Ogden LiDAR Data Acquisition for Utah Division of Emergency Management

Box Elder and Weber Counties, Utah

COMPLETION REPORT

UtahStateUniversity
LASSI Service Center

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SUMMARY OVERVIEW

Executive Summary

This project encompasses an area in two Utah counties and encompasses about 103 square miles shown below. Data was collected in October, 2011.

Study Area	County	Size (mi²)
Desired lidar acquisition area including the re-fly zone	Weber, Box Elder	103

Contractor

This project was completed under contract DEM111019 between Utah Automated Geographic Reference Center (Utah AGRC) and Utah State University (USU) LASSI Service Center.

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Scope Overview

Our responsibilities included:

- Flight planning;
- Identification of ground control to be applied as airborne GNSS base stations and for DEM processing;
- Aerial data acquisition;
- Collection of GNSS base station data during flight;
- Collection of GNSS RTK ground data for application in DEM accuracy testing;
- Processing, calibration and classification of LiDAR returns;
- Output of data deliverables including metadata;
- Compilation of Project Completion Report, including Flight, Data Processing and LiDAR DEM Accuracy reporting in compliance with National Standards for Spatial Data Accuracy (NSSDA) guidelines.

Specifications for Deliverables

The required accuracy and file formats for each delivery was as follows:

LiDAR Deliverables	
Grid Projection:	UTM Zone 12N
Horizontal Datum:	NAD83(CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 M
Average Post Spacing:	0.85 m
Average Data Density:	1.37 sh/m2
File Formats:	*.las (v. 1.2)
Classified Datasets:	ASPRS/LAS Default Classes

Grid Model Deliverables	
File Format:	IMG (.img)
Grid Projection:	UTM Zone 12N
Horizontal Datum:	NAV83(CORS96)
Vertical Datum:	NAVD88 using GEOID09
Tile Size:	2000 m X 2000 m
Cell Size:	1.00m

Miscellaneous Deliverables	
Breakpoint Files:	LAS 1.2 (.las) on specific code
Metadata Files:	FGDC compliant XML file. (.xml)
Project Tile Index:	Portable Document Format (.pdf)
Completion Report:	Portable Document Format (.pdf)

LiDAR data acquisition was performed using a Riegl LMS Q560 airborne laser sensor system capable of up to a maximum 200 kHz pulse repetition rate and collection of full waveform returns.

Project Area Extents and Project Tile Index

The tile layout and project extents for the area surveyed is provided in Appendix A. The number of tiles collected totals 105.

Tiles were designed on a 2000 m by 2000 m grid and were automatically generated.

Pre-Flight Planning

Appendix B provides a map showing flightline layout for the subject area. Table 1 provides the pre-flight mission parameters used for the project.

Table 1. Pre-flight mission parameters.

Mission Summary	750 m AGL	
	Riegl Q560	
	Metric	English
GSD - Cross Track	0.848 m	2.8 ft
GSD - Long Track	0.848 m	2.8 ft
Data Density	1.4 sh/m2	0.13 sh/ft2
Shot/Pixel Size	0.40 m	1.3 ft
Swath Width	866.0 m	2840.6 ft
Flightline Spacing	519.6 m	1704.3 ft
Shot or Frame Rate	67 kHz	
Total Numbers	0.55	Gpoints

Control

The area surrounding the study area was searched for candidate vertical control monuments over which the GNSS ground station could be placed. The goal was to tie to A- or B-order vertical control, while at the same time, be in or within 10 km of the study area. Benchmark WC-108 was used for this study.

A GPS base station for this project was established in Weber County on NGS benchmark H 23 and was occupied for several days. This enabled the calculation of a strong static GPS solution which has been compared with the published vertical coordinates. Moreover, this GPS station was active during the lidar flight thereby enabling differential GPS corrections.

The RTK GPS base station was set up directly over the this monument and the height to the antenna measured within 1 mm. This was used to compare calculated coordinates with published coordinates. In order to make proper comparisons, the height measured at a previous date needed to be adjusted according to observed HTDP point velocity published by NGS for nearby CORS stations. This point was thereby brought up to date.

Figure 1. Benchmark WC-108 in Weber County.

Final Planning – Procedures and Activities

Planning

Weather forecasts and project schedule identified an aerial acquisition window during the month of October 2011. Prior to each acquisition campaign, the following was completed:

- Brief flight crew and ground support personnel on project requirements
- Investigate PDOP forecast for location (Flights to be conducted with PDOP below 3.0)
- Decision to mobilize Bob Pack to site to set up targets and GNSS base stations.
- Complete a reconnaissance of the project area was conducted to report on ground conditions.

The aircraft was mobilized out of Logan, Utah and the acquisition was completed during a single day.

Summary of Supporting Documents

- Weber WC-108 DATASHEET.pdf– *Supplied by Weber County.*
- PDOP Plots subdirectory – contains *PDOP forecasts for periods of data acquisition.*

(The above listed documentation is provided in softcopy format only.)

Data Processing Procedures Report

Data Storage

After each flight, all raw navigation data, raw LiDAR data, raw image data, coverage data, and flight logs were off-loaded to a computer and an additional backup storage copy created.

Navigation System

The airborne GNSS data were processed using GrafNet software from NovAtel. Data was also collected from nearby International GPS Service for Geodynamics (IGS) stations for the periods of the flight. Airborne GNSS data was processed based on the ITRF05 Ellipsoid model.

The computed trajectories and the base station coordinates were used in the processing of the IMU data using Inertial Explorer from Waypoint. A smoothed trajectory was produced with error estimates based on the separation between trajectories processed forward and backward in time. The trajectory files were then transformed to the NAD83(CORS96) and NAVD88(GEOID09) project datum and the UTM Zone 12N projection for use in the LiDAR processing.

LiDAR System

LiDAR waveform files were analyzed using RiAnalyze software to discriminate data points. These points are output in the internal coordinate system of the LiDAR scanner. Each data point is assigned an echo value so it can be used in point classification work. RiProcess then uses the trajectory files created from the raw navigation data to generate XYZ points in a world coordinate system. A boresight calibration and strip (single scan line) adjustment was performed in RiProcess to improve data accuracy. This project's data were processed in strip form, meaning each flight line was processed independently. Processing the lines individually provides the data analyst with the ability to quality control (QC) the overlap between lines. To assess trajectory integrity, individual flight strips were then checked against adjacent strips to ensure good matching in the dataset.

The low gradient terrain within the study area resulted in highly visible manifestations of errors within overlap regions. For example, on some of the shoreline slopes a gradual 10 cm drop in elevation occurs over a distance of 1000 m. Hence a 1 cm contour interval would be 100 m wide and a 2 cm vertical error would result in a 200 m shift in a contour location. It was therefore necessary to develop custom strip overlap adjustment methods that would not only optimize the lidar system calibration but also correct GPS/IMU navigation errors manifested within individual strips.

A method has been implemented that corrects for aircraft roll and aircraft altitude error detected by analyzing elevation differences in all overlapping strips simultaneously. Figure 2 shows an example color-coded map of overlapping regions where blue equals a -10 cm difference, cyan a -5 cm difference, green 0 cm, yellow +5 cm, and red +10 cm. Figure 3 shows the same series of strips after adjustment. Because the center of the overlap zone is where adjacent strips are mosaicked via a mosaic line, it is important that these lines are consistently green. As shown in Figure 3 this is the case for all strips which results in smooth contouring across the entire project. This wouldn't have been the case using traditional methods that ignore within-strip errors associated with the

GPS/IMU system.

