PhotoSat
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PhotoSat WorldView-2 stereo satellite surveying accuracy study, Asmara, Eritrea, 21 GCP, 14cm RMSE

- **100 km^2 surveyed using twenty one ground reference survey points**
- **This WorldView-2 satellite elevation surveying accuracy is accurate to 14cm RMSE, determined by 775 survey checkpoints**
- **January 2010 WorldView-2 stereo satellite photos processed by PhotoSat in June 2016**

Gerry Mitchell, P. Geo, Geophysicist, President PhotoSat
July 2016

A 1m grid of elevation values, covering an area of 100 square kilometres, was produced over the PhotoSat test area in Eritrea. The elevation grid was made using geophysical processing of 50cm ground resolution stereo satellite photos taken by the DigitalGlobe WorldView-2 satellite. The stereo satellite elevation processing was referenced to twenty one ground survey points. The elevation surveying accuracy was measured with 775 survey checkpoints.

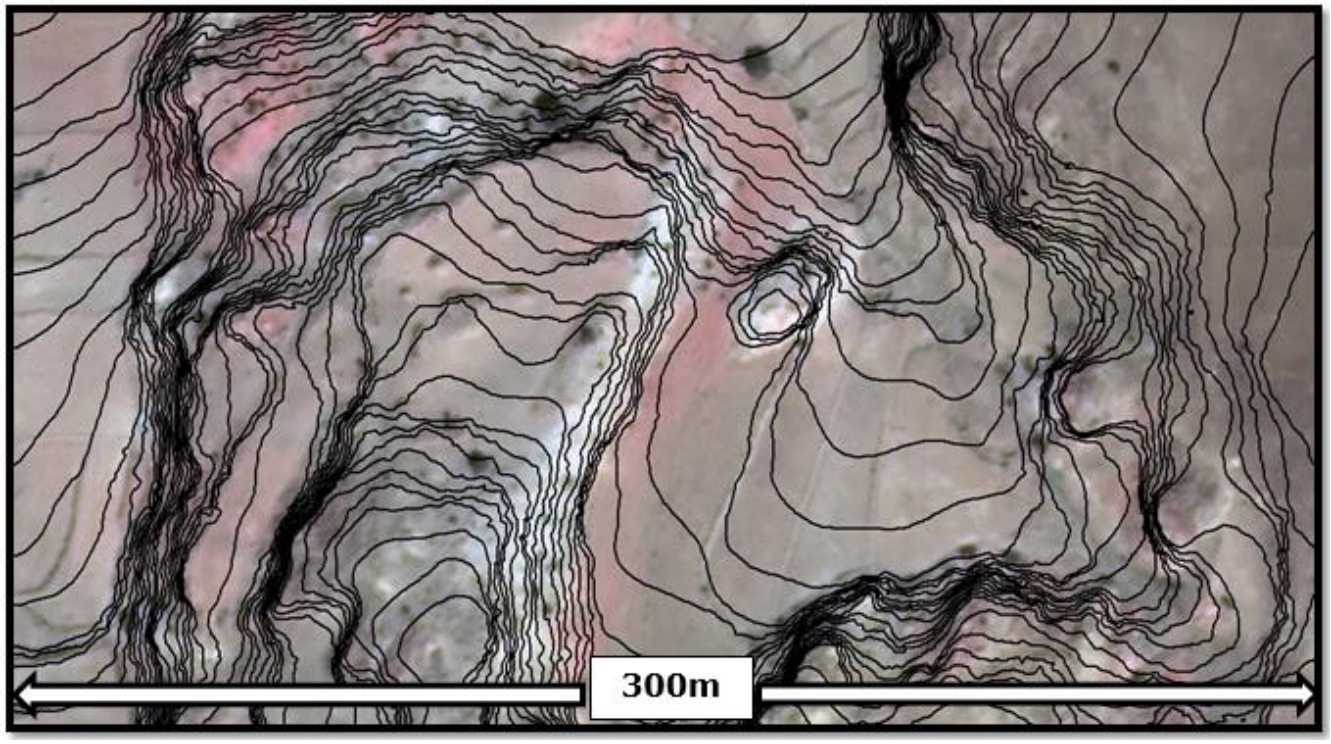

Figure 1. WorldView-2 color image with 50cm contours from the stereo WorldView-2 elevation surveying for the Asmara Eritrea test area.

Stereo satellite photos:

PhotoSat satellite surveying uses high quality stereo satellite photos. These photos are taken by the satellite as it passes over the survey area along a north to south satellite orbit. The process of taking the stereo photos is illustrated in Figure 2.

The satellite photographs the same ground area within a minute or two. The ground conditions are close to identical on the two photos. The difference in appearance of ground features on the photos is due to the different look directions of the satellite camera.

