PhotoSat
1188 West Georgia Street, Suite 580
Vancouver, British Columbia, Canada, V6E 4A2
Tel: +1 (604) 681 9770

PhotoSat WorldView-3 stereo satellite surveying accuracy study, Asmara, Eritrea, 21 GCP, RMSE 15cm

- **100 km^2 surveyed using twenty one ground reference survey points**
- **This WorldView-3 satellite elevation surveying accuracy is accurate to 15cm RMSE, determined by 881 survey checkpoints**
- **October 2014 WorldView-3 stereo satellite photos processed by PhotoSat in July 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 a 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-3 satellite. The stereo satellite elevation processing referenced twenty one ground survey points. The elevation surveying accuracy was measured with 881 survey checkpoints.

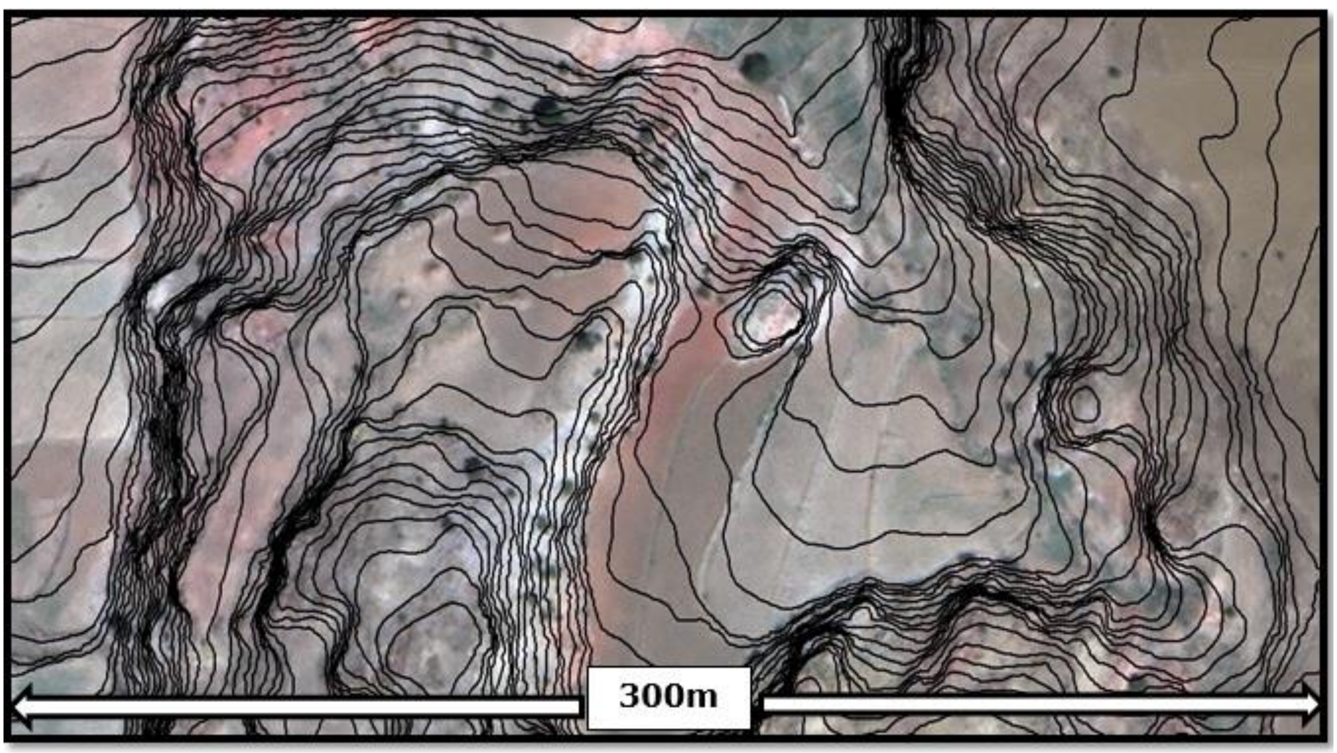

Figure 1. WorldView-3 color image with 50cm contours from the Photosat WorldView-3 survey for the Eritrea test area.

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.

