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Mapping Project Report Table of Contents

1. LiDAR System Description and Specifications

This survey was performed with an Optech GEMINI Airborne Laser Terrain Mapper (ALTM) serial number 06SEN195 mounted in a twin-engine Piper PA-31-350 Navajo Chieftain (Tail Number N931SA) owned by MARC Inc of Raymond, MS and piloted by Butch Miller.

The instrument specifications are listed in Table 1.

Operating Altitude	150 - 4000 m, Nominal
Horizontal Accuracy	1/5,500 x altitude (m AGL); 1 sigma
Elevation Accuracy	5 - 30 cm; 1 sigma
Range Capture	Up to 4 range measurements, including 1^{st}, 2^{nd}, 3^{rd}, last returns
Intensity Capture	12-bit dynamic range for all recorded returns, including last returns
Scan FOV	0 - 50 degrees; Programmable in increments of ±1degree
Scan Frequency	0 – 70 Hz
Scanner Product	Up to Scan angle x Scan frequency = 1000
Roll Compensation	±5 degrees at full FOV – more under reduced FOV
Pulse Rate Frequency	Variable from 33 - 167 kHz
Position Orientation System	Applanix POS/AV 510 OEM includes embedded BD950 12-channel 10Hz GPS receiver
Laser Wavelength/Class	1047 nanometers / Class IV (FDA 21 CFR)
Beam Divergence nominal (full angle)	Dual Divergence 0.25 mrad (1/e) or 0.80 mrad (1/e)

Table 1 – Optech GEMINI specifications.

See http://www.optech.ca for more information from the manufacturer.
http://www.optech.ca/pdf/Brochures/ALTM-GEMINI.pdf

2. Description of PI's Areas of Interest.

The area of interest is a corridor located over (several fault lines and) the rupture caused by the April 4th 2010 El Mayor – Cucapa Earthquake in Baja, MX. The surveyed corridor begins at the international border between the USA and Mexico roughly 27 km west of Mexicali, Mexico and continues southeasterly for 107 kilometers while varying in width from 2.7 to over 5 kilometers. The planned polygon is shown below in Figure 1 (Google Earth image) in a yellow outline while the red shaded area represents the actual survey coverage.

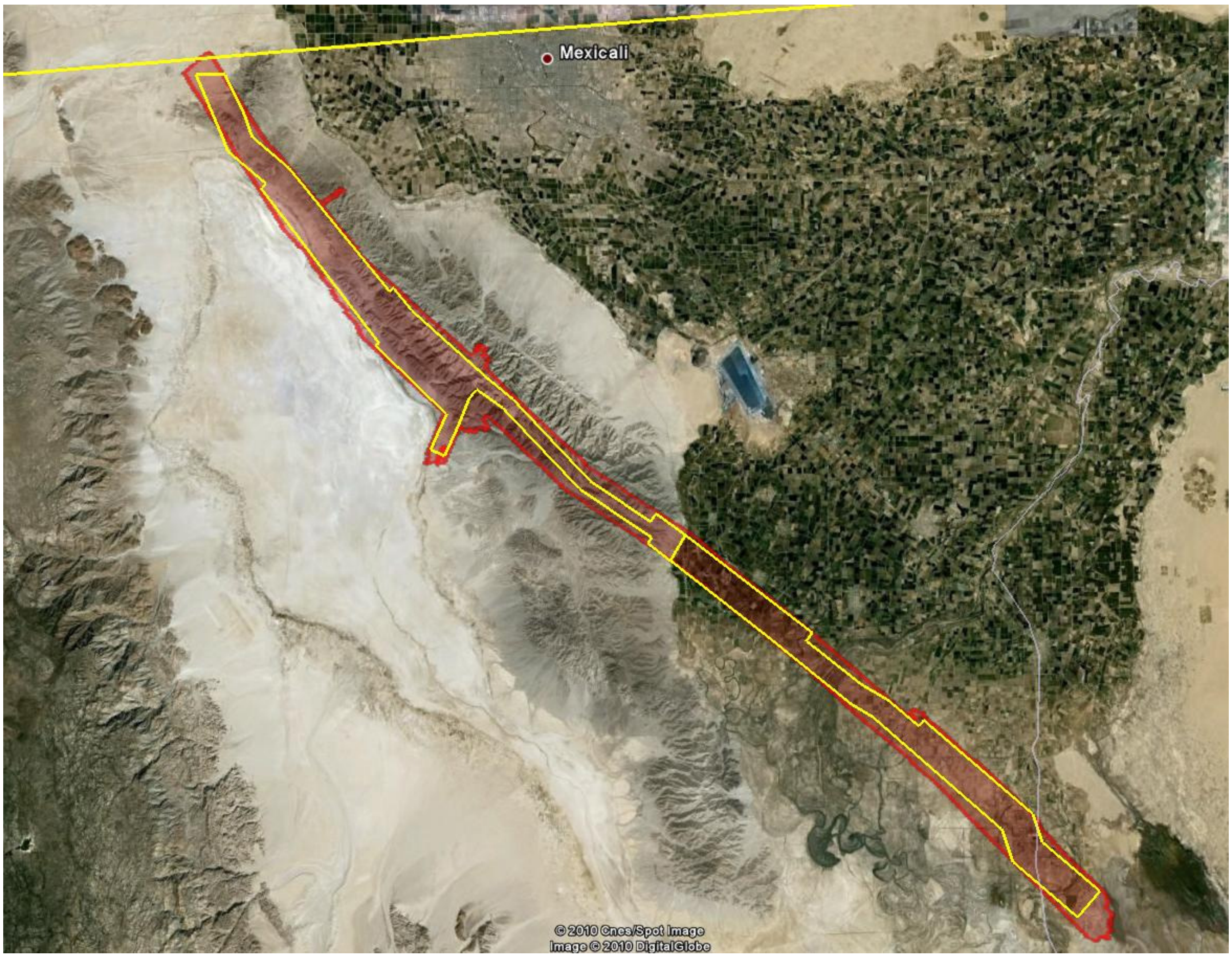

Figure 1 – Shape and location of survey polygon (Google Maps).

3. Airborne Survey Planning Process.

The survey planning was performed considering nominal values of 600m for flight altitude above the terrain, a mean flying speed of 65 m/s, and a swath overlap of 50%. The optimized flight plan consisted of a total of 74 flight lines including 11 cross lines centered at latitude 32 23.5 north longitude, 115 31.2 west longitude inserted in order to double point density in this area.

To obtain the highest point density with respect to range measurement noise the laser Pulse Repetition Frequency (PRF) was set to 100 kHz. Scan frequency (mirror oscillation rate) was held at 60 Hz and the scan angle (Field-of-View or FOV) was limited to +/- 14 degrees. Beam divergence was set to the narrow setting (0.25 milli-radians) which yields a 15 cm spot at 600 meters. The scan product (scan frequency x scan angle) equaled 840 out of a system maximum of 1000, or about 84% of system limits. Table 2 (below) summarizes the survey parameters.

Nominal Flight Parameters		**Equipment Settings**		**Area Totals**	
Flight Altitude	600 m	Laser PRF	100 kHz	Total Passes	74
Flight Speed	65 m/s	Beam Divergence	0.25 mrad	Flight line spacing	116.6 m
Swath Width	233 m	Scan Frequency	60 Hz	Total Flight Time	20.9 hrs
Swath Overlap	50%	Scan Angle	± 14°	Total Laser Time	13.3 hrs
Point Density	9.2 p/m²	Scan Cutoff	3°	Total Swath Area	373 km^2

Table 2 – Survey parameters. Area of Interest is abbreviated AOI.

Three degrees of scan were cut off during processing to minimize the positioning errors that propagate as a function of scan angle. Final point density averaged over 9 nine points per square meter outside of the cross-line area, and over 18 points per square meter in the cross line area.

Figure 2 (following page) shows screen captures of the plotted trajectories.

