A GEOPHYSICAL STEREO SATELLITE ELEVATION MAPPING SYSTEM

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ABSTRACT

A significant technological advance has been achieved by applying concepts and software developed for oil and gas exploration seismic data processing to produce detailed elevation maps from the new generation of high resolution satellite photos. We call this a geophysical processing system since the system is developed by geophysicists, using geophysical processing tools, including a 3D seismic workstation, and the processors never view the photos in stereo. PhotoSat has recast the stereo satellite elevation mapping problem so that it closely resembles oil and gas exploration seismic processing. Seismic processors have been matching pixels, that they call time samples, to better than 0.01 pixels for many years. Seismic processors routinely match over 100 coincident images at a time to improve signal to noise ratios in their images from less than 10% to over 500%. While seismic processors map subsurface elevation surfaces rather than surface elevations, there are enough similarities in the problems that we are able to use many of the sophisticated seismic processing tools to process the stereo satellite elevations. By substituting profiles of stereo photo correlation amplitudes as a function of elevation for seismic reflection amplitudes as a function of elevation, we are able to use powerful 3D seismic workstations to display and interpret the stereo satellite correlation profiles. The concept of displaying profiles of stereo photo correlation amplitudes as a function of elevation was first published by Nicolas Paparoditis in 2001.

INTRODUCTION

PhotoSat is applying processing and interpretation concepts and software from the fields of oil and gas exploration and mining exploration geophysics to map elevations from stereo satellite photos. These geophysical concepts, algorithms and software were developed for mapping subsurface geological features from seismic, gravity, magnetic, electrical and electromagnetic surveys. We have discovered ways to effectively apply many of these concepts, algorithms and computer programs to the mapping of surface topography from stereo satellite photos with surprising results.

GEOPHYSICAL INTERPRETATION PROCESS

The procedure used by geophysicists to interpret most types of exploration geophysical surveys may be summarized in three broad steps:

1. Plotting the geophysical field data in ways that facilitate geological interpretation,
2. Making geological interpretations of the the geophysical data plots, and
3. Verifying the geological interpretation by comparing data from numerical models to the geophysical field data.

PLOTTING CONVENTIONS TO FACILITATE INTERPRETATION

To illustrate how geophysicists plot data in ways that facilitate geological interpretation, a plot of a seismic survey "section" is shown in Figure 1. In this plot, the acoustic signals detected by the seismic geophones are plotted at a location midway between the location of each explosive seismic source and each geophone. The acoustic signals are plotted as vertical profiles of the amplitude of the acoustic signal with time increasing downwards. While this is a representation of the seismic data, not a geological cross section, it is quite easy to identify vertical layering in the geological section and horizontal variations in some of the layers.