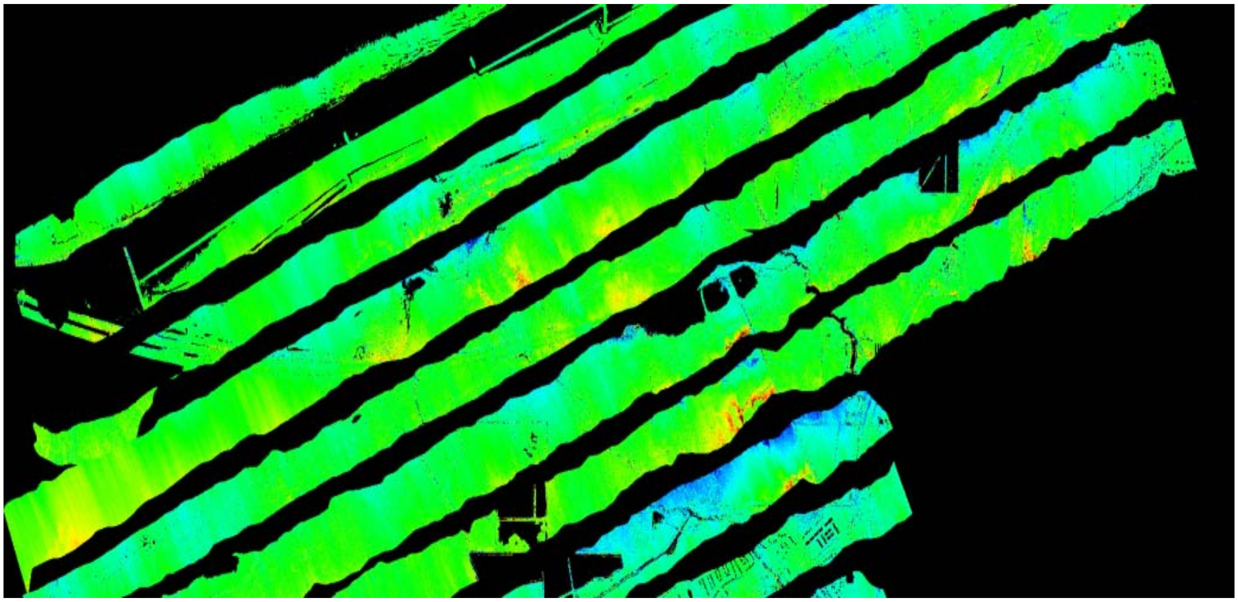


Figure 2. Overlap data prior to within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

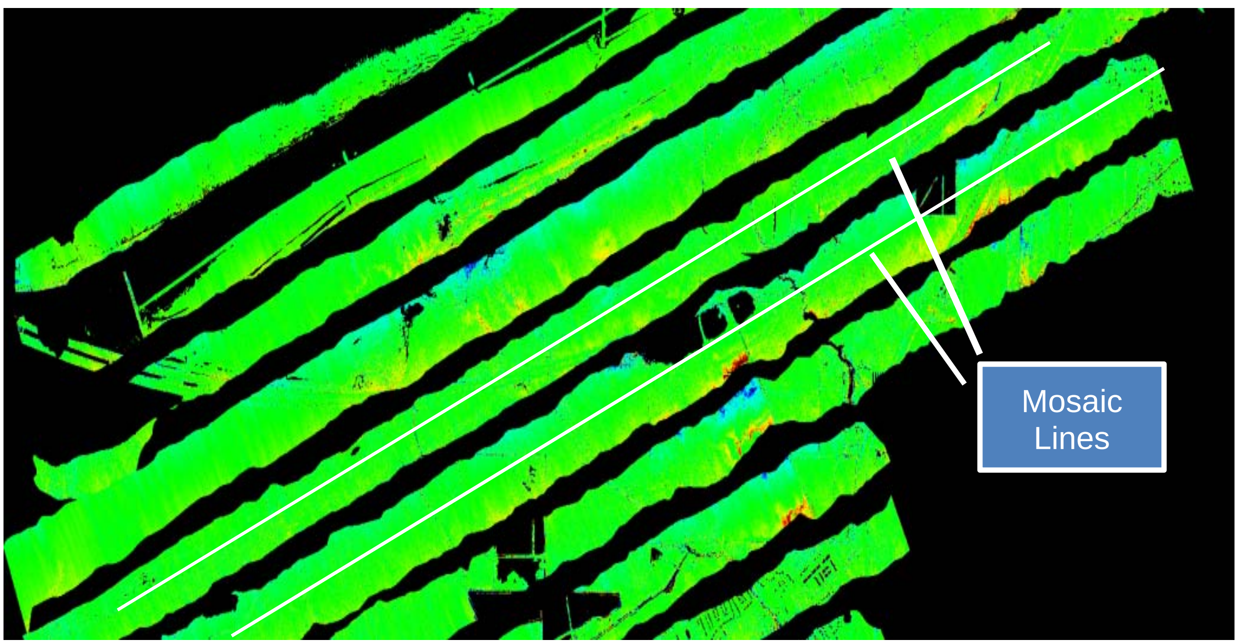


Figure 3. Overlap data after the within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

Each flightline (strip) was then brought into TerraScan (by Terrasolid) in the project datum and coordinate system. These flightlines were then combined and several classification routines, customized for the given terrain and vegetation, were then run to classify the points into standard ASPRS/LAS default classifications.

Significant effort was given to the creation of automated routines that would detect the river banks and lake shorelines within the subject areas. The routine then automatically creates polylines that then serve as breaklines for hydro-flattening. For this work, custom tools were developed using LAS-tools, a set of routines developed by Martin Isenburg (out of Germany), and custom Matlab scripts developed in-house. These breaklines, consisting of a series of closely spaced points were then added to the point cloud LAS files with a unique classification code. When combined in a LAS file with original lidar points, the quality of the hydro-flattening can immediately be exploited as a triangulated irregular network (TIN) in any LAS viewer or GIS system (such as ArcGIS).

Using the point classifications and breakline points, digital elevation models (DEMs) of the bare earth and digital surface models (DSMs) of all points were generated for each tile and carefully checked for data quality assurance.

Methodology

The QC check was intended to ensure that data would meet contractual standards set in FEMA (2003, Section A.8) and USGS NGP Guidelines v.13 (2010). Table 4 provides a summary of their standards for root mean squared error in the z (height) direction (RMSEz):

Table 4. Standards for RMSEz used in this project.