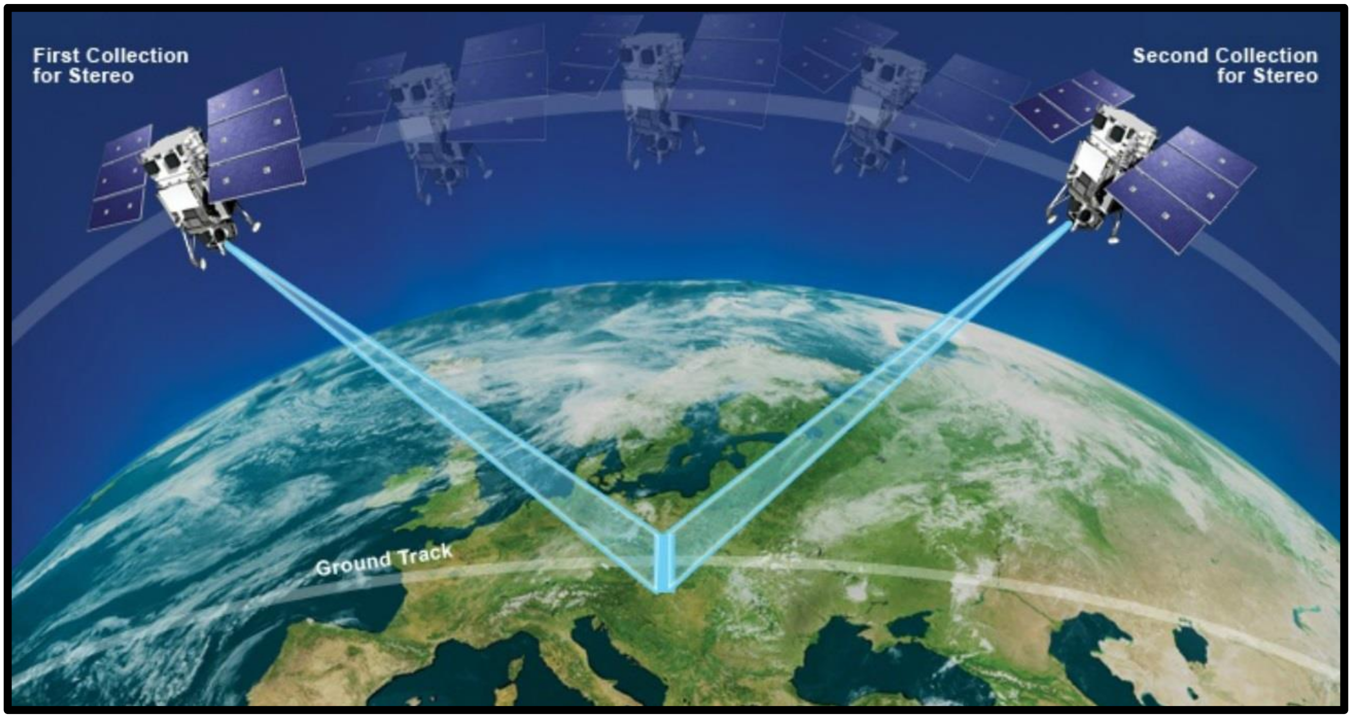

Figure 2. Illustration showing the process of taking satellite stereo photos. The satellite points forward to take the first photo. About one minute later, and 300 km further along its orbital track, the satellite rotates to take the second photo looking backwards along the track. Hundreds of km^2 can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