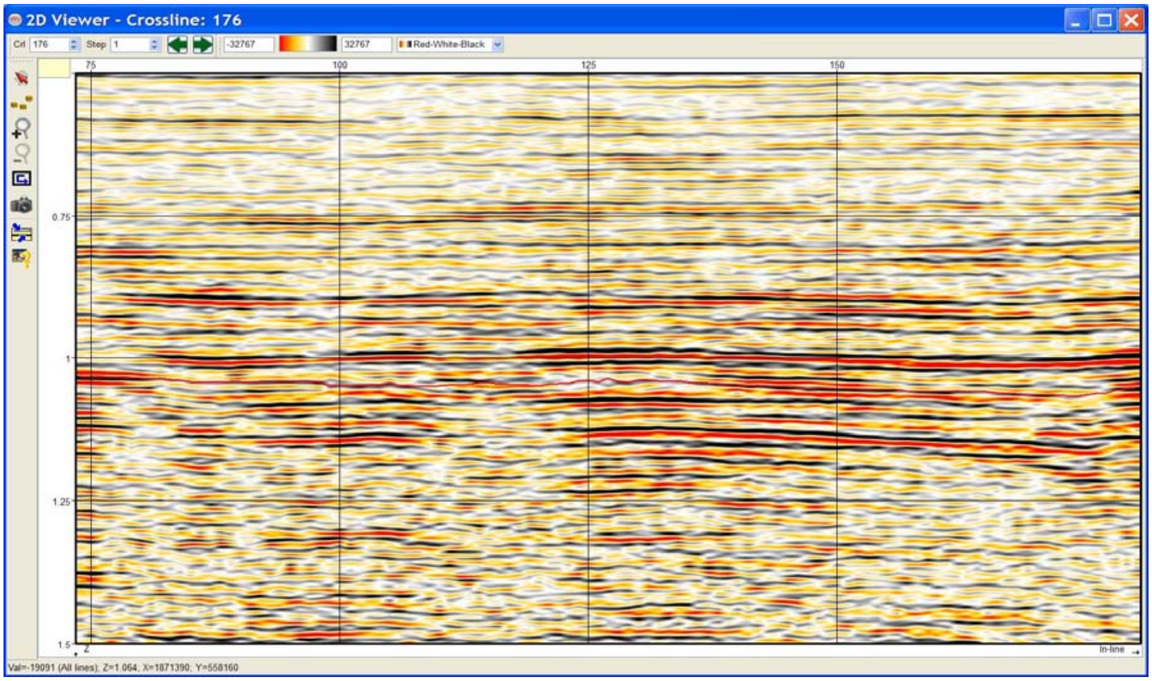

Figure 1. Seismic section showing the amplitudes of the acoustic signals recorded on seismic geophones. The acoustic signals originate from a large number of individual explosive seismic shots. The acoustic amplitude profiles are plotted in colour with the time after the seismic shot increasing downward towards the bottom of the plot. Each acoustic profile is plotted midway between the seismic shot and geophone location. This is not a geologic cross section; it is simply a plotting convention that facilitates the interpretation of the geologic cross section.

CROSS SECTIONS OF THE CORRELATIONS BETWEEN STEREO SATELLITE PHOTOS

In order to visualize the relationship between stereo satellite photos in a way that facilitates the interpretation of surface topography, we developed a process to calculate the correlation between the stereo photos as a function of elevation. We believe that profiles of correlation as a function of elevation were first proposed by Nicholas Paparoditis in 2001. This concept is illustrated in Figure 2. The strongest correlation between the photos will usually occur at the elevation of the ground surface at each location.

A cross section of stereo satellite correlation profiles for a pair of GeoEye-1 photos across a hill in Northeast Mexico is shown in Figure 3. The hill is readily apparent and easy to interpret in this plot of the stereo satellite photo correlations.

A plot of stereo GeoEye-1 correlation profiles with the correlation amplitudes represented as colours is shown in Figure 4. In this example, there is a bare ground upland and a valley with both bare ground and a grove of trees. It is fairly easy to recognize the strong correlations from the bare ground and the the weaker correlations and short wavelength elevation variations from the trees in the valley. This plot is generated with OpendTect, a free, open source 3D seismic workstation.

With this development, we believe that we have clearly succeeded in making plots of the stereo satellite photo data that facilitates the interpretation of the topographic surface. We have a display of the data in which we can easily identify the hills, valleys and in some places, trees and buildings, without having done any interpretation.