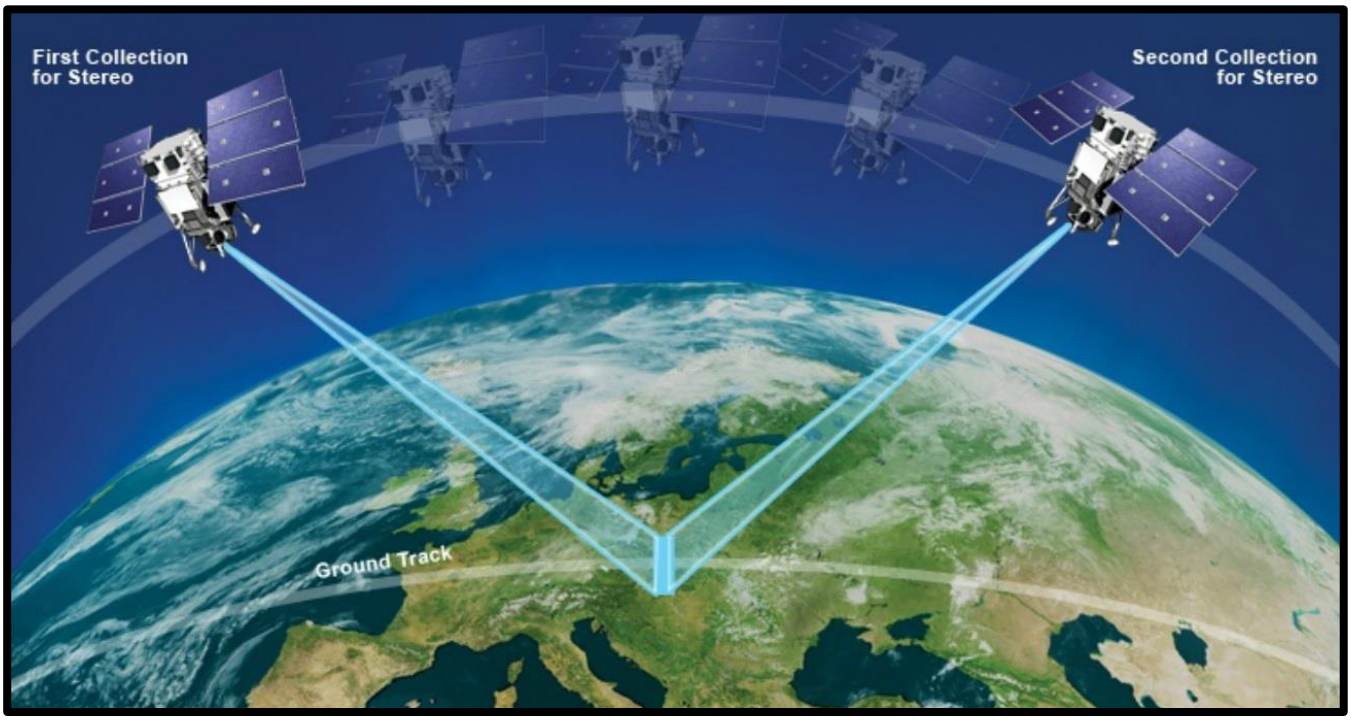

Figure 2. Illustration showing the process of taking satellite stereo photos. The satellite points forward to take the first photo. About one minute later, and 300 km further along its orbital track, the satellite rotates to take the second photo looking backwards along the track. Hundreds of km^2 can be accurately surveyed with a single pair of stereo satellite photos. Illustration copyright DigitalGlobe.

PhotoSat geophysical stereo satellite processing system:

Survey coordinates of ground features are determined by measuring the apparent shift in location of the features between the two satellite photos. PhotoSat uses a proprietary geophysical processing system to generate survey coordinates from stereo satellite photos. This system is described in a PhotoSat white paper published at the 2010 ASPRS annual conference.

PhotoSat has conducted research to identify and characterize the systematic distortions in most of the commercial available high resolution stereo satellite photos. Using this proprietary information we continuously develop processing methods to automatically identify and attenuate these systematic distortions. The accuracy, reliability and speed of our stereo satellite processing is constantly improving.

The current study used the 2016 version of the PhotoSat processing system. It produces more accurate results than the previous versions of the system as is discussed below.

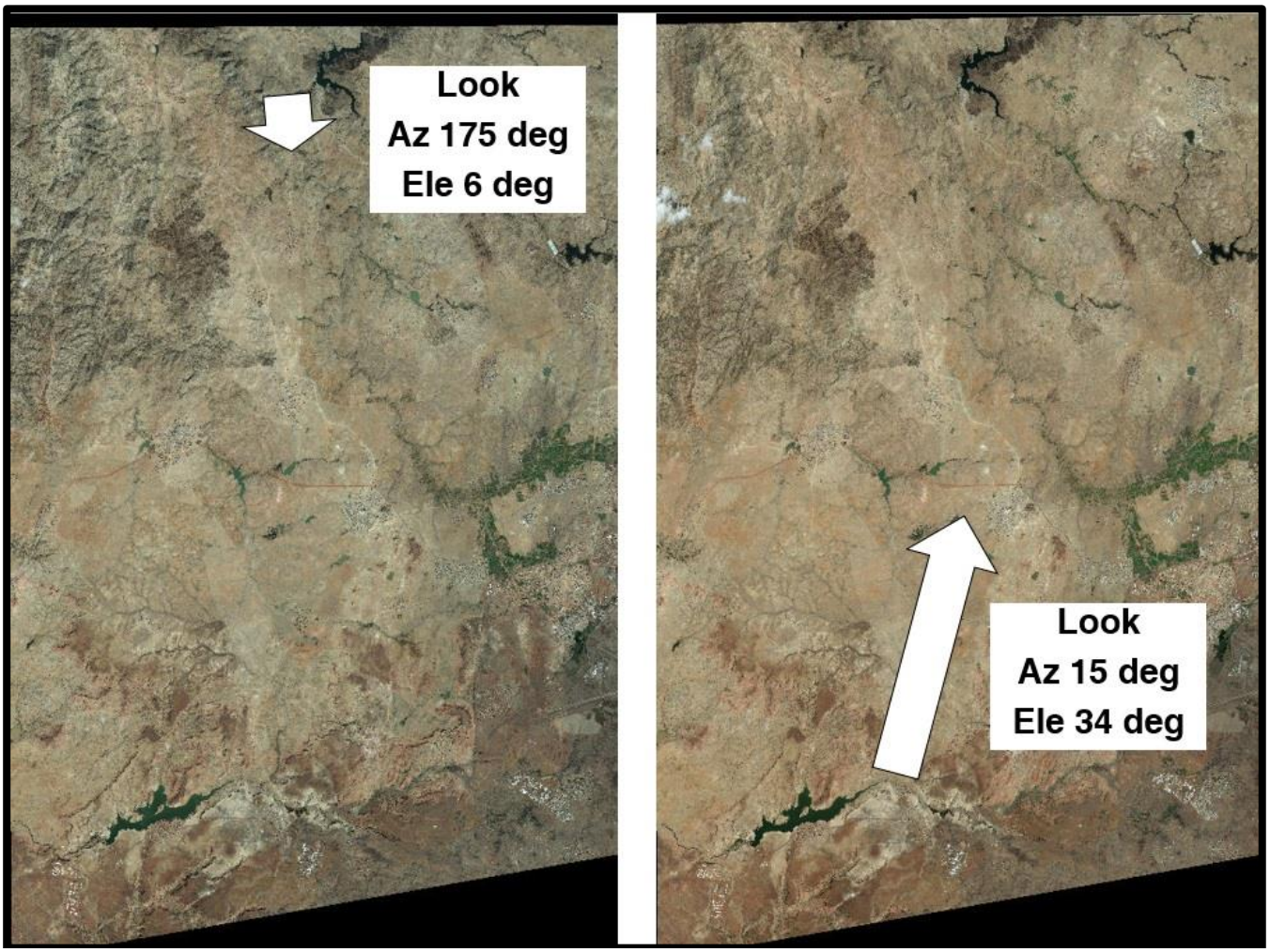

Figure 3. WorldView-2 satellite photos of PhotoSat's Eritrea test area taken on January 27, 2010 at approximately 10:30 AM local time. The photo on the left was taken looking at an azimuth of 175 deg and angle from vertical of 6 deg. The photo on the right was taken looking at an azimuth of 15 deg and angle from vertical of 34 deg. The arrows on the photos indicate the satellite look direction. The lengths of the arrows are proportional to the look angles from vertical. This stereo pair has a convergence angle of 46 deg, a bisector azimuth of 74 deg and bisector angle of 14 deg from vertical.

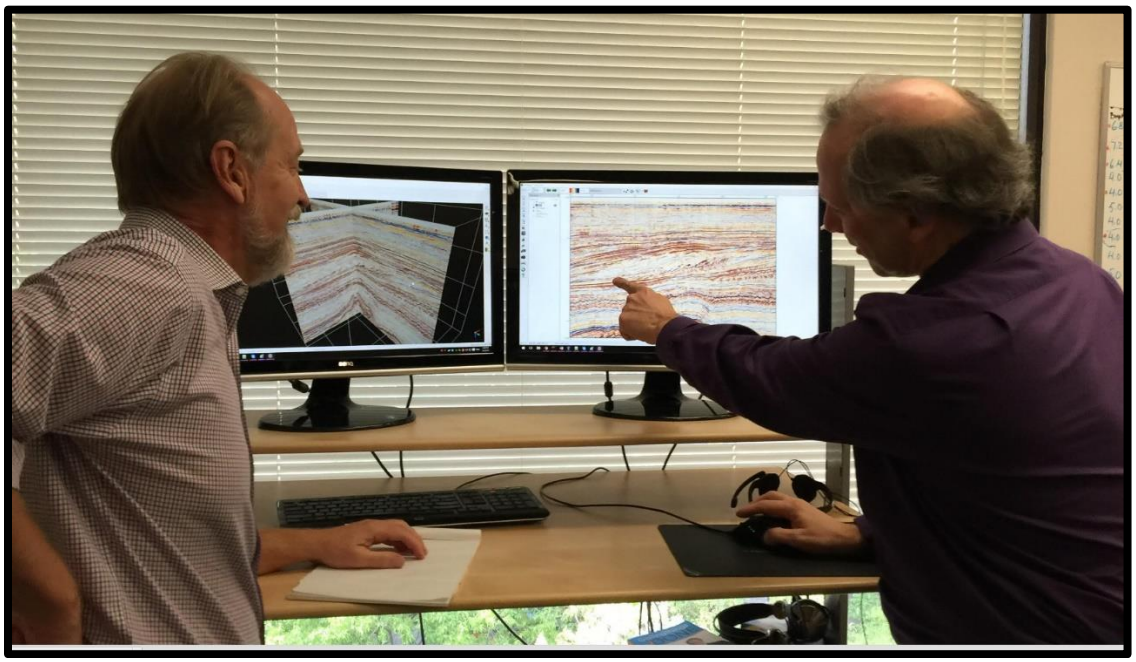

Figure 4. Gerry Mitchell, left and Michael Ehling with an Oil and Gas seismic processing workstation. This technology is the basis for the PhotoSat geophysical stereo satellite processing system named the PhotoSat Process Manager.

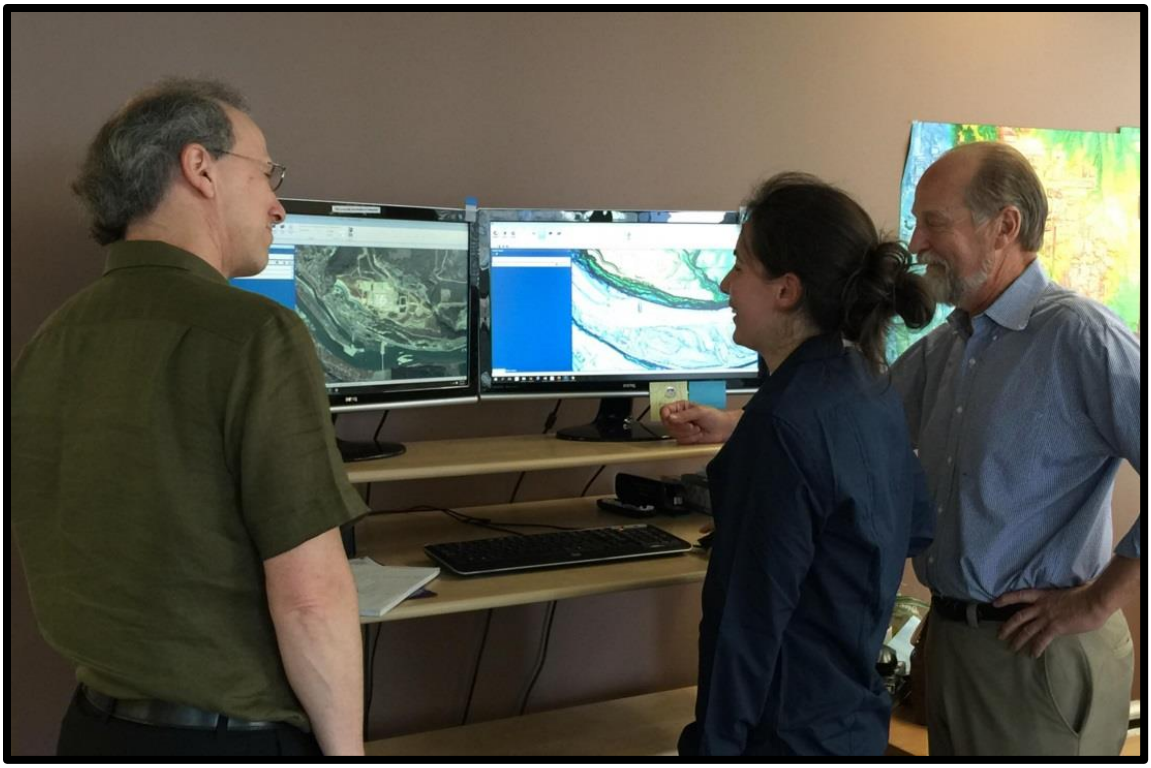

Figure 5. Michael, Gerry and Jayda Akatsuka with the PhotoSat Process Manager.

Improvements in PhotoSat satellite surveying accuracy 2010 to 2016:

In 2016 PhotoSat is routinely achieving better than 15cm elevation surveying accuracy on projects that have extensive existing ground survey data. We have made significant improvements in the accuracy of our stereo satellite topographic mapping over the past six years. We produced our first stereo WorldView-2 (WV2) elevation surveying accuracy study of the Eritrea test area in 2010.

In the 2010 Eritrea WorldView-2 accuracy study we used two ground control points to reference the stereo WV2 surveying. In that study we achieved an elevation surveying accuracy of 28cm RMSE. We repeated this exact same accuracy study using the 2016 version of our processing system using the same two ground control points. In this repeated study we achieved accuracy of 20cm RMSE.

Using many existing ground survey points to characterize and attenuate distortions in the WorldView satellite photos we are routinely achieving better than 15cm elevation mapping accuracy on many oil sands mining projects. We have also achieved this accuracy on a number of oil and gas projects where we have used existing seismic source point survey data to attenuate the stereo satellite photo distortions. We do not have our clients permission to publish many of these results.

To provide a publishable version of our ability to produce stereo WorldView elevation survey data accurate to 15cm we have reprocessed 100km^2 of the 2010 stereo WV2 photos over of the Eritrea test area with the 2016 version of our processing system. In this study we used 21 ground survey points to attenuate the distortions in the stereo WV2 photos.

Eritrea satellite photos:

The pair of stereo WorldView-2 satellite photos over the Eritrea test area are shown in Figure 3. The photos were taken on January 27, 2010 at approximately 10:30 AM local time. The stereo satellite photo look directions, convergence angle, bisector azimuth and bisector angle from vertical are shown in the figure caption. The convergence angle of 46 deg is optimum for surveying elevations in level to moderate terrain.

Eritrea stereo WorldView elevation grid:

PhotoSat produced a 1m grid of elevations over the entire 100km^2 project area. We processed the stereo WorldView photos with our geophysical stereo satellite processing system in June 2016. An image of the 1m elevation grid is shown in Figure 7. A 50cm resolution WorldView-2 orthophoto is generated as part of the processing work flow. This orthophoto is shown in Figure 6. As the orthophoto and elevation grid are derived from the same satellite photos they match perfectly.

Ground reference points:

With this accuracy study we are demonstrating that we can produce highly accurate WorldView-2 surveys with a reasonable distribution of ground reference survey points.

On operating mine sites and oil and gas project sites there are usually hundreds of existing ground survey points. PhotoSat uses these existing ground survey points to identify and attenuate the distortions in the WorldView satellite photos to achieve elevation surveying accuracies of better than 15cm.

