An Evaluation of the Horizontal Positional Accuracy of Google and Bing Satellite Imagery and Three Roads Data Sets Based on High Resolution Satellite Imagery

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Abstract

This paper tests the horizontal positional accuracies of five geospatial data sets of different scales in comparison with ALOS/PRISM imagery, which has a 2.5m resolution and an expected positional accuracy of 6.1 meters RMSE at nadir. The evaluation was done using ALOS/PRISM scenes for 10 cities in different regions of the world. Root mean square errors (RMSEs) were calculated for control points in each of the 10 cities. RMSEs are a measure of the average deviation or distance of points in a candidate data set from their known positions on the ground, or in this case, from their know positions in the ALOS/PRISM imagery. The RMSE for the satellite imagery represented in Google Maps and Bing Maps was 8.2m and 7.9m respectively, and for OpenStreetMap it was 11.1m. Two small spatial scale data sets, ArcGIS ver. 10.1 World Roads dataset and Vector Map level 0 (evaluated for 9 cities) have RMSEs of 121.3m and 838.3m respectively. These RMSEs are less than the distance corresponding to 1mm at the respective designated map scales. These results suggest that the RMSEs relative to the designated spatial scales for the data sets are reasonable. The research also shows that ALOS/PRISM imagery can be used for evaluating horizontal positional accuracy of different scale geospatial data sets.

Keywords:

Optical remote sensing, horizontal positional accuracy, PRISM, high-resolution imagery, Bing aerial imagery, satellite imagery from Google Map, VMAP0

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1. Introduction

In the past decade, the expanding use of high resolution satellite imagery, GIS technologies and global positioning system (GPS) technologies coupled with significant innovation in web services, has resulted in the increasing availability of local and global geospatial information, including high resolution satellite imageries, mapping services through the internet, crowd-made GIS data like OpenStreetMap (OSM), and many other GIS data sets. There are more opportunities to overlay or “mash up” several geospatial data sets from different sources. Most desktop GIS software (e.g. ArcGIS and QuantumGIS) can import the different scale data sets as layers. New technologies, like OpenLayers, make it easier to display various map tiles and markers from different sources, not only in Desktop GIS software but also in dynamic web-based maps.

To enhance synergies among the data sets from different sources, it is necessary to evaluate their positional accuracies when we overlay or mash them up together. For example, the Global Roads Open Access Data Set (gROADS) project is an effort that required the evaluation of the positional accuracy of several geospatial data sets to develop a globally consistent road network (CIESIN, 2013). While some data sets have clear documentation about their expected positional accuracies (i.e. VMAP0 in its specification: MIL-v-89039), some data sets do not. For example, for both Bing aerial imagery and satellite imagery from Google Maps, the data providers make no representation or warranties regarding the accuracy or completeness of any content of the product (Google Maps/Earth Additional Terms of Service; Microsoft Bing Maps and MapPoint Web Service Terms of Use). These disclaimers may force data users to evaluate the quality of the data sets by themselves. In this context, a globally consistent and efficient evaluation method is especially crucial for those who deal with global geospatial data sets. For example, Bing has granted users the right to trace from their aerial imagery for the purpose of contributing content to OSM. Meanwhile, the developers of OSM have openly discussed the accuracy of Bing aerial imagery (see OSM wiki), as the positional accuracy of Bing aerial imagery seems to affect that of OSM significantly.

Potere (2008) evaluated 436 Google Earth control points relative to Landsat GeoCover imagery, which has a known absolute positional accuracy of less than 50 meter RMSE, and found an overall positional accuracy of 39.7 meters. He suggested that using satellite imagery enables a globally consistent accuracy check, as we do not have to visit the sites to obtain the location of ground control points (GCPs). In this study, we evaluated the horizontal positional accuracies of several geospatial data sets using

ALOS/PRISM imagery which has a higher spatial resolution than Landsat GeoCover, and also a higher expected positional accuracy.