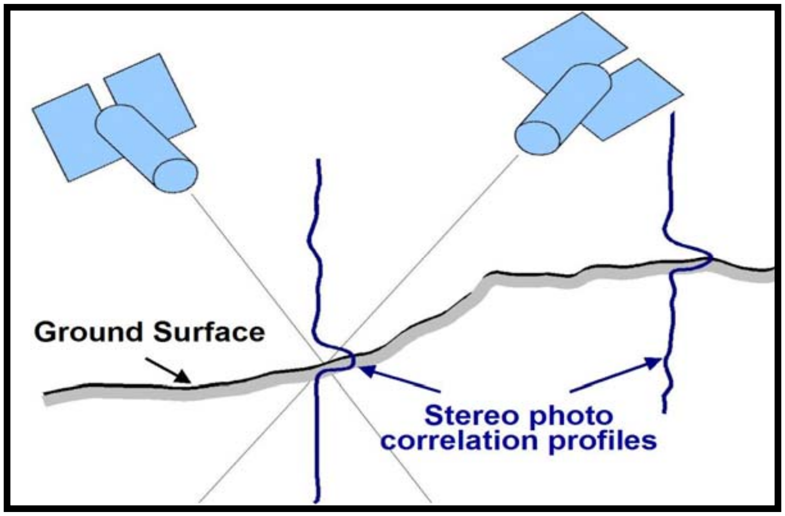

Figure 2. The correlations between stereo satellite photos plotted as a profile of the correlation amplitude as a function of the elevation.

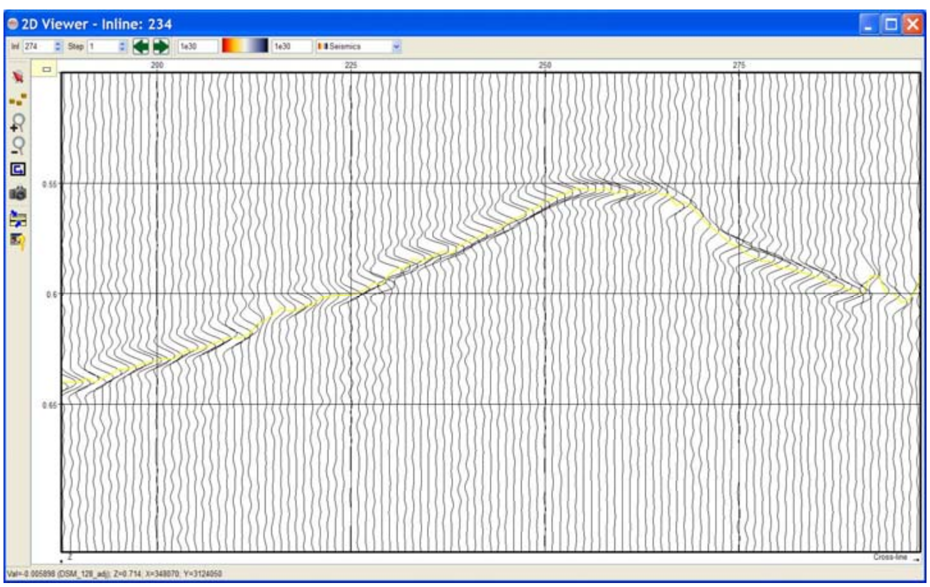

Figure 3. Cross section of stereo photo correlation profiles from GeoEye-1 stereo photos across a hill in Northeast Mexico. The correlation profiles are displayed in the OpendTect 3D seismic workstation.

