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Project Name: Furnace Creek and Fish Lake Valley Fault Zones in Death Valley National Park

1. Survey areas

The project area consisted of 2 rectangular boxes, the northern one approximately 11 kilometers by 2.2 kilometers (26 square kilometers) and the southern box 10 kilometers by 2 kilometers (21 square kilometers). Corner coordinates in NAD27 UTM Zone 11 for these rectangles are:

North Box (North of Ubehebe Crater):

455630 E, 4107060 N = upper left
457340 E, 4108080 N = upper right
462490 E, 4098600 N = lower left
464280 E, 4099505 N = lower right

South Box (Red Wall Canyon Area):

472630 E, 4085319 N = upper left
474200 E, 4086400 N = upper right
477690 E, 4078170 N = lower left
479300 E, 4079345 N = lower right

This area was flown on February 28, 2005. Figure 1 (next page) is an image showing the location of the two project areas.

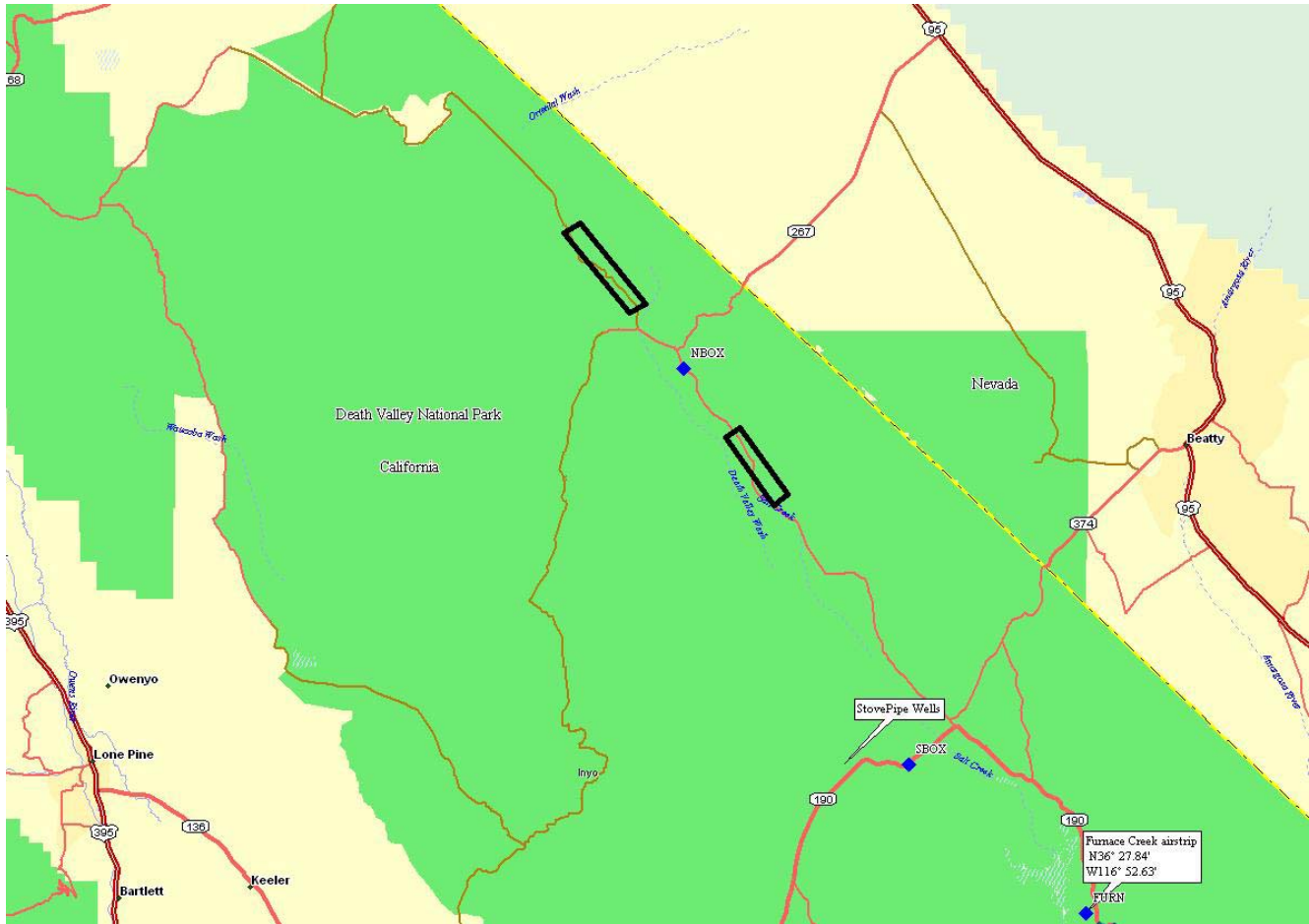


Figure 1 - Project location map (blue triangles represent locations of GPS base stations).

