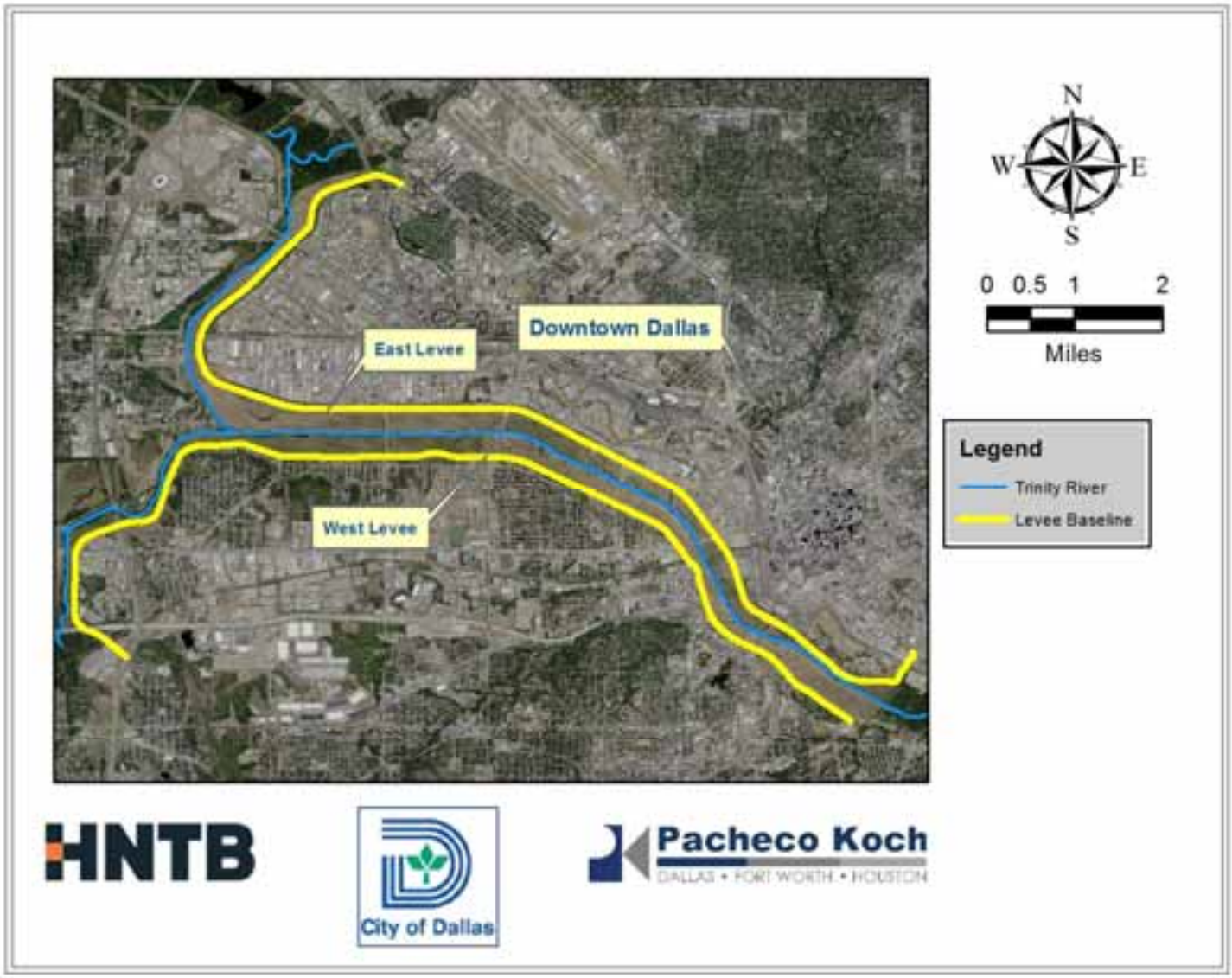
ESRI 2012 UC Paper UC 496

Vertical Component of Topographic Survey Vs. SRTM, ICESat, and NED Elevations for Dallas Levees Project Area

Nijaz Karacic, PLS, MS Randall Marshall, RPLS



ESRI 2012 UC Paper UC 496
Vertical Component of Topographic Survey Vs. SRTM, ICESat, and NED Elevations for Dallas Levees Project Area

Nijaz Karacic, PLS, MS Randall Marshall, RPLS

Abstract

This paper documents the differences in results of the vertical component of obtained topographic survey for the larger area of Dallas Levees versus the NASA/NGA Shuttle Radar Topography Mission (SRTM), the USGS National Elevation Dataset (NED), and NASA laser altimetry mission the Ice, Cloud, and land Elevation Satellite (ICESat). The typical mean vertical difference between the SRTM and the vertical component of the topographic survey was determined as approximately 4.4 meters, the typical mean vertical difference between the SRTM and ICESat elevations in this paper was determined as approximately 2.1 meters over bare ground, with the SRTM measuring lower elevations and the typical mean vertical difference between the NED and ICESat was determined as approximately 1.2 meters. Significant changes in the SRTM DEM uncertainties have been identified over different surface types e.g., bare ground, urban, and forested areas. Based on this result the difference of the SRTM 30-m DEM and ICESat elevations could be removed from the DEM and make available for improved hydrological applications.

Introduction

The elevations can be incorporated and utilized for a variety of applications including terrain reductions for regional geoid modeling (Marti, 2004), characterization of urban areas and assessing the absolute vertical accuracy of existing (global) DEMs, to name a few.

The purpose of this paper is to identify and assess methods/data for comparing and calibrating the SRTM elevations and NED dataset for larger Dallas Levees Area.

Although other elevation data sets exist on global and regional scales (i.e., GTOPO30, regional digitized DTM maps, GPS benchmarks), the selection of the NED, SRTM and ICESat data from the high-resolution altimetry mission was intentional for the region. Therefore it is important for many practical industry applications to compare the accuracy of these terrestrial conventionally-surveyed vertical values with space-based techniques (Fotopoulos et al., 2005).

The objectives of this study are (a) to assess computed differences between SRTM, NED and ICESat elevations over project area, and (b) to determine the feasibility of augmenting topographic survey data with space-based elevations.

The discussion begins with a description of the three elevation data sets used in this study, namely SRTM, ICESat, and NED. This is followed by an outline of the data comparison with a emphasis on the inherent vertical datum issues involved with using elevation data originating from different (space and terrestrially-based) instruments.

Study Area

In April of 2010, HNTB contracted Pacheco Koch Consulting Engineers (PKCE) to complete Topographic surveying and mapping of the entire levee system through the Downtown Dallas Area, extending 30 miles and a topographic corridor width of 800 feet. The project consisted of LiDAR performed by TerraPoint and on the ground surveying. LiDAR data sets, obtained by mobile and airborne methods, were incorporated to all GPS and conventional topographic shots. The final submittal

of LiDAR data sets consisted of: break lines, contours, DTM, ASCII point files, planimetrics and point-to-point comparison of acquired high confidence ground survey points by surveying methods, including imagery files, mobile LiDAR video and point clouds obtain by airborne and mobile platforms. QA/QC of received LiDAR files consisted of checks in accordance to LiDAR Specifications and Accuracy and FEMA Compliance. Overall accuracy of the combined surveying and LiDAR methods was better than 5 cm.

