

BUILDING A CONSISTENT GEOMETRIC FRAME OVER SPARSE ISLANDS USING SPOT 5 DATA

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ABSTRACT:

Operating in panchromatic mode onboard SPOT 5, the HRS instrument has two telescopes, one pointing forward and one aft of the satellite. HRS is thus able to cover an area of 600 km x 120 km in a single pass (i.e. 72 000 km² stereoscopic strips). Moreover, the extremely precise ancillary metadata of SPOT 5 allows accurate geometric processing with no ground control points. Thus SPOT 5 stereoscopic imagery becomes one of main satellite data sources for accurate DEM extraction as well as for building a common geometric frame over large areas. Spot Image and French National Cartographic Institute (IGN) decided in 2002 to design and build a worldwide accurate database called Reference3D™ using HRS data. This database consists of three information layers: Digital Elevation Model at 1-arc-second resolution (DTED level 2), Orthoimage at 5m resolution and Quality Masks. The production process aiming at drastic accuracy requirements (circular horizontal accuracy better than 16m and elevation accuracy better than 10m for 90% of the points), is therefore rather complex. Huge efforts have been made to standardize the production process in order to offer attractive delivery times and affordable prices. As of June 30th 2008, the Reference3D database will cover more than 30 million km². Technically speaking, the above-mentioned accuracy requirements, achieved without any control points nor map support, would have been regarded as a totally utopian goal by the whole mapping community even one decade ago. However, the dramatic progression of space-photogrammetry techniques in the recent years really allows the challenge to be overcome, as shown by scientific assessments of the Reference3D products performed by independent users. The 1st part of the paper will summarize the most significant assessments performed by major players within the geospatial community. The large 120km swath of HRS is particularly helpful over maritime areas populated by sparse islands, where achieving a global consistent frame is really challenging. To confirm this ability, ImageONE Co., Ltd. performed accuracy assessment on two Reference3D geocells over sparse islands located off-shore the Northern coast of Japan. The production area also includes a portion of Hokkaido province. The paper will then focus on the assessment performed by ImageONE Co., Ltd. comparing Reference3D against digital map and National DEM from the Geographical Survey Institute (GSI), government of Japan. In conclusion, the assessments show that the 120km swath of HRS is a very powerful tool to build highly consistent frame over areas that were once very difficult to map with a good relative accuracy.

1. INTRODUCTION

The Reference3D is a world wide accurate DEM data base generated from HRS sensor on board SPOT 5 without any ground control points. Some assessments performed world wide showed that the Reference3D met its standard specifications. Two most significant assessments are presented in this paper, one comparing against STRM DEM, another comparing against geodetic points of network and nation-wide DTM. In last year, twelve Reference3D tiles over Japan became available. This paper will focus on the assessment of DEM of two Reference3D tiles performed by ImageONE Co., Ltd. comparing against a set of points of Japan Triangulation Network and National DEM of GSI. The horizontal accuracy assessment of the orthoimage from the same Reference3D tiles will also be presented in this paper.

2. THE REFERENCE3D

The Reference3D is designed and built by Spot Image and French National Cartographic Institute (IGN) using HRS data. This world wide data base consists of three information layers:

Digital Elevation Model of 1-arc-second resolution (DTED level 2), orthoimage of 5m resolution and Quality Masks.

The DEM layer absolute requirements are:

- horizontal circular absolute accuracy of 15m at 90%
- vertical absolute accuracy depending on the slope:
 - 10m at 90% for slopes lower than 20 degrees
 - 18m at 90% for slopes between 20 degrees and 40 degrees
 - 30m at 90% for slopes greater than 40 degrees

The orthoimage layer absolute horizontal accuracy is 16m (circular error for 90% of the points). The Reference3D product is delivered as a geographic tile of 1 degree by 1 degree with a raster DEM data set of 3601 x 3601 cells.

3. MAJOR ASSESSMENT OF THE REFERENCE3D

Several accuracy assessments of the Reference3D products have been performed at international level by independent users. The results showed that the Reference3D product met all its

specifications. We would like to present two results of the assessments.

An across evaluation of the SRTM and the Reference3D was conducted by NGA and IGN (Bouillon et al., 2006). Table 1 shows the full compatibility of SRTM DTED level 2 and the Reference3D products over various landscapes, from very flat desert areas up to very high mountain areas.

Cell #	landscape	Figures @ 90 % (m)			
		Min	Max	Mean	Std. Dev
e035n29	high relief	-5	15	4.4	4.0
e035n33	high relief	-10	4	-2.7	3.0
e048n32	flat + relief	-21	1	-7.3	4.4
	high relief	-27	3	-9.4	6.0
	flat terrain	-9	-1	-5.3	2.0
e049n30	flat + relief	-6	5	-0.4	2.4
	high relief	-5	4	-0.5	2.2
	flat terrain	-10	7	-0.5	3.7
e033n30	medium relief	-6	10	3.7	3.3
e032n30	medium relief	-6	11	1.5	3.7
e047n30	flat terrain	-9	-1	-4.6	1.9
e048n29	flat terrain	-12	-1	-6.7	2.5
e048n30	flat terrain	-10	1	-5.5	2.2

Table 1. Cross evaluation of SRTM and the Reference3D

Figure 1 is another evaluation of the Reference3D performed by Joint Research Center Ispra (JRC) and FÖMI (Kay, Winkler, 2004). One important feature of this evaluation is the detailed evaluations of the elevation accuracy, through segmented classes describing i) the local slope (10 degree, 20 degree and 40 degree thresholds) and ii) the land use (agriculture, forest, urban). All of them confirmed that the Reference3D accuracy specifications were met at each slope class.

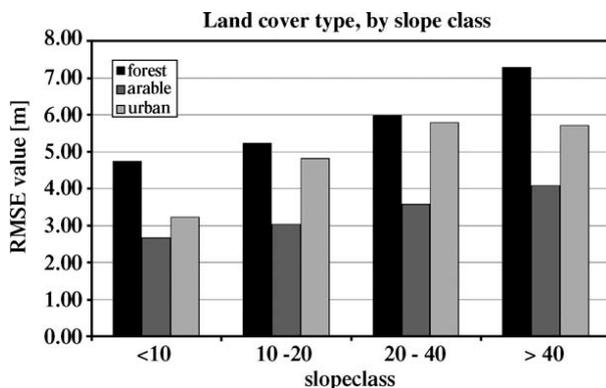


Figure 1. Elevation accuracy of the Reference3D, displayed for difference classes of slopes and land uses (from Kay, Winkler, 2004)

4. ASSESSMENT OF THE REFERENCE3D TILES OVER HOKKAIDO PROVINCE IN JAPAN

4.1 Assessment region

The assessment region is located in the east of Hokkaido province. Two Reference3D tiles (N43E144 and N43E145) cover the region from 144-degree E to 146-degree E longitude and from 43-degree N to 44-degree N latitude (Figure 2). The region includes mountains with maximum elevation 1400m, volcano, lakes, agricultural land use, and sparse islands. In most part of the mountains, the slopes are between 20 degrees and 40 degrees, and the maximum slope of the mountains is more than 50 degrees.

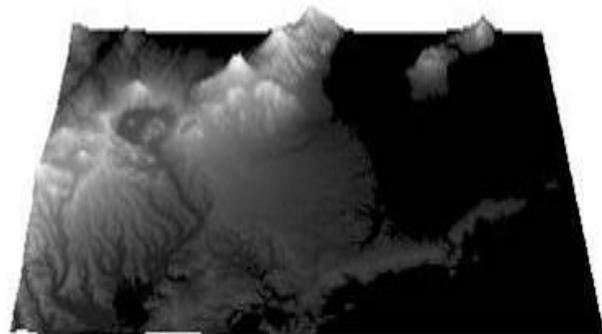


Figure 2. DEM layer of the Reference3D of the assessment region (two adjacent Reference3D geocells)

4.2 Assessment method of the DEM layer

Two reference DEM data sets are used for this assessment. One is a set of 2207 points from Japan Triangulation Network maintained by GSI. These points have very high cm-level horizontal and vertical accuracies maintained by the following procedures: each point of this triangulation network is checked from time to time, and if its errors in X, Y and Z are over their thresholds (10 cm in X, Y and 20 cm in Z), then the data of that point will be corrected by on-site survey.

Another is a raster data set of 50m mesh DEM produced by GSI from the contours of GSI topographic map (1:25,000), and the standard deviation of the contours of the GSI topographic map is 5m. Additional error might be introduced during the generation of the DEM raster data from the topographic map. So the vertical accuracy of the GSI 50m mesh DEM is no better than STDEV 5m. The GSI 50m mesh DEM is provided in Tokyo Datum geodetic system with pixel spacings of 2.25 seconds in longitude and 1.5 seconds in latitude, corresponding to approximately 50m.

