MULTIPLE DEM MEASURED ACCURACY

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ABSTRACT

Multiple Digital Elevation Models of varying resolutions and accuracies are compared in a pair-wise and sequential manner using multiple registration algorithms. The results from these comparisons are assessed to evaluate the differences in accuracies between pair-wise and sequential registrations. Measured results include horizontal error and pre/post shift absolute and relative vertical errors. Relationships between assessed errors and scene relief, as well as DEM spatial frequency, are examined. Differences between the pair-wise and sequential comparisons are assessed for evidence of spatial aliasing due to the capability of the finer post spacing to support higher spatial frequencies. The potential for improvement of existing DEM products by DEM to DEM registration is explored. The DEMs assessed include: Shuttle Radar Topography Mission (1`` ≈ 30m posts), Star3i IFSAR (10m posts), RTV IFSAR (3m posts) and RTV Lidar (1m posts).

Nomenclature

CE = Circular Error
CFE = Coarse/Fine Exhaustive Algorithm
Comparison DEM = The lower resolution DEM being compared in HAT
CWP = Coarse with Parabolic Refinement Algorithm
DEM = Digital Elevation Model
DTED2® = Level 2 Digital Terrain Elevation Data®
HAT = HRTI Analysis Tool
HRTI = High Resolution Terrain Information
IFSAR = Interferometric Synthetic Aperture Radar
Lidar = *Laser Imaging Detection and Ranging*
RTV = Rapid Terrain Visualization
SRTM = Shuttle Radar Topography Mission
THED = Terrain Height Error Data
Truth DEM = The higher resolution DEM being compared in HAT
ULS = Unified Least Squares Algorithm

INTRODUCTION

Digital Elevation Models (DEMs) provide vertical height information at regularly spaced horizontal intervals. The 3D representation of the terrain can be used for numerous purposes ranging from modeling watersheds to terrain visualization and geopositioning. The amount of insight and information a DEM provides depends greatly on the accuracy (the absolute position of the model relative to an accepted coordinate system). The accuracy of a model depends both on the systems and the techniques used in the collection of the data. Two remote sensing systems currently being used for DEM generation are Interferometric Synthetic Aperture RADAR (IFSAR) and Laser Imaging Detection and Ranging (Lidar). Other methods for DEM generation include photogrammetric stereo compilation and direct survey of points. Each of these DEM generation techniques have their own unique characteristics and the accuracy achieved with each varies tremendously (Maure, 2001).

DEMs are usually registered using image matching techniques and control points for geolocation. Techniques such as these generally rely on a relatively small list of control points (latitudes, longitudes and heights) which may also have some errors, to evaluate the vertical errors of the DEM. Because of the limited number of points evaluated an assessment of the horizontal position of the DEM cannot be made. A DEM to DEM registration utilizes all the terrain information available from both DEMs, and has the potential to assess not only the vertical error of the lower resolution product, but also to assess the relative horizontal position of the DEMs being compared.

In February of 2000 the Shuttle Radar Topography Mission (SRTM) collected data to support the production of Level 2 Digital Terrain Elevation Data® (DTED-2®) covering over 80% of the Earth's land mass. Several studies have been conducted to assess and report the accuracy of the SRTM. Using the SRTM studies as examples, this study uses existing data at four different resolutions and accuracies to investigate the use of the higher resolution elevation data to improve the accuracy of lower resolution products. Direct comparisons of each resolution pair are made before and after a DEM to DEM horizontal registration is preformed. The issue of aliasing associated with the direct comparison of DEMs differing in resolutions by ratios greater than 3:1 was explored. Additionally this study explores the capabilities of DEM to DEM registration, evaluating the effectiveness by analyzing the calculated vertical errors and the resulting horizontal shifts. Direct comparisons of all resolutions will be investigated. However, due to the large difference in resolutions, it is believed aliasing effects will be seen in comparisons involving a large delta resolution and that the error will be greater in these comparisons than in the sequential comparisons. Finally a Chain Analysis is preformed to examine the improvement of a low resolution DEM through a series of comparisons to higher resolution DEMs.

STUDY DATA

SRTM data encompasses most the Earth's land surface with 1``or approximately 30m resolution DEMs. An assessment of the accuracy of that collection by means of DEM to DEM comparison with Star3i 10m DEMs for a large number of SRTM sub cells was made in an earlier study, *Accuracy Assessment of Elevation Data from the Shuttle Radar Topography Mission*. The *HRTI Chain Analysis* study continues a similar type of accuracy comparison for a region in San Diego, Ca. with a portion of the same Star3i data as well as additional 3m and 1m DEMs of the same area. The collections were made utilizing different systems, at different times, over a five year time period from 1998 to 2003. A 4km x 4km area, uninterrupted by any seams or boundaries in all four data sets, was selected. Error values used in this study were provided in the metadata files for each source and are estimated at the 90^{th} percentile.

Data Sources

Shuttle Radar Topography Mission, Level 2 Digital Terrain Elevation Data®. The SRTM was a joint venture between the National Imagery and Mapping Agency (now the National Geospatial-Intelligence Agency, or NGA) and the National Aeronautic and Space Administration (NASA). Flown in 2000, an Interferometric Synthetic Aperture Radar (IFSAR) was used to collect DTED-2® topographic data between 60 degrees north latitude and 56 degrees south latitude. For latitudes less than 50 degrees, a DTED-2® cell covers an area of one degree latitude by one degree longitude with post spacing of one arc second in latitude and longitude or approximately 30 meters. Elevations are referenced to mean sea level as defined by WGS84-EGM96 (Integrity, 2006).