Included in the project were locating and mapping of all visible utilities, utilities of record, abrupt variations in topography, buildings, roads, outfall structures and pressure sewers. Microstation drawings included DTM's of the levees, and all outfall structures and pressure sewers within the levee system, planimetrics, and cross-sections at 100 foot intervals and all utility crossing. Trinity River cross-sections located and mapped every 2500 feet totaling 46 cross-sections.

The area covered by the project was approximately 27,000 acres. Control stations for this project were placed around the perimeter of the project and spaced between two (2) and three (3) miles from each other. This control was used for performing all of the design and topographic surveys. (See Fig. 1)

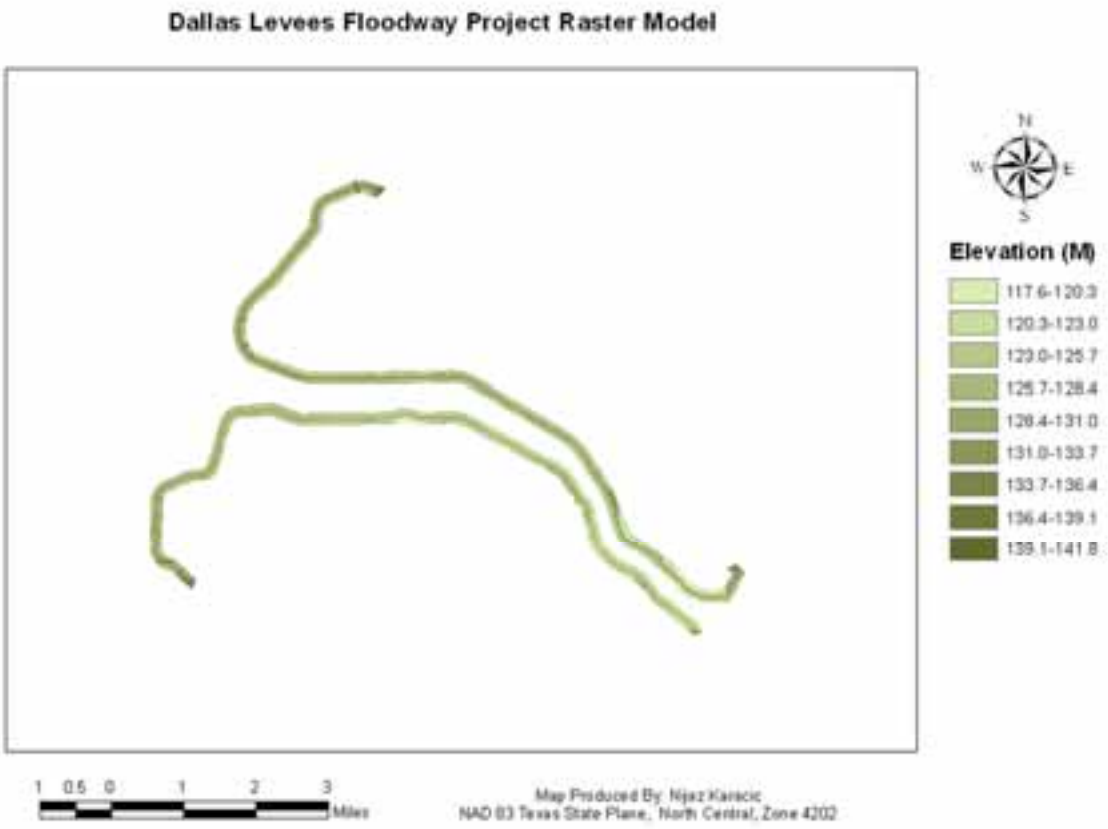


Fig. 1

The project horizontal datum was the North American Datum of 1983, CORS 96 Adjustment. The project vertical datum was the North American Vertical Datum of 1988 (NAVD88), utilizing GEOID03 to determine the orthometric heights and Grid Coordinates for all control are provided in Texas State Plane Coordinate System, North Central Zone (4202).

Datasets

Figure 2 shows the ICESat ground tracks on the project's SRTM coverage area from available mission period in 2006. Some tracks have been flown several times, and the ground track location may change by a few kilometers (Schutz et al., 2005), which does not affect the comparisons conducted in this study because each footprint is treated separately. A detailed description of each data set follows.

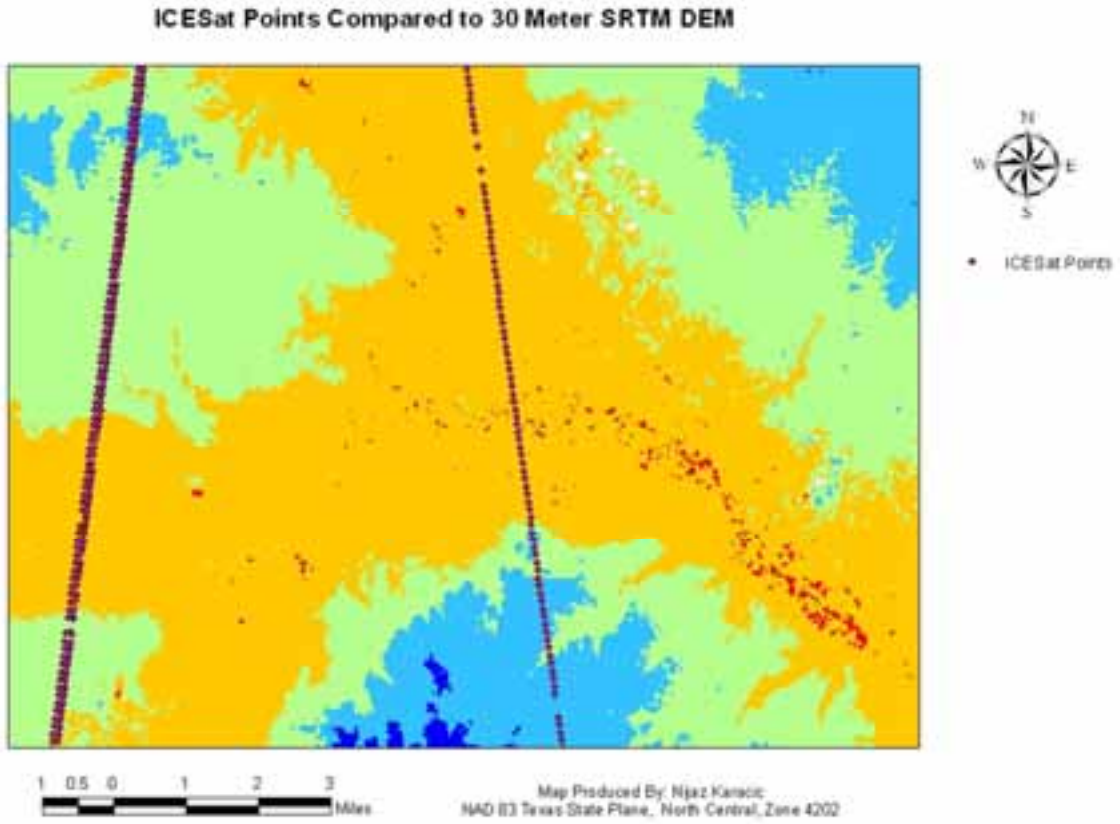


Fig. 2

SRTM Data

The Shuttle Radar Topography Mission collected data over a period of eleven days in February 2000 (Werner, 2001; Farr and Kobrick, 2000). C-band and X-band data was processed separately by the Jet Propulsion Laboratories (JPL) and the German Aerospace Center (DLR), respectively. In this study, only C-band SRTM data is used and more specifically, the Digital Elevation Model (DEM) derived from processing the synthetic aperture radar (SAR) data. In order to analyze the intrinsic accuracy of the derived SRTM C-band DEM, the "unfinished" SRTM data is used rather than the modified "finished" data of SRTM DTED® level 2. The latter was modified by filling voids and altering elevations over oceans, lakes, and lake islands. The "unfinished" SRTM data is provided on a 1"X1"grid, which roughly translates to a 30-meter horizontal spatial resolution. The footprint size of ICESat is on the order of approximately 173-meters in between points within the project area and NED Dataset is on 10 meters grid; all comparable with 3 meters grid of topographic survey. The SRTM DEM is referenced to mean sea level realized by the EGM96 geoid model. Hence, the DEM is provided in terms of orthometric heights. More details on datum issues are provided in the next section. (See Fig. 3)

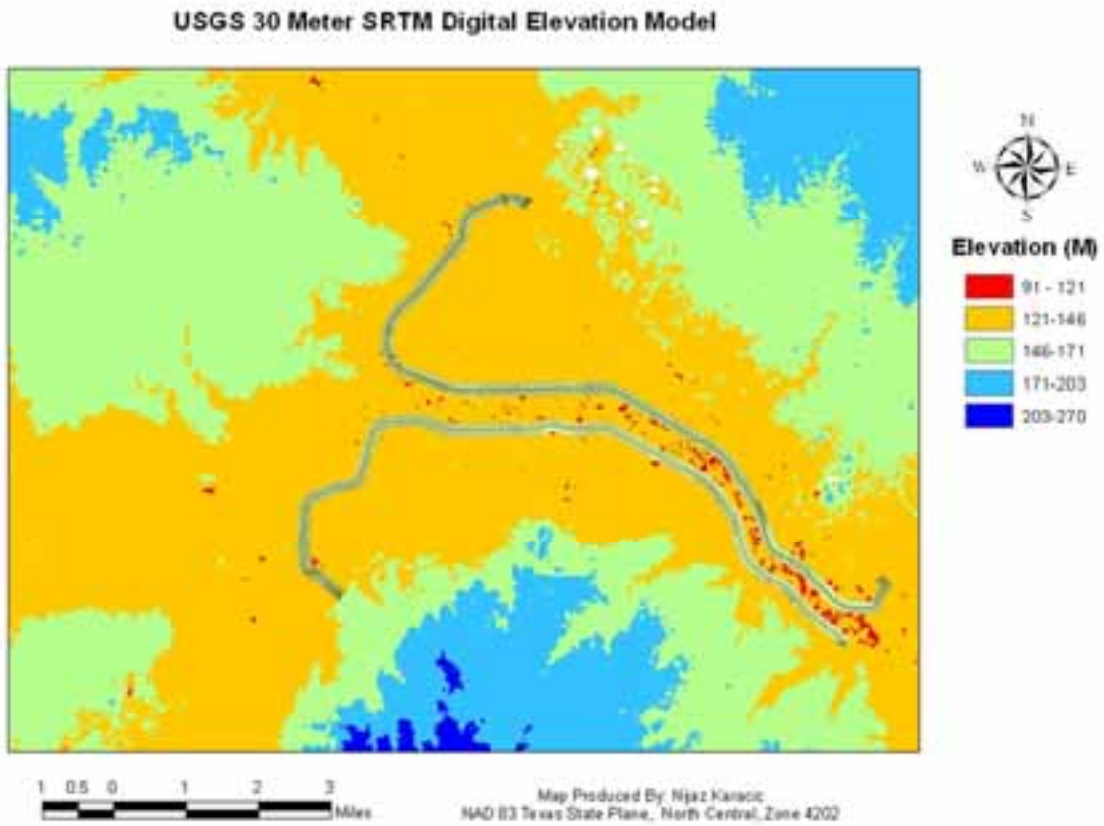


Fig. 3

ICESat Data

ICESat is a NASA laser altimetry mission launched in February 2003. The specifications of the mission, the acquired data, and accuracies are discussed in Zwally et al. (2002), Schutz et al. (2005). The data used in this study consists of the GLA06 global elevation product of release 31 which were available online. The dedicated land product, GLA14, and the GLA01 waveform products were not evaluated in this project; rather, the simpler GLA06 product was selected. . The ICESat is referenced to mean sea level realized by the TOPEX/POSEIDON geoid model, only 10 centimeters different from NED and vertical component of Topographic survey of Dallas Levees. (See Fig. 4)

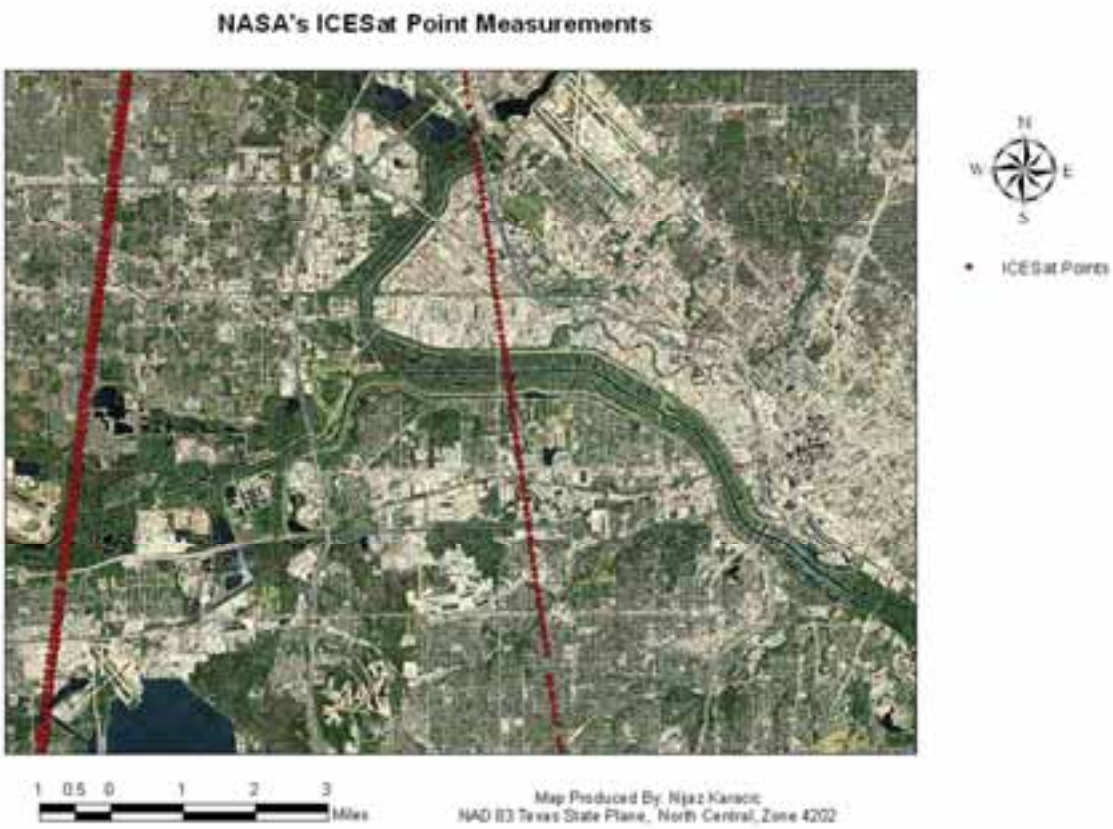


Fig. 4

The USGS National Elevation Dataset (NED)

The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the U.S into a seamless raster format. NED is essentially a digital terrain model (DTM) depicting bare earth (ground) elevations in a consistent projection (geographic coordinates), resolution (1 arc-second), and elevation units (meters). The horizontal datum is NAD83 and the vertical datum is NAVD88. The NED DTM of the study area (Fig. 5) consists of point elevations in a 10 meter grid.

The National Elevation Dataset (NED) is the primary elevation data product produced and distributed by the U.S. Geological Survey (USGS). Since its inception, the USGS has compiled and published topographic information in many forms, and the NED is the latest development in this long line of products that describe the land surface. The NED provides seamless raster elevation data of the conterminous United States, Alaska, Hawaii, and the island territories. The NED is derived from diverse source data sets that are processed to a specification with a consistent resolution, coordinate system, elevation units, and horizontal and vertical datums. The NED is the logical result of the maturation of the long-standing USGS elevation program, which for many years concentrated on production of map quadrangle-based digital elevation models (DEM). The NED serves as the elevation layer of the The National Map, and it provides basic elevation information for earth science studies and mapping applications in the United States. The consistent, seamless structure of the NED removes the requirement for users to handle and individually process multiple input files. Instead, the NED provides application-ready data and allows users to focus on analysis rather than data preparation. The NED is designed to address the requirement for large-area coverage of the “best available” elevation data. This approach fulfills the framework data concept as promoted by the National Spatial Data Infrastructure

(NSDI) in which the most commonly needed geographic data themes are integrated into coherent data sets based upon source data from multiple public and private entities. The USGS has been designated as the agency having the lead responsibility for national elevation data.

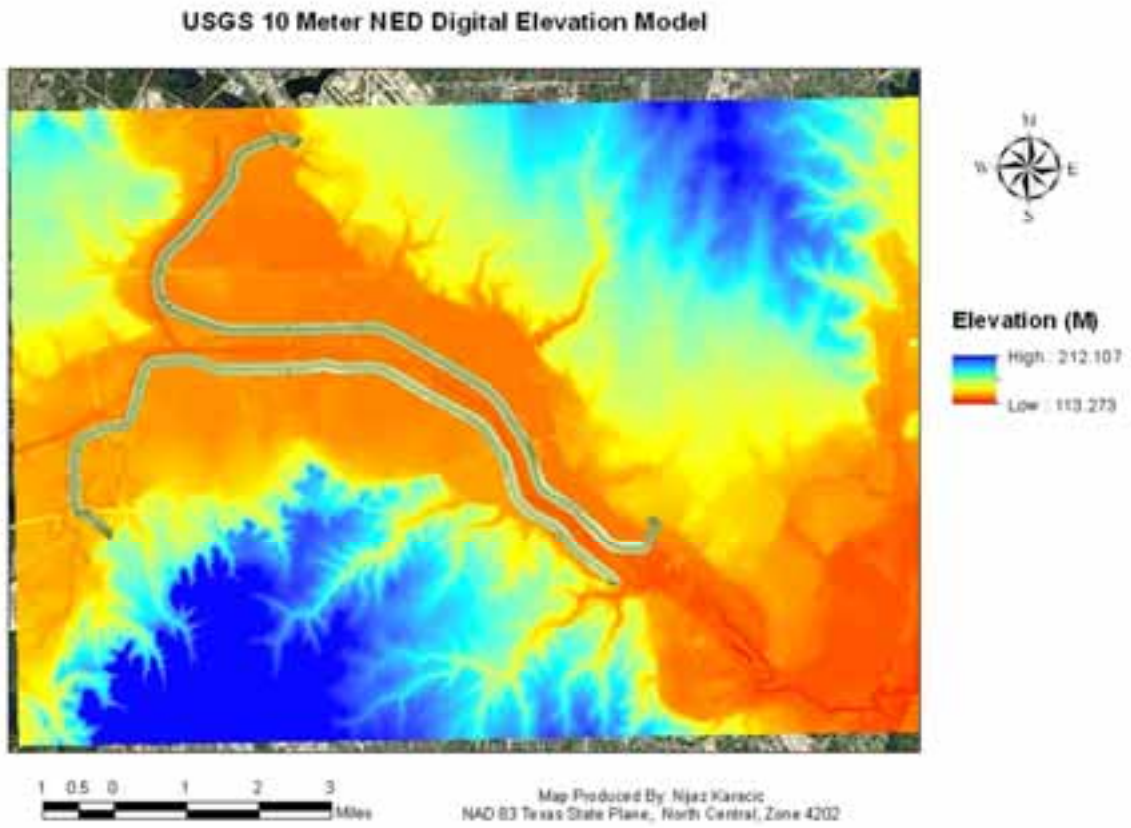


Fig. 5

To maintain seamlessness in its national coverage, the NED uses a raster data model cast in a geographic coordinate system (horizontal locations are referenced in decimal degrees of latitude and longitude). The NED employs a multi-resolution structure, with national coverage at a grid spacing of 1-arc-second (approximately 30 meters). The exception is Alaska where lower resolution source data warrant the use of a 2-arc-second spacing. Where higher resolution source data exist, as our Project Area, the NED also contains a layer at a post spacing of 1/3-arc-second (approximately 10 meters). Some areas are also available at a 1/9-arc-second (approximately 3 meters) post spacing, where every high-resolution source data exist. The NED production approach ensures that georeferencing of the layers results in properly nested and coincident data across the three resolutions. In the context of the raster data model used for the NED, the area represented by one elevation post in the 1-arc-second layer is represented by nine elevation posts in the 1/3-arc-second layer, and by eighty-one elevation posts in the 1/9-arc-second layer. Where all three resolution layers can be produced, each layer is constructed independently from the same high-resolution source data using an aggregation method appropriate to the grid spacing being produced. In all three NED resolution layers, the elevation units are standardized to decimal meters.

As a primary source of basic topographic information for the United States, the NED is used innumerous applications that require elevation as an input. Elevation data are critically important for many hydrologic studies, and these studies are one of the main uses of the NED and associated derived products.

Orthometric Heights Comparison

In order to conduct a realistic and consistent comparison amongst the available height data sets, it was imperative that all heights refer to the same vertical datum. This is a rather complicated task considering that the available height data is not obtained in its original form and detailed accounts of the altered state of the height elevations are not readily available. Therefore, for the purposes of this study, it was decided to perform the data comparisons in terms of orthometric heights with respect to WGS84, which for any further future analyses, is consistent with the geocentric reference system employed by GPS.

GEOID03 is a state-of-the-art refined hybrid model of the geoid in the conterminous United States (CONUS), combining the gravimetric geoid USGG2003 that uses the EGM96 global geopotential model (GGM) as an underlying long wavelength model , together with datum transformations and 14185 NAD83 GPS-derived ellipsoid heights on NAVD 88 leveled bench marks (the so called GPSBM2003 dataset). It should be noted that the GEOID03 models geoid heights above the North American Datum of 1983 (NAD 83) which uses the GRS80 ellipsoid. However, latitudes and longitudes in the GRS-80 and WGS84 (G873) systems are very close to those of the NAD 83 system (with only 1-2 meters of horizontal shift). So any of these types of latitude and longitude (NAD 83 and WGS84) may be input, without affecting the interpolated geoid value. Since for the entire CONUS area the geoid is below the ellipsoid, the GEOID03 geoidal heights in the area of interest range from a height of about -27 meters. A straightforward comparison of the GEOID03 vs. the EGM96 geoid showed, as anticipated, that the former model provides a finer local detail of the geoid, with the differences of the two models ranging between 0.04 to -0.9 meters. Therefore, it was decided to use the geoid undulations corresponding to the GEOID03 model and to add them to the available DEMs so that to derive the required ellipsoidal heights with respect to WGS84. It is important to note that evidently these geoid values are not identical with the values used in the original C-band processing of the SRTM data. On the other hand, the use of these values compensates somewhat for the 'discretization' error of up to 0.7 meter that is inherent in the available SRTM DSM values which are truncated integer-valued orthometric heights.

Processing

The analysis portion of this research consisted at looking and comparing ArcMap shapefiles with raster imagery.

The Dallas Floodway Project Raster Model began as an .asc file containing a northing, easting, and elevation for the points collect during the survey. This .asc file was used to create points shapefile for each unique position. From this shapefile a .tif raster image was created using ArcMap's feature to raster tool, using elevation in meters as the assigned value.

The ICESat points shapefile also began as an .asc file. However instead containing a northing, easting, and elevation, it had a latitude, longitude, ellipsoid height, geoid height, and saturation. Once the shapefile was created a new field named "Orthometric Height" was added to the data table so that the values could be calculated using ArcMap's field calculator.

Both of the rasters comparing the Dallas Floodway Project raster and the SRTM raster and the Dallas Floodway Project raster and the NED raster were created by using ArcMap's Raster Math Tools (in this case it was the Minus tool). The values were calculated by taking the value of the Dallas Floodway Project raster and subtracting the corresponding values of the SRTM raster (See Fig. 6) and the NED raster (See Fig. 7) respectively.

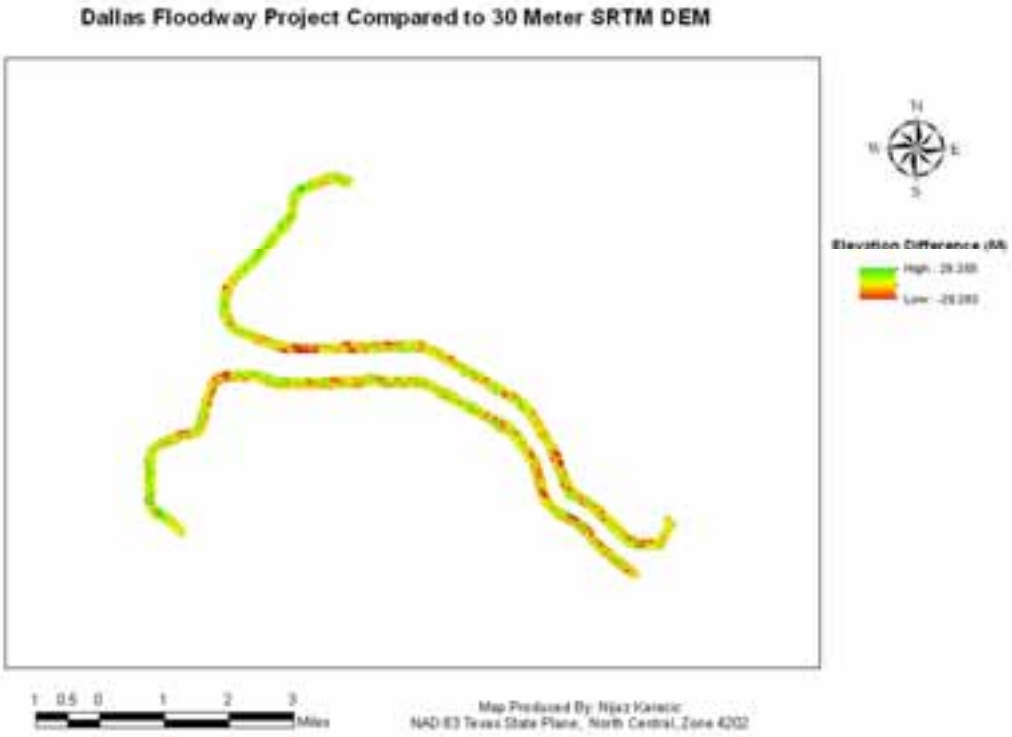

Dallas Floodway Project Compared to 30 Meter SRTM DEM
N
W
E
S
Elevation Difference (M)
High : 29.189
Low : -29.193
1 0.5 0 1 2 3
Miles
Map Produced By: Nijaz Karacic
NAD 83 Texas State Plane, North Central, Zone 4202

Fig. 6

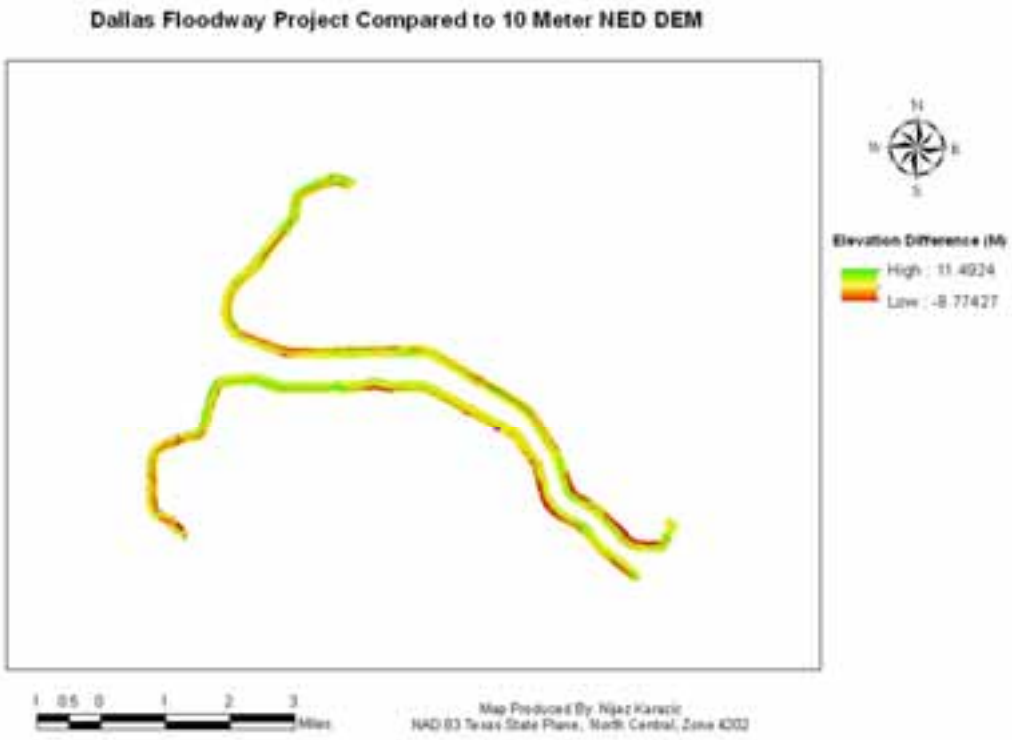

Dallas Floodway Project Compared to 10 Meter NED DEM
N
W
E
S
Elevation Difference (M)
High : 11.4924
Low : -8.77427
1 0.5 0 1 2 3
Miles
Map Produced By: Nijaz Karacic
NAD 83 Texas State Plane, North Central, Zone 4202

Fig. 7

THE ICESat point elevation comparisons comparing the ICESat points with the SRTM raster, the NED raster, and the Dallas Floodway Project raster were created by using ArcMap's Extract Values to Points tool. This tool reads the value (and creates a field in the point shapefile's data table) of the selected raster image at the location of each ICESat point that crossed each raster. Once the points shapefile was updated, a new field named "Elevation Difference" was added to the data table so that the values could be calculated using ArcMap's field calculator. These values were created by subtracting the Orthometric Height value from the corresponding raster value (Elevation). (See Fig. 8-12)

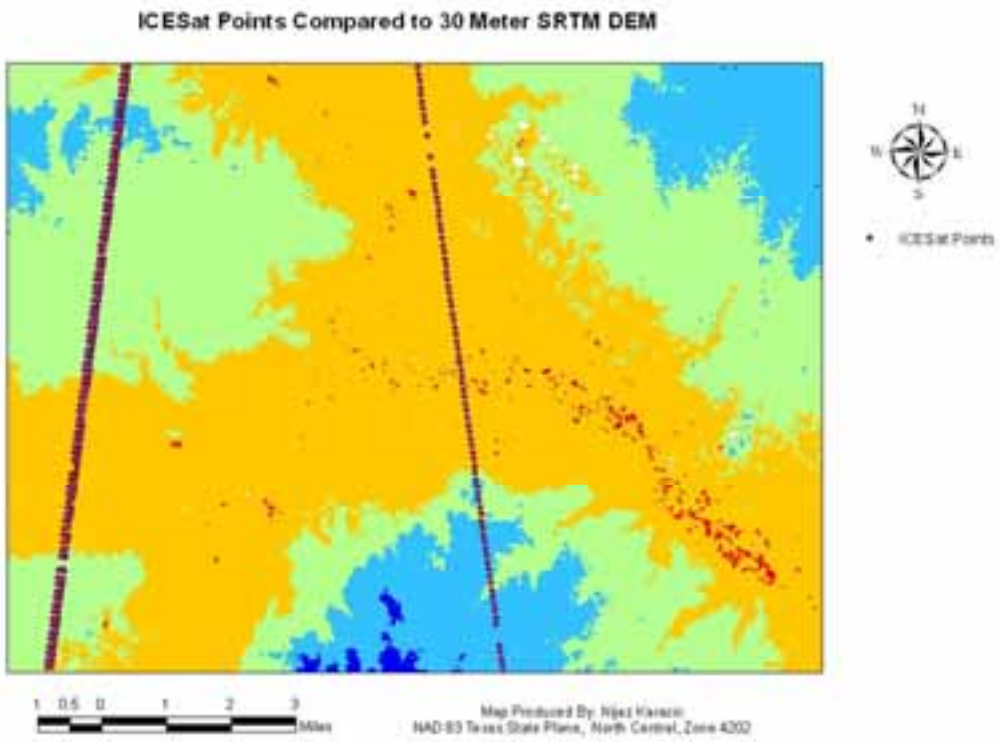


Fig. 8

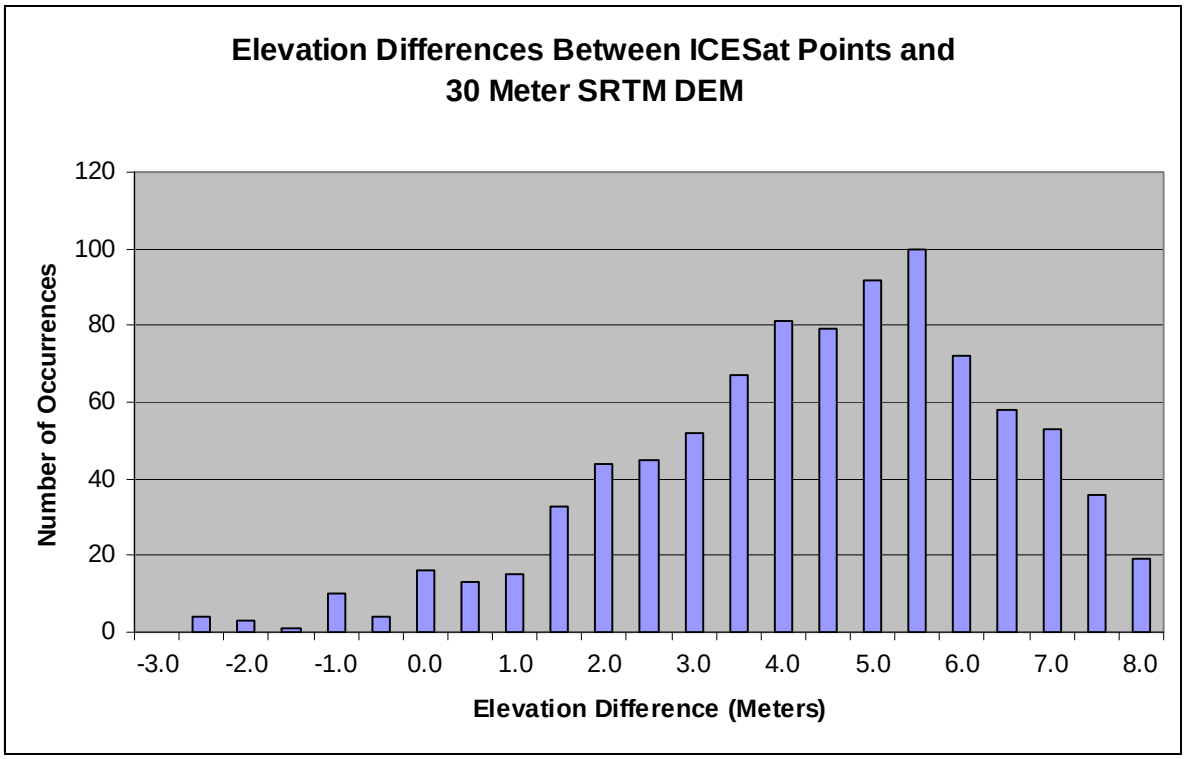

Elevation Differences Between ICESat Points and
30 Meter SRTM DEM
Number of Occurrences
120
100
80
60
40
20
0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Elevation Difference (Meters)

Fig. 9

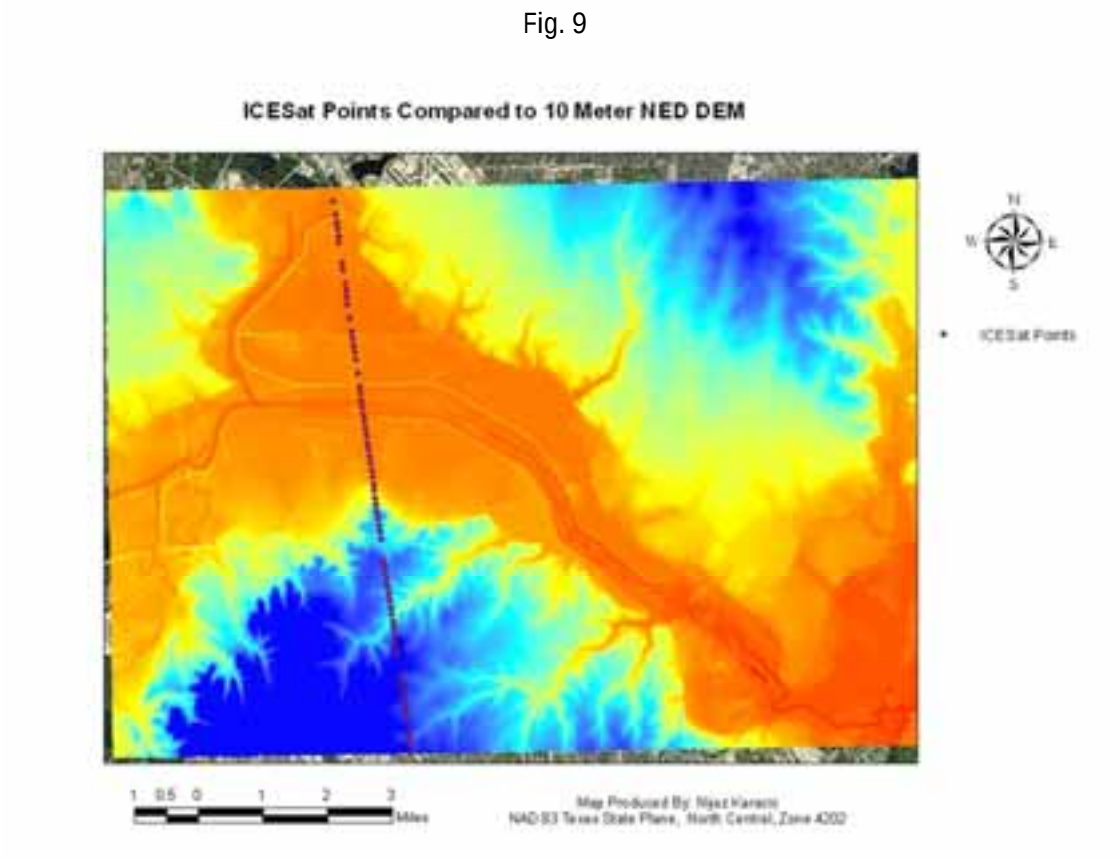

ICESat Points Compared to 10 Meter NED DEM
N
W
E
S
ICESat Points
1 0.5 0 1 2 3
Miles

Fig. 10

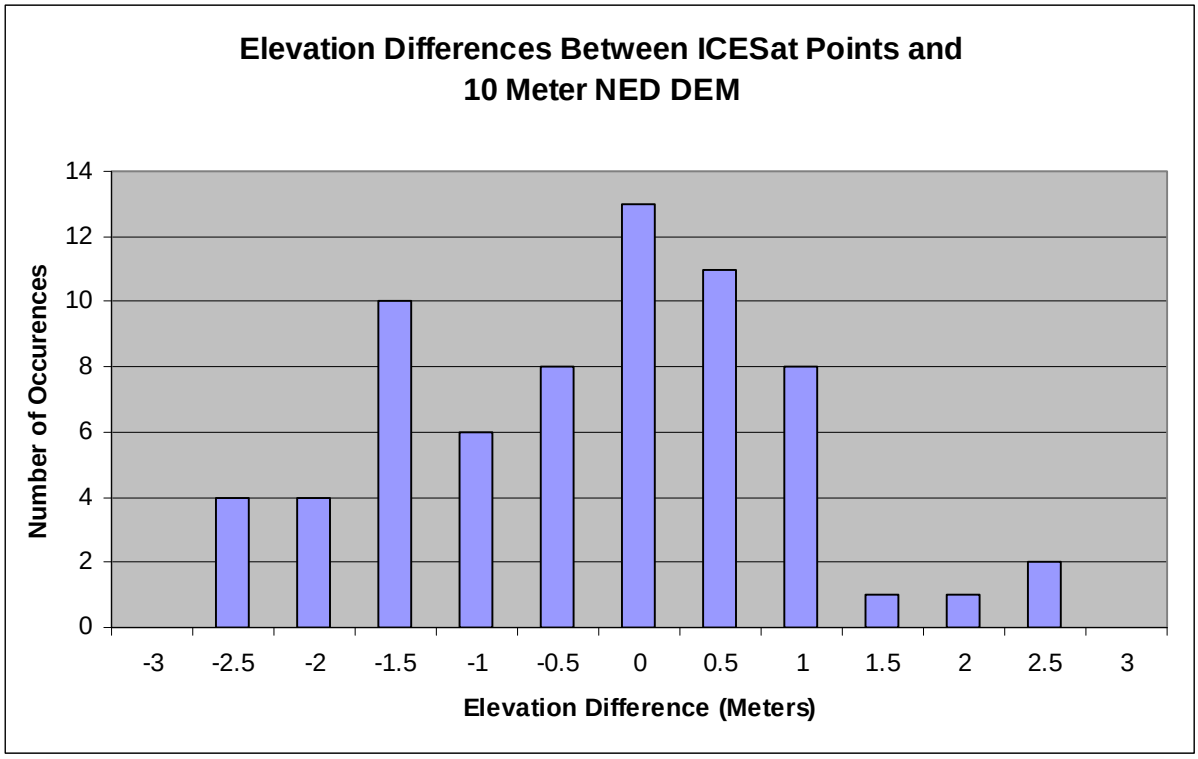

Elevation Differences Between ICESat Points and
10 Meter NED DEM
Number of Occurences
0
2
4
6
8
10
12
14
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
Elevation Difference (Meters)

Fig. 11

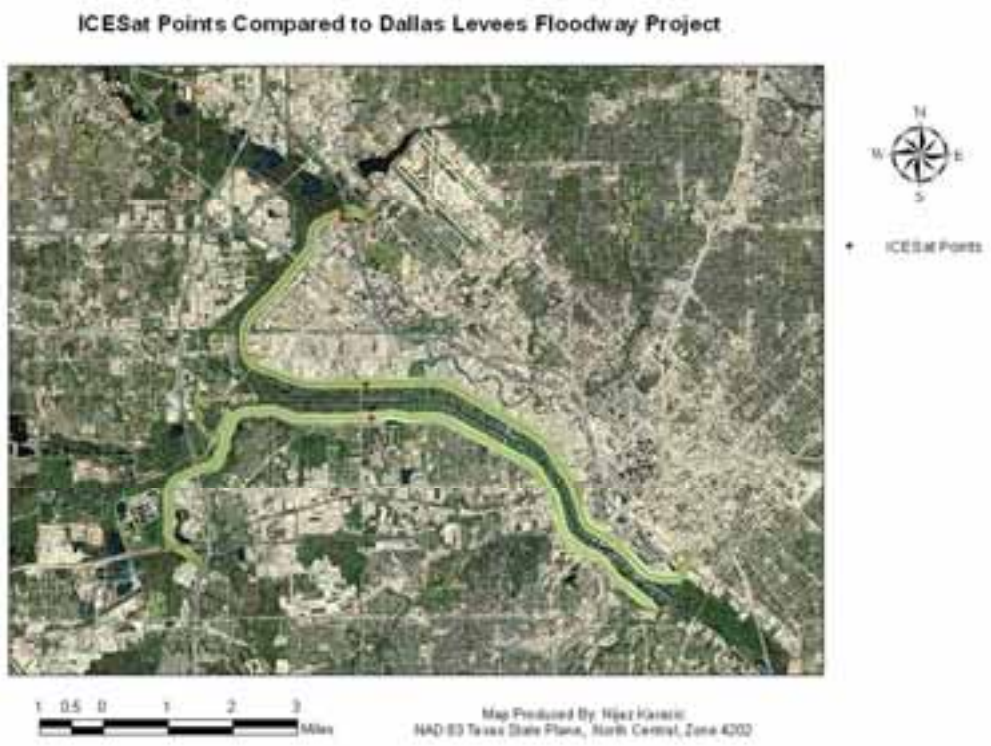

ICESat Points Compared to Dallas Levees Floodway Project
ICESat Points
Miles

Fig. 12

Discussion and Concluding Remarks

It has been demonstrated that there are significant effects that influence the comparison of the SRTM-derived DEM and other elevation data. The SRTM DEM has a slight elevation shift as compared to other elevation datasets. These effects can primarily be attributed to dynamic changes of the Earth's surface or instrument-based specifications such as different penetration depths of radar and laser sensors. The laser pulses of ICESat are able to penetrate vegetation. The differences involving the SRTM height dataset result in standard deviations of approximately five meters, which can mostly be attributed to the intrinsic random noise level in the SRTM data (Braun and Fotopolous, 2007). In our case, as seen in table 1, the results were 4.60 meters and 4.21 meters respectively for the east and west levees.

In comparison, ICESat elevations must be considered separately because the ICESat values are provided on a point-wise basis, while the SRTM and NED elevations are averaged over a 30 m X 30 m and 10X10 m area. Depending on the location of the ICESat points, the computed difference with the SRTM elevations varied. For instance, averaged SRTM elevations were typically lower than the discrete ICESat elevations that are located along roads, or at outcrops, which are elevated with respect to the surrounding land area. Consequently, the SRTM DEM cannot replace existing NED points for engineering applications such as well-site surveying and pipeline planning. However, it may assist in the assessment of accessibility and pre-survey planning.

Table 1. Mean and Standard Deviation of the Computed Differences for the Individual Data Sets

	MEAN (Meters)	Standard Deviation (Meters)
Dallas Floodway Project Compared to 30 Meter SRTM DEM (East Levee)	-4.02	4.60
Dallas Floodway Project Compared to 30 Meter SRTM DEM (West Levee)	-3.12	4.21
Dallas Floodway Project Compared to 10 Meter NED DEM (East Levee)	0.06	2.65
Dallas Floodway Project Compared to 10 Meter NED DEM (West Levee)	-0.04	2.35
ICESat Points Compared to 30 Meter SRTM DEM	4.13	2.06
ICESat Points Compared to 10 Meter NED DEM	-0.57	1.19

The results validate the intrinsic random noise level of approximately five meters in the SRTM DEM (Rodriguez et al., 2006). The results achieved in this paper show 4.5 m in comparison. This value is well below the original mission requirements of 15 meters and thus a major improvement. Independent data sources such as ICESat, which is two orders of magnitude more accurate, can be used to validate and calibrate the SRTM DEM for diverse applications. For example, ICESat data was employed as ground control points to remove the bias in the ERS-1 SAR interferometry data for creating a DEM. In the case of the SRTM X-band SAR data was calibrated using radar altimetry over the oceans to remove any bias/tilt prior to the generation of the DEM.

Future investigations will focus on the use of the SRTM DEM for local and regional applications and a comparison with higher resolution (1-meter) lidar data, which is frequently used in oil and gas field surveying and planning. More precise applications such as elevation change detection must also involve proper and consistent datum conversions for all data sets, as previously outlined. Finally, ICESat waveform analysis must be employed in order to find the true reflective surface in the vegetation cover.

Acknowledgments

The authors would like to thank Alexander Braun, Ph.D., Professor of Geosciences at The University of Texas at Dallas for his comments on earlier versions of this paper.

References

1. Bhang, K.J.; Schwartz, F.; Braun, A.. Verification of the Vertical Error in C-Band SRTM DEM Using ICESat and Landsat-7, Otter Tail County, MN. IEEE Trans on Geosci. Remote Sens. 2007, 45, 36-44.

2. Braun, A.; Fotopoulos, G.. "Accuracy assessment of SRTM, ICESat, and survey control monument elevations of multifaceted terrain in Alberta, Canada," presented at the SRTM Workshop, (2005,Jul.).[Online].Available:http://edc.usgs.gov/conferences/STRM/presentations/Slides20_Braun.pdf

3. Braun, A.; Fotopoulos, G.. Assessment of SRTM, ICESat, and Survey Control Monument Elevations in Canada. Photogramm. Eng. Remote Sens. 2007, 73, 1333-1342.

4. Carabajal, C.C.; Harding, D.J.. "ICESat validation of SRTM C-band digital elevation models," Geophys. Res. Lett., vol.32, no.22, 2005. L22S01.1–L22S01.5.

5. Karacic, N.; Holt, S.; Marshall, R.L., 2011. *Applying GIS, GPS, and LiDAR for Urban Infrastructure Renewal Projects - A Case Study of the Trinity River Levees*, ESRI 2011 User Conference UC 4060, San Diego, California.

6. Karacic, N., 2008. Master's Thesis, Quality Control of Benchmark Data for 8(eight) Cities in the Dallas-Fort Worth area, Texas A&M University, Corpus Christi

7. Farr, T.; Kobrick, M., 2000. Shuttle radar topography mission produces a wealth of data, American Geophysical Union Eos,81: 583–585.

8. Lilles, T.M.; Kiefer, R.W.. Remote Sensing and Image Analysis, 4th ed. New York: Wiley, ch.7, pp.534–536.

9. Miliaresis, G.; Paraschou, Ch. Vertical Accuracy of the SRTM DTED Level 1 of Crete. Int. J. Appl. Earth Observ. GeoInfo. 2005, 7, 49-59.

10. Osborn, K.; et al. Digital Elevation Model Technologies and Applications, the DEM Users Manual; Maune, D., Ed.; American Society for Photogrammetry and Remote Sensing: Bethesda, MD, USA, 2001; Chapter 4, pp. 83-120.

11. Pacheco Koch Consulting Engineering, 2010. Final Survey Report, Dallas Floodway Project Control and Re-establishment of the Trinity River Levee Baselines

12. Rodriguez, E.; Morris, C.S.; Belz, J.E.. A Global Assessment of the SRTM Performance. Photogramm. Eng. Remote Sens. 2006, 72, 249–261.

References (Continued)

13. Rodriguez, E.; et al., 2005. An Assessment of the SRTM Topographic Products, Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California.

14. Rosen, P.; et al. "SRTM – Mission —Cross comparison of X and C band at a properties," in Proc.IGARSS, Jul.9 – 13, 2001, vol.2, pp.751–753.

15. Schutz, B.E.; et al. "Overview of the ICESat mission," Geophys. Res. Lett., vol.32, no.21, 2005. L211S01.

16. U.S. Army Corps of Engineers, Engineering Manual: Engineering and Design —Geodetic and Control Surveying (EM1110-1-1004), Jun. 2002, Washington, DC.

17. Van Zyl, J., 2001. The shuttle radar topography mission (SRTM): A breakthrough in remote sensing of topography, Acta Astronautica, 48 (5–12): 559–565.

18. Zwally, H.J.; et al. "ICESat's laser measurements of polarice, atmosphere, ocean, and land, "J. Geodyn., vol.34, no.3, pp.405 –445, Oct./Nov. 2002.