The locations of the ground reference points used in the current processing and accuracy report are shown in Figure 7. The survey crew and system are shown in Figure 8.

Global shift of stereo satellite survey to match ground reference:

The WorldView ortho photo and elevation grid needed a constant shift of only -10cm E, -60cm N and -15cm in elevation to match the ground surveying. The global accuracy of most WorldView stereo satellite photos pairs is better than 3m.

Accuracy evaluation check points:

The accuracy of the PhotoSat 1m survey grid was evaluated with 775 ground survey check points. These points were originally surveyed for a large mining exploration gravity survey conducted between 2004 and 2008 by MWH Geophysics. The distribution of the elevation check points is shown in Figure 7.

The elevation check points were surveyed to an accuracy of 2cm using Real Time Kinematic GPS survey equipment. One of the MWH Geophysics survey teams and their equipment are shown in Figure 8. The accuracy check points were extracted from a 250m by 250m regional grid of survey points.

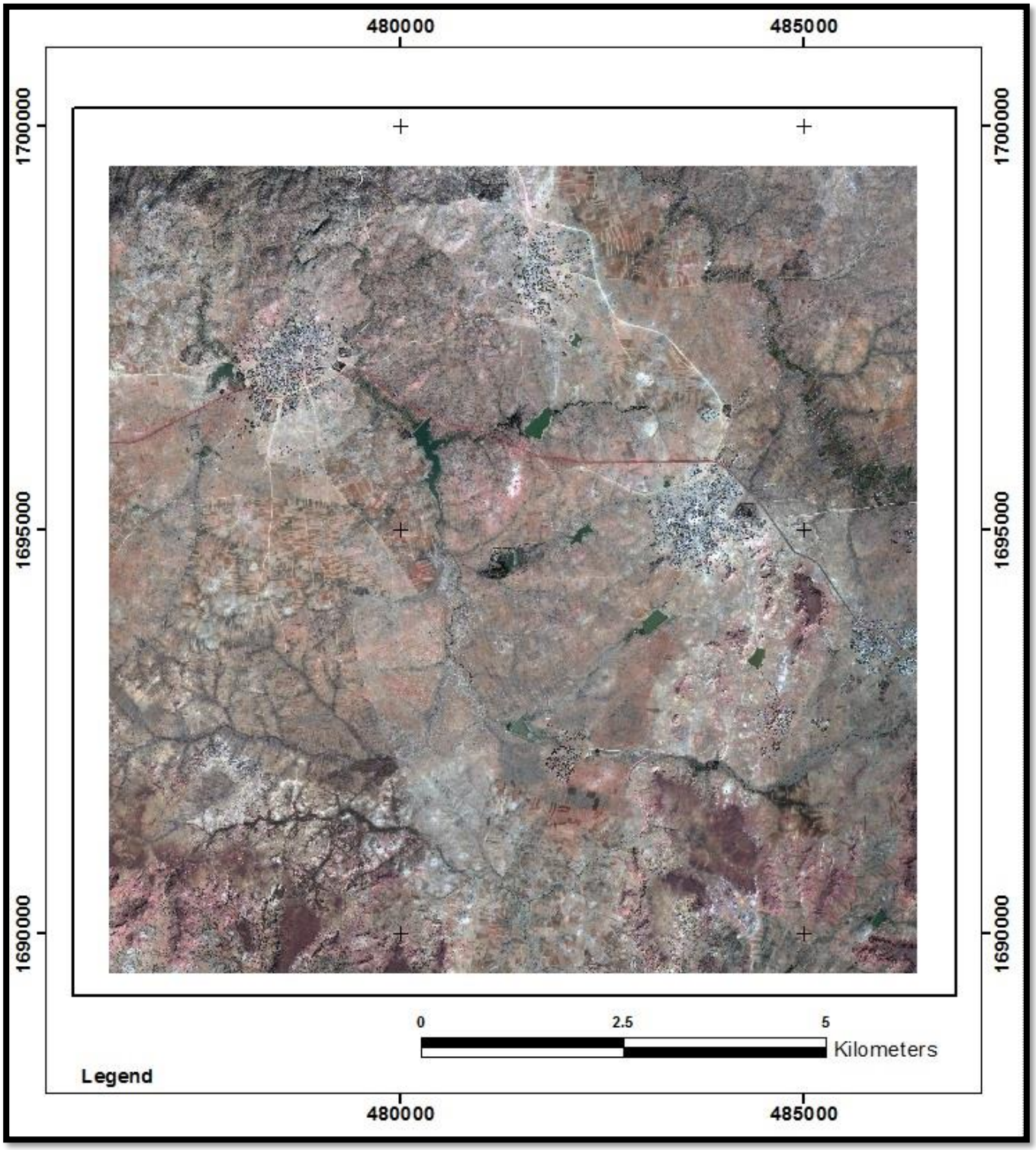

Figure 6. WorldView-2 50cm stereo satellite photo. 10km by 10km area Asmara, Eritrea.