2. Data

Targeted data sets

The targeted data sets for evaluation in this analysis were high resolution satellite imagery from Google Maps, Bing aerial imagery, OpenStreetMap (OSM), ArcGIS ver. 10.1 World Roads data set, and Vector Map Level 0 (VMAP0) (Table 1, hereafter their abbreviations will be used). Although some data sets have several feature classes, only road classes were extracted for the purpose of evaluation. Although the map scales for the first three data sets are not fixed, they are often used in large scale on the internet. ESRI and VMAP0 have designated map scales of 1: 250K and 1:1M, respectively.

Table 1. List of targeted data sets for evaluation

Data set	Abb.	Organization	Coverage	Scale
High resolution imagery from Google Map (accessed from Dec. 2012 – Feb. 2013)	Google	Google	global	-
Bing Aerial imagery (accessed from Dec. 2012 – Feb. 2013)	Bing	Microsoft	global	-
OpenStreetMap (accessed from Dec. 2012 – Feb. 2013)	OSM	OSM	global	-
ArcGIS ver. 10.1. data set (World Roads)	ESRI	ESRI	global	1:250K
Vector Map Level 0 (VMAP 0)	VMAP0	NIMA (currently NGA)	global	1:1M

ALOS/PRISM imagery and evaluation sites

To evaluate the positional accuracy of the above mentioned data sets, we compared selected evaluation points to their equivalent position in ALOS/PRISIM satellite imagery (level 1B2). ALOS/PRISM is a panchromatic radiometer with 2.5 meter spatial resolution at nadir. The PRISM level 1B2 product has an expected absolute positional accuracy of 6.1 meters RMSE at nadir (Tadono et al., 2009; JAXA website), and is projected into WGS84. The sceneIDs, observed dates, paths and frames are shown in table 2. The footprint for a PRISM scene is about 35 km by 35 km (Figure 1). Swath width is 35 km with triplet observing mode and 70 km with nadir plus backward observing mode.

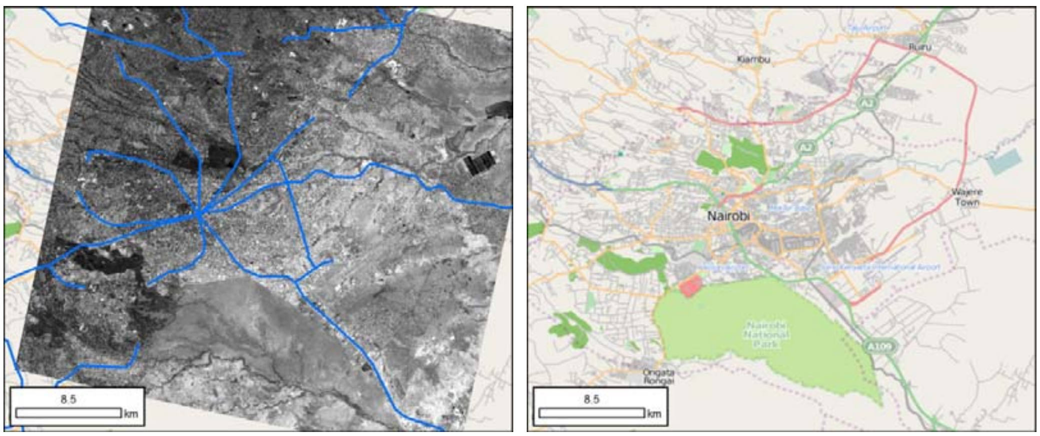


Figure 1. ALOS/PRISM imagery for Nairobi, Kenya with VMAP0 road lines (left), and OpenStreetMap data for the same site (right). The scale bar indicates 8.5 kilometers.

The evaluations were done using 10 PRISM scenes each covering one of 10 cities around the world (Table 2), namely Birmingham (United Kingdom), Melbourne (Australia), west of New York City (USA), Bamako (Mali), Santiago (Chili), Montreal (Canada), Nairobi (Kenya), Dhaka (Bangladesh), Tangerang (Indonesia), and Shanghai (China). We chose PRISM scenes which encompassed urban and suburban areas to ensure enough points for evaluation, but VMAP0 did not have sufficient road coverage over the evaluation site in Bangladesh, and was thus evaluated using imagery for only 9 cities.