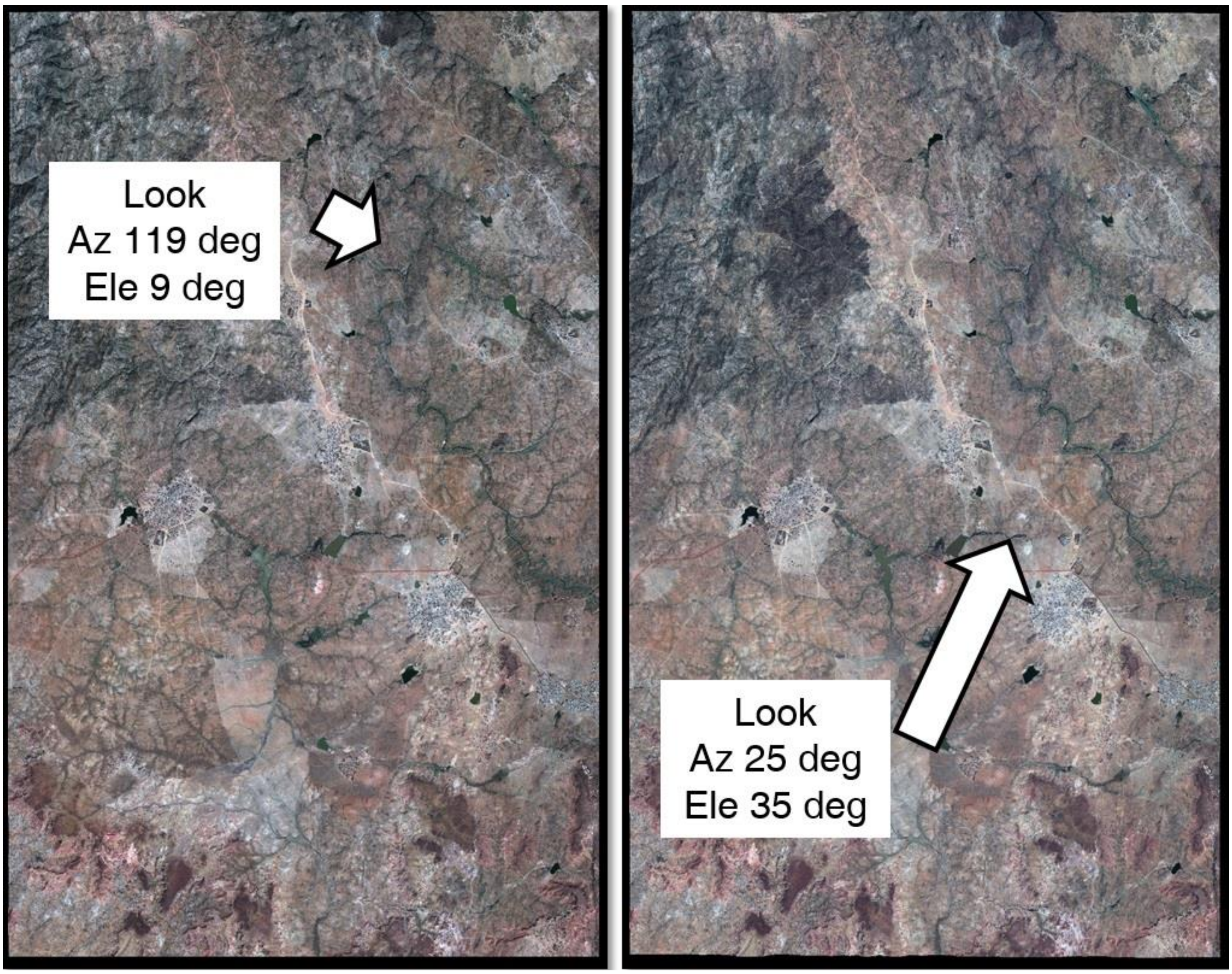

Figure 3. WorldView-3 satellite photos of PhotoSat's Eritrea test area taken on October 30, 2014 at approximately 10:30 AM local time. The photo on the left was taken looking at an azimuth of 119 deg and angle from vertical of 9 deg. The photo on the right was taken looking at an azimuth of 25 deg and angle from vertical of 35 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 36 deg, a bisector azimuth of 40 deg and bisector angle of 18 deg from vertical.

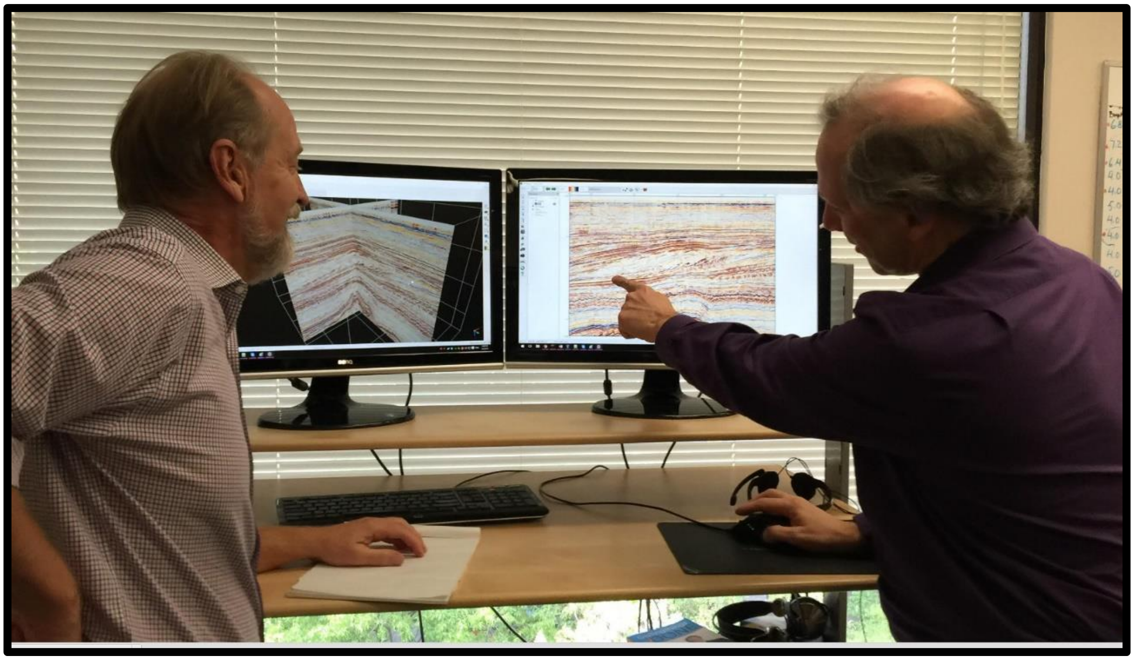

Figure 4. Gerry Mitchell, left and Michael Ehling with an Oil and Gas seismic processing workstation. This technology is the basis for the PhotoSat geophysical stereo satellite processing system named the PhotoSat Process Manager.