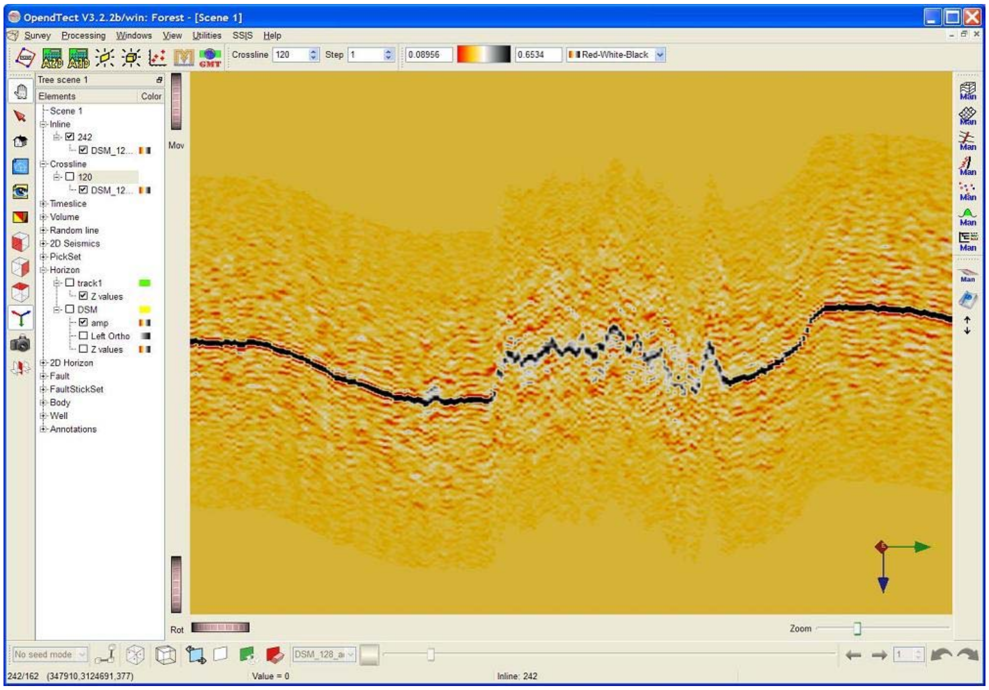

Figure 4. Cross section of stereo GeoEye-1 correlation profiles for a project in Northeast Mexico displayed in the OpendTect 3D seismic workstation. Strong correlation amplitudes are shown in dark colours and weaker correlation amplitudes are shown in red.

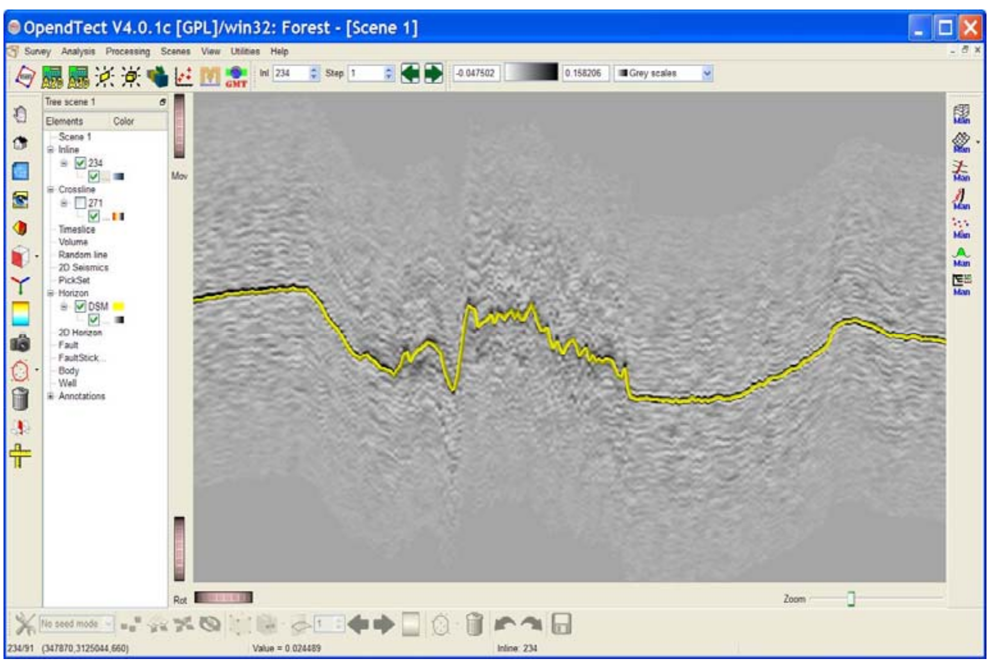

Figure 5. Cross section of the correlation profiles in the OpendTect 3D seismic workstation, showing the automatic picking of the highest correlation amplitude on each profile. On most of the correlation profiles, this pick represents the reflective surface, either bare ground or tree and building tops.

INTERPRETATION OF THE BARE GROUND TOPOGRAPHIC SURFACE

To make maps of the bare ground elevations in areas of trees and buildings, where the bare ground surface is not visible in the stereo satellite photos, we can interactively interpret the bare ground elevations. Figure 7 shows an example of the interpretation of bare ground elevations through a grove of trees.