The study area is covered by the upper right corner of SRTM cell 32n118w (cells are named for lower left corner coordinate). Most of this cell covers the Pacific Ocean southwest of California. The previous studies verified the cell meets the SRTM specifications of an absolute horizontal error of 20m, an absolute vertical error of 16m, and a relative vertical error of 11m. In this paper SRTM data may be referred to as 30m data or just as 30 when referred to in comparisons with other data (Integrity, 2006).

Star-3i IFSAR. The Star-3i elevation data were collected in June of 1998 by Intermap Technologies using the Star-3i X-band IFSAR sensor. Elevations are referenced to mean sea level as defined by WGS84-EGM96 and provided at a post spacing of 10m. The horizontal accuracy is reported as 2.5m and the vertical accuracy as 2m. Each Star-3i cell covers $1/64^{th}$ of a SRTM cell and the cells are labeled A through H, South to North and 1 through 8, East to West. This study uses Star-3i cell N32W117H2. In this paper, Star-3i data may be referred to as 10m data or abbreviated as 10 when referred to in comparisons with other data.

Rapid Terrain Visualization (RTV) IFSAR. The RTV IFSAR data have a 3m post spacing, a horizontal error of 3m, and a vertical error of 2-4m. LA-SD Corridor North-Tile 7 was collected in March 2002 by the Army Corps of Engineers Topographic Engineering Center and used in this study. In this paper, RTV IFSAR data may be referred to as 3m data or abbreviated as 3 when referred to in comparisons with other data. Additional information is available in *IFSAR for Rapid Terrain Visualization Demonstration* by Burns, Eichel, Hensley, and Kim.

Rapid Terrain Visualization (RTV) Lidar. The RTV Lidar data has 1m post spacing, a horizontal error of 0.5m and a vertical error of 0.3m. Miramar - Tile 1, the scene used in this study, was collected by the Army Corps of

Engineers Topographic Engineering Center in August 2003. This data set represents absolute truth for this study as ground survey data were not available. In this paper lidar data may be referred to as 1m data or abbreviated as 1 when referred to in comparisons with other data.

Scene Relationships

Each of the four data sets was partitioned to create 21 scenes representing the full study area at three scene sizes: one full 4km x4km scene, four 2km x 2km quadrant scenes, and sixteen 1km x 1km sub-quadrant scenes. Figure 1 provides a graphical representation of the scene divisions and illustrates where each scene is in the data set. The total area represented by each data set is equal. Figure 2 demonstrates this relationship. The enlargement of the posts in the upper left corner shows that the 1m posts continue outside the horizontal location of the 30m corner post, but do not include posts that represent area outside the area represented by the 30m posts (outlined by the red square). Additionally, the areas represented by adjacent quadrants and sub-quadrants do not overlap. This is seen in the enlargement of the inner corners of the four upper left sub-quadrants in Figure 2. The horizontal location of the posts for each data set is outlined. Dividing the quadrants and sub-quadrants this way prevents a post from being used in more than one quadrant or sub-quadrant.

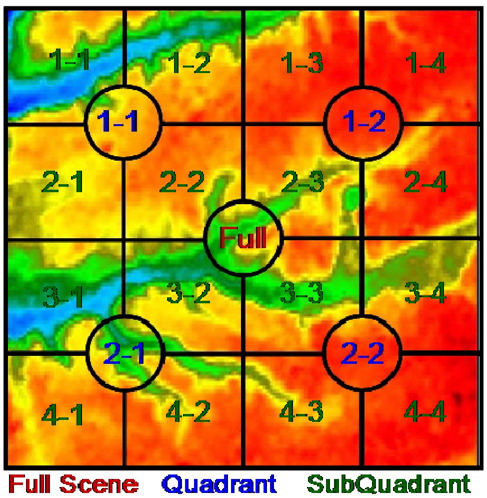

Figure 1. Graphical representation of Study Area. *Each resolution follows the illustrated convention. The SRTM data is used for reference. The Full scene is 4km x 4km, Quadrants (Blue) and Sub-quadrants (Green) are numbered by row#-column#.*

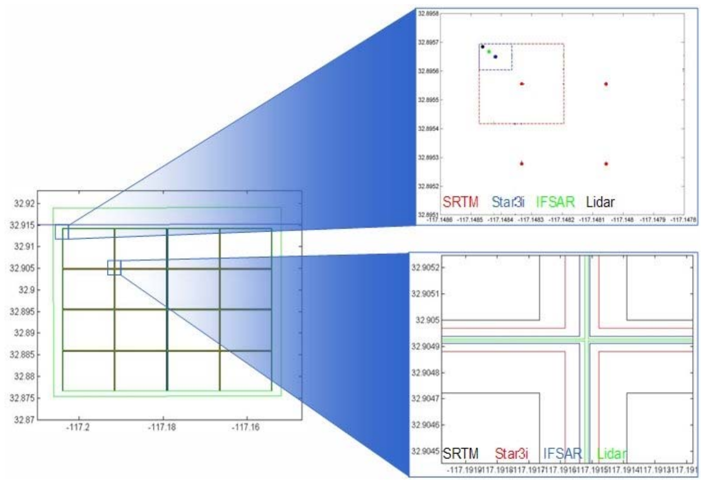

Figure 2. Graphical representation of Study Area. *The enlargement of the upper left corner shows the outer corner post for each resolution and the area that post represents. The enlargement of the inner division of scenes shows the outline of the outer most post for each sub-quadrant. Quadrants have the same relationship.*

DEM TO DEM ACCURACY

The comparison of DEMs was used to evaluate the vertical and horizontal accuracy of the data in each product. The HRTI Analysis Tool (HAT) was used to perform and report the results from each comparison evaluated. HAT was developed by IAI from software code used to perform DEM comparisons in the *Elevation Data Enhancement Initiative: Shuttle Radar Topography Mission Data Analysis* into a stand alone executable. HAT includes three algorithms to perform horizontal registration. These algorithms use the higher resolution DEM as the truth DEM in each comparison, elevations were calculated using bi-linear interpolation at horizontal locations corresponding to the post locations of the lower resolution, comparison DEM. A difference matrix D was calculated for each comparison by differencing the truth DEM elevations with the comparison DEM. HAT then used D to compute systematic error, random error, representative random error, and absolute and relative vertical error as described below. The 1m resolution RTV Lidar data was taken to be the absolute truth for this study, as no surveyed control points were available for registration of the lidar data. Because this study aims to identify issues and trends in DEM to DEM registration, the absolute location of the ‘truth’ is a non factor.

The bias or systematic error (Integrity, 2006): $b = \text{mean(D)} = \frac{1}{n}\sum_j d_j$

The random error (Integrity, 2006): $E = D - b = \{e_j \mid 1 \le j \le n\}$

The representative random error (Integrity, 2006): $\sigma_{RRE} = \text{StdDev(D)} = \sqrt{\frac{1}{n}\sum_j e_j^{\ 2}}$

The Absolute Vertical error (Integrity, 2006): $\text{AV} = \sqrt{\frac{1}{n}\sum_j d_j^{\ 2}} = \sqrt{b^2 + \sigma_{RRE}^{\ 2}}$

The Relative Vertical error (Integrity, 2006): $\text{RV} = \sqrt{\frac{1}{n(n-1)}\sum_{i \ne j} \left| d_i - d_j \right|^2} = \sigma_{RRE}\sqrt{\frac{2n}{n-1}} \cong \sqrt{2}\sigma_{RRE}$

Every Comparison DEM, Truth DEM pair was analyzed four times. The initial comparison between scenes does not include a horizontal registration algorithm (HRA), and the errors reflect the results from comparing two DEMs "as delivered". The initial comparison results were also used to determine the relative magnitude and effectiveness of the reduction in error achieved in the following comparisons. The three subsequent comparisons utilized one of three horizontal registration algorithms (a Coarse/Fine Exhaustive Algorithm (CFE), a Coarse with Parabolic Refinement Algorithm (CWP), and a Unified Least Squares Algorithm (ULS)) to find a best fit between the DEMs being compared. These algorithms are provided in HAT. The best fit was determined by minimizing the mean-square of the representative random error. Once the best fit was found, a shift for the comparison DEM was reported in UTM Easting and Northing. The shift was applied and the statistical analysis performed.

Vertical Error Assessment

The horizontal shifts calculated for a given comparison of DEMs were found by minimizing the Random Vertical Error. Therefore it was important to have an understanding of the relationship between the scenes and the effects each HRA has on the vertical error. To examine this, the vertical error calculated in HAT when comparing a lower resolution dataset (comparison DEM) to a higher resolution dataset (truth DEM) was plotted for each set of the sub-quadrants. The X-axis of each graph orders the sub-quadrants from the minimum to the maximum Absolute Vertical Error as calculated for the Star3i to RTV IFSAR comparison (shown in Figure 5) using the Coarse/Fine Exhaustive Algorithm. This order provides a more insightful view of the data than simply ploting the errors by sub-quadrant number. When presented by sub-quadrant number the trends in the data are not as discernable. The same order was used for each vertical error plot so that a direct comparison of different plots was possible. The Star3i to RTV IFSAR CFE comparison was used because the 10m and 3m data was used in a majority of comparisons as either the comparison DEM or truth DEM, and because the order allows the data to be shown from minimum to maximum vertical error with very few exceptions in all the graphs. For each pairing graphed the stated error from each data set was root sum squared to calculate an expected error for each pairing and is indicated by the red line on each plot. The RTV IFSAR data include a range of stated vertical errors from 2m-4m and as a result comparisons including the RTV IFSAR data have a range of expected errors.

All the comparisons demonstrate a significant reduction in the calculated vertical error between the two compared DEMs when any of the HRAs are used. This indicates the given datasets' coordinates are not exactly aligned and improvements in the accuracy of the comparison DEM may be possible. The graphs also show that the difference in vertical error calculated by each of the different algorithms is negligible. The effects of temporal changes to an open pit quarry in the study area are believed to be the cause of the largest error, and the quarry's effect will be further considered in the examination of the horizontal shifts.

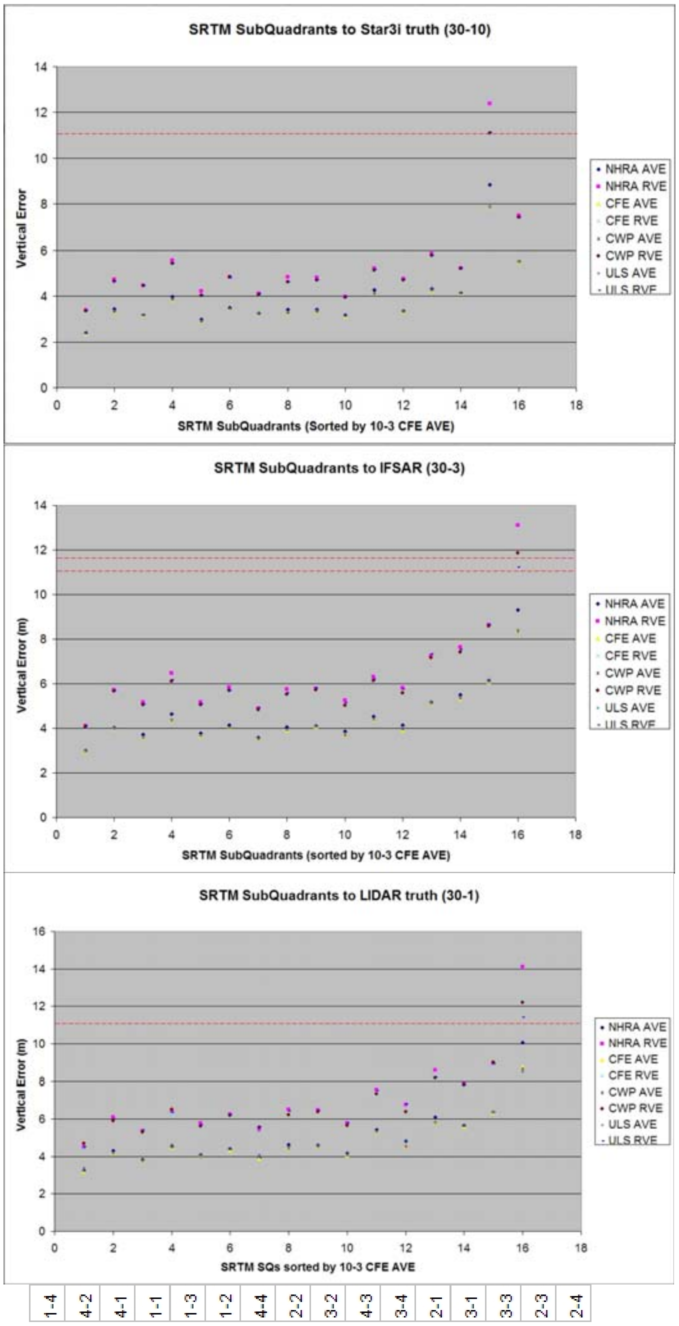

Figure 3. 30m comparisons. *SRTM sub-quadrants compared to each higher resolution used as truth, and the order by sub-quadrant.*

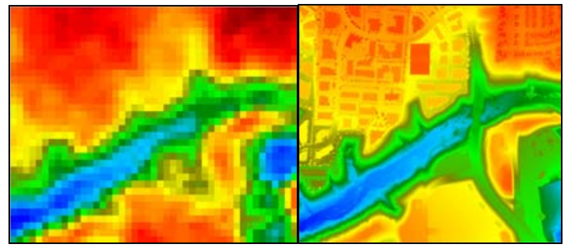

Figure 4. 30m & 1m Sub-quadrant 2-3. *30m data lacks the detail and precision of the 1m data.*

Comparisons of only one step in resolution (such as 30-10, 10-3 and 3-1) demonstrate the lowest vertical error both before and after registration. The 30-1 comparison has the largest step in resolution in the study and shows the most vertical error both before and after registration. These observations are shown in Figure 3, which illustrates the comparison of the SRTM sub-quadrants to each of the additional resolutions used as truth and shows the computed vertical error increases as the resolution of the truth DEM increases. In both the 30-3 and 30-1 comparisons the vertical error is approximately one meter or more than any of the other comparisons.

The data collection method may be a source of the increased error in the 10-3 and 10-1 comparison and to a lesser extent in the 3-1 comparison (Figures 5, 6 & 7). Each method that can be used to generate a DEM (Lidar, IFSAR, auto-correlation, etc…) will have its' own unique characteristics. In this study a combination of lidar and IFSAR is being utilized. The IFSAR processing technique will insure that contributions from a representative area on the ground are used to generate each DEM post. For the IFSAR collections there may also be additional filters run over the data to smooth it. In contrast, the lidar data represents more distinct measurements at a specific X-Y location. Although the lidar collection has a footprint associated with its beam, that footprint may be equal to or smaller than an individual post. The collection geometries are also very different for an IFSAR sensor versus a lidar. While IFSAR must look oblique to operate, lidar generally collects data near nadir. So, the shadows and illumination areas may vary greatly between the two datasets.

These differences in collection and data processing techniques, along with the difference in the frequency of posts at different resolutions, are believed to cause an aliasing effect in HAT during the comparisons (Maure, 2001). Figure 4 illustrates the significant difference in the horizontal resolution of the SRTM data and the lidar data. The aliasing effect emerges when HAT performs the bi-linear interpolation of the high resolution truth data to create posts at the same horizontal location as the lower resolution comparison posts. When HAT interpolates a height from the truth data at the same horizontal position as the comparison data, an error may be introduced. A comparison DEM may have several buildings, trees, ditches or other terrain features that vary greatly in height within one resolution cell. These height variations may be averaged out during DEM generation and the final post

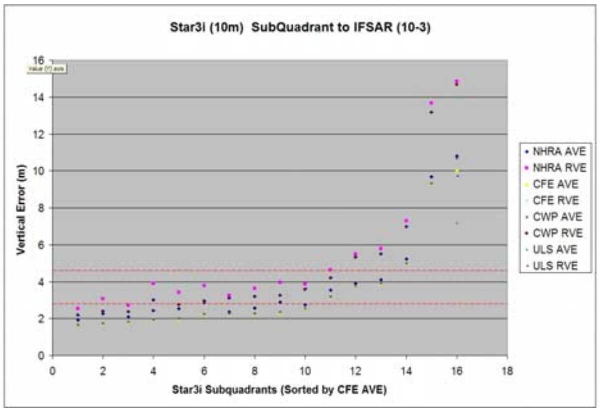

Figure 5. Star3i Sub-quadrants to 3m truth.

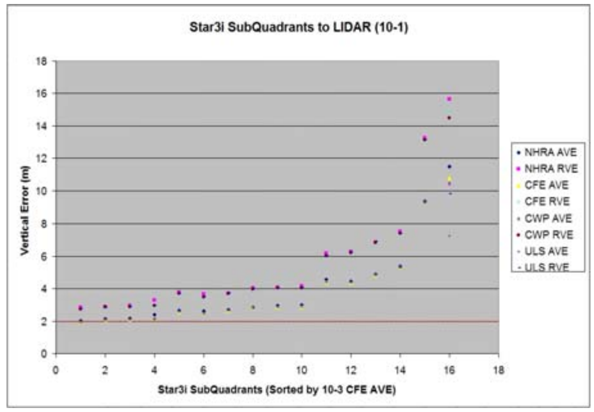

Figure 6. Star3i Sub-quadrants to 1m truth.

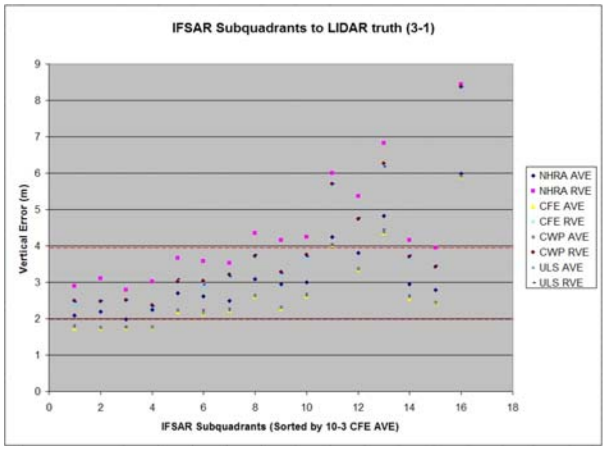

Figure 7. IFSAR Sub-quadrants to 1m truth.

elevation can be greatly affected by a few outlying measured heights. The corresponding truth DEM may be able to represent the terrain much more precisely, with several posts to each object of differing height. This difference in post frequency results in the comparison DEM reporting a height that is the average of height of the buildings and the ground height at a horizontal position in between those buildings, while the corresponding interpolations of truth DEM yields a height representative of the ground alone. Discrepancies like this result in a large vertical error being calculated in HAT even if the two DEMs being compared are perfectly aligned.

Horizontal Error Assessment

For each comparison performed in HAT utilizing an HRA, a shift in UTM Easting and Northing (meters) is reported for the comparison DEM. The horizontal shift calculated provides an additional means to explore the data. The Easting and Northing shifts returned for each comparison provide insight into the relative position of the DEMs before the shifts, as well as insight into situations where simply minimizing the vertical error is an unreliable method for DEM to DEM registration. Trends in the results were best identified in a graphical representation. Each chart represents a full set of 21 comparison DEMs to the same truth DEM (Figure 8). The charts show the magnitude and direction of each calculated shift. Sub-quadrant comparisons are shown in their corresponding square as labeled in Figure 1. The quadrant results are represented in the four outer circles and the full scene result is represented by the center circle. The circles also provide scale for all of the results in the graph, as each circle's radius represents an eight meter distance.

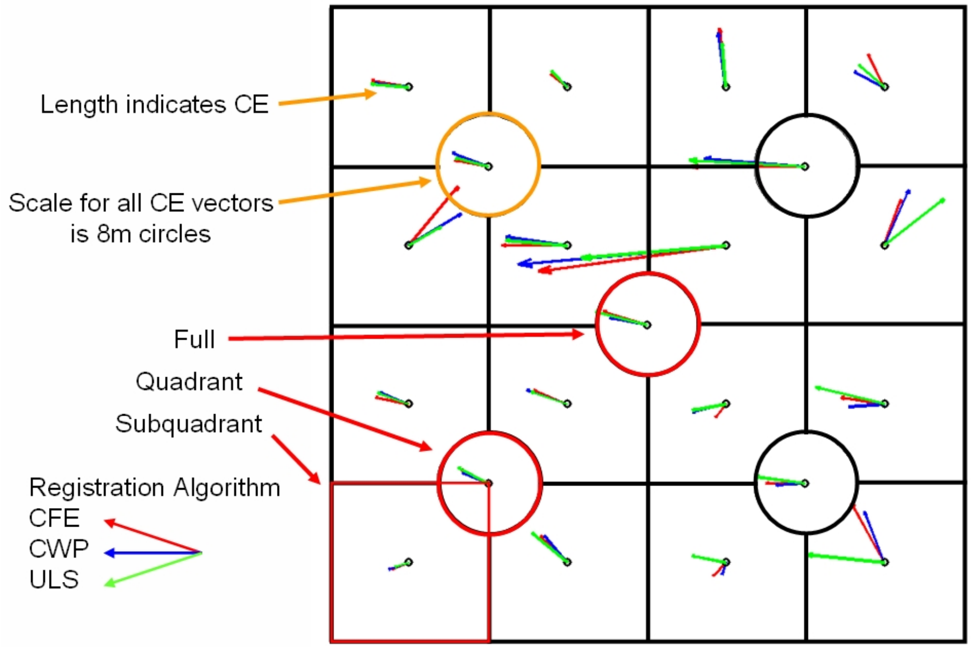

Figure 8. Graphical representation of shift results. *Each Comparison DEM is represented by a set of arrows. The outer circles represent the 4 quadrants and the center circle represents the Full scene. The circles also provide a scale and have an 8m radius.*

The first comparison is again the 30m SRTM scenes compared to each higher resolution as truth. Figure 9 displays the results for all of these comparisons. Although not very uniform the 30-10 comparison again shows stronger correlation between individual sub-scenes at both sub-quadrant and quadrant scene division levels than the 30-3 or the 30-1 comparisons. As in the Vertical Analysis, the major outliers are in sub-quadrants 2-3 and 2-4. Poor registration in 2-3 and 2-4 are again believed to be caused by an open pit quarry. The quarry was excavated and

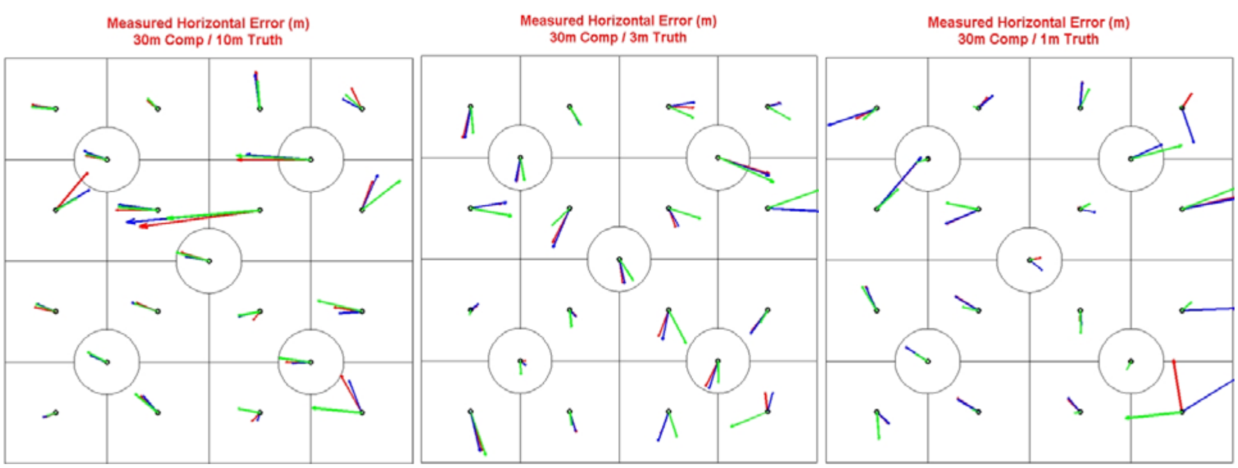

Figure 9. SRTM Circular Error Plots. *Graphical representation of the horizontal shifts calculated in HAT for the 30m scenes compared to 10m, 3m and 1m truth.*

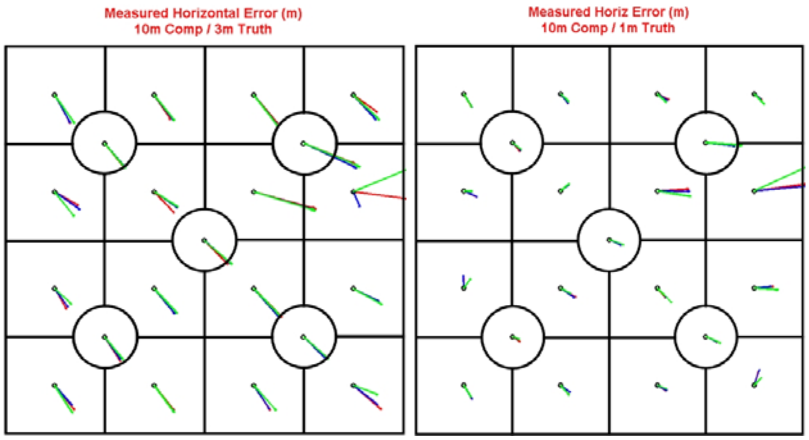

Figure 10. Star3i Circular Error Plots. *Graphical representation of the horizontal shifts calculated in HAT for the 10m scenes compared to 3m and 1m truth.*

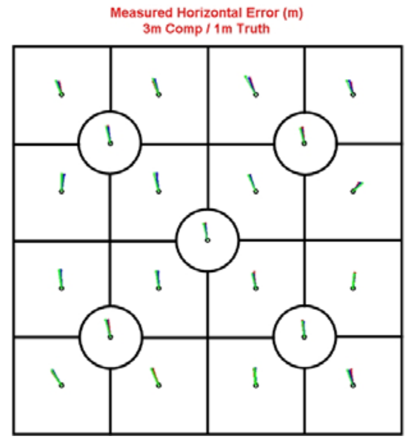

Figure 11. IFSAR to Lidar Circular Error Plots. *Graphical representation of the horizontal shifts calculated in HAT for the 3m scenes compared to 1m truth.*

dramatically changed shape between data collections for each source. Figures 14, 15, 16, and 17 in Appendix A show the full color gradient DEMs of each data set and the changes in the quarry over time can be seen. The effects of this temporal change can be seen in the relatively large and non-uniform horizontal shift results calculated for sub-quadrants 2-3 and 2-4. The quarries effect on the registration can be observed even at the larger scene division level, in quadrant 1-2, where the calculated shift is longer and more northern than predicted by sub-quadrants 1-3 and 1-4. While the changes in the quarry do not obviously dominate the full scene comparison it can be understood to affect those shift results as well. Figure 10 shows the 10m data comparison. The 10-3 comparison results show much more uniformity, but the quarry still appears to be causing outliers. The 10-1 comparison show more uniformity than the 30m comparisons but there is still some obvious irregularities between adjacent sub-quadrants and quadrant that the temporal changes don't support. Figure 11, the 3-1 comparison has the most consistent shift throughout all scene and divisions.

These results are congruent to the data from the vertical analysis. They show direct comparisons between DEMs of more than one step in resolution are not reliable. The non-uniform shift results calculated from comparisons of both sub-quadrant and quadrant SRTM scenes to all of the other resolutions indicates that accurate results are not likely when such relatively small scenes are used.

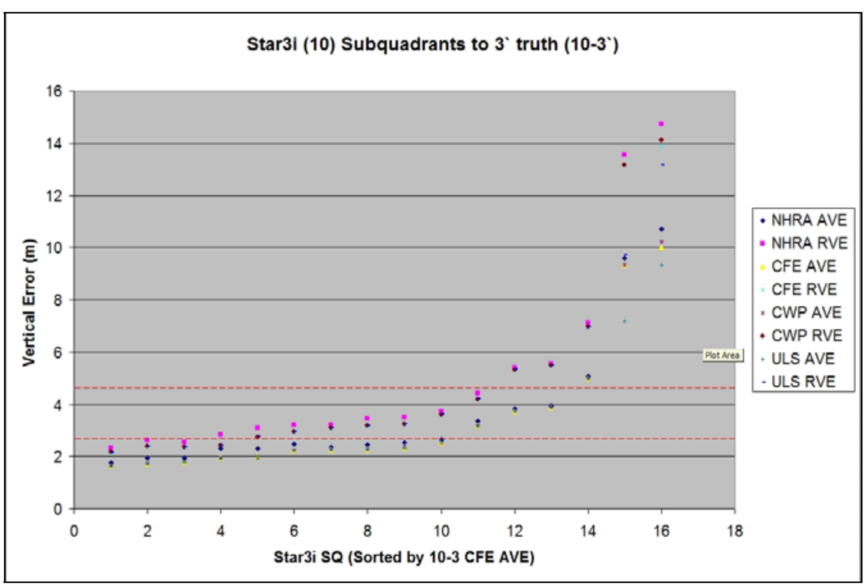

**Figure 12. 10-3` Vertical Error plot.** *Graphical representation of the vertical error calculated in HAT for the 10m scenes compared to 3` as truth.*

Improving Low Resolution Accuracy

The study of the vertical and horizontal errors has shown that direct comparison of widely different resolution digital elevation models does not provide a reliable means to more accurately geolocate the lower resolution data set. The error assessment does indicate that through a sequential comparison of the DEMs differing by only one step in resolution, a more accurate

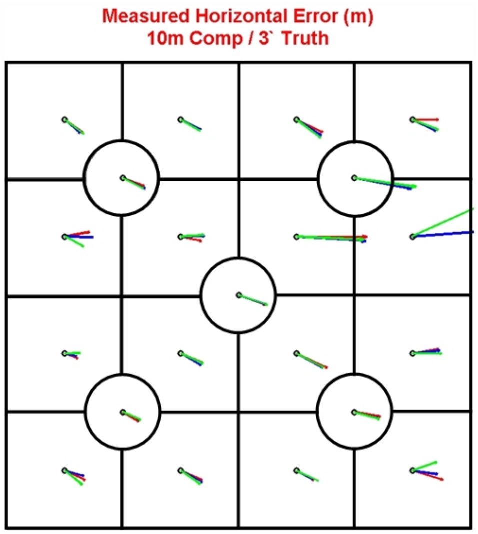

**Figure 13. 10-3` Vertical Error plot.** *Graphical representation of the horizontal shifts calculated in HAT for the 10m scenes compared to 3` as truth.*

position may be provided. In order to make comparisons between DEMs more than one step in resolution different, shifts to the comparison DEMs were made in a sequential manner. The 3m IFSAR full scene was compared to 1m lidar scene in HAT. Using the shift from the CFE algorithm the 3m data was shifted to the new position. The newly shifted 3m data, now referred to as 3`, was then used as truth to calculate a shift for the 10m Star3i full scene. The shifted 10m data from the 10-3` comparison is now referred to as 10``. An additional comparison of the 10`` data to the 30m SRTM data is not perused in this paper. The analysis of the vertical error data and the non-uniform shift results from all comparisons of the 30m data indicate that comparisons of the SRTM data at the scale of the scenes in this study is not reliable.

Figure 12 shows the vertical errors calculated in the 10-3` comparison, which are similar to the errors from the 10-3 comparison in figure EE for the horizontal registration algorithms. It also shows that both the 10-3` and 10-3 comparison have less error than the 10-1 comparison shown in Figure 6. This result is expected because the height data in the 3` data set is the same as the original IFSAR data, only it has been shifted to a more accurate location relative to the 1m truth data set. The horizontal results from the 10`` data demonstrate how much better a sequenced adjustment may be. In Figure 10 both 10-3 and 10-1 horizontal shifts are shown. The 10-3 CE plot, Figure 13, shows uniform results at sub-quadrant, quadrant and full scene levels, unlike the 10-1 comparison. Although the 10-1 shows smaller magnitude shifts, the direction of the shifts at the quadrant and especially the sub-quadrant level is not uniform and in conjunction with the vertical error data the shifts do not represent the most accurate location on which to base a shift of the 10m data. The 10-3` CE plot in Figure MM demonstrates that a shift of the 10m data based on the truth adjusted 3m data provides a much more uniform result at all levels and using all algorithms, even though the 3` shift was based on the full scene result from the CFE algorithm. Additionally vector addition of the full scene shifts calculated from the 3-1 comparison (-0.5m east and 4.41m north) and the 10-3 comparison (5.99m east and -6.32m north) sum to 5.49m east and -2.09m north, which is nearly the exact result calculated from the 10-3` comparison of 5.69m east and -2.01m north.

SUMMARY

Low resolution digital elevation models exist for large portions of the Earth. The improvement in the accuracy of these products through current methods such as control point registration or line matching is limited by the resolutions of the product to be improved. DEM to DEM registration with the use of higher resolution truth DEMs shows the potential to further increase the accuracy of these lower resolution DEMs beyond the capabilities of the original data collection system.

Due to the near total coverage of the Earth on the SRTM mission, that data is an immense tool, especially for large area models where high resolution is not value added and for areas that are too large for more accurate sensing systems to cover. The relatively small scene size in this study has shown that comparison of the 30m to any of the other datasets is inconsistent and unreliable, because of the coarse spacing of height data and the large temporal changes between the other data collections. This also may be a result of the combination of data from different passes during the SRTM collection, using regridding and adaptive filtering methods to reduce noise, in effect smoothing the SRTM data over large regions (Integrity, 2006).

In comparisons of the higher resolution data sets where only one step in resolution was used, 10-3 and 3-1, the vertical errors were reduced below the vertical error calculated for comparisons involving more than one step in resolution. The shifts also indicated that one step in resolution was a more reliable method of comparison as opposed to large differences in resolutions. The uniformity of the shifts at all scene levels in the one step comparisons support that assessment. The irregular shifts calculated when large steps in resolution were compared indicate that there may be an aliasing effect caused by the bi-linear interpolation used in HAT to calculate the random error.

Using this information, a sequential series of comparisons and shifts were used to calculate a position for the 10m data that is more accurate relative to the 1m truth data set than could be found reliably through direct comparison. This process may have implications for improving many types of lower resolution digital elevation models.

To better assess the final geolocation of the shifted data, a collection of several surveyed control points from within the study area would be needed. Additionally a follow on study in different terrain, where height is more uniform (such as plains or desert) may allow for better accuracy in direct comparisons of lower resolution products to significantly higher resolution products. This would allow further investigation into the aliasing affect detected in this study. A larger study area may also provide better analysis of the ability to find more accurate positioning of the SRTM for scenes relatively small compared to the one degree by one degree SRTM DTED2 cells.

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Appendix A

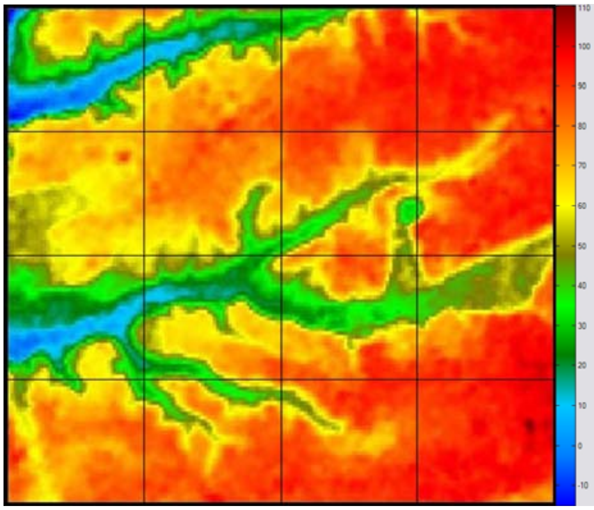

Figure 14. Color gradient SRTM Full scene.

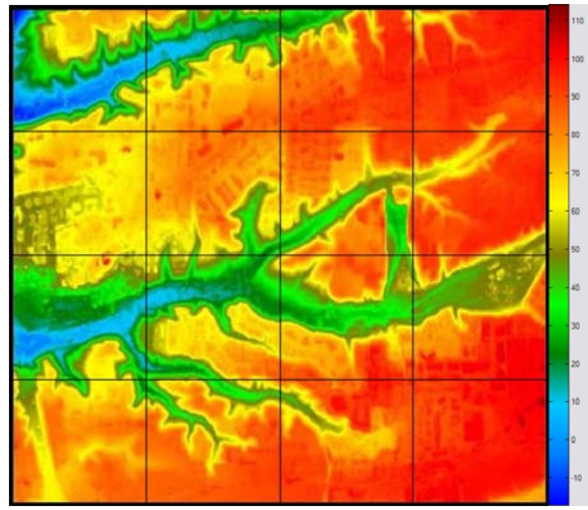

Figure 15. Color gradient STAR3i Full scene.

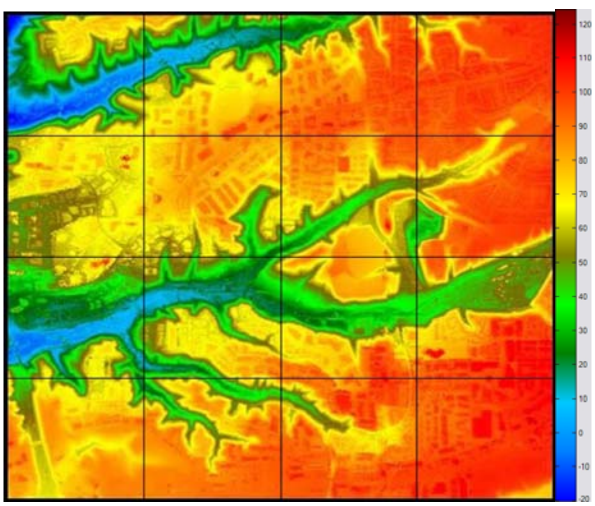

Figure 16. Color gradient IFSAR Full scene.

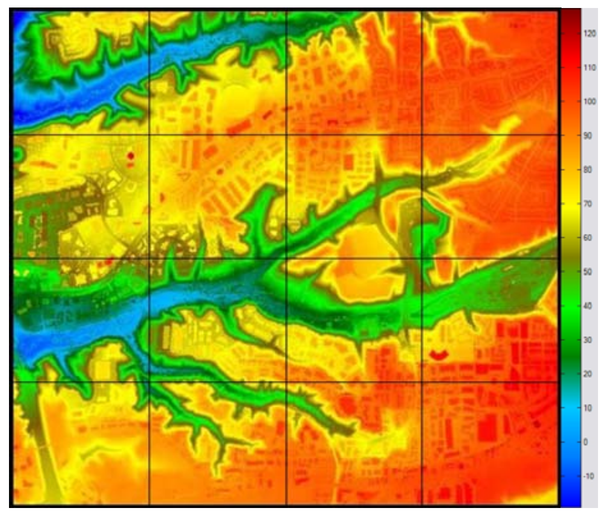

Figure 17. Color gradient LIDAR Full scene.