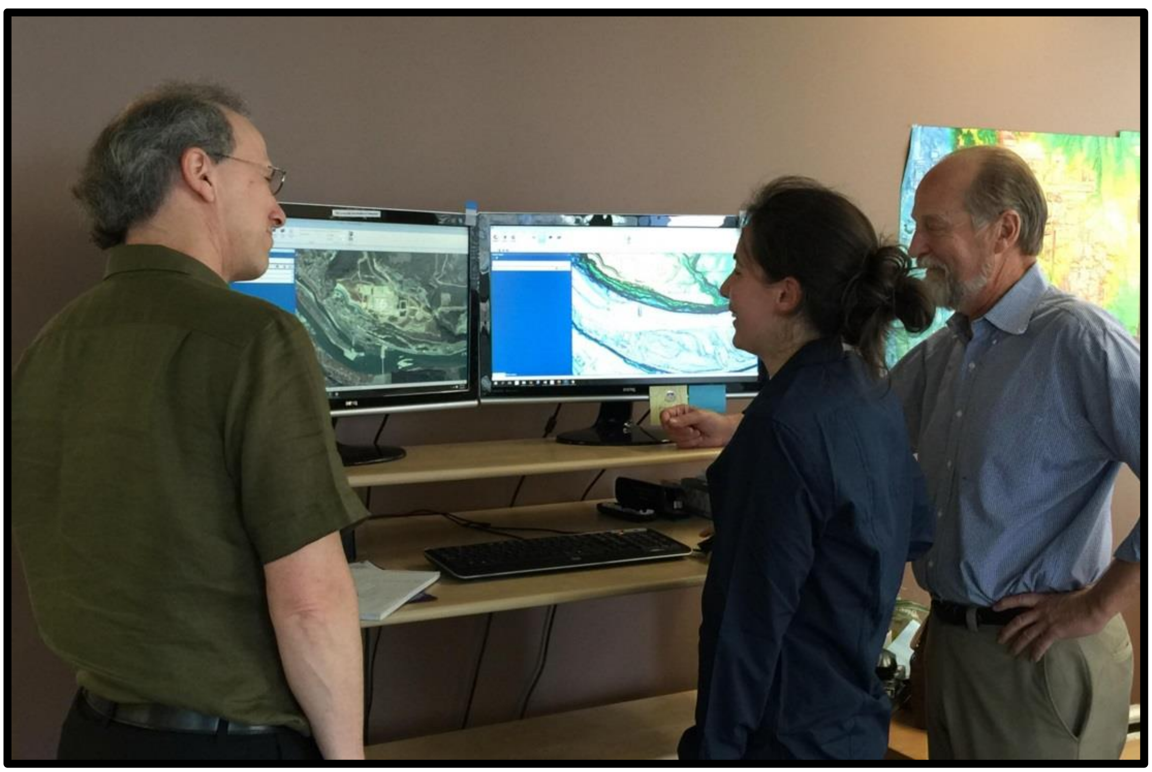

Figure 5. Michael, Gerry and Jayda Akatsuka with the PhotoSat Process Manager.

Eritrea satellite photos:

The pair of stereo WorldView-3 satellite photos over the Eritrea test area are shown in Figure 3. The photos were taken on October 30, 2014 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 36 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 July 2016. An image of the 1m elevation grid is shown in Figure 7. A 50cm resolution WorldView-3 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-3 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 -3.1m E, -50cm N and 2m 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 881 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.

