ASTER GDEM Version 2
Validation Report

Japan's Validation Report

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Horizontal shift and elevation error estimation

<u>Validation method</u>

The ASTER GDEM version 2 was validated against the 10 m-mesh DEM produced by the Geographical Survey Institute (GSI) of Japan. The tiles selected for validation study were N35E136, N35E137, N36E136 and N36E137 (Fig. 1). They were located in central Japan which covers sea level to very steep over 3000 m high peaks.

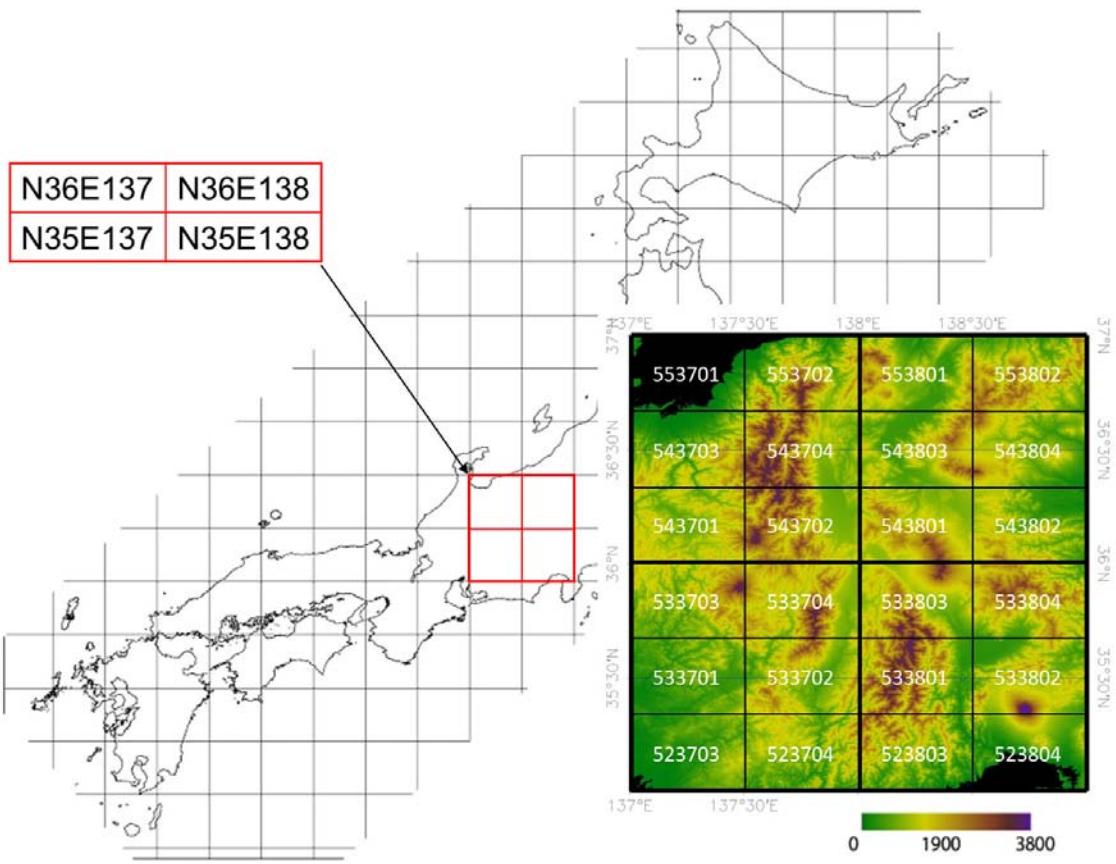

Fig. 1 Target Area

1. Preprocessing

Two-by-two degree study site was divided into 24 sub-areas for analysis. ASTER GDEM was resampled to 0.4 arc second grid. As the GSI 10 m DEM uses special format and special datum and it is divided into small areas, the datasets were transformed to the same format, datum and grid as the ones used for the resampled ASTER GDEM and mosaicked.

2. Horizontal shift analysis

The standard deviation of elevation difference between the ASTER GDEM and the GSI 10 m DEM was calculated by moving ASTER GDEM on the corresponding GSI 10 m DEM by 0.4 second grid basis. When geolocation of the GDEM and the GSI 10 m DEM is matched, the standard deviation of elevation residual becomes the lowest. The difference between the

original position and the matched position indicates horizontal shift. Table 1 shows an example of standard deviation table. The lowest standard deviation is observed at -3 of east-west and -4 of north-south, which means the horizontal shift is 1.2 arc-second to the west and 1.6 arc-second to the north. Then the shift in sub grid is calculated by interpolation.

Table 1 SD table by moving

	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6
-6	7.46	7.36	7.31	7.29	7.31	7.37	7.46	7.60	7.76	7.95	8.17	8.42	8.69
-5	7.35	7.26	7.21	7.20	7.23	7.29	7.39	7.53	7.70	7.90	8.13	8.38	8.66
-4	7.31	7.23	7.19	7.18	7.21	7.28	7.39	7.53	7.71	7.91	8.15	8.40	8.68
-3	7.34	7.26	7.22	7.22	7.26	7.33	7.45	7.59	7.77	7.98	8.22	8.48	8.75
-2	7.43	7.36	7.32	7.33	7.37	7.45	7.57	7.72	7.90	8.11	8.35	8.60	8.88
-1	7.58	7.52	7.49	7.50	7.55	7.63	7.75	7.90	8.08	8.29	8.53	8.78	9.06
0	7.79	7.74	7.72	7.73	7.78	7.87	7.99	8.14	8.32	8.53	8.76	9.01	9.28
+1	8.06	8.01	7.99	8.01	8.07	8.15	8.27	8.42	8.60	8.80	9.03	9.28	9.54
+2	8.36	8.32	8.32	8.34	8.40	8.48	8.60	8.75	8.92	9.12	9.34	9.59	9.85
+3	8.71	8.68	8.68	8.71	8.76	8.85	8.97	9.11	9.28	9.48	9.69	9.93	10.1
+4	9.10	9.07	9.07	9.10	9.16	9.25	9.37	9.51	9.67	9.86	10.0	10.3	10.5
+5	9.51	9.49	9.50	9.53	9.59	9.68	9.79	9.93	10.1	10.2	10.4	10.7	10.9
+6	9.95	9.93	9.94	9.98	10.0	10.1	10.2	10.3	10.5	10.7	10.9	11.1	11.3

3. Elevation analysis

After registration by horizontal shift, elevation error was calculated by taking the difference between GDEM and GSI 10 m DEM and statistically analyzed.

<u>Validation result</u>

Table 2 presents the validation results for 24 sub-areas from central Japan.

Table 2 Validation result for 24 sub-areas from central Japan

Sub-area ID	Horizontal Shift (arc-second)		Elevation Error (m)		
	+ EW -	+ NS -	Mean	SD	RSM
553701	-0.04	-0.05	1.9	6.2	6.5
553702	0.15	-0.01	5.4	12.8	13.8
553801	-0.25	-0.09	3.9	11.4	12.1
553802	-0.34	-0.04	7.4	12.2	14.2
543701	0.08	-0.14	8.4	11.7	14.4
543702	-0.03	-0.05	5.8	14.5	15.6
543703	-0.07	-0.14	6.1	11.5	13.0
543704	0.01	0.03	7.8	15.6	17.4
543801	-0.49	-0.13	5.3	12.1	13.2
543802	-0.10	-0.19	10.0	14.3	17.5
543803	-0.35	-0.20	5.3	12.1	13.2
543804	-0.32	-0.12	6.3	12.3	13.8
533701	0.16	-0.28	8.2	10.3	13.2
533702	-0.17	-0.19	7.3	14.2	16.0
533703	0.07	-0.19	11.7	12.4	17.1
533704	-0.12	-0.07	6.6	14.7	16.1
533801	-0.50	-0.31	11.8	16.2	20.1
533802	0.04	-0.33	7.0	12.0	13.9
533803	-0.52	-0.13	9.3	14.0	16.8
533804	0.03	-0.17	11.7	14.7	18.7
523703	0.07	-0.37	-5.6	9.7	11.2
523704	-0.19	-0.44	15.4	14.1	20.9
523803	-0.27	-0.40	15.2	15.5	21.7
523804	0.11	-0.53	5.3	10.0	11.3
Mean	-0.13	-0.19	7.4	12.7	15.1

1. Horizontal shift

The horizontal shift in 24 sub-areas and mean are shown in Fig. 2. They ranged from -0.52 to +0.16 arc-seconds in the east-west direction and from -0.53 to +0.03 arc-seconds in the north-south direction. (The plus means shift to the east and the north.) In average the error was 0.13 arc-seconds to the west and 0.19 arc-seconds to the south and the standard deviation of 24 sub-areas was 0.21 arc-seconds in the east-west and 0.14 arc-seconds in the north-south directions. Fig. 3 shows the distribution of horizontal shift of 24 sub-areas in version 2. The sub-areas only in third column show larger shifts to west.

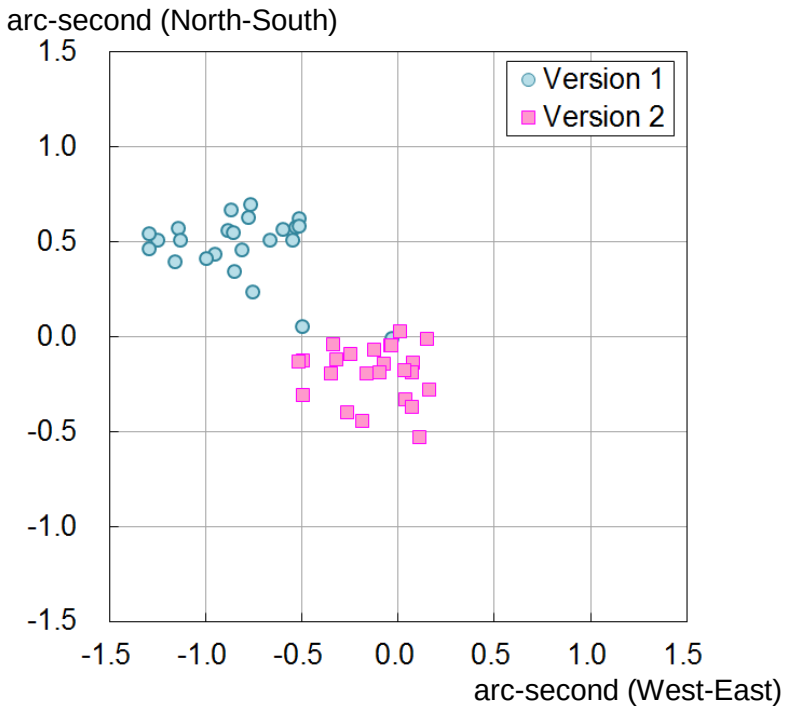

Fig. 2 Horizontal shift

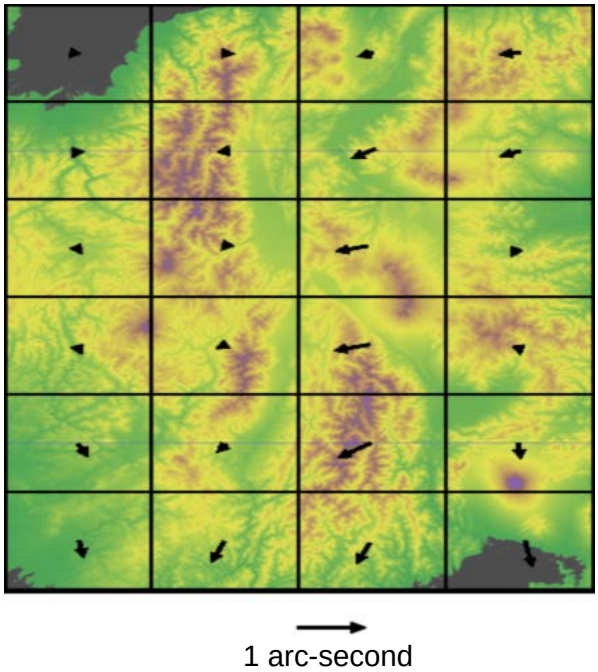

Fig. 3 Horizontal shift distribution in version 2

2. Elevation error

The mean of elevation error in 24 sub-areas ranged from -5.58 to +15.45 m with +7.4 m in average (Fig. 4) and the standard deviation (SD) from 6.20 to 16.19 m with 12.7 m in average (Fig. 5). The plus 7.4 m offset of the mean results from a forest coverage in which GDEM shows the elevation of treetop but reference DEM shows the elevation of ground.

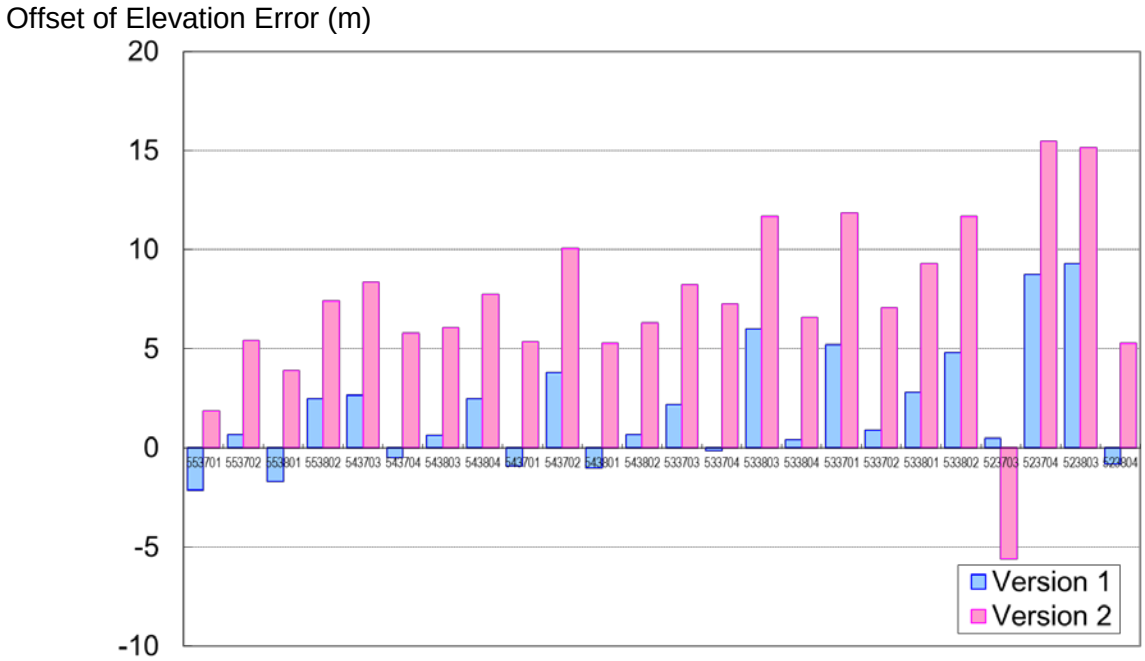

Fig.4 Offset of elevation error

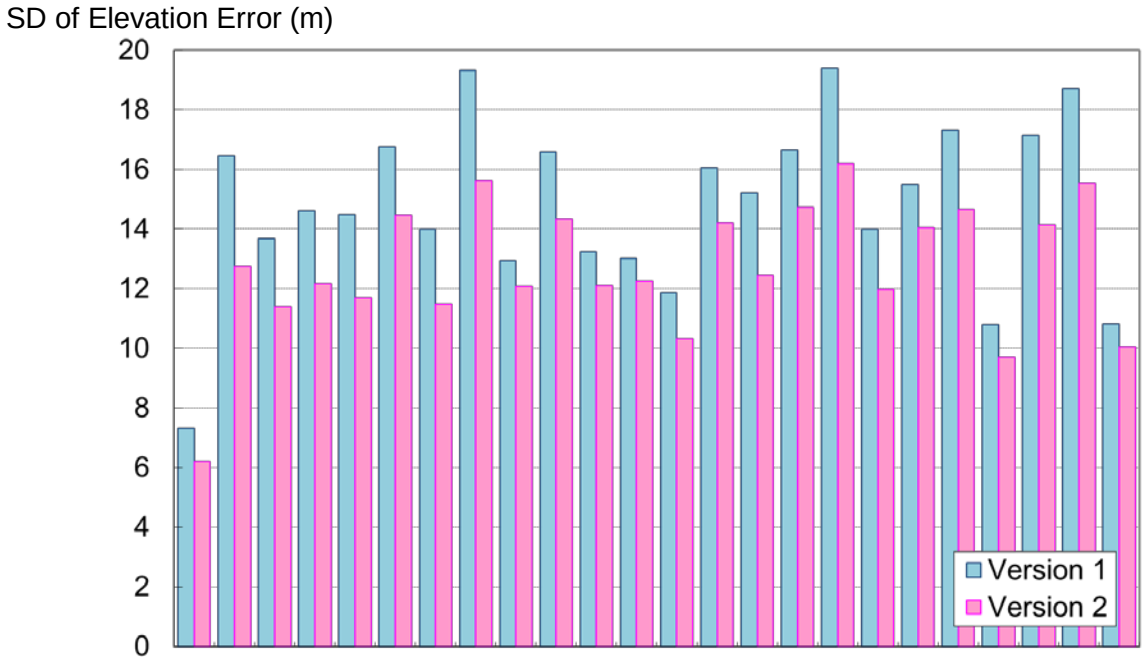

Fig.5 Standard deviation of elevation error

Elevation offset estimation by using land coverage

Validation method

The land cover data of Japan is provided in “Subdivision Land Use Data of Digital National Land Information” produced by the Geographical Survey Institute, Japan.
This 100m-grid land cover dataset is derived from satellite, aerial photos and field measurements. The latest version was released in 2007. Eleven land cover categories used in the 2007 version are shown in Table 3.

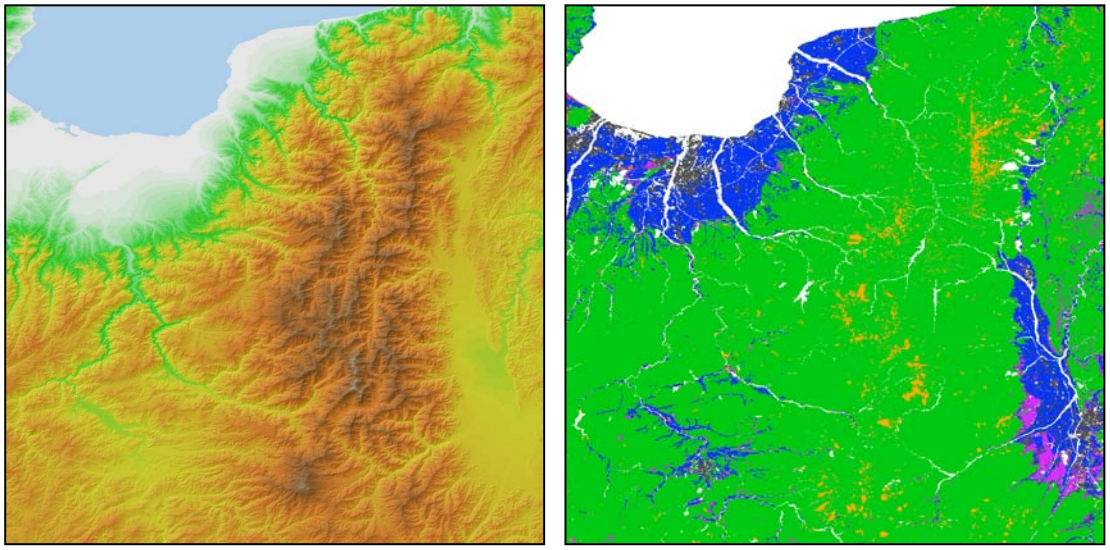

Fig. 6 Land use mapping
(Left: Colored relief image / Right: Land use mapping)

Table 3 Land use categories

	Land Cover	Comment
	Rice Farm	Rice Field
	Farm	Wheat, Vegetable, Meadow, Tea, Orchard,
	Forest	Forest,
	Bare	These “Land Use” occupy only small area and they are out of this work.
	Urban	
	Road/Railway	
	Others	
	River/Lake	
	Beach	
	Sea	
	Golf Course	

The dataset is in a unique XML format called the Japan Profile for Geographic Information Standards (JPGIS). A specialized tool for shape format conversion is available. In this validation, 1 arc-second grid data having the same format as GDEM were obtained by preprocessing that involved conversion to shape format and change to ellipsoidal projection

followed by transformation into raster format. Then, land cover types 4-11 were excluded because of very limited distribution in this area, and error derived from GSI 10m DEM was statistically analyzed for each area corresponding to Rice Farm, Farm, and Forest. Especially Rice Farm is useful for estimation of offset because rice plant is short and shows elevation of ground surface in GDEM. N36E137, the quarter of above validation, is used as target area.

Validation result

The residual histogram and statistics in three ground cover type are shown in Fig. 7 and Table 4, respectively. While the open areas such as rice farm show little offset, forest covered area shows plus offset. Forest is located in steep mountainous area but rice farm is located in plain area. Therefore, the standard deviation and RMSE are high in forest and low in rice farm. The rice farm shows smooth Gaussian curve with the peak located at -0.7 m which indicates the offset of GDEM version 2.

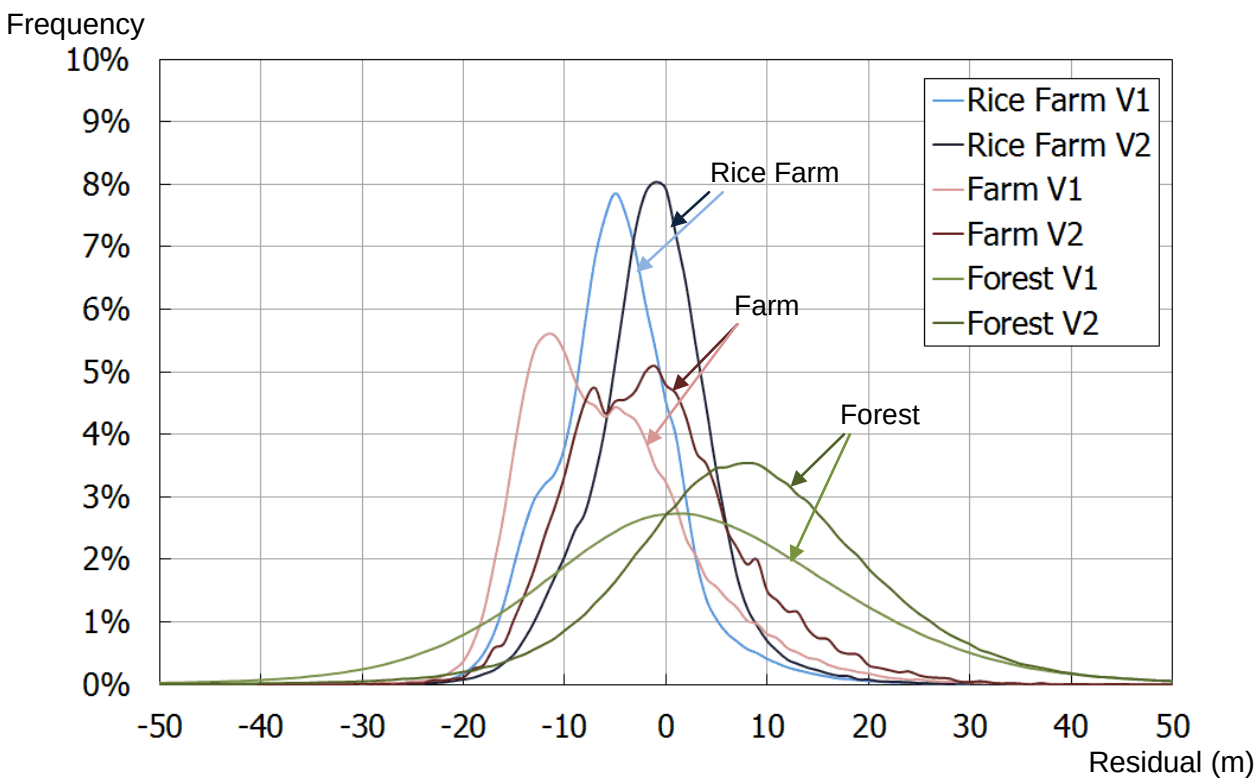

Fig.7 Residual histogram of each ground coverage

Table 4 Statistics of each ground cover type

Version 2	Mean	Peak	SD	RMSE
Rice Farm	-1.32	-0.74	5.91	6.06
Farm	-1.09	-1.23	8.50	8.57
Forest	+8.68	+7.98	13.26	15.85

Horizontal resolution estimation

Fig. 8 shows the shaded relief images of GDEM versions 1 and 2 over the same area. Resolution is higher and topographic features are more clearly depicted in version 2. Quantitative resolution was then estimated as described below.

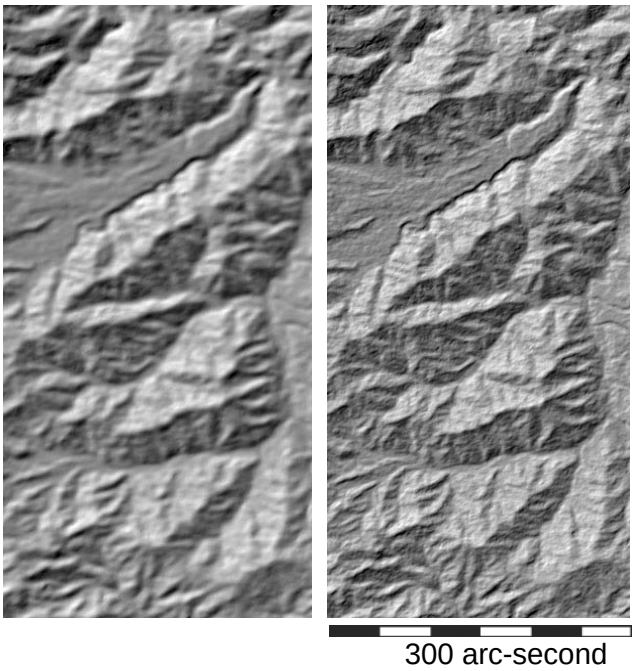

Fig.8 Comparison of shaded relief between version 1 and 2
(Left: Ver.1 / Right: Ver.2)

<u>Validation method</u>

DEMs with nine different resolutions, from 1 arc-second to 9 arc-second (Fig. 9), were created from the reference GSI 10 m DEM. The standard deviations of the elevation difference between GDEM and nine each resolution DEMs were calculated to determine the DEM showing the lowest standard deviation. The matched DEM resolution represents the practical horizontal resolution of GDEM.

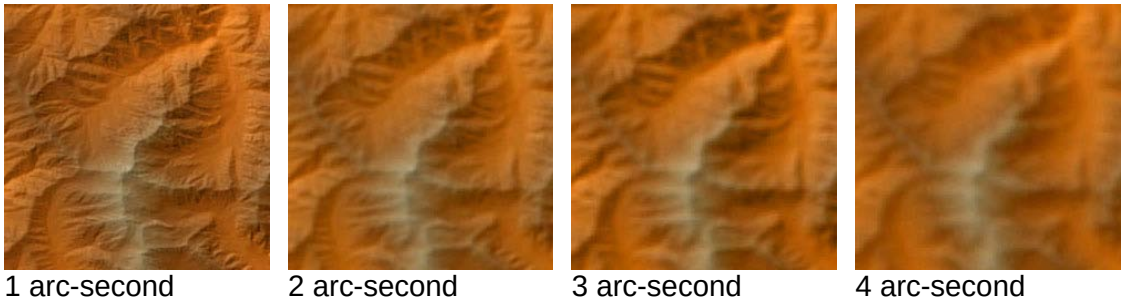

Fig. 9 DEMs with different resolutions

Validation result

Fig.10 shows the standard deviation of elevation difference between the ASTER GDEM and nine different resolution DEMs. Resampling by parabola fitting showed the lowest standard deviation near 2.4 arc-second (72 m, 1 arc-second converted into 30 m). This value is considered to be the practical horizontal resolution of the GDEM version 2. It was demonstrated that the horizontal resolution was much improved in the GDEM version 2 compared to the version 1 with the practical horizontal resolution of 3.8 arc-second (114 m).

