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2003-2005 Hawaii Lidar Data Validation Report

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Introduction

The National Oceanic Atmospheric Administration (NOAA) Coastal Service Center Topographic Change Mapping (TCM) project seeks to aid coastal managers with their topographic needs. This can include issues ranging from beach geomorphologic change to storm surge inundation to determination of invasive species habitat. Additionally, the TCM project creates derived information products and analysis tools to facilitate the coastal resource manager's decision-making process. The TCM project received Light Detection and Ranging (Lidar) data collected along the coast of Hawaii in September 2005 and will distribute the data from its web-based Lidar Data Retrieval Tool (LDART).

EarthData, Inc. collected elevation point data derived from multiple return (first and last) lidar measurements over sections of Oahu and Maui. Two surveys where conducted over portions of Oahu and a single survey over Maui. In October 2003, a 500 meter strip around the entire coastline of Oahu was collected under tidally controlled conditions at a nominal two-meter posting. In February 2005, a 175 square kilometer area over the Ewa plain was surveyed at a nominal two-meter posting. In March 2005, a strip along the west coast of Maui was surveyed at a nominal two-meter posting. Final data was delivered in the LAS format with several embedded attributes: return number, number of returns, intensity, classification ("bare ground" or "not bare ground"). (*Figure 1*). The contract with Earth Data, Inc. specified a vertical accuracy requirement of ±0.15-meter root mean square error ($RMSE_{(z)}$).

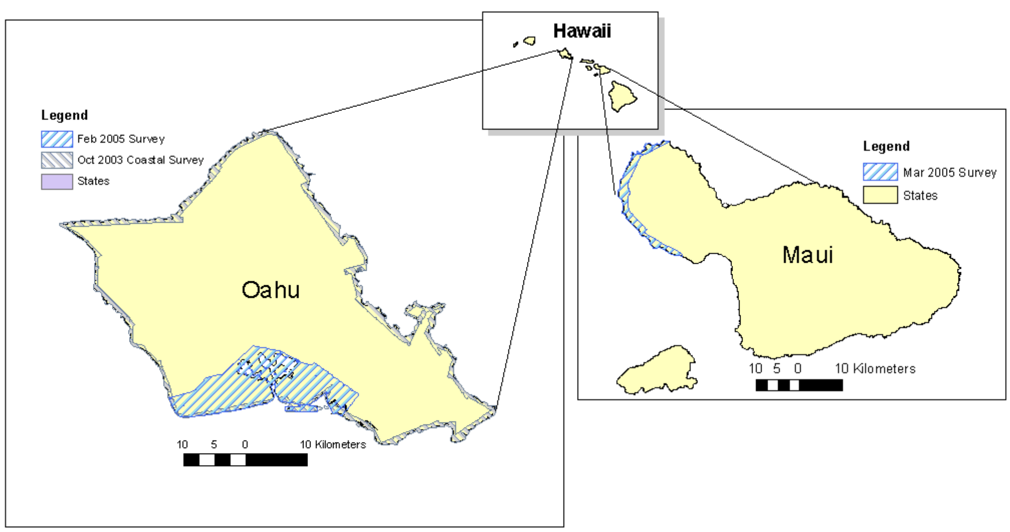

Figure 1. Extent of the Hawaii lidar surveys.

This report presents the results of a quantitative error assessment conducted to verify the vertical accuracy of the lidar data in open terrain using the independent check points as validation points. The data collected during the 2003 coastline survey were assessed independently of the Oahu/Maui 2005 surveys. This assessment followed procedures and recommendations presented in the *Guidelines for Digital Elevation Data* prepared by the National Digital Elevation Program (NDEP) and the *ASPRS Guidelines for Vertical Accuracy Reporting for Lidar Data* prepared by the ASPRS Lidar Committee.

Methods

The Center conducted a check point survey December 6-12, 2004. Two ground control networks were established on Oahu and Maui tied to the NGS CORS points *ZHN1* and *Maui*, respectively. Points in flat, open terrain distributed throughout the study area were selected for occupation. Two Thales Z-Max dual frequency GPS receivers were operated in static differential mode to collect vector information. The vector data was post-processed and adjusted using Thales Navigation's GNSS Studio software. The final independent check point data set for Oahu consisted of thirty-six check points with a vertical confidence (at 95%) of 5 cm or better. The final independent check point data set for Maui consisted of thirty-one check points with a vertical confidence (at 95 %) of 8 cm or better.