2. Survey Parameters

The Furnace Creek/Fish Lake Valley project area contained 20 flight lines (10 lines per box) oriented Northwest-Southeast and 4 additional cross lines for field calibration purposes. These lines were flown in the following manner: the plane began surveying line 1 in the northern box (box 1) heading southeast, turning the laser off while continuing southeast to box 2, then turning the laser back on and flying line 1 of box 2 still flying southeast. At the end of line 1, the aircraft would turn and head northwest, flying line 2 of box 2, then continue northwest and survey line 2 of box 1. This strategy minimized the number of required turns. The flying height was targeted at 600 meters Above Ground Level (AGL) but was varied during the survey from 600 to 820 meters due to the mountainous terrain. Flying speed was variable, averaging approximately 60 meters/second. Planned point spacing per swath was approximately 1 meter along-track at nadir, 2.1 meters at the scan edge and 1.0 meters cross-track. Overlap coverage was targeted at approximately 100%, (50% sidelap). Additional parameters are shown below in Table 1.

Flying Speed (m/s)	Scan Spacing (m)	Pulse Rate (p/sec)	
60.0	2.1		33333.0
Indicated Air Speed (nm/h)	Scan Width (m)	Pulses Per Scan	
116.6	436.8		595.2
Scan Rate (+/- degrees)	Scan Angle (d)	Distance Between Range Points Along Scan (m)	
28.0	20.0		0.73
Flying Height (meters AGL)	Flight line Spacing (m)	Swath Overlap (m)	
600	219.8		260.0

Table 1 - Survey Parameters at 600 meters AGL.

Flying Speed (m/s)	Scan Spacing (m)	Pulse Rate (p/sec)	
60.0	2.1		33333.0
Indicated Air Speed (nm/h)	Scan Width (m)	Pulses Per Scan	
116.6	582.4		595.2
Scan Rate (+/- degrees)	Scan Angle (d)	Distance Between Range Points Along Scan (m)	
28.0	20.0		0.98
Flying Height (meters AGL)	Flight line Spacing (m)	Swath Overlap (m)	
800	219.8		363.0

Table 2 - Survey Parameters at 800 meters AGL.

Table 3 (below) gives the combined laser-on and air time totals for the project.

Laser-on	2.50	Hours
Air Time(Laser-off)	1.47	Hours
Total Flight Time	3.97	Hours

Table 3 - Laser-on time, air time, and total flight time.

3. GPS Reference Stations

Three GPS reference station locations were used during the survey. One receiver was placed on a set mark (FURN) at the Furnace Creek airstrip. This station was observed on February 26, 27, and 28 for a total of 19 hours. Two additional receivers were placed on newly set marks named SBOX and NBOX (see blue triangles in Figure 1 for the relative locations). These marks were observed for 4.5 and 3.0 hours respectively on the day of the flight. All GPS observations were logged at a 1-second rate and were submitted to the NGS on-line processor OPUS with solution files included as Appendix A. The repeat session results on mark FURN yielded reference station coordinate differences of less than 0.020 meters in both horizontal and vertical positions. Final coordinates for the reference station FURN were calculated from the OPUS solutions as a weighted average, while the OPUS solutions for SBOX and NBOX were held as final. 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/> . Ground equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 2-meter fixed-height tripods.

4. Navigation Processing

Airplane trajectories for this survey were processed using both KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory, and REALM processing software by Optech, Inc. The KARS solution is dual-frequency phase-differenced fixed integer, while the REALM solution is phase-differenced L1 only, without fixing phase ambiguities; these types of solutions (REALM) are generally less suitable over long baseline lengths (over 25 kilometers) but usually very good over short baseline separation distances. Trajectories were processed separately using two reference stations and then coordinate differences between the separate solutions were plotted. Figure 2 (below) is a plot of the differences in Easting, Northing, and Height of two trajectories one being the L1 REALM trajectory from NBOX and the other being the dual-frequency KARS solution from SBOX. A systematic height difference introduced by the processing software between these 2 trajectories has been removed.

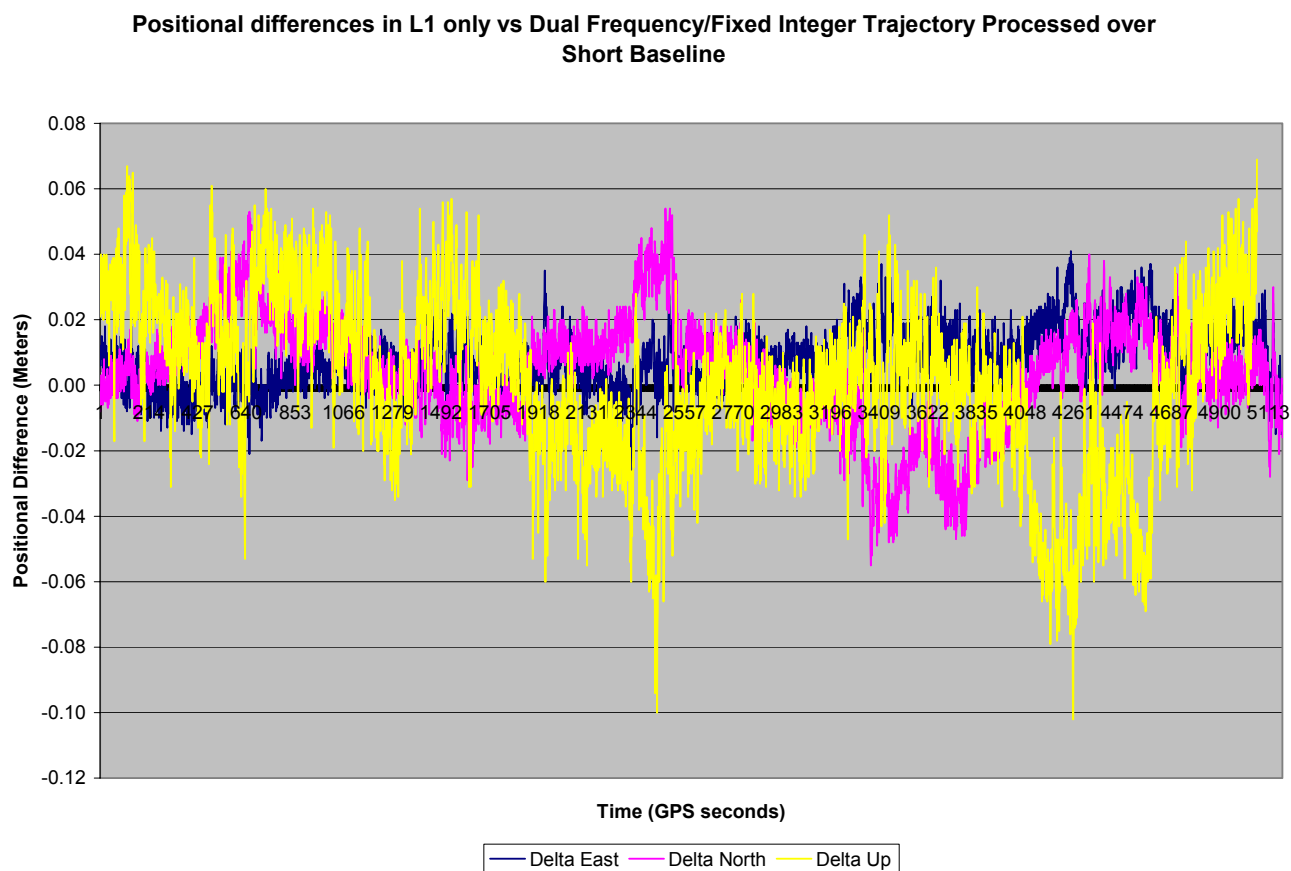


Figure 2 – Positional differences in trajectory positions

The standard deviation of the differences in the Easting position of these two trajectories is 1 cm, in Northing 2 cm, and in height 3 cm.

Both the REALM L1 trajectory and the KARS dual frequency/fixed integer solution were used for the processing of the final navigation solution because the L1/L2 solution was incomplete due to a problem with the aircraft GPS antenna and/or cable, which has since been corrected.

5. Laser Point Processing

All coordinates were processed with respect to NAD83 and referenced to the national CORS network. The projection is UTM Zone 11, with units in meters. Heights are NAVD88 orthometric heights computed using NGS GEOID03 model.

The most complete output format is nine-column ASCII (space delimited), one file per flight strip. The nine columns are as follows: 1. GPS time (seconds of week); 2. Easting last stop; 3. Northing last stop; 4. Height last stop; 5. Intensity last stop; 6. Easting first stop; 7. Northing first stop; 8. Height first stop; 9. Intensity first stop. . Note that in these 9-column files no geoid model has been applied - height values are ellipsoid heights and these height values will NOT match orthometric heights (elevations) found in the 3-column output or in the 1-meter DEM grid nodes.

Note that the UTM zone code (12) is appended to the Easting coordinate in this nine-column format. The UF has utility software to reformat these files, for example to extract last stop elevations and intensities and remove the UTM zone code. These utilities are written in C /C++ programming language and are available for distribution.

During processing, a scan cutoff angle of 1.5 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy (points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements). Points with very low intensity values were also filtered out (intensity values less than 7), because these points also tend to be the least accurate. This is due to the fact that very weak return pulses yield the noisiest range measurements. These points represent a very small percentage of the total number of points, usually in the neighborhood of a few hundredths of one percent. An almost total absence of vegetation makes this project area ideal, because removal of these types of points does not reduce the point density of bare-earth shots as it might in a heavily canopied project area.

All calibration files as well as all raw observation files (both GPS and ALTM) necessary to reprocess this project in its entirety are archived by UC Berkeley.

After GPS processing was complete, the final trajectories were combined with raw IMU measurements and a final navigation solution was developed using Applanix POSPAC software. This software employs a Kalman Filter and various smoothing algorithms to determine a best estimate of trajectory.

6. Ground Truth and Calibration

In order to provide on-site calibration and ground truth, a section of Badwater road running south from the Furnace Creek Resort was surveyed using vehicle-mounted GPS, and then surveyed with the

ALTM during the flight. Comparisons were made between the heights of the vehicle-collected GPS and the airborne laser scanner. This allowed for a check on the calibration of the airborne scanner as well as a measure of the accuracy of the scanner heights. After analysis, the REALM trajectory height shift was -0.10 meters while the KARS trajectory needed -0.25 meter height shift.

Another procedure used to calibrate these data was to survey four cross lines perpendicular to the flight lines, two cross lines for each box. Profiles cut from the cross lines were then compared with profiles cut from the survey lines. This allows a comparison of an edge to edge profile (prone to calibration errors) with an along-nadir profile (relatively free from calibration errors). This procedure is illustrated below in Figure 3.

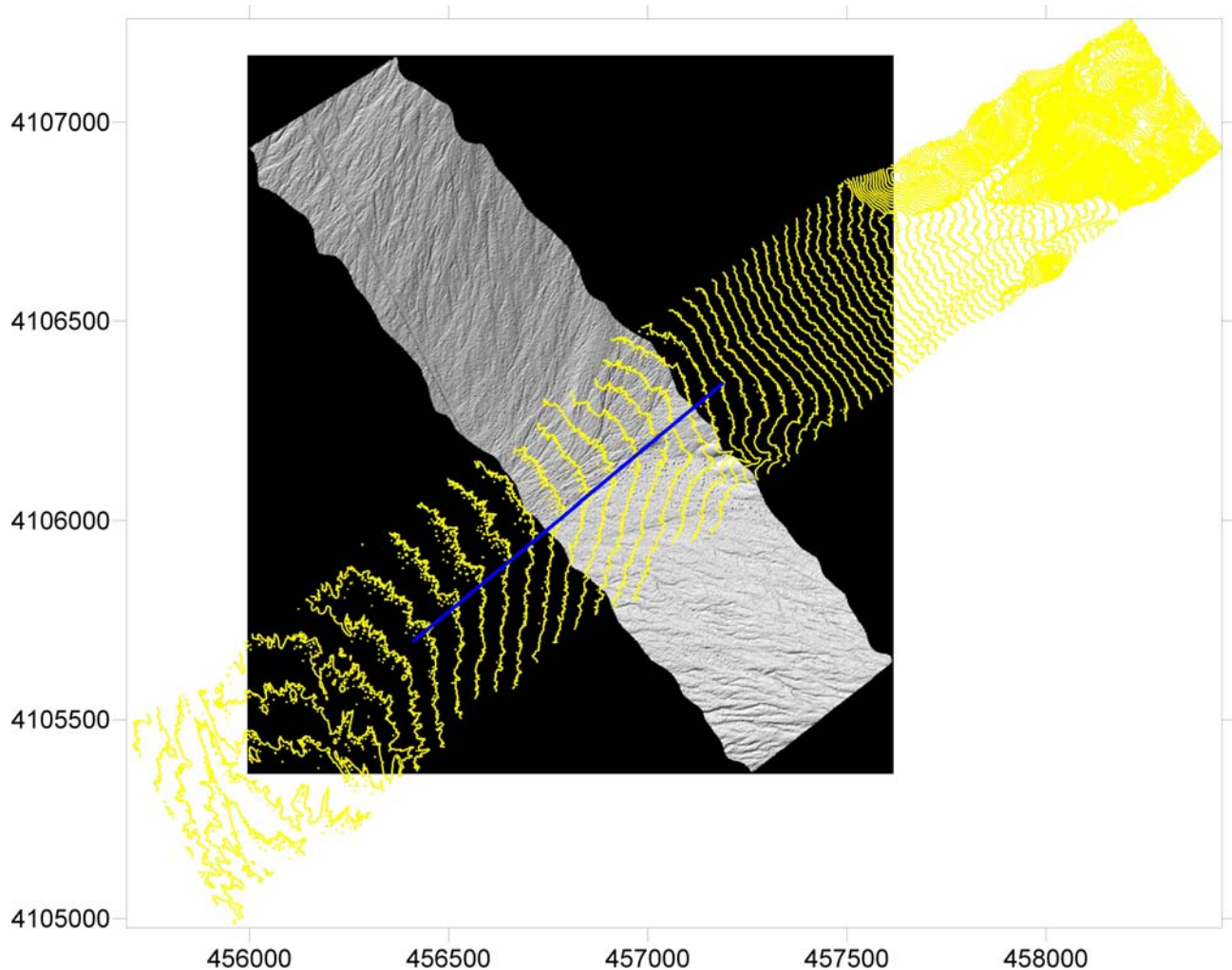


Figure 3 - Contour map of a cross line on a shaded relief image of a survey line. The profile is cut along the blue line.

The profile comparison appears below in Figure 4 where differences in elevation along the profile line are plotted.

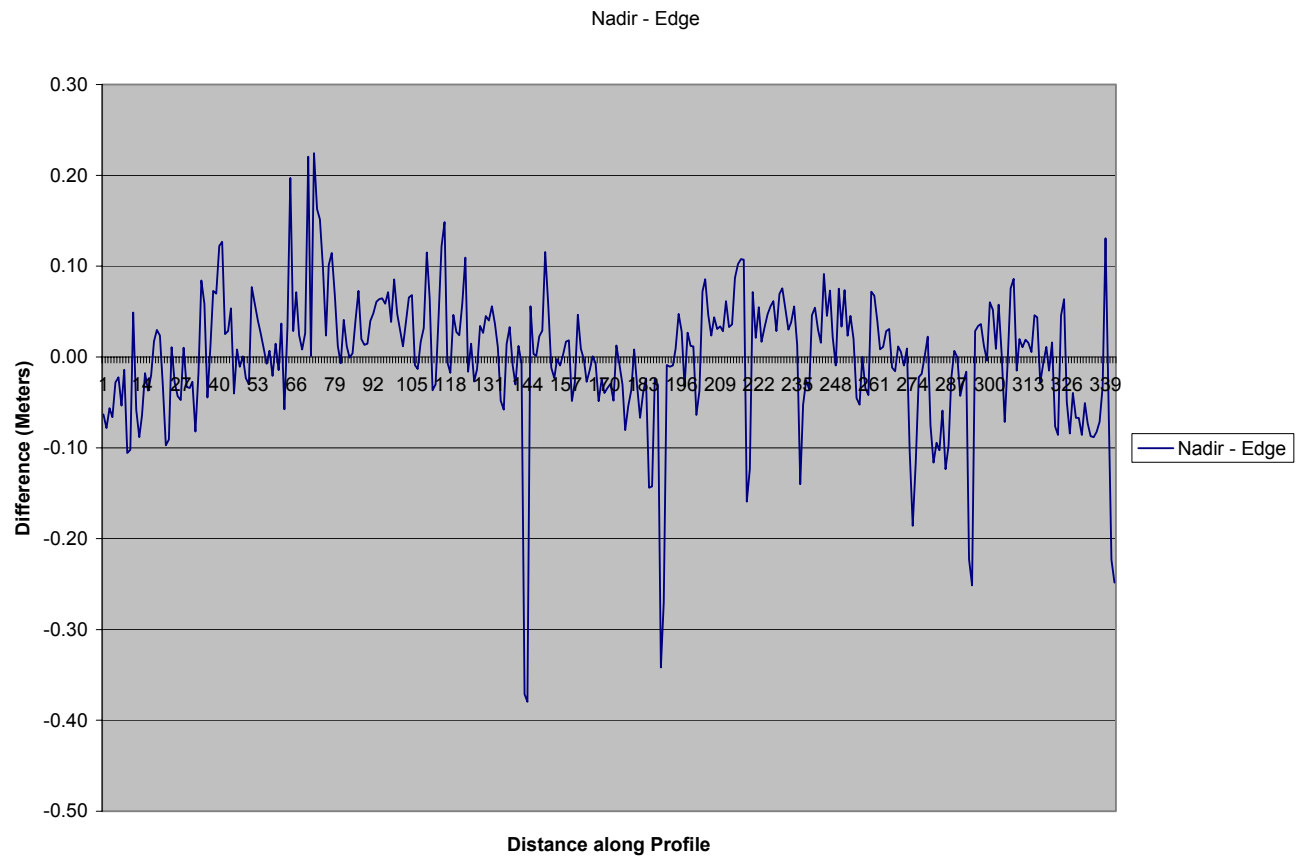


Figure 4 - Differences in Elevation along 2 profile lines.

This procedure is repeated for all cross lines. These profiles are then evaluated in terms of aircraft roll calibration – which would show a rotation – and the mirror angle scale value, which would show a smile or frown. The profile comparison in Figure 4 does not indicate any problems with aircraft roll calibration or the mirror scale factor.

7. Filtering and DEM Production

Digital Elevation Models were produced at 1.0 meter spacing for all areas from last stop elevations using SURFER (Golden Software) Version 8.04. Interpolation parameters were as follows in Table 3.

Algorithm	Kriging
Variogram	Linear
Nugget Variance	0.10 meters
MicroVariance	0.00 meters
Quadrant Search	4
Search Radius	5 meters
Minimum points per quadrant	5
Maximum points per quadrant	7

Table 3 - Gridding parameters.

No vegetation removal (filtering) was done for this project.

APPENDIX A.

GPS Reference Station Coordinates from OPUS

NGS OPUS SOLUTION REPORT

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USER: michael@ufl.edu
RINEX FILE: furn059p.05o

DATE: March 10, 2005
TIME: 18:21:39 UTC

SOFTWARE: page5 0411.19 master28.pl
EPHEMERIS: igr13121.eph [rapid]
NAV FILE: brdc0590.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 2.000

START: 2005/02/28 15:30:00
STOP: 2005/03/01 04:17:00
OBS USED: 17891 / 17993 : 99%
FIXED AMB: 82 / 82 : 100%
OVERALL RMS: 0.010 (m)

REF FRAME: NAD83 (CORS96) (EPOCH:2002.0000)

ITRF00 (EPOCH:2005.1614)

X:	-2321829.586 (m)	0.008 (m)	-2321830.287 (m)	0.008 (m)
Y:	-4580718.588 (m)	0.028 (m)	-4580717.282 (m)	0.029 (m)
Z:	3769582.400 (m)	0.018 (m)	3769582.382 (m)	0.018 (m)

LAT:	36 27 47.07203	0.030 (m)	36 27 47.08790	0.031 (m)
E LON:	243 7 15.27533	0.008 (m)	243 7 15.22650	0.008 (m)
W LON:	116 52 44.72467	0.008 (m)	116 52 44.77350	0.008 (m)
EL HGT:	-96.947 (m)	0.015 (m)	-97.640 (m)	0.015 (m)
ORTHO HGT:	-67.519 (m)	0.029 (m)	[Geoid03 NAVD88]	

UTM COORDINATES

STATE PLANE COORDINATES

UTM (Zone 11)

SPC (0404 CA 4)

Northing (Y) [meters]	4035319.085	627456.477
Easting (X) [meters]	510833.252	2190078.875
Convergence [degrees]	0.07185733	1.26530754
Point Scale	0.99960145	0.99994478
Combined Factor	0.99961666	0.99995999

US NATIONAL GRID DESIGNATOR: 11SNA1083335319 (NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE (m)
AI8802	DYER DYER CORS ARP	N374434.077	W1180221.559	175537.8
DG4265	NVTR TROPICANA CORS ARP	N360557.001	W1151944.433	145006.0
AJ1826	LVWD LAS VEGAS VALLEY CORS ARP	N360934.026	W1151128.797	155275.6

NEAREST NGS PUBLISHED CONTROL POINT

GS0250	-178	N362726.	W1165203.	1225.3
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This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT

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USER: michael@ufl.edu
RINEX FILE: furn058r.05o

DATE: March 10, 2005
TIME: 18:35:51 UTC

SOFTWARE: page5 0411.19 master17.pl
EPHEMERIS: igr13120.eph [rapid]
NAV FILE: brdc0580.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 2.000

START: 2005/02/27 17:57:00
STOP: 2005/02/27 22:59:30
OBS USED: 7845 / 7903 : 99%
FIXED AMB: 41 / 41 : 100%
OVERALL RMS: 0.011 (m)

REF FRAME: NAD83 (CORS96) (EPOCH:2002.0000)

ITRF00 (EPOCH:2005.1585)

X:	-2321829.589 (m)	0.010 (m)	-2321830.290 (m)	0.010 (m)
Y:	-4580718.589 (m)	0.013 (m)	-4580717.282 (m)	0.013 (m)
Z:	3769582.405 (m)	0.007 (m)	3769582.387 (m)	0.007 (m)

LAT:	36 27 47.07211	0.010 (m)	36 27 47.08801	0.010 (m)
E LON:	243 7 15.27524	0.009 (m)	243 7 15.22640	0.009 (m)
W LON:	116 52 44.72476	0.009 (m)	116 52 44.77360	0.009 (m)
EL HGT:	-96.942 (m)	0.011 (m)	-97.636 (m)	0.011 (m)
ORTHO HGT:	-67.514 (m)	0.027 (m)	[Geoid03 NAVD88]	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 11)	SPC (0404 CA 4)
Northing (Y) [meters]	4035319.088	627456.480
Easting (X) [meters]	510833.249	2190078.873
Convergence [degrees]	0.07185732	1.26530753
Point Scale	0.99960145	0.99994478
Combined Factor	0.99961665	0.99995999

US NATIONAL GRID DESIGNATOR: 11SNA1083335319 (NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE (m)
DG4265	NVTR TROPICANA CORS ARP	N360557.001	W1151944.433	145006.0
AJ1826	LVWD LAS VEGAS VALLEY CORS ARP	N360934.026	W1151128.797	155275.6
DG4673	NVCS CARLTON SQUARE CORS ARP	N361311.196	W1151019.335	155610.3

NEAREST NGS PUBLISHED CONTROL POINT

GS0250	-178	N362726.	W1165203.	1225.3
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This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT

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USER: michael@ufl.edu
RINEX FILE: furn057u.05o

DATE: March 10, 2005
TIME: 18:18:09 UTC

SOFTWARE: page5 0411.19 master24.pl
EPHEMERIS: igr13116.eph [rapid]
NAV FILE: brdc0570.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 2.000

START: 2005/02/26 20:47:00
STOP: 2005/02/26 22:59:30
OBS USED: 4289 / 4330 : 99%
FIXED AMB: 28 / 28 : 100%
OVERALL RMS: 0.010 (m)

REF FRAME: NAD83 (CORS96) (EPOCH:2002.0000)

ITRF00 (EPOCH:2005.1559)

X:	-2321829.588 (m)	0.021 (m)	-2321830.289 (m)	0.020 (m)
Y:	-4580718.603 (m)	0.014 (m)	-4580717.297 (m)	0.014 (m)
Z:	3769582.402 (m)	0.011 (m)	3769582.383 (m)	0.011 (m)

LAT:	36 27 47.07180	0.010 (m)	36 27 47.08766	0.010 (m)
E LON:	243 7 15.27553	0.018 (m)	243 7 15.22670	0.018 (m)
W LON:	116 52 44.72447	0.018 (m)	116 52 44.77330	0.018 (m)
EL HGT:	-96.934 (m)	0.018 (m)	-97.628 (m)	0.018 (m)
ORTHO HGT:	-67.506 (m)	0.031 (m)	[Geoid03 NAVD88]	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 11)	SPC (0404 CA 4)
Northing (Y) [meters]	4035319.079	627456.471
Easting (X) [meters]	510833.257	2190078.880
Convergence [degrees]	0.07185736	1.26530757
Point Scale	0.99960145	0.99994478
Combined Factor	0.99961665	0.99995999

US NATIONAL GRID DESIGNATOR: 11SNA1083335319 (NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE (m)
DG4265	NVTR TROPICANA CORS ARP	N360557.001	W1151944.433	145006.0
AJ1826	LVWD LAS VEGAS VALLEY CORS ARP	N360934.026	W1151128.797	155275.6
DG4673	NVCS CARLTON SQUARE CORS ARP	N361311.196	W1151019.335	155610.3

NEAREST NGS PUBLISHED CONTROL POINT

GS0250	-178	N362726.	W1165203.	1225.3
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This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT

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USER: michael@ufl.edu
RINEX FILE: nbox059w.05o

DATE: March 10, 2005
TIME: 18:22:36 UTC

SOFTWARE: page5 0411.19 master16.pl
EPHEMERIS: igr13121.eph [rapid]
NAV FILE: brdc0590.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 2.000

