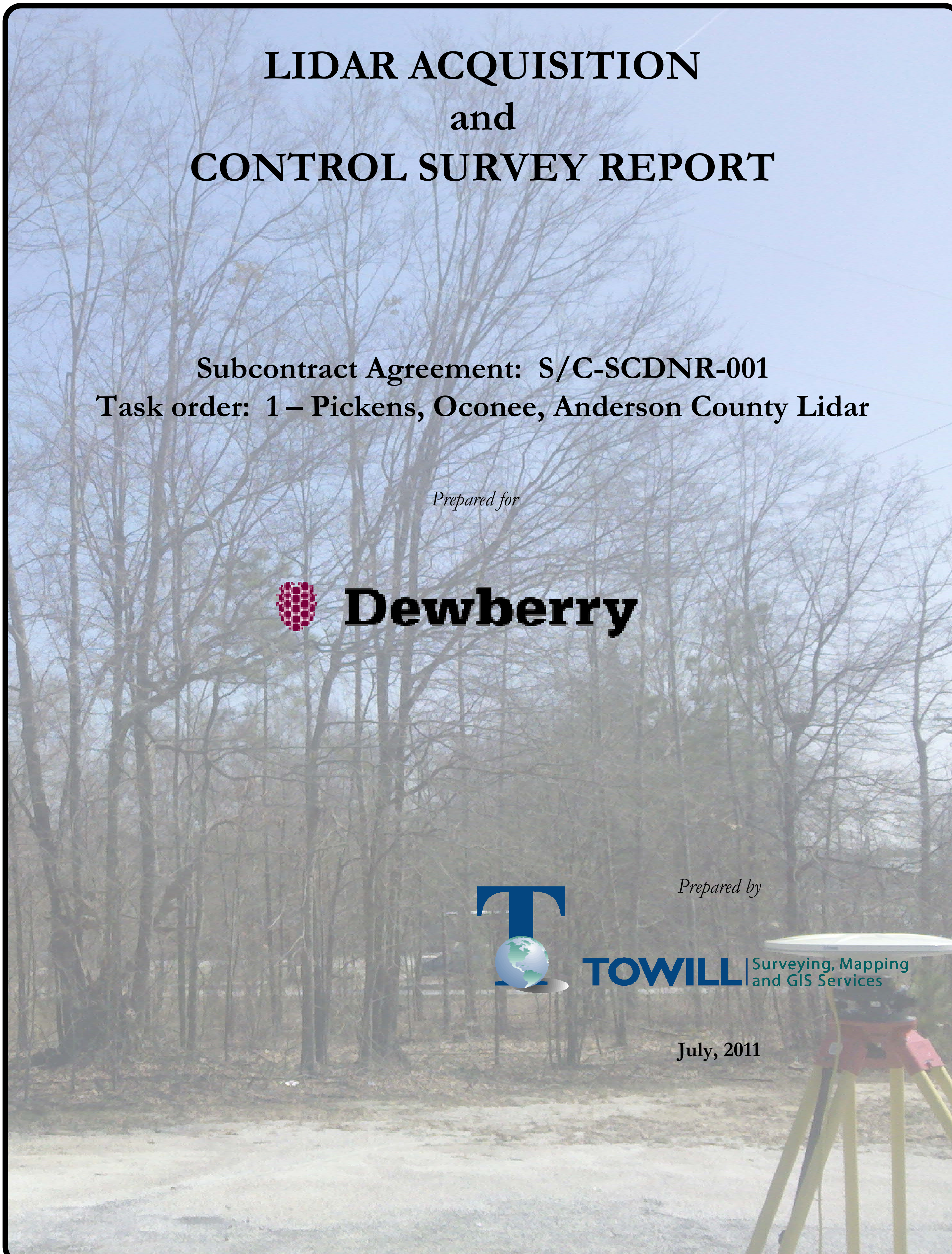

LIDAR ACQUISITION
and
CONTROL SURVEY REPORT

Subcontract Agreement: S/C-SCDNR-001
Task order: 1 – Pickens, Oconee, Anderson County Lidar

Prepared for

Dewberry

Prepared by

TOWILL | Surveying, Mapping and GIS Services

July, 2011

EXECUTIVE SUMMARY

Under contract with Dewberry and Davis (Dewberry), Towill acquired Lidar data (nominal point spacing of 1.0 meters) within the 100-meter buffered boundary of Pickens, Oconee, and Anderson Counties, South Caroliina. The data were acquired in 15 missions over the course of 13 days in March, 2011.

As part of the campaign, a 3-dimensional primary survey network consisting of local South Carolina Geodetic Survey VRS and North Carolina CORS stations and a semi-permanent base station point was observed to establish the basis of control for the Lidar data. The selected horizontal and vertical datums upon which the Lidar data are processed are NAD83(NSRS2007); epoch of 2007.0 and the North American Vertical Datum of 1988 (NAVD88) as realized by the reported coordinates and ellipsoid heights of the VRS and CORS and the application of GEOID09. This primary network satisfied U.S. Federal Geodetic Control Subcommittee (FGCS) standards for Order B geodetic GPS surveys (8mm + 1 part per million).

In addition, 40 check points and 6 existing NGS bench marks were surveyed to demonstrate the absolute accuracy of the Lidar data. The root-meant-square (RMS) of the differences between the check point surveyed elevations and the Lidar-derived surface model was 0.064 meters (0.21 foot).

Rigorous Lidar sensor calibration and quality control procedures were applied during the course of the campaign. Calibration passes were flown at the beginning and end of each mission and analyzed to verify the performance of the sensor and to make small adjustments to the final processing parameters.

In summary, all of the project's geodetic surveying and mapping goals were achieved. This report provides detailed documentation of all aspects of the work.

Towill, Inc.

Keith Kirkby
Geodetic Engineer
July, 2011

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1. Introduction

This document provides a comprehensive overview of the Lidar acquisition campaign to acquire Lidar data of Pickens, Oconee, and Anderson Counties, South Carolina. The report describes the field survey associated with establishing base stations to support the airborne GPS (AGPS) component of the campaign, Lidar system calibration, Lidar data post-processing, and QA/QC of the data.

The Lidar acquisition was completed in a total of 15 separate flight missions between March 13th and March 25th, 2011 inclusive. Flight operations were staged out of the Anderson Regional Airport located in Anderson, South Carolina.

All data acquisition field work, data post-processing and quality analysis was completed by Towill personnel. The components of the campaign include:

• Establishing and surveying AGPS base stations, control, and check points;
• Verifying Lidar system calibration and post-processing parameters;
• Airborne GPS (AGPS) and IMU data post-processing;
• Pre and post-mission control surface overflight data analysis;
• Surface check point survey analysis;

1.1 Points of Contact

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2. Control Survey and Datums

2.1 Introduction

The underlying basis of the Lidar survey campaign are the published coordinate and elevation values of the South Carolina Geodetic Survey (SCGS) active VRS network stations. The coordinates and elevations were provided to Towill directly from the SCGS.

Towill observed a primary geodetic network consisting of the local VRS stations and a base station point established at the airport of operations to support the airborne GPS component of the Lidar campaign thereby ensuring a consistent horizontal and vertical datum realization across the entire extent of the project area (see Figure 1). The network consists of 4 SCVRS, 1 North Carolina CORS, and 1 designated GPS base station.

Independent CORS and VRS observation data were downloaded in the days leading up to the start of the acquisition campaign to establish the relative baseline observations between the stations. The remaining baselines were observed using the data from the base station occupations during acquisition and additional VRS data from those respective days.

Final coordinates and elevations of the base station locations were established via a 3-dimensional network adjustment constrained to the published horizontal coordinates and ellipsoid heights of the SCVRS (as described in section 2.5, below).

In addition, 40 check points and 6 existing NGS bench marks were surveyed during the Lidar acquisition. These locations were surveyed with respect to the operating base stations and nearby VRS and base stations.

2.2 Project Survey Datums

The horizontal datum for this project is NAD83(NSRS2007); epoch of 2007.0. The datum is realized by the horizontal coordinates reported by the South Carolina Geodetic Survey of the VRS stations and the published coordinates of the North Carolina CORS (see Table 2).

The vertical datum for this project is NAVD88. The datum is realized by the ellipsoid heights of the same VRS and CORS stations reported from SCGS and the application of the geoid model GEOID09.

2.3 Field Equipment and Procedures

All GPS observations were accomplished using Trimble Navigation R7 dual frequency GPS receivers and accompanying Trimble Zephyr Geodetic antennae. Relative static surveying techniques were used for all baseline observations. Instrument heights were measured twice in units of feet and meters and the values reduced and compared in the field prior to leaving each station.

In general, base station data were logged for the duration of the acquisition on any given day (typically 4 to 12 hours) and check point data were logged for a minimum of 30 minutes and as much as 90 minutes depending on proximity to operating base stations and/or VRS station.

2.4 Primary Survey Network and Adjustment

Observed relative GPS baselines were processed in Trimble Business Center. All processed observations consist of quasi-independent baselines (i.e. in accordance with the "*n*-1 baselines" rule where n = number of receivers in a given 'session'). The International GPS Service for Geodynamics (IGS) rapid precise orbits (igr) were used in the processing of all baseline vectors. The 'igr' orbits are published with a latency of approximately 30 hours. These orbits are globally accurate to within ~5cm and are particularly important when processing long baselines.

The absolute horizontal and vertical GPS loop misclosures for the primary network are presented in Table 1. The spatial misclosures in parts per million (ppm) are also listed. All loops comprise quasi-independent baselines from at least two 'sessions'.