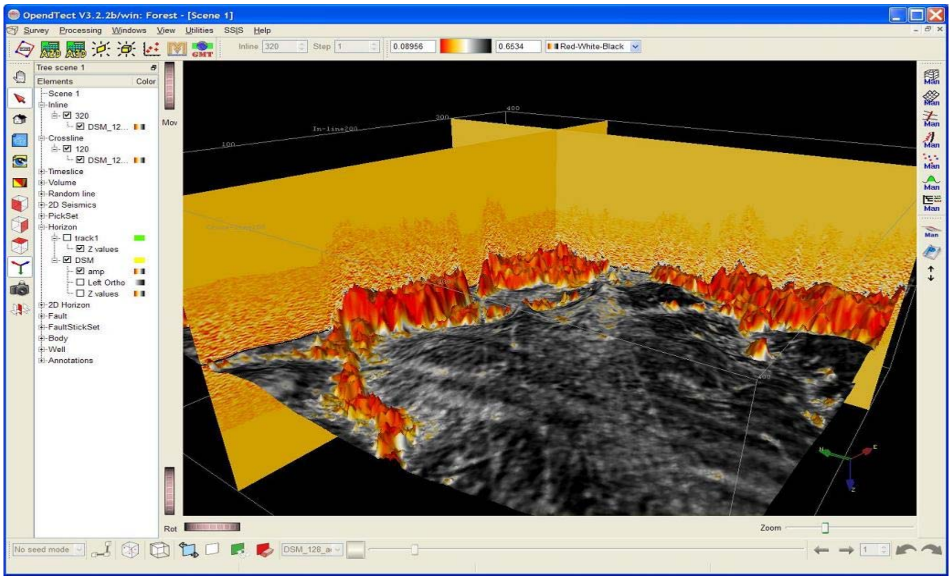

Figure 6. 3D display of the interpreted reflective surface in the OpendTect 3D seismic workstation. The colours displayed on the surface represent the correlation amplitudes. The combination of the correlation amplitudes and the surface elevations clearly differentiate the trees from the bare ground.

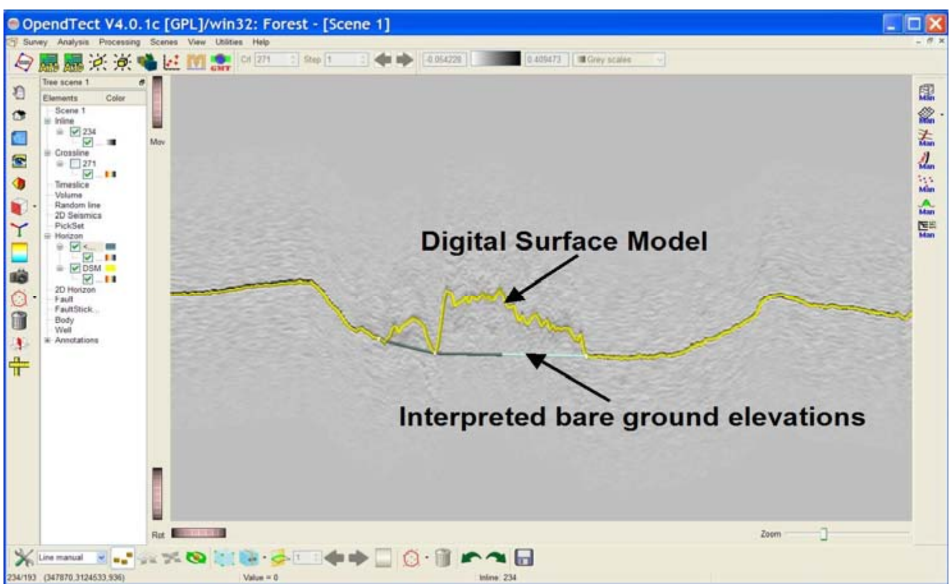

Figure 7. Cross section displayed in the OpendTect 3D seismic workstation, showing the interpretation of bare ground elevations.

