HIGH RESOLUTION STEREO SATELLITE ELEVATION MAPPING ACCURACY ASSESSMENT

Gerry Mitchell, P. Geo, Geophysicist, President
PhotoSat Information Ltd.
Vancouver, BC V6E 3S7
gerry@photosat.ca
Kevin MacNabb, Geophysicist, President
MWH Geo-Surveys, Inc.
Vernon, BC V1T 2C2
kevin@mwhgeo.com

ABSTRACT

The availability of over 45,000 accurately surveyed ground points covering an area of 1,000 km^2 in central Eritrea has enabled comprehensive accuracy assessments of elevation mapping from IKONOS, GeoEye-1, WorldView-1 and WorldView-2 stereo satellite photos. The ground survey points were acquired for a base metal mining exploration gravity survey. All of the ground points were surveyed with Real Time Kinematic GPS instruments and are accurate to 2 cm. The IKONOS, GeoEye-1 and WorldView-1 stereo photos were each registered to a single ground control point, and the WorldView-2 stereo photos were registered to two ground control points. Each of the stereo pairs covers a slightly different ground area. Using elevation checkpoints in areas with slopes of less than 20% grade, the elevation mapping accuracies were determined as follows: IKONOS acquired August 2006, 200 km^2, RMSE 48cm using 10,081 points; GeoEye-1 acquired February 2009, 240 km^2, RMSE 44cm using 10,824 points; GeoEye-1 acquired September 2009, 225 km^2, RMSE 31cm using 8,983 points; WorldView-1 acquired October 2008, 374 km^2, RMSE 44cm using 15,020 points; WorldView-2 acquired January 2010, 400 km^2, RMSE 28cm using 16,687 points. The stereo satellite elevation mapping was carried out with PhotoSat's Geophysical Stereo Satellite Elevation Mapping System. The survey points were used in the development and verification of the system. The PhotoSat Geophysical Stereo Satellite Elevation Mapping System is the subject of another paper submitted for the ASPRS conference.

INTRODUCTION

PhotoSat has been providing resource industry customers with detailed elevation maps from high resolution stereo satellite photos since stereo IKONOS satellite photos first became available in 2004. From 2004 to 2007, PhotoSat's elevation mapping was carried out using conventional photogrammetric processes. Since 2007, we have been using an automatic, repeatable, geophysical process for stereo satellite elevation mapping in rural areas with sparse vegetation.

Until 2008, we had difficulty determining the elevation accuracy of our stereo satellite Digital Elevation Models (DEMs). Each project typically had a few surveyed ground control points provided by our clients. While these survey points usually fit the elevation mapping data to better than one meter, there were never enough points on any project to provide a statistically significant measure of the elevation mapping accuracy. By 2007, after a number of projects, we became convinced that the relative accuracy of the stereo IKONOS elevation mapping was probably better than 1m Root Mean Square Error (RMSE), but we were unable to prove this accuracy until 2008.

In 2008, one of our clients, Sunridge Gold, provided PhotoSat with over 45,000 precisely surveyed ground points covering a 20km by 50km area in Eritrea. We have used these survey points to carry out elevation accuracy assessments for stereo photo elevation mapping from the IKONOS, GeoEye-1, WorldView-1 and WorldView-2 satellites.

In Q4 2009, PhotoSat learned of the very high quality LiDAR data over the Garlock Fault in Southeast California, publicly available from OpenTopography. GeoEye has provided PhotoSat with stereo GeoEye-1 photos from November 30, 2009 over a portion of the LiDAR survey. DigitalGlobe has provided PhotoSat with stereo

WorldView-1 and WorldView-2 photos from January 28, 2010 over a different portion of the LiDAR survey. The standard deviations of the differences between the stereo GeoEye and WorldView satellite DEMs and the LiDAR DEM are in the range of 25cm to 35cm.

ERITREA STEREO SATELLITE ELEVATION ACCURACY STUDIES

The 45,000 ground survey points provided to PhotoSat by Sunridge Gold are shown in Figure 3. These points cover a 20km by 50km area just west of Asmara Eritrea in Northeast Africa, 75 km west of the Red Sea. These survey points are from a mining exploration gravity survey. The objective of this gravity survey is the discovery of high density buried massive metal deposits. The accuracy and quality control of the gravity survey elevation data is very high. Elevation errors of as little as 10 cm will affect the gravity data interpretation. The elevation points were surveyed in Real Time Kinematic (RTK) mode with accuracies of 2 cm or better using differential GPS instruments from Magellan. One of the survey crews is shown in Figure 1.

The stereo satellite elevation maps were all referenced to the ground control point shown in Figure 4. The 400 km^2 WorldView-2 elevation mapping was also referenced to a second ground control point in the southern portion of the area, shown in Figure 5. Except for the two points used for ground reference, none of the other survey points were used in the creation of the stereo satellite elevation maps. The thousands of survey points were all used as independent checkpoints to measure the accuracy of the stereo satellite DEMs. The accuracy of the 400 km^2 Worldview-2 elevation mapping is demonstrated in Figures 6 through 9. The elevation processing for these studies was done using PhotoSat's Geophysical Stereo Satellite Elevation Mapping System. This automatic processing system produces repeatable results. The PhotoSat Geophysical Stereo Satellite Elevation Mapping System is described in a separate presentation at the ASPRS 2010 conference.

The results of the Eritrea stereo satellite elevation mapping accuracy studies are shown in Table 1. These results demonstrate that PhotoSat's automatic geophysical processing system produces DEMs with better than 50cm RMSE using stereo photos from the IKONOS, GeoEye-1, WorldView-1 and WorldView-2 satellites.

Table 1. Summary of the results from the five stereo satellite elevation mapping accuracy studies carried out by PhotoSat on the Eritrea project area

Satellite	**Photo Date**	**Area (km^2)**	**DEM Processing Date**	**Number of GCPs**	**Number of Check points**	**RMSE <20% grade**
IKONOS	Aug 2006	200	Dec 2008	1	10,081	48cm
WorldView-1	Oct 2008	374	Nov 2008	1	15,020	44cm
GeoEye-1	Feb 2009	240	Feb 2009	1	10,824	44cm
GeoEye-1	Sept 2009	225	Oct 2009	1	8,983	31cm
WorldView-2	Jan 2010	400	Feb 2010	2	16,687	28cm

A major upgrade to the PhotoSat geophysical stereo satellite elevation processing system in August 2009 probably contributes to the better accuracy values for the Oct 2009 and Feb 2010 results.

Figure 1. Asmara Project, Eritrea. MWH Geo-Surveys differential GPS survey crew and equipment. Over 45,000 gravity stations were surveyed from 2004 through 2008 using differential GPS instruments from Magellan. All the GPS positions were surveyed in RTK mode with accuracies of 2 cm or better. The Magellan RTK GPS base with a ProMark™ 500 GPS rover are shown in this photo.

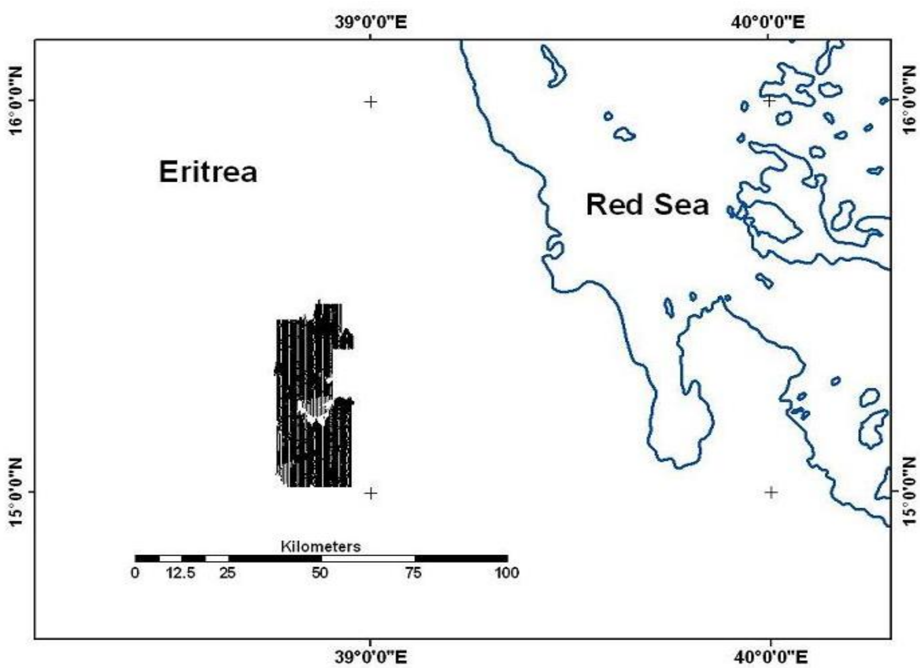

Figure 2. Location of over 45,000 ground survey points covering a 20km by 50km area in Eritrea. These survey points were provided to PhotoSat by Sunridge Gold and were surveyed by MWH Geo-Surveys.

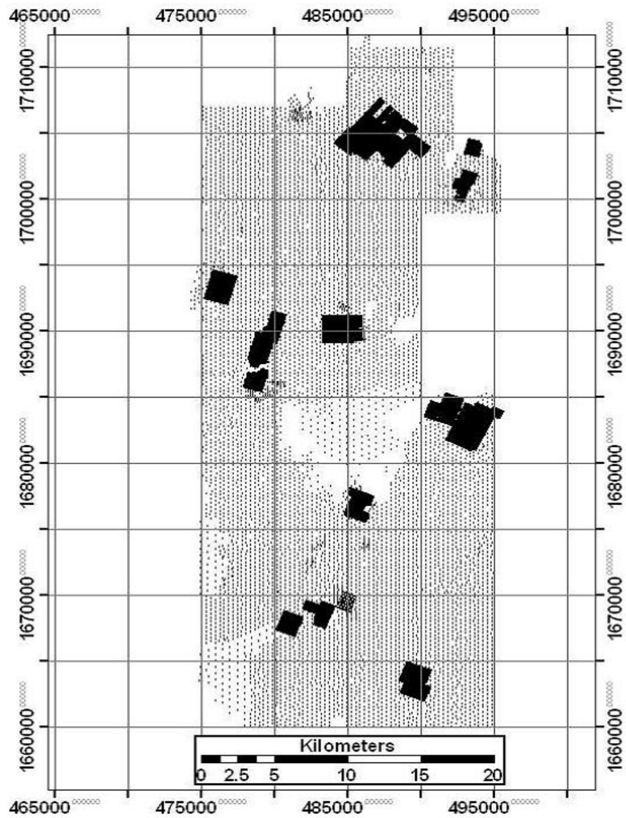

Figure 3. Distribution of over 45,000 survey points from the Eritrea project. The regional survey points are on a 250m by 350m grid. The densely spaced survey points are on 20m by 100m grids.

Figure 4. The ground control point used to reference the five different stereo satellite elevation maps for the accuracy studies. This was the only ground control point used for four of the studies. For the 400 km^2 WorldView-2 elevation mapping, we used a second ground control point.

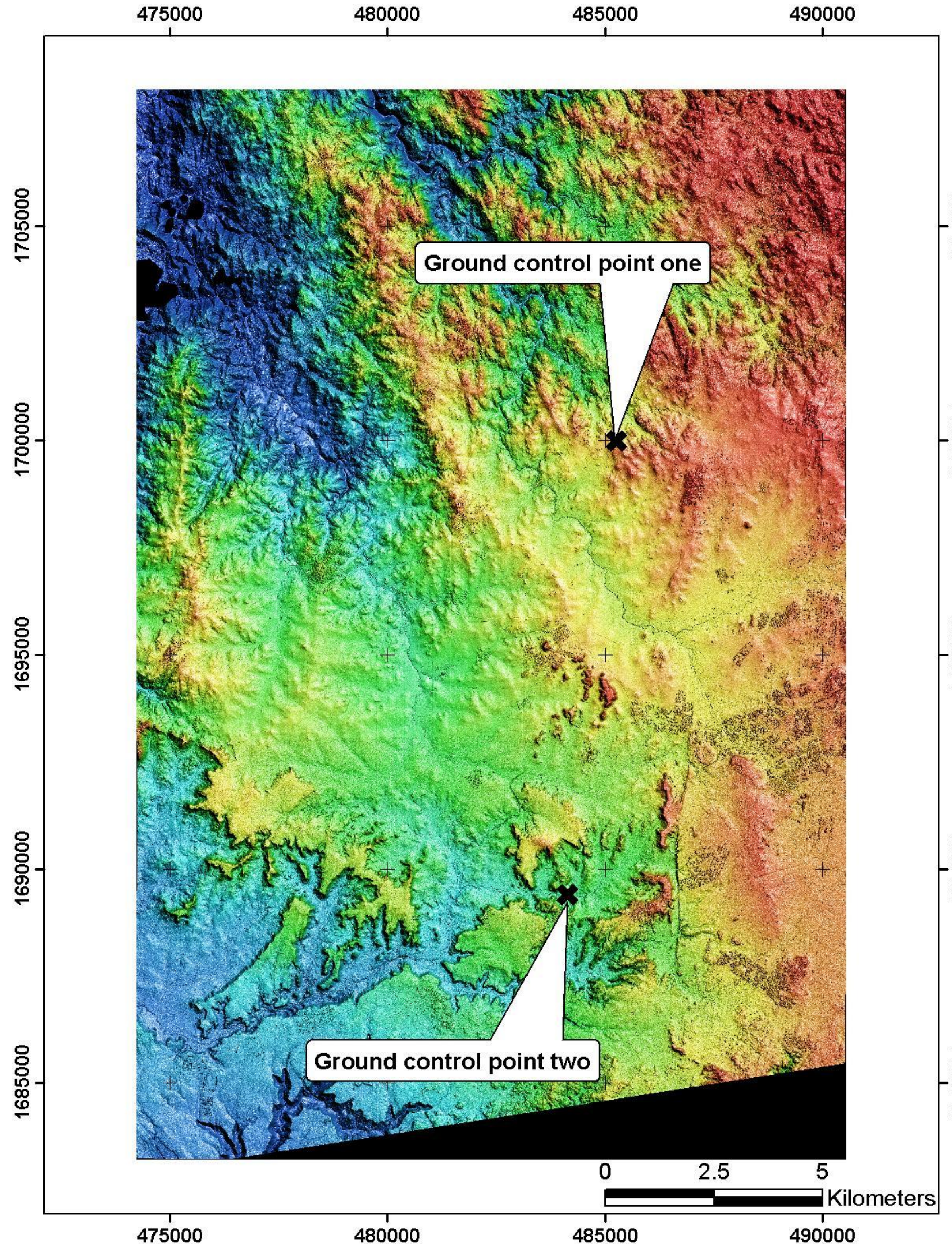

Figure 5. WorldView-2 elevation image created from a 1m posted DEM showing the two ground control points.

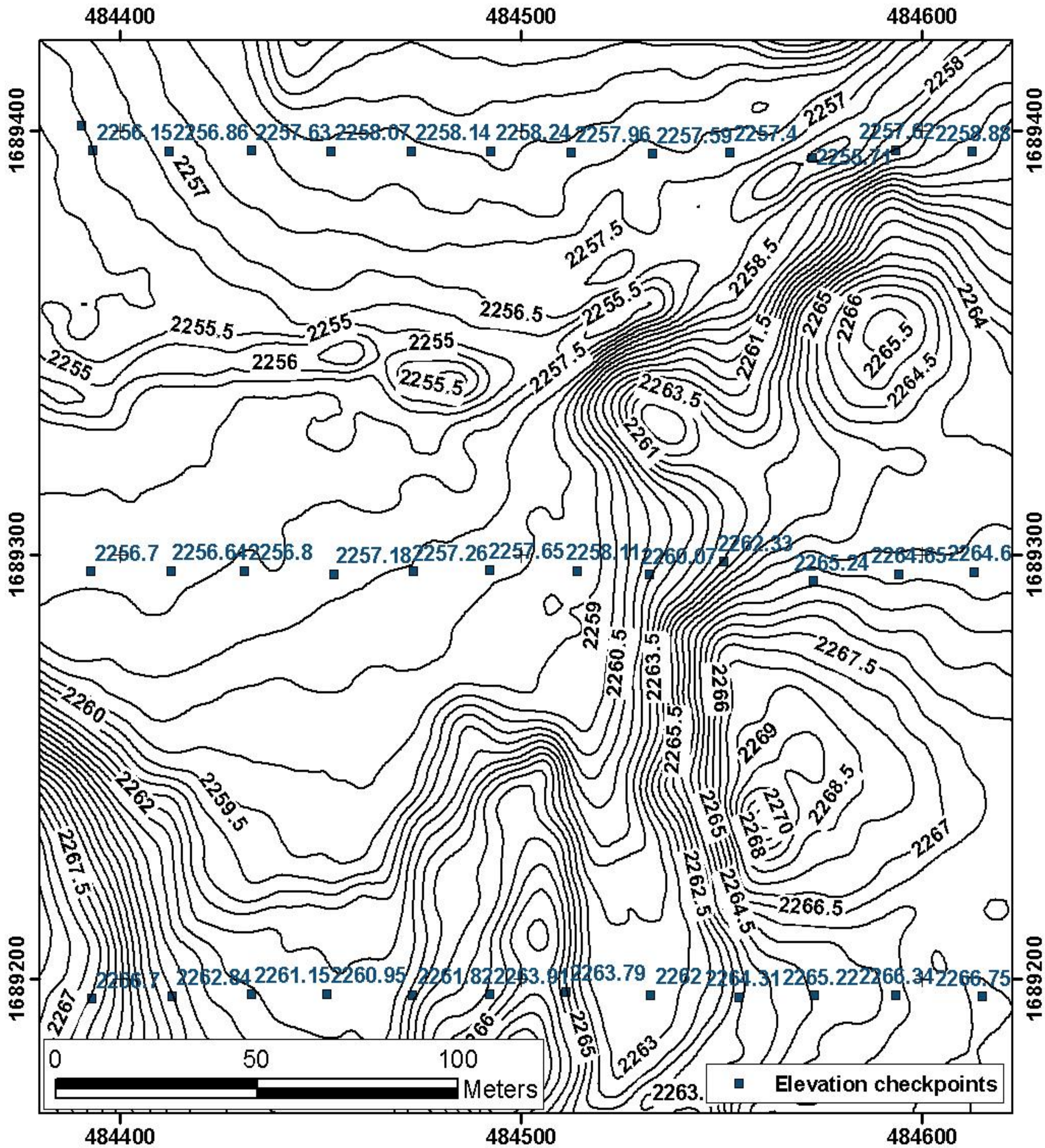

Figure 6. 50cm contours from the stereo WorldView-2 elevation mapping showing the elevations of some of the 16,687 elevation checkpoints used to determine the stereo satellite elevation mapping accuracy of 28cm RMSE.

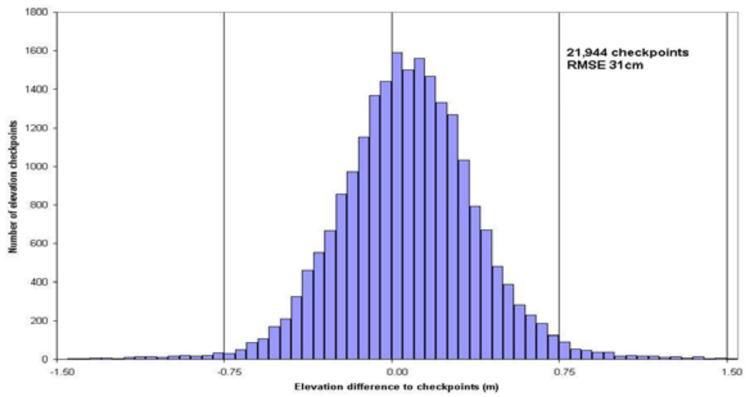

Figure 7. Histogram of the elevation differences between the WorldView-2 stereo satellite elevations for the 25km by 16km area and the 21,944 elevation checkpoints. RMSE 31cm.

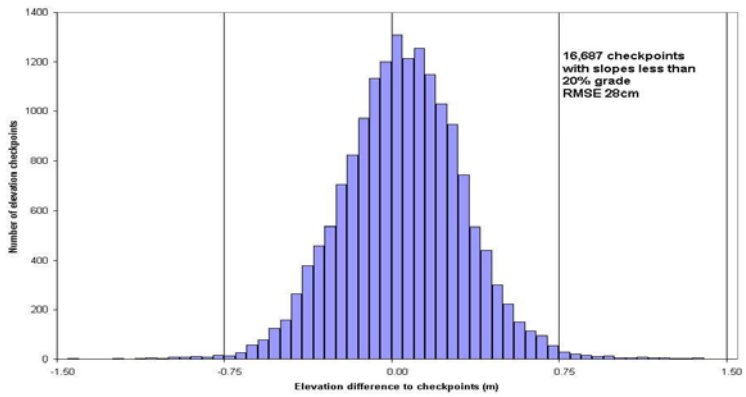

Figure 8. Histogram of the elevation differences between the WorldView-2 stereo satellite elevations for the 25km by 16km area and the 16,687 elevation checkpoints with slopes less than 20% grade. The *Guidelines for Digital Elevation Data* of the US National Digital Elevation Program (NDEP) recommends that elevation checkpoints should not be chosen in areas with slopes greater than 20% grade. RMSE 28cm.

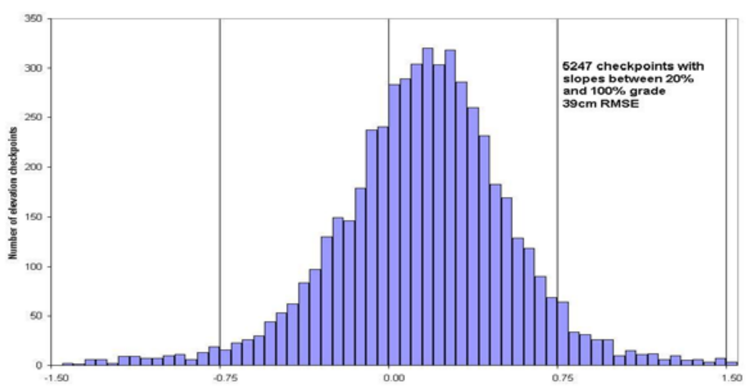

Figure 9. Histogram of the elevation differences between the WorldView-2 stereo satellite elevations for the 25km by 16km area and the 5,247 elevation checkpoints with slopes between 20% and 100% grade. RMSE 39cm.

STEREO SATELLITE ELEVATION ACCURACY ASSESSMENT USING THE OPENTOPOGRAPHY GARLOCK FAULT LiDAR SURVEY

In December 2009, a study was conducted to measure the elevation mapping accuracy and resolution of PhotoSat's GeoEye-1 stereo satellite DEMs compared to LiDAR DEMs. For this comparative study, GeoEye, the owner of the GeoEye-1 satellite, provided a GeoEye-1 stereo satellite photo pair over a 10km section of the Garlock Fault in Southeast California.

The Garlock Fault was mapped with a LiDAR survey in April 2008 by OpenTopography. The Garlock Fault LiDAR DEM data is available on the OpenTopography website www.OpenTopography.org. This material is based on services provided by the Plate Boundary Observatory operated by UNAVCO for EarthScope (www.earthscope.org) and supported by the National Science Foundation (No. EAR-0350028 and EAR-0732947). The location of the Garlock Fault LiDAR survey and the area of the comparison with the GeoEye-1 stereo satellite DEM is shown in Figure 10. The comparisons of the LiDAR and stereo GeoEye-1 DEMs are shown in Figures 11 through 18.

Figure 10. The Garlock Fault OpenTopography LiDAR survey shown on Google Earth. The Garlock Fault LiDAR survey was flown in April 2008. The location of the GeoEye-1 stereo satellite photos, acquired November 30, 2009, is shown by the circle.

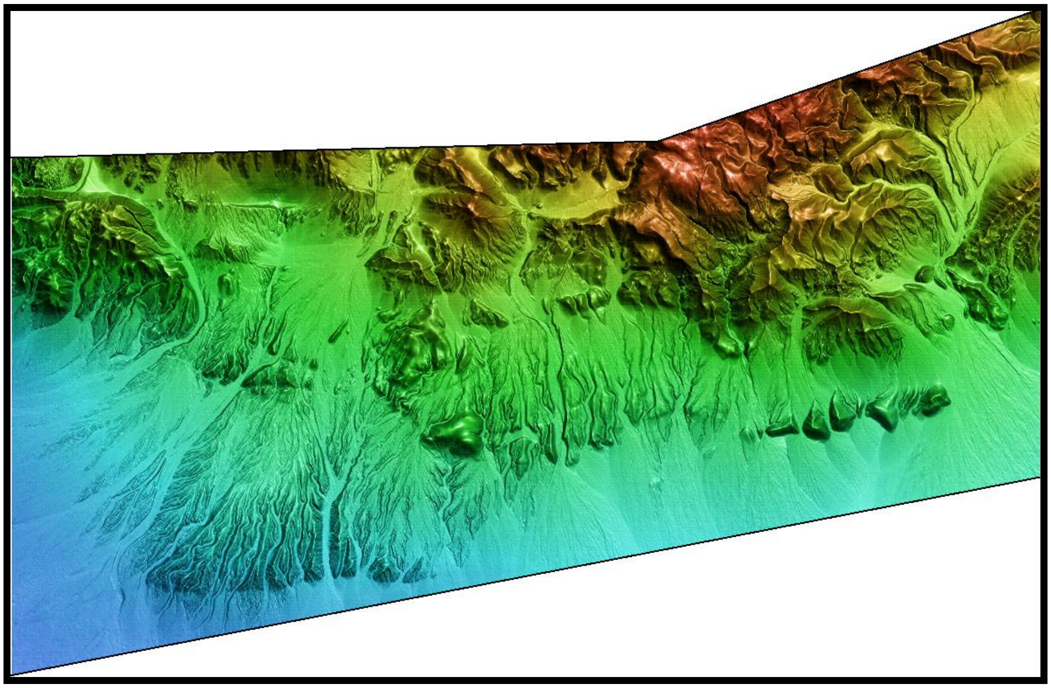

Figure 11. An image showing a portion of the Garlock Fault OpenTopography LiDAR DEM. The dimensions of the area are 10 km east–west by 5km north–south. Lower elevations are blue and higher elevations are red.

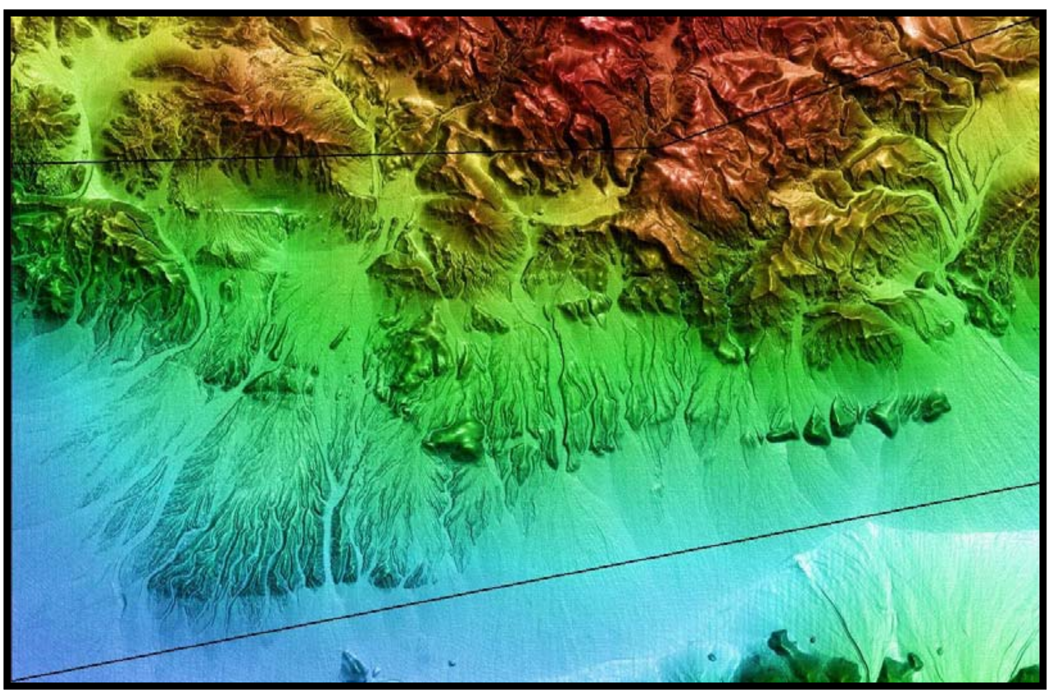

Figure 12. Stereo GeoEye-1 DEM image covering the area of the LiDAR DEM in Figure 11. This DEM has an elevation point every meter. At this scale, the LiDAR and GeoEye-1 images appear identical. Lower elevations are blue and higher elevations are red.

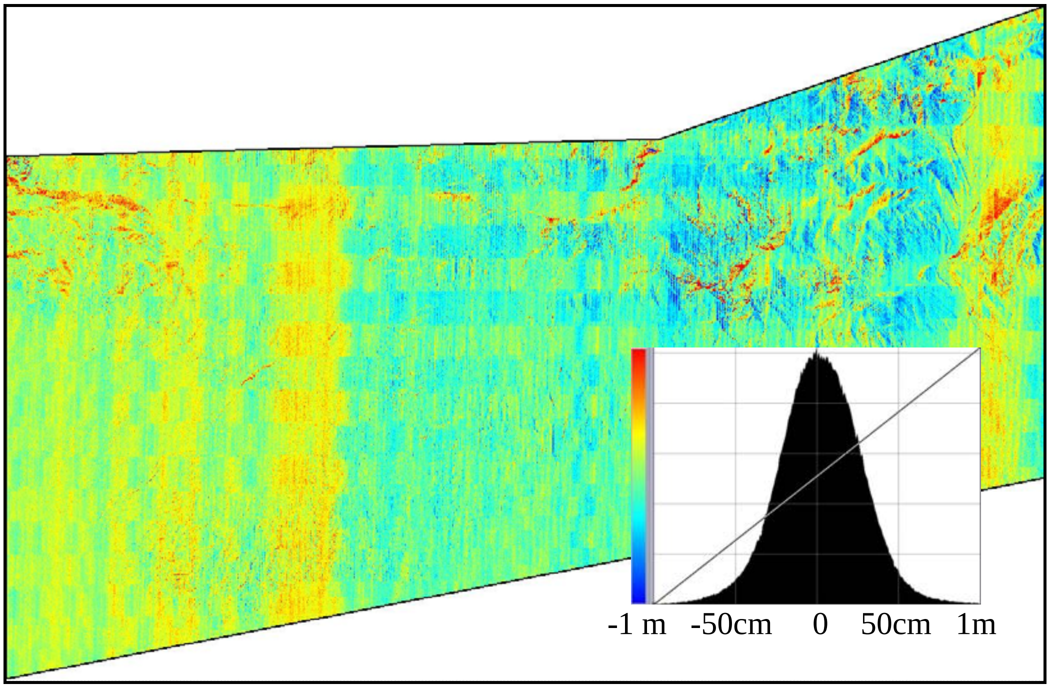

Figure 13. Image of the elevation differences between the GeoEye-1 and LiDAR DEMs displayed as blue for -1m to red for +1m differences. The image and histogram were created in ERMapper. The standard deviation of the elevation differences is 25cm.

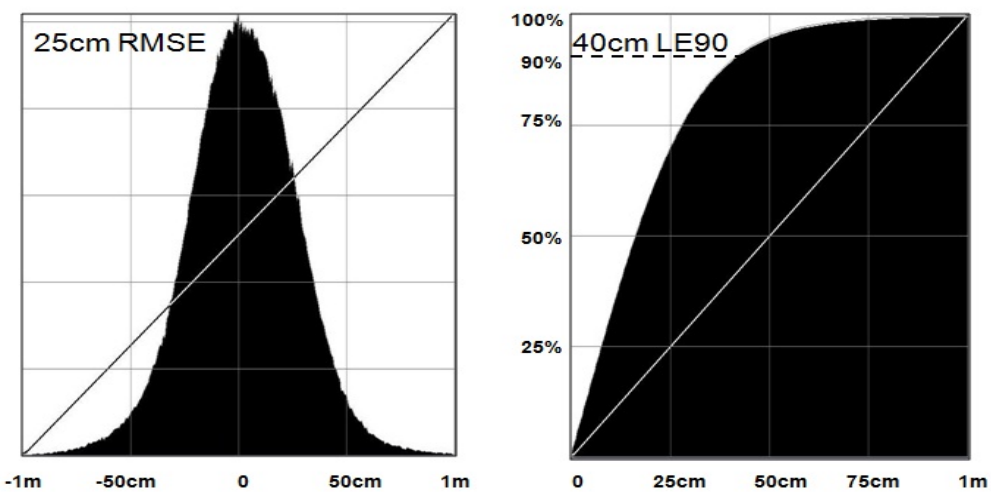

Figure 14. The elevation differences between the GeoEye-1 and LiDAR DEMs are shown in a standard histogram on the left and a cumulative histogram on the right. These histograms were created in ERMapper. If we assume that the LiDAR DEM is perfect, the GeoEye-1 DEM elevations have an RMSE of 25cm. Ninety percent of the stereo GeoEye-1 elevations are within 40cm of the LiDAR elevations, giving a 90% Linear Error (LE90) of 40cm.

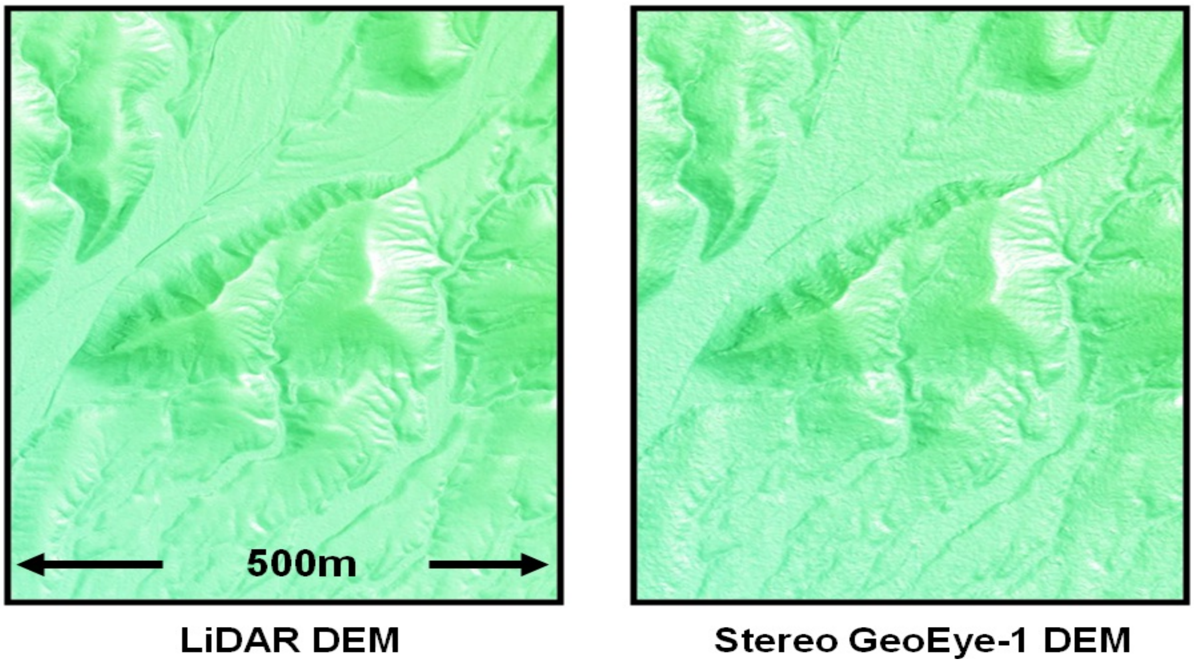

Figure 15. Images of the LiDAR and GeoEye-1 DEMs for a 500m wide area. At this scale, fine topographic features are much clearer on the LiDAR DEM.

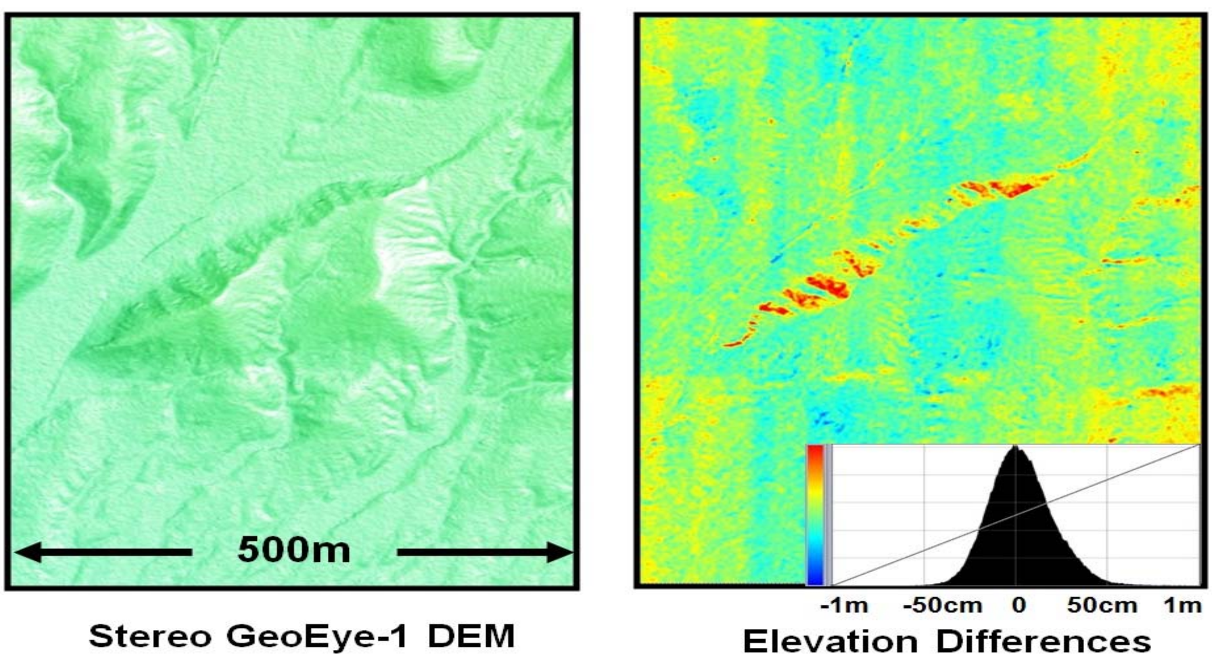

Figure 16. Image of the GeoEye-1 DEM and the elevation differences between the GeoEye-1 and LiDAR DEMs. There are elevation differences, shown in red, of up to 1m on the steep Northwest-facing slope. The standard deviation of the elevation differences is 18cm.

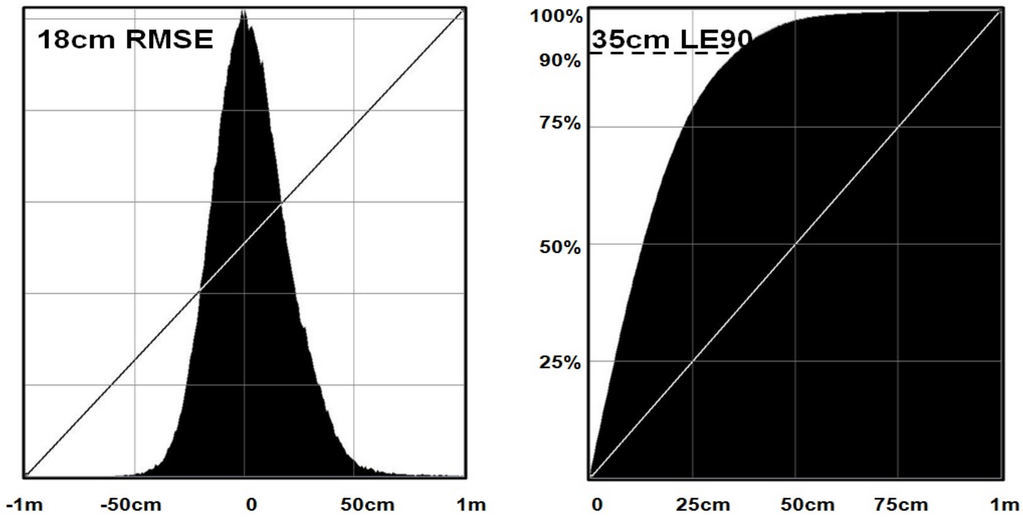

Figure 17. The elevation differences between the GeoEye-1 and LiDAR DEMs for the 500m wide area are shown in a standard histogram on the left and a cumulative histogram on the right. If we assume that the LiDAR DEM is perfect, the GeoEye-1 DEM elevations have an RMSE of 18cm. Ninety percent of the stereo GeoEye elevations are within 35cm of the LiDAR elevations, giving a 90% Linear Error (LE90) of 35cm for this area.

The high quality OpenTopography LiDAR DEM has spectacular resolution and accuracy. When we make the conservative assumption that the OpenTopography LiDAR DEM is perfectly accurate and use it to measure the accuracy of the GeoEye stereo DEM, we get the following elevation accuracy results for the 1m GeoEye DEM:

Entire 50 km^2 area	25cm RMSE	40cm LE90
500m x 650m area	18cm RMSE	35cm LE90

ADVANTAGES OF STEREO SATELLITE DEMs

Some advantages of stereo satellite DEMs are as follows:

- Large areas of stereo satellite photos can be acquired and processed quickly.
- Mapping projects may be anywhere in the world as the satellites have global coverage.
- No government survey permits are required, so there are no mapping project delays due to government bureaucracy.
- No charges for aircraft standby and crew waiting for favourable survey weather.
- No in-country presence is required.

REFERENCES

Fraser, C. and Ravanbakhsh, M., 2009. Georeferencing Accuracy of GeoEye-1 Imagery, *PE&RS*, 75(6): 634-638.

NCALM LiDAR, 2008. Southern California and Washington (Yakima) Fault Systems LiDAR Survey Processing Report, http://opentopo.sdsc.edu/metadata/SOCAL_REPORT_final.pdf.

OpenTopography. Standard DEMs, http://opentopo.sdsc.edu/gridsphere/gridsphere?cid=standarddems.