In addition to the check points collected by the Center, an additional twenty check points were collected by an independent surveyor around the perimeter of Oahu. These points were combined with the Center's thirty-six points for evaluating the Oahu lidar surveys.

The post edited bare earth lidar data were used by the Center to perform this data validation. The nature of topographic lidar data collection limits the ability to survey precise horizontal (xy) locations; therefore, a form of interpolation of lidar data is required to accurately compare check points and lidar derived elevation models. The Guidelines for Digital Elevation Data by NDEP recommends interpolation from a surface generated from a triangulated irregular network (TIN) derived from the lidar point data for assessing the accuracy of mass points. This method was employed in this evaluation. Elevation values at the location of each of the check points were interpolated from the triangulated bare earth point data. The vertical error at each check point location was calculated by subtracting the interpolated lidar elevation value from the check point elevation value. After calculating the error at each check point, the overall root mean square error ($RMSE_{(z)}$) for the survey was calculated. The overall vertical accuracy at the 95th percentile was then calculated with equation[1]:

[1] Vertical Accuracy at 95% confidence level = 1.9600 * $RMSE_{(z)}$
(assuming errors were normally distributed)

Results

2003 Oahu Coastal Lidar Survey

The overall $RMSE_{(z)}$ error for the 2003 Oahu coastal lidar survey was 0.156 meters which is based on 22 samples. A Shapiro-Wilk statistical test performed on the errors for the quantitative assessment indicated the errors were normally distributed ($W = 0.94$; $p = 0.17$) and, therefore, reporting the vertical accuracy using equation [1] is appropriate. The Shapiro-Wilk test was chosen because it works well with a small sample size as long as there are no identical values.

Figure 2 shows the elevation difference calculated at each of the ground control stations. A mean error of 0.050 meters and a standard deviation of 0.151 meters were reported. The range of elevations differences was between 0.348 and -0.246 meters (see *Appendix A*).

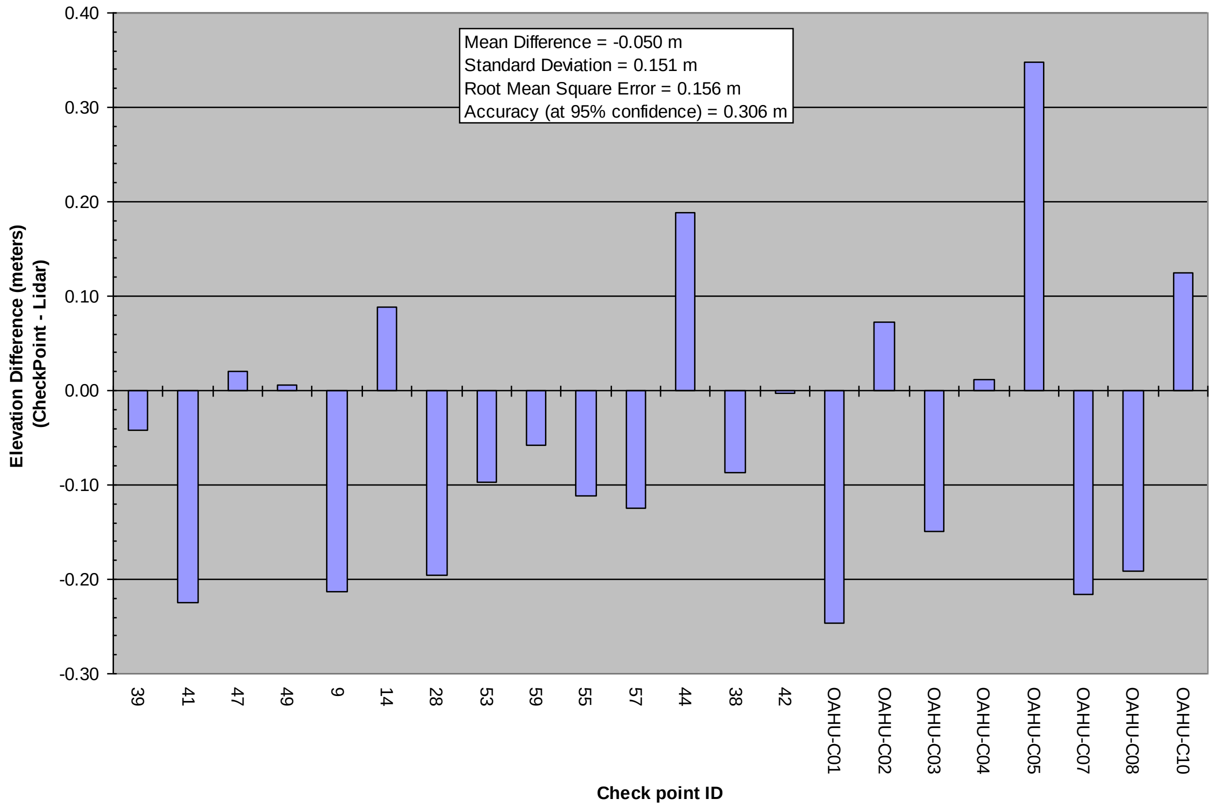

Figure 2. 2003 Oahu coastal survey - Elevation differences at each check point (Check point elevation – Lidar elevation).

The spatial distribution of the elevation differences is presented in *Figure 3* and the actual values are presented in a table in *Appendix A*. Each check point is colored according to the magnitude of the error identified for the lidar elevation calculated at the check point's horizontal (xy) location.

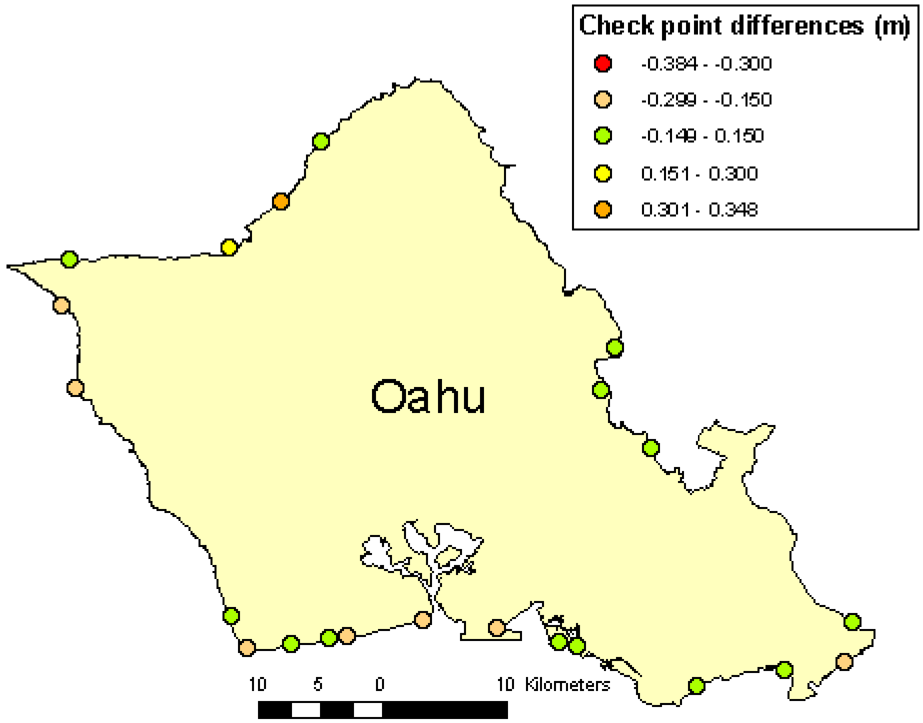

Figure 3: Oahu coastal survey - Map showing the spatial distribution of elevation differences between check point elevations and interpolated lidar elevations (Check point elevation – Lidar elevation).

2005 Oahu/Maui Lidar Survey

The overall $RMSE_{(z)}$ error for the Oahu/Maui lidar survey was 0.159 meters which is based on 63 samples. A Shapiro-Wilk statistical test performed on the errors for the quantitative assessment indicated the errors were normally distributed ($W = 0.94$; $p = 0.17$) and therefore reporting the vertical accuracy using equation [1] is appropriate. The Shapiro-Wilk test was chosen because it works well with a small sample size as long as there are no identical values.