VERIFYING GEOPHYSICAL INTERPRETATIONS

Geophysical interpretations are commonly verified by comparing numerical models of the interpretation to the geophysical field results. This verifies that the interpreted geological structure will indeed produce the observed geophysical response.

The dilemma for the geophysical interpreter is that, while the model results match the data, there are an infinite number of models of subsurface geology with different geometries and physical properties that will also exactly match the geophysical field data. The modeling process will tell the interpreter that the interpretation is possibly correct but not that it is correct. Usually the only way to determine which model correctly represents the subsurface geology is to drill.

VERIFYING STEREO SATELLITE ELEVATION INTERPRETATIONS

Unlike geophysical interpretation where there is never a unique interpretation, there is always some unique topographic surface that will exactly match each pair of stereo satellite photos. When both photos are projected onto the correct topographic surface, the photos should match each other exactly. Mismatches between the stereo photos when they are projected onto the same topographic surface may be due to errors in the topographic surface, distortions in the photos or errors in the transformation used to project the photos on the surface.

We test the topographic surface produced by our elevation mapping process by projecting the two photos onto the surface and creating a movie that switches the display between the two photos. For a correct digital surface model, there should be no motion in the movie. For a correct digital terrain model, the areas of bare ground should be motionless and the trees and building should flicker back and forth as the photos switch.

RESULTS

Since we began developing the Geophysical Stereo Satellite Elevation Mapping System in Q4 2007, PhotoSat has completed over 50 stereo satellite elevation mapping projects using the system. In December 2009, we did a direct comparison of stereo GeoEye-1 elevation mapping and LiDAR elevation mapping in Southeast California. Figure 8 shows the comparison of the LiDAR Digital Elevation Model (DEM) and the stereo GeoEye-1 DEM for this area. The standard deviation of the elevation differences between these DEMs is 25cm.

We have also carried out quantitative accuracy assessments for stereo pairs of IKONOS, GeoEye-1, WorldView-1 and WorldView-2 photos. The results of an elevation mapping accuracy assessment for a 260 km^2 stereo WorldView-1 elevation mapping project in Chihuahua Mexico are shown in Figures 9, 10 and 11. On the Chihuahua project, using a single ground control point and 1,115 independent elevation checkpoints, the stereo satellite elevation mapping accuracy is 19cm Root Mean Square Error (RMSE).