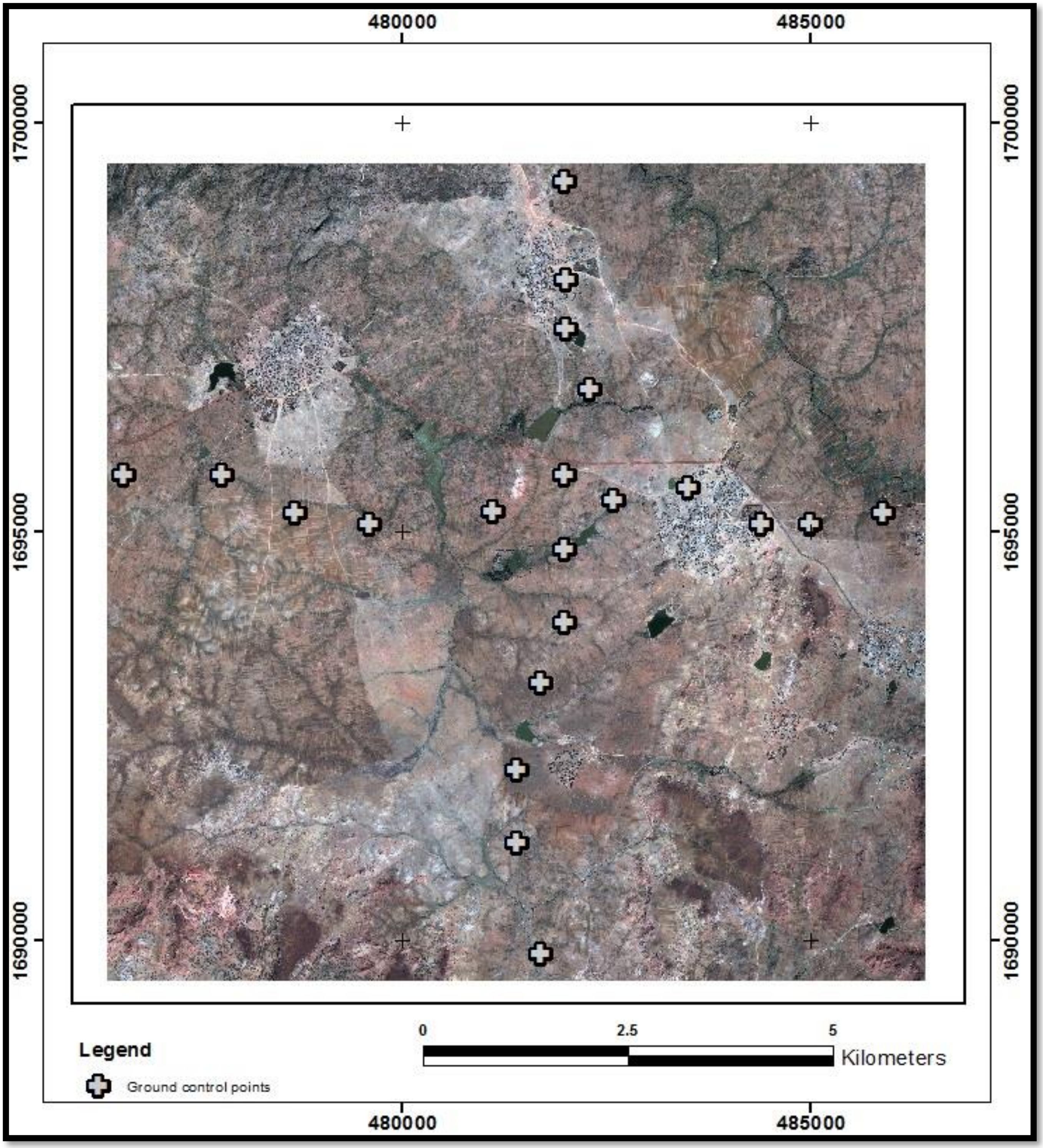

Figure 6. WorldView-3 50cm stereo satellite photo. Asmara, Eritrea.