Table 2. List of ALOS/PRISM scenes for evaluation

Location (neighboring city)	PRISM Scene ID	Date	Center Lat.	Center Long.	Center Angle	Center Orient.
Birmingham, United Kingdom	ALPSMN230532540	2010/5/23	52.458	-2.02	R1.4	15.5
Melbourne, Australia	ALPSMN169054360	2009/3/28	-37.7	144.835	R1.4	13.5
New York City, USA	ALPSMN189862775	2009/8/17	40.898	-74.13	L1.2	13.8
Bamako, Mali	ALPSMN252703345	2010/10/22	12.672	-7.901	L1.2	12.1
Santiago, Chili	ALPSMN258414275	2010/11/30	-33.513	-70.668	R1.4	13
Montreal, Canada	ALPSMN261922680	2010/12/24	45.564	-73.821	L1.2	14.4
Nairobi, Kenya	ALPSMN266833625	2011/1/27	-1.275	36.872	L1.3	12
Dhaka, Bangladesh	ALPSMN271773125	2011/3/2	23.665	90.34	R1.4	12.3
Tangerang, Indonesia	ALPSMW187743725	2009/8/3	-6.227	106.499	R0.1	12.1
Shanghai, China	ALPSMW258632970	2010/12/2	31.316	121.38	R0.2	12.8

3. Methods

All data sets, except the satellite imagery from Google Maps, were projected into geographic coordinates (longitude-latitude) with WGS84 datum using GIS software (ArcGIS), and their coordinates were measured in ArcGIS. The XY coordinates of evaluation points in the Google Maps imagery were measured directly in the browser because the imagery cannot be displayed in ArcGIS.

We chose several points for each PRISM scene to calculate the errors of the target data sets. To choose the evaluation points, we generated a fishnet (0.1 degree by 0.1 degree) and used the intersections as reference points. Then for each reference point we selected the closest recognizable road feature, usually an intersection, as one of our evaluation points. Our evaluation data sets in this study were road classes because natural landscape features and land cover boundaries (i.e. river edge, agricultural field boundary), are less permanent. When there was no recognizable road feature near the reference point, we omitted acquiring an evaluation point for that reference point. A small scale data set, such as VMAP0, was strongly generalized, so we carefully chose the corresponding points in PRISM imagery as shown in figure 3.

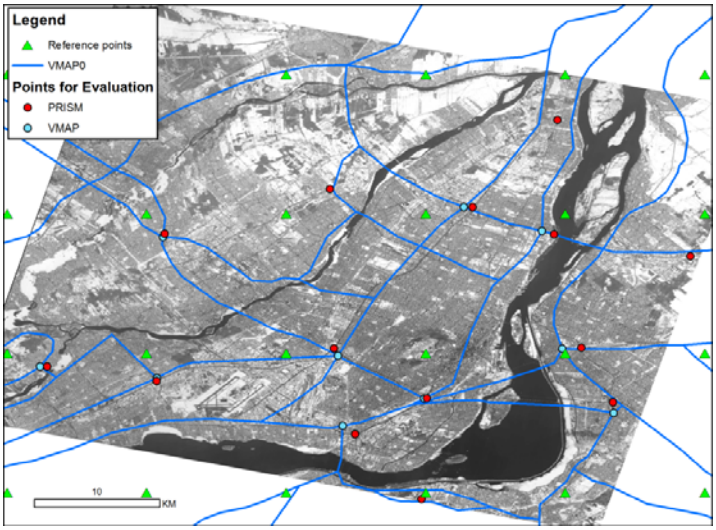


Figure 2. Evaluation site of Montreal (Canada). VMAP0 road class (blue line) overlaid on PRISM imagery. Well recognized intersections were selected as evaluation points (red and blue points) referring to the reference points (green) generated at intersections of each 0.1 by 0.1 degree grid.

