Field Test Report

for

CHARTS

Contract Number: DACW42-01-C-0023

Prepared For:
Joint Airborne Lidar Bathymetry
Technical Center
of Expertise

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Revision History

Revision	Date	Description
A.0	Sep 03	Preliminary draft for early distribution and comments
A.1	Oct 03	Added field test results
A.2	Nov 03	Added field test results
A.3	Dec 03	Added field test results
A.4	Mar 04	Added field test results
A	May 04	Release

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1 OVERVIEW

This report describes the results of the CHARTS system field tests conducted from July to September 2003. The field tests confirmed that the CHARTS system met the following acceptance test criteria:

Hydrographic Mode

- Depth penetration
  - Maximum depth
  - Minimum depth
- Sounding vertical accuracy (depth measurement accuracy)
- Sounding and elevation positional accuracy
- Hazard detection

Topographic Mode

- Elevation accuracy and topographic vertical accuracy
  - Elevation (1 kHz)
  - Topographic (9 kHz)
- Horizontal position accuracy
  - Elevation (1 kHz)
  - Topographic (9 kHz)

- Digital camera.

In July 2003, the CHARTS SHOALS-1000T system was sent to the field test site in Fort Lauderdale, Florida. Before shipment, it was installed on a Dynamic Aviation Beechcraft King Air 90 at Buttonville Airport, Toronto. During the field trials in Florida, the system was removed from the King Air 90 on August 22, 2003 and installed on a Kenn Borek Air Ltd. Beechcraft King Air 200 on August 24,2003. The field trials were completed successfully in September 2003.

The Naval Oceanographic Office (NAVO) conducted extensive ground truthing of the Navy test area before the field trials commenced. In April 2003 the *USNS Mary Sears* and a Hydrographic Survey Launch (HSL-15) surveyed the SFTF Test Area for three weeks collecting EM-1002, EM-3000 and sidescan sonar data. The *Mary Sears* (T-AGS 65) is the sixth ship in the *Pathfinder* T-AGS 60 class. Crewed by civilian mariners, the ship is operated for the Oceanographer of the Navy by the Military Sealift Command (MSC). In June a NAVO Dive Team investigated dozens of specific locations/targets and collected diver-assisted lead-line depths and pressure gauge depths. Thus the sonar data was verified by non-acoustic measurements.

Tide measurements were also begun several months before the trials so that consistency could be confirmed. Two bottom-mounted tide gauges were established at Dania Beach pier on April 1. One reporting tide gauge was established at Port Everglades Inlet. A NOAA gauge at Virginia Key (20 miles south) was used for barometric pressure corrections of bottom mounted gauges.

The final piece of the ground truth efforts was the characterization of the water properties. Teams from the Naval Research Labs (NRL), Stennis and Cornell University measured water column optical properties during the first two and a half weeks of the test period.

Appendix A summarizes major events during the test period of July to September 2003. Appendix B summarizes details about the flights during the field trials. Appendix C provides additional detail on the vertical depth accuracy results, and Appendix D provides the map coordinates of the control areas.

2 FIELD TEST OBJECTIVES

The objectives of the field tests were to:

- Confirm that the CHARTS airborne system operates properly after installation in the aircraft and during flight
- Calibrate the system using real flight data
- Confirm the system performance specifications
- Assess some of the operating limits of the system, to the extent permitted by time and environmental conditions
- Acquire sufficient airborne data to be able to evaluate the software algorithms used in the airborne system and in ground-based data processing
- Assess the ability of the system to detect 2×2×2 m targets at various depths and water clarities.

The five main performance tests evaluated during the field tests were:

Depth penetration capability	Kd > 3
Depth measurement accuracy	IHO Order 1
Underwater horizontal position accuracy	IHO Order 1
Topographic elevation accuracy	1/9 kHz: ±0.5 m, 95% confidence
Topographic elevation positional accuracy	1 kHz: 1% of altitude, 95%
Hazard detection	2-m cube
Digital camera performance.	

The initial installation and flights confirmed that CHARTS functioned correctly while airborne, and familiarized the system operators and pilots with using the system and flying the required flightlines.

Optech also carried out additional data-gathering flights during the field tests to simulate operational surveys.

3 RESOURCES AND LOGISTICS

The following groups and institutions supported the field tests:

Optech Incorporated

- Provided overall management of the CHARTS system field tests
- Responsible for operation and maintenance of the CHARTS airborne system and ground-based data processing system
- Responsible for flight planning
- Analyzed airborne data to validate performance specifications
- Responsible for training personnel in system operation and ground-based data processing

Optech processed the CHARTS data from the field tests, and summarized in a report how the CHARTS data compared to the ground-truth data.

JALBTCX

- Customer
- Managed ground support:
  - Survey of target area
  - Tide data

South Florida Test Facility (SFTF)

- Provided site facilities, public relations and general support

NAVO

- Sonar data was gathered and processed to generate an extensive ground truth data set in the Navy Test Area.

4 TEST SITE AND TARGET AREAS

Field trials were conducted in southeast Florida between Fort Lauderdale and Key West. As shown in the figures below, the test site was the Naval Surface Warfare Center's South Florida Testing Facility in John U. Lloyd State Park, Fort Lauderdale.

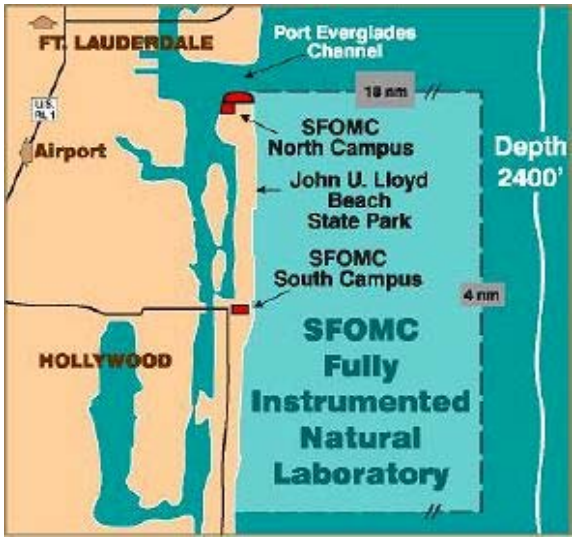


Figure 1: Test Site At Fort Lauderdale

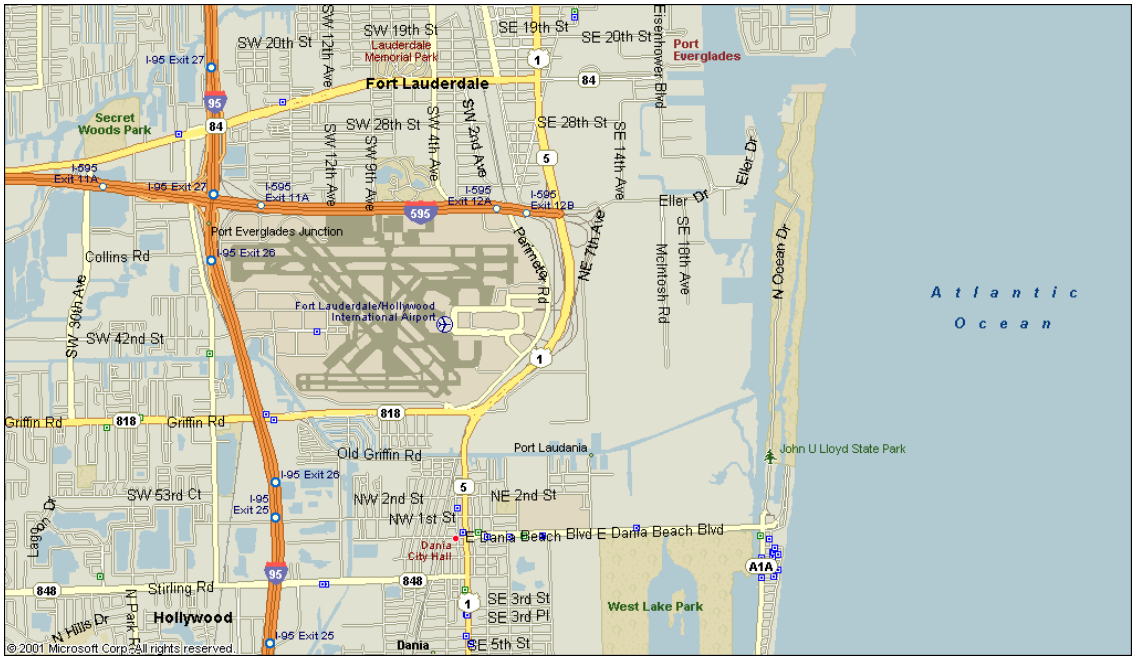


Figure 2: Test Site Area Close-Up

A CHARTS field office was set up at 8010 North Ocean Drive, South Florida Test Facility building, Dania. CHARTS system operation and maintenance was carried out from the Jet Center FBO, Hollywood International Airport, throughout the field tests.

Optech flew the CHARTS system over target lines in the Hollywood Beach area and the Navy test area in Port Everglades. To collect topo data, Optech also flew CHARTS over the Gainesville Airport Runway and the South Florida Test Facility building. The system flew for approximately 65 hours during this phase. During the field tests, over 90 million topo elevations and over 40 million hydro soundings were collected.

5 OPERATIONS

Test flights took place at Fort Lauderdale, Florida.

During the test flights, the pilots flew under normal visual flying rules (VFR) over targets at the airport. Daily operations involved briefing the pilots, ground support personnel and CHARTS airborne operators.

For the acceptance test flights, mission planning consisted of generating a preliminary plan for each mission (flight) on the evening before the mission.

At the end of the mission, Optech used ground-based data processing to examine the test data briefly, and to determine their suitability for later data stripping and analysis.

6 ACCEPTANCE TEST SETUP

6.1 GPS Base Station

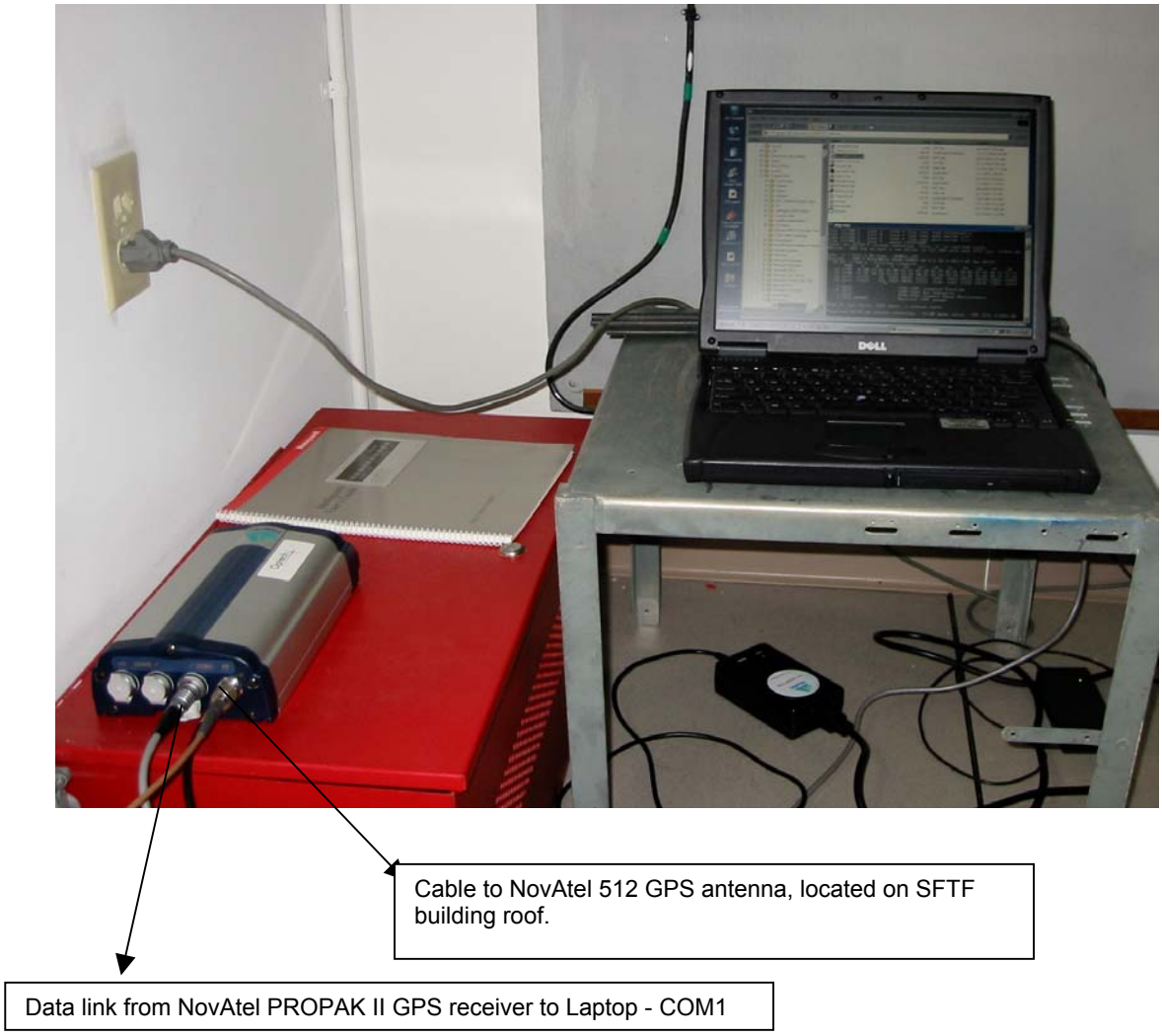


Figure 3: GPS Base Station

A GPS base station was set up at the South Florida Test Facility (SFTF) building for most of the CHARTS kinematic GPS (KGPS) data processing during the field trials. The above figure shows the hardware arrangement, a NovAtel PROPAK II dual-band receiver and a laptop to collect ground-based GPS data.

The coordinates for the base station were calculated by post-processing about 17 hours of its data acquired on August 4, 2003, with three nearby CORS GPS base stations as reference (results provided by Richard Barker, Fugro Chance Inc.).

The following table lists the base station coordinates.

Table 1: SFTF Base Station Antenna Coordinates

Item	Measurement	Standard Deviation (meters)
Latitude (degrees)	26 05 32.12959	0.0054
Longitude (degrees)	-80 06 35.06098	0.0103
Ellipsoid Height (m)	-13.8248 (WGS84)	0.0218

6.2 Port Everglades Datum Transformation (WGS 84 to MLLW)

This section describes survey results and relationship calculations, (analyzed by C. E. Wiggins of JALBTCX).

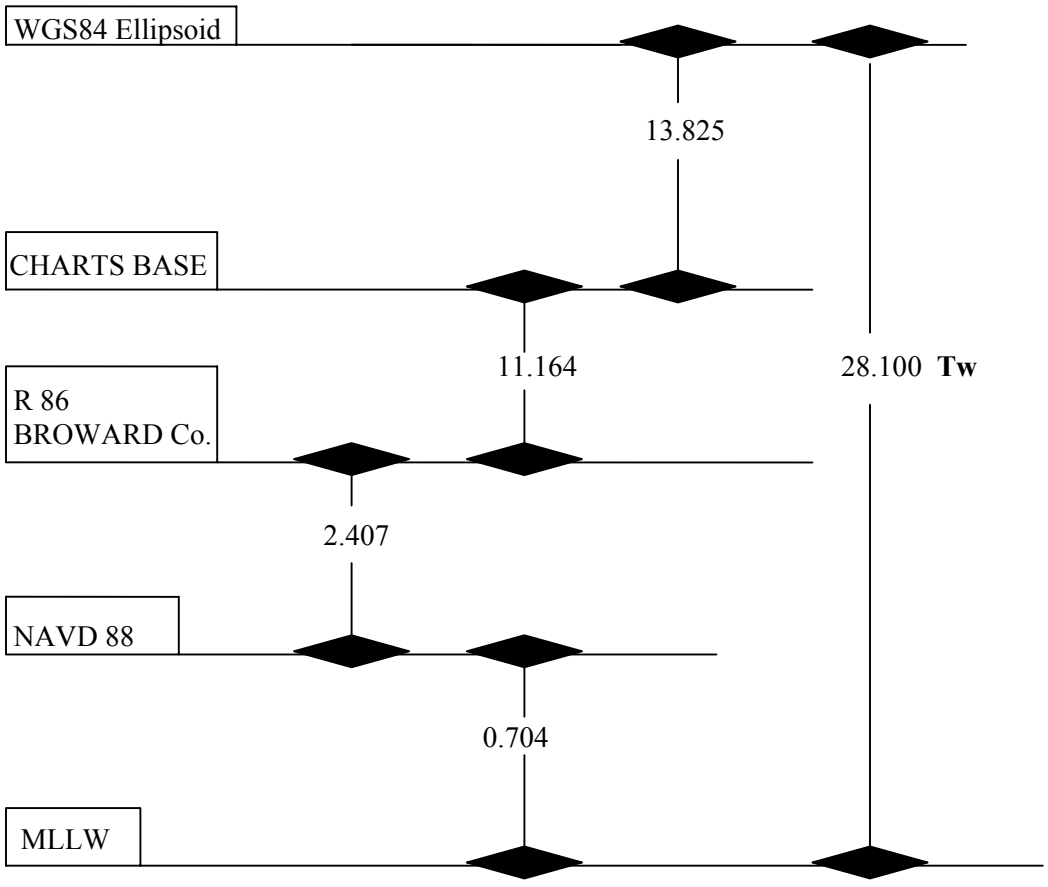


Figure 4: Corrections From WGS 84 To MLLW *(All Heights In Meters)*

Dania	**m**	**ft**
NAVD 88 to MLLW	0.623	2.04 based on South Dania Sound NOS Benchmark Publication, Station 8722971
Port Everglades	**m**	**ft**
NAVD 88 to MLLW	0.704	2.31 approximation based on published sheets from locations south and north of Port Everglades
Monuments S 314	**m**	**ft**
	2.449	8.03 NAVD 88
Monuments R 86	**m**	**ft**
	2.407	7.90 results from leveling based on S 314 control

CHARTS Base **m**

-13.825 WGS84 El Ht., from Richard Baker's GPS processing
-12.182 NAD83 El Ht., from Richard Baker's GPS processing
13.547 NAVD 88 Ortho Ht., from Richard Baker's GPS processing

R 86 Broward Co. **m**

-24.989 WGS84 EL Ht.
-23.346 NAD83 EL Ht.
2.383 2.407 -0.024 NAVD88 ht., (GPS – levels = diff.) will use leveling results
3.111 MLLW Ht., (based on levels and approx. NAVD88 – MLLW correction)
-28.1 WGS84 El to MLLW

Current T	**New T**	**Diff.**
-27.961	-28.100	0.139 difference based on NAVD 88 calculations

7 ACCEPTANCE TEST RESULTS

The CHARTS system met all acceptance test criteria and passed the acceptance test. This section describes the following acceptance test results:

Hydrographic Mode

- Depth penetration
  - Maximum depth
  - Minimum depth
- Sounding vertical accuracy (depth measurement accuracy)
- Sounding and elevation positional accuracy
- Hazard detection

Topographic Mode

- Elevation accuracy and topographic vertical accuracy
  - Elevation (1 kHz)
  - Topographic (9 kHz)
- Horizontal position accuracy
  - Elevation (1 kHz)
  - Topographic (9 kHz)

- Digital camera.

7.1 Hydrographic Mode

7.1.1 Depth Penetration

This test determined whether CHARTS meets the design specification for maximum detection depth of Kd > 3, where k is the diffuse attenuation coefficient of the water.

Three flightlines were flown and analyzed for depth penetration capability. The flightlines were flown from deep to shallow and from shallow to deep water. The extinction depth was determined from the lidar data by inspecting the area where the lidar depths started to become sparse.

The physical measurements taken were also used for comparison with a new software program, Ocean Scientific Target (OST) 2003, developed by Viktor Feygels and Yuri Kopilevich. It simulates the lidar performance very well and can be used to derive the water properties from the lidar waveform shape itself.

The table below outlines the results of this test, which demonstrate that CHARTS meets the Kd * D > 3 specification.

Table 2: Depth Penetration Test Results

Flightline	Reported Depth (m)	Kd	Kd * D	Meets Specification
11	-39.40	0.08 m^{-1}	3.152	YES
13	-44.45	0.1 m^{-1}	4.445	YES
14	-39.79	0.1 m^{-1}	3.979	YES

7.1.1.1 Test Sets

The following sets of three figures each summarize the results of this test.