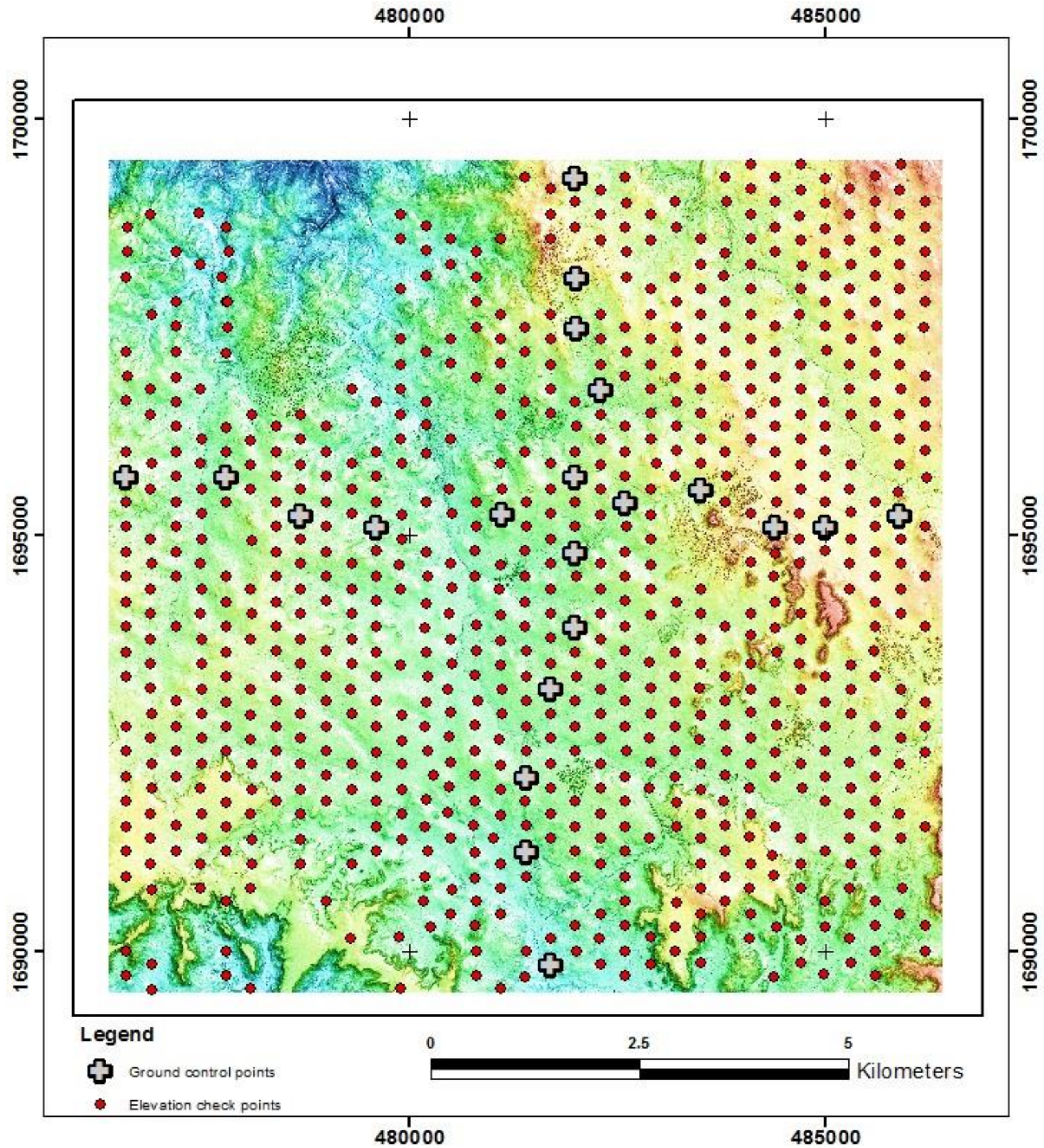

Figure 7. Area of the 10km by 10km Eritrea Stereo WorldView-3 1m elevation grid showing the 21 ground survey points used for ground reference and the 881 gravity survey stations used as elevation checkpoints to determine the accuracy of the stereo satellite survey.

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 point and 881 points were used as elevation checkpoints for the WorldView-3 stereo satellite elevation mapping accuracy assessment. The Magellan RTK base with a ProMark^{TM} 500 GPS rover are shown in this photo.

Elevation survey accuracy statistics:

The stereo WorldView elevation surveying accuracy statistics show an accuracy of 15cm RMSE and LE90 of 24cm.

A histogram of the elevation differences between the 881 elevation check points and the stereo WorldView satellite surveying 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 881 elevation checkpoints with slopes less than 20% grade are shown in Figure 7.

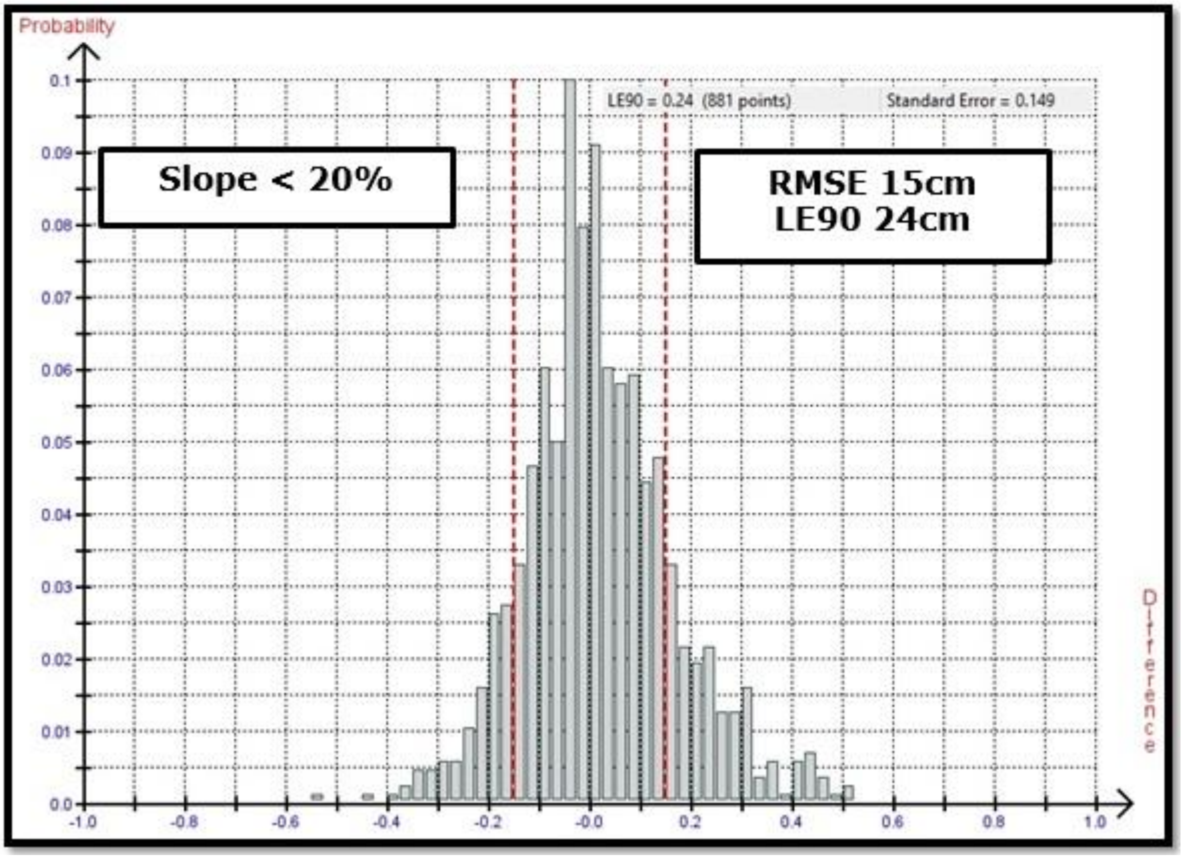

Figure 9. Histogram of the elevation differences between the WorldView-3 stereo satellite elevations for the 10km by 10km area and the 881 elevation checkpoints with slopes less than 20% grade. The *Guidelines for Digital Elevation Data* of the US National Digital Elevation Program (NDEP) recommends that elevation checkpoints should be chosen in areas with slopes less than 20% grade. RMSE 15cm, LED90 24cm.

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 for a small area of one of the dense survey grids. This figure is typical of the agreement between the PhotoSat survey and the ground survey over the entire survey area.