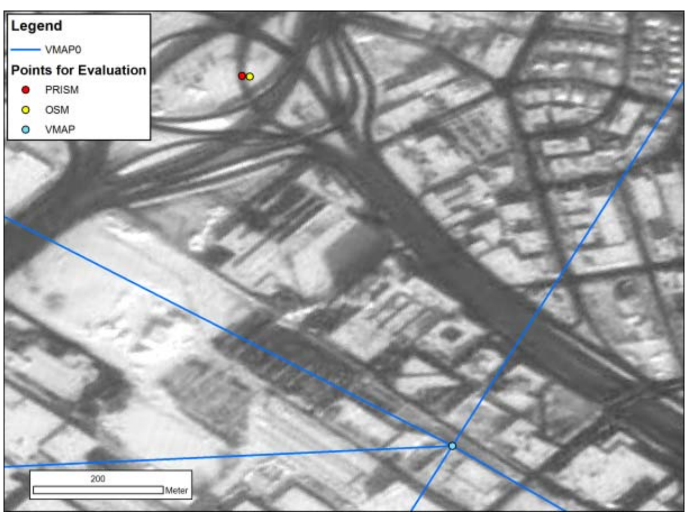


Figure 3. VMAP0 road class (blue line) overlaid on PRISM imagery for Montreal, Canada. The red dot is a PRISM control point, the yellow dot is the corresponding point in the OSM data set, and the pale blue dot is the corresponding point in the VMAP0 data set. The scale bar indicates 200 meters.

The distance errors (or positional gaps of each data set from ALOS/PRISM) were calculated from the measured XY coordinates (in decimal degrees), then elevation effects were removed. For each evaluation point, the distance from the corresponding point in ALOS/PRISM (*D*) was calculated based on Hubeny's distance calculation formula, as shown below, such that the distances in X (D_x : distance in west-east) and the distances in Y (D_y : distance in north-south) were obtained respectively.

$$D = sqrt\ (D_x^2 + D_y^2) \qquad (1)$$

$$D_y = M * dP \qquad (2)$$

$$D_x = N * cos(P) * dR \qquad (3)$$

Where *dP* is the latitude difference of the two points, *dR* is the longitude difference of two points, *P* is the average latitude of the two points, *M* is the radius of curvature of the meridian, and *N* is the transverse radius of curvature. As the data sets were projected into the WGS 84 datum, we used the following ellipsoid parameters: 6,378,137 meter for the semi-major axis (*a*), and 1/298.257223563 for the flattening (*f*).

$$M = a * (1-e^2) / (1-e^2 sin^2 P)^{3/2} \qquad (4)$$

$$N = a / sqrt(1-e^2 sin^2 P) \qquad (5)$$

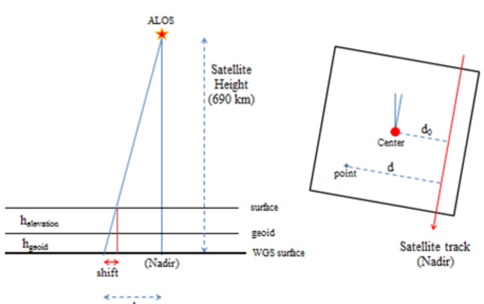
where $e = sqrt\ (2f - f^2)$ (6)

Although Hubeny's distance calculation formula is a simple approximation which is not suitable for calculating a great distance between two points, we used it because we felt the observed gaps were small enough for simple approximation.

As reported on the OSM wiki (http://www.wiki.openstreetmap.org/wiki/bing), we also observed that the alignment of Bing aerial imagery was not consistent across zoom levels for several places (Figure 4). In such cases, we enlarged the map scale to 1:1,000 in ArcGIS so that the larger imagery was displayed to measure the location.