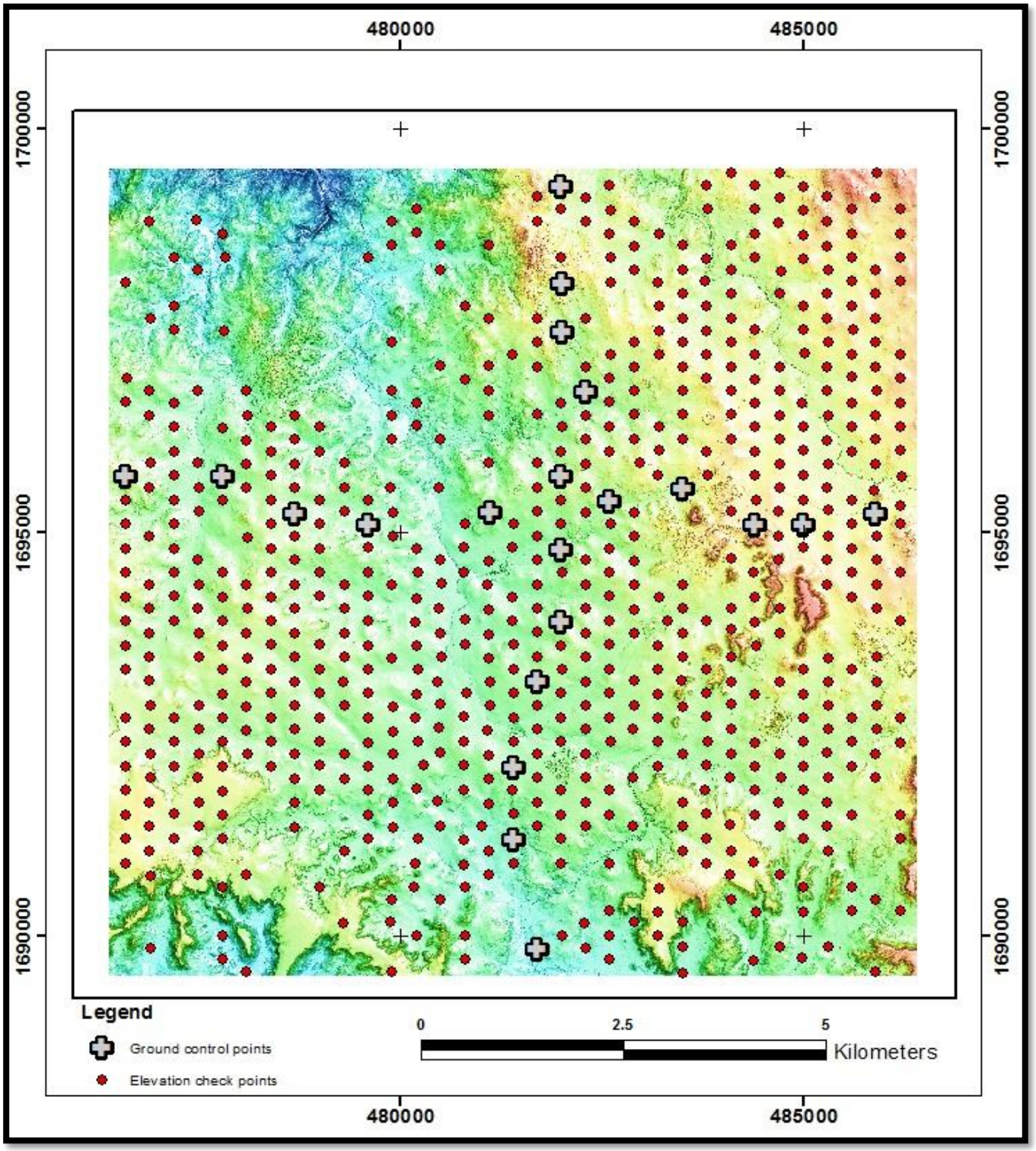

Figure 7. Area of the 10km by 10km Eritrea Stereo WorldView-2 1m posted topographic grid. The figure shows the 21 ground survey points used for ground reference and to attenuate systematic distortions in the stereo WV photos. The ground reference points are shown as white crosses. It also shows the 775 gravity survey stations used as elevation checkpoints to determine the accuracy of the stereo satellite elevation surveying. The checkpoints are shown as dots.

Figure 8. Asmara Project, Eritrea. MWH Geo-Surveys differential GPS survey crew and equipment. Over 45,000 points were surveyed from 2004 through 2008 using differential GPS instruments from Magellan. All of the GPS positions were surveyed in Real Time Kinematic (RTK) mode with accuracies of 2cm or better. 21 of these survey points were used as ground control points and 775 points were used as elevation checkpoints for this WorldView-2 stereo satellite elevation mapping accuracy assessment. The Magellan RTK base with a ProMark™ 500 GPS rover are shown in this photo.

Elevation survey accuracy statistics:

The stereo WorldView elevation surveying accuracy statistics show an accuracy of 14cm RMSE and LE90 of 23cm.

A histogram of the elevation differences between the 775 elevation check points and the stereo WorldView satellite surveying are shown is shown in Figure 9.

The *Guidelines for Digital Elevation Data* of the US National Digital Elevation Program (NDEP) recommends that elevation checkpoints should be chosen in areas with slopes less than 20% grade. The 775 elevation checkpoints with slopes less than 20% grade are shown in Figure 7.