To assess the Reference3D, the Reference3D DEM was superimposed on the reference DEM data sets. Since the Reference3D and the reference DEM data sets have different geodetic system and different raster cell size, bilinear interpolation was used to derive elevations from the Reference3D tiles for comparison. Using the differences between the elevations derived from the Reference3D DEM and the reference data sets, the standard deviations, mean values, maximum and minimum values were calculated. The linear errors at the 90% confidence level were calculated to assess the accuracy of the Reference3D.

4.3 Assessment result of the DEM layer

Assessment against Japan Triangulation Network: There is a triangulation network in Japan providing a set of geographically accurate points for survey, mapping and so on. Various attributes such as longitude, latitude and elevation of these points are freely available through a web service from GSI. The latitudes, longitudes and elevations of the 2207 points of the triangulation network in the assessment area were manually extracted from the web service and used as one reference data set to assess the two Reference3D tiles (Figure 3). The black dots in higher elevation area and white dots in lower elevation area (Figure 3) indicate the positions of the points used.

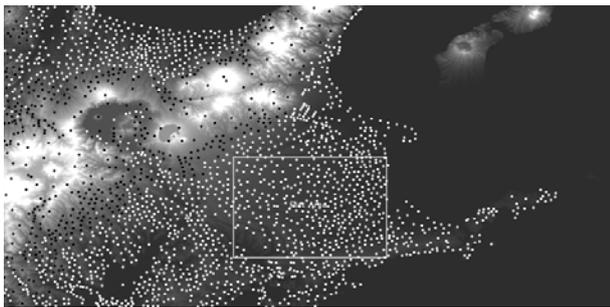


Figure 3. Points of Japan Triangulation Network over DEM layer of the two Reference3D tiles (N43E144, N43E145)

Because the points of the triangulation network are not aligned with the grid vertices of the Reference3D, an interpolation is necessary to superimpose the two data sets. The elevation of each point of the triangulation network was kept unchanged, and the correspondent value of the Reference3D at the point location was calculated by bilinear interpolation of four vertices of the Reference3D grid enclosing the point. The elevation difference was calculated for each point, then from those differences, standard deviation and mean value were calculated (Table 2a).

	Whole area	Flat area
Mean (m)	-2.2	-1.7
STDEV (m)	5.3	1.9
Max (m)	11.7	3.3
Min (m)	-91.7	-8.3
LE90 (m)	6.7	4.1

Table 2a. the Reference3D compared against Japanese Triangulation Network: general statistics

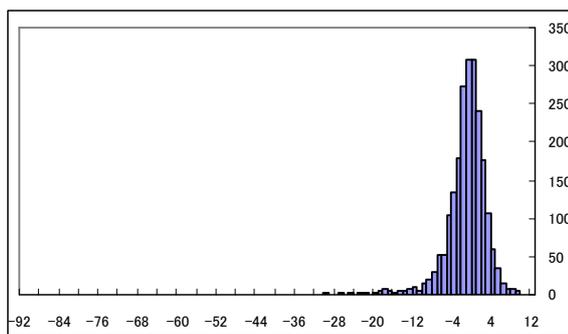


Figure 4. The histogram of the elevation differences between Reference3D and the Japan Triangulation Network

To confirm the specification of the Reference3D, the linear error at 90% confidence level was also calculated (Table 2a). An agricultural area of low slope was separately assessed (area within the white rectangle in the Figure 3) and the result is also shown in table 2a. The histogram of the whole area is shown in Figure 4. Difference intervals were summarized in table 2b.

Difference intervals	Whole area 2,207 points	Flat area 367 points
-5 / +5m	85.5%	98.4%
-10 / +10m	96.6%	100%
-15 / +15m	98.3%	100%
-20 / +20m	99.0%	100%

Table 2b. the Reference3D compared against Japan Triangulation Network: error intervals

The difference intervals (Table 2b) show that the difference for 99% of the points over the whole assessed area is less than 20m. In the flat area, the difference is less than 5m for more than 98% of the points.

Unfortunately there are very few points in the mountain area (white part of Figure 3) so we did not assess mountain area alone. There is no point of the triangulation network over the two islands within the assessment area, so no assessment was done for the two islands.

Cross evaluation between Reference3D DEM layer and GSI DEM:

To superimpose the two raster data sets of the Reference3D (30m mesh, WGS-84) and GSI DEM (50m mesh, Tokyo Datum), the common raster cell size, geodetic coordinate system and matrix size (number of rows and columns) are prerequisites. Therefore, at the beginning of this assessment, the Reference3D DEM raster data was transformed to the geodetic coordinate system of GSI DEM (Tokyo Datum) through the sophisticated software (ENVI), and a bilinear interpolation approach was used to resample the Reference3D DEM to the same raster cell size and matrix size. Then by superimposition of the corresponding samples, the difference between the two DEMs was calculated as "Reference3D DEM - GSI DEM" (see histogram in Figure 5).

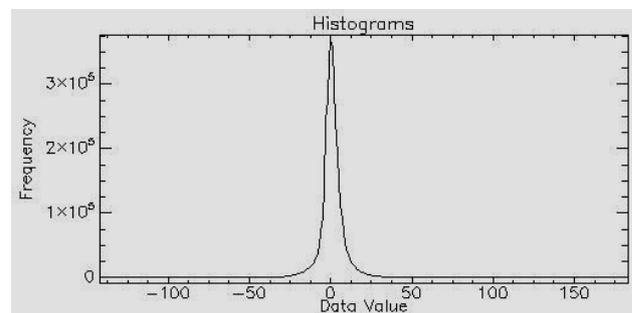


Figure 5. Histogram of the elevation differences between the Reference3D and GSI (whole area)

From those differences, standard deviation and mean values were calculated for tiles N43E144 and N43E145 as shown in Table 3a. The Table also includes LE 90% as well as maximum and minimum differences for reference. The cell with elevation

value 0 in both Reference3D and GSI DEM were masked out during the statistic calculation. The two islands in tile N43E145 were masked out because there was no reference DEM available from GSI DEM.

	N43E144			N43E145
	Whole	area 1	area 2	
Mean (m)	0.8	0.3	-0.2	0.3
STDEV (m)	7.1	10.5	2.3	4.9
Min (m)	-142	-142	-23	-71
Max (m)	183	183	21	54
LE90 (m)	11	16	4	7

Table 3a. Reference3D compared against DEM of GSI

Two typical areas with different slopes in tile N43E144 were selected for detail assessment (Figure 6). Area 1 is a mountain area with a complex terrain including mountains, lakes and ravines and some locations have steep slopes (more than 50 degrees) that associate with worse elevation accuracy. Area 2 is agricultural land of low slopes (less than 20 degrees) that associate with better elevation accuracy (Table 3a).

The difference intervals (Table 3b) show that the differences for over 93% of the cell in the mountain area are globally within 20m range, to be compared against the 10m / 18m / 30m specification of Reference3D along slopes.

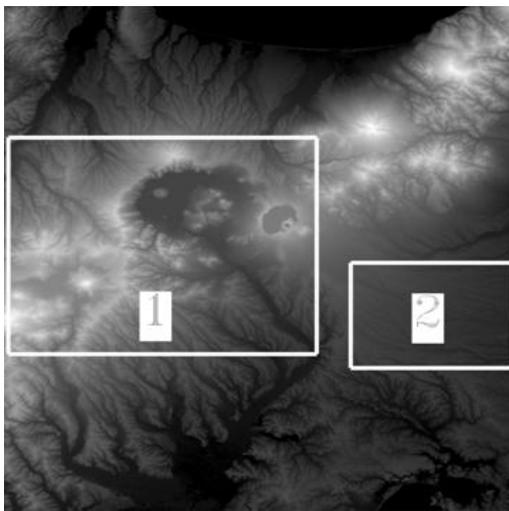


Figure 6. area 1 (mountain) and area 2 (flat)

Difference intervals	N43E144			N43E145
	Whole	Area 1	Area 2	
-5 / +5m	73.6%	53.9%	97.6%	83.6%
-10 / +10m	89.7%	76.2%	99.9%	95.6%
-15 / +15m	95.2%	87.7%	100.0%	98.3%
-20 / +20m	97.7%	93.7%	100.0%	99.3%

Table 3b. Reference3D compared against DEM of GSI.

Note that Area 1 is very steep (max slope > 50 degrees)

4.4 Qualitative analysis

The maximum difference occurred in a steep relief. A detail check was done for the places with maximum and minimum difference (183m and -142 m) between the two DEM by comparing their horizontal profiles (white lines in Figure 7).