RMSEz	Condition	Source
7.0 cm	Relative accuracy within individual swaths	USGS
10.0 cm	Within swath overlap regions	USGS
12.5 cm	Fundamental vertical accuracy (in the clear)	USGS
18.5 cm	Under all major vegetation categories in flat areas	FEMA
37.0 cm	Under all major vegetation categories in hilly areas	FEMA

Relative Accuracy

Relative DEM accuracy was checked for the urban subdivision terrain type within this project using an RTK GPS surveys. A total of 26 points were collected on streets and curbs within the vicinity of benchmark WC108. The GPS point elevations were then compared with DEM tiles 86 and 87. This resulted in an average difference of 3.5 cm where the DEM is on average higher than the GPS points. A RMSEz of 2.5 cm was determined for these 26 points which is well under the 7.0 cm specification required by the contract.

Within Swath Overlap Accuracy

The mean and RMSEz difference between all DEM cells within overlapping regions has been calculated by custom Matlab scripts in USU's custom strip adjustment software. Systematic shifts within a given overlap region are less than 1 cm and the RMSEz between overlapping surfaces is 4.4 cm These results are within the required 10 cm specification.

Fundamental Vertical Accuracy

The results of the relative accuracy assessment given in Table 5 indicate that compared to the RTK points collected, the DEM was an average of 3.5 cm higher than the GPS points. Also, the RMSEz of only 2.5 cm was found. These values indicate that the fundamental vertical accuracy is well within the 12.5 cm specification required for this project.

Horizontal positional accuracy was not formally tested in this project and was not a specification of this contract.

Vegetation Penetration

It is our understanding that this project is to be used in floodplain mapping applications. Therefore we did a check to see how well the lidar shots are penetrating the cottonwood trees that densely occupy some of the floodplain areas. In tile 61 and dense stand of cottonwoods was analyzed. Figure 4 shows a cross-section where penetration to ground is continuous and the bare earth DEM has fine topographic detail. Figure 5 shows a cross-section in tile 52 through a river oxbow. This cross-section also shows excellent lidar point penetration. After some extensive searching in the project area, some cottonwoods were found in tile 51 that could not be penetrated across a gap of about 10 m. Figure 6 shows this case. It is therefore expected that this is a worst case for this project area.

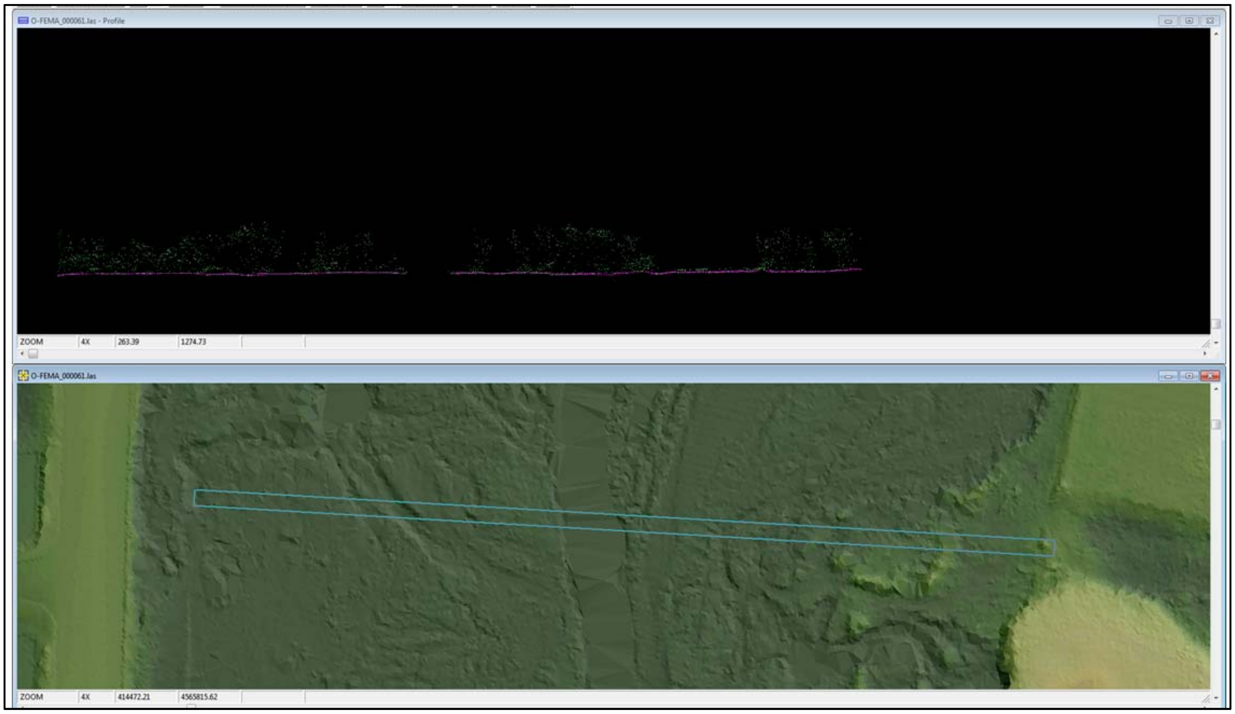


Figure 4. Cross-section through the river floodplain in tile 61.