The primary survey network, consisting of 6 points and 11 baselines, was designed to provide a basis for the Lidar control (i.e. AGPS base stations) and establishing additional quality control points for this project. A minimally constrained adjustment was executed to verify the internal integrity of the network, establish *a priori* weights for the GPS observations, and judge the absolute fit of the constraints.

The GPS baselines vector components were adjusted using Microsearch™ GEOLAB 2001 (version 2001.9.20.0). *A priori* weights for the observations were based on the scaled variance–covariance sub–matrices estimated by the Trimble Business Center software. In the resulting adjustment, the estimated variance factor ($\hat{\sigma}_o^2 = 1.003$) passed the χ^2–test indicating appropriate *a priori* estimates of the accuracy of the GPS baseline vectors. None of the 33 vector component residuals or associated standardized residuals were flagged for possible rejection under the τ-max test at the 95 percent level of confidence. The relative horizontal accuracy of the network can be assessed by reviewing the relative 95 percent confidence regions (ellipses) of the adjustment. All station pairings meet the Federal Geodetic Control Subcommittee (FGCS) relative positioning standard for Order B surveys (8mm + 1ppm).

In a second, fully constrained adjustment, the NAD83 latitude, longitude and ellipsoid height of the 4 SCVRS stations and 1 NC CORS were held as *weighted* constraints (see Table 2). The estimated variance factor ($\hat{\sigma}_o^2 = 0.8691$) indicates that the network is not being unduly distorted by the imposition of the constraints and is maintaining its internal integrity. The adjustment yields coordinates on the NAD83 and orthometric elevations relative to NAVD88 via the GEOID09 geoidal model. These coordinates serve as the control for the post-processing of all Lidar data and subsequent products derived from the Lidar data. See Appendix II for the primary constrained adjustment listing.

A third and final adjustment was run to incorporate the check point and bench mark observations. The adjusted coordinate values from the fully constrained adjustment were held as *fixed* constraints to derive final coordinate and elevation values of the check points. Appendix I tabulates the final adjusted coordinate and elevation values of all surveyed points.

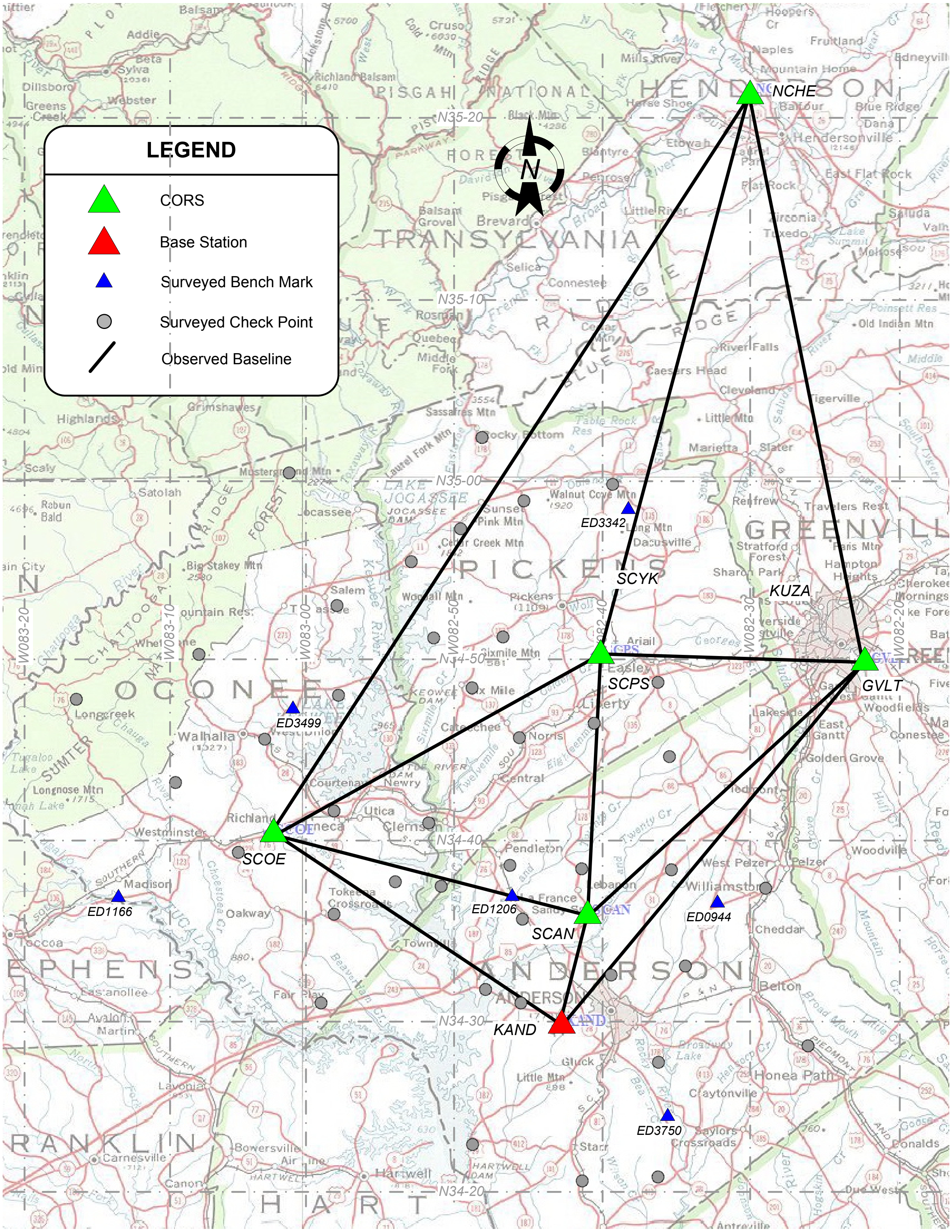


Figure 1. Primary Survey Network Diagram

Table 1.

Absolute Loop Misclosures

Loop	Horizontal Misclosure [mm]	Vertical Misclosure [mm]	Loop Length [meters]	PPM
NCHE - GVLT - SCPS - NCHE	3	38	146706	0.26
SCPS - GVLT - SCAN - SCPS	4	65	92699	0.70
GVLT - KAND - SCAN - GVLT	6	32	98724	0.33
SCPS - SCAN - KAND - SCOE - SCPS	4	11	112180	0.11
NCHE - SCPS - SCOE - NCHE	4	39	188162	0.21

Table 2.

Primary Network Adjustment Weighted Constraints

Horizontal Datum: NAD83(NSRS2007)
Epoch: 2007.0
Linear Unit: International Meter

Point	Source	Latitude				Longitude				Ellipsoid	Adjustment Residua	
			º	'	"		º	'	"	Height	Lat.	Lng.
SCPS	SCGS	N	34	50	13.06816	W	82	40	15.72001	300.783	-0.002	0.004
SCAN	SCGS	N	34	35	48.45792	W	82	41	00.47566	229.892	-0.012	0.000
SCOE	SCGS	N	34	40	19.81527	W	83	02	15.01590	232.457	0.004	0.007
GVLT	SCGS	N	34	49	46.94102	W	82	22	15.37249	250.260	0.003	-0.007
NCHE	USGS	N	35	21	21.89186	W	82	30	03.99744	654.460	0.006	-0.004

Notes: Ellipsoid heights are to the Antenna Reference Point (ARP) of the VRS and CORS

3. Lidar Data Acquisition and Processing

3.1 Introduction

Following is an overview description of the procedures applied in this Lidar campaign from acquisition to final processed data. Figure 2 illustrates the general flow of the data through the multiple processes required to generate the Lidar point cloud in the 'LAS' version 1.2 format.

3.2 Data Acquisition

The Lidar data acquisition was completed within 15 lifts, or missions. All missions originated and/or terminated at the Anderson Regional Airport. A GPS base stations was operating at the airport during every lift. The South Carolina Geodetic Survey was contacted prior to the start of the Lidar acquisition to arrange for 1 Hertz data logging of several of the VRS stations included in the primary survey network. The data from these stations were downloaded and applied in the post-processing of the kinematic AGPS data.

Figure 3 illustrates the general flight plan. The target flying height of the flight lines was 1,500 meters above mean terrain. Figure 4 summarizes the general acquisition parameters applied project-wide.

Kinematic GPS and Inertial Measurement Unit (IMU) data were acquired by the Applanix POS Inertial Navigation System during the missions. The post-processed POS data results in a 200 Hertz, 6-parameter aircraft trajectory (x, y, z, roll, pitch, yaw).

The Airborne GPS (AGPS) and IMU data were processed immediately following each mission. In addition, a sample of the Lidar data was post-processed at the completion of the missions and the data was reviewed to ensure correct system operation and data coverage.

3.3 Airborne GPS Processing

The quality of the Airborne GPS data represents a significant component of the overall error budget with respect to the accuracy of the Lidar data. It is important to exercise vigilance in the validation of the integrity of the AGPS solution. This effort begins prior to acquisition with careful mission planning to identify periods of the day during which satellite availability and/or geometry may not be conducive to an acceptable solution. Data acquisition is generally scheduled around these periods (other constraints such as airspace restrictions, daylight conditions and weather notwithstanding).

The kinematic AGPS data was post-processed using Novatel, Inc.'s Grafnav version 8.30 software, the *de facto* kinematic GPS post-processing package in the airborne remote sensing industry. Data is post-processed forward and backward in time exploiting the software's robust Kinematic Ambiguity Resolution and Multi-Baseline features to mitigate ambiguity drift and minimize poor data as a result of satellite loss of lock (see example in Figure 5). Figure 6 illustrates the comparison of the forward and reverse solutions of the post-processed GPS data for one of the missions. The plot exhibits a very satisfactory solution and it represents the standard results achieved in the post-processing of all missions.

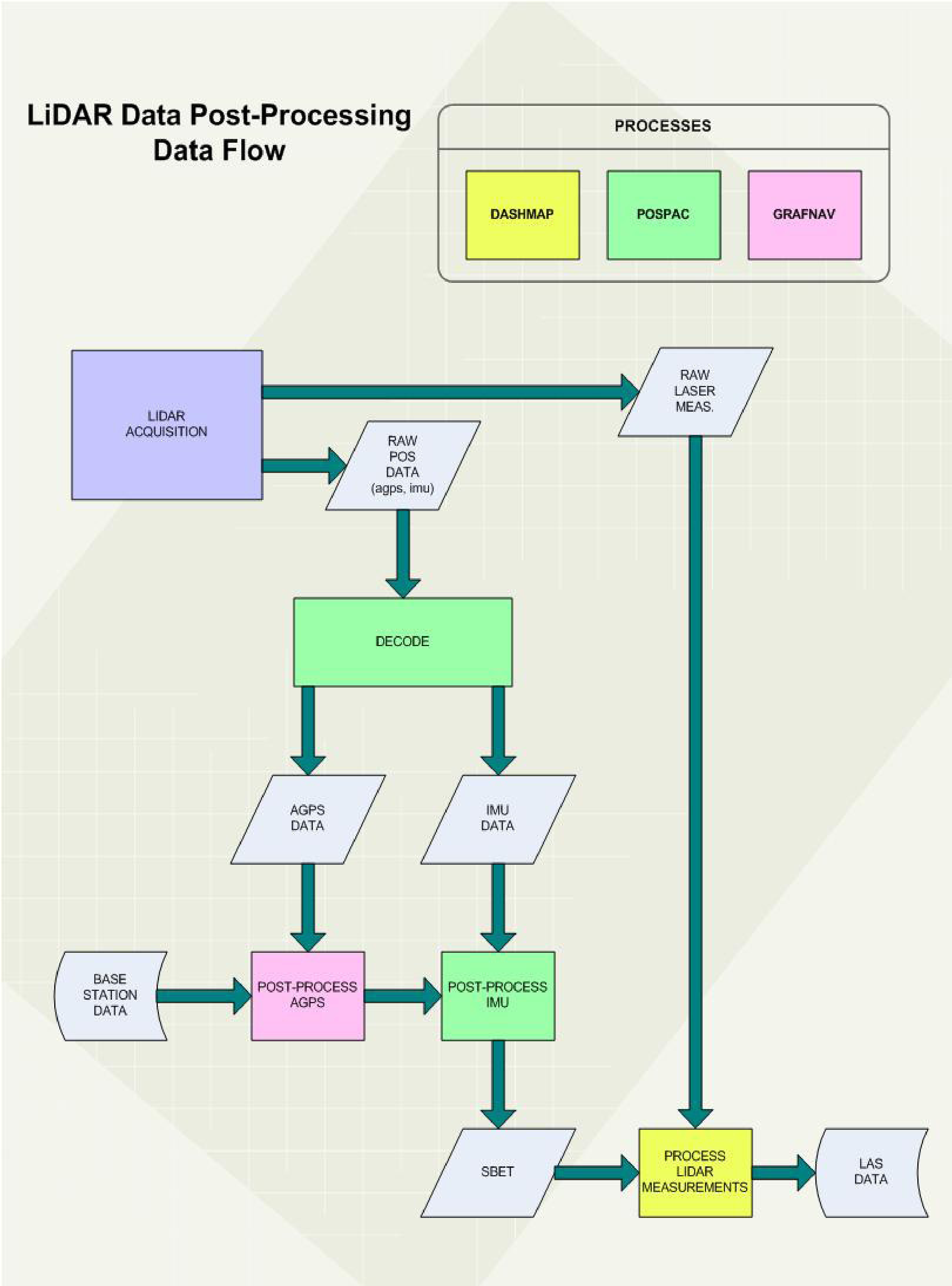


Figure 2. Lidar Data and Post-Processing Data Flow

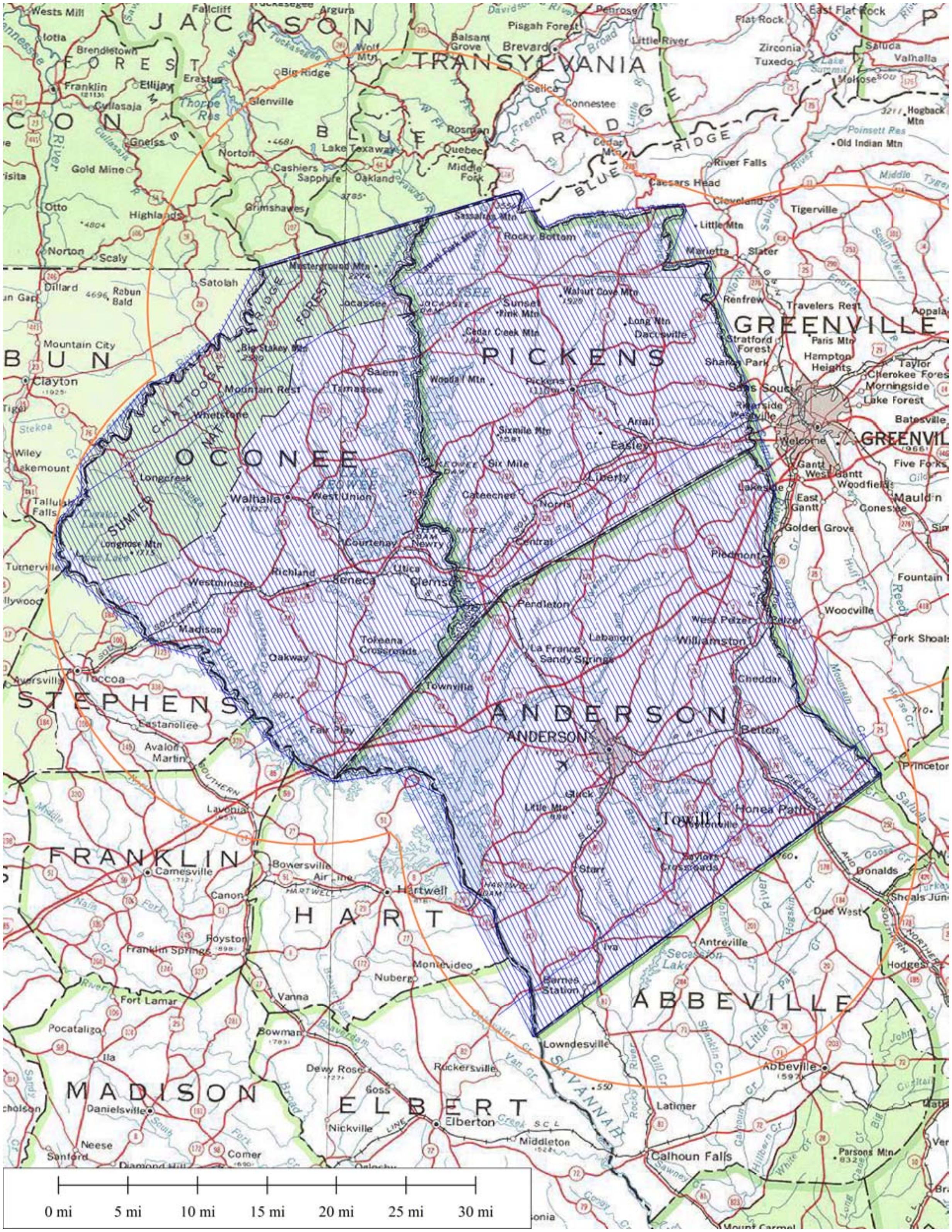


Figure 3. Lidar Flight Layout

Flight Profile	
Altitude (m AGL)	1500
Unaided NOHD (m)	163
Pass Heading (deg)	332
Overlap (%)	50
Speed (kts)	150
Turn Time (min)	5
Passes	154
Pass Spacing (m)	545.36
Min DEM Altitude	0
Max DEM Altitude	0

LIDAR Settings	
System PRF (kHz)	70
Scan Freq (Hz)	38
Scan Angle +/-	20
Scan Offset	0
Desired Res (m)	1.097
CT Res	1.186
DT Res	1.015
PPM^2	0.83
Scan Cutoff (deg)	0.02
Swath (m)	1090.72

Figure 4. General Project Lidar Acquisition Parameters

3.4 IMU Processing and Best Estimated Trajectory

The post-processed AGPS trajectory is combined with the raw 200 Hertz IMU observations in a loosely-coupled Kalman filter-based processing algorithm to produce the final high-frequency Smoothed Best Estimated Trajectory (SBET). Applanix's POSPac software, version 4.4, is employed in this process.

Given a good quality AGPS solution and clean, gap-free IMU data, this process generally runs very smoothly. The field procedure includes several minutes of static GPS and IMU data collection prior to departure to allow sufficient time for the IMU to acquire a fine local level. The data is acquired in duplicate in real-time to ensure a high-quality record set. The IMU processing was clean and consistent for all missions during this campaign.

The final, high-frequency SBET is the source of absolute geo-referencing of the post-processed Lidar point cloud. The SBET is introduced into the final phase of the Lidar data processing.

3.5 LIDAR Point Cloud Processing

Final Lidar data processing is accomplished using Optech's DASHMap software, version 5.20. The decoded raw laser observations (ranges, intensities, and mirror angles) and the final processed SBET are combined within DASHMap to compute the final 3-dimensional coordinates of the return(s) of each laser pulse.

Based on the daily calibration analysis, described in the following section of this report, several of the Lidar parameters are slightly adjusted within DASHMap on a mission-by-mission basis.

The calibrated data is output in LAS format, version 1.2 with "adjusted" GPS times (defined as GPS seconds of the week minus 1 x 10^{-9} seconds).

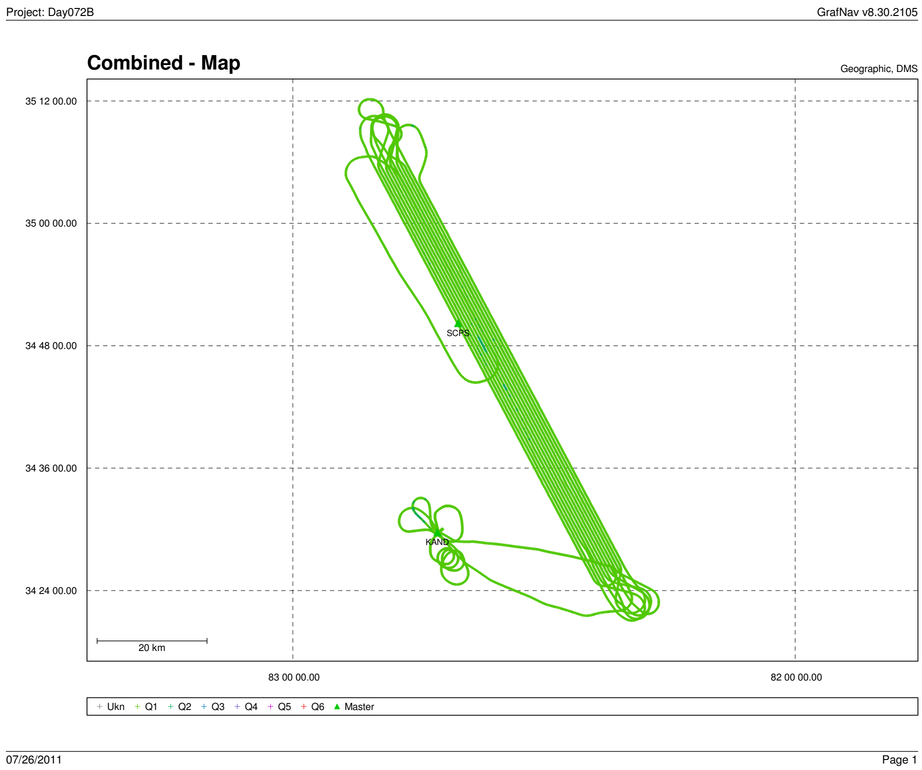


Figure 5. Post-Processed GrafNAV Solution - Lift 072B

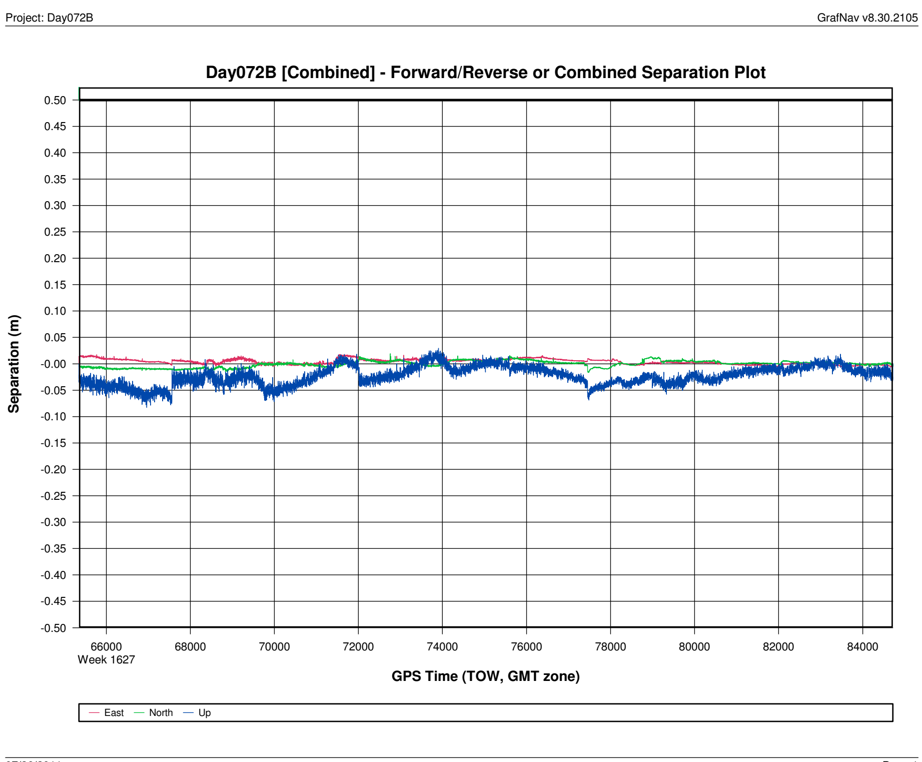


Figure 6. Forward vs. Reverse Post-Processed Solution - Lift 072B

4. LIDAR Calibration and QC

4.1 Introduction

The Optech Orion M200 Lidar system is subject to a regular maintenance and calibration schedule. The intent of periodic calibration is to monitor and validate components of the overall error budget including IMU boresight and performance, mirror angle readings and pulse gate timing. Several of these parameters can vary during and between missions due to changes in ambient meteorological conditions, different flying heights above ground, and different acquisition variables. As such, regular checks on the calibration were carried out during every mission.

4.2 Calibration Overflights

To assure that the LIDAR system is performing within specifications, on a mission-by-mission basis, a snapshot of data is captured over a known surface, most often one of the runways located at the airport of operations. The runway surface is surveyed by collecting hundreds of topographic points using a post-processed kinematic GPS procedure.

At the beginning and end of each mission, two passes are made in opposite directions at right angles to and over the surveyed runway (see Figure 7, below). On average, approximately 50,000 Lidar points are acquired over the runway surface per pass. The surveyed topographic points that define the "known" surface of the runway are used to develop a surface model and the Lidar points from each pass are draped over this model and residuals computed. The residuals from each pass are graphed versus distance along the runway to provide an effective vertical cross-section of the entire Lidar swath at a short moment in time.

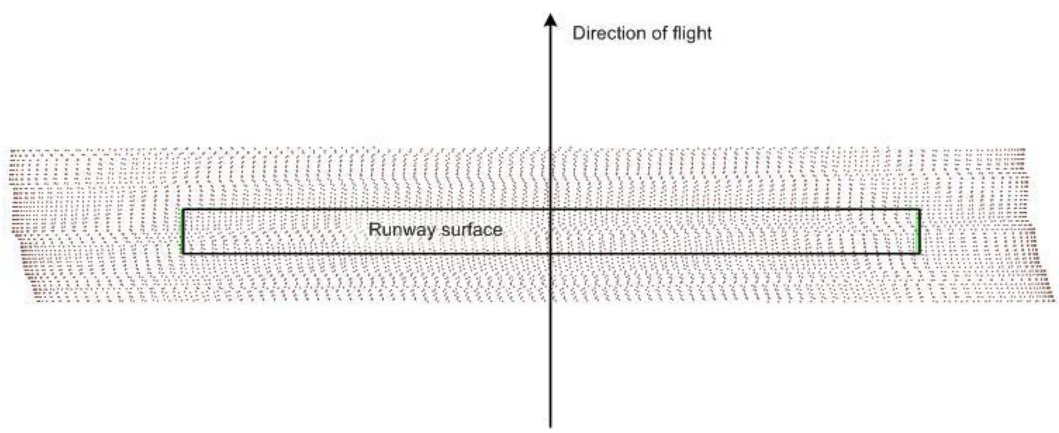


Figure 7. Example of a Calibration Overflight

The graphs from each pass are used to check that the mirror angle offset and scale, IMU solution roll and pitch bias, and elevation bias are within acceptable tolerances and to finely tune the general parameters on a mission-by-mission basis. This "snapshot" of the Lidar swath also ensures that the system is operating normally and that there are no anomalies contained in the data.

Figure 8 contains a plot of an unbiased runway overflight computed for each mission during the campaign. The following information may be obtained through careful examination of the graphs:

- The 99-percent noise band of the data is consistent at approximately 10 centimeters or less;
- There is no significant mirror scale error (characterized by a smile or frown);

- There is no significant roll error (characterized by a tilt in the noise band);
- There are no evident data anomalies;

Each plot is accompanied by the average residual and root mean square (RMS) of the residuals for the respective data set. Of the 7 data sets, the largest RMS is 10.3 centimeters, a representation of the combined stochastic noise and bias of the Lidar data prior to any vertical adjustment. The plots and statistics demonstrate that the system is working well within the system specifications.

4.3 Additional Calibration

The runway passes also serve to examine potential pitch and yaw biases that may be present in the data. These parameters are typically more stable over the course of the campaign and are therefore checked only peridoically during the acquisition period.

The pitch bias can be analyzed by examining data flown in opposite directions over an area with a sharp change in elevation, such as the edge of a building perpendicular to the direction of flight. A pitch bias will manifest itself as a "ghosting" of the edge of the building by virtue of the opposite direction passes.

In a similar fashion, a bias about the normal axis (yaw) can be detected simply by observing the intensity return images from orthogonal flight lines of obvious features such as the runway center line. A yaw bias will cause a difference in orientation yielding an obvious displacement of visible features.

The results of these various calibration and QC analyses are applied in the mission-by-mission processing of the data to ensure a consistent and accurate overall data set.

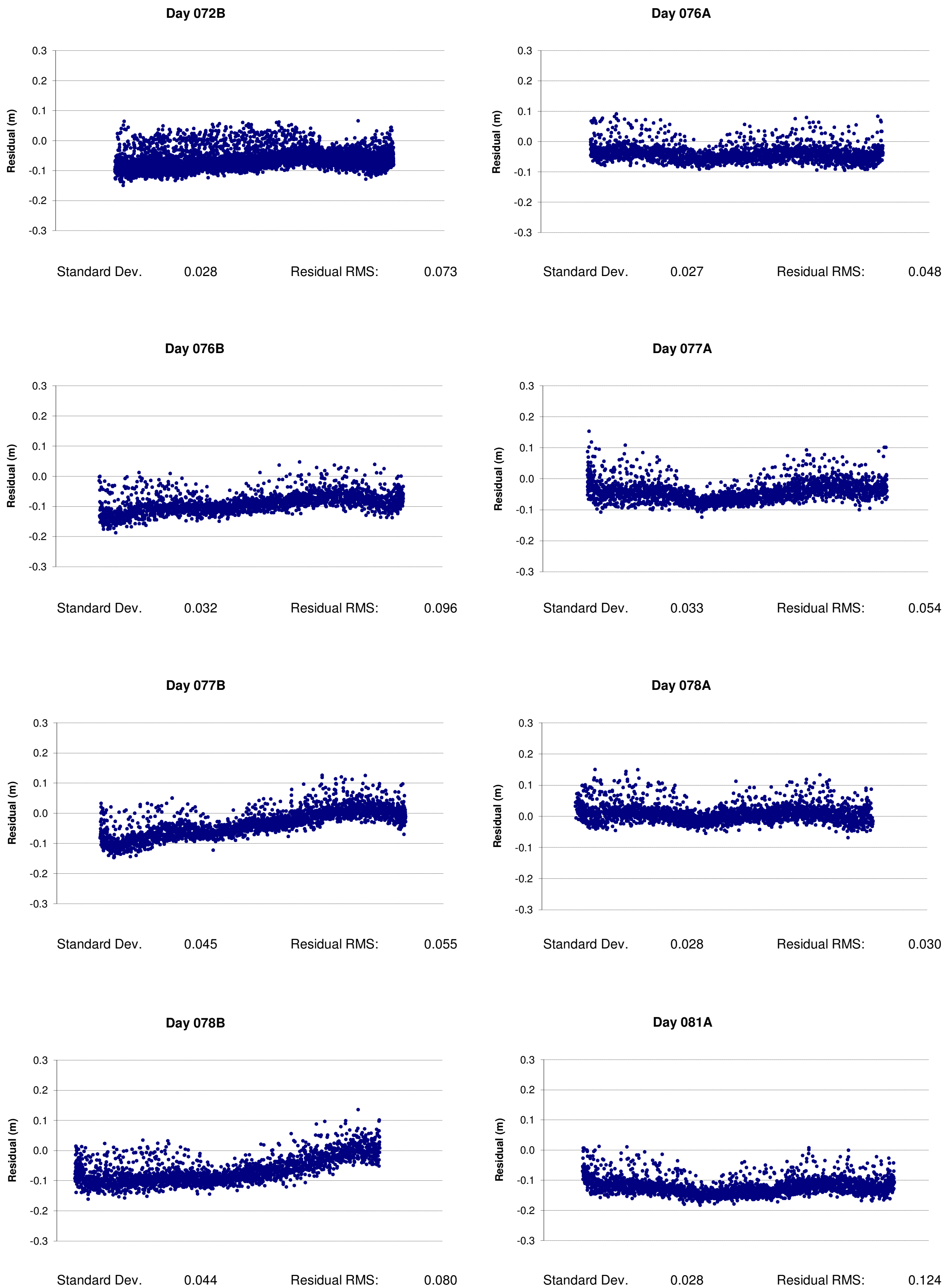
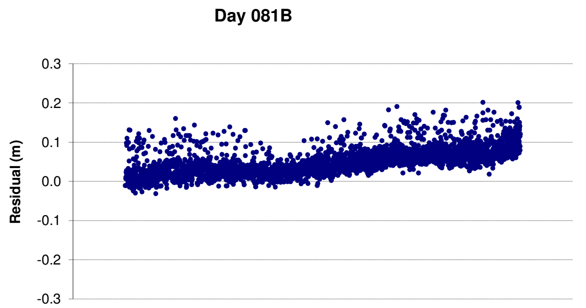
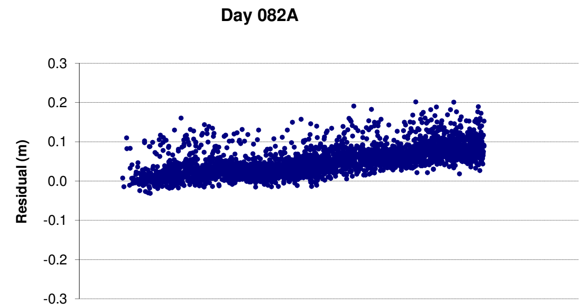


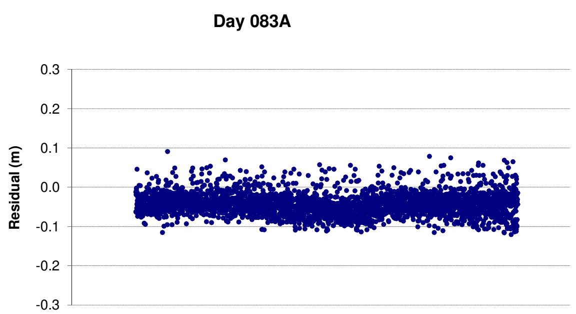
Figure 8. Mission-by-Mission Calibration Pass Analyses



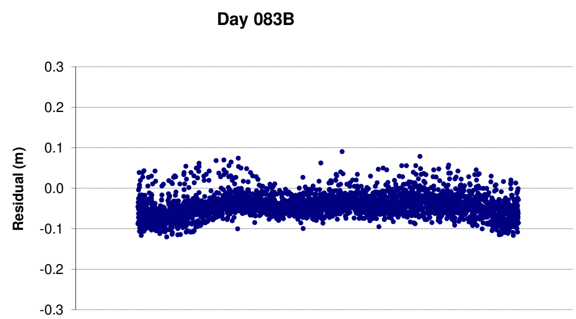
Avg. Residual: 0.035 Residual RMS: 0.062



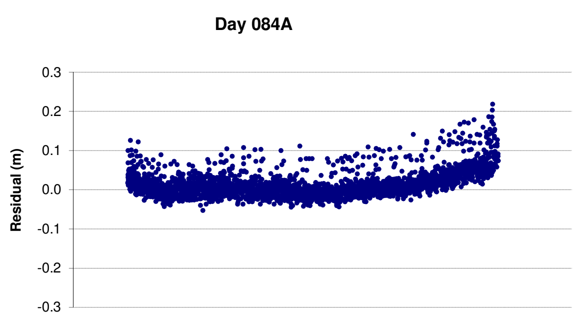
Avg. Residual: 0.028 Residual RMS: 0.059



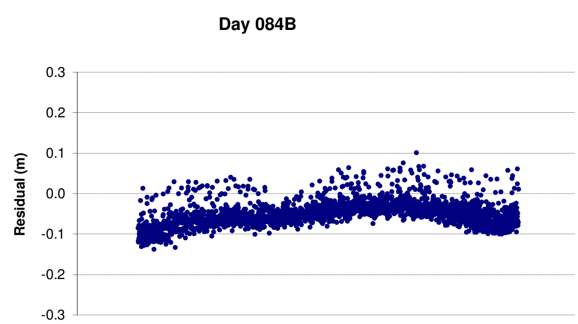
Avg. Residual: 0.027 Residual RMS: 0.040



Avg. Residual: 0.028 Residual RMS: 0.051



Avg. Residual: 0.033 Residual RMS: 0.037



Avg. Residual: 0.031 Residual RMS: 0.058

5. LIDAR Checkpoint Quality Assurance

In a further effort to validate the absolute vertical accuracy of the Lidar-derived elevations, 40 well-distributed check points were established and surveyed with respect to the AGPS base stations and VRS stations that were included in the primary survey network.

In the vicinity of each check point, the post-processed Lidar data is used to generate a surface model upon which the check point is draped. The residual elevation difference is computed at each check point location. Table 3 summarizes the results of the check point analysis in meters. The RMS of all check point differences is 0.064 meters (0.21 foot).

Table 3.

LIDAR CHECK POINT RESIDUALS

Orthometric Elevations (International Feet)

Point	Surveyed Elev.	LIDAR Elev.	Residual
ED1206	797.793	798.060	0.267
ED3342	1214.949	1215.310	0.361
ED3499	883.844	883.530	-0.314
ED3750	701.004	701.570	0.566
KAND	757.195	757.130	-0.065
TC01	957.049	957.110	0.061
TC02	1150.388	1150.510	0.122
TC03	1791.639	1791.730	0.091
TC04	1034.646	1034.900	0.254
TC05	1072.954	1073.520	0.566
TC06	881.871	882.120	0.249
TC07	1083.388	1083.650	0.262
TC08	967.402	967.540	0.138
TC09	1051.346	1051.400	0.054
TC10	2466.743	2466.640	-0.103
TC11	1667.062	1667.400	0.338
TC12	1712.263	1712.340	0.077
TC13	1014.209	1014.400	0.191
TC14	1016.646	1016.730	0.084
TC15	1046.878	1046.940	0.062
TC66	792.433	792.240	-0.193
TC67	777.927	778.030	0.103
TC68	921.852	922.080	0.228
TC69	1034.029	1034.140	0.111
TC70	894.348	894.210	-0.138
TC71	963.029	962.950	-0.079
TC72	821.169	821.040	-0.129
TC73	670.217	670.350	0.133
TC74	914.373	914.250	-0.123
TC75	878.250	878.420	0.170
TC76	671.518	671.160	-0.358
TC77	884.098	884.280	0.182
TC78	910.563	910.700	0.137
TC79	821.033	821.150	0.117
TC80	810.631	810.740	0.109
TC81	849.808	849.830	0.022
TC82	728.208	728.380	0.172
TC83	722.740	722.650	-0.090
TC84	669.682	669.880	0.198
TC85	818.144	817.950	-0.194
TC86	798.170	798.180	0.010
TC87	673.595	673.420	-0.175
TC88	853.486	853.600	0.114
TC89	849.906	849.730	-0.176
TC90	791.532	791.590	0.058
Average			**0.077**
Standard Deviation			**0.197**
RMS			**0.210**

Appendix I
Final Coordinates and Elevations

Dewberry and Davis

SCDNR - Pickens, Oconee, Anderson Counties Campaign Control Survey

FINAL ADJUSTED COORDINATES

Horizontal Datum: NAD83(NSRS2007)
Epoch: 2007.0
Linear Unit: International Meter

Point	Latitude				Longitude				Ellipsoid	Standard Deviation		
		º	'	"		º	'	"	Height	ρ	λ	h
Base Stations												
KAND	N	34	29	42.34781	W	82	42	45.15605	200.345	0.005	0.005	0.009
Lidar Check Points												
TC01	N	35	00	10.52261	W	82	39	10.63250	260.672	0.003	0.003	0.007
TC02	N	34	59	17.58088	W	82	45	12.57626	319.776	0.003	0.003	0.007
TC03	N	35	02	51.09587	W	82	48	12.52591	515.586	0.004	0.003	0.008
TC04	N	34	57	42.08142	W	82	49	46.76785	284.504	0.003	0.002	0.007
TC05	N	34	55	51.56148	W	82	53	11.65211	296.170	0.003	0.002	0.007
TC06	N	34	51	29.28686	W	82	51	35.82988	237.814	0.007	0.004	0.013
TC07	N	34	51	33.34039	W	82	46	50.12846	299.196	0.003	0.003	0.007
TC08	N	34	48	09.69043	W	82	58	10.58699	263.957	0.003	0.002	0.006
TC09	N	34	53	17.28557	W	82	58	22.46411	289.665	0.005	0.003	0.009
TC10	N	35	00	51.19849	W	83	01	42.64894	721.922	0.004	0.004	0.011
TC11	N	34	50	33.92833	W	83	07	56.04691	477.748	0.004	0.003	0.010
TC12	N	34	48	00.53035	W	83	16	25.14188	491.788	0.004	0.003	0.007
TC13	N	34	43	15.09403	W	83	09	36.90270	278.530	0.003	0.003	0.007
TC14	N	34	45	45.51225	W	83	03	22.96950	279.097	0.003	0.002	0.006
TC15	N	34	48	56.65335	W	82	36	04.66277	288.029	0.003	0.003	0.009
TC66	N	34	28	12.93263	W	82	25	37.59781	211.224	0.003	0.002	0.007
TC67	N	34	20	30.76928	W	82	41	18.94656	207.168	0.003	0.002	0.005
TC68	N	34	45	46.44216	W	82	45	40.52586	249.990	0.005	0.004	0.008
TC69	N	34	48	40.95960	W	82	48	54.56339	284.168	0.002	0.002	0.006
TC70	N	34	46	35.84301	W	82	40	29.42496	241.591	0.003	0.002	0.006
TC71	N	34	44	46.99847	W	82	35	16.78645	262.550	0.003	0.003	0.006
TC72	N	34	38	32.91566	W	82	46	23.93621	219.453	0.003	0.003	0.008
TC73	N	34	31	27.82752	W	82	48	02.12049	173.722	0.004	0.004	0.009
TC74	N	34	35	45.56956	W	82	58	33.21260	247.981	0.003	0.003	0.007
TC75	N	34	37	38.13963	W	82	54	16.27854	236.870	0.004	0.003	0.007
TC76	N	34	40	54.77249	W	82	51	58.20709	173.754	0.003	0.003	0.008
TC77	N	34	41	33.87358	W	82	58	34.65674	238.608	0.002	0.002	0.006
TC78	N	34	39	18.40943	W	83	05	12.14712	246.796	0.003	0.002	0.006
TC79	N	34	30	39.64098	W	82	59	23.48096	219.701	0.003	0.003	0.006
TC80	N	34	37	11.23501	W	82	28	38.32634	216.340	0.005	0.004	0.009
TC81	N	34	32	47.28095	W	82	34	14.10416	228.458	0.005	0.004	0.011

7/26/2011 Page 1 of 2

Point	Latitude				Longitude				Ellipsoid Height	Standard Deviation		
		º	'	"		º	'	"		ρ	λ	h
TC82	N	34	27	17.09452	W	82	36	00.98697	191.670	0.004	0.004	0.012
TC83	N	34	20	49.30431	W	82	36	07.51283	190.353	0.004	0.003	0.009
TC84	N	34	22	34.25252	W	82	48	55.33526	174.013	0.005	0.004	0.009
TC85	N	34	30	40.77149	W	82	45	29.99990	218.861	0.005	0.003	0.009
TC86	N	34	35	26.06462	W	82	45	34.11187	212.555	0.003	0.003	0.008
TC87	N	34	37	18.67416	W	82	51	11.55760	174.486	0.003	0.003	0.006
TC88	N	34	38	22.04457	W	82	41	22.81162	229.331	0.003	0.003	0.008
TC89	N	34	38	15.15589	W	82	35	05.73097	228.265	0.003	0.002	0.008
TC90	N	34	32	19.70924	W	82	39	26.33537	210.693	0.004	0.003	0.006
VRS / CORS Stations												
GVLT	N	34	49	46.94102	W	82	22	15.37249	250.260	-	-	-
NCHE	N	35	21	21.89186	W	82	30	03.99744	654.460	-	-	-
SCAN	N	34	35	48.45792	W	82	41	00.47566	229.892	-	-	-
SCOE	N	34	40	19.81527	W	83	02	15.01590	232.457	-	-	-
SCPS	N	34	50	13.06816	W	82	40	15.72001	300.783	-	-	-

NOTES:

- Ellipsoid heights of the VRS and CORS are to the antenna reference point (ARP)
- Shaded records indicate constrained values

Dewberry and Davis

SCDNR - Pickens, Oconee, Anderson Counties Campaign Control Survey

FINAL ADJUSTED COORDINATES

Horizontal Datum: NAD83(NSRS2007)
Epoch: 2007.0
Projection: U.S. State Plane South Carolina Zone
Vertical Datum: NAVD88
Geoid Model: GEOID09
Linear Unit: International Foot

Point	Northing (N)	Easting (E)	Elevation (H)	Standard Deviation		
				N	E	H
Base Stations						
KAND	972733.59	1484036.04	757.20	0.01	0.01	0.02
Lidar Check Points						
TC01	1157243.00	1504944.03	957.05	0.01	0.01	0.02
TC02	1152387.02	1474744.52	1150.39	0.01	0.01	0.02
TC03	1174230.45	1460149.53	1791.64	0.01	0.01	0.03
TC04	1143128.08	1451761.04	1034.65	0.01	0.01	0.02
TC05	1132262.05	1434505.72	1072.96	0.01	0.01	0.02
TC06	1105604.30	1442006.10	881.87	0.02	0.01	0.04
TC07	1105594.72	1465819.55	1083.39	0.01	0.01	0.02
TC08	1086037.84	1408728.51	967.40	0.01	0.01	0.02
TC09	1117149.84	1408331.86	1051.35	0.02	0.01	0.03
TC10	1163358.39	1392558.41	2466.75	0.01	0.01	0.04
TC11	1101586.27	1360215.55	1667.07	0.01	0.01	0.03
TC12	1086985.70	1317448.89	1712.27	0.01	0.01	0.02
TC13	1057404.54	1350883.32	1014.21	0.01	0.01	0.02
TC14	1071971.74	1382392.84	1016.65	0.01	0.01	0.02
TC15	1088875.08	1519358.68	1046.88	0.01	0.01	0.03
TC66	962389.57	1569901.91	792.43	0.01	0.01	0.02
TC67	916866.99	1490339.35	777.93	0.01	0.01	0.02
TC68	1070428.61	1471021.57	921.85	0.02	0.01	0.03
TC69	1088349.69	1455144.89	1034.03	0.01	0.01	0.02
TC70	1074990.86	1497054.75	894.35	0.01	0.01	0.02
TC71	1063576.46	1522962.35	963.03	0.01	0.01	0.02

Point	Northing (N)	Easting (E)	Elevation (H)	Standard Deviation N	Standard Deviation E	Standard Deviation H
TC72	1026669.33	1466648.29	821.17	0.01	0.01	0.03
TC73	983845.46	1457697.56	670.22	0.01	0.01	0.03
TC74	1010860.26	1405403.85	914.37	0.01	0.01	0.02
TC75	1021834.99	1427088.29	878.25	0.01	0.01	0.02
TC76	1041499.56	1438983.23	671.52	0.01	0.01	0.03
TC77	1046067.21	1405956.45	884.10	0.01	0.01	0.02
TC78	1033027.73	1372495.59	910.56	0.01	0.01	0.02
TC79	980020.66	1400607.01	821.03	0.01	0.01	0.02
TC80	1017012.77	1555550.92	810.63	0.02	0.01	0.03
TC81	990746.48	1527086.79	849.81	0.02	0.01	0.04
TC82	957510.22	1517630.94	728.21	0.01	0.01	0.04
TC83	918324.59	1516476.94	722.74	0.01	0.01	0.03
TC84	929995.51	1452298.63	669.68	0.02	0.01	0.03
TC85	978870.25	1470342.00	818.15	0.02	0.01	0.03
TC86	1007711.84	1470488.93	798.17	0.01	0.01	0.03
TC87	1019586.89	1442486.64	673.60	0.01	0.01	0.02
TC88	1025148.99	1491785.75	853.49	0.01	0.01	0.03
TC89	1023953.56	1523277.32	849.91	0.01	0.01	0.03
TC90	988367.49	1500929.04	791.53	0.01	0.01	0.02
VRS / CORS Stations						
GVLT	1092964.52	1588565.61	923.22	-	-	0.00
NCHE	1285099.58	1552284.65	2246.89	-	-	0.00
SCAN	1009594.26	1493398.83	855.02	-	-	0.00
SCOE	1038939.05	1387412.15	863.70	-	-	0.00
SCPS	1096931.15	1498552.94	1088.75	-	-	0.00

NOTES:

- Ellipsoid heights of the VRS and CORS are to the antenna reference point (ARP)
- Shaded records indicate constrained values

Appendix II
Fully Constrained Network Adjustment
Horizontal Datum: NAD83(NSRS2007), 2007.0
Vertical Datum: NAVD88

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0            GRS 80      UNITS: m,DMS  Page 0001
================================================================================
Fri May 6 10:00:02 2011

Input file:  \\tsclient\J\13639-101 SCDNR\Geolab\Tricounty_Bases_c.iob
Output file: \\tsclient\J\13639-101 SCDNR\Geolab\Tricounty_Bases_c.lst
Options file: C:\Program Files\Microsearch\GeoLab\default.gpj

Geoid File:  c:\ngs\geoid09\g2009u07pc.gsp
```

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
No. of Stations	6	Directions	0
Coord Parameters	18	Distances	0
Free Latitudes	6	Azimuths	0
Free Longitudes	6	Vertical Angles	0
Free Heights	6	Zenithal Angles	0
Fixed Coordinates	0	Angles	0
Astro. Latitudes	0	Heights	5
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	10
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	33
Rotation Pars.	0		
Translation Pars.	0		
	--------		--------
Total Parameters	18	Total Observations	48
Degrees of Freedom = 30			

SUMMARY OF SELECTED OPTIONS

OPTION	SELECTION
Computation Mode	Adjustment
Maximum Iterations	10
Convergence Criterion	0.00100
Residual Rejection Criterion	Tau Max
Confidence Region Types	1D 2D Station Relative
Relative Confidence Regions	Connected Only
Variance Factor (VF) Known	Yes
Scale Covariance Matrix With VF	No
Scale Residual Variances With VF	No
Force Convergence in Max Iters	No
Distances Contribute To Heights	No
Compute Full Inverse	Yes

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0            GRS 80      UNITS: m,DMS  Page 0002
================================================================================
    Optimize Band Width                |   Yes
    Generate Initial Coordinates       |   Yes
    Re-Transform Obs After 1st Pass    |   Yes
    Geoid Interpolation Method         |   Bi-Quadratic
-------------------------------------------------------------------------------
```

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0             GRS 80      UNITS: m,DMS  Page 0003
================================================================================
Adjusted PLH Coordinates:
                                LATITUDE         LONGITUDE  ELIP-HEIGHT
 CODE FFF STATION                STD DEV           STD DEV      STD DEV
 ---- --- ------------ ----------------- ----------------- ------------
 PLH  000 GVLT         N 34 49 46.941129 W 82 22 15.372748      250.251 m       0
                                   0.005             0.005        0.007
 PLH  000 KAND         N 34 29 42.347812 W 82 42 45.156054      200.345 m       0
                                   0.005             0.005        0.009
 PLH  000 NCHE         N 35 21 21.892055 W 82 30  3.997599      654.472 m       0
                                   0.005             0.005        0.007
 PLH  000 SCAN         N 34 35 48.457535 W 82 41  0.475655      229.888 m       0
                                   0.005             0.005        0.007
 PLH  000 SCOE         N 34 40 19.815403 W 83  2 15.015643      232.452 m       0
                                   0.005             0.005        0.006
 PLH  000 SCPS         N 34 50 13.068104 W 82 40 15.719857      300.789 m       0
                                   0.005             0.005        0.006
```

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0            GRS 80      UNITS: m,DMS  Page 0004
================================================================================
Adjusted PLO Coordinates:
                                LATITUDE         LONGITUDE     O-HEIGHT
 CODE FFF STATION                STD DEV           STD DEV      STD DEV
 ---- --- ------------ ----------------- ----------------- ------------
 PLO  000 GVLT         N 34 49 46.941129 W 82 22 15.372748      281.398 m       0
                                   0.005             0.005        0.007
 PLO  000 KAND         N 34 29 42.347812 W 82 42 45.156054      230.793 m       0
                                   0.005             0.005        0.009
 PLO  000 NCHE         N 35 21 21.892055 W 82 30  3.997599      684.851 m       0
                                   0.005             0.005        0.007
 PLO  000 SCAN         N 34 35 48.457535 W 82 41  0.475655      260.611 m       0
                                   0.005             0.005        0.007
 PLO  000 SCOE         N 34 40 19.815403 W 83  2 15.015643      263.257 m       0
                                   0.005             0.005        0.006
 PLO  000 SCPS         N 34 50 13.068104 W 82 40 15.719857      331.850 m       0
                                   0.005             0.005        0.006
```

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0             GRS 80      UNITS: m,DMS  Page 0005
================================================================================
Geoid Values:
 CODE     STATION         N/S DEFLECTION    E/W DEFLECTION   UNDULATION
 ----     ------------ ----------------- ----------------- ------------
 GEOI     GVLT            0  0      2.39    0  0      0.81      -31.147 m
 GEOI     KAND            0  0      5.61 -  0  0      0.65      -30.449 m
 GEOI     NCHE         -  0  0      4.39    0  0      6.77      -30.379 m
 GEOI     SCAN            0  0      3.99 -  0  0      0.45      -30.723 m
 GEOI     SCOE            0  0      1.64    0  0      1.86      -30.805 m
 GEOI     SCPS            0  0      1.37    0  0      0.62      -31.061 m
```