START: 2005/02/28 22:50:00
STOP: 2005/03/01 02:02:00
OBS USED: 5464 / 5550 : 98%
FIXED AMB: 37 / 37 : 100%
OVERALL RMS: 0.009(m)

REF FRAME: NAD83 (CORS96) (EPOCH:2002.0000)

ITRF00 (EPOCH:2005.1617)

X:	-2344465.067 (m)	0.016 (m)	-2344465.770 (m)	0.016 (m)
Y:	-4531109.100 (m)	0.018 (m)	-4531107.805 (m)	0.018 (m)
Z:	3816157.743 (m)	0.003 (m)	3816157.728 (m)	0.004 (m)

LAT:	36 58 54.44256	0.011 (m)	36 58 54.45831	0.011 (m)
E LON:	242 38 32.15118	0.021 (m)	242 38 32.10188	0.021 (m)
W LON:	117 21 27.84882	0.021 (m)	117 21 27.89812	0.021 (m)
EL HGT:	629.651 (m)	0.012 (m)	628.982 (m)	0.012 (m)
ORTHO HGT:	657.476 (m)	0.028 (m)	[Geoid03 NAVD88]	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 11)	SPC (0404 CA 4)
Northing (Y) [meters]	4092912.025	684167.454
Easting (X) [meters]	468162.430	2146202.563
Convergence [degrees]	-0.21520176	0.97975373
Point Scale	0.99961249	0.99996000
Combined Factor	0.99951372	0.99986120

US NATIONAL GRID DESIGNATOR: 11SMA6816292912 (NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE (m)
AH2502	MINS MINARET SUMMIT CORS ARP	N373913.532	W1190339.184	168432.8
AI8802	DYER DYER CORS ARP	N374434.077	W1180221.559	103842.6
AI8811	RAIL RAILROAD VALLEY CORS ARP	N381649.535	W1153953.379	207639.6

NEAREST NGS PUBLISHED CONTROL POINT

GS0789	MESQUITE	N365849.972	W1172058.279	743.4
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This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

NGS OPUS SOLUTION REPORT

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USER: michael@ufl.edu
RINEX FILE: sb059w.05o

DATE: March 10, 2005
TIME: 18:21:48 UTC

SOFTWARE: page5 0411.19 master11.pl
EPHEMERIS: igr13121.eph [rapid]
NAV FILE: brdc0590.05n
ANT NAME: ASH700936D_M
ARP HEIGHT: 2.000

START: 2005/02/28 22:02:00
STOP: 2005/03/01 02:38:00
OBS USED: 7903 / 7953 : 99%
FIXED AMB: 43 / 43 : 100%
OVERALL RMS: 0.009 (m)

REF FRAME: NAD83 (CORS96) (EPOCH:2002.0000)

ITRF00 (EPOCH:2005.1617)

X:	-2334474.503 (m)	0.015 (m)	-2334475.201 (m)	0.015 (m)
Y:	-4563857.383 (m)	0.020 (m)	-4563856.080 (m)	0.020 (m)
Z:	3782217.283 (m)	0.027 (m)	3782217.268 (m)	0.027 (m)

LAT:	36 36 15.80008	0.033 (m)	36 36 15.81598	0.034 (m)
E LON:	242 54 34.72015	0.016 (m)	242 54 34.67127	0.015 (m)
W LON:	117 5 25.27985	0.016 (m)	117 5 25.32873	0.015 (m)
EL HGT:	-38.286 (m)	0.010 (m)	-38.971 (m)	0.010 (m)
ORTHO HGT:	-9.251 (m)	0.027 (m)	[Geoid03 NAVD88]	

	UTM COORDINATES	STATE PLANE COORDINATES
	UTM (Zone 11)	SPC (0404 CA 4)
Northing (Y) [meters]	4050991.210	642736.554
Easting (X) [meters]	491919.062	2170835.847
Convergence [degrees]	-0.05387779	1.13926936
Point Scale	0.99960080	0.99994083
Combined Factor	0.99960681	0.99994684

US NATIONAL GRID DESIGNATOR: 11SMA9191950991 (NAD 83)

BASE STATIONS USED

PID	DESIGNATION	LATITUDE	LONGITUDE	DISTANCE (m)
AH2502	MINS MINARET SUMMIT CORS ARP	N373913.532	W1190339.184	210341.0
AI8802	DYER DYER CORS ARP	N374434.077	W1180221.559	151890.6
AJ1826	LVWD LAS VEGAS VALLEY CORS ARP	N360934.026	W1151128.797	177402.6

NEAREST NGS PUBLISHED CONTROL POINT

GS0537	T 1373	N363604.	W1170541.	534.3
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This position was computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.