Set 1

$$K_d \cdot depth = 0.08\ m^{-1} \cdot 39.40\ m = 3.152$$

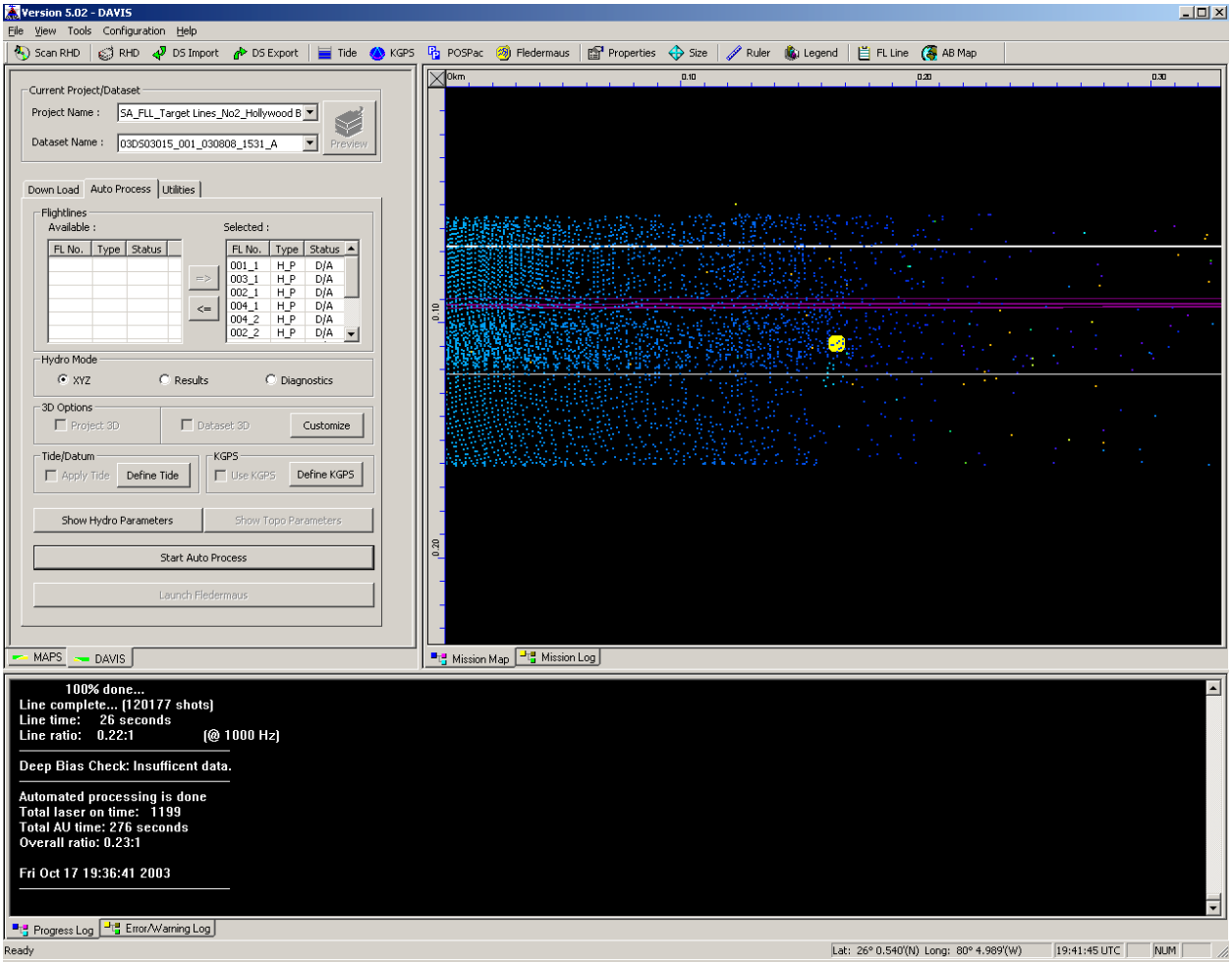


Figure 5: DAVIS Window For Extinction Flightlines Of August 8, 2003

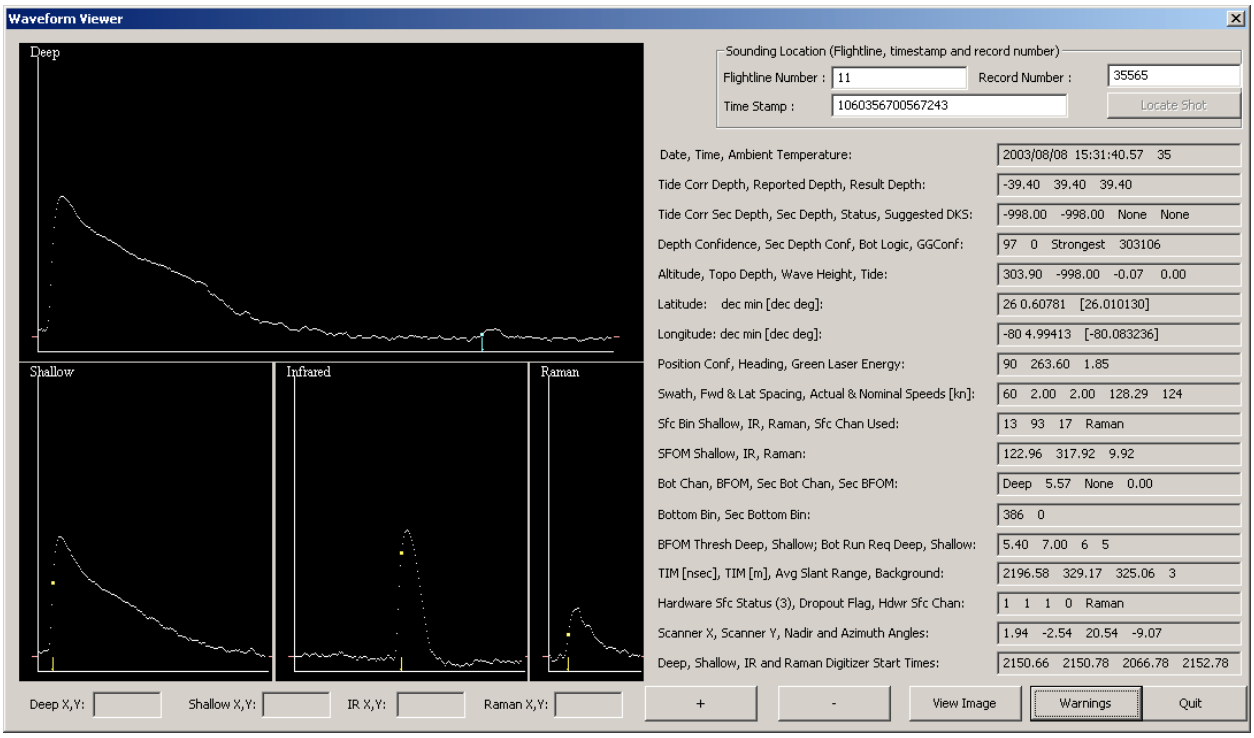


Figure 6: Waveform Window Showing Depth Of 39.4 Meters

Dr. Alan Wiedemann of the Naval Research Laboratory (NRL) took simultaneous measurements of various water parameters. Included in these measurements was the diffuse attenuation coefficient, which is the value used below. An example of this measurement is shown in the figure below.

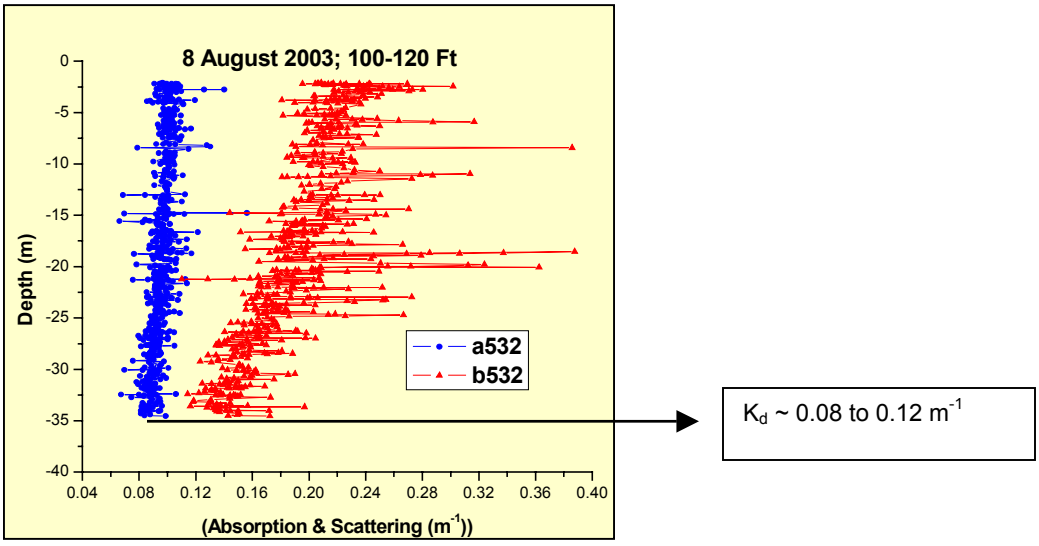


Figure 7: Absorption And Scattering Measurements

Extracted from: *Ocean Scientific Target 2003: PC Program for Bottom and Target Return Simulation*
Dr. Victor I. Feygels and Dr. Yuri I. Kopilevich

Set 2

$$K_d \cdot \text{depth} = 0.1\ m^{-1} \cdot 44.45\ m = 4.445$$

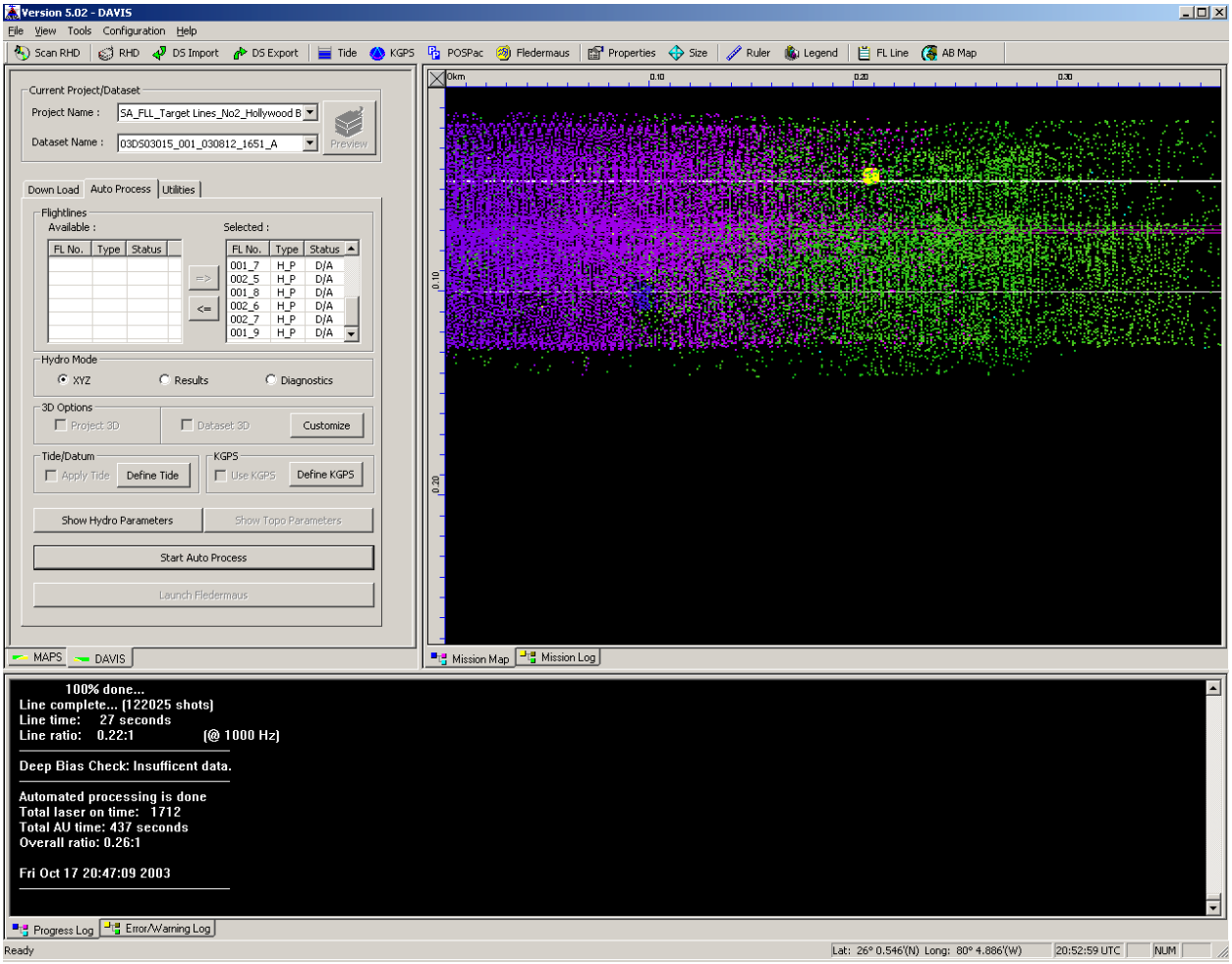


Figure 8: DAVIS Window For Extinction Flightlines On August 12, 2003

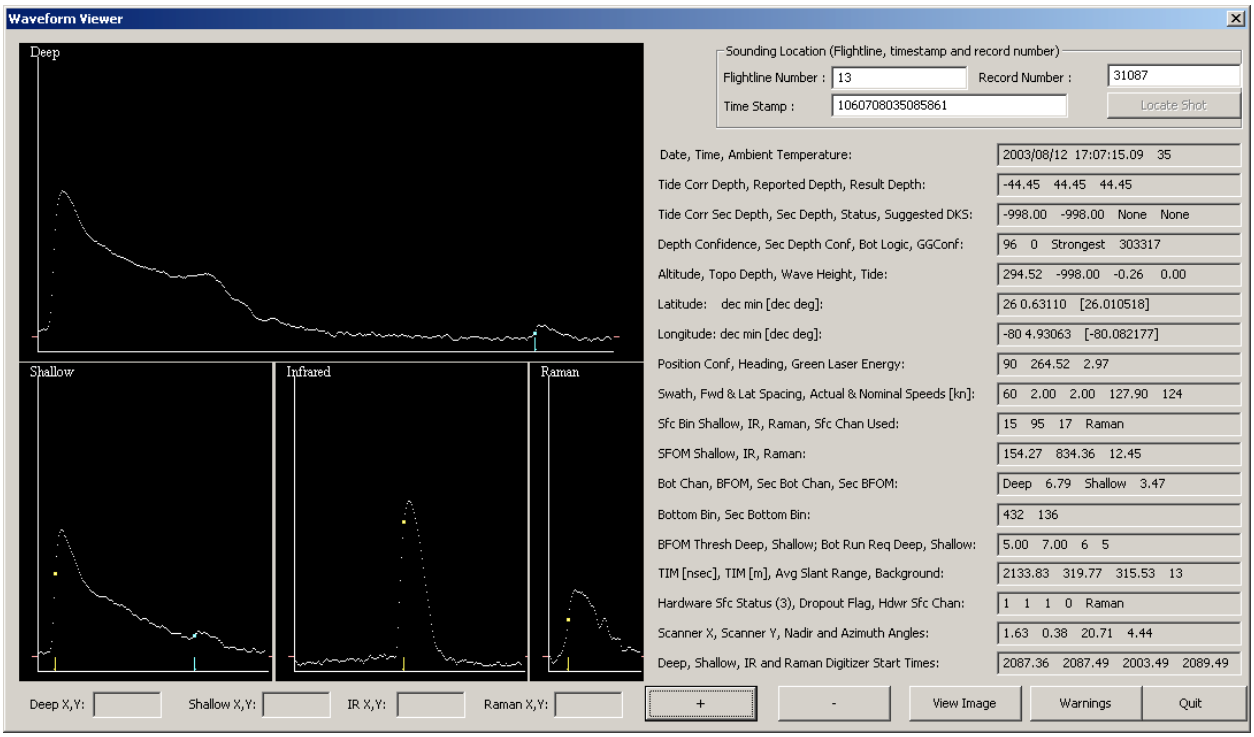


Figure 9: Waveform Window Showing Depth Of 44.45 Meters

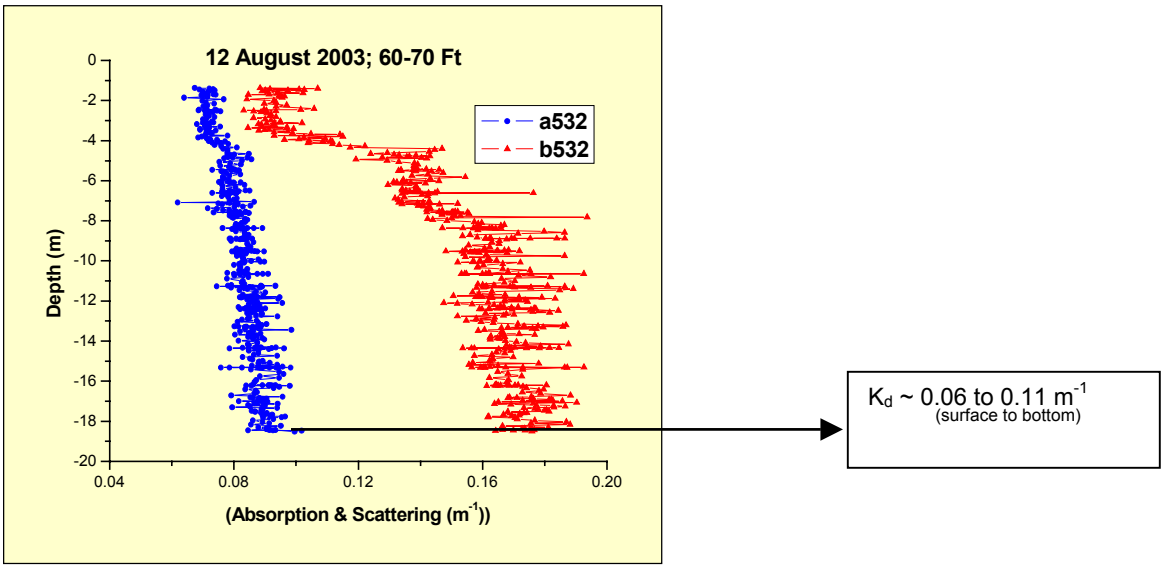


Figure 10: Absorption And Scattering Measurement

Extracted from: *Ocean Scientific Target 2003: PC Program for Bottom and Target Return Simulation Dr. Victor I. Feygels and Dr. Yuri I. Kopilevich*

Set 3

$$K_d \cdot \text{depth} = 0.1\ m^{-1} \cdot 39.79\ m = 3.979$$

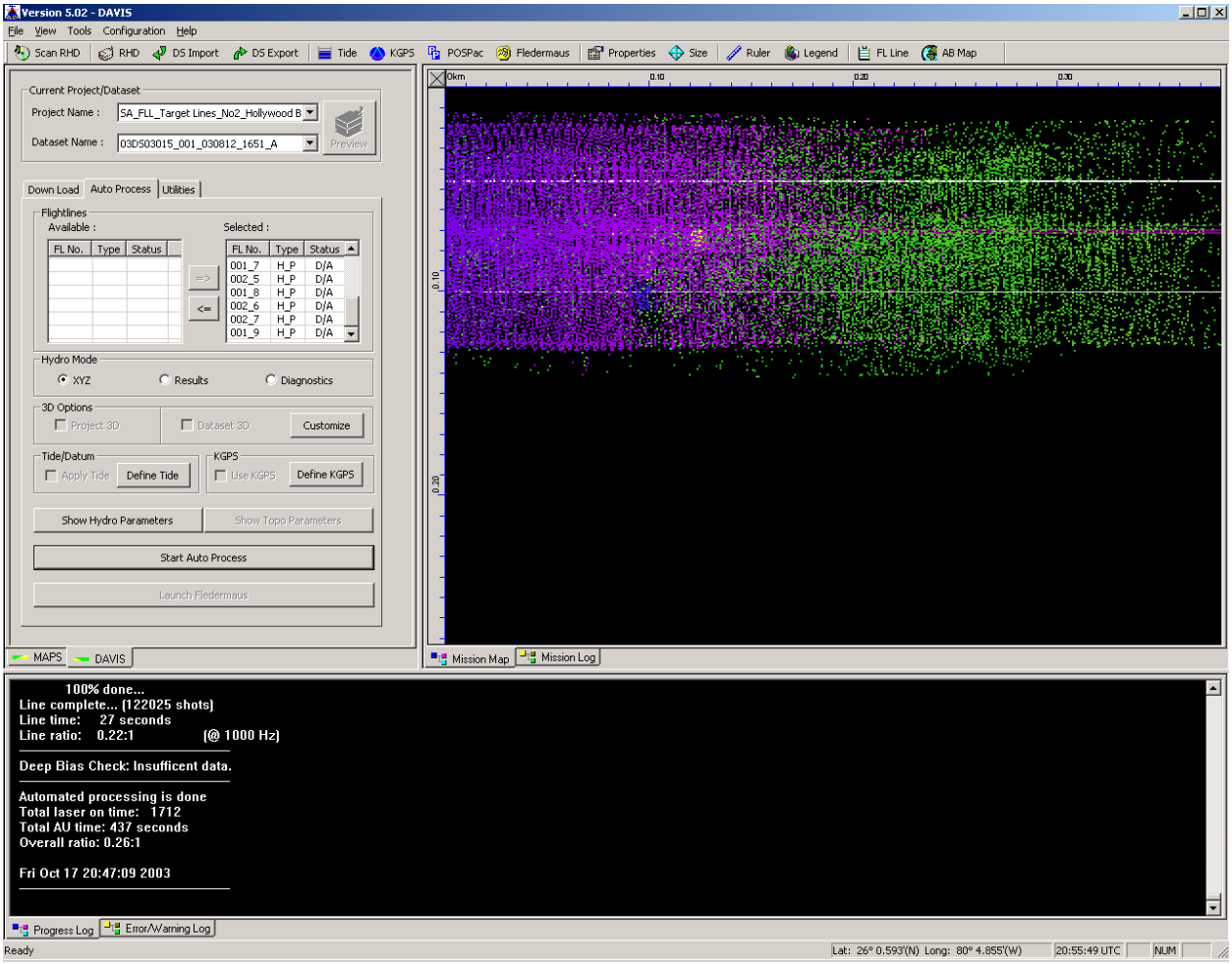


Figure 11: DAVIS Window For Extinction Flightlines Of August 12, 2003

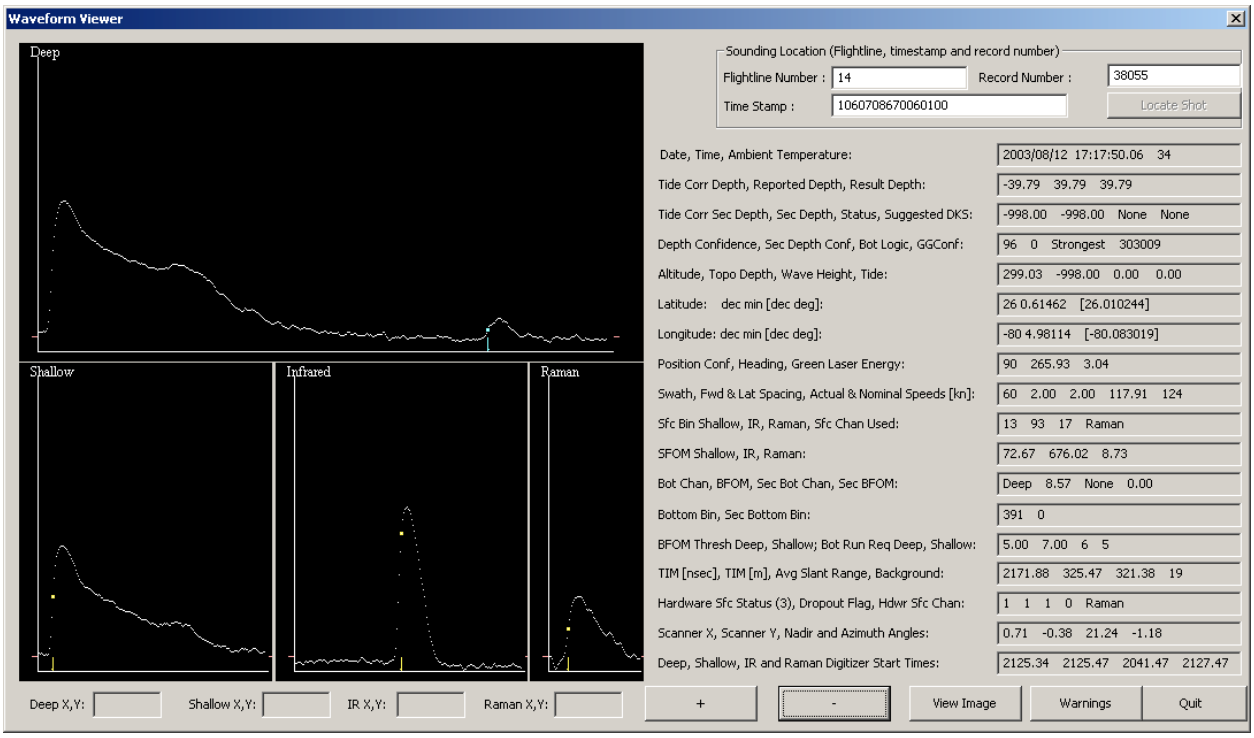


Figure 12: Waveform Window Showing Depth Of 39.79 Meters

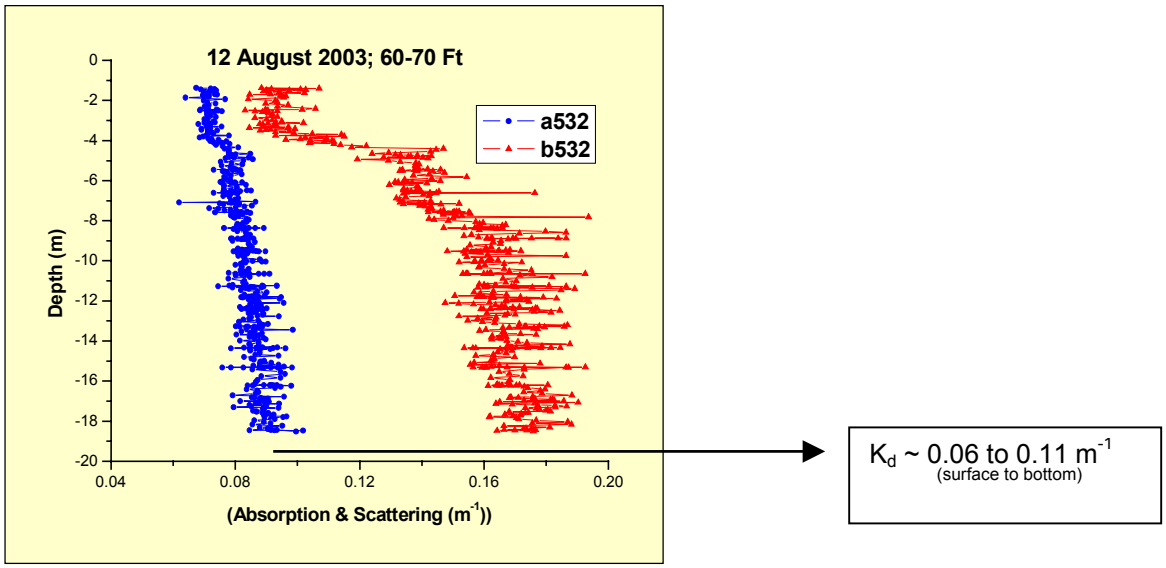


Figure 13: Absorption And Scattering Measurements

7.1.1.2 Maximum Depth

As shown in the following four figures, a maximum depth of 45 meters was detected at the Navy test site in Port Everglades.

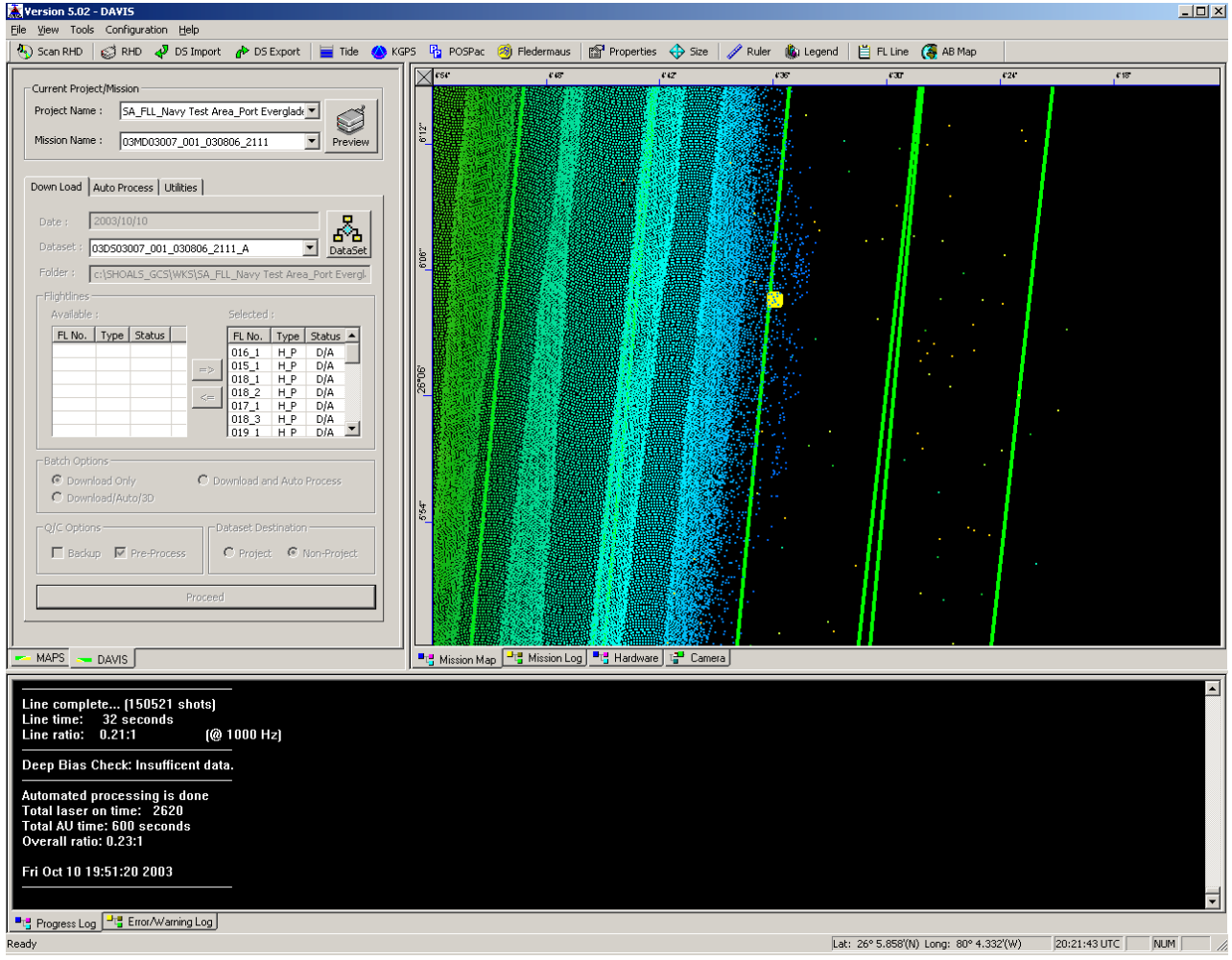


Figure 14: Maximum Depth, Screen 1

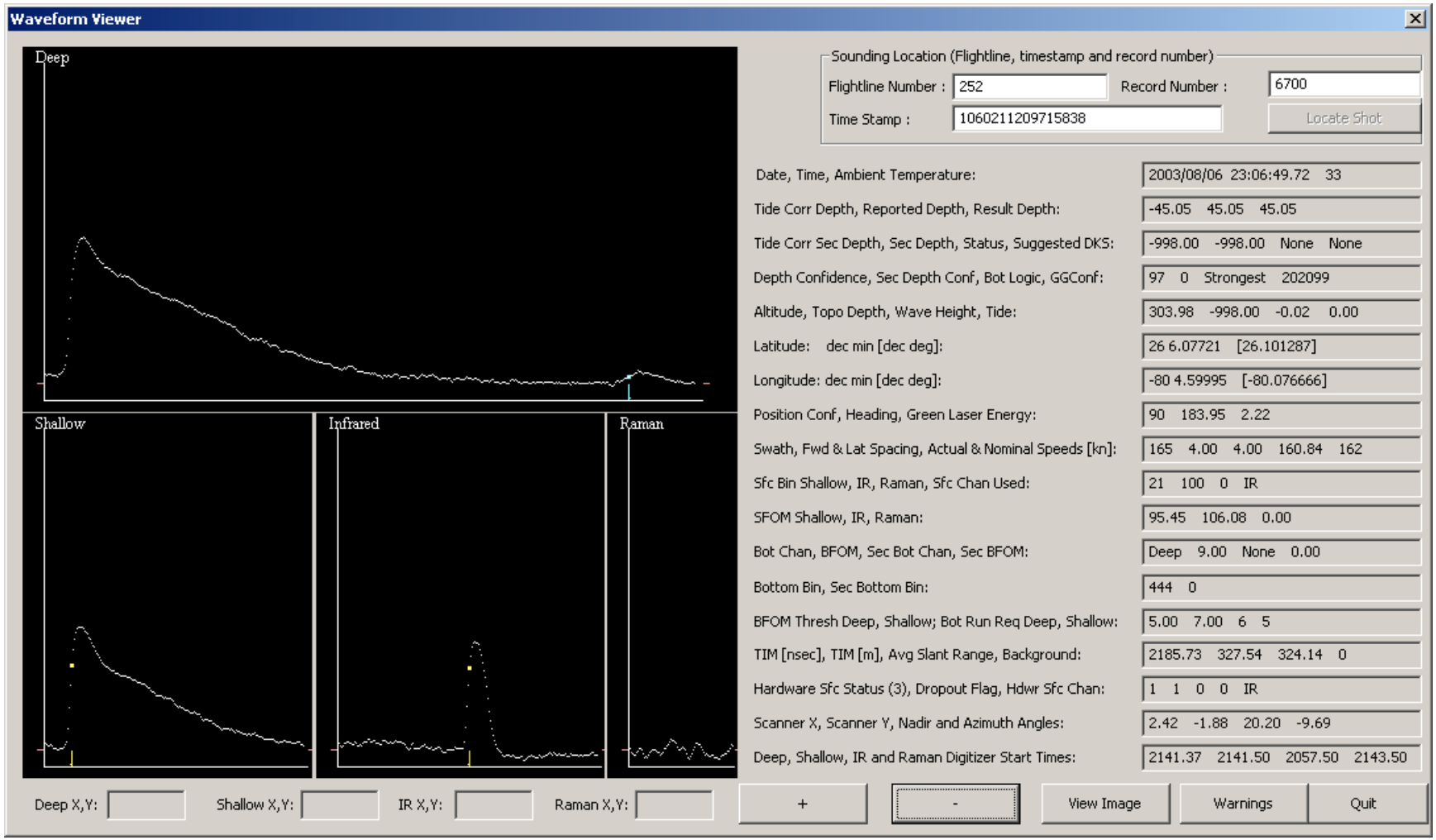


Figure 15: Maximum Depth, Screen 2

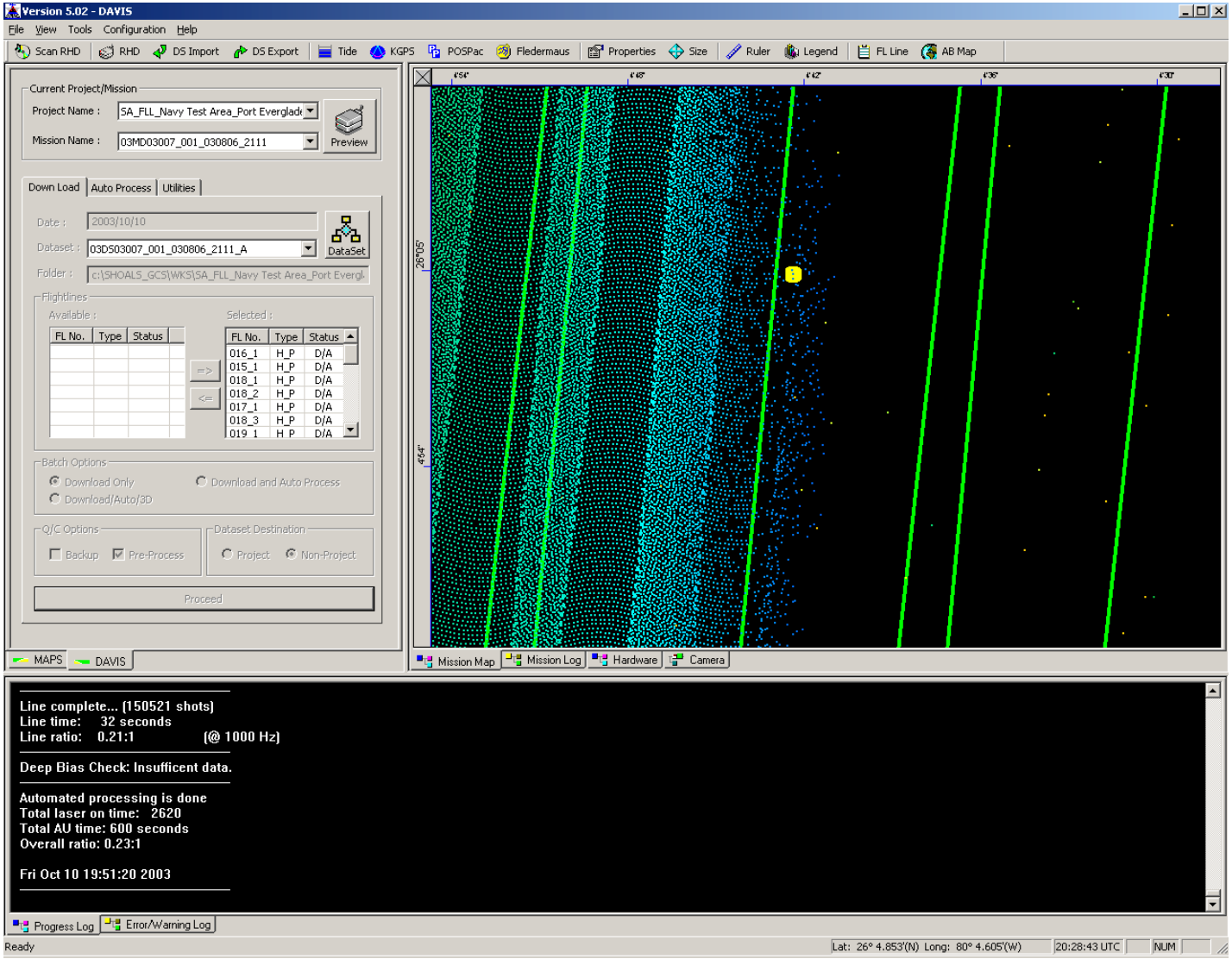


Figure 16: Maximum Depth, Screen 3

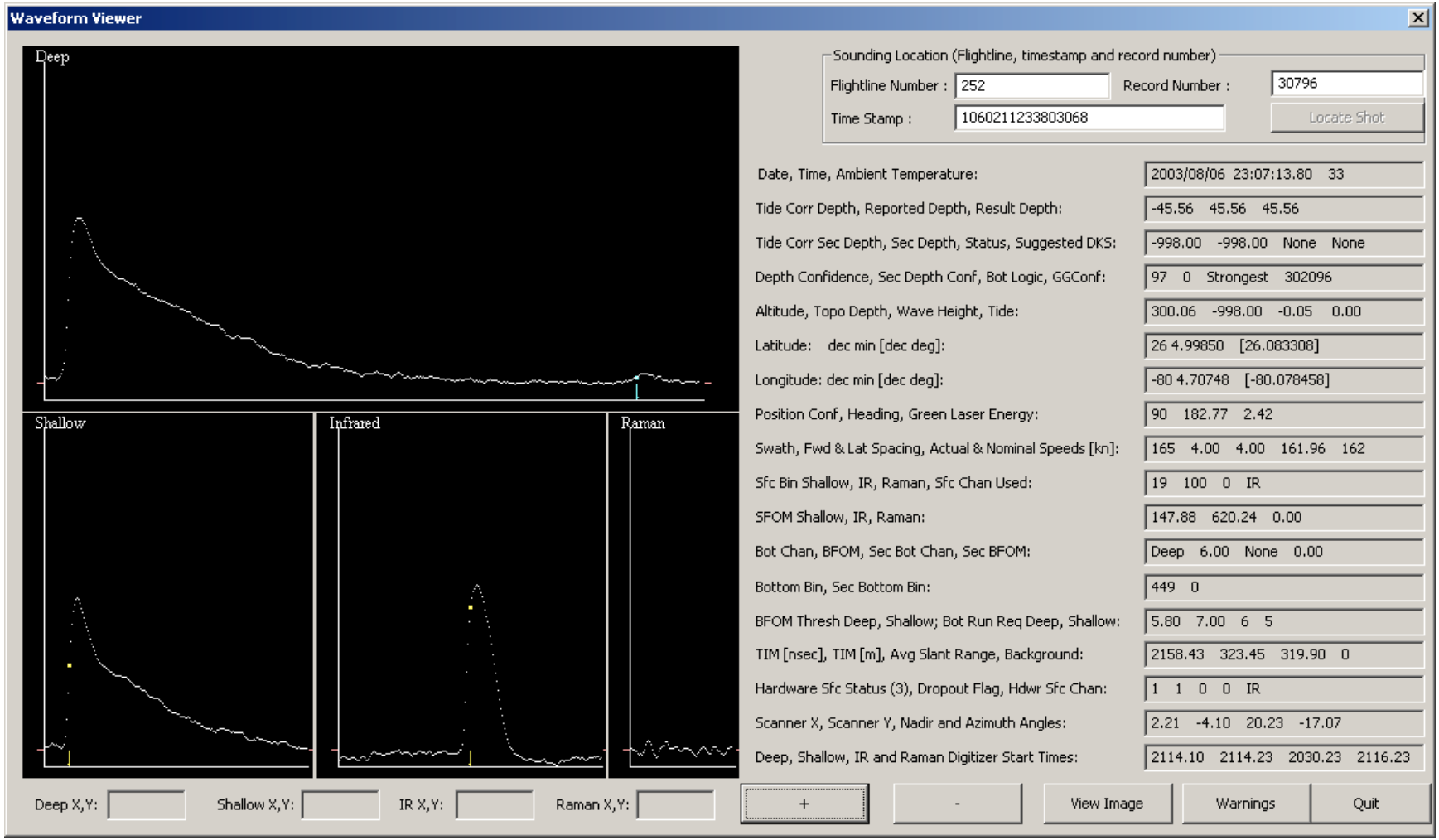


Figure 17: Maximum Depth, Screen 4

7.1.1.3 Minimum Depth

The shoreline depth swap utility was used near shore to enhance the coverage in the land/water interface zone. As illustrated in the figure below, the coverage is continuous from water up onto land.

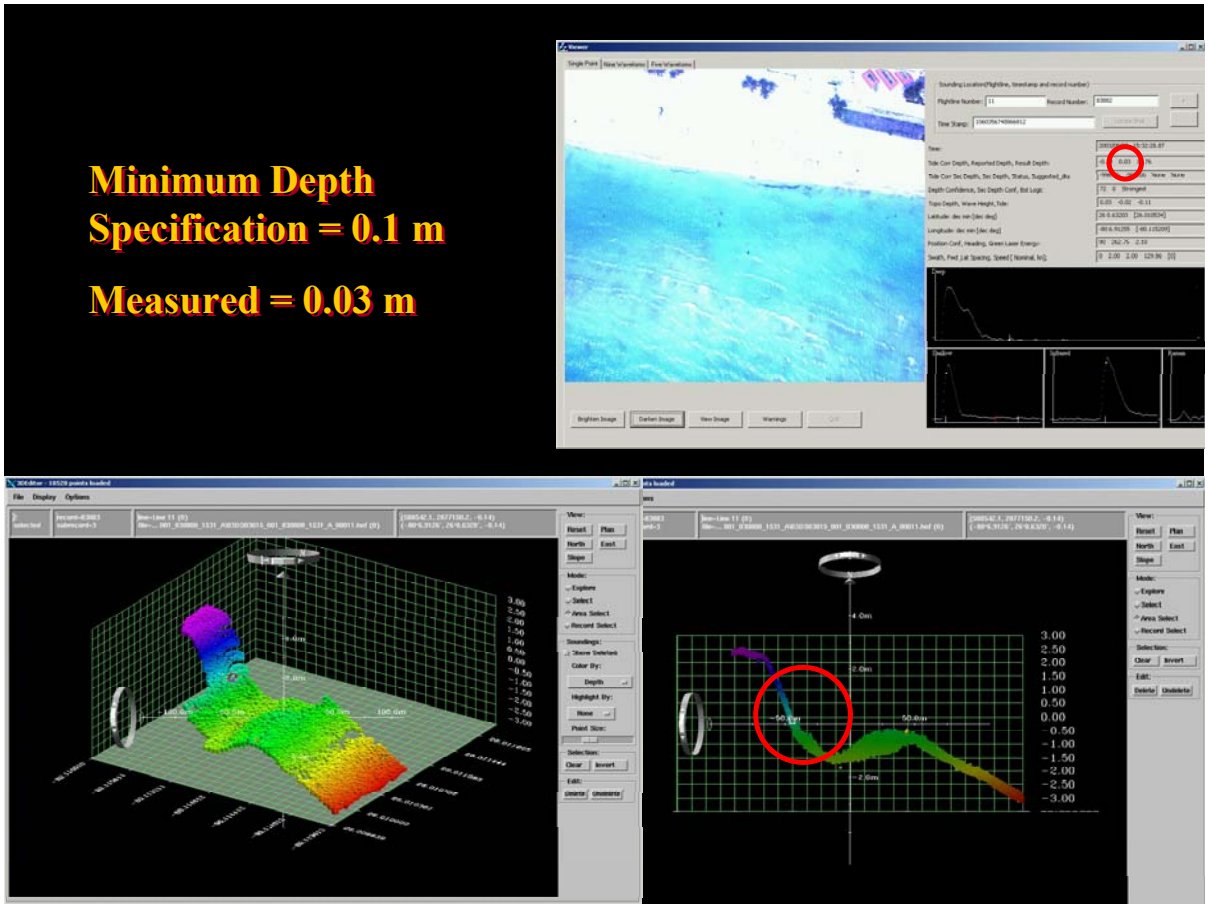


Figure 18: Minimum Depth - DAVIS Window

7.1.2 Sounding Vertical Accuracy

This test determined whether CHARTS met the design specification of depth measurement accuracy of IHO Order 1. This specification is to be within at least 50 cm for 95% confidence (which is the same as 2 standard deviations). It is not adequate to have the difference between the lidar and the sonar be within the IHO specification, as the standard deviation is also a factor. The benchmark for this comparison is to have the mean difference **plus twice** the standard deviation within the IHO specification.

Table 3 below outlines the results of vertical depth measurement accuracy test, which shows that CHARTS meets IHO Order 1.

Table 3: Results Of Sounding Vertical Accuracy Test

Area	Depth Range (m)	Flightline Comparisons	Worst case of Mean Difference (cm)	Worst Case of Std Dev of Diff. (cm)	Worst case of Mean + 2 SD (cm)	IHO 95% Specification (cm)	Meets Specification
1	7 – 8	8	17.37	12.76	41.00	50.94	YES
5	9	7	22.71	15.81	50.00	51.35	YES
2	11-13	9	17.99	11.49	34.00	52.38	YES
6	11.5 -12.5	7	22.46	10.61	41.00	52.38	YES
7	17.5 -18	5	01.24	20.87	55.00	55.07	YES
3	19 - 20.5	9	14.79	15.76	41.00	56.21	YES
10	26	7	07.96	22.09	54.00	60.35	YES
11	28 - 34	2	21.29	20.52	62.00	64.22	YES
8	35 - 38	1	06.90	23.82	55.00	68.93	YES
4	37 - 43	1	07.28	27.70	63.00	72.14	YES
9	45 - 50.5	1	09.60	18.13	46.00	79.71	YES

The primary target areas that served as control areas for depth accuracy comparisons were areas 1 through 11, as shown in Table 4 below. To build up a database for each area, many lines were flown over each control areas, with depths ranging from 7 meters to 50.5 meters.

Table 4: Control Areas For Sounding Vertical Accuracy Test

Area	Range (m)	Area Size in Meters		Y-Axis Latitude	X-Axis Longitude	Bounds Min and Max			
		North/South	East/West			X	X	Y	Y
1	7-8	136	125	26.02557		-80.103798	-80.102577	26.024958	26.026184
2	11-13	170	152	26.02557		-80.098145	-80.096626	26.024813	26.026329
3	19-20.5	170	152	26.02556		-80.093788	-80.092270	26.024813	26.026329
4	37-43	172	153	26.02557		-80.084023	-80.082504	26.024813	26.026329
5	9	173	152	26.00976		-80.104675	-80.103157	26.008997	26.010513
6	11.5-12.5	172	153	26.00976		-80.098801	-80.097282	26.008997	26.010513
7	17.5-18	173	172	26.00976		-80.090454	-80.088951	26.008997	26.010513
8	35-38	142	124	26.00975		-80.084740	-80.083496	26.009140	26.010368
9	45-50.5	172	153	26.02557		-80.082161	-80.080643	26.024813	26.026329
10	26 (middle of dredged area)	102	71			-80.091397	-80.090775	26.025078	26.025982
11	28-34 (North area - not in T lines)	161	142	26.04734	-80.0842	Created using radius			

7.1.3 Sounding and Elevation Positional Accuracy

One of the objectives of the field trials was to investigate the capability of the lidar system to detect 2×2×2 m cubes on the bottom. To this end, ten 2×2×2 m cubes were planted at various depths in the test area. A full reporting of this capability will be the subject of a later study. However, the cubes were also very useful in determining the underwater horizontal position accuracy. We show the results for two 2×2×2 m cubes placed at water depths of 19 and 28 meters.

Although many flightlines were flown over the targets, we concentrate on 14 flightlines flown on two days. The data from these flightlines was separated into the two easterly and westerly directions. The number of lidar hits on each target ranged between 10 and 15 for each direction. The average position was calculated for each direction separately, and the difference computed. We can surmise that the true location of the target is halfway between these two positions, and thus the error is half the separation between the two opposing directions.

Note that the spot diameter of the beam is quite large at these depths. The spot diameter is 2 meters at the surface of the water, and it spreads significantly at depths of 17-26 meter. This is the reason for the apparent wide spread of lidar hits on the targets shown in the figure.

The results are shown in Table 5 below, which demonstrates that the results fall well within the IHO specification of 2.5 m (1 sigma) for the horizontal position accuracy.

Table 5: Test Results For Horizontal Position Accuracy

Target Depth	E-W Separation	Position Difference
17 m	1.30 m	0.65 m
26 m	1.90 m	0.95 m

Figure 19 below illustrates the results of the test. The diamonds are lidar hits in the East direction; squares are lidar hits in the West direction. The large squares are the average position for the two directions. The grid consists of 1×1 m squares.

The waveform in Figure 20 shows the resolved 26 m deep target and the 28 m bottom returns. The reported depths from the post-processor were 26.29 m and 28.39 m.

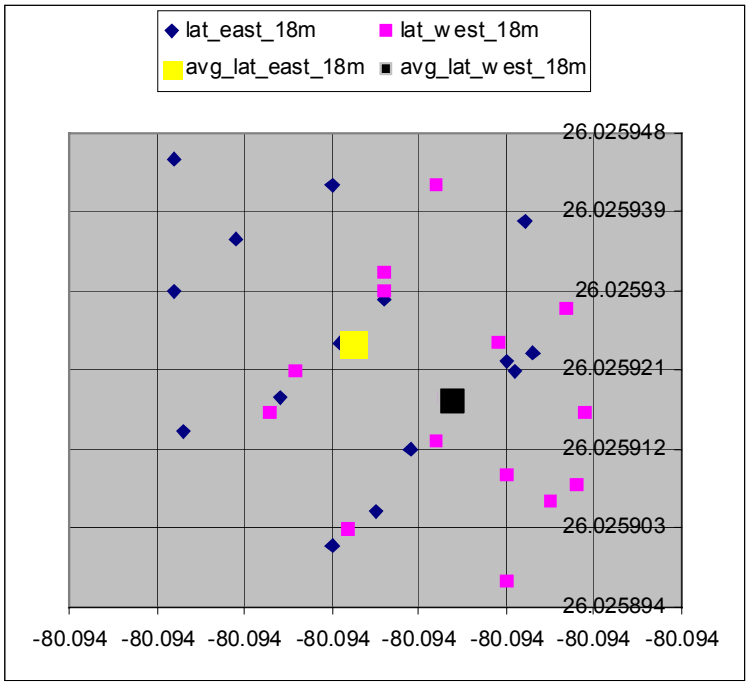


Figure 19: Results Of Sounding And Elevation Positional Accuracy

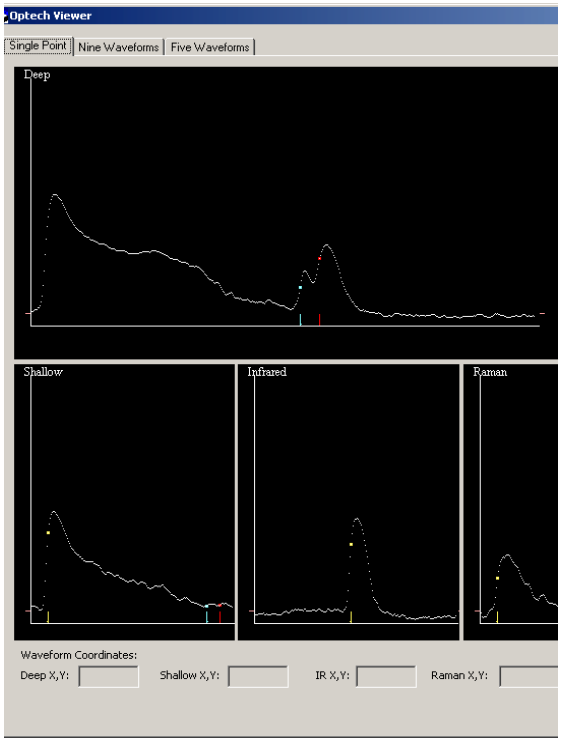


Figure 20: Underwater Horizontal Position Accuracy Waveform

7.1.4 Hazard Detection

This test determined how deep and under what conditions CHARTS could detect 2×2×2 m targets placed on the bottom. Table 6 below shows the preliminary results of target detection. It confirms that CHARTS detected all targets at all depths.

Table 6: Preliminary Results Of Hazard Detection Test

Target ID	Bottom Depth (m)	2×2 Spot Spacing	3×3 Spot Spacing	4×4 Spot Spacing
1S	4.87	63%	0%	0%
2S	9.75	100%	100%	50%
3S	16.46	n/a	75%	27%
4S	18.90	82%	64%	30%
5S	24.08	100%	86%	0%
6S	28.35	71%	82%	0%
1N	6.10	100%	67%	0%
2N	11.89	57%	61%	40%
3N	18.60	100%	94%	93%
4N	20.12	91%	78%	47%
	All inclusive	2×2 spot spacing	3×3 spot spacing	4×4 spot spacing
	5-10	88%	65%	16%
	11-15	57%	61%	40%
	16-20	89%	79%	53%
	21-25	100%	86%	0%
	25-30	71%	82%	0%

In this test, ten targets were planted in the water at varying depths from 5 m to 28 m, as shown in the table below. Six targets were planted on one east-west line (South line), and four were planted on another east-west line (North line). More than 40 flightlines were flown over the targets in opposing directions. The target lines were flown at 2×2, 3×3 and 4×4 spot spacing.

Some of the planted targets collapsed during field-testing. According to the SFTF, the 2-meter cube targets that collapsed were 1S, 2S and 1N. They were removed on August 6, re-welded and returned on August 11. Tropical Storm Erika passed through the field test site on August 14.

Table 7 below shows planted target position at various water depths.

Table 7: Planted Target Positions

Target ID	Lat Planted	Long Planted	Bottom Depth (meters)
1S	26 00.598	80 06.740	4.87
2S	26 00.590	80 06.330	9.75
3S	26 00.609	80 05.775	16.46
4S	26 00.618	80 05.674	18.90
5S	26 00.626	80 05.178	24.08
6S	26 00.615	80 05.149	28.35
1N	26 01.539	80 06.696	6.10
2N	26 01.539	80 05.905	11.89
3N	26 01.556	80 05.648	18.60
4N	26 01.554	80 05.554	20.12

Figure 21 below shows the target placement.

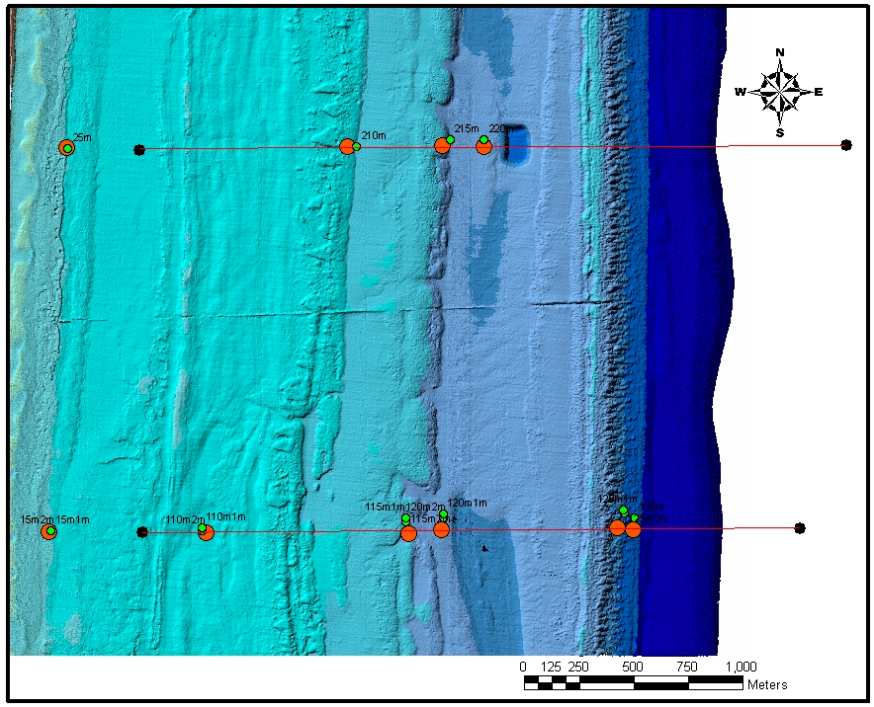


Figure 21: Target Placement

7.2 Topographic Mode

7.2.1 Elevation Accuracy (1 kHz) and Topographic Vertical Accuracy (9 kHz)

This test determined that CHARTS met the design specification for topographic elevation accuracy of within 50 cm with 95% confidence at both 1 kHz and 9 kHz.

Test results demonstrated that:

- Measured elevation accuracy (1 kHz) is ±5 cm, against requirements of 50 cm, 95% confidence
- Measured topographic vertical accuracy (9 kHz) is ±6 cm, against requirements of 50 cm, 95% confidence.

Test data is discussed below. Missions were flown over the US Navy South Florida Testing Facility (Figure 22). GPS data was collected over the SFTF east side parking lot by Fugro Chance personnel, and used to generate the ground truth surface shown in Figure 23.

Figure 22: US Navy South Florida Testing Facility (SFTF) Building

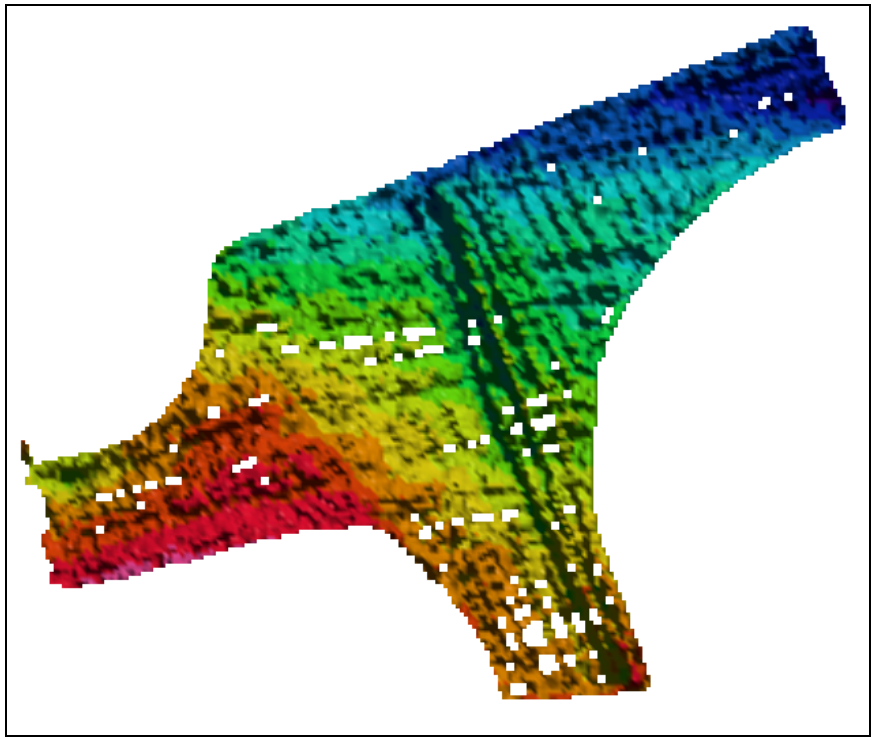


Figure 23: SFTF Parking Lot Ground Truth Surface Generated From Surveyed Data

Table 8: CHARTS Flight Summary For Elevation Accuracy (1 kHz Laser) And Topo Vertical Accuracy (9 kHz)

Date Flown	Project Name	KGPS	Dataset	Flight Parameters
030813	Test Facility Building	YES YES*	03AB03021_001_030813_2007 03AB03021_001_030813_2126	HT; 12 Hydro lines: 300 m/3x3 02 Hydro lines: 300 m/3x3; 09 Topo lines: 300 m Note: No KGPS for lines 4-1(H), 5-1(H),and 4-2(T)
030815	Test Facility Building	YES	03AB03025_001_030815_1841	02 Hydro lines: 400 m/3x3; 06 Topo lines: 400 m

Date Flown	Project Name	KGPS	Dataset	Flight Parameters
030816	Test Facility Building	YES	03AB03025_002_030816_1827	HT; 03 Hydro lines NS over SFTF: 400 m/3x3; 06 Topo lines NS over SFTF: 400 m
		YES	03AB03025_002_030816_1947	03 Topo lines EW over SFTF: 400 m; 03 Hydro lines EW and NS over SFTF: 400 m/3x3; HO + HT
030817	Test Facility Building	YES	03AB03025_002_030817_1548	HO + HT + TO; 04 Hydro lines: 300 m/3x3 over SFTF; 09 Topo lines: 300 m over SFTF
		YES	03AB03025_002_030817_1919	HT; 04 Topo lines @ 300 m over SFTF; 04 Hydro lines: 300 m/2x2 over SFTF

HT - Hydro mode line with Timing test data; HO - Hydro mode line with optical simulator data; TO - Topo mode line with optical simulator data

CHARTS data over the SFTF parking lot was post-processed and compared to the ground truth using IVS CrossCheck software. The differences were analyzed to produce the following CHARTS bias constants:

1 kHz: bathy_topo_bias_300: - 0.07
bathy_topo_bias_400: 0.03

9 kHz: topo_elevation_bias_300: 0.15
topo_elevation_bias_700: 0.29.

The following data compare lidar data and ground-truth data from the SFTF Driveway Patch.

Table 9: Set 1 Data

Range (m)	Mean (m)	Std. Dev. (m)	No. of Flightlines	No. of Points
1 kHz				
300	0.07	0.05	20	791
400	-0.03	0.05	3	180
9 kHz				
300	-0.15	0.04	21	6046
400	-0.20	0.06	15	1857

Table 10: Parameters Derived

1 kHz	9 kHz
bathy_topo_bias_300: **-0.07**	topo_elevation_bias_300: **0.15**
bathy_topo_bias_400: **0.03**	topo_elevation_bias_700: **0.29**

Table 11: Results After Applying Parameters

Range (m)	Mean (m)	Std. Dev. (m)	No. of Flightlines	No. of Points
1 kHz				
300	0.00	0.05	20	791
400	-0.00	0.05	3	180
9 kHz				
300	0.01	0.04	21	6046
400	-0.02	0.06	15	1857

7.2.2 Topographic Horizontal Position Accuracy Test

This test determined whether CHARTS met the design specification for topographic horizontal position accuracy of:

- 4 m, 95% confidence at 9 kHz (Section 7.2.2.1)
- 1% of altitude, 95% confidence at 1 kHz (Section 7.2.2.2).

Missions were flown over the US Navy SFTF building. GPS data was collected over the facility's roof and used to generate ground truth control points, as seen in Figure 24 below. Lidar data was then compared to the ground truth data.

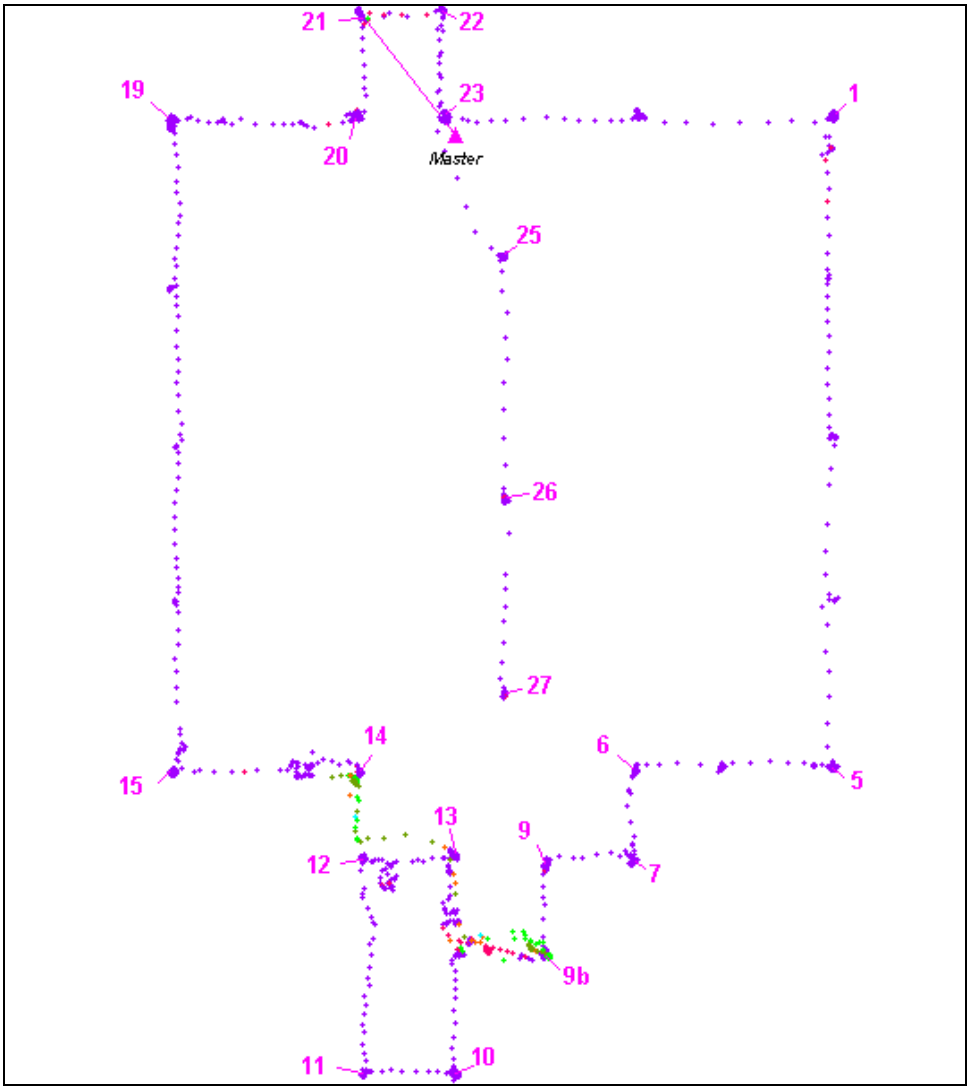


Figure 24: SFTF Building Roof Truth Contour Generated From Surveyed Data

7.2.2.1 Topographic Positional Accuracy (9 kHz)

In this test, the 9-kHz topo laser mode was flown over the SFTF building and the resulting elevation map used to define the edges and corners of the roof. A ledge on the perimeter of the roof was used as the defining points for the lidar system. Figure 25 below shows how well the lidar system captured this 30-cm wide ledge.

The results of this test demonstrated that the horizontal distance between the surveyed corners and the lidar-derived positions are <0.5 m in the three chosen examples (against requirements of 4 m, 95% confidence). In addition, the height difference is only a few centimeters.

Details of the test are discussed below. CHARTS data (Table 12) over the SFTF building roof were post-processed (with all appropriate bias constants applied), and the corresponding points (Figure 25) were directly compared to specific ground truth points (Table 13).

Table 12: CHARTS Flight Summary For Topo Horizontal Accuracy (9 kHz)

Date	Project Name	KGPS	Dataset	Flight Parameters
030817	Test Facility Building	YES	03AB03025_002_030817_1548	HO + HT + TO; 04 Hydro lines: 300 m/3x3 over SFTF; 09 Topo lines: 300 m over SFTF

HT - Hydro mode line with timing test data; HO - Hydro mode line with optical simulator data; TO - Topo mode line with optical simulator data

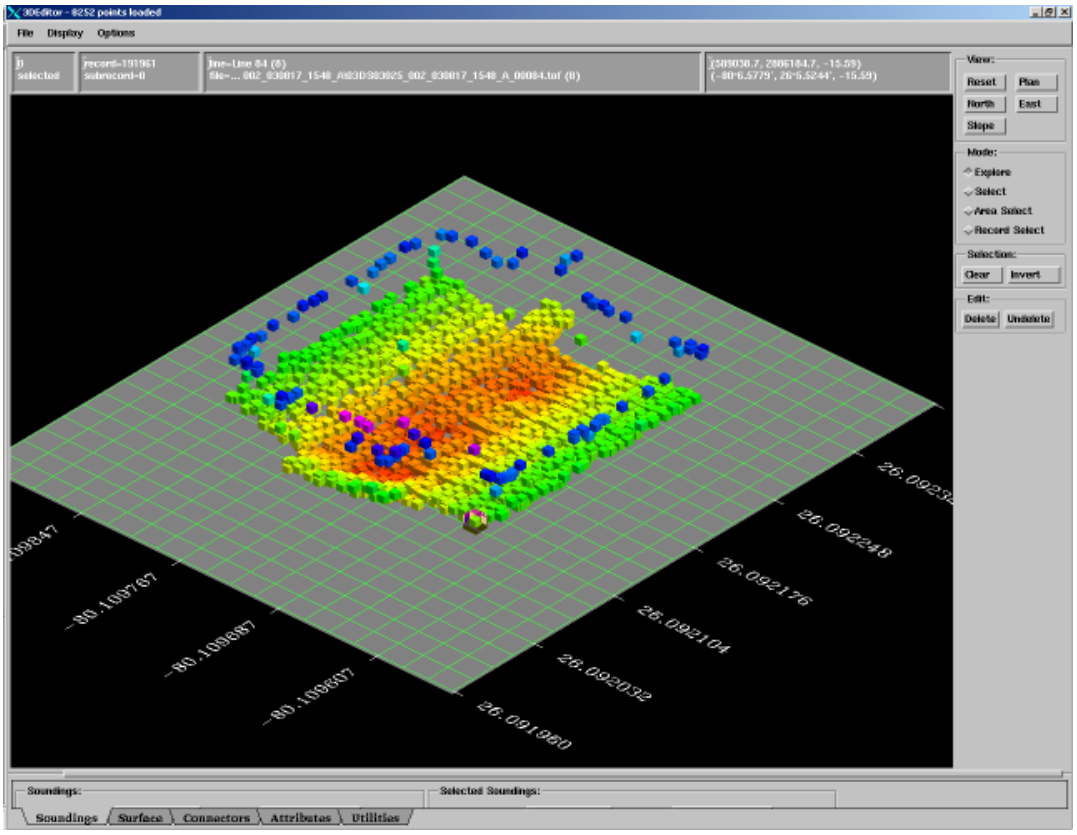


Figure 25: Fledermaus Visualization Of Lidar Points Over The SFTF Building Roof

Table 13: Selected SFTF Bulding Roof Points

Point	Latitude	Longitude	WGS84 Elli	MLLW
1	26.09226429	-80.10961539	-14.8774	13.2226
5	26.09207371	-80.10961555	-14.8831	13.2169
6	26.09207259	-80.10967991	-14.8813	13.2187
7	26.09204619	-80.10968063	-14.8733	13.2267
9	26.09204441	-80.10970944	-14.8546	13.2454
9b	26.09201859	-80.1097099	-14.8397	13.2603
10	26.09198383	-80.10973904	-11.4889	16.6111
11	26.09198353	-80.10976918	-11.4843	16.6157
12	26.09204696	-80.10976917	-11.4946	16.6054
13	26.09204807	-80.10973965	-11.4692	16.6308
14	26.09207168	-80.10977071	-14.834	13.266
15	26.09207202	-80.10983162	-14.8603	13.2397
19	26.09226283	-80.1098318	-14.8904	13.2096
20	26.09226431	-80.10977127	-14.8986	13.2014
21	26.09229458	-80.10977068	-14.8927	13.2073
22	26.09229501	-80.1097429	-14.8748	13.2252
23	26.09226352	-80.10974221	-14.8643	13.2357
25	26.09222281	-80.10972325	-15.8454	12.2546
26	26.09215183	-80.10972298	-15.865	12.235
27	26.09209482	-80.10972306	-15.8746	12.2254

The results for points 1, 20, and 22 are summarized on the following tables.

Table 14: Final Horizontal Position Difference Between Lidar And Truth Data

Corner	Observation *			Truth		
	Latitude (degrees)	Longitude (degrees)	Height (m) (WGS84)	Latitude (degrees)	Longitude (degrees)	Height (m) (WGS84)
1	26 5.5357	-80 6.5770	-14.89	26.09226429	-80.10961539	-14.88
20	26 5.5358	-80 6.5863	-14.93	26.09226431	-80.10977127	-14.9
22	26 5.5376	-80 6.5848	-14.89	26.09229501	-80.1097429	-14.87

* *Lidar data already corrected with topo_elevation_bias_300: 0.15 and topo_elevation_bias_700: 0.29*

Table 15 below shows the results of the test at 9 kHz, using corners 1, 20 and 22 as examples.

Table 15: Test Results For Points 1, 20 And 22

Corner	Difference in Latitude (m)	Difference in Longitude (m)	Horizontal* Difference (m)
1	-0.291	0.128	0.32
20	-0.108	0.04	0.12
22	-0.186	0.376	0.42

* *Square root of* $[(Diff.\ Lat)^2 + (Diff.\ Long)^2]$

7.2.2.2 Elevation Positional Accuracy (1 kHz)

The 1-kHz hydro laser points are more challenging to use for horizontal position, as the laser spot size at the ground is so much larger. The topo laser spot size is only 15-20 cm; the hydro laser spot size is 2 m, as this is a requirement for the eyesafety of the lidar system. Even so, the ledge was located by the hydro laser points, as shown in the figures below. Quantitative numbers were not derived for the hydro horizontal accuracy over the building, but the comparison of the different directions over the building ledge demonstrates CHARTS's consistency.

Figure 26 on the following page shows data from four flightlines over the SFTF building. Each color is one of an East, West, North and South flightline.

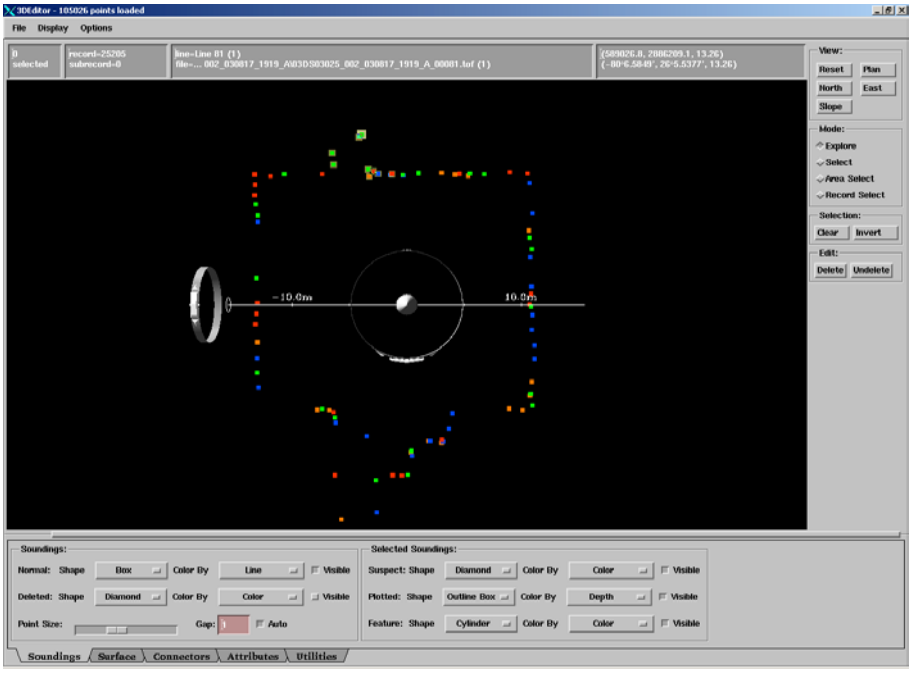


Figure 26: Flightline Data From The SFTF Building

Figure 27 on the following page shows the East and West flight data only on the left, and the North and South data only on the right.

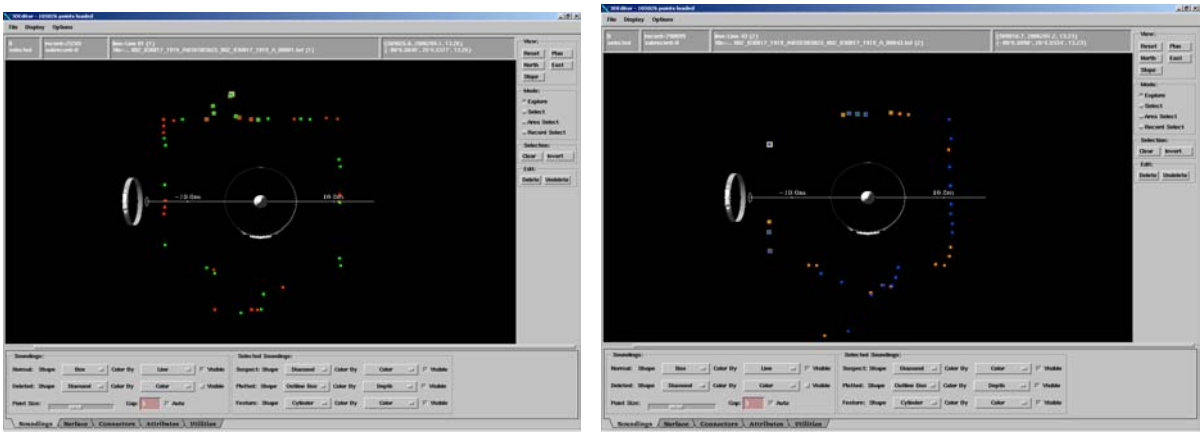


Figure 27: Comparative Flightline Data

7.3 Digital Camera Performance

The measured position accuracy has been found to be:

- <3 m at an altitude of 300 m
- <3.5 m at an altitude of 400 m.

There was no specification for the digital camera position accuracy, but the following analysis shows that the camera can be a valuable tool for locating objects to within a few meters.

The camera parameters or boresight angles (*camera_boresight_roll, camera_boresight_pitch* and *camera_boresight_heading*) were derived before the Acceptance Tests in Florida from flights over the Kennedy Road Ground Control Points in Toronto.

The boresight angles were found as a solution of a linear system of equations based on residuals between the measured and true coordinates of several ground control points. They are:

Camera_boresight_roll: -0.2°
Camera_boresight_pitch: 11.3°
Camera_boresight_heading: 0.0°.

During the Acceptance Tests in Florida, a photo target was built at the SFTF parking lot to verify the accuracy of the above parameters.

Ground Truth - Black Cross on SFTF Parking Lot

The photo target consists of a black cross made of two pieces each 3 feet long by 1 foot wide. It was located on the parking lot surface to the east of the SFTF building.

Using the WGS84 ellipsoid, it has the following data associated with it:

Latitude: 26.09207562°
Longitude: -80.10916584°
Elevation: -25.3919 meters.

Using GEOTRANS V2.2.3, it has the following data associated with it:

Easting: 589085.207 meters
Northing: 2886185.306 meters.

CHARTS Measurements

After the CHARTS data from the SFTF photo target was post-processed, the performance of the boresight angles was tested by entering its values on the Camera tab in the SHOALS GCS (DAVIS → Utilities → Show Camera Parameters (Figure 28 below). Once these values are input, all images in the dataset are automatically updated. There is no need to re-process the data to observe the effect of different values.

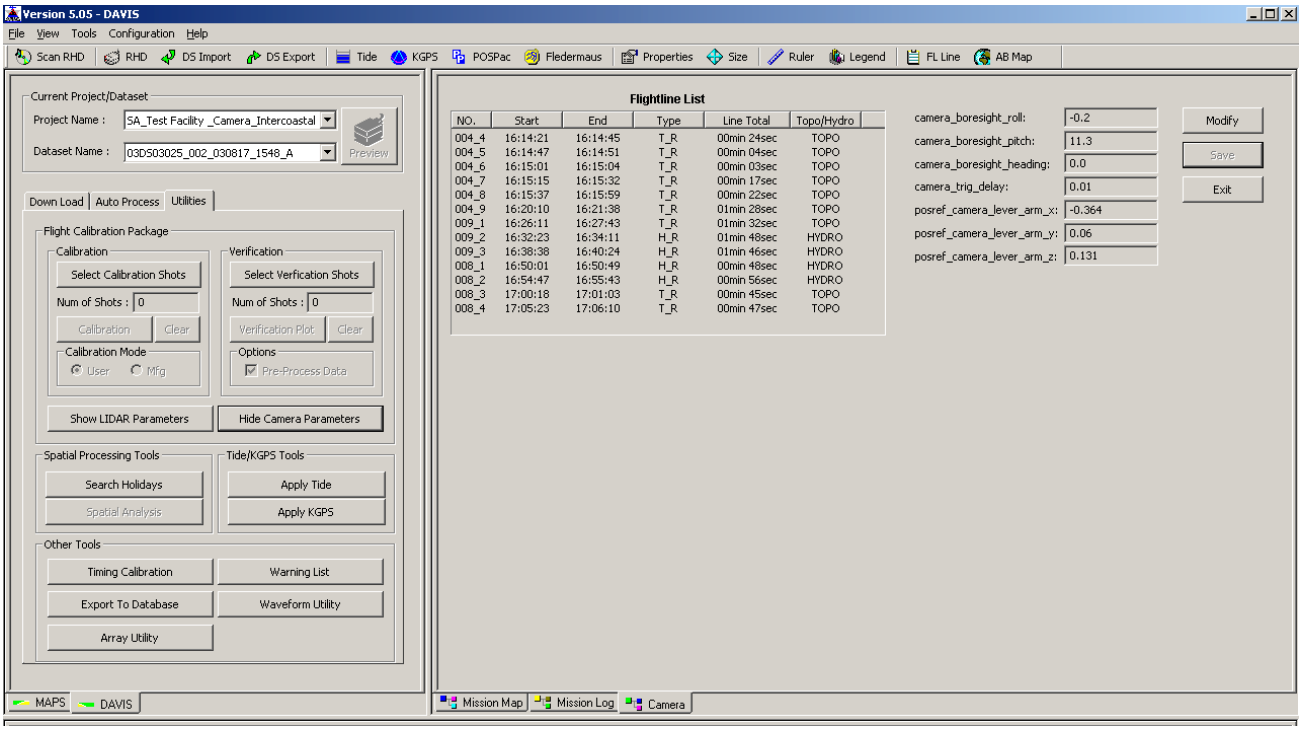


Figure 28: Camera Tab In SHOALS GCS

In the SHOALS GCS, the image containing the photo target in each flightline was identified (see arrow in Figure 29), and the parameters for the first valid lidar shot associated with the picture were selected to identify the chosen picture (Table 16).

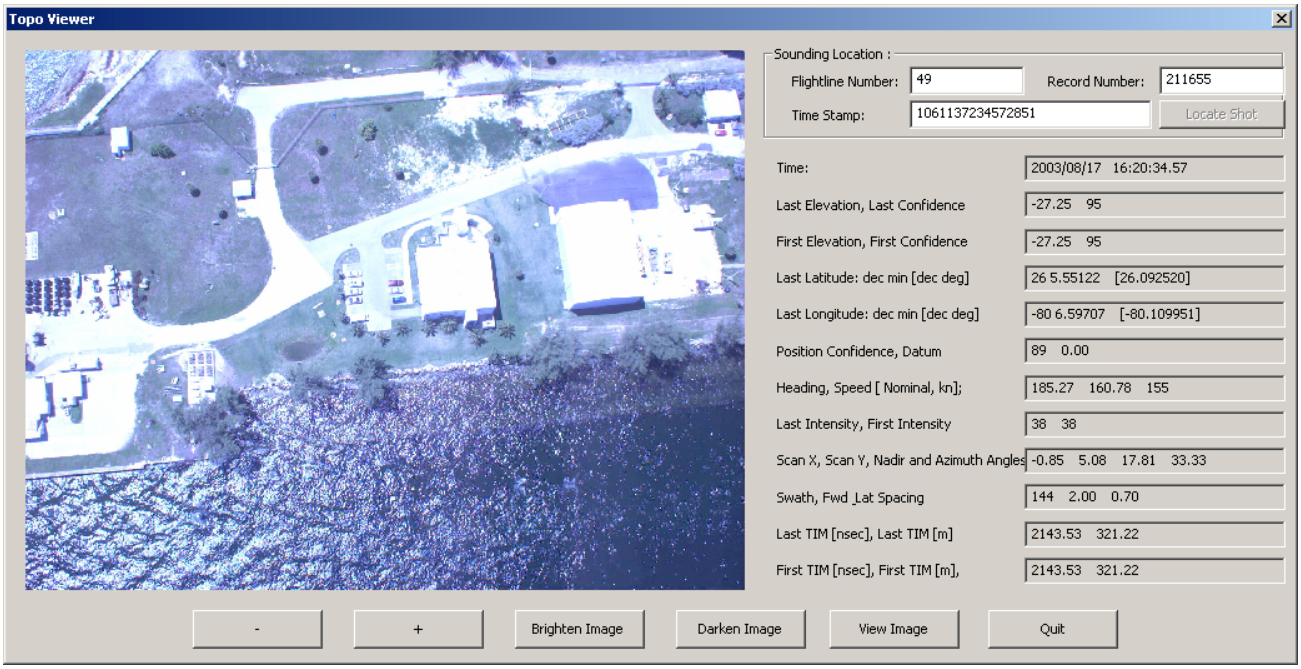


Figure 29: Topo Viewer Window With Image Of SFTF Building

Table 16: Parameters Associated With The Lidar Sounding
altitude calculated as TIM*cos (nadir)

Dataset	Line	Record	TIM	Nadir	Altitude	Heading
030817_1548	49 (T)	211655	321.22 m	17.81°	305.83 m	South

To acquire the CHARTS measured position of the photo target, the ShowImage window (Figure 30) was opened via the View Image button on the Topo Viewer window (Figure 29). The ShowImage window displays the latitude and longitude associated with the mouse cursor position on the status bar.

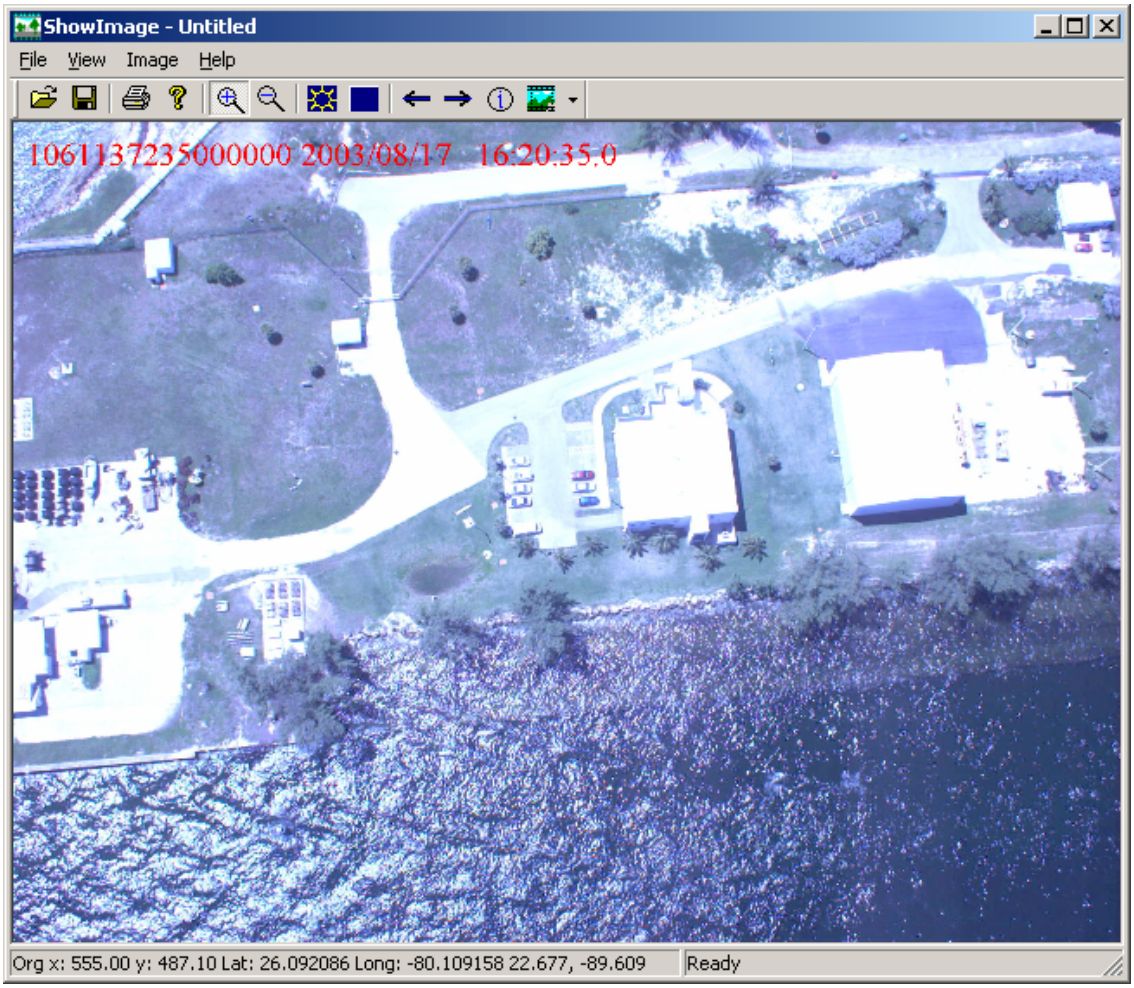


Figure 30: ShowImage Window Associated With Topo Viewer Window
(coordinates displayed on status bar at bottom)

The image was then zoomed to a convenient size over the photo target (Figure 31), and the mouse cursor positioned at the center of the cross. The latitude and longitude were then read from the window status bar:

Latitude: 26.092079°
Longitude: -80.109154°

Using GEOTRANS V2.2.3:

Easting: 589086.389 meters
Northing: 2886185.688 meters

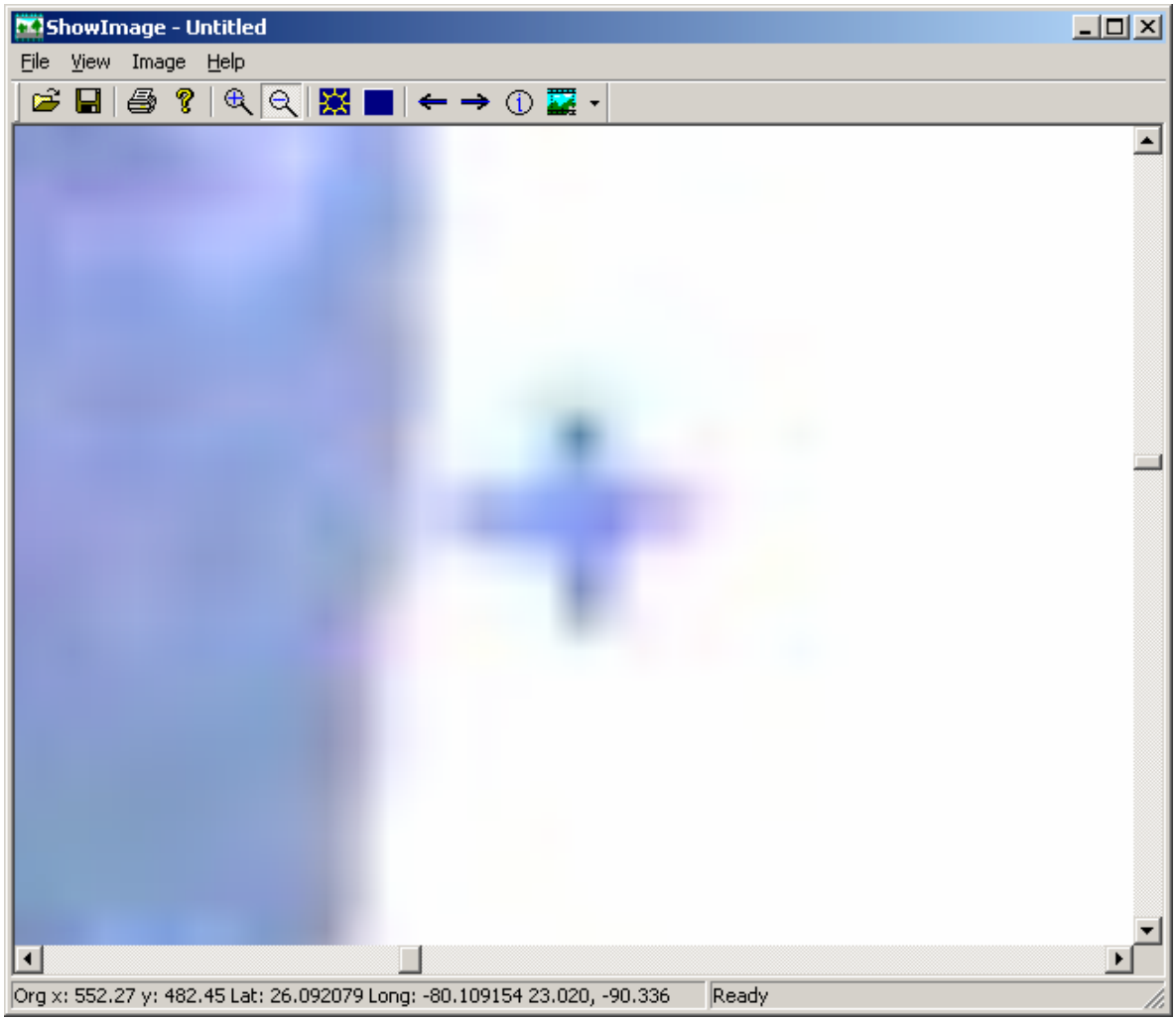


Figure 31: Zoomed ShowImage Window With Full View Of Photo Target

The converted Easting and Northing coordinates for the photo target were then compared to the photo target surveyed coordinates, producing the Diff East and Diff North values shown in Table 17 below. The Horizontal difference was calculated as the squared root of the sum of the squares of the Diff East and Diff North values.

Table 17: Parameters Associated With The Lidar Sounding Shown In Figure 29, And Accuracy Of Photo Target Coordinates Measured By CHARTS

Dataset	Line	Record	TIM (m)	Nadir	Altitude	Heading	Diff East	Diff North	Horizontal
030817_1548	49 (T)	211655	321.22	17.81°	305.83 m	South	0.382	1.182	1.24

The above process was repeated for all the lines flown over the SFTF photo target, as shown in the tables below.

Measurements at Altitude of 300 m

Camera_boresight_roll: -0.2°

Camera_boresight_pitch: 11.3°

Camera_boresight_heading: 0.0°

Table 18: Measurements At 300 M

Dataset	Line	Record	TIM	Nadir	Altitude (m)	Heading	Diff East	Diff North	Horizontal Diff. (m)
030817_1548	49 (T)	211655	321.22	17.81	305.83	S	0.382	1.182	1.24
"	83 (T)	197100	301.79	15.50	290.81	E	-0.280	1.586	1.61
"	84 (T)	184810	317.46	16.91	303.73	W	-1.271	2.393	2.71
"	91 (T)	564400	322.41	16.76	308.71	N	-1.390	1.194	1.83
030817_1919	42 (T)	561450	348.01	17.23	332.39	N	-0.844	-0.010	0.84
"	43 (T)	804102	324.88	17.04	310.62	S	0.721	2.180	2.30
"	81 (T)	024190	349.74	16.23	335.80	W	-0.840	0.590	1.03
"	82 (T)	184106	315.22	17.94	299.89	E	-0.191	-1.615	1.63

Measurements at Altitude of 400 m

Camera_boresight_roll: -0.2°

Camera_boresight_pitch: 11.3°

Camera_boresight_heading: 0.0°

Table 19: Measurements At 400 M

Dataset	Line	Record	TIM	Nadir	Altitude (m)	Heading	Diff East	Diff North	Horizontal Diff (m)
030816_1827	33 (T)	570342	449.22	17.53	428.36	N	2.481	0.367	2.51
"	41 (T)	202092	447.75	17.98	425.88	N	1.699	-0.627	1.81
"	42 (T)	219908	445.70	15.48	429.53	S	-2.830	1.104	3.04
030816_1947	82 (T)	211058	437.99	15.32	422.43	E	0.066	3.484	3.48
"	83 (T)	256040	443.10	17.71	422.10	W	-3.070	-1.595	3.46

APPENDIX A: CHRONOLOGY OF FIELD TESTS

31 Jul 03 Thu

Unpacked all the GCS hardware boxes and arranged all equipment on work bench at CHARTS office, South Florida Test Facility building.

Beechcraft King Air 90 aircraft arrived at Fort Lauderdale Hollywood International Airport at around 8.00 p.m.. CHARTS system was installed earlier at Buttonville airport, Toronto.

1 Aug 03 Fri

Set up Optech's field office and the CHARTS ground-based processing system at CHARTS office, 8010 North Ocean Drive, South Florida Test Facility building, Dania.

Found hard drives missing. Found also that there is no GPS antenna and receiver for base station. Arrangement done from Optech for shipment of hard drives, GPS receiver, antenna and cables.

FAA meeting held at 10.30 a.m. at Fort Lauderdale-Hollywood International Airport traffic control tower office with air traffic manager. This meeting was arranged to establish relationship between the CHARTS pilots and the control tower. In attendance were:

Bob Pope	NAVOCEANO
James Heslin	JALBTCX
Joel	Pilot, Dynamic Aviation
Haresh Hirpara	Optech
Pete Tatro	Director, NSWCCD SFTF
Ronald Boyd	Manager, Federal Aviation Administration
Harlan Mumnqa	Federal Aviation Administration
Maria Femandez	Federal Aviation Administration.

Testing of system was carried out at airport at 3.00 p.m. using GPU. System went well.

2 Aug 03 Sat

Prepared mission plan files for test flight #1 for Target Racetrack in Hollywood area.

Hard drives, GPS receiver and antenna arrived at 1.30 p.m..

First flight of field trials occurred over water in Hollywood area for target lines (racetrack) at 2.30 p.m.. Flew 2 hours over survey lines east west and collected some useful data. This flight was planned for 2 flight lines for pattern 3×3 and 4×4 at 300- and 400-meter altitudes. During flight shallow green APD broke down. This was experienced once at Optech before system left from Toronto, but system recovered.

Tried to figure out problem on ground using GPU. Found that problem might be due to shallow APD detector or high voltage power supply. Planned to swap shallow APD detector.

Tried to fly second time in late evening, but did not collect anything because of shallow green problem.

Collected raw data was processed at field test site CHARTS office.

Data collected: 030802 A1
B1
C1

Note: C data is not usable due to shallow green problem.

KGPS: NO

3 Aug 03 Sun

In attempt to fix the unstable green APD, Optech changed out the shallow green detector module (S6D004) with spare delivered from Optech (IRD003). This did not work. It was decided that the high voltage power supply microcontroller might be the problem. It was advised to try resetting the HVPS microcontroller if problem occurred in the air. Tried this on ground and went well so decided to fly.

Flight over water occurred in the afternoon. Flew over Navy test area (Port Everglades) and surveyed 20 hydro lines offshore at 300 m 4×4, 2 topo lines onshore and 5 hydro cal lines. Total mission time 3 hours and 30 minutes. No problems in collection.

Data collected: 030803A

Note: No ground truth.

KGPS: NO

4 Aug 03 Mon

Flew over target lines but instability in shallow green detector reappeared so aborted mission without collecting data.

Arrangement made from Optech for shipment of sensor power supply.

Established base GPS antenna set-up and started collecting data for antenna location.

GCS: Reprocessed target lines 030802A with new calibration values. Data given to JALBTCX for prelim comparison.

Data collected: NO

KGPS: NO

5 Aug 03 Tue

Sensor power supply arrived at 11.30 a.m.

Optech replaced the sensor power supply with one delivered from Optech (SSM 002). All the indications on the ground showed that the IR and shallow green instability was resolved. Went for a flight over target lines, Hollywood beach area and surveyed hydro lines at 300 m 3×3 and cal lines at 400 m 5×5. This time Raman went into breakdown and got many *TR728 High voltage turned off* errors, so only some data was collected.

Changed Raman nominal voltage from 1720 to 1680, breakdown and temperature coefficient value from 1.7 to 1.6, and decided to fly again.

Evening flight occurred over target lines in Hollywood area. Initially experienced instability problem on Raman channel but after trying things it went away. No more instability observed during the flight thereafter. Surveyed over 47 hydro lines at 300 m and 400 m (3×3 and 4×4). Total mission time 4 hours.

GCS: Reprocessed target lines 030802B with new calibration values. Data given to JALBTCX for prelim comparison.

Data collected: 030805 A, B

KGPS: YES (evening flight only)

6 Aug 03 Wed

First flight occurred for topo lines over NAVY test area at Port Everglades. Experienced scan pattern problem on a few lines and instability in Raman APD. To fix the problem in air tried to reboot microcontroller. Flew over water from shore and then landed to refuel. Total flight duration 4 hr 20 minutes.

Second flight occurred over water to complete hydro lines. Similar problem of instability of Raman APD experienced again. Resolved by disconnecting the power to microcontroller and re-connecting in order to reboot the microcontroller. Total flight duration 2 hrs 30 minutes.

Surveyed over 15 lines at 300 m 4×4, 02 N-S crosscheck lines, 14 topo lines at 300 m and over 40 hydro lines at 300 m 4×4.

GCS: Processed KGPS data 030805.

Data collected: 030806 A, B

KGPS: YES

Note: No KGPS for data 030806_1500.

7 Aug 03 Thu

In attempt to fix the unstable Raman APD, Optech changed the Raman nominal voltage to a lower value – 1680 – and changed temperature coefficient to 1. Raman still ran away into instability.

Flew over Navy test area at Port Everglades. Surveyed over 40 lines at 300 m 3×3. Frequently reset the HVPS microcontroller so that Raman could not go into instability. Total flight duration 5 hrs 15 minutes.

Data collected: 030807 A

KGPS: YES

8 Aug 03 Fri

Flew over target lines, Hollywood Beach area in the morning. Surveyed about 13 target lines at 300 m 2×2. Experienced scanner problem during initial boot-up and twice during flight, requiring two reboots. During one reboot, aircraft flew too far offshore causing Customs to ask us to land aircraft to explain our intentions.

Sensor high voltage power supply PCB and Raman APD arrived at 11.30 a.m. In the evening Optech changed sensor high voltage power supply PCB 0000671, s/n HVP 003.

Data collected: 030808 A, B

KGPS: YES

Note: No KGPS for data 030808_1640.

9 Aug 03 Sat

Flew 2 topo lines, 10 minutes in duration over water for calibration. One line into the waves and one line against the waves.

Went to Gainesville and landed at airport in order to start the system on the ground. Flew over Gainesville Airport runway. Flew over hydro and topo lines at 300 m and some of the lines at 400 m, but landed when the northing and easting jumped >30 m. Upon landing it recovered. Took off to complete 400-m survey. Landed again to allow low clouds to move away. Took off and completed 700-m topo lines.

Surveyed about 30 topo lines at 300-m, 400-m and 700-m altitude. Also surveyed about 20 hydro lines at 300-m and 400-m altitude. Came back to Fort Lauderdale airport in the late evening.

Data collected: 030809 A, B, C, D

KGPS: YES, ground data collected by U of Florida.

Note: No KGPS for 02 topo lines.

10 Aug 03 Sun

Attempt was made to fly in the morning but could not fly because of PDU problem. PDU controller board was reporting wrong voltage value of 28 V. This was a problem with PDU microcontroller sense lines. To fix the problem, the PDU microcontroller firmware was modified to ignore inputs. Reporting of all other voltage found OK. There was no flight today and so did not collect any data.

In the late afternoon Optech modified scanner firmware for sensitivity. Decreased sensitivity from 0.96 to 0.90.

Data collected: NO

KGPS: NO

11 Aug 03 Mon

Target lines flown with a 300-m 2×2 pattern (8 lines). Five lines over the Navy Test Area were filled in (300 m 3×3). Five topo cal lines were flown over the water at 400 m.