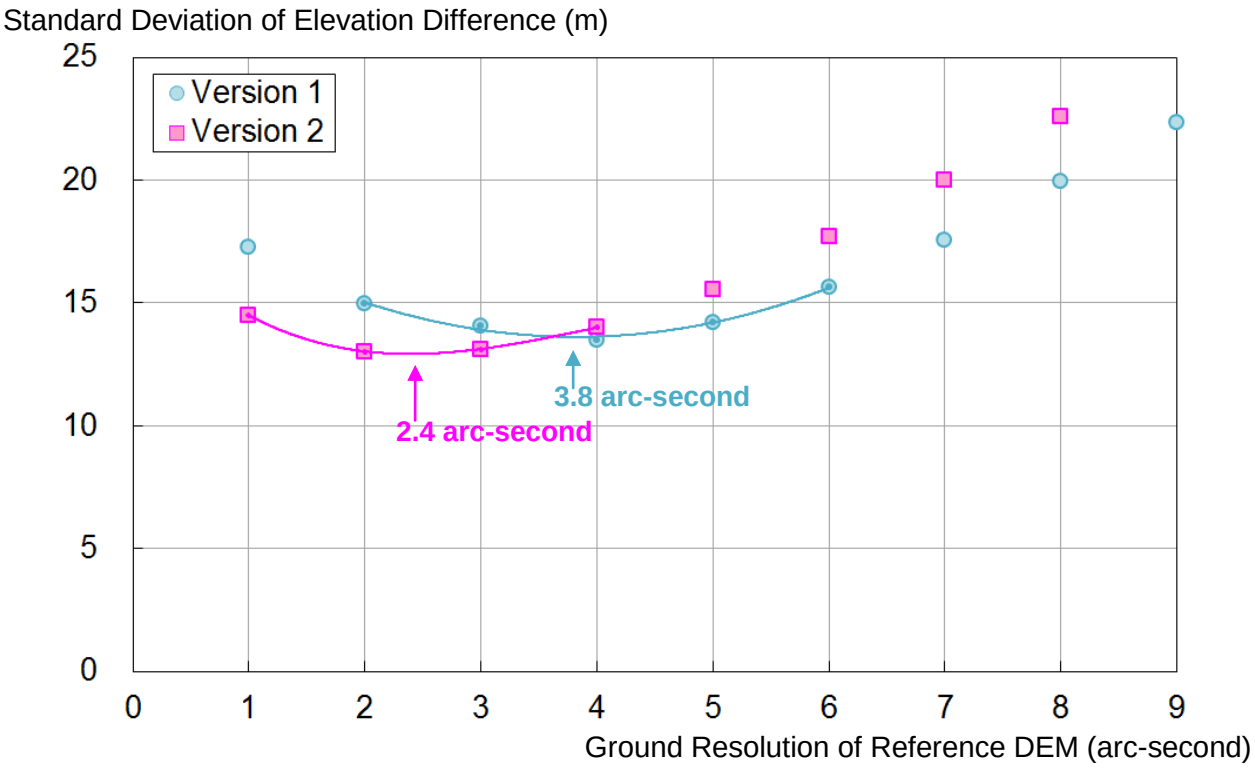

Fig.10 Estimation of practical ground resolution

Voids in northern area

In version 2, the voids and artifacts arising from the lack of ASTER data are expected to be improved as new ASTER data observed after September 2008 are incorporated. Fig. 11 and Fig. 12 show the area north of 60 degrees north latitude. There were many voids resulted from no ASTER observation in version 1 but most of the voids are filled by new ASTER observation in version 2.

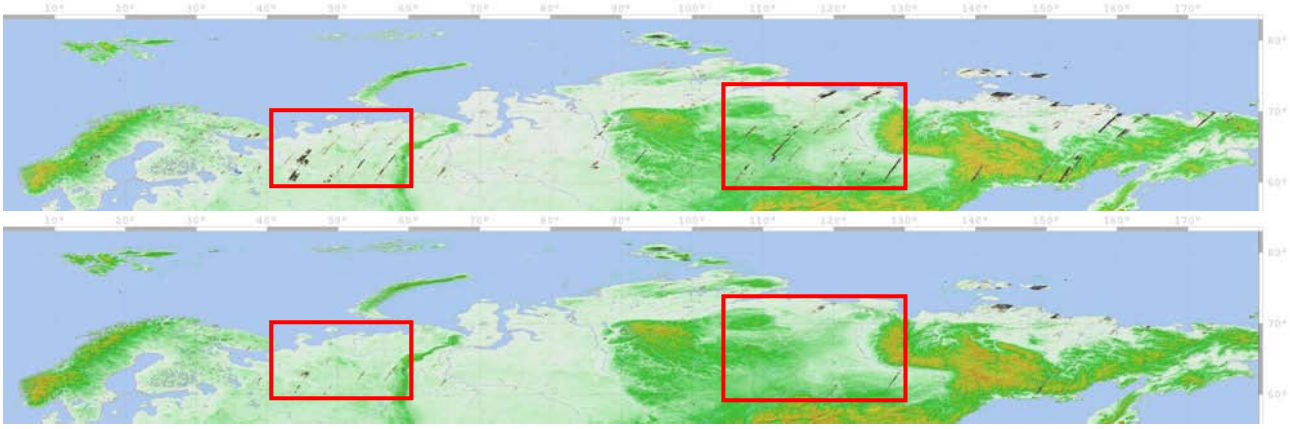

Fig.11 Voids distribution (black color) in northern area
(Upper: Ver.1 / Lower: Ver.2)

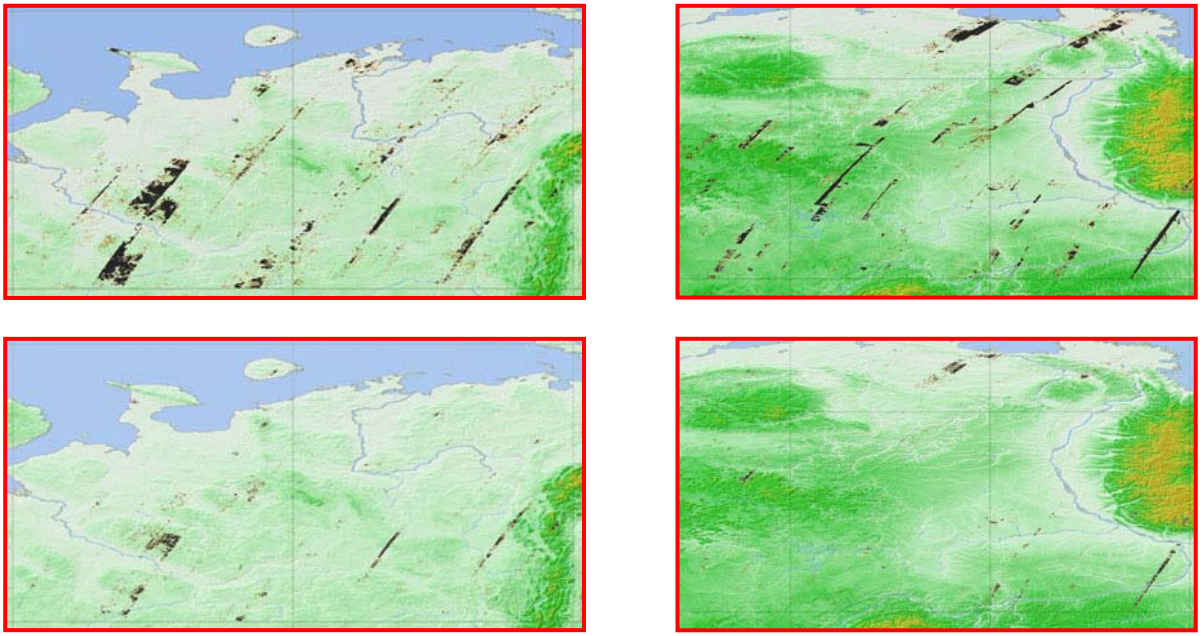

Fig. 12 Voids distribution in northern area (enlargements)
(Upper: Ver.1 / Lower: Ver.2)

Artifacts in few stacking area

ASTER GDEM version 1 contained many artifacts such as linear step, mole-run, pit-in-bump (Fig. 13). These artifacts appear in the regions where ASTER data are lacking and the number of stacks is insufficient. Three areas with insufficient number of stacks in version 1 (S31E023, S32E125, N11W008) were extracted to investigate the artifacts in version 2.

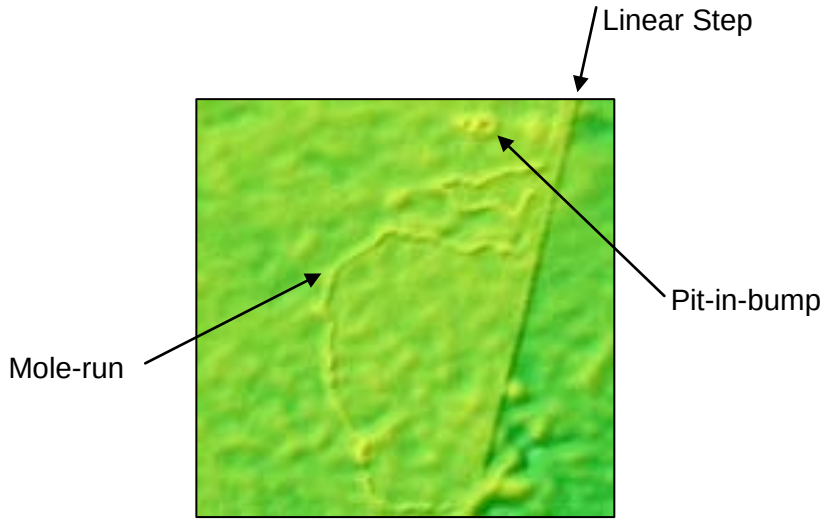

Fig. 13 Artifacts

<u>S31E023 (Fig. 14, 15)</u>
Linear steps are observed in version 1. The number of stacks is very low. Some areas have no ASTER stack scenes and are filled by other data source. After incorporation of new ASTER data in version 2, the stacking number increased to 5 or more and the steps disappeared. Profile shows the steps around 20m in version 1 are completely removed in version 2.

<u>S32E125 (Fig. 16, 17)</u>
Linear steps are observed in version 1. The number of stacks is low and only a few in the areas where linear steps are observed. Even after incorporation of new ASTER data in version 2, the stacking number is 3 at most. The linear steps are less apparent and remain slightly. Profile shows that the height of steps is reduced from approximately 15m to less than 10m.

<u>N11W008 (Fig. 18, 19)</u>
In version 1, there are many artifacts such as mole-run and pit-in-bump. Overall stacking number is low and holes as a result of significantly low stacks are observed. After incorporation of new ASTER data in version 2, all the artifacts are eliminated. Profile also shows the complete disappearance of the artifacts.

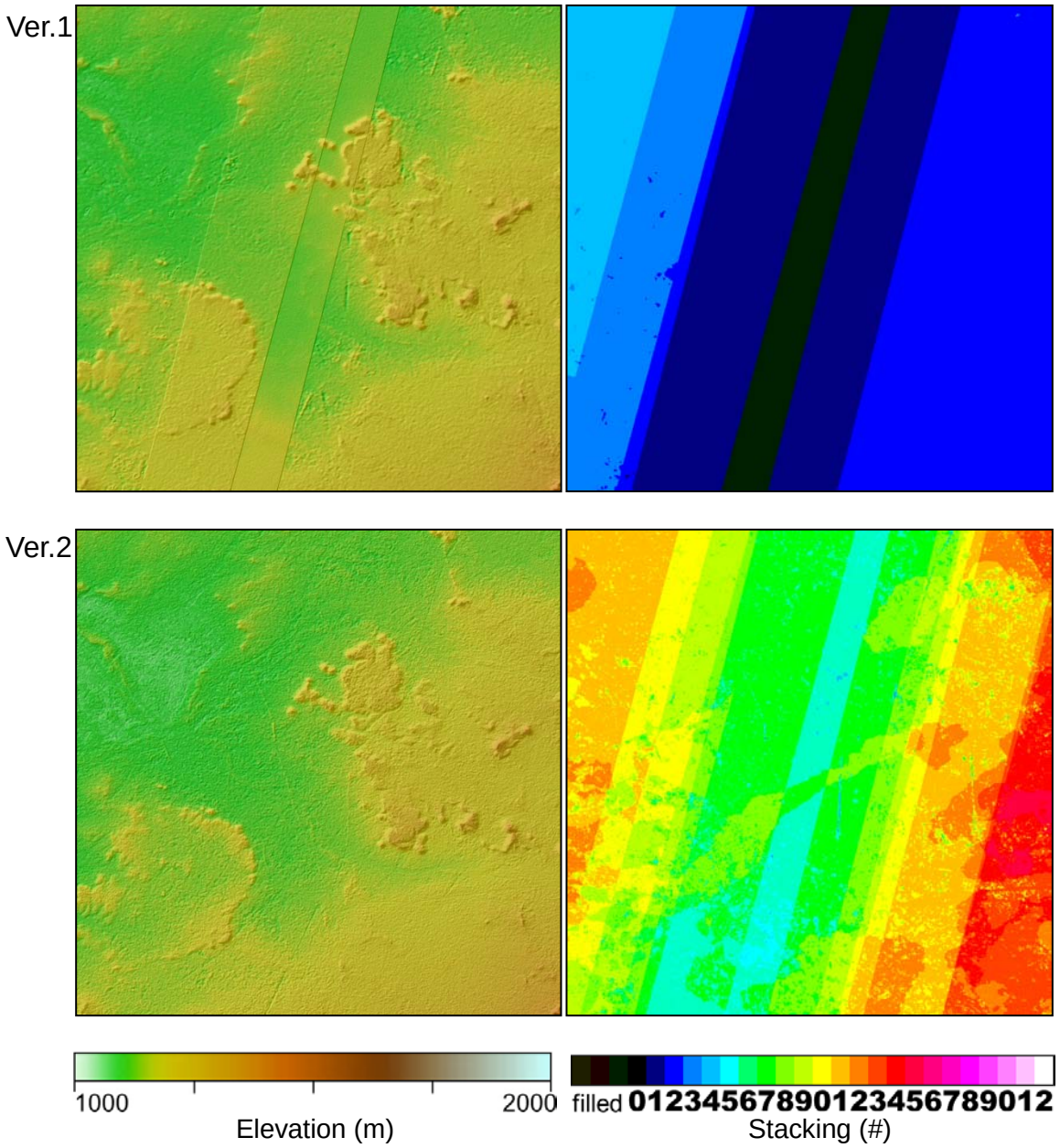

Fig. 14 Elevation and Stacking in S31E023 (Southern Africa)
(Upper: Ver.1 / Lower: Ver.2) (Left: Elevation / Right: Stacking)

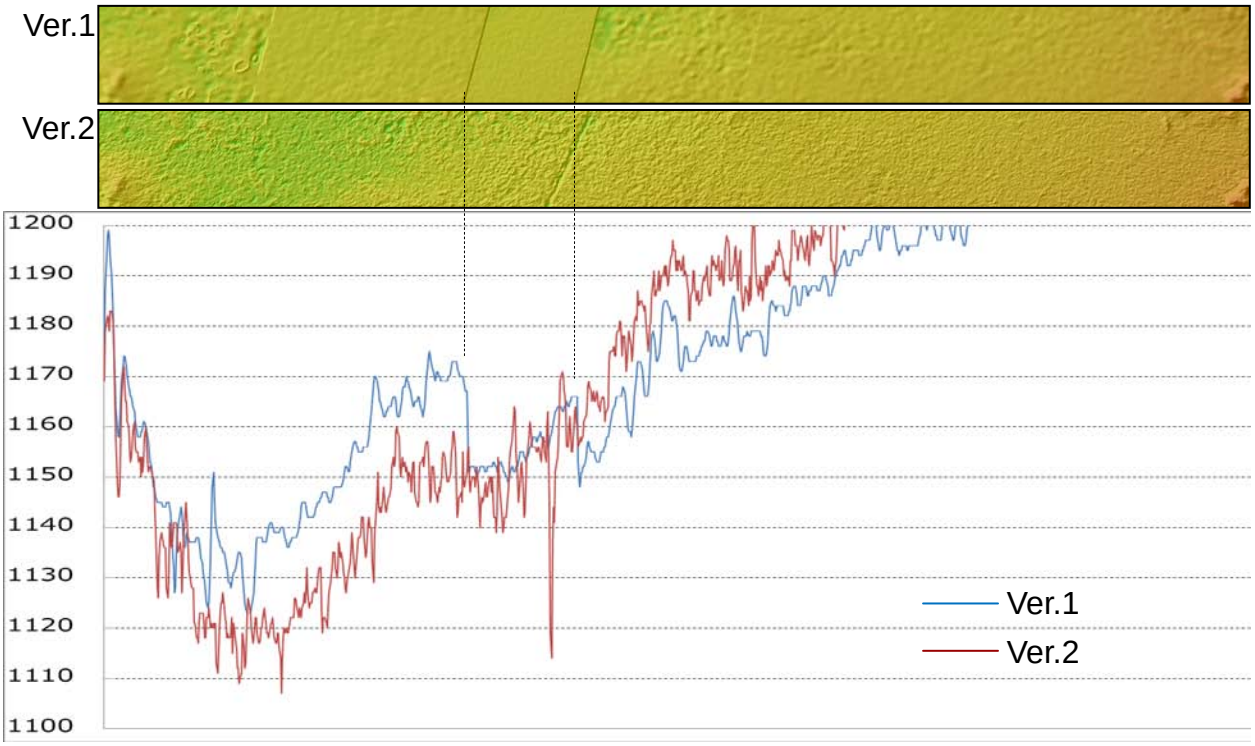

Fig. 15 Profile in S31E023 (Southern Africa)
(Upper: Elevation images of Ver.1 and Ver.2 / Lower: Profile)

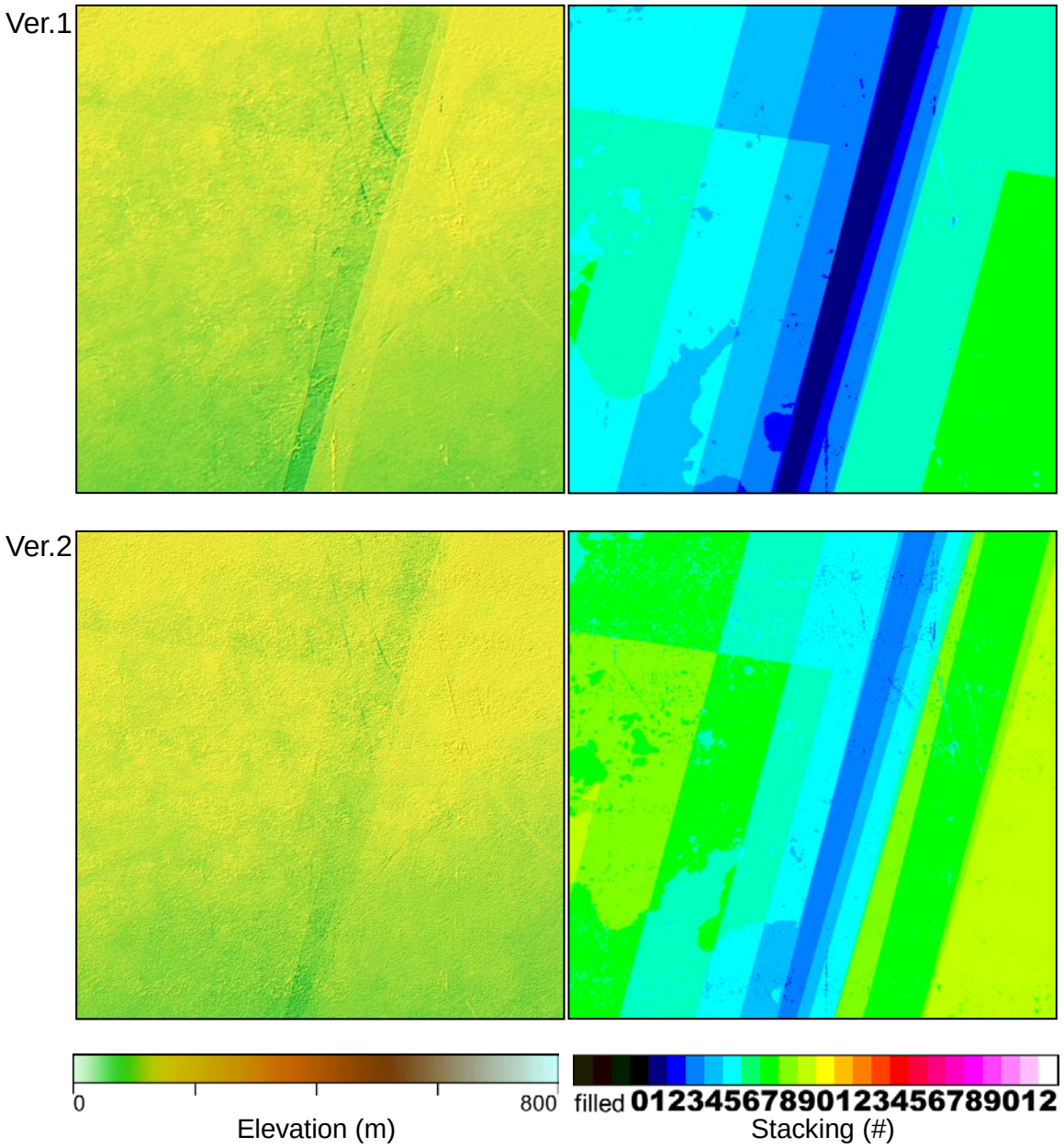

Fig. 16 Elevation and Stacking in S32E125 (Australia)
(Upper: Ver.1 / Lower: Ver.2) (Left: Elevation / Right: Stacking)

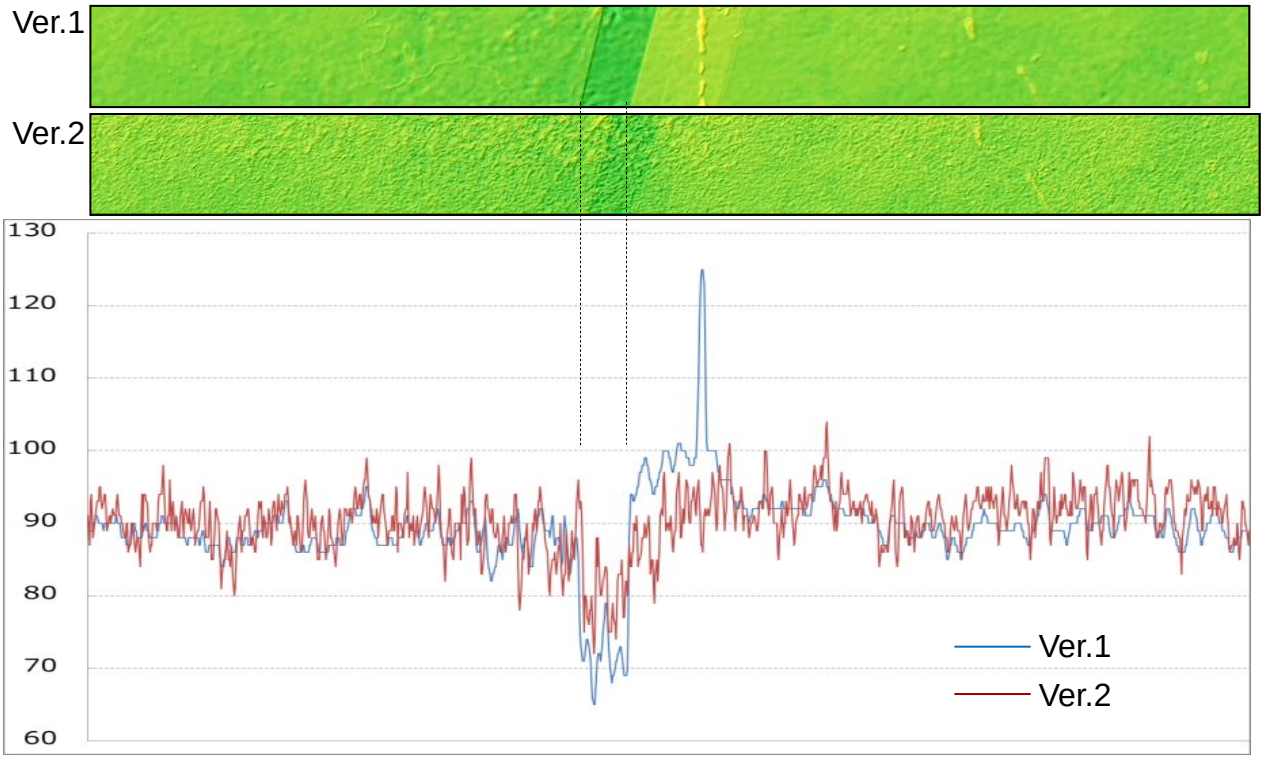

Fig. 17 Profile in S32E125 (Australia)
(Upper: Elevation images of Ver.1 and Ver.2 / Lower: Profile)

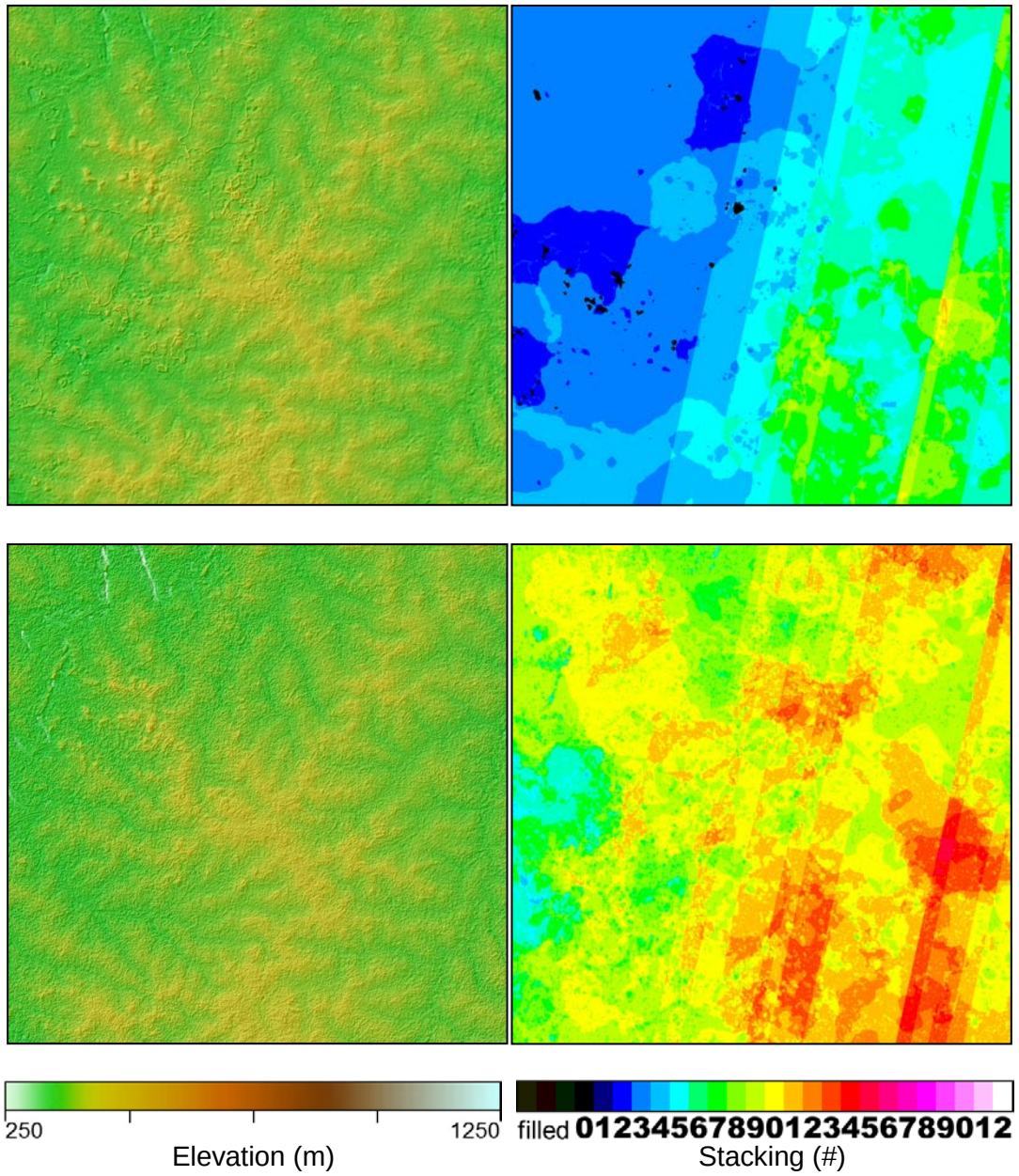

Fig. 18 Elevation and Stacking in N11W008 (Mali/Africa)
(Upper: Ver.1 / Lower: Ver.2) (Left: Elevation / Right: Stacking)

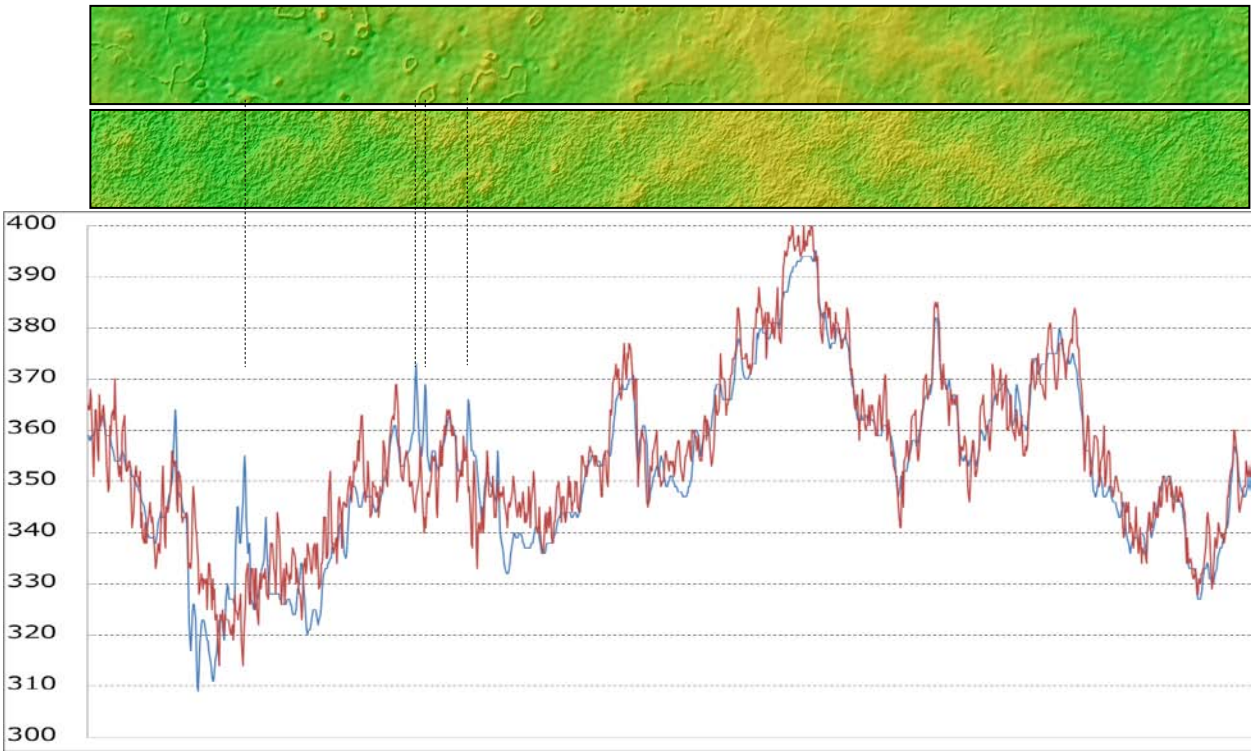

Fig. 19 Profile in N11W008 (Mali/Africa)
(Upper: Elevation images of Ver.1 and Ver.2 / Lower: Profile)

Artifacts in lakes and coastlines

Fig. 20 and Fig. 21 show the west end of Lake Nicaragua. By the new water body detection algorithm of version 2, the lake surface is completely flat and the west shoreline of the lake is successfully mapped.

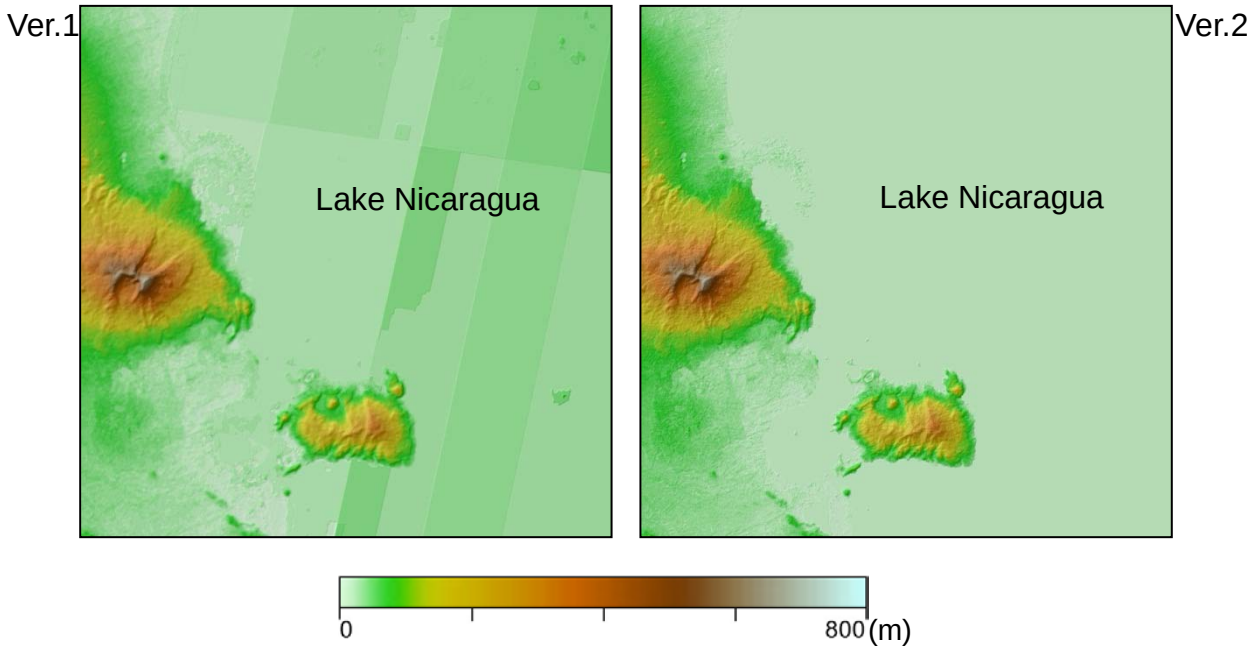

Fig. 20 Elevation in N11W086 (Lake Nicaragua)
(Left: Version 1/ Right: Version 2)

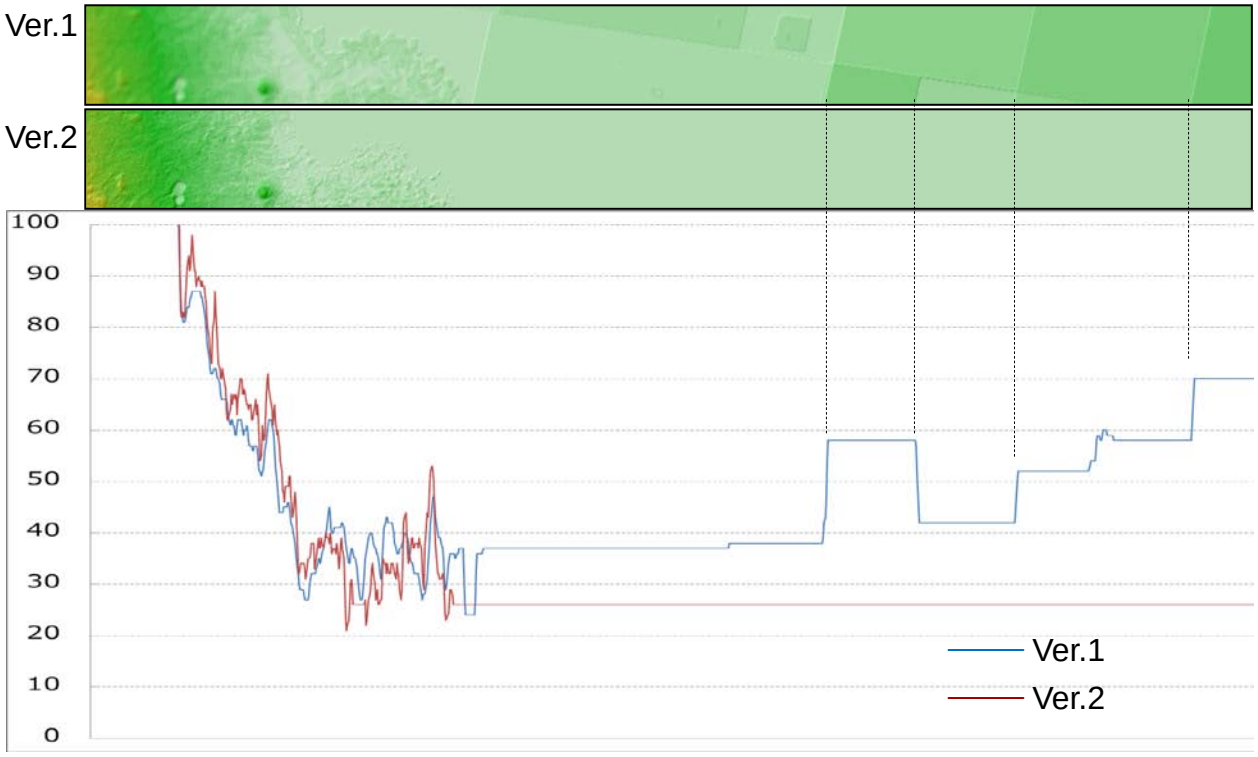

Fig. 21 Profile in N11W086 (Lake Nicaragua)
(Upper: Elevation images of Ver.1 and Ver.2 / Lower: Profile)

Conclusion

The ASTER GDEM version 1 was released in July 2009 and the version 2, now under processing, will be released in the October 2011. The GDEM version 2 is reproduced using the updated algorithm. Validation study of the GDEM version 2 confirmed that elevation offset and horizontal resolution will be greatly improved in GDEM version 2 and the enhanced horizontal resolution will serve to reduce the standard deviation of elevation and horizontal error (Table 5).

Table 5 Validation result of GDEM version 2

			Version 1	Version 2
Horizontal Error			0.82 arc-sec. to west 0.47 arc-sec. to south	0.13 arc-sec. to west 0.19 arc-sec. to north
Elevation Error	Flat and open area (rice farm)	offset	-4.8 m	-0.7 m
		SD	6.2 m	5.9 m
		RMSE	-	6.1 m
	Mountainous area almost covered by forest	offset	+2.2 m	+7.4 m
		SD	15.4 m	12.7 m
		RMSE	-	15.1 m
Horizontal Resolution			3.8 arc-sec. (114m*)	2.4 arc-sec. (72m*)

*1 arc-second corresponds to 30m

There are other improvements obtained from the update of algorithm and addition of new ASTER data.

- ✓ The voids in northern area decrease by new ASTER data.
- ✓ The artifacts mostly disappear by new ASTER data.
- ✓ All lakes are perfectly flat by new water body detection algorithm.

[Extra Content]　Horizontal shift and elevation error estimation in all over Japan

Validation method

The ASTER GDEM version 2 was validated against the 10 m-mesh DEM produced by the Geographical Survey Institute (GSI) of Japan.　The tiles selected for validation study cover all over the Japan except for small islands.

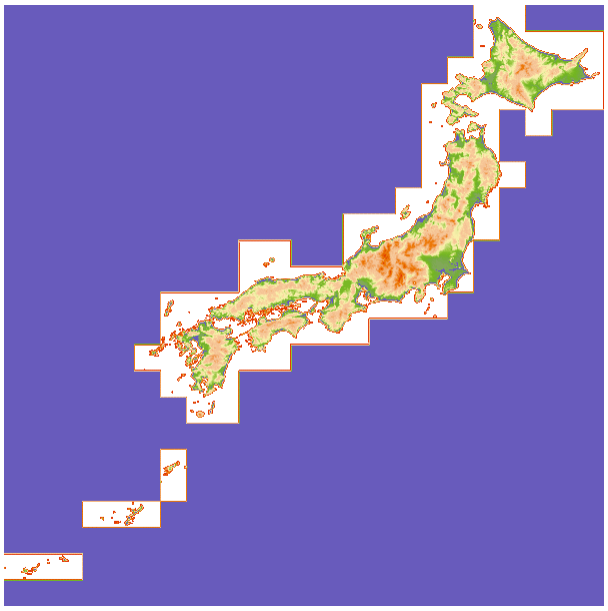

Fig.A1 Target Area.

1. Preprocessing

The GSI 10m DEM are decimated and mosaicked to 1 arc second grid basis, which is the same posting as ASTER GDEM, as shown in Fig. A1.　Since the original GSI DEM adopts XML format, the new 1 arc-second DEM is written in the RAW format.

2. Horizontal shift analysis

Horizontal shifts in the North-South and East-West directions relative to the GSI DEM are detected using normalized cross correlation with 41X41 window size. Image shift at sub-grid level is obtained using parabolic fitting for every grid on 3601X3601.

3. Elevation analysis

Elevation error was calculated by taking the difference between GDEM and GSI 10 m DEM and error map is obtained for every grid on 3601X3601.

Validation result

1. Horizontal shift analysis

Figure A2 shows the horizontal shift map in both directions. Although no pattern is obtained in the NS direction, a periodic pattern is observed in the EW direction, which is oblique to the map and related to the satellite flight path. It should be noted that good correlation is not obtained at the flat area, such as Tokyo and part of Hokkaido areas (shown as black).

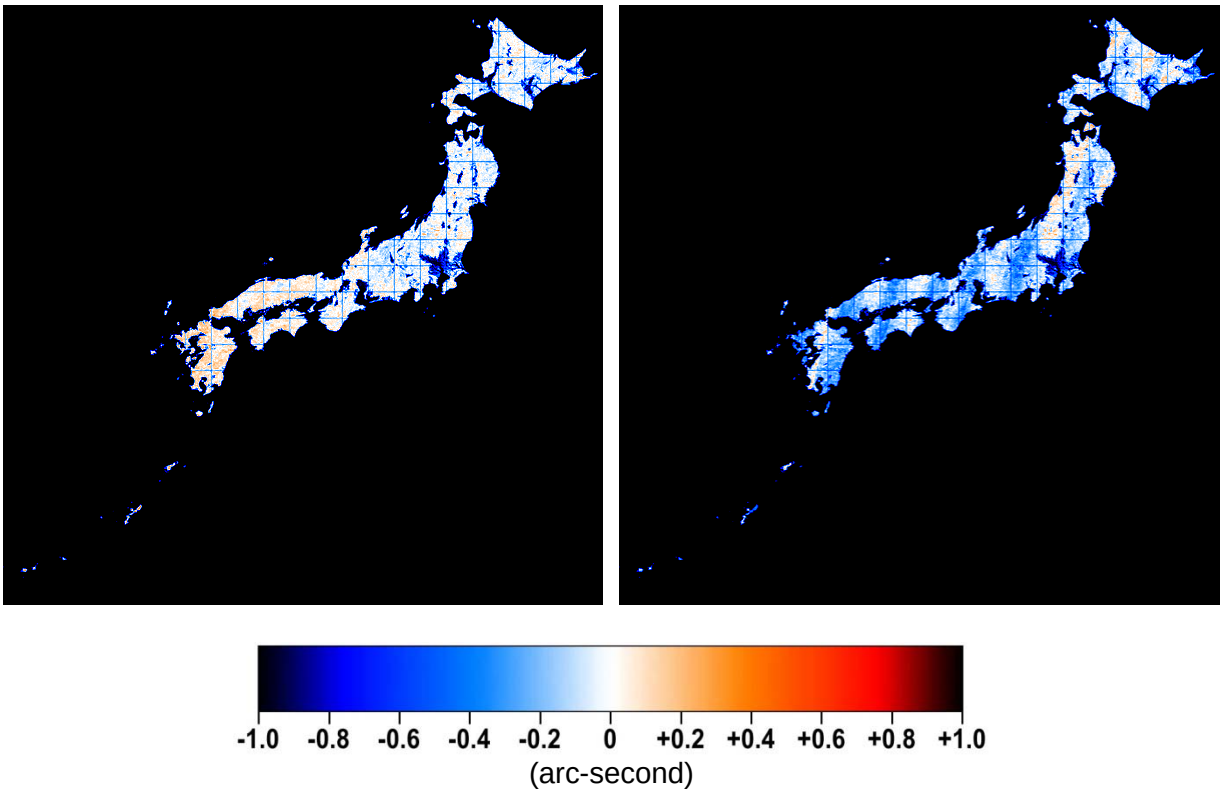

Fig.A2 Horizontal shift pattern maps
(Left: North-South directions, Right: East-West directions).
(The plus means shift to the east and the north.)

2. Elevation analysis

Figure A3 shows the difference in elevation relative to the GSI DEM. The forest covered area shows plus offset. Periodic pattern is also observed, particularly in Hokkaido Area, is related to the horizontal shift in the EW direction.
These results show that there remain some systematic errors in ASTER GDEM, which may be corrected based on the analysis for more accurate DEM in the future version.

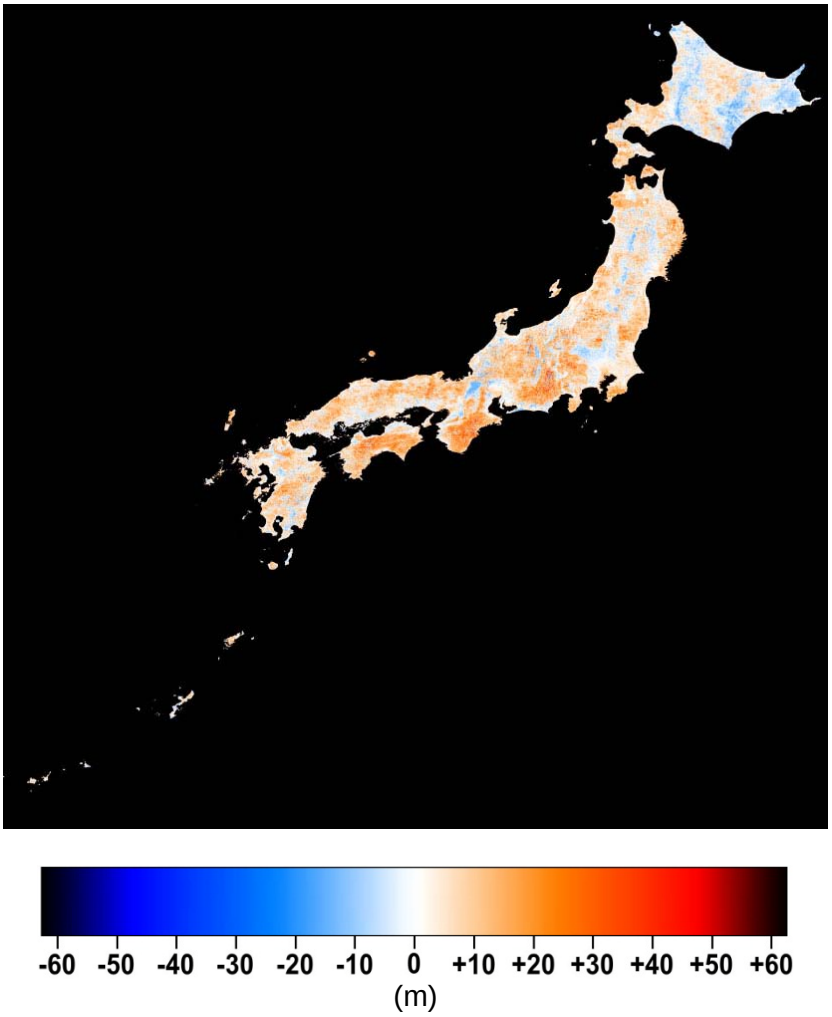

Fig.A3 Elevation error map.