Figure 7. Profile positions (white lines) of maximum and minimum difference

Figure 7 shows that the largest errors arise over steep volcano slopes. The elevations of Reference3D and GSI DEM cross the profiles (white lines in Figure 7) are depicted in Figure 8 (Max error profile) and Figure 9 (Min error profile).

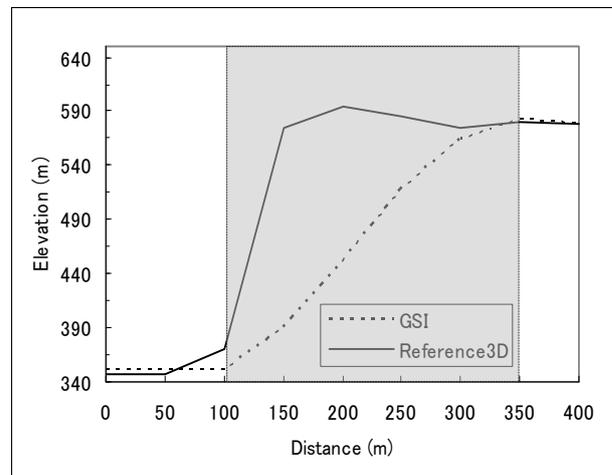


Figure 8. Profile of the place with maximum positive difference: 183m over the shore of a volcanic lake gray zone: the MQU mask

It is interesting to note that Figure 8 shows that the maximum difference occurs over a steep slope that is depicted as regular by GSI DEM, whereas Reference3D shows more details. The affected area shows a 250m elevation difference within a very short distance, about 200m long, ie 4 GSI posting values only.

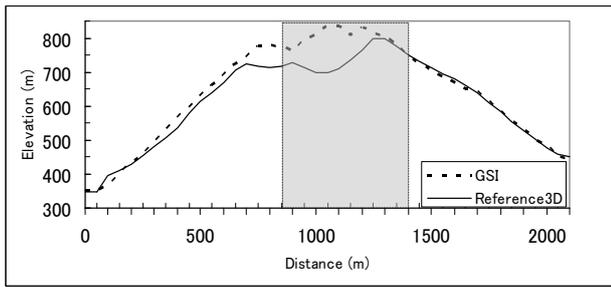


Figure 9. Profile of the place with maximum negative difference: 142m at the top of the volcano.
gray zone : MQU mask

These errors can be interpreted in several ways:

1. either an effective modification of the relief since the GSI data were acquired ,
2. or an artefact within Reference3D,
3. or an artefact within the GSI DEM,
4. or an interpolation or smoothing effect in either DEM,
5. or any combination of the above.

The best way to know the exact reason for these errors would be to compute the DEM from a 3rd source, or to perform field works. However, as mentioned above, Reference3D includes a set of Quality Masks which give information about the quality of the DEM. One of the masks, named MQU, shows the reliability of the elevation given by the Reference3D DEM, as seen by the producer himself at the end of the production chain.



Figure 10. Reference3D Reliability Mask over the maximum error areas (black areas)

MQU masks (black zone in Figure 10) shows that artefacts were suspected by IGN over the minimum and maximum error areas. The gray zones in Figure 8 and 9 represent MQU masks over the two profile lines and suggest that the elevation values within the gray zones of Figure 8 and 9 have less reliability. Therefore the most probable causes should be #2 or #5 in the above list.

4.5 Horizontal accuracy assessment of the orthoimage

To assess the horizontal accuracy of the orthoimage, a preliminary check was done for the two Reference3D tiles. Because the small land coverage and snow over the islands in tile N43E145, the horizontal accuracy of the orthoimage was only assessed for the tile N43E144 (Figure 11).

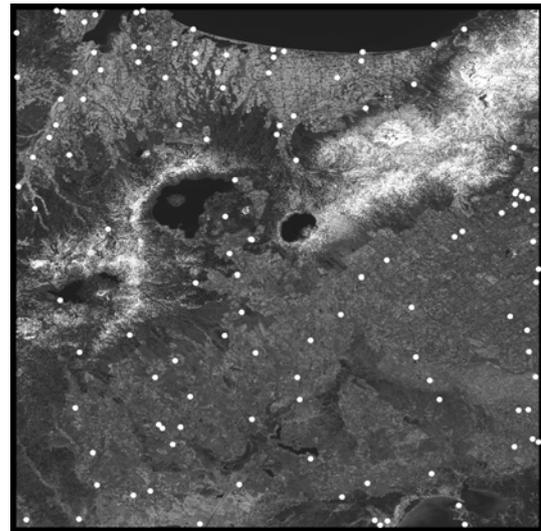


Figure 11. Checking points (White dots) in tile N43E144

The 1:25,000 digital map of GSI, which can be freely accessed online, was used as the reference. The first step of the assessment was to find checking points which could be identified clearly in both the orthoimage and the digital map. Then the longitudes and latitudes in the orthoimage and in the digital map were recorded. The differences between the two latitudes and longitudes of each checking point were calculated and converted from degrees to meters (ΔX for longitude and ΔY for latitude). Finally the horizontal circular errors were calculated from ΔX and ΔY of all checking points and the statistics were made. 120 checking points were manually found (white points in Figure 11). Because the Reference3D data was acquired in winter, snow in the orthoimage limited the number and location distribution of the checking points. Most of the 120 points were centres of road junctions which were easy to identify in the orthoimage and the digital map.

Figure 12 shows the circular errors of the 120 checking points. All points are within a circle of 18.2m radius.

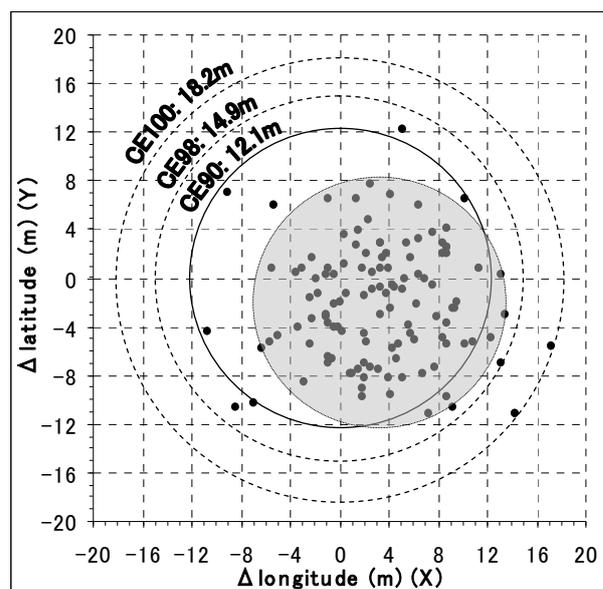


Figure 12. Circular errors for the 120 checking points

	ΔX (longitude)	ΔY (latitude)		Circular Error
Mean (m)	3.3	-2.1		-
STDEV (m)	5.2	4.8		-
Max (m)	17.2	12.2		18.2
Min (m)	-10.7	-11.2		-
90% (m)	-	-		12.1
98% (m)	-	-		14.9

Table 4. Statistics on coordinate differences and circular errors of the 120 checking points

The statistic of the 120 checking points (Table 4) shows that the circular absolute horizontal accuracy is less than 12.1m for 90% of the points, far within the CE90 16m specification of Reference3D. Actually the absolute circular error is less than 15m for 118 out of the 120 points (98%). Table 4 and Figure 12 show a horizontal bias of 3.3m to East and 2.1m to South. Once this bias is removed, the horizontal circular accuracy will be improved to better than CE90 10.2m (Gray circle in Figure 12).

5. CONCLUSION

The accuracy of the Reference3D product was assessed against the Japanese Triangulation Network, GSI DEM and 1:25,000 scale vector maps.

The comparison against the highly accurate DEM of the triangulation network shows that the assessed Reference3D tiles perform better than its specification, with a LE90 error of 6.7m.

During the assessment against GSI DEM, Reference3D was transformed to Tokyo datum, and then the 1 arc-second (approx. 20m by 30m) Reference3D DEM was compared to the 50m GSI

DEM. The statistics of the vertical assessment show that the DEM of the Reference3D meets its specification. The assessment also shows that the Quality Masks is very useful when judging possible error sources for location with significant errors. With a smaller posting size than GSI DEM, Reference3D is a good alternative DEM solution over whole Japan or other areas for applications needing high consistency over large territories (e.g. for mapping needs).

The horizontal accuracy of the Reference3D orthoimage, assessed over the Japanese territory against 120 checking points extracted from GSI 1:25,000 map, is absolute CE90 accuracy of 12.1m. This shows that Reference3D is a very powerful tool to build highly consistent frame over areas that were once very difficult to map with a good accuracy, such as, by instance, the neighbouring Northern Islands.

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