Figure 2 shows the elevation difference calculated at each of the check point locations. A mean error of -0.035 meters and a standard deviation of 0.156 meters were reported. The range of elevations differences was between 0.310 and -0.384 meters (see *Appendix A*).

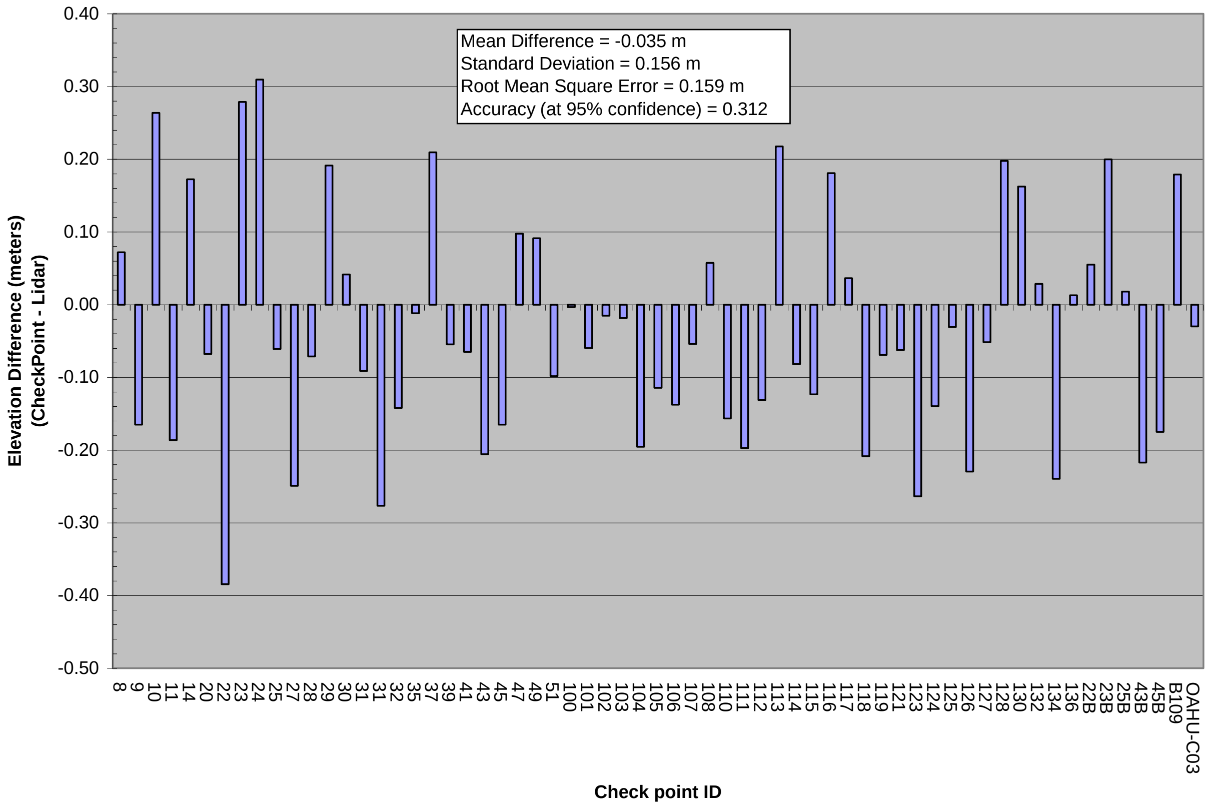

Figure 4. Maui - Elevation differences at each check point (Check point elevation – Lidar elevation).

The spatial distribution of the elevation differences is presented in *Figure 3* and the actual values are presented in a table in *Appendix A*. Each check point is colored according to the magnitude of the error identified for the lidar elevation calculated at the check point's horizontal (xy) location.

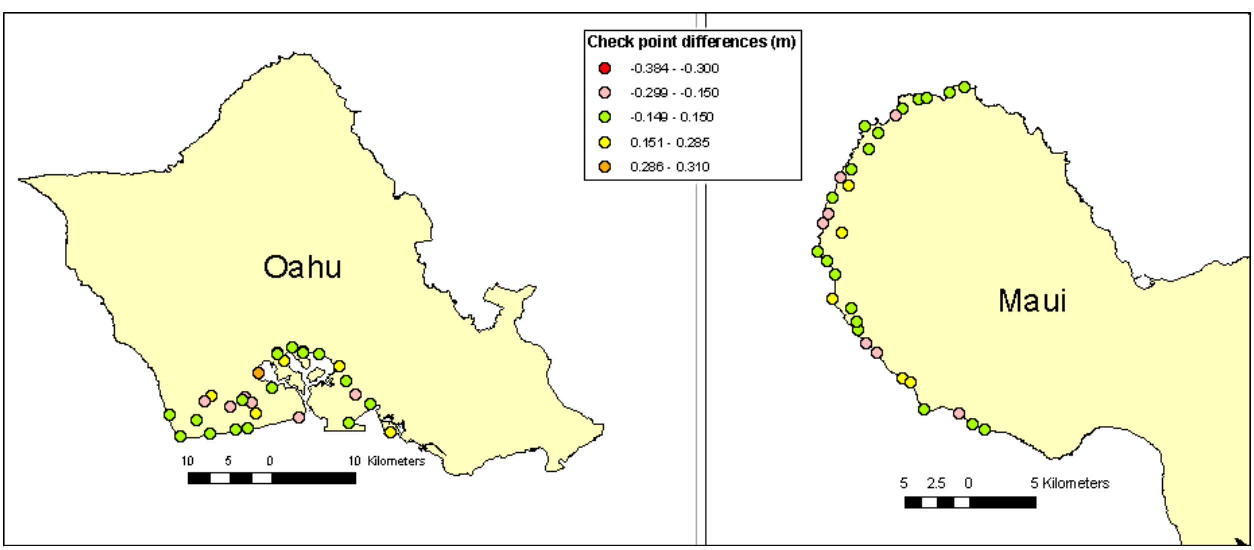

Figure 5: Maui - Map showing the spatial distribution of elevation differences between check point elevations and interpolated lidar elevations (Check point elevation – Lidar elevation).

Discussion

The overall vertical error calculated from the collection of check points exceeds the prescribed accuracy limits for both the Oahu and Maui lidar surveys by less than 1 centimeter. Given that the check points were located in flat and open terrain, these errors are generally believed to be random errors in the lidar sensor system as opposed to systematic errors generated from vegetated areas.

The horizontal accuracy of this lidar data was not assessed. The high vertical accuracy is indicative of good horizontal accuracy, though slight horizontal inaccuracies are difficult to detect using these check points because they were located in relatively flat terrain.

Based on this assessment, the National Standard for Spatial Data Accuracy (NSSDA) of the 2003 Oahu coastal lidar data may be reported as:

> **"Tested 0.306 meter fundamental vertical accuracy at 95 percent confidence level in open terrain using $RMSE_{(z)}$ x 1.9600."**

Based on this assessment, the NSSDA of the 2005 Oahu/Maui lidar data may be reported as:

> **"Tested 0.312 meter fundamental vertical accuracy at 95 percent confidence level in open terrain using $RMSE_{(z)}$ x 1.9600."**

Appendix A

The following table shows the elevation difference calculated at each of the 2003 Oahu coastal survey check points. The differences (Delta Z) were calculated by subtracting the interpolated (via tinning) orthometric lidar heights (meters) from the coincident check point heights.

Check Point	Longitude	Latitude	DeltaZ (m)
9	-157.976918	21.317642	-0.213
14	-157.8779188	21.3017148	0.088
28	-157.9224914	21.3111101	-0.195
38	-157.836305	21.5158131	-0.088
39	-158.1168508	21.3206743	-0.043
41	-158.1045399	21.2970356	-0.224
42	-158.0507463	21.6648483	-0.003
44	-158.1186131	21.5887802	0.188
47	-158.0729109	21.2991595	0.020
49	-158.0450288	21.3046467	0.006
53	-157.7773959	21.2691033	-0.097
55	-157.7133123	21.2816355	-0.112
57	-157.6636985	21.3158763	-0.124
59	-157.8467602	21.4843621	-0.058
OAHU-C01	-157.6693384	21.2870684	-0.246
OAHU-C02	-157.8108369	21.442554	0.073
OAHU-C03	-158.0323406	21.3056469	-0.150
OAHU-C04	-158.2349383	21.5794026	0.012
OAHU-C05	-158.0800852	21.6223326	0.348
OAHU-C07	-158.2401355	21.5457244	-0.216
OAHU-C08	-158.2297822	21.4864615	-0.191
OAHU-C10	-157.8643108	21.2978235	0.125
		Mean	-0.050
		$RMSE_z$	0.156
		NSSDA $accuracy_z$	0.306

Appendix B

The following table shows the elevation difference calculated at each of the 2005 Oahu/Maui check points. The differences (DeltaZ) were calculated by subtracting the interpolated (via tinning) orthometric lidar heights (meters) from the coincident check point heights.

Check Point	Longitude	Latitude	DeltaZ (m)
8	-158.0064506	21.3487669	0.072
9	-157.9769180	21.3176420	-0.165
10	-157.9329157	21.3721986	0.264
11	-157.9148373	21.3418483	-0.187
14	-157.8779188	21.3017148	0.172
20	-157.9551752	21.3861692	-0.068
22	-157.9722872	21.3880641	-0.384
23	-157.9920801	21.3781942	0.279
24	-158.0204763	21.3660813	0.310
25	-158.0000575	21.3865582	-0.061
27	-158.0356431	21.3389495	-0.249
28	-157.9224914	21.3111101	-0.071
29	-158.0229525	21.3222911	0.192
30	-157.8995424	21.3312236	0.042
31	-157.9839867	21.3937518	-0.091
31	-158.0277612	21.3330926	-0.277
32	-157.9258172	21.3571172	-0.142
35	-158.0875261	21.3139022	-0.012
37	-158.0718246	21.3403510	0.209
39	-158.1168508	21.3206743	-0.055
41	-158.1045399	21.2970356	-0.065
43	-158.0785528	21.3346227	-0.206
45	-158.0503426	21.3290722	-0.165
47	-158.0729109	21.2991595	0.098
49	-158.0450288	21.3046467	0.091
51	-158.0384189	21.3368325	-0.098
100	-156.6271650	21.0220872	-0.003
101	-156.5952525	21.0301626	-0.060
102	-156.6379899	21.0158073	-0.015
103	-156.6210914	21.0223605	-0.019
104	-156.6808397	20.9682395	-0.196
105	-156.6542907	20.9983758	-0.115
106	-156.6864714	20.9544160	-0.138
107	-156.6610860	20.9876670	-0.054
108	-156.6733803	20.9734116	0.058
110	-156.6889213	20.9426344	-0.157
111	-156.6924688	20.9368235	-0.197
112	-156.6896076	20.9108114	-0.131
113	-156.6799035	20.9299383	0.218
114	-156.6964480	20.9172676	-0.082
115	-156.6050581	21.0268442	-0.124

116	-156.6864621	20.8850217	0.181
117	-156.6640861	21.0036730	0.036
118	-156.6425128	21.0107052	-0.208
119	-156.6841021	20.9016860	-0.069
121	-156.6731589	20.8786466	-0.062
123	-156.6630002	20.8544626	-0.264
124	-156.6688942	20.8630372	-0.140
125	-156.6232994	20.8085376	-0.031
126	-156.6557656	20.8477938	-0.229
127	-156.6691080	20.8685364	-0.052
128	-156.6374105	20.8301358	0.198
130	-156.6327700	20.8273923	0.163
132	-156.5893232	20.7980777	0.029
134	-156.5993461	20.8059211	-0.240
136	-156.5816110	20.7947924	0.013
22B	-157.9721434	21.3879725	0.055
23B	-157.9920527	21.3782392	0.200
25B	-158.0006302	21.3865044	0.018
43B	-158.0785976	21.3346772	-0.217
45B	-158.0503427	21.3290723	-0.175
B109	-156.6752729	20.9629529	0.179
OAHU-C03	-158.0323406	21.3056469	-0.030
		Mean	-0.035
		$RMSE_z$	0.159
		NSSDA $accuracy_z$	0.312