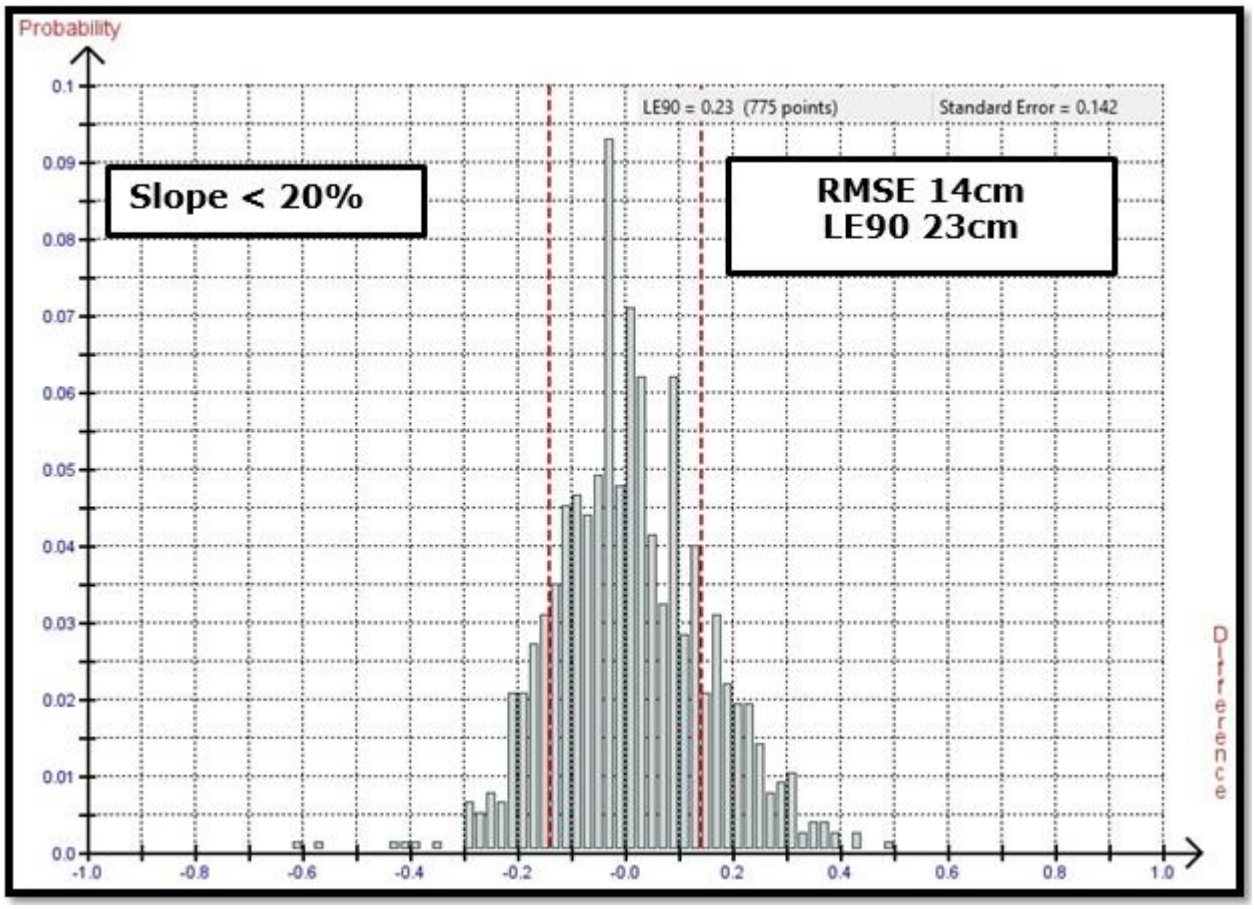

Figure 9. Histogram of the elevation differences between the WorldView-2 stereo satellite elevations for the 10km by 10km area and the 775 elevation checkpoints with slopes less than 20% grade. The *Guidelines for Digital Elevation Data* of the US National Digital Elevation Program (NDEP) recommends that elevation checkpoints should be chosen in areas with slopes less than 20% grade. RMSE 14cm, LE90 23cm.

Comparison between elevation check points and 50cm PhotoSat contours:

The very close agreement between the satellite survey elevations and the ground survey check points can be seen in Figure 10. Labeled 50cm contours are shown with the posted elevations of the ground survey points. This figure is typical of the agreement between the PhotoSat survey and the ground survey over the entire survey area.

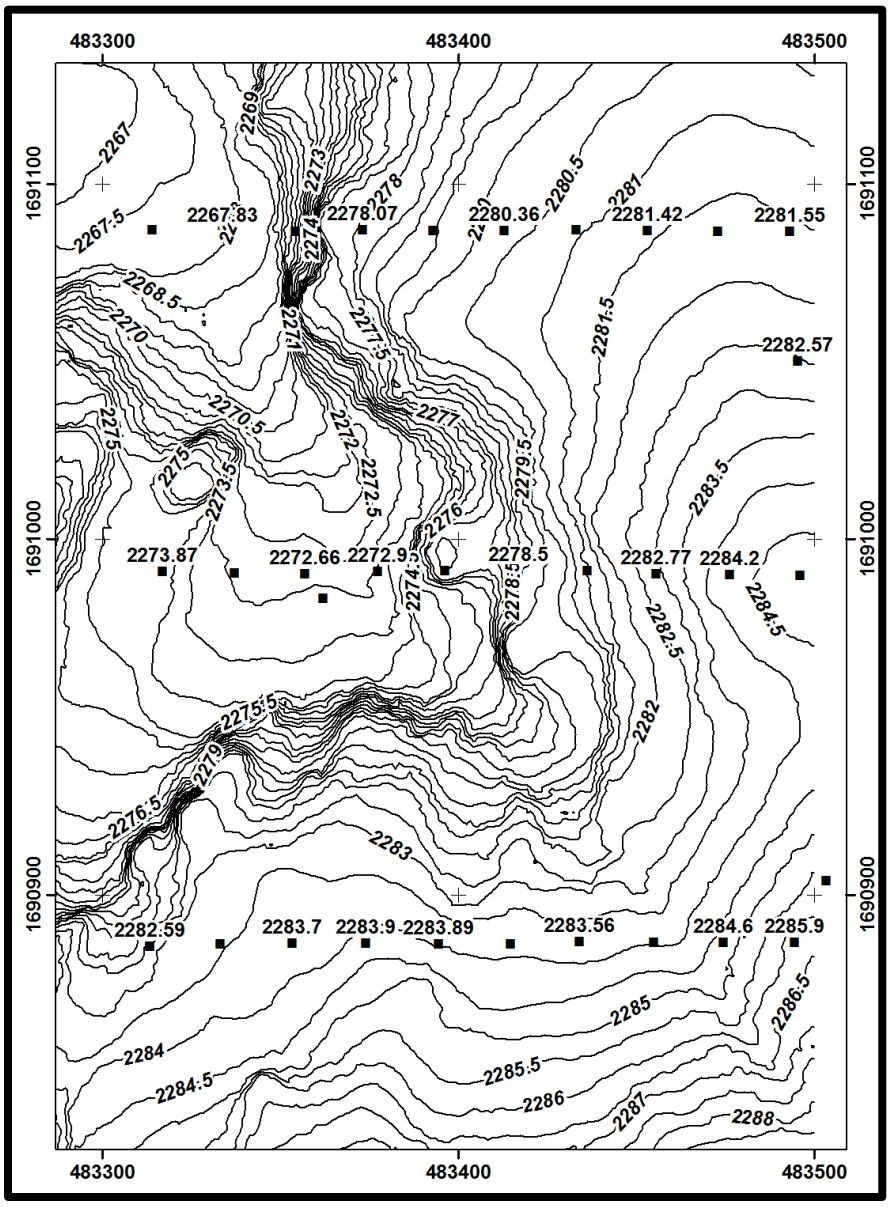

Figure 10. 50cm contours from the stereo WorldView-2 elevation survey showing the close agreement between the stereo satellite survey elevations and the elevations of some of the ground survey points.

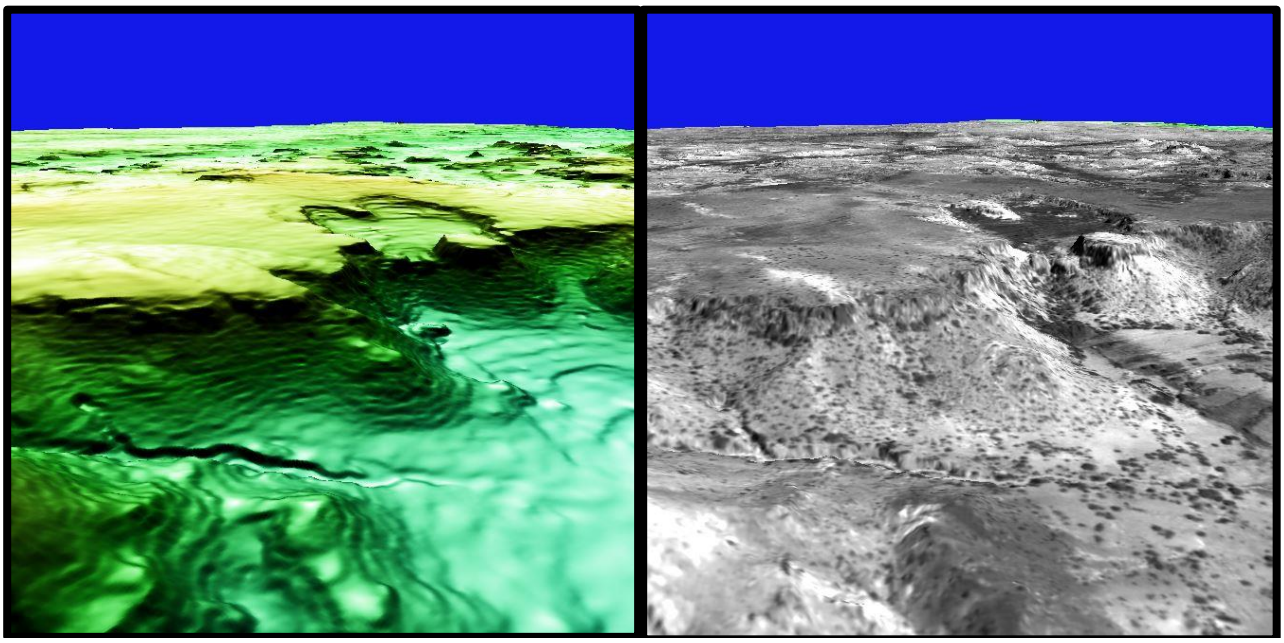

Figure 11. 3D view of 1m topographic grid and 50cm WorldView-2 ortho image.

Qualifying statement:

This is an accuracy assessment for elevation mapping from a single stereo pair of WorldView-2 satellite photos. While in our experience these results are typical for most WorldView-2 stereo photos, these results may not apply to any specific pair of WorldView-2 stereo photos.

References:

A Geophysical Stereo Satellite Elevation Mapping System, Mitchell G & Ehling M, ASPRS 2010 Annual Convention, San Diego, California, USA
http://www.photosat.ca/pdf/asprs_geophysical_mapping_system_2010.pdf

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http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf