International Conference on Space Optics—ICSO 2008

Toulouse, France

14–17 October 2008

Edited by Josiane Costeraste, Errico Armandillo, and Nikos Karafolas

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International Conference on Space Optics — ICSO 2008, edited by Josiane Costeraste, Errico Armandillo,
Nikos Karafolas, Proc. of SPIE Vol. 10566, 105660G · © 2008 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2308203

ACCURACY ASSESSMENT OF ALOS OPTICAL INSTRUMENTS: PRISM AND AVNIR-2

Takeo Tadono(1), Masanobu Shimada(1), Takanori Iwata(1), Junichi Takaku(2), and Sachi Kawamoto(2)

(1) *Japan Aerospace Exploration Agency (JAXA), 2-1-1, Sengen, Tsukuba, Ibaraki 305-8505 Japan, tadono.takeo@jaxa.jp*
(2) *Remote Sensing Technology Center (RESTEC), 2-1-1, Sengen, Tsukuba, Ibaraki 305-8505 Japan*

ABSTRACT

This paper describes the updated results of calibration and validation to assess the accuracies for optical instruments onboard the Advanced Land Observing Satellite (ALOS, nicknamed "Daichi"), which was successfully launched on January 24th, 2006 and it is continuously operating very well. ALOS has an L-band Synthetic Aperture Radar called PALSAR and two optical instruments *i.e.* the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) and the Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2). PRISM consists of three radio-meters and is used to derive a digital surface model (DSM) with high spatial resolution that is an objective of the ALOS mission. Therefore, geometric calibration is important in generating a precise DSM with stereo pair images of PRISM. AVNIR-2 has four radiometric bands from blue to near infrared and uses for regional environment and disaster monitoring *etc*. The radiometric calibration and image quality evaluation are also important for AVNIR-2 as well as PRISM.

This paper describes updated results of geometric calibration including geolocation determination accuracy evaluations of PRISM and AVNIR-2, image quality evaluation of PRISM, and validation of generated PRISM DSM. These works will be done during the ALOS mission life as an operational calibration to keep absolute accuracies of the standard products.

1. INTRODUCTION

Since January 24, 2006, the Advanced Land Observing Satellite (ALOS) is continuously operating more than 2.5 years and it works very well. ALOS has three mission instruments i.e. an L-band Synthetic Aperture Radar called PALSAR, and two optical sensors called PRISM and AVNIR-2. The global images are acquiring by each instrument and the numbers of archived images are more than 867,000 scenes by PALSAR, 1,122,000 scenes by PRISM and 511,000 scenes by AVNIR-2 as of July 2008, respectively. They are using for cartography, disaster monitoring as well as forest and environmental monitoring. The sensor calibration and accuracy evaluation are most important to use ALOS data in any application fields because they directly effect to the accuracy of the results in applications. The results of initial calibration phase (ICP) of PRISM and AVNIR-2 have been reported [1], [2]. After ICP, JAXA is continuously doing calibration and validation (Cal/Val) activities *e.g.* accuracy evaluations of standard products in term of geometry, radiometry and image quality, and updating parameters that are used in the sensor models to generate standard products to maintain and improve absolute accuracies as operational calibration. The results of Cal/Val of initial operational phase have been also presented [3]-[5].

This paper describes updated results of operational Cal/Val and accuracy evaluations of the standard product for PRISM and AVNIR-2, which includes geometry, radiometry and image quality evaluation. The accuracy degradations depend on the time since launch of the satellite (*i.e.* time trend) are confirmed, and some parameters of the sensor models are updated to keep or improve the absolute accuracies. The PRISM alignment parameters that are using in geometric system correction of standard product are operationally updating to keep geometric accuracy. The software of generating standard product is also updated or modified to improve image quality of PRISM based on evaluations of Cal/Val. Furthermore, validations of generated digital surface model (DSM) by PRISM, which is a high level product of the ALOS project defined at JAXA, are introduced.

2. GEOMETRIC CALIBRATION

The geometric calibrations of both PRISM and AVNIR-2 are carrying out separated to two steps *i.e.* relative calibration and absolute calibration. The relative geometric calibration is done by evaluating and correcting parameters related to band-to-band registration for AVNIR-2, and relative CCD alignments for PRISM. The absolute geometric calibration is done by evaluating the sensor alignments for both AVNIR-2 and PRISM. In this section, updated results of geometric calibration and its time trends are shown as operational calibration.

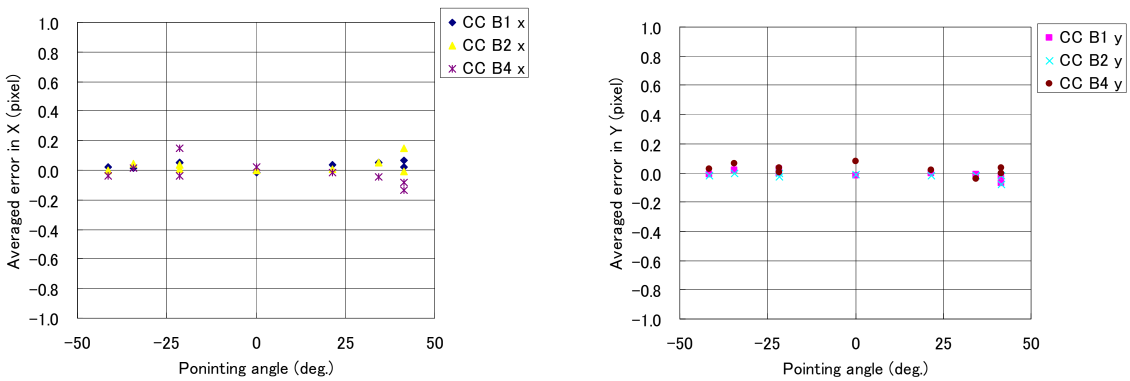
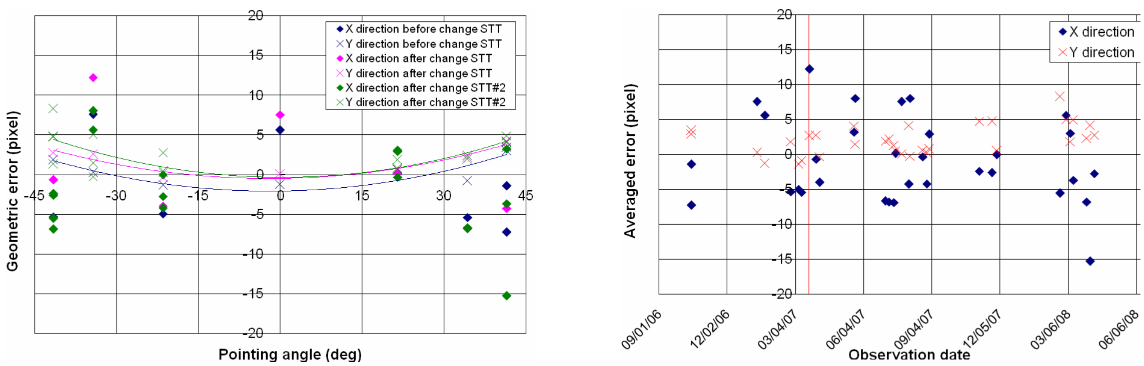


Fig. 1. Evaluation of band-to-band registration as averaged relative geometric error of AVNIR-2 for cubic convolution resampling (left: X direction, and right: Y direction, the images were acquired from April to December 2007).



(a) Comparison between before and after March 22, 2007. (b) Time trend since October 2006.

Fig. 2. Evaluation of geometric correction accuracy of AVNIR-2.

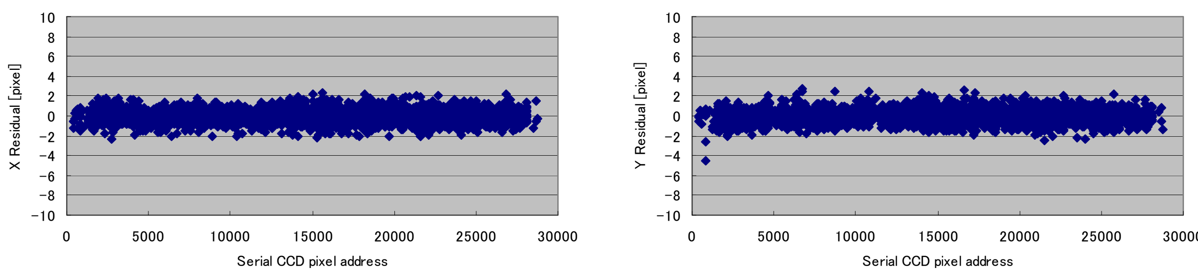


Fig. 3. Evaluation of relative CCD alignments of PRISM nadir-looking radiometer using latest version of alignment parameters (left: X direction, and right: Y direction).

2.1 Geometric calibration of AVNIR-2

The band-to-band registration is important because if it accuracy is not sufficient the color composite image runs in level 1B2 (L1B2) standard product. The band-to-band registration is defined to adjust bands 1, 2, and 4 to band 3 that is as the base band into the geometric sensor model. The current parameters which are used to generate standard product and related to band-to-band registration have been updated on December 2006.
Fig. 1 shows the relative geometric error for each band of AVNIR-2 compared with band 3 that shows the band-to-band registration. The images used this evaluation were acquired from April to December 2007 with various pointing angles from +/-41.5 degree and cubic convolution (CC) methods was applied for resampling method in Fig. 1. The plots show scene averaged relative geometric error for band 1, 2 and 4, respectively. Left graphs of Fig. 1 show X (pixel) direction and the right show Y (line) direction. These geometric errors were calculated that the special feature points were automatically identified from images, than compared between each band and band 3 by the least square matching technique. They show +/-0.2 pixels

Table 1. Standard deviations of geometric residuals on image space (pixel).

Radiometer	No. of scenes	No. of GCPs	X (pixel)	Y (pixel)
Nadir	202	3,906	0.66	0.69
Forward	142	2,910	0.63	0.62
Backward	194	3,657	0.64	0.69

from Fig. 1 (b) in both X and Y directions, which meet to previous results that have been reported for 0 degree pointing angle with CC resampling method [3]. Therefore, accuracy of band-to-band registration is keeping with our expectation.

Regarding absolute geometric calibration of AVNIR-2, Fig. 2 shows results of geometric correction accuracy evaluation using ground control points (GCPs) as a function of (a) pointing angle, and (b) observation date as time trend since October 2006. The attitude coordinate of ALOS is defined at origin of the star tracker (STT) coordinate. Through the calibration of STT itself, its coordinate is changing during recurrent of the satellite due to change the thermal condition. Therefore, STT alignment parameter has been updated to adjust this disturbance on March 22, 2007. This adjustment is caused by about 20 meter gap in Y (line) direction of AVNIR-2 imageries that can be seen in Fig. 2 (a), where x plots show scene averaged absolute geometric error in Y direction, and square plots show them in X (pixel) direction, and color indicates different observation period of the image *i.e.* blue plots show the evaluated image were acquired before March 22, 2007, on the other hand pink and green show after it. The lines show regression curves of each x plots (Y direction). The difference between curves of blue and pink is about two pixels that are corresponding to 20m on the ground. Actually, blue plots are corresponds to previous calibration results [3]. At that time, sensor alignment of AVNIR-2 has been evaluated using acquired imageries over whole pointing angle ranges of +/- 44 degree, and parameters were updated. Currently, geometric accuracies are becoming better for +/-22 deg. pointing angle ranges due to STT parameter change. In terms of time trend of geometric accuracy of AVNIR-2, significant changes could not see in Y direction before and after March 22, 2007 from Fig. 2 (b) that is also shows results of whole pointing angle ranges. However, small trend with observation date may be found in Y direction. Therefore, we have a plan to update the alignment parameter of AVNIR-2 on September 2008.

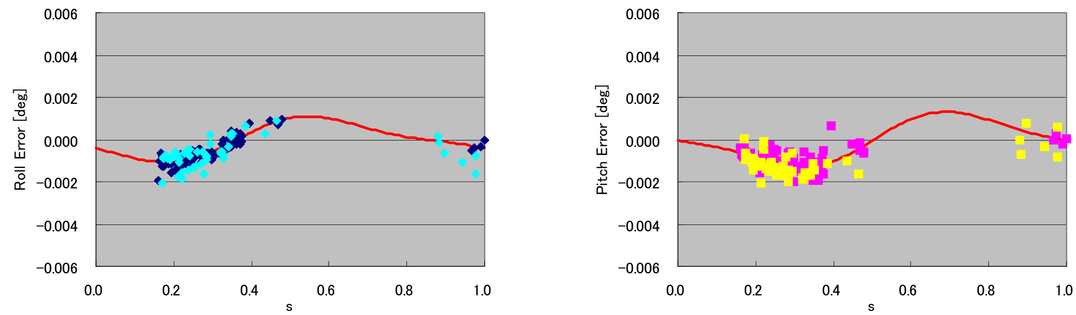
2.2 Geometric calibration of PRISM

PRISM consists of multiple CCD units and each unit has approximately 5,000 detectors. The nadir-looking radiometer of PRISM has six CCD units, which can be covered 70km observation swath width with 2.5m spatial resolution. The forward- and backward-looking radiometers have eight CCD units to observe same area with nadir's one even the earth rotating on its axis due to time gaps between those observations (about 46 seconds each). The boundary between each CCD unit is overlapped 32 pixels. Thus, these 32 pixels can be obtained image of same areas theoretically. One of parameters of sensor model is a relative alignment between CCD units called CCD alignment. The relative geometric calibration (*i.e.* self calibration) of PRISM is carried out to evaluate and update CCD alignments parameters. The latest version of it was released on June 2007 as version 2 [5]. The absolute geometric calibration is done by evaluating the pointing alignment parameters, which are calculated by the Precision Pointing and Geolocation Determination System (PPDS) that is a ground processing system to achieve determinations of precise attitude and pointing vectors for each PRISM radiometer [6]. The geometric correction accuracy shows the overall geometric accuracy, and could be calculated from comparison between the actual geographical coordination (longitude, latitude and height above ellipsoid) of GCP that could be identified on the images and the calculated one by using image coordinate (pixel, line) of GCP with transformation coefficients that are derived from sensor model at the system correction and include in the product [5].

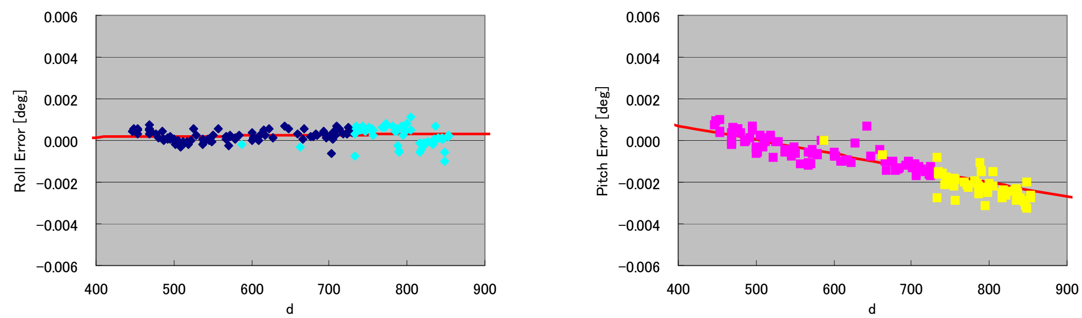
Fig. 3 shows geometric residuals in X (pixel) and Y (line) directions as a function of pixel number for nadir-looking radiometer as example. The geometric residuals of each boundary between CCD units were refined with the sub-pixel image matching on overlapping 32 pixels data with latest version of CCD alignment. Table 1 summarizes the standard deviation of accumulated exterior orientation results on image space for nadir-, forward- and backward-looking radiometers, respectively. The accuracies of CCD alignments *i.e.* interior orientation parameters are keeping the sub-pixel level from 0.6 to 0.7 pixels from latest version. It looks very good and cannot see accuracy degradation from latest evaluation.

Regarding to absolute geometric calibration, ALOS is achieving the precise attitude determination function based on STT data as well as the precise orbit determination using dual frequencies GPS receiver (GPSR) with post ground processing [6]. To improve geometric absolute accuracy of PRISM, the pointing alignment parameters that are used into the processing of standard products, have to estimate precisely including variations of recurrent as well as time dependency. The current pointing alignment parameters are version 15 that released on July 25, 2008. We will update them about each two months to keep the accuracy if accuracy degradation is confirmed.

Addition to the pointing alignment parameters, we are also trying to generate the sensor alignment model,



(a) Short term variation model as a function of parameter "s" (left: rolling direction and right: pitching direction).



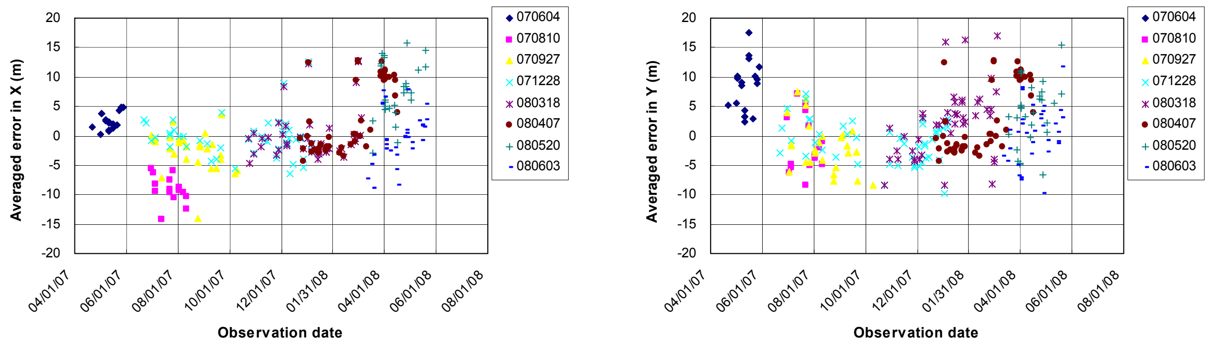
(b) Long term variation model as a function of parameter "d" (left: rolling direction and right: pitching direction).
Fig. 4. Evaluation of sensor alignment model of PRISM nadir-looking radiometer.

Table 2. PRISM sensor alignment model fitting residual.

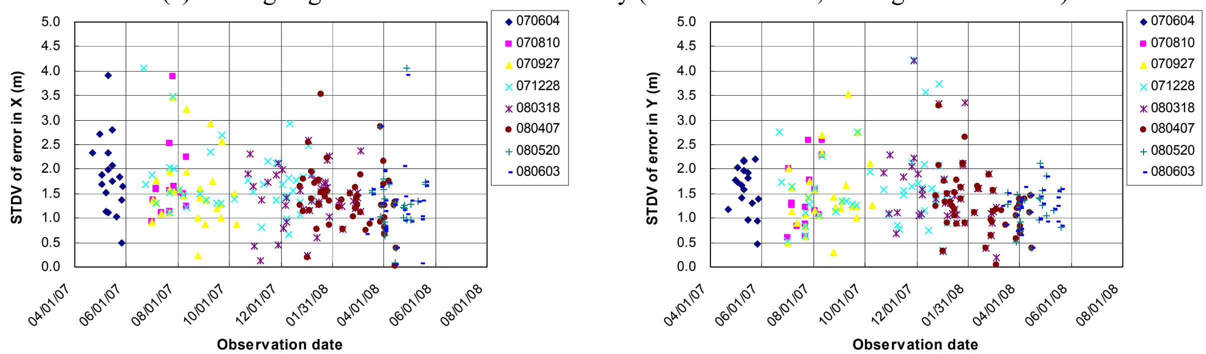
Radiometer	No. of scenes	Residual (sigma) (deg.)		At ground level (m)	
		Roll	Pitch	X (pixel)	Y (line)
Nadir	95	0.00025	0.00038	2.98	4.59
Forward	70	0.00027	0.00031	3.32	4.72
Backward	92	0.00022	0.00047	2.62	7.10

which is mainly using to confirm the accuracy of the pointing alignment as well as to create the high level products of PRISM at JAXA. The sensor alignment model consist of two time scales *i.e.* short term variation parameter "s" that is a normalized value of the observing time from satellite eclipse to orbit recurrent period (98.7 minutes), and long term variation parameter "d" that is depends on the date of observation from January 1, 2006 as a definition. The errors of PRISM sensor alignment model were expressed in Euler angles (roll, pitch and yaw) for the analysis and it was confirmed that yaw angle could be negligible. The 2nd degree Fourier series was applied to estimate the short term trend, and the linear model was applied to the long term trend as the current alignment change models from the various preliminary experiments. 70, 95 and 92 scenes for forward-, nadir-, and backward-looking image were sampled from 42 different GCP sites in the period from Mar. 2007 to Jan. 2008 for the latest model fittings. Fig. 4 shows the results of short and long term variation models fitting for nadir-looking radiometer, and rolling and pitching error angles. The standard deviation of fitting residual for each radiometer is shown in Table 2.

Fig. 5 shows results of geometric correction accuracy evaluation of PRISM nadir looking radiometer both (a) scene averaged geometric error in X and Y directions and (b) its standard deviation since April 2007. X-axis of Fig. 5 indicates observation date of evaluated image. Each color shows evaluation date, which is corresponding to update PRISM pointing alignment parameter. Previous results had been presented [5]. It looks a little bit scattered the averaged geometric accuracy of both X and Y directions from Fig. 5(a). However, many plots of them are less than +/- 10 meters. This means that most of PRISM images have +/- 10 meters of geolocation determination accuracy without GCPs. In this evaluation, we were used more than 270 scenes with 3,300 GCPs as check points that are located in the world. On the other hand, relative geometric error that shown as standard deviation of geometric error in Fig. 5 (b) is almost less than 2 meter that consists of the result of Fig. 3. Therefore, relative calibration is worked very well as I described above.



(a) Averaged geometric correction accuracy (left: X direction, and right: Y direction).



(b) Standard deviation of geometric correction error (left: X direction, and right: Y direction).
Fig. 5. Time trend of geometric correction accuracy of PRISM nadir-looking radiometer since April 2007.

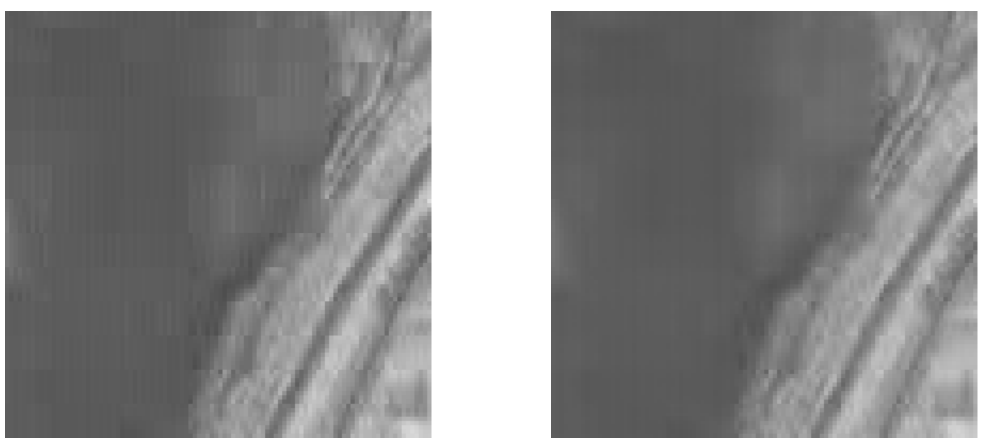


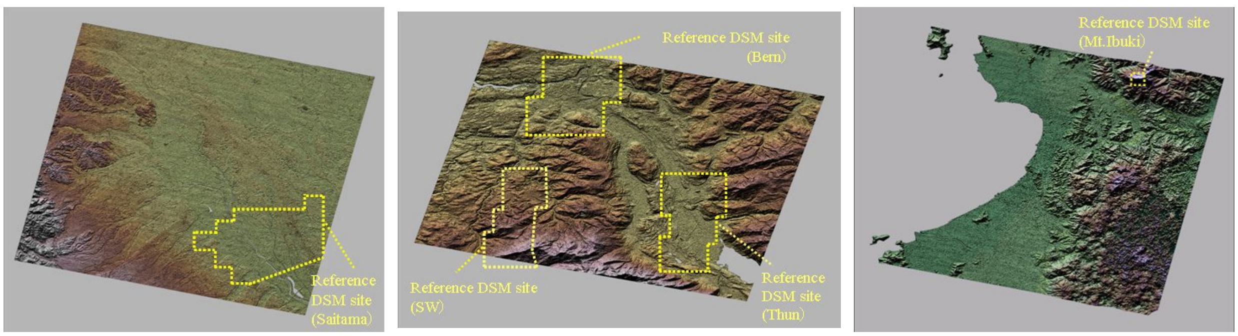
Fig. 6. Example of applying noise reduction filter for JPEG block noise to PRISM (left: before and right: after apply).

3. RADIOMETRIC CALIBRATION AND IMAGE QUALITY EVALUATION

The relative radiometric calibration, stripe noises were sometime appeared in PRISM images, therefore new algorithm was released to software, which is processing standard products on October 2007. Regarding to absolute radiometric calibration, we were performed cross-calibration with MODIS onboard TERRA and AQUA satellites. The detail of radiometric calibration of AVNIR-2 was described [5].
The image quality is another issue and also important especially in field of image interpretation. PRISM has a function of onboard data compression to reduce data rate from 960Mbps to 240Mbps by JPEG algorithm to downlink mission data via. Japanese Data Relay Test Satellite (DRTS). As the result of compression, block noises depends on JPEG are sometime appeared into the images especially radiometric homogeneous areas (*i.e.* water surface, ground, paddy field, dense forest *etc.*) are highly visible. Because the data compression rate is defined as the averaged value to keep the data transfer rate, and such targets can be relatively easy to compress compared with other target such as city area *etc*. The block noise reduction filter [7] was installed to the software to generate standard products on April 2008.

Table 3. Availability of reference DSMs and their characteristics.

Site Name.	Source	Area size (km)	Height range (m)	Ground resolution (m)	Height accuracy (m)	Source year
Saitama	LiDAR	14.0 x 12.0	100	1	< 1	2002
Okazaki	Aerial photo	6.0 x 6.0	400	10	10	2005
Thun	Aerial photo	7.5 x 14.5	500	2.5	0.5 – 2.5	2004
SW	Aerial photo	7.5 x14.5	1,000	2.5	0.5 – 2.5	2004
Bern	Aerial photo	11.0 x 11.5	400	2.5	0.5 – 2.5	2004
Fukuoka	LiDAR	12.0 x 9.0	500	1	< 1	2002
Mt. Tsukuba	LiDAR	1.5 x 1.5	200	1	0.8	2004
Chiriin	LiDAR	1.5 x 1.5	50	1	0.8	2004
Mt. Ibuki	LiDAR	1.2 x 1.9	700	1	0.8	2005



(a) Saitama (May 3, 2007). (b) Thun, SW and Bern (Jun. 24, 2007). (c) Mt. Ibuki (Sep. 11, 2007).

Fig. 7. Example of color shaded generated-PRISM DSMs of six stereo pairs (approx. 35km x 35km) and location of reference DSM areas (yellow dots).

Fig. 6 shows examples block noise reduction. Left of Fig. 6 show images processed by previous version of the software that is before applying the filter. It can be seen block noises of the 8 x 8 pixels or 16 x 8 pixels unit that is corresponding to compression unit. Right image of Fig. 6 were reprocessed data by updated software which is introducing the noise reduction filter.

4. VALIDATION OF GENERATED DSM BY PRISM

In this section, updated validation results of generated DSMs are described. We are developing the DSM generation software, which is introducing an algorithm the correlation based triplet stereo images matching exclusively developed for PRISM [8], [9]. In the software, only bias errors of roll and pitch angles are estimated as the unknown exterior orientation parameters in scene by scene basis because the yaw angles of pointing elements given by STT and PRISM sensor alignments are enough accurate against the ground location errors.

Previous validation results have been presented [5], [10]. We are using nine validation test sites, where are available the reference DSMs, covered by six PRISM stereo pairs. They are located in Japan and Switzerland.

Table 3 shows the characteristics of reference DSMs for nine test sites.

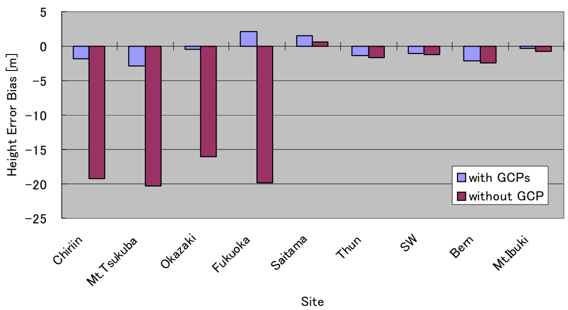
Fig. 7 shows example of generated DSMs and locations of reference DSM test sites. The DSM height accuracies of all reference DSM sites are summarized in Table 4 and Fig. 8, where the results are compared with generated DSMs using all available GCPs and 0-GCP (without GCP). The bias errors of DSM height are consistent with the triangulation accuracies and the trends of standard deviation are almost same as the previous validation results in new reference DSM sites. As the results of all-GCP models, the height accuracies are 4 to 5m in Chiriin and Saitama that consist of almost flat terrains, 5 to 7m in Fukuoka, Thun and Bern that include mixed various terrains i.e. mountains, farms, cities, etc. 5 to 6m in Okazaki and Mt. Tsukuba that includes almost mountainous terrains, and 6 to 8m in SW and Mt. Ibuki that consist of steep mountainous terrains.

5. CONCLUSIONS

In this study, we described the updated results of calibration of PRISM and AVNIR-2 and validation of generated PRISM DSMs, especially geometric calibrations, their accuracies, and time trends, image quality improvement for JPEG block noises of PRISM.

Table 4. Height accuracies of generated DSMs.

Site	Terrain	Model	Points	Bias [m]	SD [m]	RMSE [m]	Max [m]	Min [m]
Chiriin	Flat	0-GCP	33233	-19.28	4.39	19.77	3	-43
		42-GCP	33233	-1.82	4.35	4.72	19	-25
Mt.Tsukuba	Mountainous	0-GCP	35638	-20.24	4.68	20.78	-1	-44
		42-GCP	35638	-2.83	4.67	5.46	17	-25
Okazaki	Mountainous	0-GCP	548352	-16.08	6.14	17.21	85	-98
		17-GCP	548352	-0.48	6.00	6.02	99	-85
Fukuoka	Various	0-GCP	1181453	-19.82	6.87	20.98	77	-232
		24-GCP	1182903	2.14	6.80	7.13	105	-211
Saitama	Flat & Urban	0-GCP	1505339	0.64	5.12	5.16	74	-200
		213-GCP	1505512	1.50	4.74	4.97	78	-195
Thun	Various	0-GCP	1672554	-1.69	5.49	5.74	94	-79
		54-GCP	1672584	-1.40	5.36	5.54	94	-77
SW	Steep	0-GCP	1205609	-1.22	7.88	7.97	87	-105
		54-GCP	1205923	-1.12	7.80	7.88	86	-103
Bern	Various	0-GCP	2034946	-2.37	6.70	7.11	71	-57
		54-GCP	2034642	-2.08	6.68	6.99	76	-58
Mt.Ibuki	Steep	0-GCP	25868	-0.71	5.97	6.01	30	-54
		13-GCP	25868	-0.27	6.11	6.12	33	-54



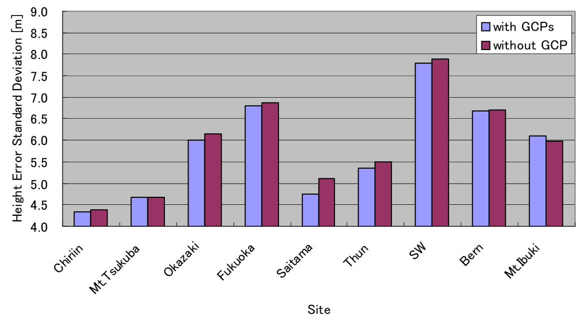


Fig. 8. Summary of validation of generated PRISM DSMs with and without GCPs for nine test sites (left: bias error, and right: standard deviation of height error).

The ALOS is currently in good health, and satellite position and attitude are also precisely determined every day. As the results of this study, geometric accuracies of both PRISM and AVNIR-2 are keeping in good that is meeting to our expectations. Regarding radiometric calibration, we did not much explain here, however it is also in good. The accuracy of PRISM DSM is depends on the terrain characteristics *i.e.* land-use and land-cover as well. The height accuracies of them were 4 to 5m for flat area, 5 to 7m for various terrain mixed areas, 5 to 6m for mountainous areas and 6 to 8m for steep terrain areas. These items will be evaluated as operational calibration during ALOS mission life.

ACKNOWLEDGMENT

The authors wish to thank our colleagues of ALOS Cal/Val and Science Team (CVST) for their many collaboration efforts in activities. We would like to continue these cooperative works until achieving a successful the ALOS mission.

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