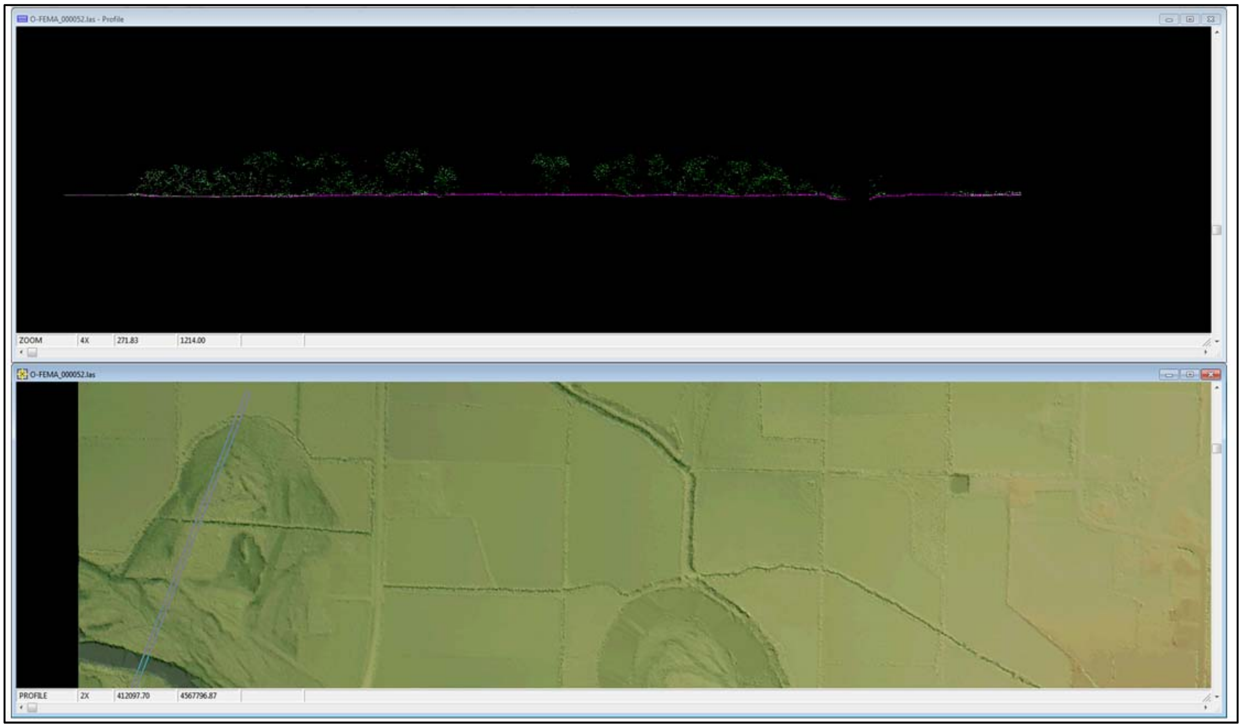


Figure 5. Cross-section through an oxbow in tile 52.

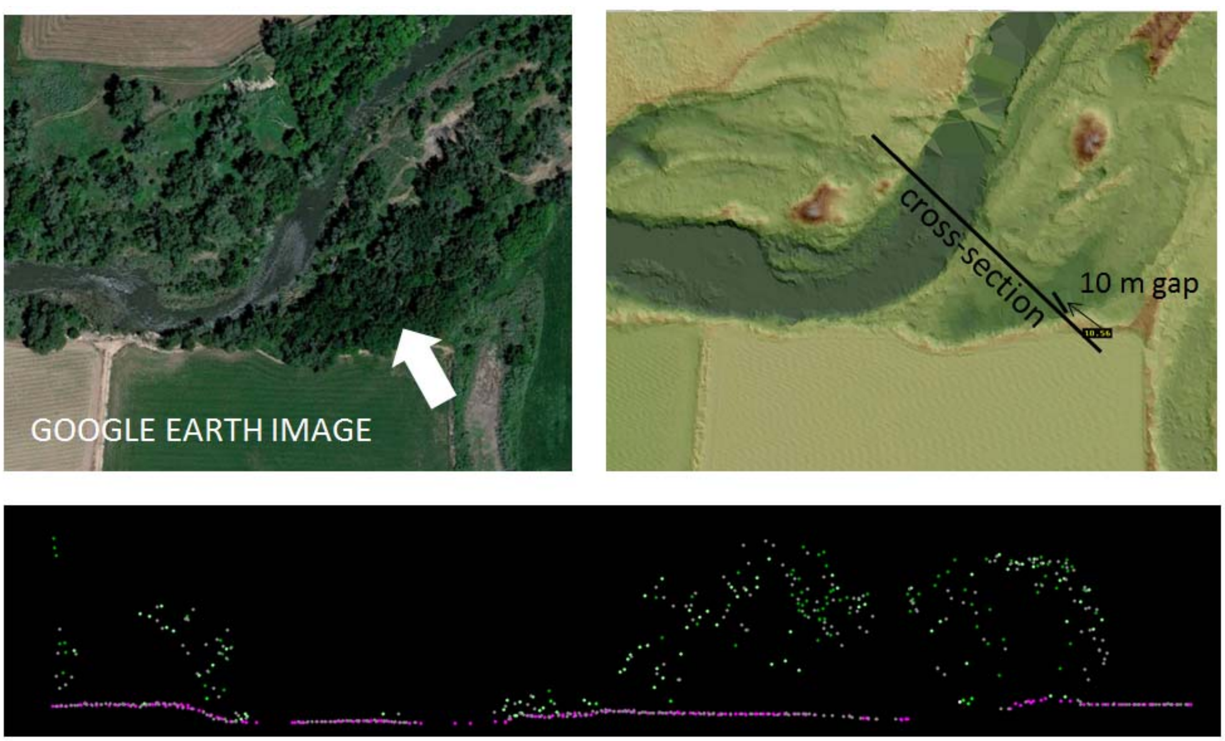


Figure 6. Cross-section showing a 10 m gap in the bare-earth model due to heavy cottonwoods in tile 51. This situation is relatively rare in the study area.

Conclusions

Given results given above, the following can be concluded:

- There is a tested < 2.5 cm RMSEz relative accuracy,
- There is a tested < 5 cm RMSEz overlap accuracy, and
- There is a tested < 3.5 cm RMSEz fundamental vertical accuracy.

FLIGHT REPORT

USU's Cessna 208B Skywagon remote sensing aircraft, N4630F, based out of Logan, Utah was utilized on this project. This aircraft was mobilized out of Logan Municipal Airport, Utah. The actual local flight time and duration of flights were controlled by weather, fuel consumption of the aircraft on the commute from Logan, Utah, and safety of flight operations around Hill Air Force Base. This limited our flexibility in planning for times when the GNSS constellation was most favorable thereby producing the highest number of satellites visible in the best geometric configuration relative to the GNSS receivers onboard the aircraft as well as at the base station on the ground.

Two flights were performed on November 18, 2011. The two flights originated from Logan, Utah. At the beginning of the day, a calibration flight pattern was flown over the USU campus. This enabled the improvement of IMU to Lidar alignment which has a tendency to drift in virtually every lidar system.

Navigation File(s):
A listing GPS base station files and raw flightline (LiDAR) files is given in Appendix C.

GROUND CONTROL REPORT

Introduction

A LiDAR survey was conducted for the purposes of developing a high-accuracy digital terrain model (DTM) of the Great Salt Lake Wetlands project area. In support of this work, ground control was established near the project area. This report summarizes the results.

RTK Ground Control Survey

Data Collection

RTK measurements were made with a Topcon GR-5 GNSS (including GLONASS) base/rover pair.

Data Processing and Analysis

Processing steps performed at benchmark WC 108 include ellipsoid to orthometric height conversion, and horizontal time-dependent processing of point velocities for epoch adjustment, and target leveling relative to the benchmark. The benchmark coordinate for the benchmark was provided by Weber County. A summary of their data is given in Table 5. Table 6 provides a listing of the differences in DEM height relative to the GPS points for each of the 27 points measured.

Table 5. Ground control data for benchmark WC 108 maintained by Weber County.

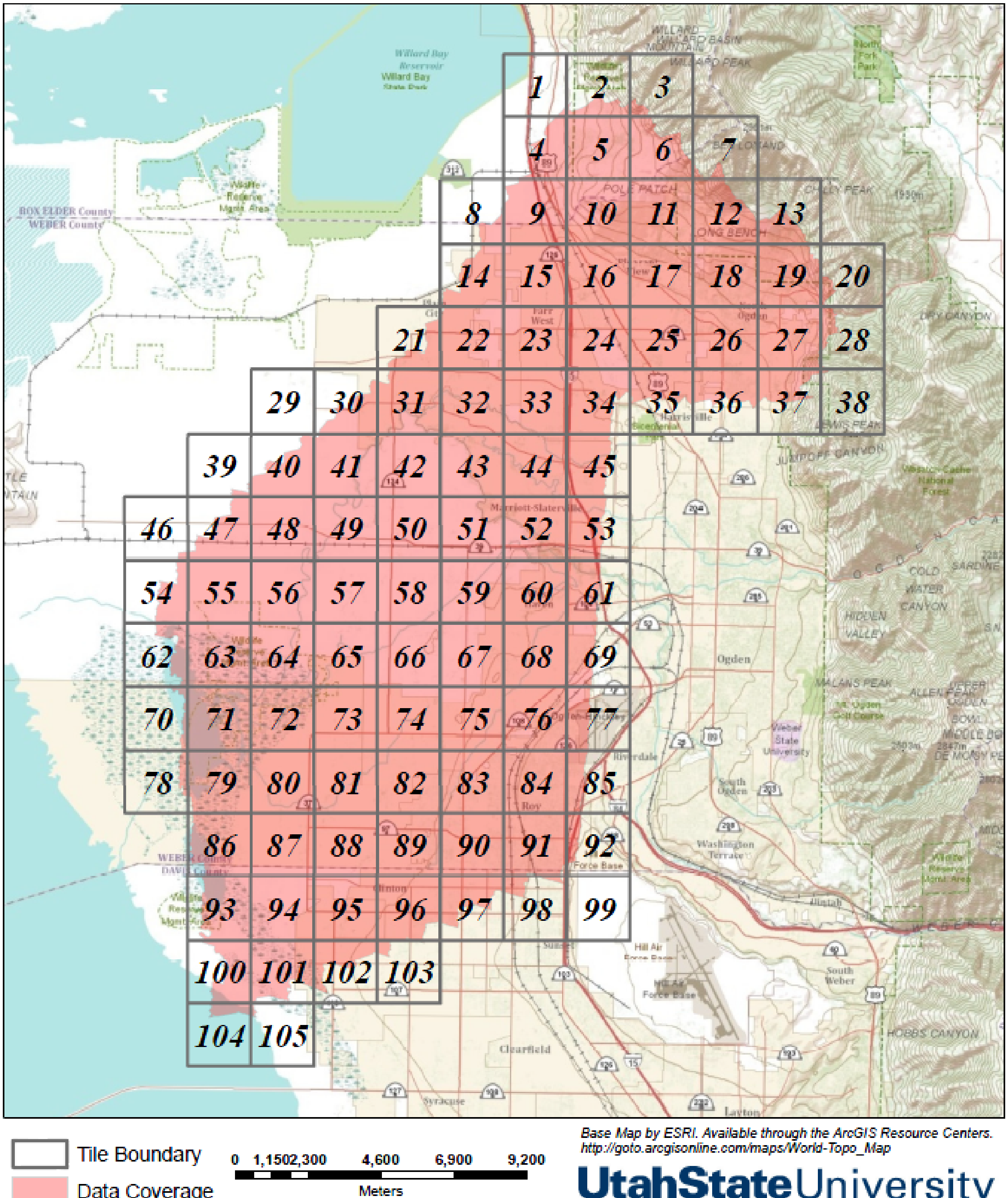
Station	NGS PID	Epoch Date	NAD83(HARN/1994)		NAVD88 (m)	Ellip.HT (m)
			Lat	Long		
Ogden FEMA						
WC-108	Weber Co	2000	41 09 50.1 (N)	112 08 33.3 (W)	1292.073	1275.083
"		2011	"	"	1292.059	1275.069

Table 6. Calculation of the relative accuracy of tiles 86 and 87 using 26 RTK GPS point.

Point	DEM Elev	GPS Elev	Diff	Adj Diff
WC 108				
100	1291.687	1291.676	0.011256	-0.02465
101	1291.486	1291.436	0.04984	0.013934
102	1291.289	1291.26	0.028818	-0.00709
103	1291.414	1291.397	0.016696	-0.01921
104	1291.284	1291.265	0.018813	-0.01709
105	1291.476	1291.454	0.02244	-0.01347
106	1291.292	1291.272	0.020114	-0.01579
107	1291.068	1291.01	0.057871	0.021965
108	1291.024	1291.009	0.015414	-0.02049
109	1290.703	1290.649	0.053637	0.017731
110	1290.638	1290.597	0.040573	0.004668
111	1290.347	1290.289	0.057558	0.021652
112	1290.268	1290.218	0.050433	0.014527
113	1290.31	1290.28	0.030059	-0.00585
114	1290.085	1289.982	0.103449	0.067544
115	1290.288	1290.277	0.01072	-0.02519
116	1289.946	1289.901	0.045411	0.009505
117	1290.174	1290.118	0.056438	0.020533
118	1290.321	1290.265	0.056289	0.020383
119	1291.177	1291.18	-0.00324	-0.03915
120	1291.137	1291.166	-0.0294	-0.06531
121	1291.118	1291.079	0.038554	0.002648
122	1291.384	1291.312	0.072399	0.036494
123	1291.545	1291.518	0.026922	-0.00898
125	1291.761	1291.726	0.03462	-0.00129
126	1292.07	1292.028	0.042312	0.006407
Average			0.035906	0
RMSEz			0.025321	0.025321

