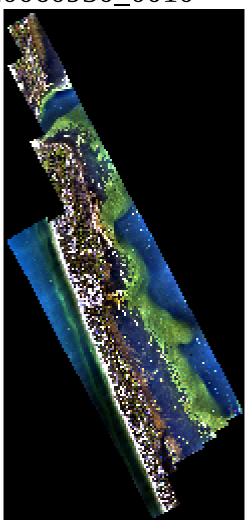
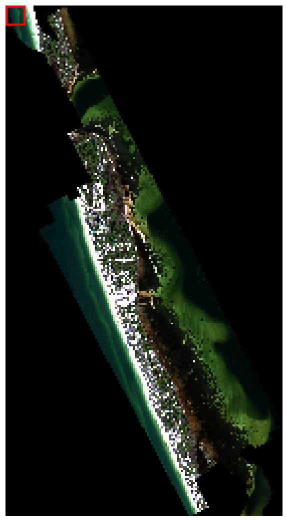
St. Joseph Bay Aquatic Preserve
Hyperspectral Imaging

FINAL REPORT

DSS 20060930_0010



SAMSON 20060930_0010



Prepared by Florida Environmental Research Institute

Prepared for the Florida Department of Environmental Protection
Office of Coastal and Aquatic Managed Areas

DEP Contract No. RM055

December 30, 2006

1.0 INTRODUCTION

Hyperspectral analysis is an excellent means of obtaining high-resolution imagery of seagrass coverage, bottom types, and some water quality measures. The primary objective of this Task Assignment is to collect and analyze hyperspectral imagery (HSI) for seagrass mapping in the St. Joseph Bay State Buffer Preserve (**Figure 1**), one of the aquatic preserves in Florida.

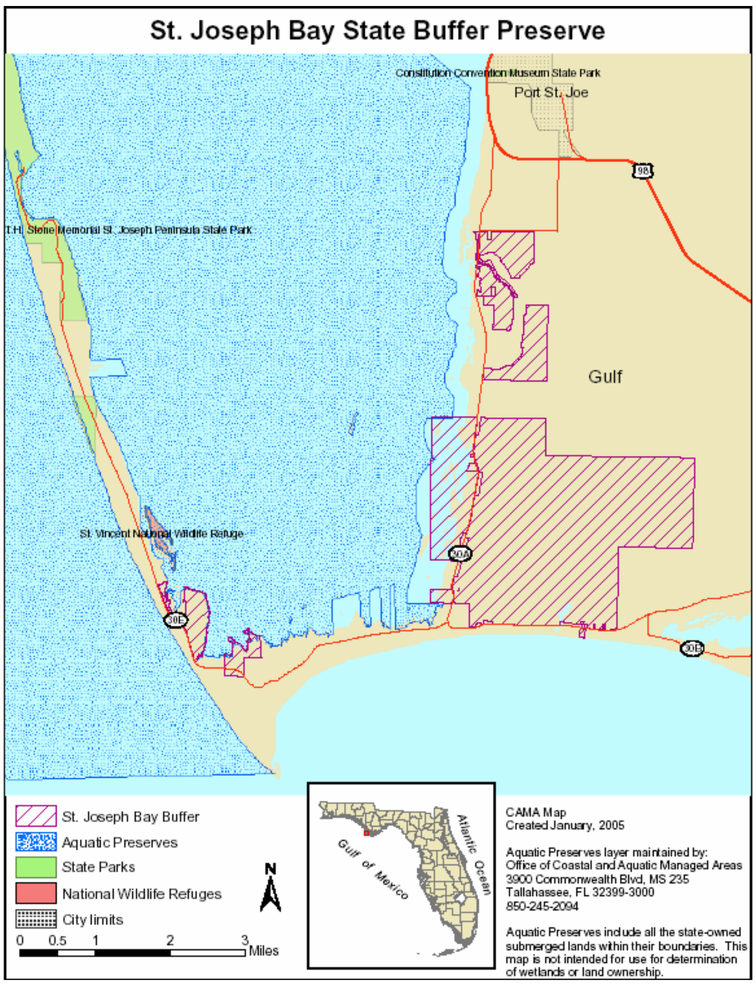


Figure 1. Map of St. Joseph Bay State Buffer Preserve (produced by CAMA).

2.0 FIELD DATA COLLECTION ACTIVITIES

Hyperspectral data were collected for St. Joseph Bay occurred on September 29 and 30, 2006. The field collection of these high resolution data involves several stages. The sensor must be radiometrically calibrated, mounted in the aircraft with appropriate adjustments for lens distortion, 3-D location of the sensor within the aircraft, and to determine the sensor's pointing direction. On the ground, the locations of aerial and aquatic targets are surveyed, and optical measurements of water quality (**Appendix A**) were collected from fixed stations throughout the project area. The raw HSI, inertial navigation data, SWFA, and flight logs were archived. Details of the field collection activities have been previously described in the Field Report (FERI 2006).

3.0 SENSOR DESCRIPTION

Operations in this low-light environment require a hyperspectral sensor designed and engineered to address four specific issues: (1) low-light sensitivity, (2) high signal-to-noise, (3) high dynamic range, and (4) absolute radiometric calibration.

The hyperspectral sensor system used for this project is SAMSON (Spectroscopic Aerial Mapping System with Onboard Navigation). The SAMSON imaging system also includes a 200 Hz survey grade positioning system (Trimble Applanix 410 Position and Orientation Systems for Aviation) on a 100 Hz 3-axis stabilized mount (Applanix IMU) and a high resolution 3-band framing digital ortho-photography system (Trimble Applanix Digital Sensor System 322). The SAMSON components are integrated with the flight management system to enable real-time management of data collection and flight orientation.

The HSI sensor incorporates improved spectral alignment, radiometric calibrations and atmospheric correction procedures. The charge coupled device (CCD) used in the SAMSON sensor is a thinned, backside-illuminated CCD (produced by Sarnoff Imaging). The CCD manufacturing process greatly increases the quantum efficiency from about 5% to 60% at 400 nm, and from about 40% to 85% at 700 nm. To improve blue light sensitivity, the Headwall HyperSpec VS-15 Offner Spectrograph was optimized for the shorter wavelengths.

4.0 FLIGHT LINE PARAMETERS

Specialized flight planning for the marine environment is a critical issue for the collection of robust HSI data. The downwelling light field (i.e. the sun) must be optimized for penetration of the water, while reducing the probability of direct solar reflection into the sensor. The optimization of the sensor deployment period and geometry relative to target is dependent on latitude, Day-Of-Year (DOY), and Time-Of-Day (TOD). Successful deployments require complex calculations that exactly place the sensor position relative to the target.

When the exact latitude, DOY, and TOD are known, then flight lines and times may be created in advance of deployment. FERI has created custom software that will make the advanced deployment calculations for any marine imaging sensors within minutes of deployment. The output from this software includes digital maps, as well as text based coordinate files that may be automatically imported into charting (e.g. Nobletec) or flight management (i.e. POSTrack) software. This software was used to pre-determine the St. Joseph Bay flight paths (**Figure 2**) and provide adaptive sampling capabilities.

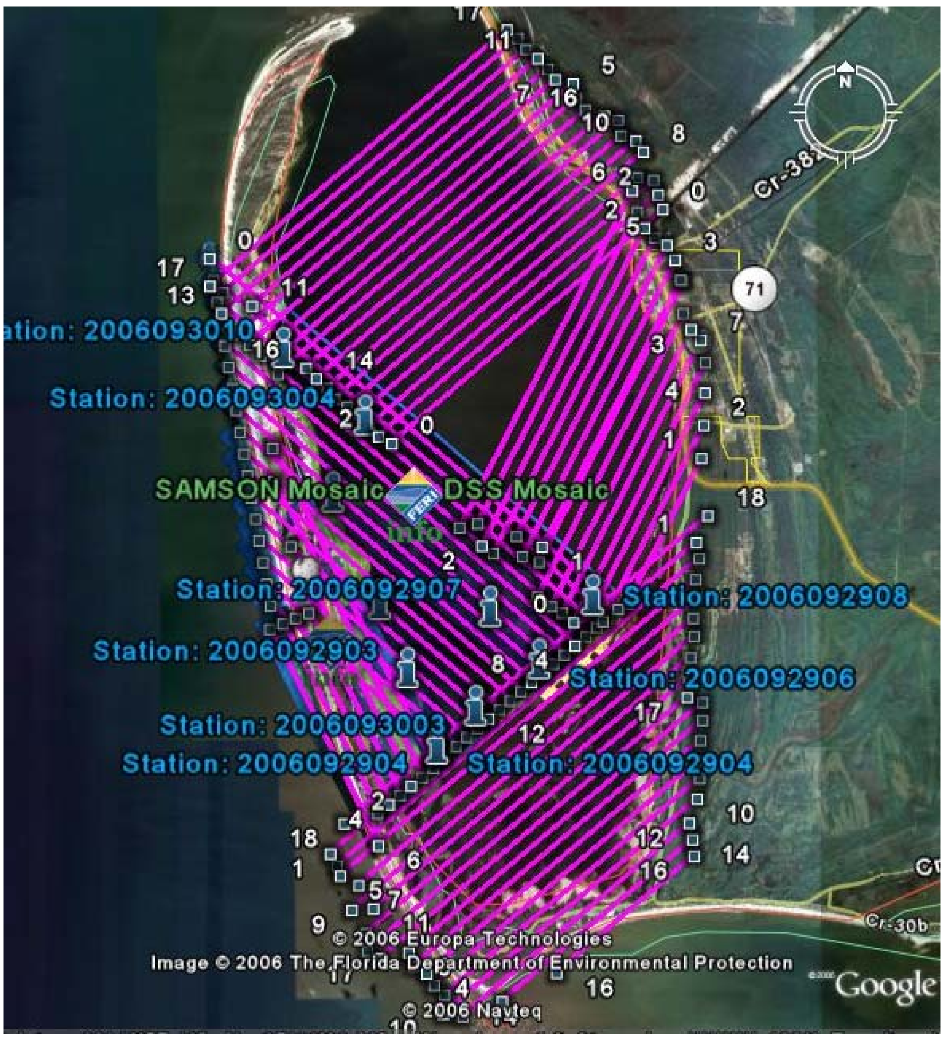


Figure 2. Actual Flight Lines for the St. Joseph Bay State Buffer Preserve Seagrass Project.

5.0 DATA PROCESSING

The raw HIS data need to be processed to remove dark areas, correct for smile, keystone, and atmospheric effects, and to georectify the images.

5.1 Level One Processing

During Level One processing, the images are radiometrically and geometrically corrected.

5.1.1 Radiometric Correction

Radiometric correction of the hyperspectral data begins with removal of the dark current. At the end of each flight line, a mechanical shutter is automatically closed and about 1,000 frames are collected. These are averaged to give the operational baseline for the data which is subtracted from each frame. A spectral calibration is applied which relates each pixel to a spectral band and corrects for ‘smile’ and ‘keystone’ effects. Smile and keystone effects represent the slight curvatures produced by the optical elements in two-dimensional image detectors. In a perfect spectral image detector, the spectral and spatial information would be orthogonally projected onto the detector matrix. Smile refers to the curvature of the spectral dispersion data; keystone refers to the curvature of the spatial information. SAMSON optics have been designed to minimize smile and keystone effects and function well below the tolerances of the ground spatial dimensions for this project. The last step in radiometric calibration is conversion of the digital readout to physical units of $W/m^2/nm/sr$ by multiplication by the radiometric calibration coefficients.

5.1.2 Geometric Correction

To derive the accurate location of each sensor pixel on the surface of the geoid, it is necessary to apply a geometric correction. The geometric correction is composed of several parts. These include:

- the pointing angles for each detector element through the lens,
- the boresighting angles relative to the aircraft and GPS antenna,
- the instantaneous inertial navigation data of GPS location, pitch, roll, and heading, and
- GPS corrections from fixed ground-based receivers.

FERI applied these factors in several applications to derive an Input Geometry file (IGM) which contains the pixel map information in two bands, x = longitude or easting and y = latitude or northing and then a Geographic Lookup Table (GLT) for the output pixel geometry.

5.1.3 Create 3-band RGB Mosaic

Two types of mosaic images are created.

- RGB mosaics for quick looks which are comparable to full spectral and RGB aerial photographs and
- full spectral images which are atmospherically corrected with a complete data analysis.

5.2 Level 2 Processing

We used the tabularized version of *Tafkaa* to atmospherically correct the HSI data sets. Derived from the standard atmospheric correction model ATmospheric REMoval (ATREM), *Tafkaa* was developed by the Naval Research Laboratory (See Montes and Gao [2004] NRL Atmospheric Correction Algorithms for Oceans: *Tafkaa* User's Guide, NRL/MR/7230—04-8760). The *Tafkaa* tables are pre-calculated for a variety of scattering aerosols and atmospheres. The sensor and solar geometries are directly derived from the data's time stamp and positional information. The environmental conditions are selected by the user. The parameters that *Tafkaa* tables use are solar irradiance, ozone concentration, aerosol optical thickness, water vapor, wind speed, aerosol model, and relative humidity. Guided by the solar and sensor geometries and the user-specified environmental conditions, the solution from the *Tafkaa* table is applied to the HSI data set.

The sensor position relative to the nadir view is absolutely critical in the application of atmospheric correction procedures over dark targets, i.e. water targets. A few degrees off nadir can significantly impact the length of the radiance path from target to sensor. In addition, the path scattered radiance is significantly altered when flying into and out of the sun, with an aircraft pitch angle of only a few degrees. Most tabularized atmospheric correction codes, including *Tafkaa*, do not account for the relative pitch error impacts on atmospheric correction. To minimize pitch error impact, we use a 100 Hz 3-axis stabilized mounting system that holds the sensor to with 0.1 degrees of nadir at all times. This provides the best positioning and viewing angle by which to retrieve any in water classification and feature mapping from the water leaving radiance signal.

We use *Tafkaa* in two modes. In the first mode, *Tafkaa* is parameterized with known atmospheric information from various ground and satellite instrumentation. In the second mode, representative Rrs spectra from the scene are collected and used in a genetic algorithm (GA) to aid in the selection of the most appropriate atmospheric conditions. The GA searches the atmospheric parameter space by testing different combinations of atmospheric constraints. Each parameter set is evaluated by running it through *Tafkaa* and comparing the output to ground truth data. Parameter sets that produced results that resemble the ground truth data are retained.

5.3 Radiometric Accuracy

FERI's calibration laboratory is equipped with a NIST-traceable, 1000 Watt (FEL) quartz-halogen, tungsten-coiled filament lamp standard of spectral irradiance. The lamp, designation F-483, was supplied by Optronics Laboratories with a calibration certification which is traceable to a NIST FEL 1000W lamp standard of spectral irradiance (S/N F-578 NIST Test No. 844/271252). The calibration certificate was issued on May 31, 2006 and is good for 50 hours of lamp operation. The lamp is powered by an Optronics Laboratories OL83 Programmable Constant Current Source S/N 06220236 which was calibrated against four precision shunts and five certified digital multimeters on May 24, 2006. The combined uncertainty for the FEL-483/OL83A from 350-900 nm is quoted by Optronics to be less than 1.34%. The lamp is operated at FERI following the NIST guidelines of a distance of 50cm, a constant current and a constant voltage of 8.0 VDC. The FEL-483/OL83A is the source of the NIST-traceable chain for all transfer calibrations within the FERI calibration laboratory. The SAMSON hyperspectral imager was calibrated against this standard on August 5, 2006, prior to installation and deployment for the St. Joseph Bay Fall 2006 flights.

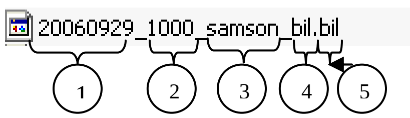
5.4 Geometric Accuracy

The Surveyor's Report (**Appendix B**, Field Report; FERI, 2006) reported the accuracy of the georeferenced photographed survey targets to be within 1 meter (SD = 2.37 ft; maximum distance = 3.06 ft).

6.0 DATA FILE STRUCTURE

The final corrected HSI data have been provided on a hard drive to FDEP. The data files are organized by image type: Hyperspectral Images and Digital High Resolution RGB Images.

The file naming conventions for each image type are similar. The file names consist of 5 basic parts.



1) Date of Collection
2) Time of Collection
   a. 0001 = AM
   b. 0010 = AM Noon
   c. 0100 = PM Noon
   d. 1000 = PM
3) Type of Sensor used
   a. Samson – Hyperspectral
   b. DSS – High Resolution Digital Frame Camera
4) Image File Format
   a. bil – Bit Interleave by Line
   b. bip – Band Interleave by Pixel
5) File Extension

6.1 Hyperspectral (SAMSON) Imagery

Hyperspectral Imagery can be found on the hard drive in the SAMSON folder:

Name	Size	Type
DSS		File Folder
FlightLogs		File Folder
SAMSON		File Folder

The contents of this folder are listed below:

Name	Size	Type
20060929_0100_samson_bil.bil	11,959,059 KB	BIL File
20060929_0100_samson_bil.hdr	10 KB	HDR File
20060929_1000_samson_bil.bil	35,843,617 KB	BIL File
20060929_1000_samson_bil.hdr	10 KB	HDR File
20060930_0001_samson_bil.bil	42,255,103 KB	BIL File
20060930_0001_samson_bil.hdr	10 KB	HDR File
20060930_0010_samson_bil.bil	16,704,205 KB	BIL File
20060930_0010_samson_bil.hdr	10 KB	HDR File
20060930_0100_samson_bil.bil	15,661,452 KB	BIL File
20060930_0100_samson_bil.hdr	10 KB	HDR File
20060930_1000_samson_bil.bil	35,605,366 KB	BIL File
20060930_1000_samson_bil.hdr	10 KB	HDR File

6.2 Digital High Resolution RGB (DSS) Images

Digital High Resolution RGB Images can be found on the hard drive in the DSS folder:

Name	Size	Type
DSS		File Folder
FlightLogs		File Folder
SAMSON		File Folder

The contents of this folder are listed below:

Name	Size	Type
20060929_1000_dss_bip.bip	30,072,702 KB	BIP File
20060929_1000_dss_bip.hdr	1 KB	HDR File
20060930_0001_dss_bip.bip	37,375,977 KB	BIP File
20060930_0001_dss_bip.hdr	1 KB	HDR File
20060930_0010_dss_bip.bip	13,362,075 KB	BIP File
20060930_0010_dss_bip.hdr	1 KB	HDR File
20060930_0100_dss_bip.bip	13,436,965 KB	BIP File
20060930_0100_dss_bip.hdr	1 KB	HDR File
20060930_1000_dss_bip.bip	30,405,405 KB	BIP File
20060930_1000_dss_bip.hdr	1 KB	HDR File

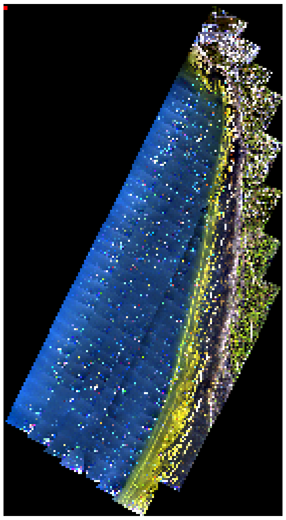
These images can be viewed using the software package, ENVI, by ITT Visual Information Systems (www.rsinc.com).

System Requirements for ENVI

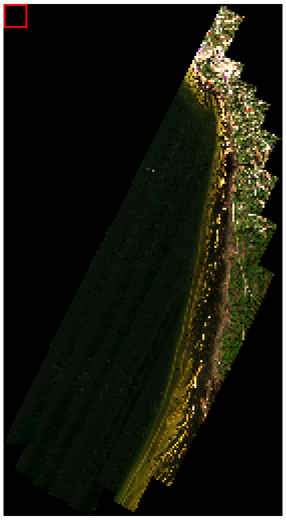
Platform	Vendor	Hardware	Operating System	Supported Version
Windows	Microsoft	Intel x86 32-bit	Windows	2000, XP
		Intel x86_64 64-bit	Windows	XP
Macintosh*	Apple	PowerMac G4, G5 32-bit	Mac OS X	10.3, 10.4
		Intel x86 32-bit	Mac OS X	10.3, 10.4
UNIX*	HP	PA-RISC 32-bit	HP-UX	11.0
		PA-RISC 64-bit	HP-UX	11.0
	IBM	RS/6000 32-bit	AIX	5.1
		RS/6000 64-bit	AIX	5.1
	SGI	Mips 32-bit	IRIX	6.5.1
		Mips 64-bit	IRIX	6.5.1
	SUN	SPARC 32-bit	Solaris	Solaris 8,9,10
		SPARC 64-bit	Solaris	Solaris 8,9,10
	various	Intel/AMD x86 32-bit	Linux**	Kernel version 2.4 Kernel version 2.6 glibc version 2.3
	various	Intel/AMD x86_64 64-bit	Linux**	Kernel version 2.4 Kernel version 2.6 glibc version 2.3

On UNIX platforms that provide 64-bit support, ENVI can be run as either a 32-bit or a 64-bit application. When both versions are installed, the 64-bit version is the default.

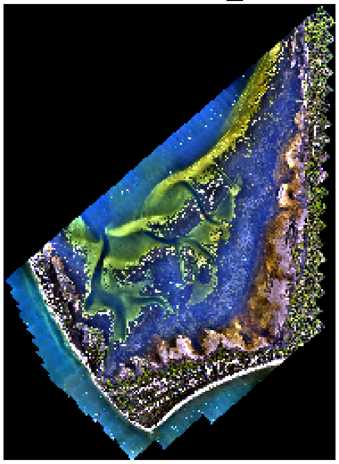
6.3 Examples of Digital High Resolution RGB (DSS) and HSI (SAMSON) Images.



DSS 20060929_0100

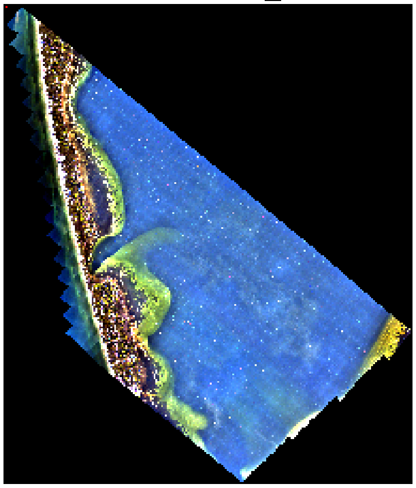


SAMSON 20060929_0100



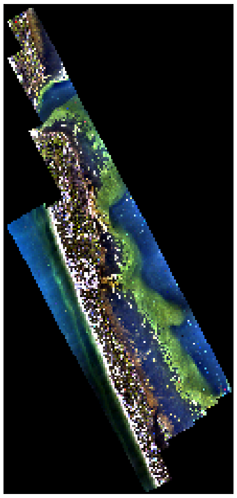
DSS 20060929_1000

SAMSON 20060929_1000

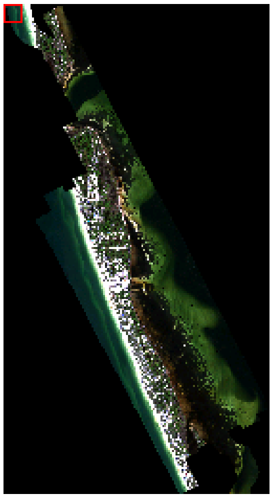


DSS 20060930_0001

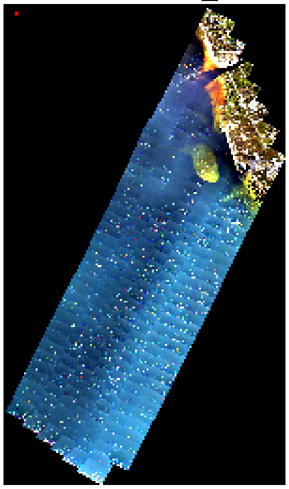
SAMSON 20060930_0001



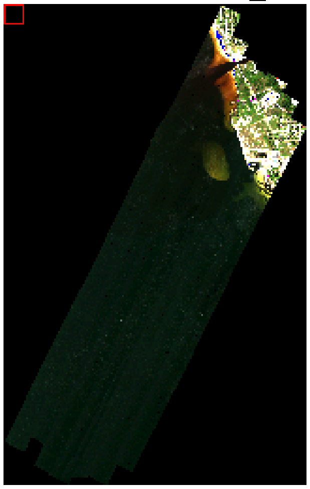
DSS 20060930_0100



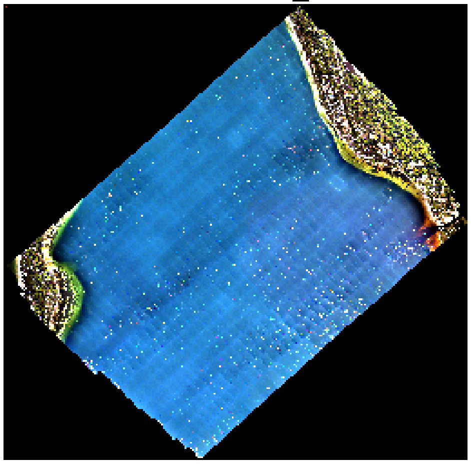
SAMSON 20060930_0100



DSS 20060930_1000



SAMSON 20060930_0100



DSS 20060930_1000

SAMSON 20060930_0100

APPENDIX A

FERI

ST. JOSEPH BAY FALL 2006

Old Dominion University

Groundtruthing Summary Report

Summary Report

Sea-Truth Support of Hyperspectral Overflights of St Joseph's Bay, Florida

8 January 2007
by

Richard C. Zimmerman, Ph.D.
Bio-Optics Research Group
Department of Ocean, Earth and Atmospheric Sciences
Old Dominion University
4600 Elkhorn Avenue
Norfolk, VA 23529

The Bio-Optics Research Group conducted sea-truth operations in support of hyperspectral overflights of St. Josephs Bay, Florida, between 28 September and 1 October 2006. We occupied 22 stations throughout the study region on successive days; the following parameters were measured at each station:

- Water leaving radiances and remote sensing reflectance at the water surface
- Quantification of optically active water column constituents, including
  - in situ measures of beam absorption (*a*) and attenuation (*c*) at 9 wavelengths
  - in situ measures of backscattering (b_b) at 6 wavelengths
  - hyperspectral measures of
    - downwelling irradiance (in air)
    - upwelling irradiance (in water) 0.2 m below the sea surface
    - upwelling radiance (in water) 0.2 and 0.65 m below the sea surface
    - K_{Lu} calculated from the two measures of upwelling radiance
  - concentrations of phytoplankton chlorophyll (mg m^{-3})
  - concentrations suspended particulate matter (g m^{-3})
  - spectral absorption of colored dissolved organic matter

Electronic data sets were provided to FERI in various file formats, (excel, ASCII, etc.) for incorporation into atmospheric correction algorithms and for validation of water leaving radiance spectra.

As agreed in the original statement of work, the development of additional data products, e.g. tuned algorithms to quantify amounts of phytoplankton chlorophyll, suspended particulate matter and colored dissolved organic matter from the remotely sensed imagery, direct *in situ* measurements of submerged aquatic vegetation (SAV) abundance in optically shallow areas for use in validating spatial maps of SAV abundance generated from remote sensing imagery and associated algorithms and bio-optically based estimates of sustainable SAV abundance modeled as a function of optical water quality and bathymetry can be provided at additional cost.

Surveyor's Report

Surveyor's Report for St. Joseph's Bay Control Survey

A Control Survey was performed to establish and coordinate aerial targets for geodetic control of aerial photography to be utilized for a hydrospectral analysis of seagrasses within St. Joseph's Bay, Florida. The surveyed positions were located in Townships 7 and 8 South, Range 10 West, Townships 7 and 8 South, Range 11 West, and Townships 7 and 8 South, Range 12 West, Tallahassee Meridian, and included sixteen (16) targets. The accuracy requirement for the photography to ground control was 4 meters (13.12 U.S. Survey Feet).

Surveyor's Notes:

1. Type of Survey: Control Survey (61G17-6.002(10)(e))
2. Bearings and Coordinates are referenced to the Florida State Plane Coordinate System, North Zone, Lambert Projection, North American Datum of 1983, 1999 Adjustment (NAD 83/99) and is tied to Florida Department of Transportation Horizontal Control Monuments 51-01-A01G and 51-01-A16V (Primary control) and referenced to Florida Department of Transportation Horizontal Control Monuments 51-01-A22V and 51-01-A24V (secondary control). Accuracy for the primary control exceeded one foot in 200,000 feet.
3. Last date of field survey: 09/27/2006
4. Survey was performed utilizing the Global Positioning System (GPS) and data was collected using Sokkia static GPS receivers and a redundant check of all known and set control points was performed with Thales RTK GPS receivers.
5. The standard deviation of the photographed targets to the ground control coordinates is 2.37 feet. No points deviated by more than 3.06 feet.
6. Aerial photography was performed by Florida Environmental Research Institute (FERI) and was geo-referenced utilizing Trimble GPS and corrected to CORS Station PNVY located at the Panama City, Florida airport.
7. Unless it bears the Signature and the ORIGINAL RAISED SEAL of a Florida Licensed Surveyor and Mapper, this report is for informational purposes only and is NOT VALID. Additions or deletions to survey maps or reports by other than the signing party or parties is prohibited without the written consent of the signing party or parties.

SURVEYOR'S CERTIFICATE:

I, the undersigned Registered Land Surveyor, hereby certify that this Survey Report and the survey on which it is based was prepared under my direct supervision, that to the best of my knowledge, information and belief is a true and accurate representation of the work performed, and that it meets the "Minimum Technical Standards for Land Surveying in the State of Florida" per Chapter 61G17-6, Florida Administrative Code, pursuant to Chapter 472.027, Florida Statutes.

David A. Puigdomenech, PSM
State of Florida Certificate No. 00006031

Bayside Engineering, Inc. (LB 6992)
1105 East Twiggs Street
Tampa, FL 33602-3135

Point No.	Northing - A	Easting - A	Northing - B	Easting - B	Description	diff in N	diff in E	Distance
	GPS		DSS					
	Northing - A	Easting - A	Northing - B	Easting - B				
AT-1	308291.389600	1709245.498350	308292.919000	1709243.914000	4X4 AERIAL TARGET	-1.53	1.58	2.20
AT-2	297607.378050	1711080.272050	297608.952000	1711078.909000	4X4 AERIAL TARGET	-1.57	1.36	2.08
AT-3	284849.231100	1714670.611400	284850.911000	1714668.149000	4X4 AERIAL TARGET	-1.68	2.46	2.98
AT-3A	288692.488850	1714151.376700	288694.353000	1714149.690000	4X4 AERIAL TARGET	-1.86	1.69	2.51
AT-4	275043.202300	1713476.705700	275045.137000	1713475.444000	4X4 AERIAL TARGET	-1.93	1.26	2.31
AT-5	263408.052900	1713437.170200	263409.851000	1713436.634000	4X4 AERIAL TARGET	-1.80	0.54	1.88
AT-6	249643.536300	1708677.565900	249645.306000	1708675.072000	4X4 AERIAL TARGET	-1.77	2.49	3.06
AT-7	246444.329100	1699730.764900	246445.614000	1699729.721000	10X10 AERIAL TARGET	-1.28	1.04	1.66
AT-7A	246949.293300	1696991.496700	246949.946000	1696989.910000	10X10 AERIAL TARGET	-0.65	1.59	1.72
AT-7B	249867.144700	1693047.315800	249868.943000	1693044.987000	10X10 AERIAL TARGET	-1.80	2.33	2.94
AT-8	253633.110950	1690923.999700	253635.056000	1690922.416000	4X4 AERIAL TARGET	-1.95	1.58	2.51
AT-9	261895.171600	1687758.528600	261896.726000	1687757.454000	4X4 AERIAL TARGET	-1.55	1.07	1.89
AT-10	268643.087500	1684688.420900	268644.653000	1684686.120000	4X4 AERIAL TARGET	-1.57	2.30	2.78
AT-11	279017.874250	1681882.492300	279020.435000	1681881.809000	4X4 AERIAL TARGET	-2.56	0.68	2.65
AT-12	290991.604950	1680270.121800			4X4 TARP TARGET			
AT-13	309538.178950	1679704.765700			4X4 TARP TARGET			
					RMS	-1.68	1.57	2.37