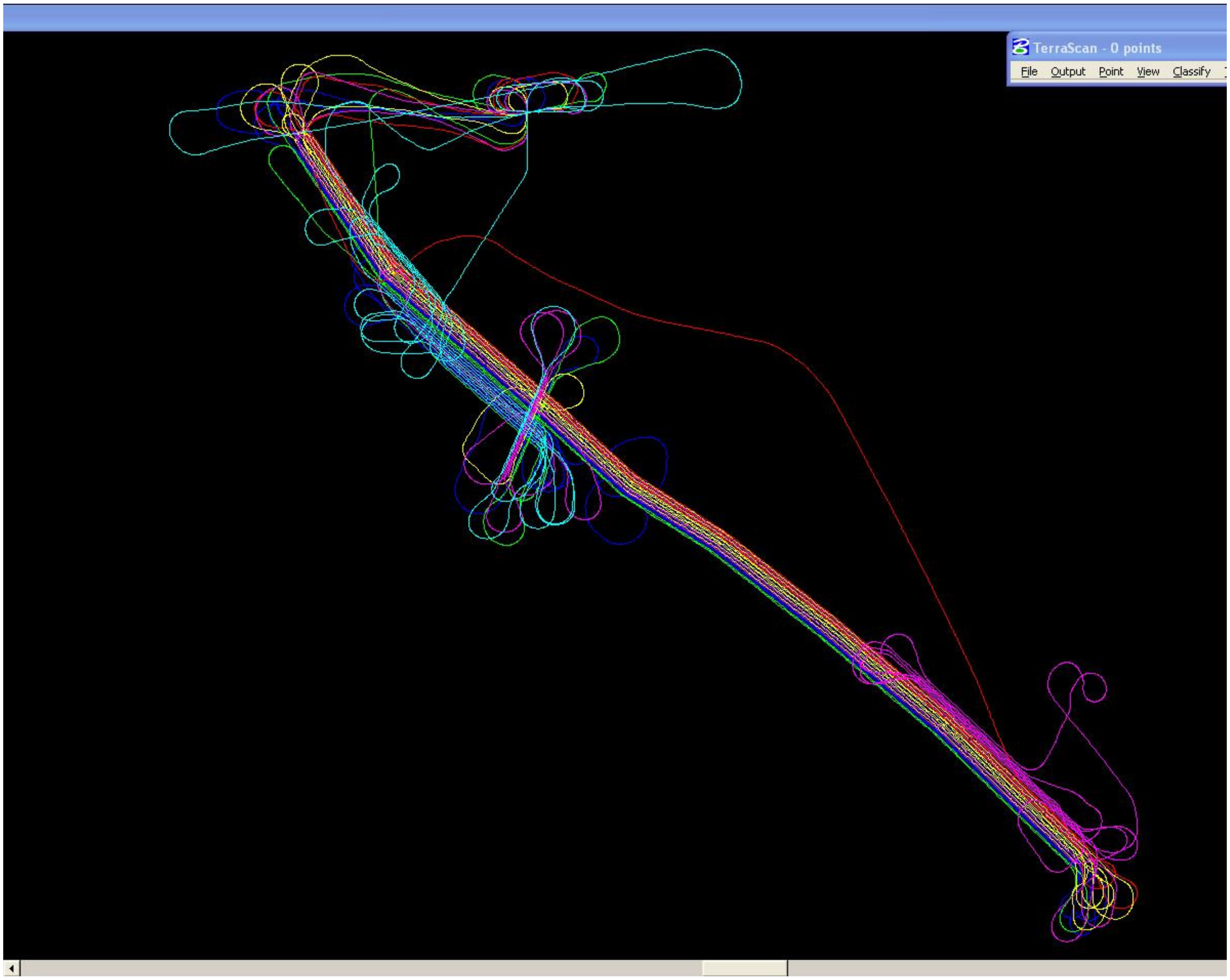

Figure 2. Plotted trajectories.

4. LiDAR and GPS Data Collection Campaign.

This survey was flown on 6 flights over 4 days beginning on August 16, 2010 (DOY 228) and ending on August 19, 2010 (DOY 231). The total flight time was 20.9 hours, with a total Laser-On Time of 13.3 Hours. For the project 3.96 billion laser shots are included in 1788 tiles measuring 500 m square. Table three (below) summarizes the flight information.

Project	Date	DOY	GMT begin	GMT end	Flight time	Laser-on Time
Oskin_Mexico_F01	16-Aug-10	228	20:32	20:37	1:58:49	1:11:59
Oskin_Mexico_F02	17-Aug-10	229	13:33	13:36	4:41:52	3:16:11
Oskin_Mexico_F03	17-Aug-10	229	21:14	21:17	2:20:39	1:29:22
Oskin_Mexico_F04	18-Aug-10	230	12:56	12:25	4:34:36	3:41:53
Oskin_Mexico_F05	19-Aug-10	231	13:07	13:10	4:32:57	2:47:00
Oskin_Mexico_F06	19-Aug-10	231	20:57	21:00	2:46:29	0:54:16
				TOTALS	**20:55:22**	**13:20:41**

Table 3 –Flight information.

Below in Table 4 is information showing the file names and point source ID information for the separate flight strips for all flights.

Point Source ID	Strip File name	GMT start	GMT end	SOW start	SOW end
1	R_228a_004.las	21:00:45	21:28:42	162045	163722
2	R_228a_005.las	21:32:22	21:58:41	163942	165521
3	R_228a_006.las	22:03:48	22:10:29	165828	166229
4	R_228a_007.las	22:15:10	22:17:55	166510	166675
5	R_228a_008.las	22:22:41	22:25:15	166961	167115
6	R_228a_009.las	22:27:52	22:30:46	167272	167446
7	R_229a_004.las	13:54:45	14:22:31	222885	224551
8	R_229a_005.las	14:26:34	14:54:27	224794	226467
9	R_229a_006.las	14:58:00	15:10:16	226680	227416
10	R_229a_007.las	15:14:57	15:15:19	227697	227719
11	R_229a_008.las	15:19:12	15:34:11	227952	228851
12	R_229a_009.las	15:37:32	16:04:52	229052	230692
13	R_229a_010.las	16:09:45	16:37:02	230985	232622
14	R_229a_011.las	16:40:44	16:59:14	232844	233954
15	R_229a_012.las	17:04:19	17:06:59	234259	234419
16	R_229a_013.las	17:10:25	17:13:10	234625	234790
17	R_229a_014.las	17:15:22	17:20:20	234922	235220
18	R_229a_015.las	17:26:06	17:29:18	235566	235758
19	R_229a_016.las	17:32:13	17:37:03	235933	236223
20	R_229a_017.las	17:42:37	17:45:55	236557	236755
21	R_229a_018.las	17:49:07	17:54:15	236947	237255

22	R_229a_019.las	17:58:48	18:02:21	237528	237741
23	R_229a_020.las	18:05:31	18:14:44	237931	238484
24	R_229b_004.las	21:36:50	22:05:10	250610	252310
25	R_229b_005.las	22:07:45	22:34:34	252465	254074
26	R_229b_006.las	22:38:13	23:06:12	254293	255972
27	R_229b_007.las	23:09:50	23:12:46	256190	256366
28	R_229b_008.las	23:30:16	23:31:34	257416	257494
29	R_230a_004.las	13:18:36	13:45:58	307116	308758
30	R_230a_005.las	13:48:49	14:15:37	308929	310537
31	R_230a_006.las	14:20:06	14:47:34	310806	312454
32	R_230a_007.las	14:52:02	15:19:39	312722	314379
33	R_230a_008.las	15:23:52	15:51:00	314632	316260
34	R_230a_009.las	15:55:10	16:22:17	316510	318137
35	R_230a_010.las	16:24:47	16:51:49	318287	319909
36	R_230a_011.las	16:55:02	17:13:28	320102	321208
37	R_230a_012.las	17:17:27	17:19:53	321447	321593
38	R_230a_013.las	17:21:52	17:31:20	321712	322280
39	R_231a_004.las	13:31:09	13:57:31	394269	395851
40	R_231a_005.las	14:01:19	14:28:40	396079	397720
41	R_231a_006.las	14:32:18	14:58:32	397938	399512
42	R_231a_007.las	15:04:03	15:09:44	399843	400184
43	R_231a_008.las	15:13:27	15:19:14	400407	400754
44	R_231a_009.las	15:22:44	15:28:29	400964	401309
45	R_231a_010.las	15:31:55	15:37:50	401515	401870
46	R_231a_011.las	15:40:40	15:42:01	402040	402121
47	R_231a_012.las	15:46:05	15:52:01	402365	402721
48	R_231a_013.las	15:56:07	15:59:18	402967	403158
49	R_231a_014.las	16:04:18	16:08:18	403458	403698
50	R_231a_015.las	16:13:01	16:14:58	403981	404098
51	R_231a_016.las	16:26:29	16:44:02	404789	405842
52	R_231a_017.las	16:47:46	16:50:22	406066	406222
53	R_231a_018.las	16:54:30	16:57:04	406470	406624
54	R_231a_019.las	17:00:26	17:03:12	406826	406992
55	R_231a_020.las	17:07:09	17:09:52	407229	407392
56	R_231a_021.las	17:12:30	17:16:54	407550	407814
57	R_231a_022.las	17:20:56	17:24:47	408056	408287
58	R_231a_023.las	17:30:07	17:39:52	408607	409192
59	R_231b_006.las	21:45:36	21:48:25	423936	424105
60	R_231b_007.las	21:52:01	21:55:00	424321	424500
61	R_231b_008.las	21:58:27	22:01:02	424707	424862
62	R_231b_009.las	22:06:20	22:08:24	425180	425304

63	R_231b_010.las	22:12:39	22:14:08	425559	425648
64	R_231b_011.las	22:18:16	22:19:16	425896	425956
65	R_231b_012.las	22:23:18	22:27:53	426198	426473
66	R_231b_013.las	22:32:50	22:36:56	426770	427016
67	R_231b_014.las	22:41:01	22:45:22	427261	427522
68	R_231b_015.las	22:50:15	22:53:43	427815	428023
69	R_231b_016.las	22:57:30	23:01:59	428250	428519
70	R_231b_017.las	23:06:58	23:10:32	428818	429032
71	R_231b_018.las	23:14:03	23:17:57	429243	429477
72	R_231b_019.las	23:23:01	23:25:37	429781	429937
73	R_231b_020.las	23:29:47	23:32:17	430187	430337
74	R_231b_021.las	23:35:26	23:38:50	430526	430730

Table 4 –Point Source ID information.

Table 5 (below) lists the stations and coordinates for the GPS reference marks.

Station	Geocentric X	Geocentric Y	Geocentric Z	Latitude	Longitude	Ellipsoid Height
P500	-2296231.172	-4857729.620	3425068.229	32.6900463	115.2999316	-20.589
CP13	-2278845.847	-4901797.212	3373866.441	32.1430618	114.9337196	-14.647
LPUR	-2308417.596	-4874046.974	3393826.713	32.3557300	115.3428971	14.081
MAY3	-2309161.521	-4897759.501	3359163.721	31.9866644	115.2426134	-25.632
PTAX	-2317887.675	-4869098.728	3396424.817	32.3774865	115.4563350	1060.367
VM15	-2302923.156	-4883888.578	3383391.856	32.2446269	115.2455062	-24.994
KCLX	-2314482.083	-4850584.153	3422900.245	32.6668964	115.5083917	-33.673

Table 5 –Reference Station locations – coordinates in ITRF00 Epoch 2010.6265.

The above reference station coordinates and all of the data products produced by NCALM for this project are in the ITRF00 Epoch 2010.6265

5. Data Processing and Final Product Generation.

Reference coordinates for all GPS reference stations were derived from observation sessions taken over the project duration and submitted to the NGS on-line processor OPUS which processes static differential baselines tied to the international CORS network. For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ .

Airplane trajectories for this survey were processed using KARS (Kinematic and Rapid Static) software by Dr. Gerald Mader of the NGS Research Laboratory. KARS kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers to determine a high-accuracy fixed integer ionosphere-free differential solution at 1 Hz. Trajectories are obtained per reference station then the trajectories are differenced with one another. Further information is available from NCALM.

After GPS processing, the trajectory solution and the raw inertial measurement unit (IMU) data collected during the flights are combined in APPLANIX software POSPac MMS (Mobile Mapping Suite Version 5.2). POSPac MMS implements a Kalman Filter algorithm to produce a final, smoothed, and complete navigation solution including both aircraft position and orientation at 200 Hz. This final navigation solution is known as an SBET (Smoothed Best Estimated Trajectory).

Calibration of roll, pitch, and heading bore site angles as well as the scale factor of the mirror angles, was done using automated routines (TerraMatch Version 10. Software by Terrasolid) and then checked using both automated and manual means. Root mean square differences in the heights from surfaces formed from individual adjacent flight strips varied from 4 to 9 cm in the locations where these checks were performed.

Check points were collected by roof-mounted GPS on an east-west road running parallel to the Calexico airport and then this road was surveyed with the Gemini during multiple flights. The heights of nearest neighbor points from the vehicle survey and the airborne survey were then differenced in order to check for any vertical bias. A consistent 75 mm bias was found and removed from the entire LiDAR point cloud on the basis of these checkpoints.

LAS format (Version 1) was output strip by strip using Optech's DashMap (Version 5.1).

The individual flight strips were combined into 500 meter square tiles with the file naming convention based on the minimum value X and Y in the UTM projection.

The point tiles are gridded using Golden Software's Surfer 8 Krigging at 0.5m cell size, using a 5m search radius for the unfiltered point data.

The gridding parameters are:

```
Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.15 m
MicroVariance: 0.00 m
SearchDataPerSector: 7
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 5m
```

The resulting tiled Surfer grid sets are transformed using in-house Python and AML scripts into ArcInfo binary seamless tiles at 0.5m cell size. Due to the large area covered by the survey and the ArcInfo software limitations it is not possible to create one large mosaic for the entire area so the 0.5m tiles are mosaiced at 1m resolution into shorter segments.

The point tiles and the corresponding grids and mosaics are all positioned in the ITRF2000 reference frame and projected into UTM coordinates Zone 11N, all units in meters. The elevations are heights above the ellipsoid. Because ArcInfo doesn't support directly this particular projection, the grids are assigned the following projection information: UTM Zone 11N, WGS84 (original) datum.

Special note on the LiDAR data georeferencing

All plane coordinates are in the UTM projection of the ITRF00 epoch 2010.6265. The zone is 11N (N for Northern Hemisphere).

Users who intend to integrate this LiDAR data with other geospatial data (especially data referenced to datums other than WGS84) should be aware that alignment issues may occur because the data is positioned in the ITRF2000 reference frame. There are several iterations of the WGS84 datum definition and the most recent ones are tied to ITRF (which is continually in motion because it accounts for plate tectonic movements) and thus by simply specifying WGS84 as datum is not enough to clearly identify which version is used. In fact, ArcInfo's WGS84 datum definition implies WGS83_original which is equivalent with the NAD83(CORS96) datum and doesn't account for plate tectonic velocities.

Currently, ITRF2000 is equivalent to WGS84(G1150). Therefore, it is important to use the transformation that is appropriate for the version of WGS84 used by these data in order to minimize alignment errors. For instance, ArcGIS provides 8 different transformations for aligning NAD83 data with WGS84 data. Failure to select the correct datum transformation can yield mismatches greater than 1.5 meters ArcGIS users should also note that ESRI does not yet offer a transformation for WGS84 tied to ITRF00 (G1150), however the ITRF96-based WGS84 (G873 - the edition of ITRF previous to ITRF00) is only a few centimeters different than ITRF00 so transformations based on ITRF96 should work reasonably well. For example, ArcInfo users should use the "NAD_1983_To_WGS84_5" transformation method for projecting the LiDAR data (now assumed to be WGS84(G873) which is equivalent to ITRF96) into NAD83.

For more information about the currently supported ArcInfo transformation visit this webpage:
http://support.esri.com/index.cfm?fa=knowledgebase.techarticles.articleShow&d=24159

The online HTDP (Horizontal Time Dependent Positioning) toolkit provides many resources and interactive point data transformation between the various reference frames: http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml

The users should also be aware that the elevation values of all datasets are heights above the ellipsoid (WGS84) and not orthometric heights. The ellipsoid-heights are measured along the ellipsoid normal in contrast to the orthometric heights which follow the direction of the gravity. In many applications the term "elevation" most commonly refers to the orthometric height of a point. Ellipsoid heights from GPS surveys are converted to traditional orthometric values by applying a geoid height using the latest geoid model from the National Geodetic Survey (NGS).

The Corps of Engineers Coordinate Conversion (CORPSCON, currently at v.6.0) tool can be used to transform the point data (XYZ ASCII tiles) ellipsoid heights into NAVD88 elevations using various GEOID models, including the latest iteration - GEOID09. The converted point data files can be then re-grided to ArcInfo raster format using your preferred interpolation technique. CORPSCON can be downloaded from this address:

http://crunch.tec.army.mil/software/corpscon/corpscon.html

6. Deliverables Description.

Deliverables include the following:

1. Point Cloud in LAS 1.0, classified as ground or non-ground, in ¼ km tiles.
2. Point Cloud in LAS 1.0 flight strips NOT CLASSIFIED.
3. ESRI format 0.5-m MOSAIC DEM from default-class (first-stop) points.
4. ESRI format 0.5-m MOSAIC DEM from ground-class points
5. SURFER rasters if requested.

7. APPENDIX A – Google Earth KML of the survey boundary.


```
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File</name><open>1</open><Placemark><name>e792c008 b127 4d99 8838
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yIs><LinearRing><coordinates>
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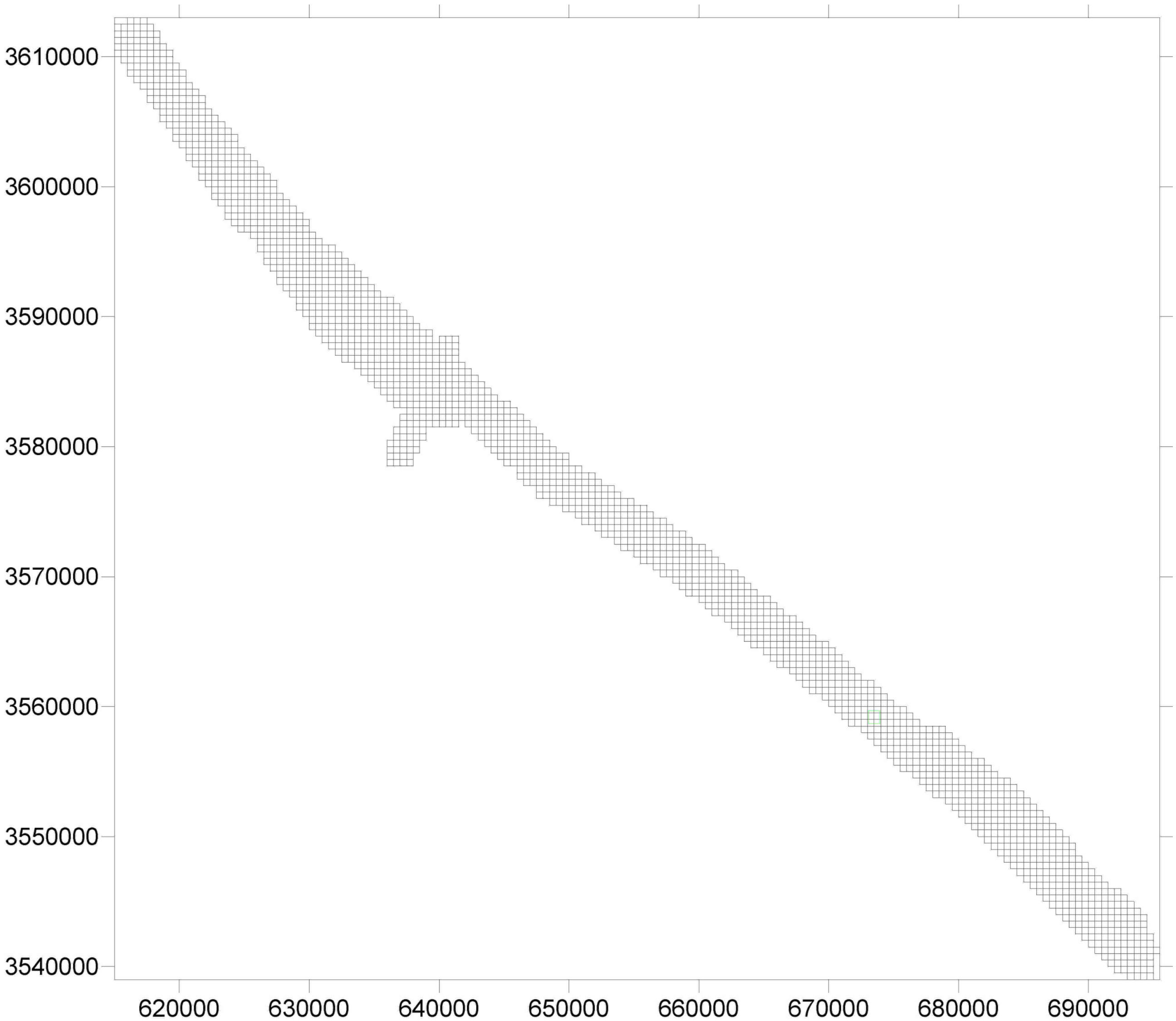

Figure 3 - Tile footprints.