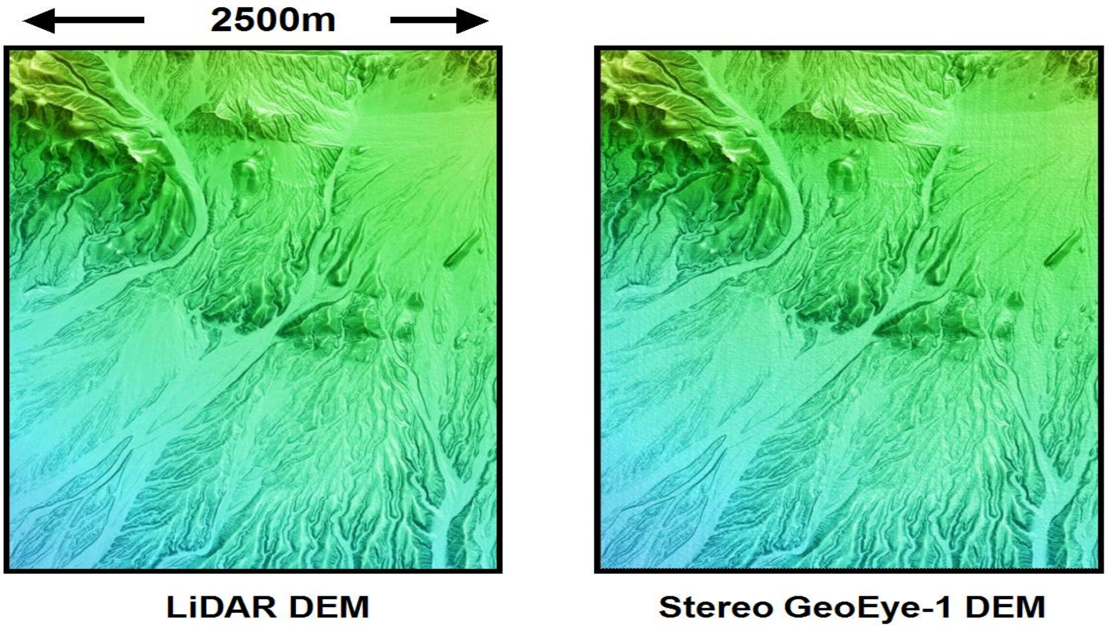

Figure 8. Images of a 1m LiDAR DEM and a 1m stereo GeoEye-1 DEM from the same area in Southeast California. The LiDAR DEM was produced by OpenTopography and is available from the www.OpenTopography.org website. The standard deviation of the elevation differences between these two DEMs is 25cm.

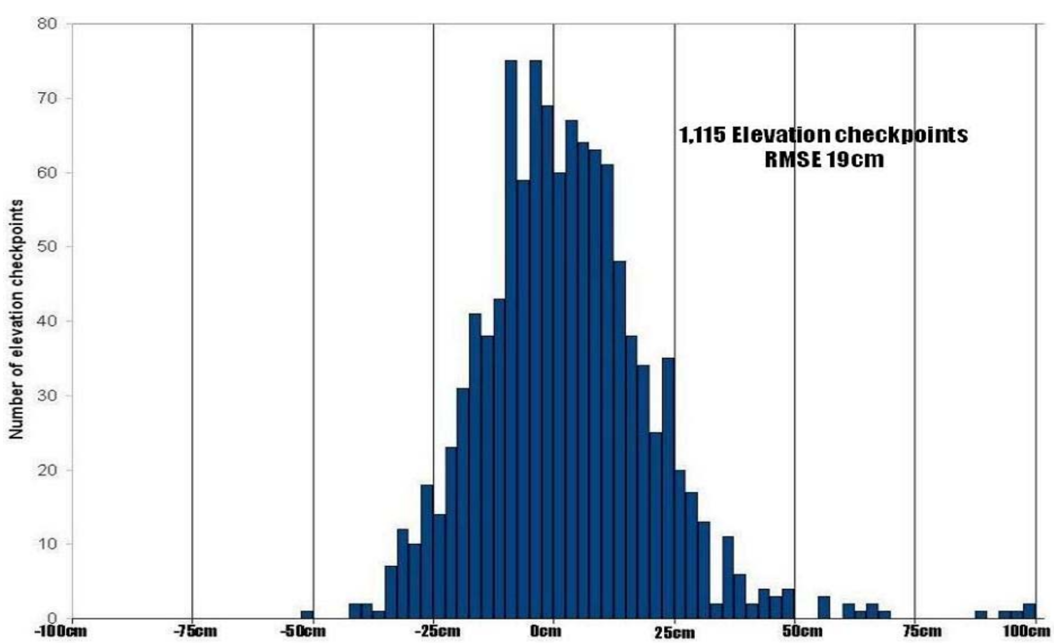

Figure 9. Histogram of the elevation differences between the stereo WorldView-1 elevation mapping and the 1,115 elevation checkpoints for the 260 km^2 project in Chihuahua, Mexico, shown in Figure 10. RMSE 19cm.

