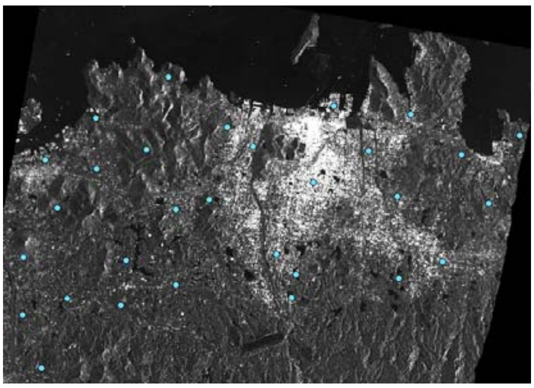
The pixel location accuracy of the mountain area was evaluated using digital map at the scale of 2500 because the pixel location accuracy of the reference data was better than 2 m. Table 10 shows the specification of the used data. The study sites were Toya (Hokkaido prefecture) for SpotLight and Kagawa (Kagawa prefecture) for StripMap. Figure 4 shows the part of TerraSAR-X image and validation points of both sites.
More than 20 validation points were extracted mainly from the intersections of the roads (Fig. 5). The recorded position of these points on TerraSAR-X images were compared with those from digital map.

	Toya	Kagawa
Acquisition Date	21th Oct. 2007	4th Jan. 2008
Mode	SL	SM
Incidence Angle	31.3	35.3
Orbit	Descending	Descending
Scene Center	42.6 N, 140.8 E	34.1 N, 134.0 E

Table 10. Specification of used TerraSAR-X data.

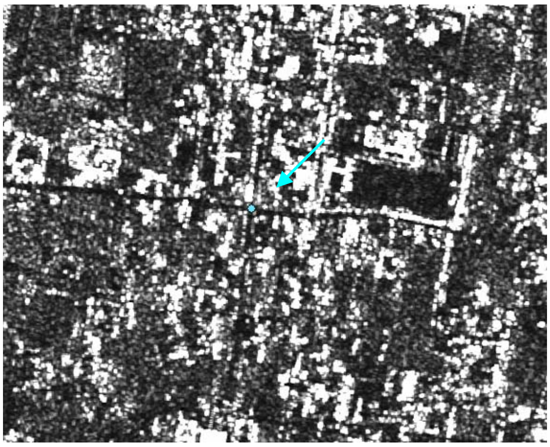


(a) Toya

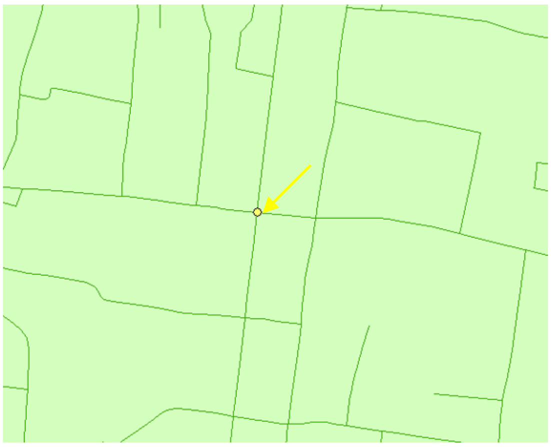


(b) Kagawa

Figure 4. TerraSAR-X EEC product of Toya and Kagawa. Points show the validation points for each site.



(a) TerraSAR-X image



(b) Digital Map

Figure 5. The example of the validation point used in this study.

Table 11 shows the pixel location accuracy. The accuracy for X is worse than 10 m, while that for Y about 5 m. It is noted that the errors include the errors of extracting intersections from SAR images due to the difficult interpretation. However, the fact that the geometric errors of range (X) direction are larger for both sites implies that the quality of the used DEM affects the pixel location accuracy of EEC products.

The DEM elevation errors were estimated using the simulation results of table 4. About 10 m of pixel location accuracy corresponds to 6 m of elevation errors in case of 32 degree of the incidence angle. This value includes the effects of the low-spatial resolution of referenced DEM as well as the actual elevation error.

Figure 6 shows the comparison between the pixel location accuracy for X and the elevation at Kagawa site. The pixel location accuracy is partly related with the elevation (r = 0.13, without the point with 350 m of elevation). Further analysis is required to better understand the exact dependencies on the pixel location accuracy in mountainous areas.

Site	Toya	Kagawa
Number of GCPs	20	30
dX (m)	-1.0±12.9	-11.0±12.8
dY (m)	-1.1±4.7	2.4±4.6
dXY (m)	9.8±8.7	12.6±12.3

Table 11. Pixel location accuracy evaluated by digital map 2500.

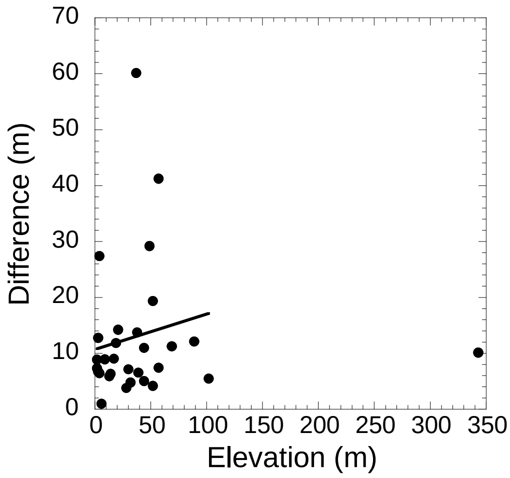


Figure 6. Comparison between the geometric accuracy and the elevation.

4. CONCLUSIONS

TerraSAR-X satellites of high-spatial resolution images are being investigated recently for preparing topographic maps. One of the critical points for SAR system is geometric accuracy of the products as it is a side-looking system and the geometric accuracy of the ortho-products is strongly influenced by the accuracy of the DEM used for production.

We focused on the applicability of sophisticated high-spatial resolution TerraSAR-X data for our objectives, and the study evaluated the geometric accuracy of TerraSAR-X by the following two methods, using corner reflector (CR) and by comparison with a digital map.

The geometric accuracy of SSC products was firstly estimated from comparing the positions of the CR on TerraSAR-X image and in-situ data. It showed that the accuracy is better than 1 m. Then the accuracy of the orthorectified EEC products was evaluated. It revealed that the geometric accuracy was better than about 5 m in the flat area. Secondly, the accuracy was evaluated using a digital map at a scale of 2500 in order to evaluate the accuracy in mountainous areas. The measured accuracy degraded to more than 10 m due to the poor DEM quality used for the orthorectification.

Further analysis is necessary for more accurate evaluation because the validation points were not enough. However, the fact that these results show the same tendency revealing the validity of the two methods as well as the reliability of the estimated accuracy.

Our study shows the possibility to generate topographic maps using TerraSAR-X data, however, the geometric errors in mountainous areas are large when insufficient DEMs are used. Therefore, further analysis is required to evaluate the impact of high resolution DEMs on the pixel location accuracy.

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ACKNOWLEDGEMENTS

The authors are grateful to the German Aerospace Center (DLR) and Infoterra GmbH for providing their valuable advice for this study.