Figure 4. Misalignment of Bing aerial imagery in Bangladesh. The red dot indicates the same location displayed over Bing imagery at different zoom levels. (Left: smaller scale, right: larger scale)

With the product level 1B2, however, ALOS/PRISM is projected into WGS84 surface. Therefore, the DEM correction is required except for Japanese region (i.e. Gonçalves, 2009) to estimate the shift from the real location. Although all scenes except for Nairobi and Santiago have low elevation and relatively flat topography, the shift for each evaluation point caused by the elevation effect was calculated and removed by using the satellite parameters (incident angle at the center of the scene and orientation of the track at the center shown in the table 2), the ASTER GDEM global elevation model (by Japan’s Ministry of Economy, Trade and Industry and NASA), and the EGM96 global geoid model. The model used for this calculation is shown in Figure 5.



$$\text{Shift} = (h_{elevation} + h_{geoid}) * d / 690{,}000$$

Figure 5. A simple model for calculating the elevation effect

4. Result

The overall accuracy of each data set is shown in table 3 and figure 6. Over all ten scenes, Google, Bing and OSM have 8.2 meters, 7.9 meters, and 11.1 meters RMSE, respectively. These three data sets have similar offsets relative to PRISM as shown by the similar mean error vectors (x, y) and their standard deviations (SD) in X and Y. The ESRI data set has an RMSE of 121.3 meters, which corresponds to about 0.5 mm at its 1:250,000 map scale. VMAP0 has an RMSE of 838.3 meters, which corresponds to about 0.8 mm at its 1:1,000,000 map scale. These RMSE values can be considered good for such small scale data sets.

Table 3. Positional Accuracy by data sets

Data set	Points # (Scene #)	**RMSE (meters)**	Mean Error (meters)	SD (meters)	Range (meters)	Mean error vectors (x,y) (meters)	SD of error (x,y) (meters)
Google	140 (10)	**8.2**	7	4.2	(0.5-20.1)	(1.7,-1.9)	(4.6,6.3)
Bing	137 (10)	**7.9**	7	3.6	(1.6-22.1)	(2.2,-2.2)	(4.5,5.7)
OSM	116 (10)	**11.1**	8.8	6.9	(0.2-55.1)	(2.8,-2.2)	(8,7)
ESRI	75 (10)	**121.3**	76.1	95.1	(3.1-594.7)	(14,-24.8)	(103.8,57.6)
VMAP0	54 (9)	**838.3**	652.8	530.8	(104.3-3699.6)	(-25,102.1)	(470.5,695.2)