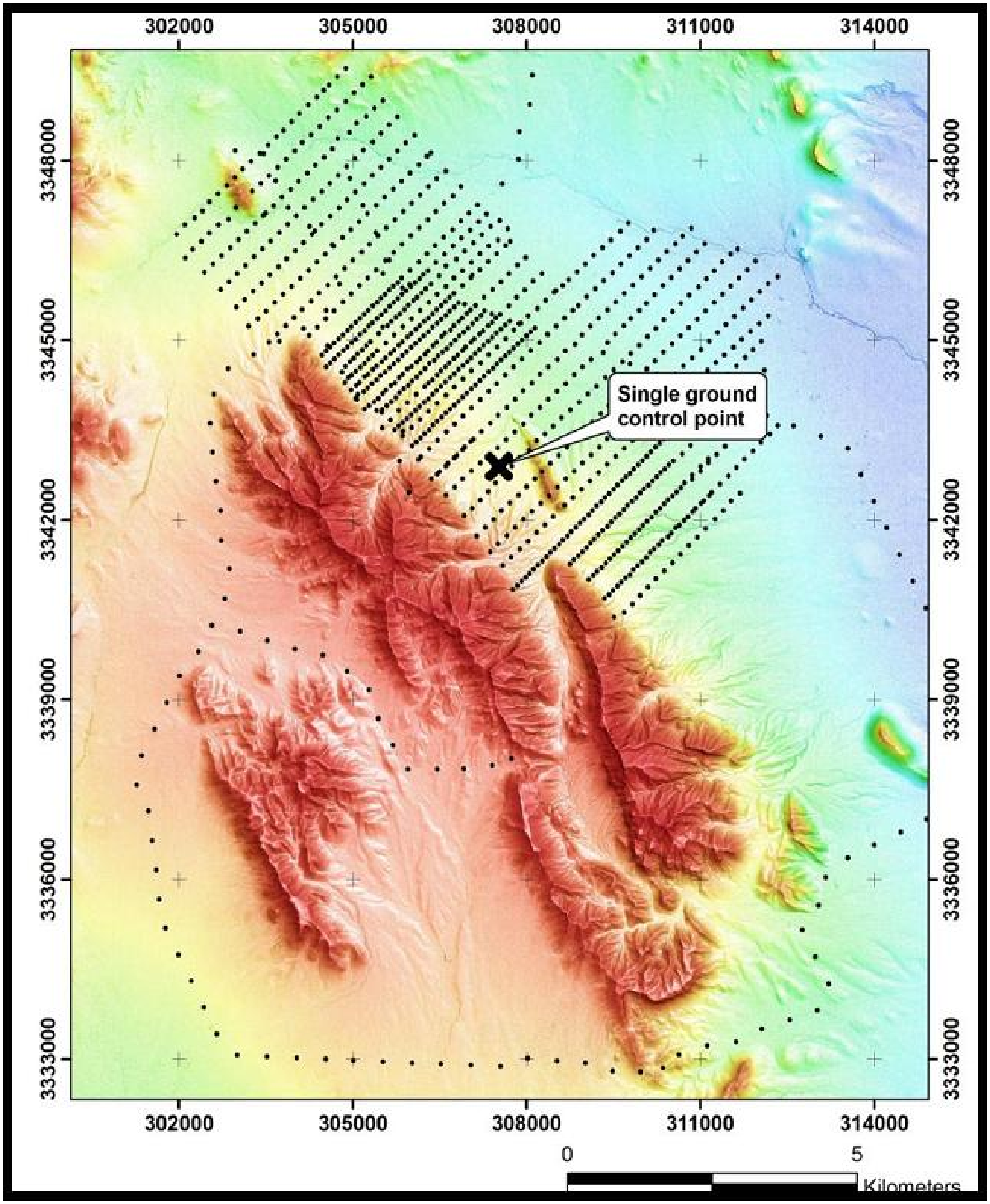

Figure 10. Image of a 1m DEM for the 260 km^2 stereo WorldView-1 elevation mapping project in Chihuahua, Mexico. The entire mapping project was referenced to a single ground control point shown in the figure. The elevation mapping accuracy of 19cm RMSE was determined by the 1,115 elevation checkpoints shown in the figure.

Figure 11. The single ground control point used to reference the 260 km^2 stereo WorldView-1 elevation mapping project in Chihuahua, Mexico.

REFERENCES

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

OpendTect. Open Source Seismic Interpretation System, http://opendtect.org.

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

Paparoditis, N., 2002. 3D Data Acquisition From Visible Images, *In: Digital Photogrammetry,* Taylor & Francis, New York, pp. 168-220.