```
================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0            GRS 80      UNITS: m,DMS  Page 0006
================================================================================
Residuals (critical value = 3.214):
NOTE: Observation values shown are reduced to mark-to-mark.
                                                  OBSERVATION RESIDUAL  STD RES
TYPE AT           FROM         TO                     STD DEV  STD DEV      PPM
---- ------------ ------------ ------------ ----------------- -------- --------
ELAT SCPS                                   N 34 50 13.068160   -0.002   -0.330
                                                        0.010    0.005
ELON SCPS                                   W 82 40 15.720010    0.004    0.443
                                                        0.010    0.009
ELAT SCAN                                   N 34 35 48.457920   -0.012   -2.384
                                                        0.010    0.005
ELON SCAN                                   W 82 41  0.475660    0.000    0.016
                                                        0.010    0.009
ELAT SCOE                                   N 34 40 19.815270    0.004    0.816
                                                        0.010    0.005
ELON SCOE                                   W 83 02 15.015900    0.007    0.748
                                                        0.010    0.009
ELAT GVLT                                   N 34 49 46.941020    0.003    0.682
                                                        0.010    0.005
ELON GVLT                                   W 82 22 15.372490   -0.007   -0.750
                                                        0.010    0.009
ELAT NCHE                                   N 35 21 21.891860    0.006    1.299
                                                        0.010    0.005
ELON NCHE                                   W 82 30  3.997440   -0.004   -0.462
                                                        0.010    0.009
EHGT SCPS                                           300.78300    0.006    0.776
                                                        0.010    0.008
EHGT SCAN                                           229.89200   -0.004   -0.534
                                                        0.010    0.008
EHGT SCOE                                           232.45700   -0.005   -0.651
                                                        0.010    0.008
EHGT GVLT                                           250.26000   -0.009   -1.203
                                                        0.010    0.008
EHGT NCHE                                           654.46000    0.012    1.624
                                                        0.010    0.007
GROUP: 00000, Tri_County_Bases.asc
DXCT              SCAN         KAND               -1837.45330   -0.002   -0.616
                                                        0.004    0.003     0.14
DYCT              SCAN         KAND               -6660.81010    0.007    0.991
                                                        0.010    0.007     0.60
DZCT              SCAN         KAND               -9309.31210   -0.004   -0.852
                                                        0.007    0.005     0.34
GROUP: 00001, Tri_County_Bases.asc
DXCT              SCOE         KAND               30964.98360    0.002    1.185
                                                        0.003    0.002     0.06
DYCT              SCOE         KAND               -7339.60700   -0.007   -1.344
                                                        0.008    0.005     0.19
DZCT              SCOE         KAND              -16191.13990    0.004    1.235
                                                        0.006    0.003     0.11
GROUP: 00002, Tri_County_Bases.asc
DXCT              NCHE         GVLT               16143.33570    0.001    0.367
```

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================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0            GRS 80      UNITS: m,DMS  Page 0007
================================================================================
Residuals (critical value = 3.214):
NOTE: Observation values shown are reduced to mark-to-mark.
                                                  OBSERVATION RESIDUAL  STD RES
TYPE AT           FROM         TO                     STD DEV  STD DEV      PPM
---- ------------ ------------ ------------ ----------------- -------- --------
                                                        0.004    0.003     0.02
DYCT              NCHE         GVLT              -31392.49050    0.002    0.237
                                                        0.010    0.008     0.03
DZCT              NCHE         GVLT              -48017.48900   -0.002   -0.258
                                                        0.009    0.008     0.03
GROUP: 00003, Tri_County_Bases.asc
DXCT              SCPS         SCAN                 797.13790   -0.000   -0.116
                                                        0.005    0.004     0.02
DYCT              SCPS         SCAN              -15138.15890    0.006    0.614
                                                        0.011    0.009     0.21
DZCT              SCPS         SCAN              -21941.44480   -0.003   -0.357
                                                        0.010    0.009     0.12
GROUP: 00004, Tri_County_Bases.asc
DXCT              NCHE         SCPS              -11129.41980    0.001    0.150
                                                        0.005    0.003     0.01
DYCT              NCHE         SCPS              -34550.84560    0.000    0.033
                                                        0.009    0.007     0.00
DZCT              NCHE         SCPS              -47327.73670    0.004    0.727
                                                        0.008    0.006     0.07
GROUP: 00005, Tri_County_Bases.asc
DXCT              SCPS         SCOE              -32005.30390    0.001    0.229
                                                        0.005    0.004     0.02
DYCT              SCPS         SCOE              -14459.35220    0.009    1.274
                                                        0.009    0.007     0.24
DZCT              SCPS         SCOE              -15059.62210   -0.006   -0.952
                                                        0.008    0.006     0.16
GROUP: 00006, Tri_County_Bases.asc
DXCT              GVLT         SCPS              -27272.75000   -0.006   -1.036
                                                        0.007    0.006     0.22
DYCT              GVLT         SCPS               -3158.38460    0.028    2.529
                                                        0.012    0.011     1.02
DZCT              GVLT         SCPS                 689.77660   -0.018   -2.980
                                                        0.008    0.006     0.65
GROUP: 00007, Tri_County_Bases.asc
DXCT              NCHE         SCOE              -43134.72390    0.002    0.323
                                                        0.006    0.005     0.02
DYCT              NCHE         SCOE              -49010.16570   -0.023   -2.172
                                                        0.012    0.010     0.25
DZCT              NCHE         SCOE              -62387.38150    0.021    1.800
                                                        0.013    0.012     0.23
GROUP: 00008, Tri_County_Bases.asc
DXCT              SCOE         SCAN               32802.44400   -0.003   -0.939
                                                        0.005    0.004     0.10
DYCT              SCOE         SCAN                -678.82300    0.013    1.427
                                                        0.010    0.009     0.37
DZCT              SCOE         SCAN               -6881.81100   -0.009   -0.922
```

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================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0             GRS 80      UNITS: m,DMS  Page 0008
================================================================================
Residuals (critical value = 3.214):
NOTE: Observation values shown are reduced to mark-to-mark.
                                                  OBSERVATION RESIDUAL  STD RES
TYPE AT           FROM         TO                     STD DEV  STD DEV      PPM
---- ------------ ------------ ------------ ----------------- -------- --------
                                                        0.011    0.009     0.26
GROUP: 00009, Tri_County_Bases.asc
DXCT              SCAN         GVLT               26475.62130   -0.003   -0.787
                                                        0.005    0.003     0.07
DYCT              SCAN         GVLT               18296.49280    0.017    2.087
                                                        0.010    0.008     0.45
DZCT              SCAN         GVLT               21251.70790   -0.019   -2.109
                                                        0.010    0.009     0.48
GROUP: 00010, Tri_County_Bases.asc
DXCT              GVLT         KAND              -28313.06760   -0.006   -0.869
                                                        0.008    0.007     0.12
DYCT              GVLT         KAND              -24957.32650    0.013    0.646
                                                        0.022    0.021     0.27
DZCT              GVLT         KAND              -30560.99840   -0.007   -0.583
                                                        0.013    0.012     0.14
```

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================================================================================
           SC Base Station Survey - Tricounty; NAD83 VRS Coordinates
Microsearch GeoLab, V2001.9.20.0             GRS 80      UNITS: m,DMS  Page 0009
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                               |:::|   |:::|:::|
F                              *:::|   |:::|:::*
r                              |:::|   |:::|:::|
e                             *|:::|   |:::|:::|*
q  0.2 -                       |:::|---|:::|:::|---
u                            * |:::|:::|:::|:::|:*:|
e                              |:::|:::|:::|:::|:::|
n                              |:::|:::|:::|:::|:::|
c                           *  |:::|:::|:::|:::|::*|
y                              |:::|:::|:::|:::|:::|
                           *   |:::|:::|:::|:::|:::*
                    ---     ---|:::|:::|:::|:::|:::|
   0.1 -           |:::|  *|:::|:::|:::|:::|:::|:::|*
                   |:::| * |:::|:::|:::|:::|:::|:::| *
                   |:::|   |:::|:::|:::|:::|:::|:::|
                   |:::|*  |:::|:::|:::|:::|:::|:::|--*
                   |:::*   |:::|:::|:::|:::|:::|:::|:::*
                   |::*|   |:::|:::|:::|:::|:::|:::|:::|*
                ---|:*:|   |:::|:::|:::|:::|:::|:::|:::|-*- ---
               |::***::|   |:::|:::|:::|:::|:::|:::|:::|::***::|
   +---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
      -4      -3      -2      -1       0       1       2       3       4
               Histogram of Standardized Residuals (48 residuals)
```

```
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 -----------------------------------------------------------------------------
|                                                                             |
|                   S T A T I S T I C S     S U M M A R Y                     |
|                                                                             |
 -----------------------------------------------------------------------------
|                                     |                                       |
|     Residual Critical Value Type    |              Tau Max                  |
|     Residual Critical Value         |               3.2141                  |
|     Number of Flagged Residuals     |                    0                  |
|     Convergence Criterion           |               0.0010                  |
|     Final Iteration Counter Value   |                    2                  |
|     Confidence Level Used           |              95.0000                  |
|     Estimated Variance Factor       |               0.8691                  |
|     Number of Degrees of Freedom    |                   30                  |
|                                     |                                       |
 -----------------------------------------------------------------------------
|                                                                             |
|                  Chi-Square Test on the Variance Factor:                    |
|                                                                             |
|                   5.5501e-01  <  1.0000  <  1.5529e+00  ?                   |
|                                                                             |
|                              THE TEST PASSES                                |
|                                                                             |
 -----------------------------------------------------------------------------

 -----------------------------------------------------------------------------
|                                                                             |
| NOTE:  All confidence regions were computed using the following factors:    |
|        ----------------------------------------------------------------     |
|        Variance factor used      =          1.0000                          |
|        1-D expansion factor      =          1.9600                          |
|        2-D expansion factor      =          2.4477                          |
|                                                                             |
|        Note that, for relative confidence regions, precisions are           |
|        computed from the ratio of the major semi-axis and the spatial       |
|        distance between the two stations.                                   |
|                                                                             |
 -----------------------------------------------------------------------------
```

```
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2-D and 1-D Station Confidence Regions (95.000 and 95.000 percent):
STATION            MAJOR SEMI-AXIS  AZ     MINOR SEMI-AXIS            VERTICAL
------------ --------------------- --- ------------------- --------------------
GVLT                         0.012 163               0.012                0.013
KAND                         0.013  74               0.012                0.017
NCHE                         0.012  25               0.012                0.013
SCAN                         0.012  39               0.012                0.013
SCOE                         0.012  44               0.012                0.013
SCPS                         0.012  28               0.012                0.012
```

```
================================================================================
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================================================================================
2-D and 1-D Relative Station Confidence Regions (95.000 and 95.000 percent):
FROM         TO           MAJ-SEMI  AZ MIN-SEMI  VERTICAL     DISTANCE      PPM
------------ ------------ -------- --- -------- --------- ------------ --------
GVLT         KAND            0.008  55    0.008     0.018    48564.109     0.17
GVLT         NCHE            0.008  16    0.007     0.015    59596.771     0.14
GVLT         SCAN            0.008 178    0.007     0.015    38566.241     0.20
GVLT         SCPS            0.008 169    0.007     0.014    27463.689     0.28
KAND         SCAN            0.007  81    0.005     0.016    11593.356     0.57
KAND         SCOE            0.006  82    0.004     0.015    35705.086     0.17
NCHE         SCOE            0.009  24    0.008     0.015    90303.851     0.10
NCHE         SCPS            0.009  29    0.007     0.014    59645.110     0.14
SCAN         SCOE            0.006  76    0.005     0.013    33523.430     0.19
SCAN         SCPS            0.008  27    0.007     0.014    26668.826     0.28
SCOE         SCPS            0.008  34    0.006     0.013    38212.621     0.21
```