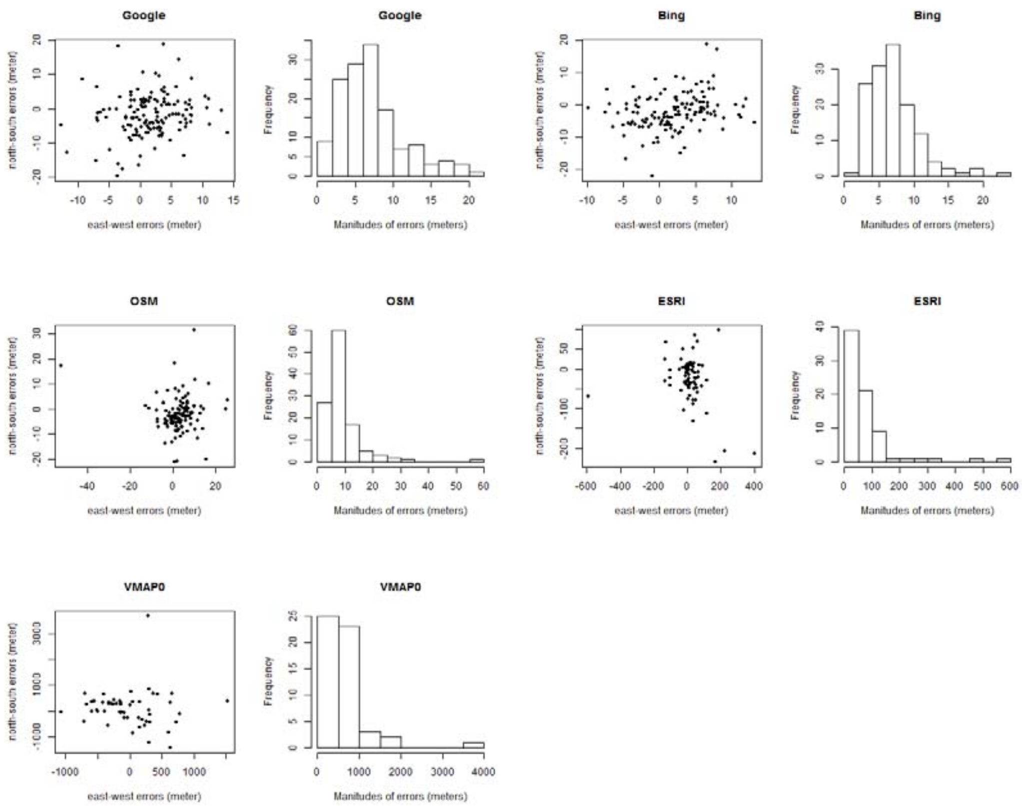


Figure 6. Error vectors and histograms

In Google, Bing, and OSM, it turned out that most gaps are less than about 20 meters RMSE. The summary for each scene is shown in table 4.

Table 4. Summary of the result for each scene

Area (neighbouring city)	Data set	Sample #	**RMSE (meters)**	Mean Error (meters)	SD (meters)	Range (meters)	Mean error (x,y) (meters)	SD of error (x,y) (meters)
Birmingham	google	16	**11.4**	10.1	5.5	(3.1-20.1)	(0.2,-5.8)	(4.1,9.3)
	bing	16	**8.6**	7.9	3.6	(2.2-15.2)	(1.2,-5.6)	(5.1,4.4)
	osm	16	**9.3**	8	4.8	(3.2-20.8)	(1.2,-5.7)	(5.3,5.2)
	esri	15	**94.2**	75.6	58.3	(5.5-213.5)	(-2,-16.2)	(79.7,53.6)
	vmap	11	**542.3**	519.7	162.4	(347.9-791.8)	(-240.3,381.4)	(298.5,104.1)

Melbourne	google	12	**8.5**	7.3	4.7	(3-18.1)	(-1,-6.3)	(3.4,4.9)
	bing	12	**9.4**	7.9	5.3	(2.8-22.1)	(-0.9,-7.3)	(2.7,5.5)
	osm	12	**11**	8.4	7.4	(2-25.3)	(1.6,-7.7)	(4.8,6.5)
	esri	8	**197**	129	159.1	(10.8-456.8)	(105.6,-54.2)	(130.6,105.7)
	vmap	8	**672.9**	520.8	455.5	(104.3-1551.6)	(205,-431.3)	(239.3,446.8)
New York City	google	12	**6.9**	6.6	2.3	(2.8-10.4)	(4.4,-3.2)	(2.5,3.8)
	bing	12	**6.2**	6	2	(2.6-9.4)	(4.1,-3.1)	(2.2,3)
	osm	12	**6.7**	6.1	2.7	(2.4-10.7)	(4.3,-3.5)	(2.4,3)
	esri	11	**37.1**	25.9	27.9	(3.1-103.7)	(-5.4,-4.5)	(35.1,15.1)
	vmap	8	**1443**	979.4	1133	(148.5-3699.6)	(25.1,593.2)	(490.6,1317.6)
Bamako	google	8	**6.6**	6	2.9	(3.6-11.1)	(4.8,-1.5)	(3.2,3.1)
	bing	8	**6.8**	6.1	3.2	(2.5-10.1)	(3.7,-4)	(2.5,3.4)
	osm	7	**8.2**	7.6	3.1	(3.2-13.1)	(0.3,-5.5)	(4.4,4.8)
	esri	3	**105.5**	92.2	62.8	(39.8-161.7)	(43.6,-75.4)	(62.3,37.8)
	vmap	4	**880.5**	708	604.6	(291.8-1578.9)	(296.6,-37.7)	(843.8,450.2)
Santiago	google	10	**9.4**	8.3	4.6	(2.2-16.8)	(-0.8,-7.9)	(3.1,4.2)
	bing	10	**9.5**	8.7	4	(4.2-17.5)	(-2.6,-7.9)	(2.3,4.1)
	osm	10	**7.6**	6.9	3.3	(3.4-14.1)	(0.3,-5.2)	(4,4.1)
	esri	7	**74**	64.1	40.1	(12.8-135.9)	(38.3,-15.2)	(17.1,64.2)
	vmap	4	**989.6**	973.2	207	(780.8-1247.2)	(600.2,-648.4)	(209.6,470)
Montreal	google	14	**8.8**	7.9	3.9	(3.5-19.3)	(4.7,3.1)	(4.2,5.6)
	bing	14	**9.3**	8.4	4.2	(4.5-20)	(6,3.7)	(3.2,5.5)
	osm	14	**13.1**	10.4	8.3	(5.3-33.1)	(7.3,2.7)	(6.1,9.1)
	esri	8	**33.4**	28	19.6	(5.4-57.6)	(-2.6,2.8)	(27.6,22.3)
	vmap	10	**652.8**	578.9	318	(156.5-1067.4)	(-328.8,-64.6)	(406.5,428.4)
Nairobi	google	12	**9.5**	8.5	4.4	(2.3-15.8)	(5.2,0.7)	(5.7,5.9)

	bing	12	**9.2**	7.9	4.8	(2.3-19.1)	(5.2,2.8)	(4.4,5.9)
	osm	10	**12.3**	11.1	5.6	(3.8-19.6)	(7.5,1.7)	(6.4,8)
	esri	4	**101.3**	96.5	35.7	(69.5-146.3)	(19.4,-11.5)	(100.4,54.3)
	vmap	4	**485.2**	476.7	104.7	(376.4-597.2)	(-391.5,220.9)	(154.9,143)
Dhaka	google	13	**7.2**	6.1	4	(1-13.6)	(-2.6,-1.7)	(4.6,5)
	bing	12	**7.7**	7	3.4	(3.2-14.4)	(-0.8,-3.1)	(6.4,3.7)
	osm	6	**23.9**	15.6	19.8	(0.2-55.1)	(-10.5,0.2)	(21.8,8.8)
	esri	4	**304.8**	205	260.5	(49-594.7)	(-118.5,-64.2)	(315.4,13.3)
Tangerang	google	21	**6.4**	4.9	4.2	(0.5-17.4)	(0,1.1)	(4.3,4.8)
	bing	19	**6**	5.4	2.5	(2.2-10.7)	(2.4,0.6)	(4.2,3.7)
	osm	12	**7.9**	7.2	3.3	(1.9-13.2)	(2.8,0.8)	(4.8,6)
	esri	6	**71.9**	58.3	46.1	(5.3-120.6)	(11.8,-11.5)	(74.5,17.8)
	vmap	7	**668**	646.9	179.8	(321.5-868.1)	(-577.2,36.1)	(185.1,309.9)
Shanghai	google	22	**6.5**	6	2.7	(1.8-12.2)	(2.9,-1)	(3.2,4.9)
	bing	22	**6.4**	5.9	2.4	(1.6-10.1)	(2.5,-1.9)	(3.4,4.6)
	osm	17	**10.6**	9.1	5.6	(3-24.6)	(4.9,-0.5)	(8,5.4)
	esri	9	**115.6**	83.8	84.5	(38.6-305.1)	(26.9,-49.8)	(78.6,72.5)
	vmap	5	**664.8**	623	259.4	(304.7-886.7)	(143.6,506.1)	(314.3,328.2)

5. Discussion

<u>The error caused by optical observation</u>

PRISM imagery has an expected positional accuracy of 6.1 meter RMSE. In addition to the errors in positional accuracy, we found there will be an error caused by the spatial resolution of PRISM imagery. PRISM has a 2.5 meter IFOV (instantaneous field of view), which makes it difficult to distinguish the road lanes exactly. In Bing or Google imagery, however, the resolution makes it possible to recognize even dashed white lines separating the lanes (Figure 7). Thus, there will be an error of a few meters when specifying a corresponding center of an intersection.

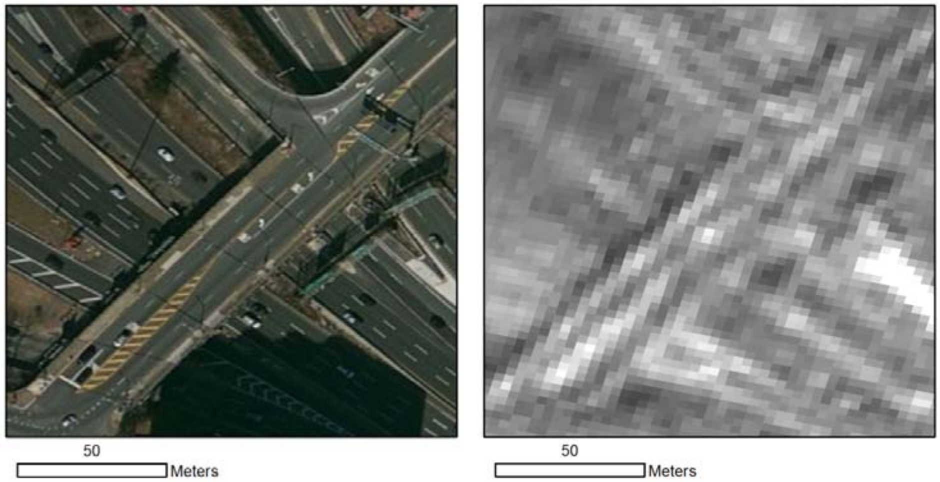


Figure 7. Bing aerial imagery (left) and PRISM imagery for the same place (around 40.8575 N, 73.9739 W).

Generalization effect

We also found that the small scale data sets were strongly generalized in some places. For example, an intersection was shifted more than 500 meters in the ESRI road data set, which is 1:250K scale data (Figure 8). The evaluation method used in this study cannot separate the errors due to cartographic generalization from true errors of positional accuracy.

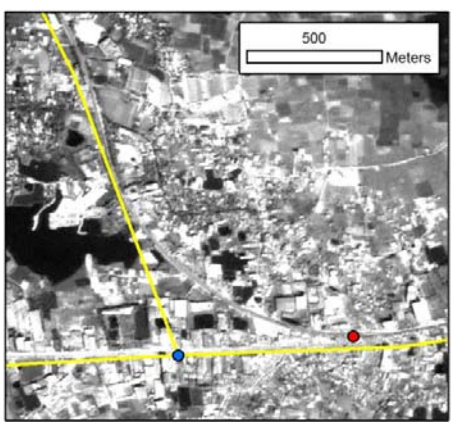


Figure 8. Generalized intersection in Bangladesh. An intersection (blue dot) from the ESRI data set (yellow line) is offset from the real location as seen in the PRISM imagery (red dot).

6. Conclusion

The horizontal positional accuracies of five geospatial data sets at different scales were evaluated. For the overall evaluated points among 10 cities, Google, Bing and OSM have 8.2, 7.9 and 11.1 meters RMSEs respectively against ALOS/PRISM imageries (nadir), which the expected accuracy for ALOS/PRISM was 6.1 meter RMSE (nadir). ESRI (overall 10 cities) and VMAP0 (over 9 cities) have 121.3 and 838.3 meters RMSEs respectively against ALOS/PRISM imageries (nadir), which would be good accuracy under their own designed scales. We also found that there was a difficulty in recognize detailed features (e.g. dashed white lines in road) with ALOS/PRISM that could causes a few meter errors in optical observation in addition to its expected RMSEs. This implies that ALOS/PRISM imagery can be used for evaluating the positional accuracy of geospatial data sets in the different scales.

7. Disclaimer

This study was done for the purpose of demonstrating the usefulness of ALOS/PRISM imagery in the context of horizontal positional accuracy evaluation of global geospatial data sets. The evaluating results in this study were only for limited number of targeted points of the imageries or data sets which were accessed on certain time period.

The author does not endorse the positional accuracy of any data set nor make warranty regarding the accuracy of any data set. The views expressed in this report are those of the author’s and do not necessarily represent the view of any organization.

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