APPENDIX A – Index Maps and Area Boundaries

Ogden FEMA



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APPENDIX B – Flight Plan Map

APPENDIX C – Raw Data File Listing

LIDAR FILES

Name	Date modified	Size
111118_070651	11/19/2011 3:54 PM	15,088 KB
111118_070848	11/19/2011 3:55 PM	19,603 KB
111118_071124	11/19/2011 3:57 PM	21,446 KB
111118_073939	11/19/2011 3:58 PM	19,385 KB
111118_074217	11/19/2011 4:01 PM	42,136 KB
111118_074522	11/19/2011 4:07 PM	89,410 KB
111118_075008	11/19/2011 4:14 PM	100,561 KB
111118_075536	11/19/2011 4:25 PM	153,485 KB
111118_080257	11/19/2011 4:36 PM	151,213 KB
111118_080915	11/19/2011 4:49 PM	185,266 KB
111118_092941	11/19/2011 4:59 PM	156,450 KB
111118_093620	11/19/2011 5:11 PM	188,273 KB
111118_094343	11/19/2011 5:22 PM	154,166 KB
111118_094957	11/19/2011 5:35 PM	192,650 KB
111118_095702	11/19/2011 5:46 PM	151,156 KB
111118_100317	11/19/2011 5:59 PM	192,219 KB
111118_101020	11/19/2011 6:10 PM	159,459 KB
111118_101652	11/19/2011 6:23 PM	192,002 KB
111118_102414	11/19/2011 6:39 PM	172,687 KB
111118_103109	11/19/2011 6:53 PM	206,092 KB
111118_103854	11/19/2011 7:05 PM	177,124 KB
111118_104546	11/19/2011 7:20 PM	217,956 KB
111118_105333	11/19/2011 7:32 PM	179,390 KB
111118_110044	11/19/2011 7:46 PM	199,231 KB
111118_110800	11/19/2011 7:57 PM	158,333 KB
111118_111431	11/19/2011 8:10 PM	181,065 KB
111118_112111	11/19/2011 8:19 PM	140,924 KB
111118_112704	11/19/2011 8:31 PM	163,935 KB
111118_113308	11/19/2011 8:40 PM	130,517 KB
111118_113844	11/19/2011 8:44 PM	65,582 KB
111118_114209	11/19/2011 8:49 PM	69,912 KB
111118_114553	11/19/2011 8:53 PM	55,237 KB
111118_114856	11/19/2011 8:58 PM	73,182 KB
111118_115236	11/19/2011 9:03 PM	75,345 KB
111118_115627	11/19/2011 9:08 PM	83,376 KB
111118_120023	11/19/2011 9:14 PM	84,861 KB
111118_120437	11/19/2011 9:20 PM	89,248 KB
111118_120900	11/19/2011 9:26 PM	87,546 KB
111118_121340	11/19/2011 9:33 PM	94,722 KB
111118_121817	11/19/2011 9:40 PM	87,105 KB
111118_122320	11/19/2011 9:46 PM	78,991 KB
111118_122742	11/19/2011 9:50 PM	57,295 KB
111118_123242	11/19/2011 9:53 PM	36,942 KB
111118_123615	11/19/2011 9:55 PM	27,164 KB

NAVIGATION FILES

p1253220.11o	12/6/2011 1:35 PM	WinZip File	1,728 KB
p1253220.11n	12/6/2011 1:37 PM	WinZip File	31 KB
eout3220.11o	12/6/2011 1:35 PM	WinZip File	1,440 KB
eout3220.11n	12/6/2011 1:37 PM	WinZip File	27 KB
Remote_20111118_01	11/18/2011 6:56 AM	Text Document	71,306 KB
p1253220.11o	12/6/2011 1:35 PM	11O File	5,276 KB
eout3220.11o	12/6/2011 1:35 PM	11O File	4,403 KB
p1253220.11n	12/6/2011 1:37 PM	11N File	102 KB
eout3220.11n	12/6/2011 1:37 PM	11N File	85 KB

Name	Date modified	Type	Size
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SPAN_0	11/18/2011 6:19 AM	ASC File	287,041 KB