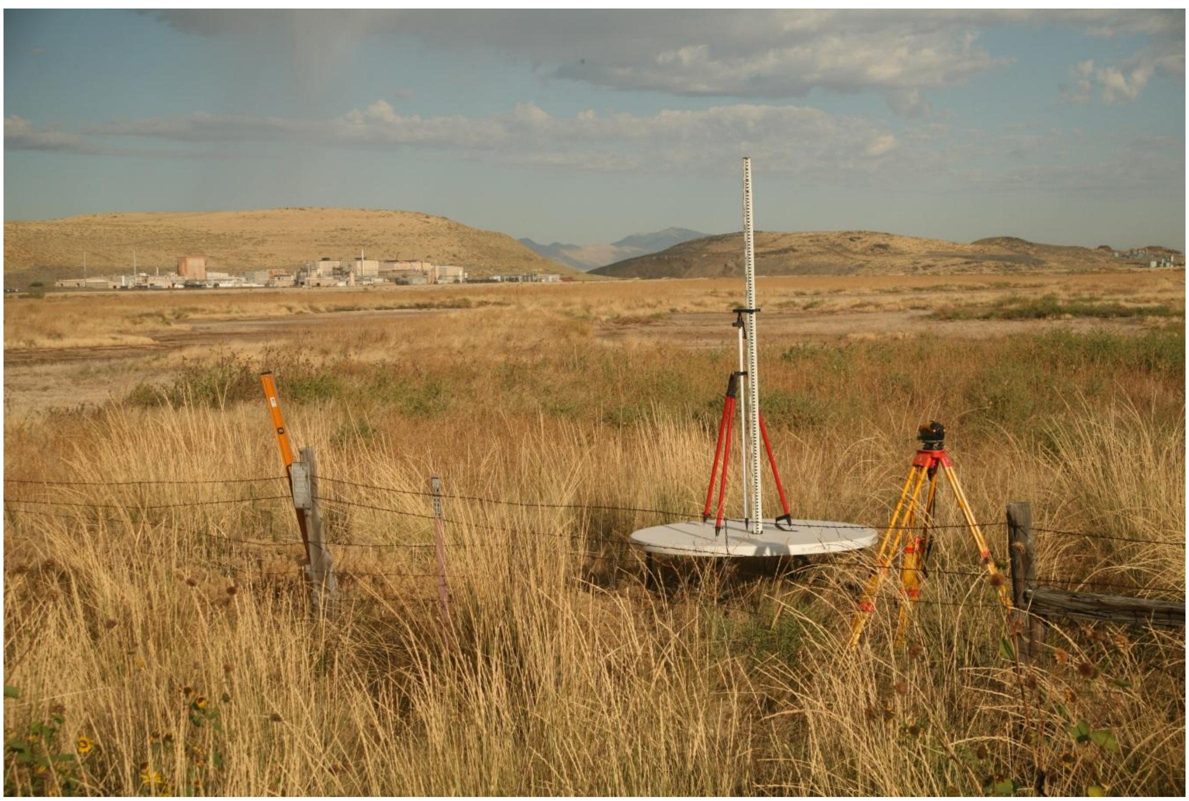
# Great Salt Lake Wetlands
# 2012 LiDAR Mapping Project
## Box Elder, Weber, Davis, Salt Lake and Tooele Counties, Utah

## COMPLETION REPORT



UtahStateUniversity
LASSI Service Center

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# SUMMARY OVERVIEW

## Executive Summary

This project encompasses five areas in five Utah counties and encompasses about 1147 square miles shown below. Data was collected on September and October, 2011.

| Study Area | County | Size (mi²) |
|---|---|---|
| Great Salt Lake Wetlands in three flight blocks labeled "North", "Middle", and "South | Salt Lake, Davis, Weber, Box Elder | 834 |
| Tooele | Tooele | 251 |
| Lower Bear River | Box Elder | 62 |
| Total | | 1147 |

## Contractor

This project was completed under contract UGS110817 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:

<u>LiDAR Deliverables</u>

| | |
|---|---|
| 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 |

<u>Grid Model Deliverables</u>

| | |
|---|---|
| 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 |

<u>Miscellaneous Deliverables</u>

| | |
|---|---|
| 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 five areas surveyed are provided in Appendix A. The number of tiles is summarized in Table 1.

Table 1. Project areas.

| Area | Number of Tiles |
|---|---|
| Bear River | 40 |
| Great Salt Lake (GSL) North | 463 |
| Great Salt Lake (GSL) Middle | 83 |
| Great Salt Lake (GSL) South | 250 |
| Tooele | 98 |

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 and target locations for the five subject areas. Table 3 provides the pre-flight mission parameters used for the project.

Table 3. 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 within 10 km of the study area. A total of 8 ground control stations were used for this project.

The benchmarks were selected on the basis of (1) vertical control accuracy, (2) accessibility, (3) security for targets and the GPS base station. Five GPS base stations were established. Benchmarks on the north shore (B 94), in Weber County (H 23) and Tooele (H 51) were occupied for several days each. This enabled the calculation of strong static GPS solutions which have been compared with the published vertical coordinates. Moreover, each of these GPS stations were active during lidar flights thereby enabling differential GPS corrections.

At each of the stations, 5-foot diameter white circular targets were established, an example of which is shown in Figure 1 for station 314RM in Davis County. The surface of each target was leveled using a five foot long construction level. The target height was then determined using an automatic level. This was done using a back-sight to the monument and a fore-sight to the table surface (see Figure 1). The accuracy of the target height relative to the monument was consistently within about 1 cm. All eight targets were scanned by the lidar in at least one flightline.

The GPS base stations were set up directly over the given 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 heights measured at previous dates needed to be adjusted according to observed HTDP point velocities published by NGS for nearby CORS stations. These points were thereby brought up to date.

Figure 1. Example of lidar target along with equipment used to level its height relative to a nearby benchmark. This is benchmark 314RM in Davis County.

## *Final Planning – Procedures and Activities*

<u>Planning</u>

Weather forecasts and project schedule identified an aerial acquisition window during the months of September and 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.

It was planned such that each time the aircraft was mobilized out of Logan, Utah each of the five areas could be completed during a contiguous block of days.

<u>Summary of Supporting Documents</u>

- CV NGS DATASHEETS.htm– *NGS Data Sheets NGS benchmarks used*
- 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 from the five base station locations 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 results in highly visible manifestations of errors within overlap regions. For example, on some of the shoreline slopes a gradual 10 cm drop in elevation can occur 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.

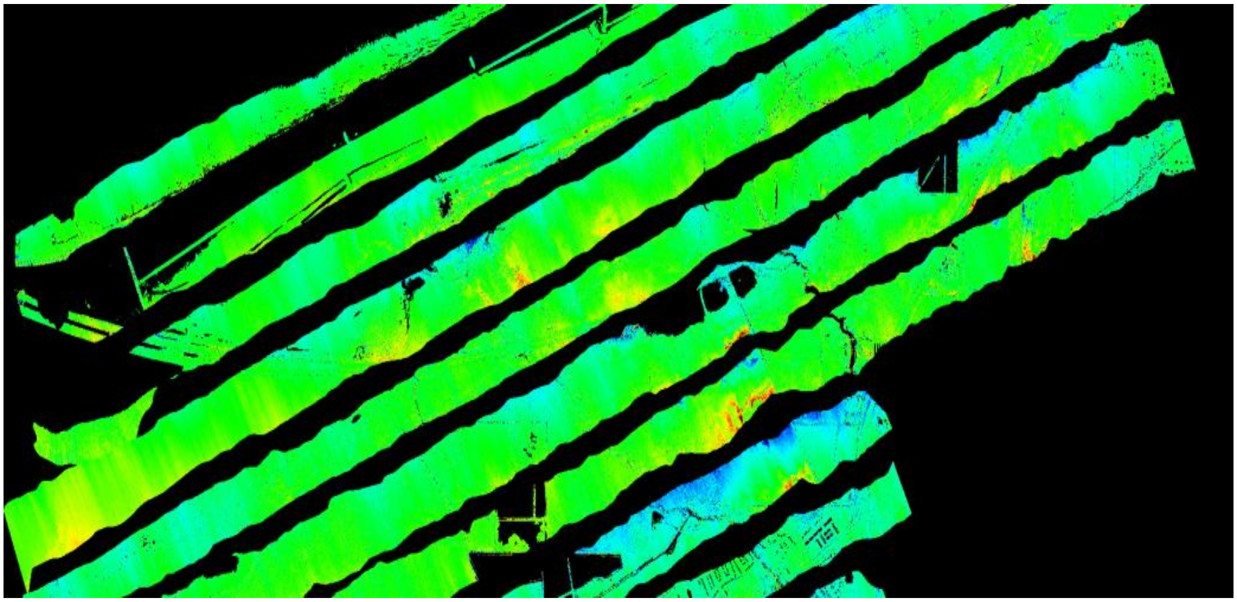


Figure 2. Overlap data prior to within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

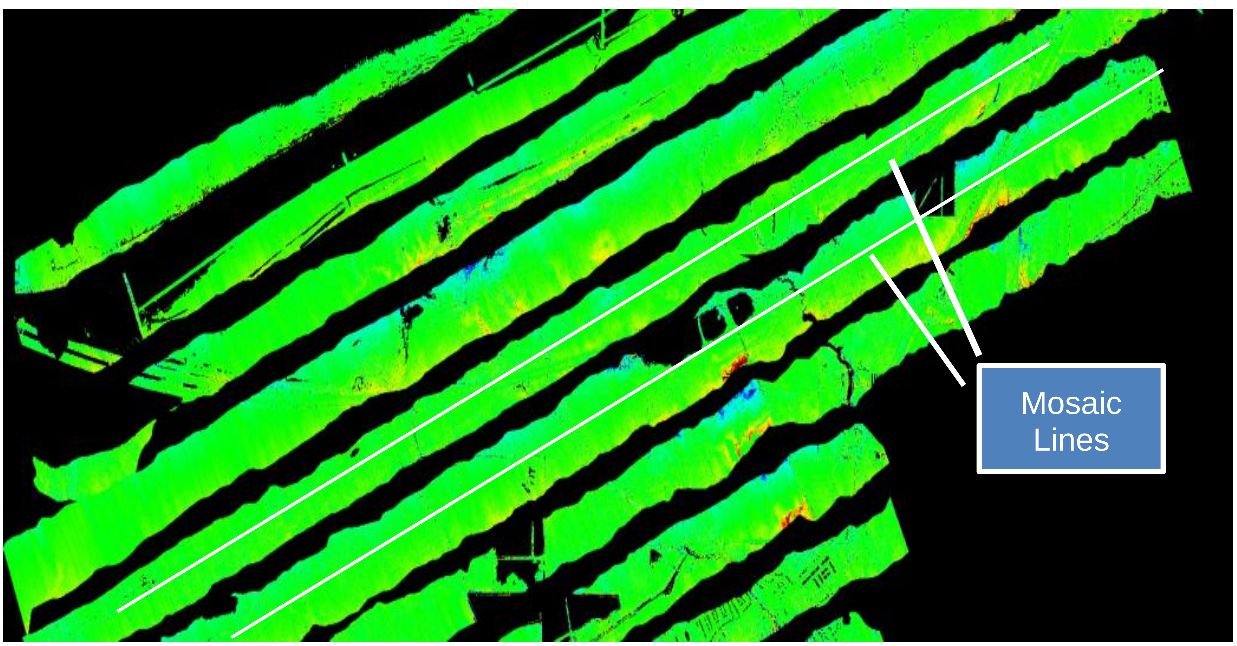



Figure 3. Overlap data after the within-strip correction, colored by elevation difference (blue = -10 cm, cyan = -5 cm, green = 0 cm, yellow = +5cm, red = +10 cm).

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 dozens of river banks and hundreds of 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 two typical terrain types within this project using RTK GPS surveys. Table 5 shows the results for these areas. The results show a relative accuracy of 3.8 cm within the typical rolling sagebrush terrain of the GSL shoreline. This is similar to the 2.8 cm relative accuracy achieve on the flat sagebrush areas of Cedar Valley (sister project). A relative accuracy of 3.6 cm is achieved in a subdivision in Hooper. These results are well under the 7.0 cm specification required by the contract.

Table 5. Relative accuracy checks.

| Point | Area | # Points | RMSEz (cm) | Terrain Description |
|---|---|---|---|---|
| B94 | North GSL | 28 | 3.8 | Sagebrush in rolling terrain |
| WC 108 | Middle GSL | 26 | 3.6 | Hooper subdivision roads and shoulders |

### Within Swath Overlap Accuracy

Table 6 shows the mean and RMSEz difference between all DEM cells within overlapping regions. These statistics were calculated by custom Matlab scripts in USU's custom adjustment software. Table 6 shows that systematic shifts within a given overlap region are less than 1 cm. The RMSEz between overlapping surfaces is consistently between 2.3 and 6.3 cm  These results are within the required 10 cm specification.

Table 6. Mean and RMSEz difference between DEM cells within overlapping regions.

| Area | Number of Overlaps | Difference in Overlap (cm) | |
|---|---|---|---|
| | | Mean | RMSEz |
| GSL Middle | 31 | 0.1 | 5.0 |
| GSL BearRiver | 10 | 0.0 | 6.3 |
| GSL South | 112 | 0.0 | 4.8 |
| GSL North | 202 | -0.1 | 4.1 |
| GSL Tooele | 56 | 0.0 | 2.3 |
| Ogden FEMA | 39 | -0.1 | 4.4 |

Fundamental Vertical Accuracy

It was proposed and accepted by AGRC that a series of 5' diameter LiDAR targets be used as a spot checks for fundamental vertical accuracy relative to a selection of know brass bench marks distributed around the subject area. The strategy was to place these targets prior to the flights and measure their height using the lidar results such that they could be compared to independently leveled heights measured in the field relative to the brass bench marks. Table 7 shows the results of this work for bench marks occupied by long GPS static observations associated with the lidar collection. The results indicate an average fundamental vertical accuracy of 8.1 cm for the three targets relative to the published bench mark elevations. It should be noted that the average difference between the GPS static measurements and the published elevations is 7.1 cm. Given the GPS residuals are in the order a less than 2 cm, it is possible some of the vertical error is associated with the published coordinates. Nevertheless, these results indicate the fundamental vertical accuracy is well within specifications required for this project.

Table 7. Fundamental vertical accuracy as determined at four lidar target locations with strong vertical control.

| Target | RSMEz BM to TGT (m) | RSMEz BM to GPS (m) | Description |
|---|---|---|---|
| B 94 RESET* | 0.029 | 0.058 | Silts on GSL Shoreline |
| H 23* | 0.076 | 0.048 | Swampy corner in silt |
| H 51* | 0.137 | 0.107 | Silts on GSL Shoreline |
| Average | 0.081 | 0.071 | |

Five targets were also placed near benchmarks that were not occupied by our static GPS surveys. These differences were found to average 17.8 cm as shown in Table 8. The largest differences are associated with RTK surveyed benchmarks maintained by Salt Lake and Weber Counties. These county surveys focused on horizontal control and did not have clearly stated vertical accuracies. A 14.7 cm discrepancy was discovered with an old 1953 benchmark given a Class II vertical accuracy by NGS. However, only a 7.4 cm difference was found with a NGS Class I vertical benchmark found in the Bear River area. Given the 8 cm accuracy results in the previous table that are cross-checked with multi-day static GPS work, it is deemed unlikely that the main source of error is associated with the lidar survey. It is also possible that since their dates of publication, some of these points may have been subject to movement associated with settlement of the silts or construction disturbances. The investigation of the vertical accuracy of these published coordinates is beyond the scope of this contract. Nevertheless, these result suggest that adjustments of the lidar data by up to 26 cm (10 inches) may be necessary in order to match local datums based on weak vertical control.

Table 8. Vertical accuracy as determined relative to benchmarks with various vertical accuracies.

| Target | RSMEz BM to TGT (m) | Source | Published Vertical Accuracy | Lidar Tile | Description |
|---|---|---|---|---|---|
| U 170 | 0.074 | NGS | 1967 Class I | BR Tile 31 | Gravel adjacent to canal |
| Z 92 | 0.147 | NGS | 1953 Class II | GN Tile 262 | Old BM on railway abutment |
| 64-FMK | 0.214 | Weber Co | +/- 10 cm | GN Tile 434 | Silts on GSL Shoreline |
| WC-108 | 0.193 | Weber Co | RTK ? | GM Tile 53 | Silts on GSL Shoreline |
| 1S3W029A | 0.263 | Salt Lk Co | RTK ? | GS Tile 238 | Silts on GSL Shoreline |
| Average | 0.178 | | | | |

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

## *Conclusions*

Given results given above, the following can be concluded:

- There is a tested < 4 cm RMSEz relative accuracy,
- There is a tested < 7 cm RMSEz overlap accuracy, and
- There is a tested < 8 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 times 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 and the Salt Lake International Airport. 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.

Ordinarily two flights were performed per day, weather permitting. Flights originated from Logan, Utah each morning with a refueling stop at a local field at mid-day. Flight durations varied between 3 and 4 hours. At the beginning or end of most days, 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.

Because of limitations associated with flying around Salt Lake International Airport, the GSL South block was flown at night. This involved two flights between midnight and 6:00am on October 13 & 14, 2011 and a flight between 2:00am and 6:00am on October 18, 2011. During these periods, virtually no interference with air traffic was encountered.

The flight dates are summarized by Table 9.

Table 9. Summary of flight dates.

| **Block** | **Dates** |
|---|---|
| Bear River | 28 September 2011 |
| GSL North | 27, 29, 30 September & 3, 4, 10 October 2011 |
| GSL Middle | 10-12 October 2011 |
| GSL South | 13, 14, 18 October 2011 |
| Tooele | 18 October 2011 |

**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.

### *Ground Control Survey*

Table 10 provides a list of coordinates for each of the 9 bench marks used in this study. The benchmarks listed with a bold font were used as static GPS stations and were occupied during the lidar flights. Stations identified with an asterisk were used as base stations for RTK surveys subsequent to the flights.

Table 10. List of benchmarks used in the five subject areas.

| STATION | PID | EPOCH | LATITUDE | LONGITUDE | NAVD88 |
|---|---|---|---|---|---|
| Bear River | | | | | |
| U 170 | MS0027 | 1991 | 41 40 52. (N) | 112 05 36. (W) | 1312.73 |
| GSL North | | | | | |
| **B 94 RESET*** | **MS0074** | **1991** | **41 35 56. (N)** | **112 17 58. (W)** | **1291.41** |
| Z 92 | MS0121 | 1991 | 41 25 16. (N) | 112 03 00. (W) | 1297.60 |
| H 23* | Weber Co | 2002 | 41 14 40. (N) | 112 10 32. (W) | 1286.37 |
| 64-FMK | Weber Co | 2004 | 41 15 00. (N) | 112 12 42. (W) | 1285.46 |
| GSL Middle | | | | | |
| **WC-108** | **Weber Co** | **2000** | **41 09 50.1 (N)** | **112 08 33.3 (W)** | **1292.07** |
| GSL South | | | | | |
| 314RM | Davis Co | 2010 | 40 57 55.4 (N) | 111 55 47.0 (W) | 1284.24 |
| 1S3W029A | SLC | 2008 | 40 46 08.7 (N) | 112 09 17.1 (W) | 1286.68 |
| Tooele | | | | | |
| H 51* | LP0025 | 1991 | 40 39 56.10422(N) | 112 27 29.72341(W) | 1287.52 |

### *Data Collection*

Using physical descriptions of benchmark locations, each of the 9 stations were occupied, some used for static GPS observations, some used for RTK data collections and all of which were used for lidar target analysis. The static observations were made with a NovAtel dual-frequency GPS receiver. RTK measurements were made with a Topcon GR-5 GNSS (including GLONASS) base/rover pair.

### *Data Processing and Analysis*

Processing steps performed at each benchmark include ellipsoid to orthometric height conversion, horizontal time-dependent processing of point velocities for epoch adjustment, and target leveling relative to the benchmarks. Static GPS solutions are disclosed for those points occupied and lidar shot elevations have been compiled for each of the targets. A summary of these processing results is given in Tables 11 and 12.

Table 11. Ground control computations.

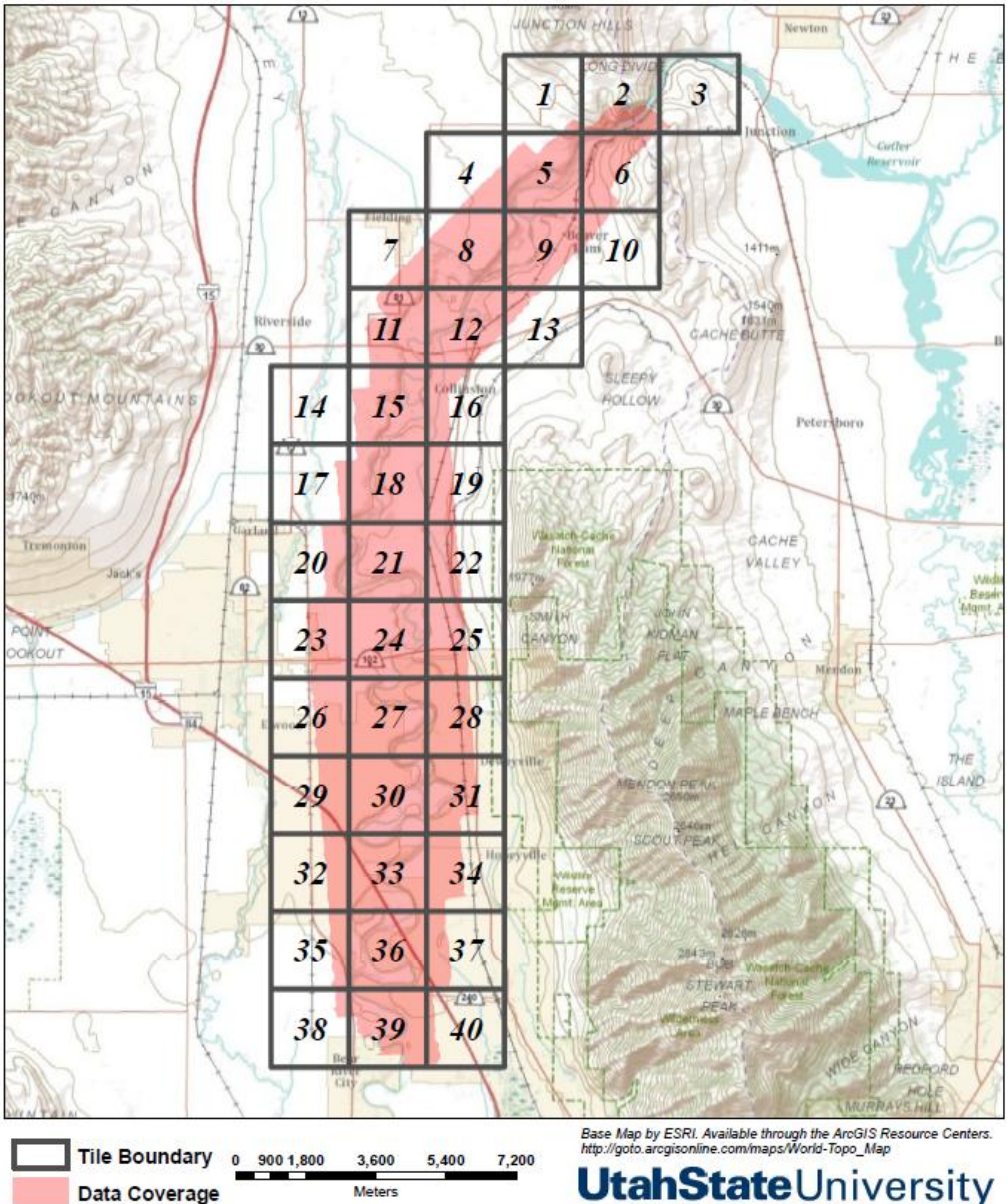
| Station | NGS PID | Epoch Date | NAD83(HARN/1994) | | NAVD88 (m) | Ellip.HT (m) | Δ BM (m) | Δ GPS (m) |
|---|---|---|---|---|---|---|---|---|
| | | | Lat | Long | | | | |
| BEAR RIVER | | | | | | | | |
| U 170 | MS0027 | 1991 | 41 40 52. (N) | 112 05 36. (W) | 1312.732 | 1297.002 | | |
| " | " | 2011 | " | " | 1312.706 | 1296.976 | | |
| TGT U 170 | | 2011 | | | 1313.306 | 1297.576 | | |
| TGT Lidar Solutions - BR Tile 31 | | | | | | | | |
| Shot 1 | | | | | 1313.38 | | 0.074 | |
| RSMEz | | | | | 1313.38 | | 0.0739 | |
| GSL NORTH | | | | | | | | |
| B 94 RESET* | MS0074 | 1991 | 41 35 56. (N) | 112 17 58. (W) | 1291.407 | 1275.367 | | |
| B 94 RESET Adj | | 2011 | " | " | 1259.301 | 1275.341 | | |
| TGT B 94 | | 2011 | | | 1292.018 | 1275.978 | | |
| USU B 94 GPS Solution | | 2011 | 41 35 55.90473(N) | 112 17 57.80501(W) | | 1275.312 | -0.029 | |
| TGT Lidar Solutions - GN Tile 63 & 81 | | | | | | | | |
| - Shot 1 | | | | | 1292.040 | | -0.022 | -0.051 |
| - Shot 2 | | | | | 1292.050 | | -0.032 | -0.061 |
| - Shot 3 | | | | | 1292.050 | | -0.032 | -0.061 |
| RSMEz | | | | | 1292.047 | | 0.0295 | 0.0583 |
| | | | | | | | | |
| Z 92 | MS0121 | 1991 | 41 25 16. (N) | 112 03 00. (W) | 1297.596 | 1281.246 | | |
| " | " | 2011 | " | " | 1297.570 | 1281.220 | | |
| TGT Z 92 | | 2011 | | | 1298.379 | 1282.029 | | |
| TGT Lidar Solutions - GN Tile 262 | | | | | | | | |
| - Shot 1 | | | | | 1298.540 | | -0.161 | |
| - Shot 2 | | | | | 1298.510 | | -0.131 | |
| RSMEz | | | | | 1298.525 | | 0.1468 | |
| | | | | | | | | |
| H 23* | Weber Co | 2002 | 41 14 40. (N) | 112 10 32. (W) | 1286.369 | 1269.54 | | |
| H 23 Adj | | 2011 | " | " | 1286.357 | 1269.528 | | |
| TGT H 23 | | 2011 | | | 1287.146 | 1270.317 | | |
| USU H 23 GPS Solution | | 2011 | 41 14 40.82494(N) | 112 10 32.45055(W) | | 1269.499 | -0.029 | |
| TGT Lidar Solutions - GN Tile 435 | | | | | | | | |
| - Shot 1 | | | | | 1287.08 | | 0.066 | 0.037 |
| - Shot 2 | | | | | 1287.07 | | 0.076 | 0.047 |
| - Shot 3 | | | | | 1287.06 | | 0.086 | 0.057 |
| RSMEz | | | | | 1287.07 | | 0.076 | 0.048 |
| | | | | | | | | |
| 64-FMK | Weber Co | 2004 | 41 15 00. (N) | 112 12 42. (W) | 1285.463 | 1268.7 | | |
| " | | 2011 | " | " | 1285.454 | 1268.69 | | |
| TGT 64-FMK | | 2011 | | | 1286.111 | 1269.35 | | |
| TGT Lidar Solutions - GN Tile 434 | | | | | | | | |
| - Shot 1 | | | | | 1286.32 | | -0.209 | |
| - Shot 2 | | | | | 1286.33 | | -0.219 | |
| - Shot 3 | | | | | 1286.31 | | -0.199 | |
| - Shot 4 | | | | | 1286.33 | | -0.219 | |
| - Shot 5 | | | | | 1286.33 | | -0.219 | |
| RSMEz | | | | | 1286.324 | | 0.2136 | |

Table 12. Ground control computations (continued).

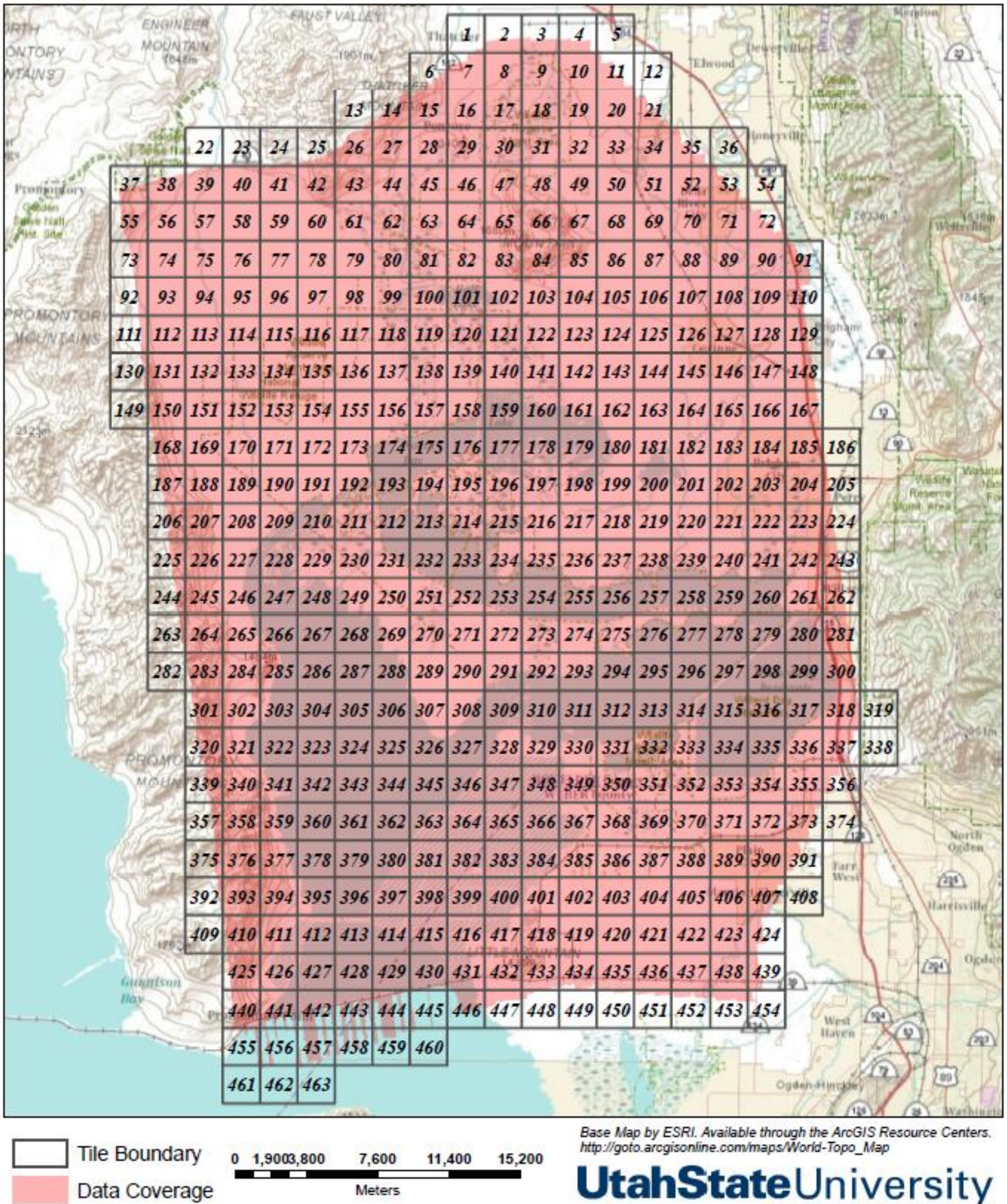
| Station | NGS PID | Epoch Date | NAD83(HARN/1994) Lat | Long | NAVD88 (m) | Ellip.HT (m) | Δ BM (m) | Δ GPS (m) |
|---|---|---|---|---|---|---|---|---|
| GSL MIDDLE | | | | | | | | |
| WC-108 | Weber Co | 2000 | 41 09 50.1 (N) | 112 08 33.3 (W) | 1292.073 | 1275.083 | | |
| " | | 2011 | " | " | 1292.059 | 1275.069 | | |
| TGT WC-108 | | 2011 | | | 1292.010 | 1275.020 | | |
| TGT Lidar Solutions - GM 53 | | | | | | | | |
| - Shot 1 | | | | | 1291.81 | | 0.200 | |
| - Shot 2 | | | | | 1291.82 | | 0.190 | |
| - Shot 3 | | | | | 1291.82 | | 0.190 | |
| RSMEz | | | | | 1291.82 | | 0.1929 | |
| GSL SOUTH | | | | | | | | |
| 314RM | Davis Co | 2010 | 40 57 55.4 (N) | 111 55 47.0 (W) | 1284.239 | | | |
| " | | 2011 | " | " | 1284.238 | | | |
| TGT 314RM | | 2011 | | | 1286.002 | | | |
| TGT Lidar Solutions - GS Tile 100 | | | | | | | | |
| - Shot 1 | | | | | 1285.23 | | 0.772 | |
| - Shot 2 | | | | | 1285.19 | | 0.812 | |
| - Shot 3 | | | | | 1285.18 | | 0.822 | |
| RSMEz | | | | | 1285.20 | | 0.8027 | |
| | | | | | | | | |
| 1S3W029A | SLC | 2008 | 40 46 08.7 (N) | 112 09 17.1 (W) | 1286.680 | 1269.431 | | |
| " | | 2011 | " | " | 1286.676 | 1269.427 | | |
| TGT 1S3W029A | | 2011 | | | 1285.802 | 1268.553 | | |
| TGT Lidar Solutions - GS 238 | | | | | | | | |
| - Shot 1 | | | | | 1286.06 | | -0.258 | |
| - Shot 2 | | | | | 1286.07 | | -0.268 | |
| RSMEz | | | | | 1286.065 | | 0.263 | |
| Tooele | | | | | | | | |
| H 51* | LP0025 | 1991 | 40 39 56.10422(N) | 112 27 29.72341(W) | 1287.517 | 1269.872 | | |
| " | " | 2011 | " | " | 1287.491 | 1269.846 | | |
| TGT H 51 | | 2011 | | | 1288.539 | 1270.894 | | |
| USU H 51 GPS Solution | | 2011 | 40 39 56.10408(N) | 112 27 29.72834(W) | 1287.521 | 1269.876 | 0.03 | |
| TGT Lidar Solutions - T 49 | | | | | | | | |
| - Shot 1 | | | | | 1288.66 | | -0.121 | -0.091 |
| - Shot 2 | | | | | 1288.69 | | -0.151 | -0.121 |
| RSMEz | | | | | 1288.675 | | 0.137 | 0.107 |

## APPENDIX A – Index Maps and Area Boundaries

# *Bear River*



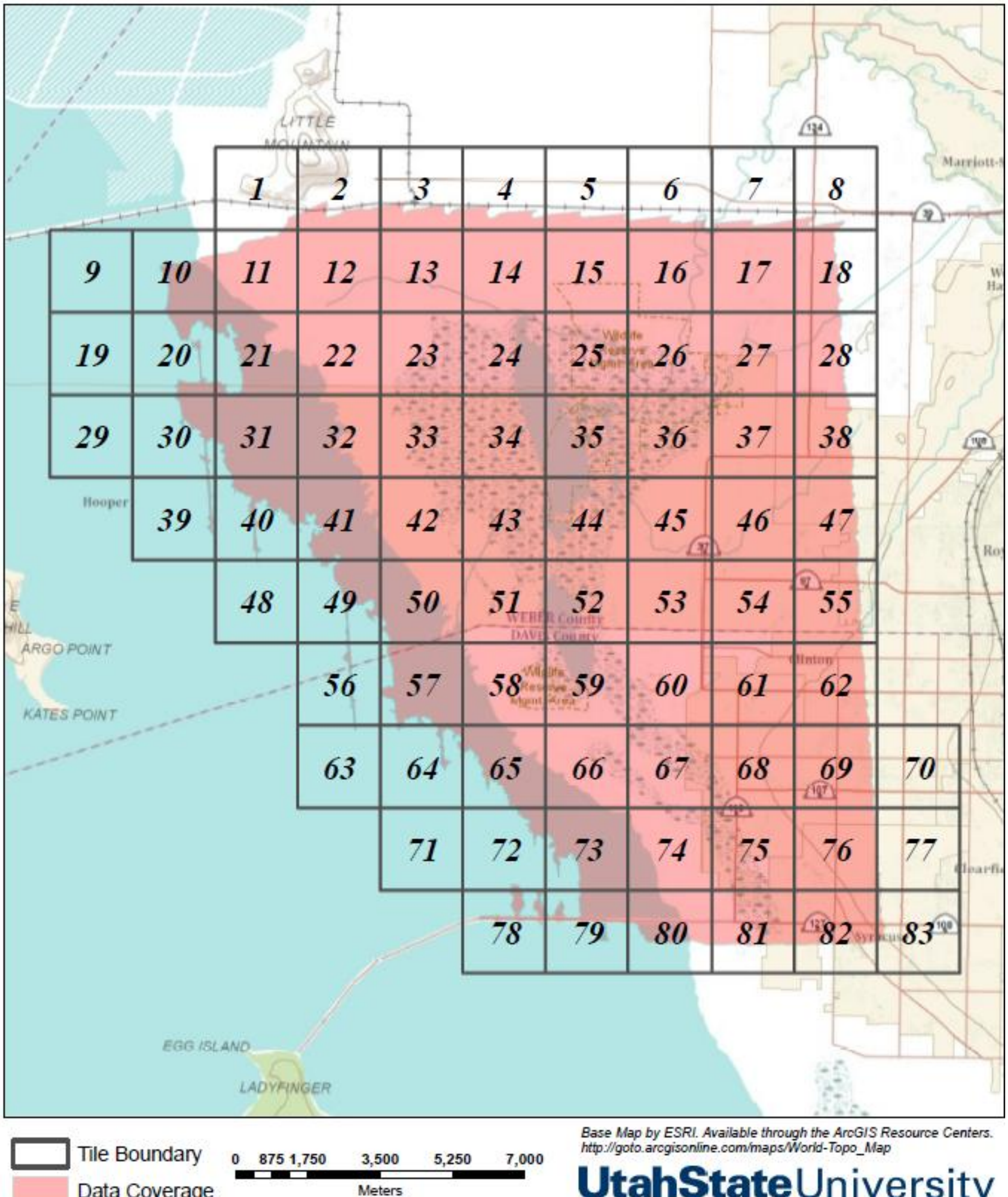
# GSL North




Base Map by ESRI. Available through the ArcGIS Resource Centers. http://goto.arcgisonline.com/maps/World-Topo_Map

**UtahState**University
*LASSI Service Center*

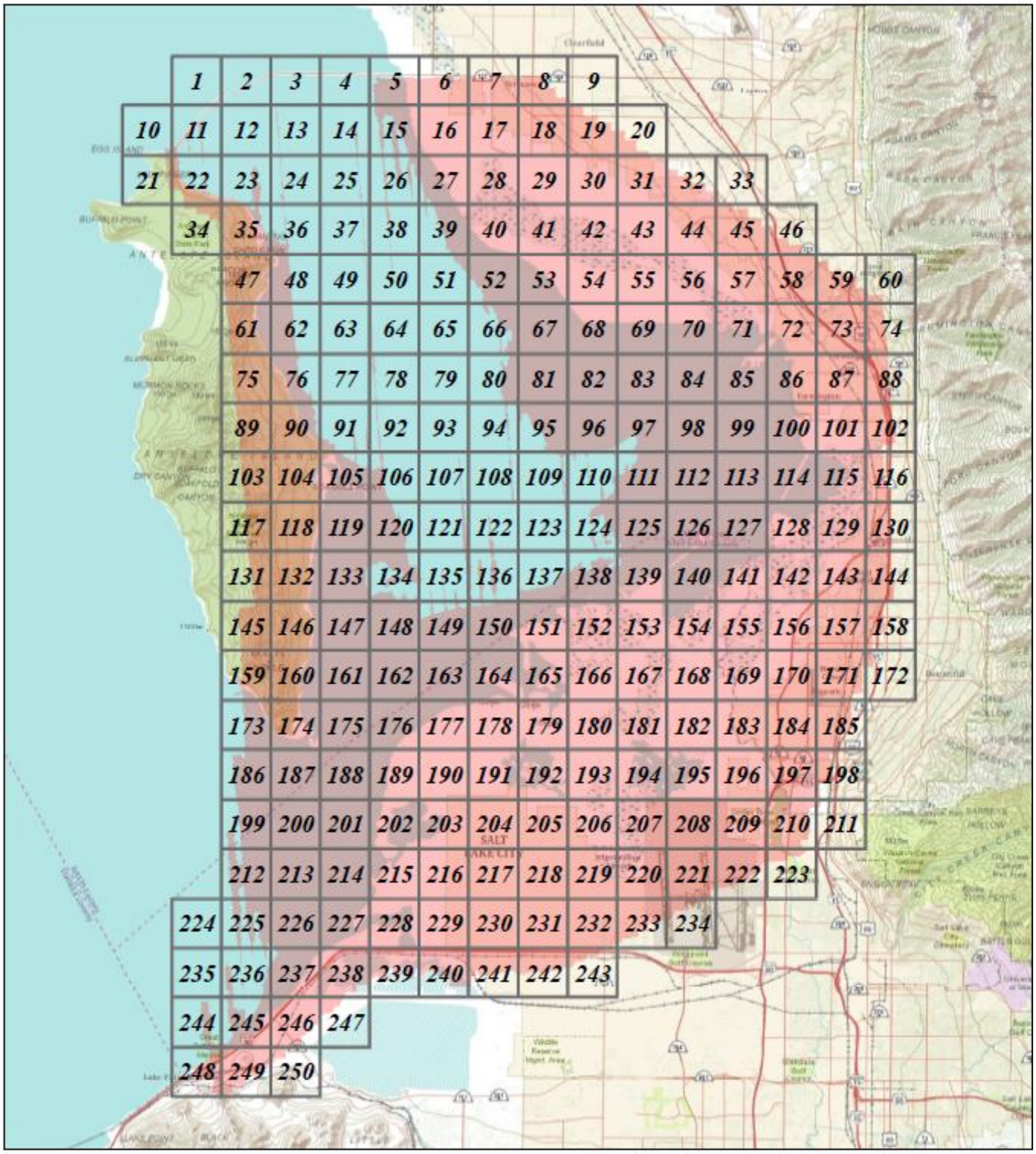
# GSL Middle




Base Map by ESRI. Available through the ArcGIS Resource Centers. http://goto.arcgisonline.com/maps/World-Topo_Map

UtahStateUniversity LASSI Service Center

# GSL South



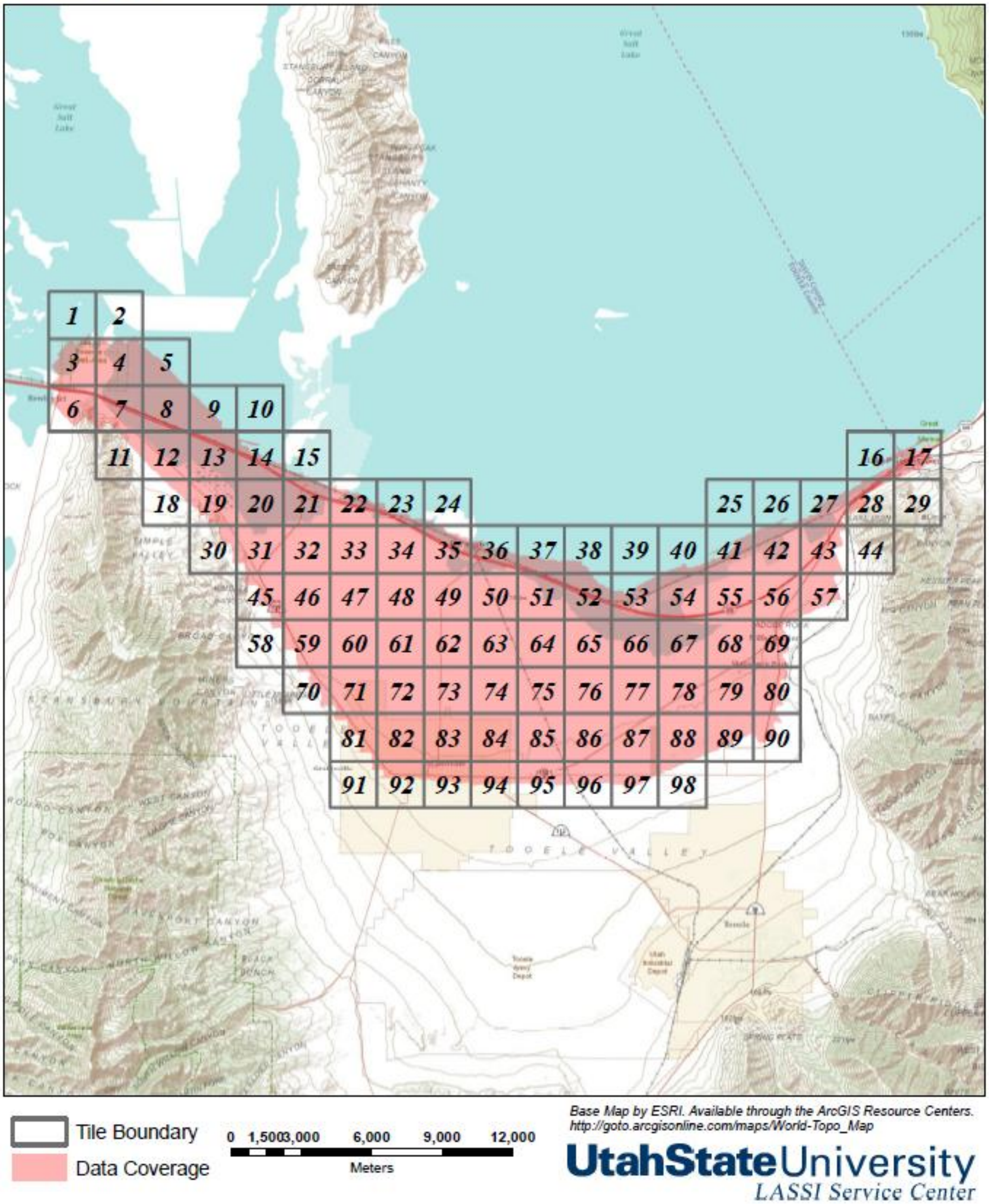

Tile Boundary
Data Coverage

0 1,500 3,000 6,000 9,000 12,000
Meters

*Base Map by ESRI. Available through the ArcGIS Resource Centers. http://goto.arcgisonline.com/maps/World-Topo_Map*

**UtahState**University
*LASSI Service Center*

# Tooele

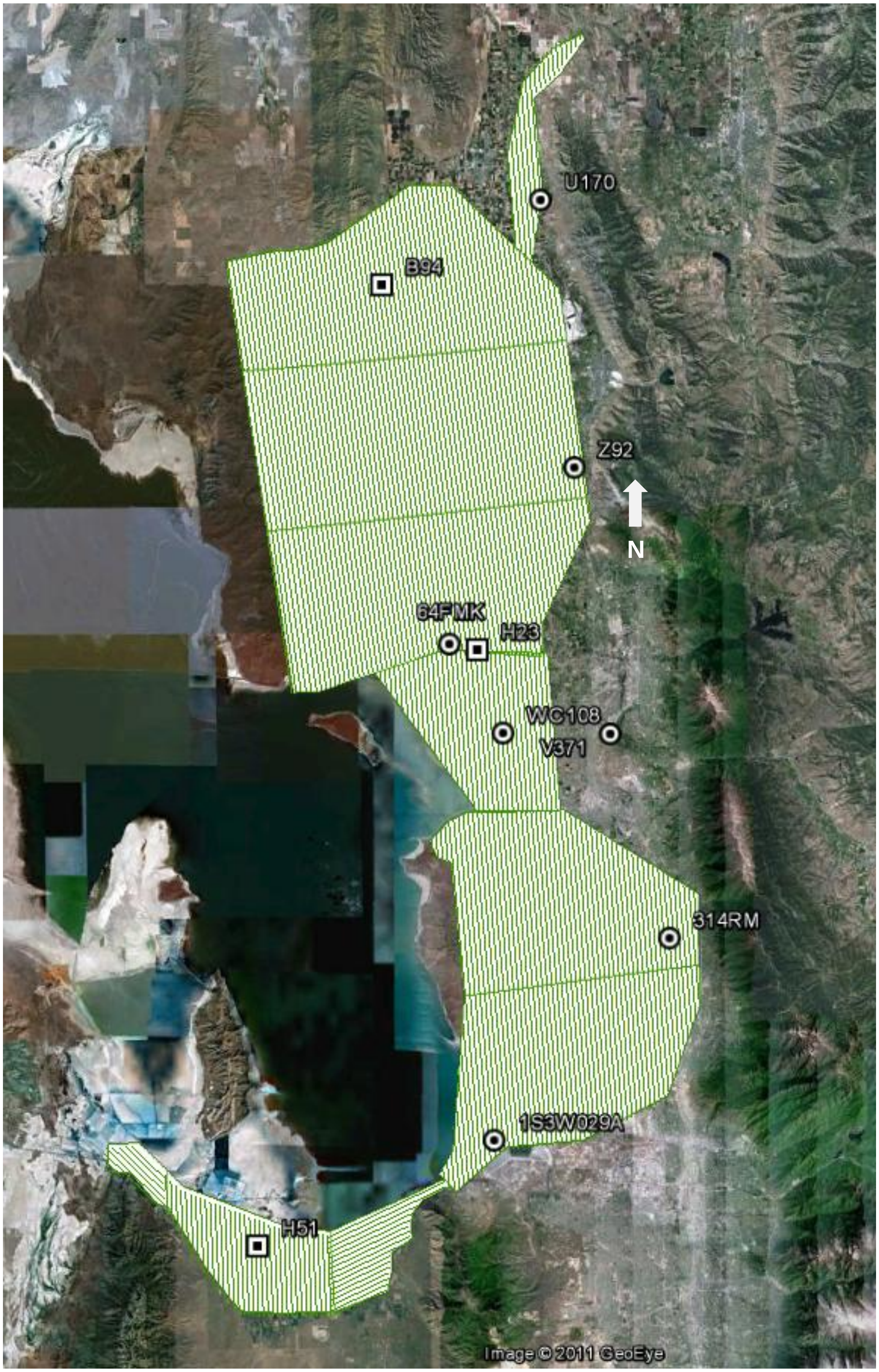



Base Map by ESRI. Available through the ArcGIS Resource Centers.
http://goto.arcgisonline.com/maps/World-Topo_Map

UtahStateUniversity
LASSI Service Center

## APPENDIX B – Flight Plan Maps

Flight line layout and target locations for the Great Salt Lake Wetlands



## APPENDIX C – Raw Data File Listing

**BEAR RIVER BLOCK:**
Flown 09/28/2011
**Navigation File(s):**
Remote_20110928_01.log
Remote_20110928_02.log
**Base Station File(s):**
BaseStation_20110928.pdc
**Raw Flightline (LIDAR) Files:**
110928_163228.sdf
110928_163543.sdf
110928_163943.sdf
110928_164406.sdf
110928_164903.sdf
110928_165319.sdf
110928_165852.sdf
110928_170513.sdf
110928_171216.sdf
110928_171959.sdf
110928_172621.sdf
110928_173252.sdf

**GSL NORTH BLOCK:**
Flown 09/27 - 09/30, 10/03 – 10/04, 10/10
**Navigation File(s):**
Remote_GSL_20110927.log
Remote_GSL_20110927_02.log
Remote_GSL_20110928_02.log
Remote_GSL_20110929_01.log
Remote_GSL_20110929_02.log
Remote_GSL_20110930_01.log
Remote_GSL_20110930_02.log
Remote_20111003_01.log
Remote_20111003_02.log
Remote_20111004.log
Remote_20111010_01.log
**Base Station File(s):**
BaseStation_20110927and28.pdc
Base_GSL_20110929_01.pdc
Base_GSL_20110929_02.pdc
Base_GSL_20110930_01.pdc
Base_GSL_20110930_02.pdc
Base_GSL_20111004_01.pdc
Base_GSL_20111004_02.pdc
Base_GSL_20111010_01.pdc
**Raw Flightline (LIDAR) Files:**
110927_163856.sdf
110927_164125.sdf
110927_164408.sdf
110927_164523.sdf
110927_164952.sdf
110927_165538.sdf
110927_170112.sdf
110927_170658.sdf
110927_171233.sdf
110927_171834.sdf
110927_172420.sdf
110927_173029.sdf
110927_173600.sdf
110927_174158.sdf
110927_174740.sdf
110927_175426.sdf
110927_180008.sdf
110927_180606.sdf
110927_181136.sdf
110927_181729.sdf
110927_182248.sdf
110927_182843.sdf
110927_183423.sdf
110927_184027.sdf
110927_184610.sdf
110927_185208.sdf
110927_185751.sdf
110927_190414.sdf
110927_190947.sdf
110927_191608.sdf
110927_192210.sdf
110927_192851.sdf
110927_193445.sdf
110927_194137.sdf
110927_194748.sdf
110927_195455.sdf
110927_200127.sdf
110927_214153.sdf
110927_214420.sdf
110927_215123.sdf
110927_215849.sdf
110927_220623.sdf
110927_221350.sdf
110927_222115.sdf
110927_222837.sdf
110927_223629.sdf
110927_224428.sdf
110927_225210.sdf
110927_230001.sdf
110927_230909.sdf
110927_231159.sdf
110928_174124.sdf
110928_174458.sdf
110928_175008.sdf
110928_175737.sdf
110928_195133.sdf
110928_195906.sdf
110928_200630.sdf
110928_201335.sdf
110928_202103.sdf
110928_202828.sdf
110928_203525.sdf
110928_204222.sdf
110928_204918.sdf
110928_205553.sdf
110928_210222.sdf
110928_210830.sdf
110928_211417.sdf
110928_212010.sdf
110928_212528.sdf
110928_213052.sdf
110928_213601.sdf
110928_214057.sdf
110928_214538.sdf
110928_215016.sdf

110928_215446.sdf
110928_215846.sdf
110928_220244.sdf
110928_220628.sdf
110928_221117.sdf
110928_221807.sdf
110928_222502.sdf
110928_223142.sdf
110928_223835.sdf
110928_224531.sdf
110929_161016.sdf (calibration)
110929_161248.sdf (calibration)
110929_161639.sdf (calibration)
110929_162747.sdf
110929_163444.sdf
110929_164129.sdf
110929_164826.sdf
110929_165515.sdf
110929_170207.sdf
110929_170912.sdf
110929_171624.sdf
110929_172306.sdf
110929_173019.sdf
110929_173719.sdf
110929_174415.sdf
110929_175114.sdf
110929_175812.sdf
110929_180503.sdf
110929_181153.sdf
110929_181853.sdf
110929_182542.sdf
110929_183252.sdf
110929_183939.sdf
110929_184632.sdf
110929_185345.sdf
110929_204033.sdf
110929_204750.sdf
110929_205439.sdf
110929_210119.sdf
110929_210833.sdf
110929_211533.sdf
110929_212224.sdf
110929_212921.sdf
110929_213614.sdf
110929_214319.sdf
110929_215013.sdf
110929_215714.sdf
110929_220409.sdf
110929_221119.sdf
110929_221812.sdf
110929_222517.sdf
110929_223217.sdf
110929_223915.sdf
110929_224602.sdf
110929_225325.sdf
110929_225958.sdf
110929_230658.sdf
110929_230904.sdf
110930_160418.sdf (calibration)
110930_160612.sdf (calibration)
110930_160837.sdf (calibration)
110930_162123.sdf
110930_162627.sdf
110930_163335.sdf
110930_164031.sdf
110930_164804.sdf
110930_165518.sdf
110930_170237.sdf
110930_170940.sdf
110930_171655.sdf
110930_172347.sdf
110930_173109.sdf
110930_173806.sdf
110930_174535.sdf
110930_175238.sdf
110930_175944.sdf
110930_180640.sdf
110930_181359.sdf
110930_182136.sdf
110930_182830.sdf
110930_202633.sdf
110930_202856.sdf
110930_203144.sdf
110930_203429.sdf
110930_203747.sdf
110930_204121.sdf
110930_204520.sdf
110930_204907.sdf
110930_205316.sdf
110930_205724.sdf
110930_210207.sdf
110930_210653.sdf
110930_211142.sdf
110930_211648.sdf
110930_212206.sdf
110930_212749.sdf
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111003_172503.sdf
111003_173133.sdf
111003_173910.sdf
111003_174606.sdf
111003_175325.sdf
111003_180006.sdf
111003_180703.sdf
111003_181345.sdf
111003_182008.sdf
111003_182648.sdf
111003_183340.sdf
111003_184017.sdf
111003_184706.sdf
111003_185332.sdf
111003_185948.sdf
111003_190634.sdf
111003_191313.sdf
111003_191959.sdf
111003_192550.sdf
111003_193154.sdf
111003_193759.sdf
111003_194437.sdf
111003_195141.sdf
111003_195842.sdf
111003_215102.sdf
111003_215807.sdf
111003_220521.sdf
111003_221130.sdf
111003_221734.sdf
111003_222350.sdf
111003_223102.sdf
111003_223301.sdf
111003_223950.sdf
111003_224710.sdf
111003_225348.sdf
111003_230025.sdf
111003_230653.sdf
111003_231433.sdf
111003_232158.sdf
111003_233007.sdf
111003_233635.sdf
111003_234305.sdf
111004_192336.sdf

111004_192540.sdf
111004_195605.sdf
111010_181334.sdf (calibration)
111010_181543.sdf (calibration)
111010_181805.sdf (calibration)
111010_183812.sdf
111010_184606.sdf
111010_185324.sdf
111010_190032.sdf
111010_190749.sdf
111010_191503.sdf
111010_192253.sdf
111010_193027.sdf
111010_193803.sdf
111010_194535.sdf
111010_195257.sdf
111010_195950.sdf
111010_200659.sdf
111010_201346.sdf
111010_202017.sdf

**GSL MIDDLE BLOCK:**
Flown 10/10 – 10/12
**Navigation File:**
Remote_20111010_02.log
Remote_20111012_01.log
**Base Station File:**
Base_GSL_20111010_02.pdc
Base_GSL_20111011_01.pdc
Base_GSL_20111012.pdc
**Raw Flightline (LIDAR) Files:**
111010_220413.sdf
111010_220620.sdf
111010_220841.sdf
111010_221137.sdf
111010_221453.sdf
111010_221756.sdf
111010_222108.sdf
111010_222454.sdf
111010_222840.sdf
111010_223233.sdf
111010_223718.sdf
111010_224213.sdf
111010_224759.sdf
111010_225356.sdf
111010_225938.sdf
111010_230539.sdf
111010_231139.sdf
111010_231802.sdf
111012_172203.sdf (Calibration)
111012_172341.sdf (Calibration)
111012_172616.sdf (Calibration)
111012_174454.sdf
111012_175144.sdf
111012_175827.sdf
111012_180533.sdf
111012_181223.sdf
111012_181921.sdf
111012_182607.sdf
111012_183317.sdf
111012_184011.sdf
111012_184718.sdf
111012_185356.sdf
111012_190101.sdf
111012_190734.sdf
111012_191434.sdf
111012_192104.sdf
111012_192800.sdf
111012_193434.sdf
111012_194129.sdf
111012_195100.sdf

**GSL SOUTH BLOCK:**
Flown 10/13 – 10/14, 10/18
**Navigation File:**
Remote_20111013_01.log
Remote_20111013_02.log
Remote_20111014_01.log
Remore_20111014_02.log
Remote_GSL_South_20111018_01
**Base Station File:**
00052851.pdc
00052861.pdc
00052871.pdc
00052881.pdc
00052901.pdc
**Raw Flightline (LIDAR) Files:**
111013_060816.sdf
111013_061515.sdf
111013_061730.sdf
111013_062014.sdf
111013_062304.sdf
111013_062617.sdf
111013_063405.sdf
111013_064138.sdf
111013_064924.sdf
111013_065718.sdf
111013_070508.sdf
111013_071243.sdf
111013_072024.sdf
111013_072800.sdf
111013_073543.sdf
111013_074301.sdf
111013_075030.sdf
111013_075747.sdf
111013_080523.sdf
111013_081245.sdf
111013_082023.sdf
111013_082745.sdf
111013_083518.sdf
111013_084246.sdf
111013_100810.sdf
111013_101529.sdf
111013_102237.sdf
111013_102936.sdf
111013_103659.sdf
111013_104416.sdf
111013_105138.sdf
111013_105844.sdf
111013_110531.sdf
111013_111304.sdf
111013_111936.sdf
111013_112608.sdf
111013_113227.sdf
111013_113846.sdf
111013_114455.sdf
111013_115108.sdf
111013_115649.sdf
111013_120217.sdf
111013_120800.sdf
111014_054202.sdf (calibration)
111014_054344.sdf (calibration)
111014_054550.sdf (calibration)
111014_061040.sdf

111014_061554.sdf
111014_062050.sdf
111014_062607.sdf
111014_063122.sdf
111014_063623.sdf
111014_064121.sdf
111014_064608.sdf
111014_065118.sdf
111014_065550.sdf
111014_070039.sdf
111014_070516.sdf
111014_071022.sdf
111014_071753.sdf
111014_072107.sdf
111014_072426.sdf
111014_072804.sdf
111014_073207.sdf
111014_073628.sdf
111014_074103.sdf
111014_074608.sdf
111014_075138.sdf
111014_075708.sdf
111014_080254.sdf
111014_080849.sdf
111014_081449.sdf
111014_082027.sdf
111014_082624.sdf
111014_083227.sdf
111014_094357.sdf
111014_095004.sdf
111014_095643.sdf
111014_100332.sdf
111014_101035.sdf
111014_101702.sdf
111014_102404.sdf
111014_103105.sdf
111014_103757.sdf
111014_104443.sdf
111014_105158.sdf
111014_105902.sdf
111014_110603.sdf
111014_111310.sdf
111014_112009.sdf
111014_112652.sdf
111014_113332.sdf
111014_114032.sdf
111014_114727.sdf
111014_115429.sdf
111014_120202.sdf

111018_083123.sdf (calibration)
111018_083301.sdf (calibration)
111018_083511.sdf (calibration)
111018_090012.sdf
111018_090707.sdf
111018_091402.sdf
111018_092053.sdf
111018_092813.sdf
111018_093514.sdf
111018_094229.sdf
111018_094925.sdf
111018_095610.sdf
111018_100309.sdf
111018_101015.sdf
111018_101739.sdf
111018_102509.sdf
111018_103159.sdf
111018_103912.sdf
111018_104444.sdf
111018_105001.sdf
111018_105409.sdf
111018_105711.sdf
111018_110028.sdf

**GSL TOOLE BLOCK:**
Flown 10/18
**Navigation File:**
Remote_GSL_20111018_02.log
Remote_GSL_20111018_03.log
**Base Station File:**
00052901.pdc
**Raw Flightline (LIDAR) Files:**
111018_162607.sdf
111018_162924.sdf
111018_163515.sdf
111018_164153.sdf
111018_164648.sdf
111018_165105.sdf
111018_165606.sdf
111018_170029.sdf
111018_170524.sdf
111018_171002.sdf
111018_171442.sdf
111018_171824.sdf

111018_172207.sdf
111018_172553.sdf
111018_173007.sdf
111018_173352.sdf
111018_173800.sdf
111018_174142.sdf
111018_174408.sdf
111018_174806.sdf
111018_175213.sdf
111018_175646.sdf
111018_180113.sdf
111018_180526.sdf
111018_181012.sdf
111018_181440.sdf
111018_181914.sdf
111018_182357.sdf
111018_182845.sdf
111018_183313.sdf
111018_183750.sdf
111018_184220.sdf
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111018_185644.sdf
111018_190130.sdf
111018_204911.sdf
111018_205408.sdf
111018_205901.sdf
111018_210355.sdf
111018_210851.sdf
111018_211342.sdf
111018_211813.sdf
111018_212307.sdf
111018_212723.sdf
111018_213138.sdf
111018_213549.sdf
111018_213955.sdf
111018_214343.sdf
111018_214713.sdf
111018_215029.sdf
111018_215345.sdf
111018_215658.sdf
111018_220149.sdf
111018_220347.sdf
111018_220702.sdf
111018_221104.sdf
111018_221529.sdf
111018_221930.sdf
111018_222314.sdf
111018_222636.sdf