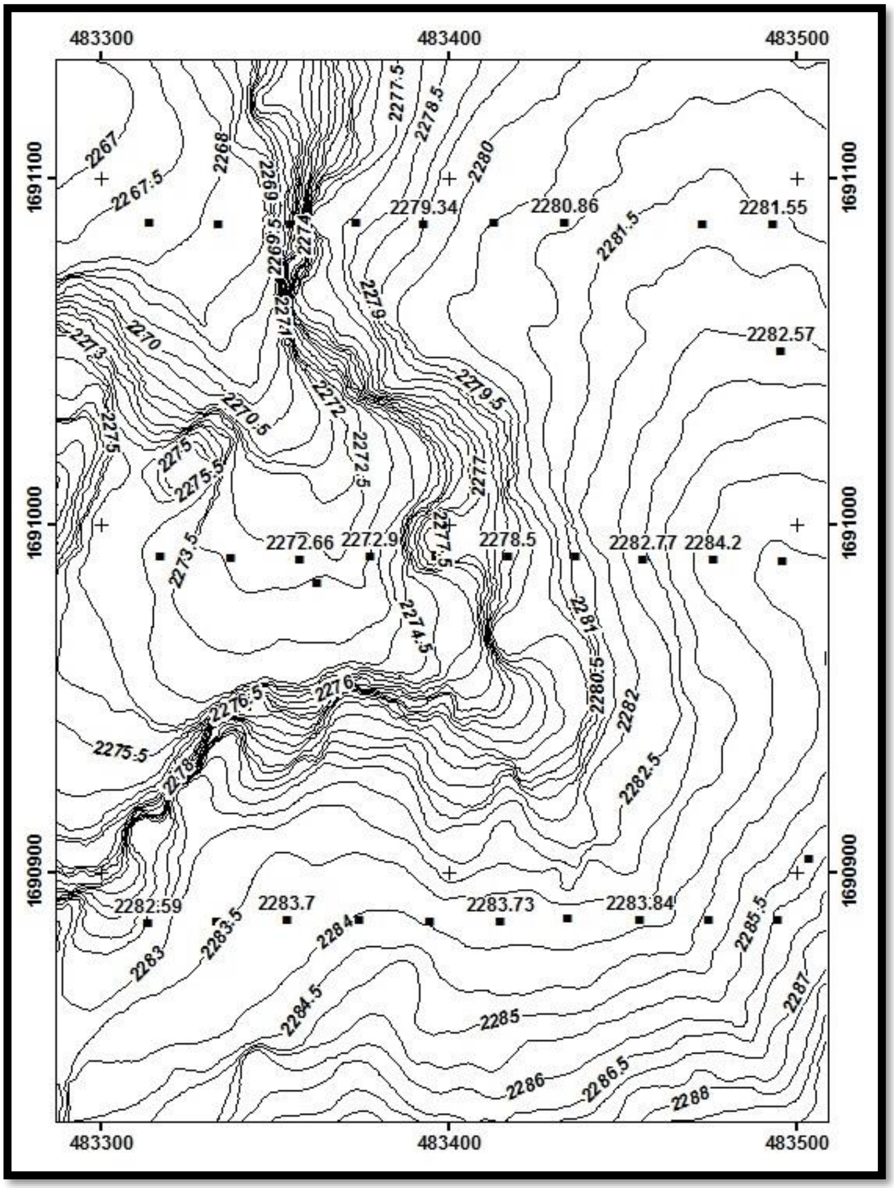

Figure 10. 50cm contours from the stereo WorldView-3 elevation survey showing the close agreement between the stereo satellite survey elevations and the elevations of some of the ground survey points.

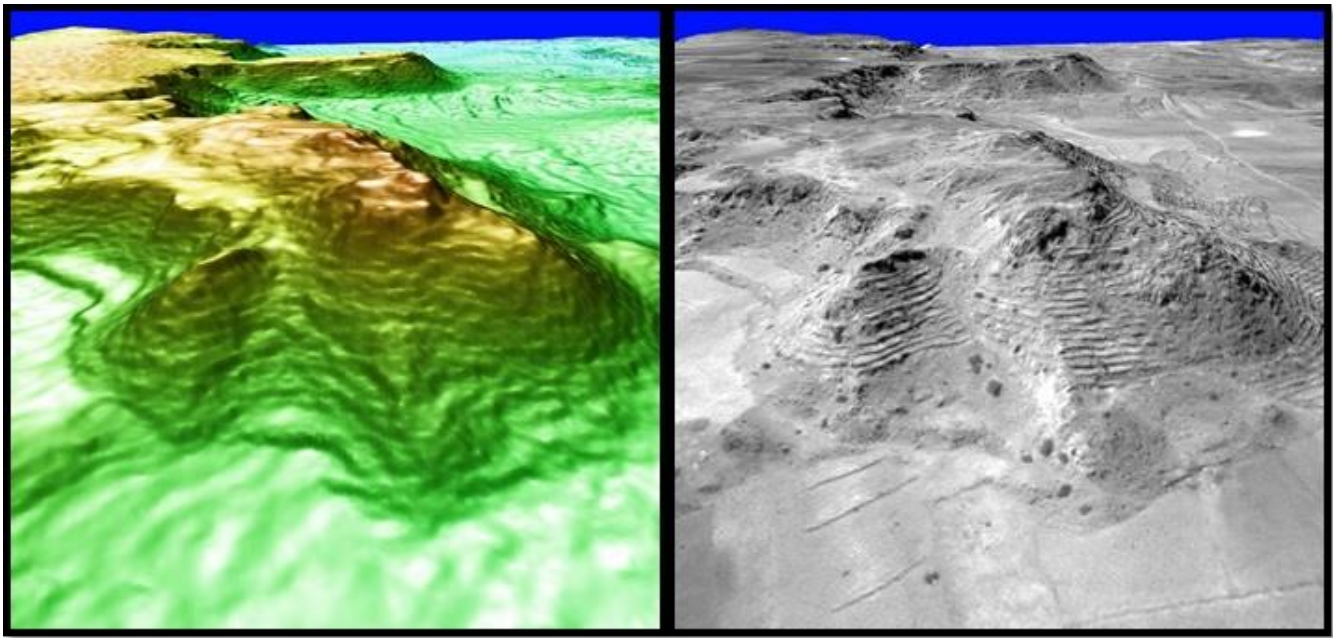

Figure 11. 3D view of 1m topographic grid and 50cm WorldView-3 ortho image.

Qualifying statement:

This is an accuracy assessment for elevation mapping from a single stereo pair of WorldView-3 satellite photos. While in our experience these results are typical for most WorldView-3 stereo photos, these results may not apply to any specific pair of WorldView-3 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

NDEP Guidelines for Digital Elevation Data.
http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf