A COMPARISON OF AUTOMATICALLY EXTRACTED ORBVIEW-3 AND IKONOS ELEVATION DATA TO SHUTTLE RADAR TOPOGRAPHY MISSION DATA

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ABSTRACT

Upon completion of the SRTM project, assessing the accuracy of the SRTM elevation data and its correlation to conventional photogrammetric methods has been a focus for many research projects. To date, elevation models derived from OrbView-3 and IKONOS have not had a significant number of comparisons to SRTM data. This study attempts to quantify the relative differences between elevation data collected under the SRTM program against OrbView-3 and IKONOS digital elevation models on a common point-by-point basis. Through the use of automated tie point matching and automated elevation extraction algorithms commonly employed in commercial software, and using no ground control points, elevation datasets were created and compared. It is hypothesized that approximately a ten meter elevation difference between the three datasets will be present with IKONOS elevation accuracy being more consistent with the SRTM dataset than OrbView-3 data. Results indicate that the SRTM elevation data, relative to OrbView-3 and IKONOS, demonstrate an 8.71 and 8.62 meter difference respectively at a ninety percent confidence interval for the study site in Santiago, Chile. Mean error differences between OrbView-3 and SRTM elevations is -8.74 meters while mean error differences for IKONOS is 0.96 meters. Further investigation was performed and it was discovered by removing the “outer” one percent of data that the mean error decreases between 33% and 54% and that correlation between SRTM and OrbView-3 and SRTM and IKONOS elevation models is above 99.8%.

INTRODUCTION

The Shuttle Radar Topography Mission (SRTM) in February of 2000 systematically mapped the Earth’s topographic features at a higher resolution and much larger scale than ever before. Across most of the Earth’s landmass, three arc-second elevation data is available for public use and one arc-second elevation data is currently available for the United States. Conventional aerial and satellite photogrammetric methods had been employed for many years to compile elevation data across the globe but at a very high economic cost. Also, access to remote geographic areas, cloud cover and political differences can make data acquisition difficult for conventional mapping methods so the SRTM project was born.

The purpose of this project is to compare elevation models extracted by satellite imagery to elevation data distributed out of the SRTM project. It is hypothesized that the difference between the datasets will not differ too greatly from previously published accuracy assessments, or approximately ten meters of vertical difference. In order to quantify the differences, a stereo pair of image data from GeoEye’s OrbView-3 and IKONOS satellites is employed, elevation is extracted and then compared on a common point-by-point basis between the datasets and the SRTM elevation data.

LITERATURE REVIEW

Extraction of terrain using conventional photogrammetric means is not uncommon in professional literature and the process for elevation extraction is well documented. Since the SRTM project completed the data acquisition phase in 2000, data validation and comparison of elevation data to previously collected data has also been available in the literature. A condensed review of the literature presents a baseline for the methodology employed in this study as well as the expected results.

SRTM Data and Accuracy

The Shuttle Radar Topography Mission, completed in February of 2000, is probably the largest and most comprehensive topographic mapping mission ever completed. Essentially, all latitudes between north 60^o and south 58^o were imaged using interferometric synthetic aperture radar (Rodriguez *et al*., 2005). Over 99.96% of the land area visible to the Space Shuttle Endeavour during the mission was mapped and various fill methods were used to complete the remaining 0.04% of the data which were due to relief or poor returns over water bodies or arid features. (Kobrick, 2006)

The accuracy of the SRTM project is quantified and the elevation errors range from 4.7 meters to 12.6 meters depending upon the geographic location in the world. South America ranges from 5.5 to 9.0 meters. (Rodriguez *et al*., 2006) Utilizing kinematic GPS, and NGA DTED data sources, potential sources of SRTM error are noted. The potential error sources are primarily radar based in nature and include phase errors, beam differential errors, timing and position errors and baseline roll errors. (Rodriguez *et al*., 2006) Interestingly enough, the same authors compared DTED Level 2 data (3-arc second postings) to the SRTM dataset and over South America noted a 16.88 meter difference at a 90% confidence level but with the inclusion of additional control information, the accuracy increased from between 5.5 to 9.0 meters for the South American continent.

In comparing SRTM data to the national elevation dataset across the United States, it was also determined that decimation of the SRTM data to 2-arc seconds statistically fits best with the "true" resolution of the SRTM dataset. (Guth, 2006) As an extension, a possible horizontal difference in the dataset due to the smoothing and removal of data could lead to differences in vertical accuracy as additional ambiguity as to the actual data posting is increased.

Satellite Elevation Extraction

The extraction of three dimensional elevation data from satellite imagery collected as stereo pairs has a very robust and documented history where much of satellite photogrammetry is based upon the methodology and processes developed from the aerial photography realm. LPS' OrthoBASE user's guide, LPS' Field Guide and LPS' Terrain Editor Tour guides document the commonly used methodology for terrain extraction from aerial and satellite stereo imagery. This methodology is employed in this study and these guides were used as the basis for the approach used here.

IKONOS has published accuracy specifications for terrain models of twenty-two meters without ground control and three meters with sufficient ground control. (Grodecki, 2001) Later, a more comprehensive comparison using twenty-four stereo pairs was conducted using IKONOS data. No ground control and only rational polynomial coefficients (RPC's) were used and the resulting accuracy was 10.1 meters at a ninety-percent confidence interval. (Dial and Grodecki, 2003) A generic sensor model has been documented using SPOT and aerial data for terrain dependent and terrain independent models where both scenarios show a requirement of ground control points in order to obtain the best accuracies. (Tao and Hu, 2001)

Comparisons of satellite extracted elevation datasets to SRTM has also been completed using the Quickbird satellite. Areas of rugged terrain demonstrated an error of thirty meters vertically while areas of gentle relief have a vertical accuracy of three meters. (Cheng and Chaapel, 2006)

Additionally, OrbView-3 specifications note a vertical accuracy for Basic Enhanced 1:50,000 scale (geopositioning based upon tie points of stereo imagery) of eight meters. (OrbView-3 Product Catalog, 2006)

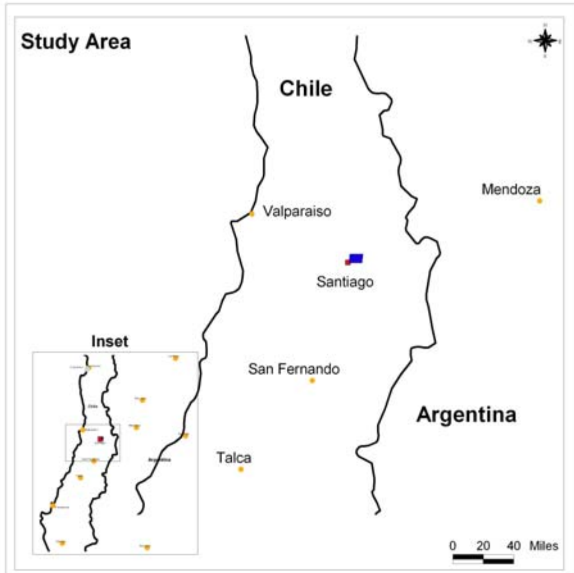
METHODOLOGY

As demonstrated by the literature review, a standard production methodology is employed that will compare the difference in elevation extracted from conventional satellite photogrammetric means and SRTM elevation datasets. A description of the data and the methodology employed in this study is described in this section.

Data - Site Selection

Chile is a country in South America that is approximately twice the size of Montana and borders Argentina, Bolivia and Peru whose capital city is Santiago (CIA World Factbook 2006, https://www.cia.gov/cia/publications/factbook/geos/ci.html). In 2003, the population of Chile was approximately 15,665,000 with a population growth rate of just over one percent (CIA World Factbook 2003, https://www.cia.gov/cia/download2003.htm). See Map 1 for the location of the study site relative to the local region.

The study site selected is an area east of Santiago, Chile in South America of approximately 90 square kilometers with a varying terrain from approximately 550 to 1050 meters above sea level. Multiple land covers dominate the landscape and include a primarily urban/suburban landscape but also include forest, agriculture and transportation. Figure 1 is a JPEG of the study site.



Map 1 - Study Site

Figure 1. Study Site Overview.

Data Selection

OrbView-3 and IKONOS data was chosen for several reasons. The primary reason was to compare the relative accuracy of high-resolution satellite data sources to a global radar dataset. This allows for comparison between two very different sensor types (active and passive sensors) with very different missions. Furthermore, the satellite data was available with currency that is similar (within four days) and at no cost to the author.

Once the satellite sensor platforms were chosen, a stereo collection area that has coverage at the same location as the SRTM project as well as imagery assessed at zero percent cloud cover was queried. A set of suitable stereo pairs near Santiago, Chile was selected with the following parameters shown in Tables 1 and 2. All parameters noted are from the metadata included with the imagery used in this study.

Table 1. OrbView-3 Image Information for Study Site

Collection Date	Collection Time (GMT)	Roll Angle	Elevation Angle	Azimuth Angle	GSD (m)
12/30/2003	14:45:52.908	-18.99	63.28	60.96	1.178133
12/30/2003	14:46:32.904	-19.94	62.92	142.09	1.1903875

Table 2. IKONOS Image Information for Study Site

Collection Date	Collection Time (GMT)	Scan Azimuth	Elevation Angle	Collection Azimuth	GSD (m)
12/26/2003	14:53	180.03	76.1356	67.9182	0.86
12/26/2003	14:54	180.03	65.18895	167.7151	0.95

Data Preparation and Terrain Extraction

As noted earlier, a standard methodology is employed that is common for satellite, and to some extent aerial, photogrammetric missions and is the same procedures as documented well in Leica's Photogrammetry Suite OrthoBASE and OrthoBASE Pro User's Guide. The following steps are taken and study specific information for each task is explained in more detail below.

- Import
- Model Setup
- Relative Triangulation
- DTM Generation
- Post-by-post elevation extraction and comparison of elevation data

Data Import

The image data is imported into Leica Photogrammetry Suite (LPS) where standard image statistics and pyramid layers are calculated to aid in the further processing of the data. Elevation data from the SRTM project was downloaded from NASA's Jet Propulsion Laboratory (ftp://e0srp01u.ecs.nasa.gov/) and imported into Leica's *.img format which require data preprocessing to note the number of samples and rows and image formatting among several other parameters (SRTM Processing – Erdas, http://www.tectonics.caltech.edu/gis/reference/srtmproc_imagine.html). The SRTM elevation data was also subset (mosaiced) from the standard one-degree by one-degree delivery methodology, into an area just larger than the footprint of the stereo pair. Once completed, both the image data and SRTM elevation data is ready for further processing.

Model Setup

The stereo pairs, once imported into LPS, must have orientation parameters calculated and stored for the triangulation process. These parameters are known as interior orientation and exterior orientation. Interior orientation, from a satellite photogrammetry perspective, is the correlation between the image coordinates and the file coordinates (or line and sample coordinates) for a given image. Exterior orientation is based upon the use of sensor attitude and ephemeris or telemetry data which includes such parameters as the position of the satellite with respect to the center of the Earth, velocity and sensor attitude information. (Leica Field Guide) Using the rational polynomial coefficients (RPC's) provided by the vendor, both the interior and exterior orientation parameters are automatically calculated for use in the triangulation solution.

Relative Triangulation

Aerial triangulation uses the interior and exterior orientation parameters, along with measured control points, to create a mathematical model of the relationship between image or file coordinates and a ground coordinate system. There are two types of triangulation methodology commonly employed: relative and absolute. Relative triangulation only uses common points between each image and calculates the parallax between the two points. These points are selected and measured based upon image matching techniques such as autocorrelation along epipolar lines. In other words, no ground control points are required nor used and as such the vertical and horizontal accuracies are typically worse than an absolute triangulation which uses surveyed or known ground locations.

For this study, a relative triangulation method is employed utilizing the measurement of more than 350 system selected points per stereo pair. No points were added manually and no points were removed from the system generated points. A final triangulation equation, using a second-order polynomial solution, was run and a final RMSE of 0.2983 meters was obtained. A sub-pixel shift within the x- and y- directions demonstrates that the solution is adequately co-registered and the extraction of elevation should provide consistent results.

Digital Elevation Model Generation

The image based elevation model is calculated from parallax between the same geographic location but with different perspective views from each image in the stereo pair. Automated methods are employed to extract the digital elevation model from the image data stereo pair. LPS uses an autocorrelation methodology which first locates points of interest and then determines the location of the corresponding point in the other image within the stereo pair and finally matches the point and extracts an elevation based on the parallax between the two points. (LPS OrthoBASE and OrthoBASE ProUser’s Guide, 2003)

From the image data, elevation points were measured on an approximately thirty meter posting basis which is three times the average sampling rate of the SRTM dataset. More than 30,000 elevation postings were extracted from the stereo pairs for further analysis and comparison to the SRTM elevation data.

Data Export

A three-dimensional shapefile of each posting from the stereo pair and the SRTM data was generated by LPS and exported for use in ESRI’s ArcView. A triangulated irregular network was then calculated using the image based elevation model to allow for elevation extraction on a post-by-post basis that is the exact same as the SRTM elevation data.

Post-by-post Elevation Extraction and Comparison

Using the image based TIN and SRTM x- and y-postings, new elevations are extracted so that original SRTM and stereo pair elevation values are known on a common point-by-point basis. The data table within the shapefile then contained x- and y- postings and elevations for SRTM, OV3 extracted elevation and IKONOS extracted elevations. Statistics (maximum, mean, standard deviations) and comparisons can then be drawn and examined to determine trends in the data. Maps and plots of the error values can also be generated to visualize the results in a different method than standard tabular statistical methods.

RESULTS

The elevation values of more than 11,000 points were calculated from the interpolated surface of the stereo pair TIN whose postings coincide with SRTM postings. A table of the standard statistics (all units in meters) is shown in Table 3.

Table 3. Summary Statistics

	Minimum	Maximum	Mean
OV3 (all points)	568	1036	684.615
IKONOS(all points)	572	1047	691.985
SRTM	571	1047	693.402

As can be seen from Table 3, the overall content of the elevation data from each of the data sources is very similar, and in fact, both datasets are 99.8% correlated (see Figures 2 and 3). The mean difference between SRTM and the OV3 datasets is -8.73 meters and the consistency of the data at the 90^{th} percentile is 8.71meters. The mean difference for the IKONOS dataset relative to the SRTM data is 0.96 meters and 8.63 meters at the 90^{th} percentile. In other words, ninety percent of all postings in the OrbView-3 derived elevation model will be within plus or minus 11.75 meters of the SRTM elevation posting and ninety percent of the IKONOS elevations will be within 8.63 meters of the SRTM posting.

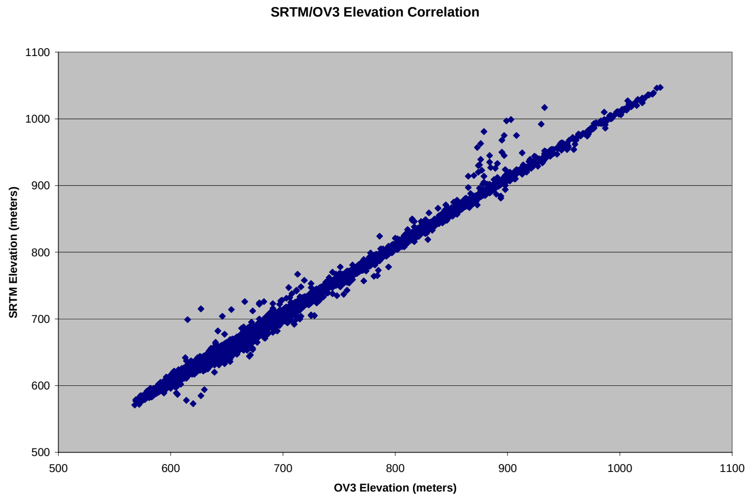


Figure 2. SRTM/OV-3 Correlation.

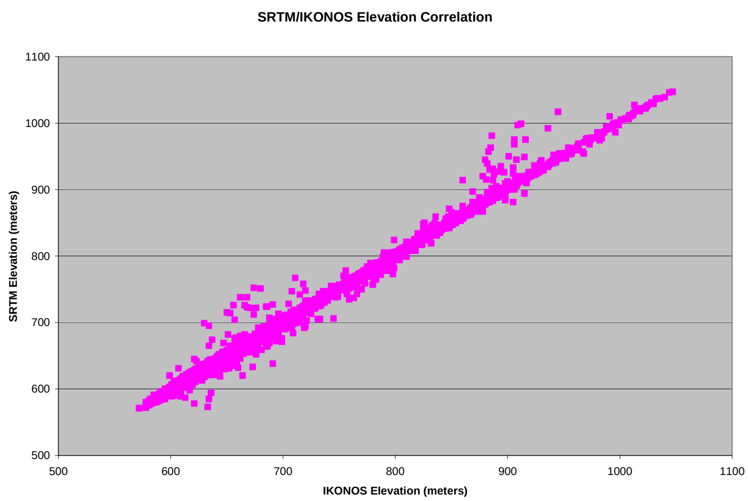


Figure 3. SRTM/IKONOS Correlation.

Data Trim

Interestingly enough, by removing the outer one percent of data which is typically the most inaccurate due to highly off-nadir viewing angles, the accuracy of the terrain model increases drastically. The mean OV3/SRTM is reduced to -8.54 meters and the consistency of the data at the 90th percentile is 6.54 meters while the IKONOS data improves to 0.73 meters and 5.59 meters respectively. This represents an improvement between 1% and 21% simply through removing statistical outliers (greater than three standard deviations difference between the individual satellite elevation point and the SRTM elevation point). Figures 4 and 5 are graphical depictions of the data after the removal of the outlying points.

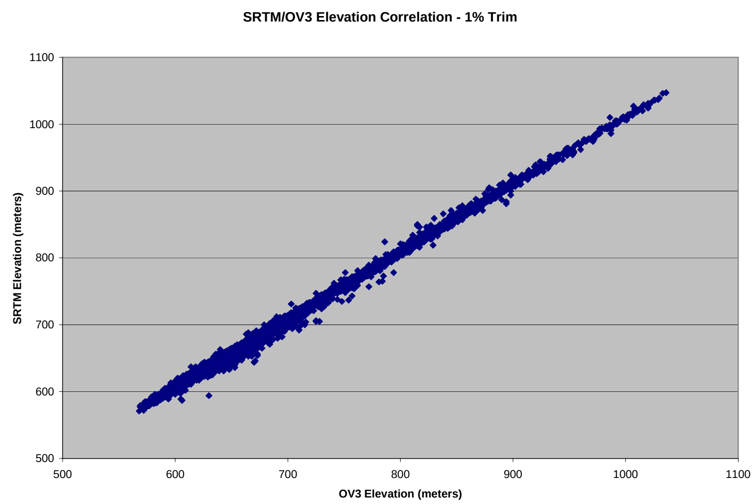


Figure 4. SRTM/OV3 Data Trim.

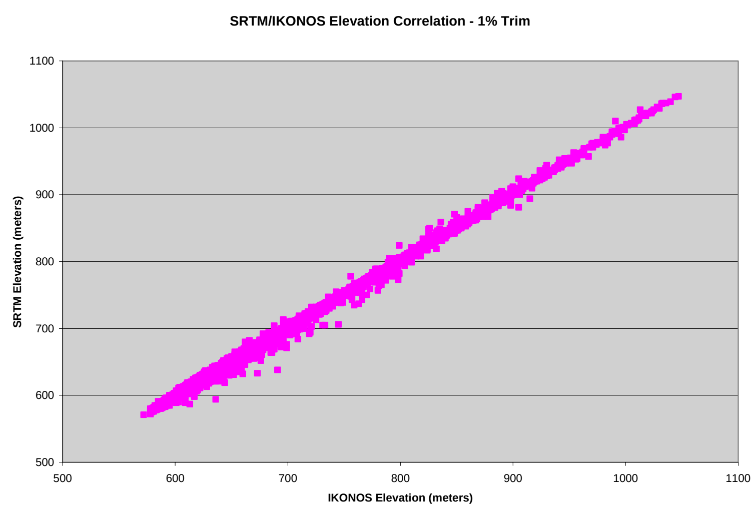


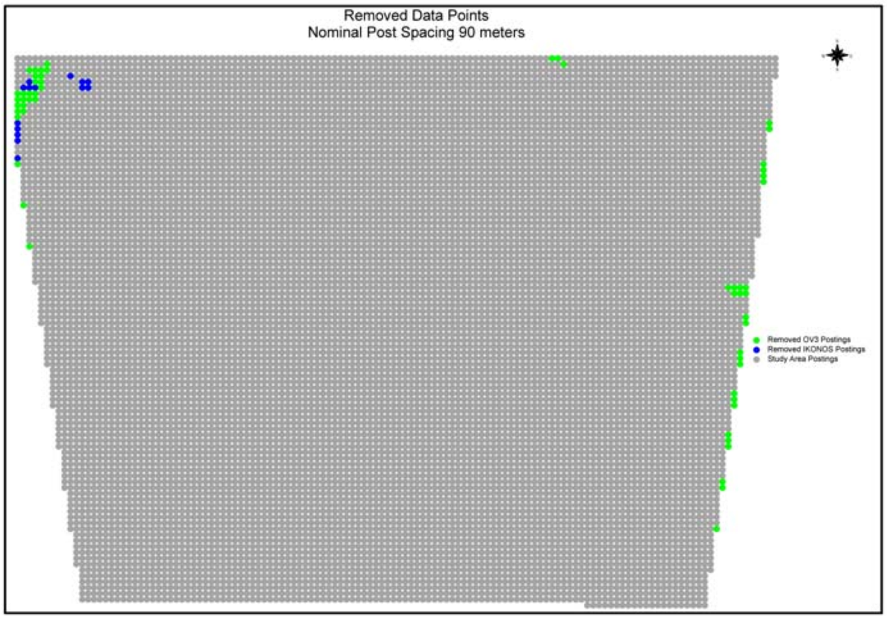
Figure 5. SRTM/IKONOS Data Trim.

The data that was removed was primarily on the eastern and western edges of the study area. These are the areas of the image where the perspective of the sensor in relation to the ground is typically the least geometrically similar to the rest of the image. Furthermore, the only data that were removed were greater than three standard deviations from the mean value (z-score greater than +/- 3.0). Another constraint placed upon the data trim was that no point could be removed if it were greater than six postings from the farthest extent of the dataset (nominally 0.5 kilometers). In other words, no points from within the interior of the study area were removed.

DISCUSSION

The results correspond well with the hypothesized results of the study and also the literature. Interestingly, the OrbView-3 data consistently provided estimated values below the SRTM data points while the IKONOS elevation postings were far less noisy. Additionally, far fewer IKONOS points were removed and those points that were removed were extremely large outliers. In many cases, the IKONOS elevation points should have been flagged as suspect points due to poor correlation results or would typically be caught in a stereo viewing environment during normal QA/QC operations.

Another trend that appears in the data is the results along the outer edges of the study area which appear to have higher elevation differences than those throughout the rest of the dataset. It may be that the spurious results are likely due to confusion within the autocorrelation algorithms during the elevation extraction phase of the study. LPS uses epipolar geometry to search for potential autocorrelation sites and as such may have been confused with shadows, by a function of sun angle or by other natural features which may confuse the autocorrelation algorithm. This is particularly evident in the northwestern portion of the study area where there is a change in elevation which could explain the potential autocorrelation errors in the area. Also, this does not suggest that the software uses an incorrect autocorrelation algorithm but operator notification of low confidence when such cases arise would be preferable. Furthermore, as noted earlier, the outer edges of satellite image data is also the least geometrically accurate, which also leads one to believe that the best results are from the internal portions of the study area.



Map 2. Potentially Spurious Samples

Trimming the outer edges of the data improves the accuracy by as much as twenty percent in some circumstances. It would be recommended that when or if one was using satellite imagery for elevation extraction, that they increase their area of coverage by a small amount to use the inherently more accurate center of the image scenes. In this case, trimming six postings from all edges (removing the outer half-kilometer) would remove all spurious results and still leave a relatively large area intact for exploitation purposes.

CONCLUSIONS

Using a previously established methodology, IKONOS and OrbView-3 have demonstrated a very high correlation (99.6+%) with SRTM elevation datasets using only ancillary data from the satellite and no ground control points. With 90% of the OrbView-3 elevation points within +/- 11.75 meters of SRTM elevation points, in areas where little to no ground control is available, or in areas where an updated elevation dataset is needed, OrbView-3 can be used to obtain a digital elevation model similar to the SRTM dataset. IKONOS improves upon that accuracy to +/- 8.63 meters. Both of these values are well within the specifications provided by GeoEye for LE90 values.

Overall, the relative accuracy with which the IKONOS and OrbView-3 dataset compares with SRTM elevation values was as expected and also slightly better than other literature mentions. However, no ground control points were used in this study. It is believed the inclusion of three to five ground control points in a stereo pair would increase the accuracy to a vertical difference of substantially better accuracy. The product catalog for both satellites (IKONOS and OrbView-3) include this scenario as value-added products but unfortunately no suitable ground control was available for this study. (GeoEye, 2006)

AVENUES OF CONTINUED RESEARCH

There are several potential avenues of research to extend this study. One would be to include up to five ground control points and calculate the difference with the inclusion of each ground control point to determine when diminishing returns occur for IKONOS and OrbView-3 geometric fidelity and when including additional ground control points have no effect on the accuracy of the elevation extracted. Secondly, another method which could increase the vertical accuracy of the elevation models is having additional stereo pairs that overlap the same region but from different dates and different look angles to strengthen the triangulation solution. Thirdly, the removal of spurious tie points and smoothing processes run over a resultant OrbView-3 DEM could enhance the vertical accuracy as well. Another approach would be to extend the experiment and perform comparisons to areas around the world, over different land covers and over different topographic extremes.

The most promising possibility would be to use a currently established geometric calibration range with sufficient ground control points and sufficient stereo pairs to perform the accuracy evaluation on a much larger scale and to also withhold ground control points for accuracy assessment of both datasets. This would lead to much more scientific and conclusive results regarding the comparative accuracy of IKONOS and OrbView-3 extracted DEM's and the SRTM dataset.

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