Camera settings were adjusted:

White balance panel:	Overall gain from 6.0 to 5.0
Exposure control:	Max. gain from 20.0 to 15.0.

Data collected: 030811

KGPS: YES

12 Aug 03 Tue

Flew the southern target line at the same time as an AUV (2.4 m long, 0.5 m diameter). 16 lines were collected in a 300-m 2×2 pattern, and 11 topo lines at 300 m.

The Navy Test Area shoreline was flown with 2 topo lines at 300 m and 12 hydro lines at 300 m 2×2. Likely to be a gap in the hydro data.

Swapped HV board from HVP003 to HVP005. Set detector HV back to 1700 (from 1680), temperature coefficient to 1.6 and shallow green to 386 (from 396).

Data collected: 030812

KGPS: YES

13 Aug 03 Wed

Installed new operator interface version, but it did not work. Scanner power supply fuse blown. Swapped back in original scanner power supply (SSM 003).

Flew over South Florida Test Facility building. Surveyed over 14 hydro lines at 300 m 3×3, and 9 topo lines at 300 m.

Data collected: 030813

KGPS: YES

Note: No KGPS for data 030813_1952. No KGPS for lines 4-1, 4-2 and 5-1.

14 Aug 03 Thu

No flight today, collected no data.

15 Aug 03 Fri

Flew over South Florida Test Facility building and surveyed over 2 hydro lines at 400 m 3×3, and 6 topo lines at 400 m.

Also flew over target lines and surveyed 8 hydro lines at 400 m 3×3.

Took out Raman high voltage converter module from HVP 005 and put in HVP 004. This seems to work now so HVP 004 (coated) was put in CHARTS.

Data collected: 030815

KGPS: YES

Note: No KGPS for data 030815_1809.

16 Aug 03 Sat

Flew over South Florida Test Facility building and surveyed over 3 hydro lines N-S at 400 m 3×3, and 6 topo lines N-S at 400 m.

Also surveyed 3 topo and 3 hydro lines E-W at 400 m 3×3.

Data collected: 030816

KGPS: YES

Note: No KGPS for data 030816_1815.

17 Aug 03 Sun

Flew over South Florida Test Facility building and surveyed over 4 hydro lines at 300 m 3×3, 4 hydro lines at 300 m 2×2, and over 15 topo lines at 300 m.

Flew also over both target lines and surveyed over 04 hydro lines at 300m 3x3 & 04 hydro lines at 300m 4x4.

Data collected: 030817

KGPS: YES

Note: No KGPS for data 030817_1900.

18 Aug 03 Mon

Flew over target lines. Surveyed over 18 lines at 300 m with a pattern 2×2, 3×3 and 4×4.

Flew also over Intracoastal Waterway E-W and N-S, and surveyed over 12 lines at 300 m 3×3. Total flight duration 4 hours.

Data collected: 030818

KGPS: YES

19 Aug 03 Tue

Morning flight occurred over target lines. Surveyed over 11 lines at 300 m 3×3 and 4×4. Total flight time 1 hour and 30 minutes.

Took out both the antennas (AT 2775-81W & AT 3065-9W) from Beechcraft King Air 90 and shipped them to Kenn Borek Air Ltd., Calgary, via FedEx for King Air 200 installation.

Data collected: 030819

KGPS: YES

20 Aug 03 Wed

No flight today, so did not collect any data.

Laser head, power monitor jig, Molectron power meter with cables, and shipping cases for equipment arrived from Optech, Toronto.

21 Aug 03 Thu

No flight today, so did not collect any data.

22 Aug 03 Fri

No flight today, so did not collect any data.

In the afternoon Optech de-installed system equipment and cables from aircraft King Air 90.

23 Aug 03 Sat

No flight today, so did not collect any data.

Sensor cover arrived via Emery from Optech, Toronto.

24 Aug 03 Sun	King Air 200 arrived from Calgary (Kenn Borek Air Ltd.). Optech tried to install system but, due to mechanical problems, could not install chiller/laser rack. Swapped camera window blank for two Quantaray ND4X filter 25% transmission each.
25 Aug 03 Mon	Fixed the mechanical problems by fabricating new brackets for mounting of chiller rack. Tried to power up the system but could not do due to problems in circuit breaker of aircraft. Changed the circuit breaker and then powered up the system. Everything found OK. Found problem in radio link of aircraft so there was no flight today. Changed camera gain from 4 to 10.
27 Aug 03 Wed	Radio comm. problem finally fixed. First flight of system in KBA Beech 200 occurred late in the day with Bob Pope and Jeff Lillycrop as passengers. Air conditioning (A/C) did not work and the cabin temp rose to over 40°C by the end of the flight. Bob and Jeff were very hot! They did six topo lines along shore (300 m 3×3) and two hydro cal lines offshore. Real-time RMS position values were very high.
29 Aug 03 Fri	Despite the lack of A/C, Vlado went on a three-hour flight to try and collect data to validate the Beech 200. He did 6 topo lines 400 m and 2 hydro lines (400 m 5×5) along shoreline. Two topo lines at 700 m over SFTF; two hydro cal lines offshore; four hydro lines (300 m 3×3) over the target lines.
1 Sep 03 Mon	A/C in aircraft finally repaired at about noon. The first cool flight will be possible tomorrow after system is put back together.
2 Sep 03 Tue	Flight not possible in the morning due to weather.
3 Sep 03 Wed	Swapping spare PDU into CHARTS to fix display on the PDU. Updating the OI firmware to give PR display nose-up for both scales.
4 Sep to 10 Sep 03	Training survey flights flown over Bal Harbour, Biscayne Bay, Deer Key, Looe Key and Florida Bay.
12 Sep 03 Fri	Field Office closed up.

APPENDIX B: FLIGHT SUMMARY

Date Flown	Project Name	KGPS	Backup Directory Raidzone/CHARTS_BACKUPS	Flight Parameters
030802	FLL_Target Lines_Hollywood Beach Location: Hollywood Beach	NO NO NO	03AB03001_001_030802_1842 03AB03001_001_030802_1943 03AB03001_001_030802_2022	300m/4x4; 300m/3x3 E-W 400m/4x4; 400m/3x3 E-W **Note:** not usable due to Shallow Green problem; no opposing directions
030803	FLL_Navy Test Area_Port Everglades	NO	03AB03007_001_030803_2140	~ 20 Hydro lines offshore: 300m/4x4 02 Topo lines onshore 05 Hydro cal lines
030805 AM	FLL_Target Lines_Hollywood Beach Location: Hollywood Beach	NO NO NO	03AB03001_001_030805_1338 03AB03001_001_030805_1422 03AB03001_001_030805_1638	HT HT + HO HT + HO
030805	FLL_Target Lines_Hollywood Beach Location: Hollywood Beach	NO NO	03AB03001_001_030805_1727 03AB03001_001_030805_1744	02 Hydro lines, 300m/3x3 05 Hydro lines, 300m/3x3; 02 cal lines 400m/5x5
030805 PM	FLL_Target Area_Hollywood Beach Location: Hollywood Beach	YES	03AB03001_001_030805_2215	47 Hydro lines 300m/3x3; 300m/4x4; 400m/3x3; 400/4x4;

Date Flown	Project Name	KGPS	Backup Directory Raidzone/CHARTS_BACKUPS	Flight Parameters
030806 (2 flights)	Target Area FLL_Navy Test Area_Port Everglades Location: Port Everglades	YES NO YES YES YES	03AB03005_001_030806_0042 03AB03007_001_030806_1500 03AB03007_002_030806_1522 03AB03007_001_030806_1712 03AB03007_001_030806_2111	15 lines: 300m/4x4; 02 N-S Crosscheck lines HO + HT 14 Topo lines: 300m/0.7x2 HO; 18 Hydro lines: 300m/4x4 22 Hydro Lines: 300m/4x4
030807	FLL_Navy Test Area_Port Everglades Location: Port Everglades	YES	03AB03014_001_030807_1623	300m/3x3, ~ 40 lines, (over 5 hours!)
030808	FLL_Target Lines_Hollywood Beach Location: Hollywood Beach	YES NO	03AB03015_001_030808_1531 03AB03015_001_030808_1640	10 Hydro lines; 300m/2x2 (Note: do not use 3-1,3-3, 4-1, 1-2, 2-2 for comparison) – some PMT background. disappear in deep water 03 Hydro lines; 300m/2x2
030809	FLL_Runway_Gainesville Location: Gainesville Airport Runway	NO YES YES YES YES	03AB03019_001_030809_1435 03AB03020_001_030809_1713 03AB03019_001_030809_1845 03AB03019_001_030809_2032 03AB03017_001_030809_2225	Topo cal lines over water (2 lines) 10 Topo lines: 300m; 12 Hydro lines: 300m/3x3 05 Topo lines: 400m; 06 Hydro lines: 400m/5x5 06 Topo lines: 400m; 04 Hydro lines: 400m/5x5 10 Topo lines: 700m
030811	FLL_Target Lines_Hollywood Beach FLL_Navy Test Area_Port Everglades	YES YES	03AB03015_001_030811_1414 03AB03014_001_030811_1514	08 Hydro lines: 300m/2x2 05 Hydro: 300m/3x3; 05 Topo lines: 400m over water

Date Flown	Project Name	KGPS	Backup Directory Raidzone/CHARTS_BACKUPS	Flight Parameters
030812	FLL_Target Lines_Hollywood Beach	YES	03AB03015_001_030812_1651	14 Hydro: 300m/2x2; HO + HT some PMT background. disappear in deep water
	FLL_Navy Test Area_Port Everglades	YES	03AB03014_001_030812_2215	02 Hydro: 300m/2x2; 11 Topo: 300m
		YES	03AB03014_001_030812_2344	12 Hydro: 300m/2x2; 02 Topo: 300m ; HO + HT
030813	Test Facility Building	NO	03AB03021_001_030813_1952	HO + HT
		YES	03AB03021_001_030813_2007	HT; 12 Hydro lines: 300m/3x3
		YES*	03AB03021_001_030813_2126	02 Hydro lines: 300m/3x3; 09 Topo lines: 300m Note: no KGPS for lines 4-1, 5-1(H),and 4-2(T)
030815	Test Facility Building	NO	03AB03024_001_030815_1809	HO + HT
	Target Lines	YES	03AB03025_001_030815_1841	02 Hydro lines: 400m/3x3; 06 Topo lines: 400m
		YES	03AB03024_001_030815_1930	HO; 08 Hydro lines: 300m/3x3
030816	Test Facility Building	NO	03AB03025_002_030816_1815	HT
		YES	03AB03025_002_030816_1827	HT; 03 Hydro lines NS over SFTF: 400m/3x3; 06 Topo lines NS over SFTF: 400m
		YES	03AB03025_002_030816_1947	03 Topo lines EW over SFTF: 400m; 03 Hydro lines EW and NS over SFTF: 400m/3x3; HO + HT
030817	Test Facility Building	YES	03AB03025_002_030817_1548	HO + HT + TO; 04 Hydro lines: 300m/3x3 over SFTF; 09 Topo lines: 300m over SFTF
		YES*	03AB03025_002_030817_1714	HT; 02 Topo lines @ 300 m over SFTF (41 no KGPS), 42 KGPS OK but over water only?!
		NO	03AB03025_002_030817_1900	01 Topo line: 300m – NO DATA?
		YES	03AB03025_002_030817_1919	HT; 04 Topo lines @ 300m over SFTF; 04 Hydro lines: 300m/2x2 over SFTF
	Target Lines	YES	03AB03024_002_030817_2021	HT; 04 Hydro lines: 300m/3x3 over both Target Lines 04 Hydro lines: 300m/4x4 over both Target Lines

Date Flown	Project Name	KGPS	Backup Directory Raidzone/CHARTS_BACKUPS	Flight Parameters
030818	Target Lines	YES	03AB03026_001_030818_1910	06 Hydro lines: 300m/4x4
		YES	03AB03026_002_030818_1838	04 Hydro lines: 300m/3x3
		YES	03AB03015_002_030818_1939	HT; 08 Hydro lines: 300m/2x2
	Intercoastal	YES	03AB03027_001_030818_1653	HT; 12 Hydro lines: 300m/3x3
030819	Target Lines	YES	03AB03026_001_030819_1245	HT; 06 Hydro lines: 300m/3x3
		YES	03AB03026_001_030819_1330	HT; 05 Hydro lines: 300m/4x4
030819	Antennas sent to Calgary			
030822	System removed from A90			
030824	System installed on KBA Beechcraft 200			
030827	Target Lines No 3 Test Facility Building	Data Collect	03AB03024_003_030827_2328 03AB03024_003_030828_0021	06 Hydro lines 300/3x3, one H_T 02 Hydro Cal Lines NOTE: real-time RMS positions VERY high for entire flight.
030829	FLL_Navy Test Area_No 3	Data Collect	03AB03028_001_030829_1307	06 Topo Lines 400 m along shoreline & inland; 02 Hydro 400/5x5 along shore; H_T
	Test Facility Building		03AB03021_002_030829_1434	02 Topo lines at 700 m over SFTF
	Target Lines_ No3		03AB03028_001_030829_1450	02 Hydro cal lines offshore 400/5x5
	FLL_Navy Test Area No 3		03AB03024_003_030829_1517	04 Hydro lines 300/3x3 over target lines; H_T
030904	Bal Harbor Production (for training)	YES YES	03AB03025_001_030904_1312 03AB03006_001_030904_2209	Test project for training – data of little value. Three different Master Projects on 3 different CHARTS machines
030905	Bal Harbor Prod (for training)	YES	03AB03003_001_030905_1239	Test project for training – see above
	Target Lines No3	YES	03AB03024_003_030905_1737	09 Hydro + 01 H_T – for calculating deep bias (300/400)
	Target Lines No3	NO	03AB03024_003_030905_1902	06 Hydro + 01 H_T – for calculating deep bias(300/400)

Date Flown	Project Name	KGPS	Backup Directory Raidzone/CHARTS_BACKUPS	Flight Parameters
030907	Biscayne Bay (028)	Got base station	03AB03028_001_030907_2035	32 Hydro lines; 01 H_T Production Survey completed
030908	Deer Key (026) Looe Key (027)	Base station	03AB03026_001_030908_1439 03AB03027_001_030908_1203	17 Hydro lines; 01 H_T Production Survey 10 Hydro lines; 01 H_T Production Survey
030909	Deer Key (026) Looe Key (027)	Got base station	03AB03026_001_030909_1203 03AB03026_002_030909_1248 03AB03026_002_030909_1444 03AB03026_002_030909_1510 03AB03027_001_030909_1320 03AB03027_001_030909_1522	01 H_O; 01 H_T Production Survey cont'd 02 Topo lines 01 Topo line 01 Topo line 10 Hydro lines Production Survey cont'd 06 Hydro lines; 01 H_T
030910	Florida Bay (Two flights, ~ 7 hours)		03AB03000_001_030910_1336 03AB03000_001_030910_1356 03AB03000_001_030910_1906	01 H_T line 18 Hydro Lines Production Survey 20 Hydro Lines Production Survey

APPENDIX C: VERTICAL DEPTH ACCURACY RESULTS

This appendix lists vertical depth accuracy results for the 11 target areas used in this test. For more information, see Section 7.1.2, page 24.

Location - Area 1

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_NTA_03DS03014_001_0308073_1623_A (1_1, 12_1, 13_1)	3x3	3171	0.1650	0.100060	0.37	-7.51	-7.67
KGPS_NTA_03DS03007_001_030806_1712 _A (10_1, 11_1)	4x4	1820	0.1299	0.085422	0.39	-7.52	-7.74
KGPS_TL_03DS03001_001_030805_2021 _A (02_2)	3x3	1604	0.1704	0.096188	0.36	-7.53	-7.70
KGPS_TL_03DS03024_001_030815_1930_A (02_1, 02_2, 02_3, 02_4)	3x3	4979	-0.0042	0.127590	0.26	-7.77	-7.76
KGPS_TL_03DS03001_001_030805_2215_A (02_1, 02_2, 02_9, 03_1, 03_2, 03_3)	3x3	8794	0.1460	0.092966	0.33	-7.53	-7.68
KGPS_TL_03DS03026_002_030818_1838_A (01_1, 01_2, 01_3)	3x3	4033	0.1195	0.099777	0.32	-7.63	-7.75
KGPS_TL_03DS03015_001_030808_1531_A (03_1, 03_2, 03_3, 04_1, 04_2)	2x2	8263	0.1737	0.116780	0.41	-7.63	-7.80
KGPS_TL_03DS03015_001_030811_1414_A (03_1, 03_2, 04_1, 04_2)	2x2	5933	0.1540	0.097949	0.35	-7.66	-7.82

Location - Area 2

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (17_1, 18_1, 19_1, 20_1)	3x3	4376	0.1315	0.095456	0.32	-11.51	-11.64
KGPS_28100_03DS03007_001_030806_1712 _A (14_1)	4x4	612	0.0357	0.049693	0.14	-11.59	-11.62
KGPS_28100_03DS03007_001_030806_2111 _A (15_1, 16_1)	4x4	2766	0.1799	0.076240	0.33	-11.47	-11.65
KGPS_TL_03DS03001_001_030805_2021 _A (02_2)	3x3	2300	-0.0080	0.062852	0.12	-11.58	-11.57
KGPS_TL_03DS03024_001_030815_1930_A (02_1, 02_2, 02_3, 02_4)	3x3	8211	-0.1486	0.094539	0.34	-11.70	-11.55
KGPS_TL_03DS03001_001_030805_2215_A (02_1, 02_2, 02_9, 03_1, 03_2, 03_3)	3x3	11565	-0.0311	0.073034	0.18	-11.61	-11.58
KGPS_TL_03DS03026_002_030818_1838_A (01_1, 01_2, 01_3)	3x3	5980	-0.0688	0.075709	0.22	-11.63	-11.56
KGPS_TL_03DS03015_001_030808_1531_A (03_1, 03_2, 03_3, 04_1, 04_2)	2x2	11500	0.0316	0.114930	0.26	-11.51	-11.54
KGPS_TL_03DS03015_001_030811_1414_A (03_1, 03_2, 04_1, 04_2)	2x2	7629	-0.0222	0.054019	0.13	-11.54	-11.51

Location - Area 3

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (22_1, 23_1, 24_3)	3x3	2985	0.1292	0.074990	0.28	-19.74	-19.87
KGPS_28100_03DS03014_001_030811_1514 _A (23_1, 24_1, 25_1)	3x3	3786	0.0642	0.083771	0.23	-19.85	-19.91
KGPS_28100_03DS03007_001_030806_2111 _A (18_1, 18_2, 18_3, 19_2, 19_3)	4x4	4856	0.1479	0.104550	0.36	-19.79	-19.94
KGPS_TL_03DS03001_001_030805_2021 _A (02_2)	3x3	2339	0.0478	0.096006	0.24	-19.82	-19.87
KGPS_TL_03DS03024_001_030815_1930_A (02_1, 02_2, 02_3, 02_4)	3x3	7483	-0.0923	0.131700	0.36	-19.94	-19.85
KGPS_TL_03DS03001_001_030805_2215_A (02_1, 02_2, 02_9, 03_1, 03_2, 03_3)	3x3	12287	0.1100	0.104470	0.32	-19.76	-19.87
KGPS_TL_03DS03026_002_030818_1838_A (01_1, 01_2, 01_3)	3x3	6220	0.0111	0.097809	0.21	-19.85	-19.86
KGPS_TL_03DS03015_001_030808_1531_A (03_1, 03_2, 03_3, 04_1, 04_2)	2x2	11763	0.0985	0.157590	0.41	-19.76	-19.86
KGPS_TL_03DS03015_001_030811_1414_A (03_1, 03_2, 04_1, 04_2)	2x2	5364	0.0449	0.128450	0.30	-19.82	-19.86

Location - Area 4

HOF File	Spacing	Points #	Diff Mean	Diff. Std. Dev	Mean + 2*Stddev	Data Mean	Ref. Mean
KGPS_28100_03DS03007_001_030806_2111 _A (26_1, 27_1)	4x4	479	0.0728	0.277030	0.63	-37.71	-37.78

Location - Area 5

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (12_1, 13_1, 14_1)	3x3	4686	0.121	0.113390	0.35	-9.05	-9.17
KGPS_28100_03DS03007_001_030806_1712 _A (10_1, 11_1, 12_1)	4x4	2647	0.2271	0.117660	0.46	-8.89	-9.11
KGPS_TL_03DS03024_001_030815_1930_A (01_1, 01_2, 01_3, 01_4)	3x3	1788	-0.1794	0.158170	0.50	-9.32	-9.14
KGPS_TL_03DS03001_001_030805_2215_A (01_2, 01_7, 01_8, 01_9, 04_1, 04_2)	3x3	10643	0.0612	0.127400	0.32	-8.99	-9.05
KGPS_TL_03DS03026_002_030818_1838_A (02_1, 02_2, 02_3)	3x3	5310	0.0311	0.142870	0.32	-8.99	-9.03
KGPS_TL_03DS03015_001_030808_1531_A (01_1, 01_2, 01_3, 02_1, 02_2)	2x2	10247	0.1483	0.121100	0.39	-8.87	-9.02
KGPS_TL_03DS03015_001_030811_1414_A (01_1, 01_2, 02_1, 02_2)	2x2	6818	0.0829	0.119700	0.32	-8.92	-9.01

Location - Area 6

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_0308073_1623 _A (18_1, 19_1, 20_1, 21_1)	3x3	4178	0.2246	0.092073	0.41	-11.56	-11.78
KGPS_28100_03DS03007_001_030806_2111 _A (15_1, 16_1, 17_1)	4x4	2961	0.1955	0.096181	0.39	-11.54	-11.73
KGPS_TL_03DS03024_001_030815_1930_A (01_1, 01_2, 01_3, 01_4)	3x3	7100	-0.0601	0.097019	0.25	-11.89	-11.83
KGPS_TL_03DS03001_001_030805_2215_A (01_2, 01_7, 01_8, 01_9, 04_1, 04_2)	3x3	11438	0.0150	0.106130	0.23	-11.80	-11.81
KGPS_TL_03DS03026_002_030818_1838_A (02_1, 02_2, 02_3)	3x3	5157	-0.0287	0.100600	0.23	-11.87	-11.84
KGPS_TL_03DS03015_001_030808_1531_A (01_1, 01_2, 01_3, 02_1, 02_2)	2x2	11221	0.0768	0.095150	0.27	-11.80	-11.88
KGPS_TL_03DS03015_001_030811_1414_A (01_1, 01_2, 02_1, 02_2)	2x2	7100	0.0311	0.083342	0.20	-11.85	-11.88

Location - Area 7

HOF File	Spacing	Points	Diff Mean	Diff Std. Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (28_1, 29_1, 30_1)	3x3	4954	-0.0003	0.126880	0.25	-17.75	-17.75
KGPS_28100_03DS03007_001_030806_2111 _A (22_1, 23_1, 24_1, 24_2)	4x4	3026	0.0124	0.166790	0.35	-17.71	-17.72
KGPS_TL_03DS03024_001_030815_1930_A (01_1, 01_2, 01_3, 01_4)	3x3	6586	-0.1464	0.149420	0.45	-17.86	-17.71
KGPS_TL_03DS03026_002_030818_1838_A (02_1, 02_2, 02_3)	3x3	4744	-0.1325	0.208710	0.55	-17.85	-17.72
KGPS_TL_03DS03015_001_030811_1414_A (01_1, 01_2, 02_1, 02_2)	2x2	5416	-0.1649	0.141410	0.45	-17.86	-17.7

Location - Area 8

HOF File	Spacing	Points	Diff Mean	Diff Std. Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03007_001_030806_2111 _A (27_1, 28_1)	4x4	1429	0.069	0.238200	0.55	-37.06	-37.13

Location - Area 9

HOF File	Spacing	Points	Diff Mean	Diff Std. Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_TL_03DS03015_001_030811_1414_A (03_1, 04_1)	2x2	577	0.096	0.181340	0.46	-45.85	-45.95

Location - Area 10

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (25_1, 26_1)	3x3	815	-0.0646	0.115180	0.29	-25.91	-25.84
KGPS_28100_03DS03014_001_030811_1514 _A (25_1, 26_1)	3x3	1320	0.0377	0.123990	0.29	-25.8	-25.84
KGPS_28100_03DS03007_001_030806_2111 _A (20_1, 20_3, 21_1)	4x4	796	0.0796	0.108590	0.30	-25.72	-25.8
KGPS_TL_03DS03024_001_030815_1930_A (02_2, 02_3, 02_4)	3x3	861	-0.0964	0.220910	0.54	-25.93	-25.83
KGPS_TL_03DS03001_001_030805_2215_A (02_1, 02_2, 02_9, 03_1, 03_2, 03_3)	3x3	4027	0.0411	0.089187	0.22	-25.78	-25.82
KGPS_NTA_03DS03026_002_030818_1838_A (01_1, 01_2, 01_3)	3x3	1951	-0.0241	0.116240	0.26	-25.85	-25.83
KGPS_TL_03DS03015_001_030808_1531_A (03_1, 04_1, 04_2)	2x2	1700	0.0073	0.124580	0.26	-25.84	-25.84

Location - Area 11

HOF File	Spacing	Points	Diff Mean	Diff Std Dev	Mean + 2*Std Dev	Data Mean	Ref Mean
KGPS_28100_03DS03014_001_030807_1623 _A (30_1, 31_1, 32_1)	3x3	3795	0.2129	0.205260	0.62	-30.59	-30.8
KGPS_28100_03DS03007_001_030806_2111 _A (23_1, 24_2, 25_1, 25_2)	4x4	2880	0.177	0.124580	0.43	-31.03	-31.2

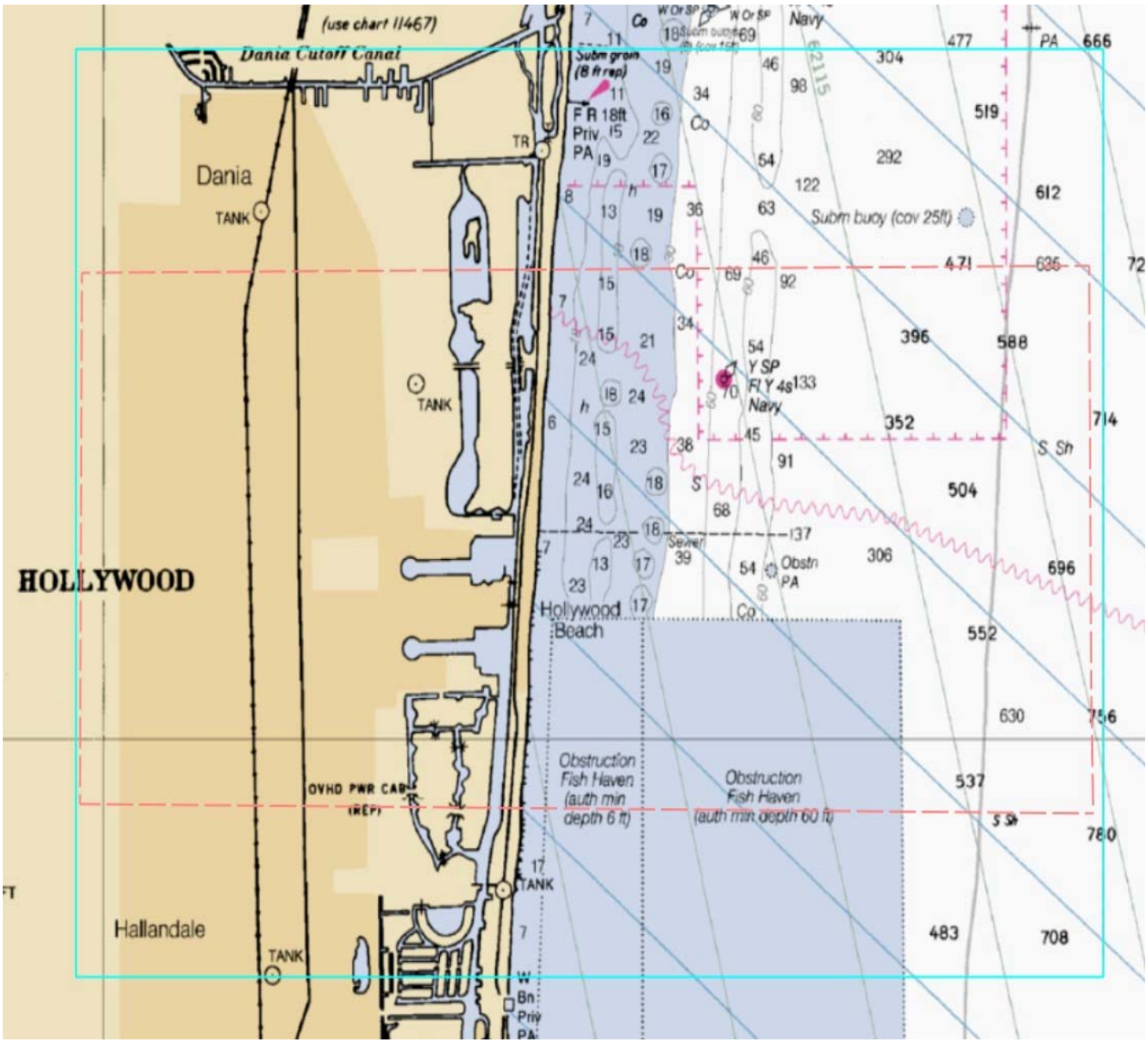
APPENDIX D: CONTROL AREA MAP COORDINATES

This appendix illustrates the map coordinates for the control areas used during the CHARTS field tests:

- Hollywood Beach
- Shoreline Bal Harbor
- Deer Key
- Biscayne Bay
- Gainesville Airport Runway
- Navy Test Area.

Hollywood Beach

Upper Left: Lat: 26° 3.791 Long: -80° 10.204	**Lower Right**: Lat: 25° 58.712 Long: -80° 2.784
Bounds of Survey Area(s):	Bounds of Project Area:



Shoreline Bal Harbor

Upper Left:

Lat: 26° 6.711

Long: -80° 8.225

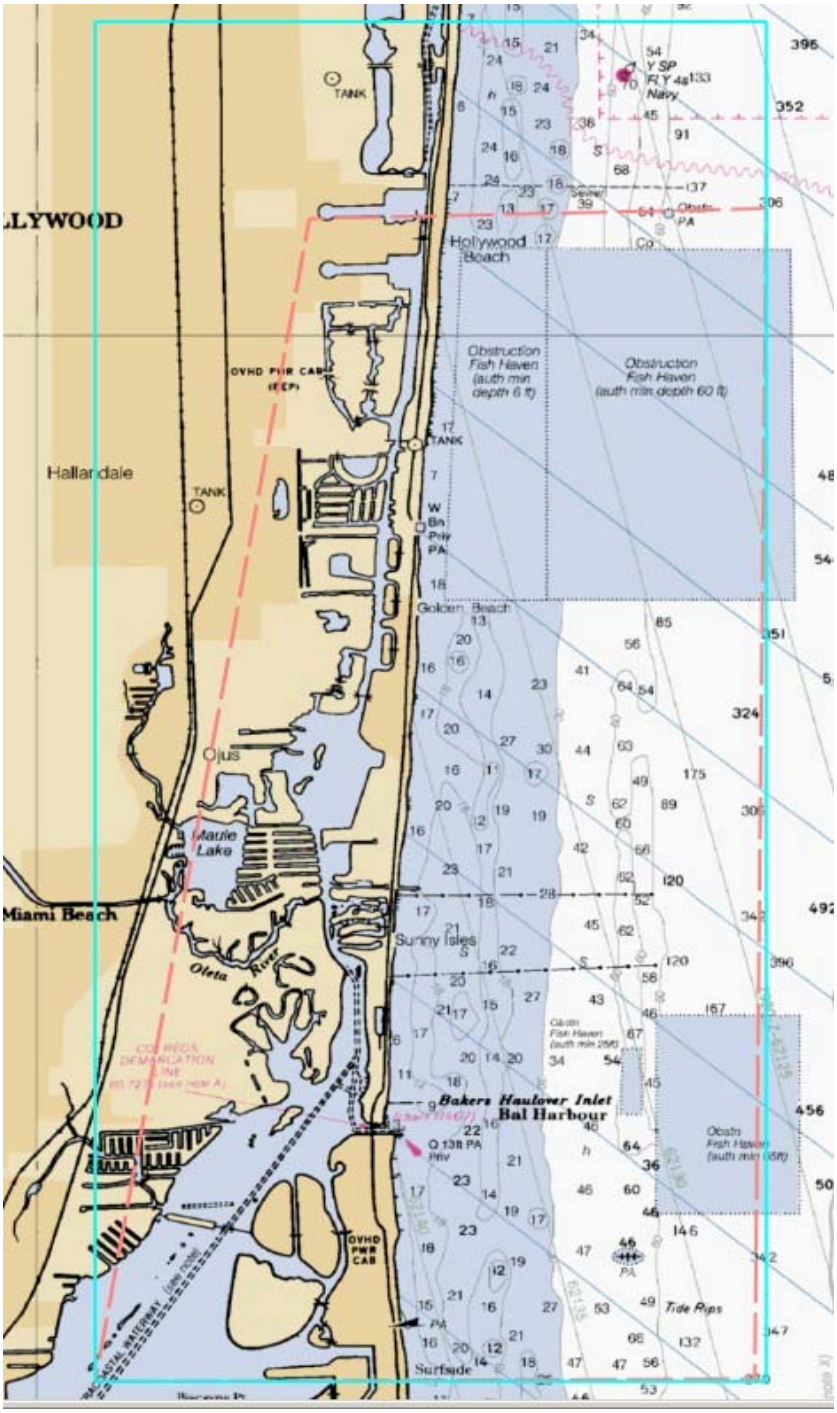
Lower Right:

Lat: 25° 59.164

Long: -80° 3.626

Bounds of Survey Area(s):

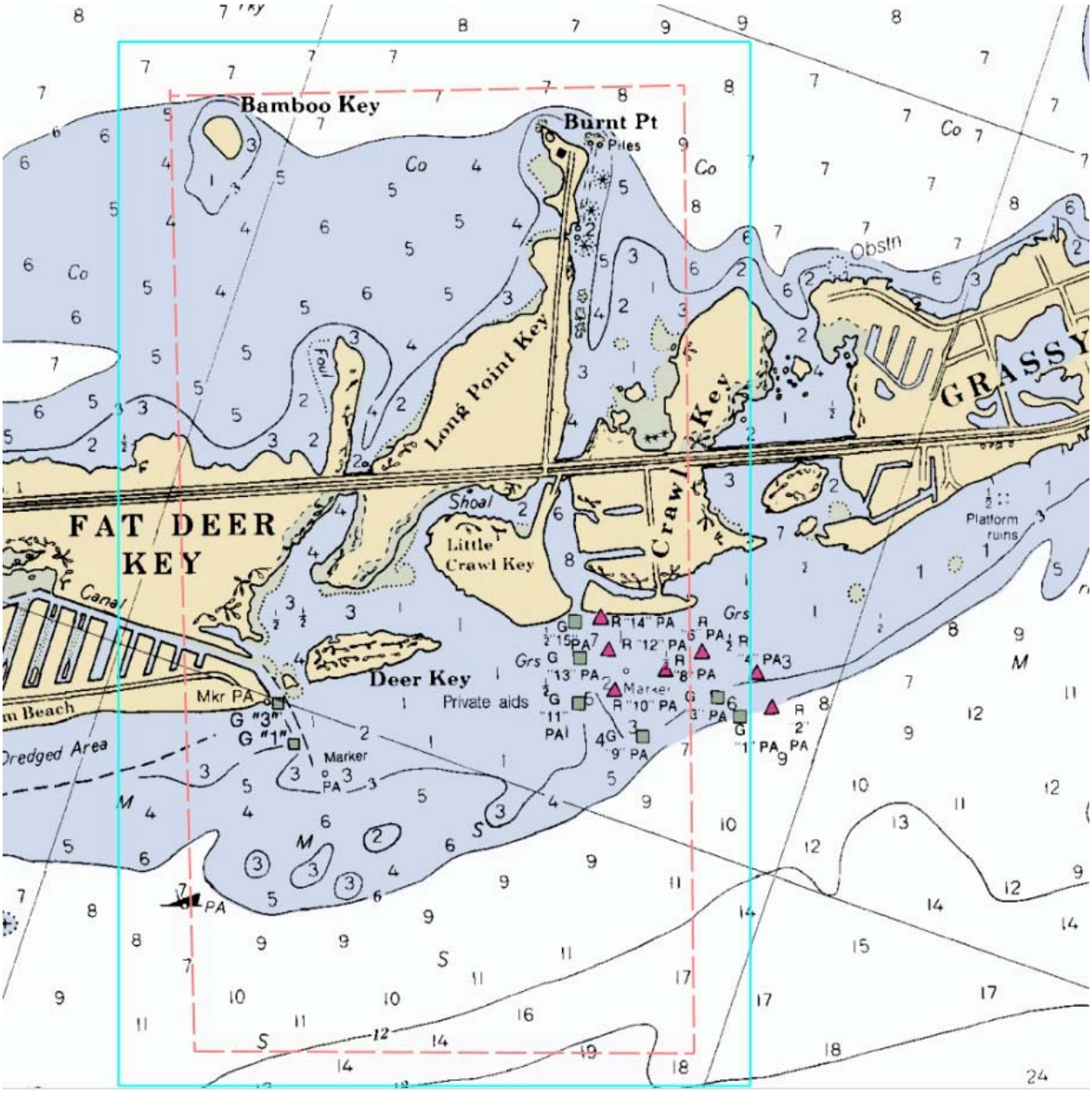
Bounds of Project Area:



Deer Key

Upper Left: Lat: 24° 45.344 Long: -81° 0.658 **Lower Right**: Lat: 24 ° 42.835 Long: -80° 58.950

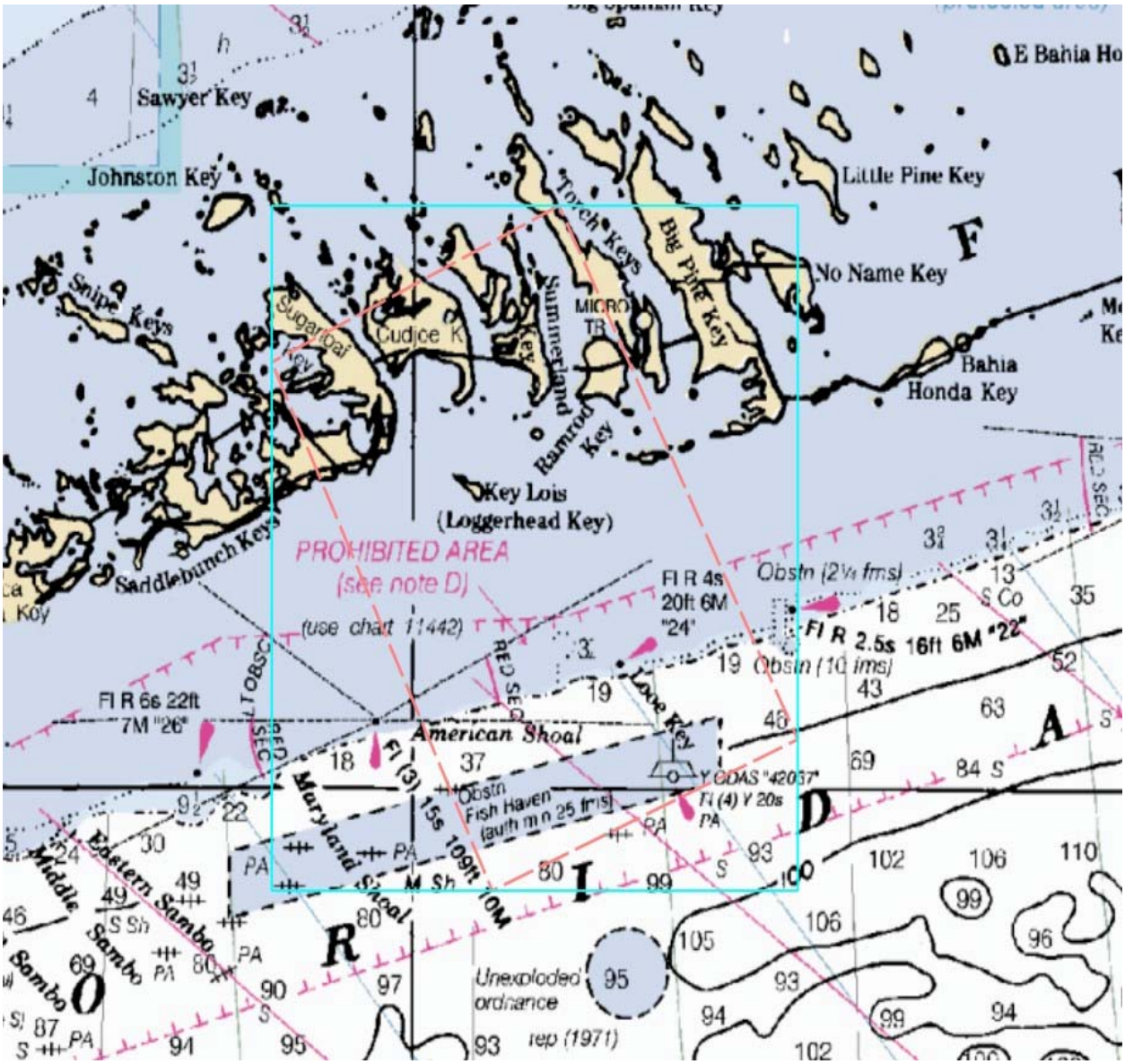
Bounds of Survey Area(s): Bounds of Project Area:



Biscayne Bay

Upper Left: Lat: 24° 42.537 Long: -81° 33.835 **Lower Right**: Lat: 24 ° 27.137 Long: -81° 19.379

Bounds of Survey Area(s) Bounds of Project Area:



Gainesville Airport Runway

Upper Left: Lat: 29.42.596 Long:-82 17.628	**Lower Right**: Lat: 29 40.206 Long: -82 14.919
Bounds of Survey Area(s):	Bounds of Project Area:

Navy Test Area

Upper Left: Lat: 26° 6.711 Long: -80° 8.225	**Lower Right**: Lat: 25° 59.164 Long: -80° 3.626
Bounds of Survey Area(s):	Bounds of Project: