NOAA COASTAL MAPPING PROGRAM
PROJECT COMPLETION REPORT

PROJECT FL1002

Palm Beach and North Lake Worth, Florida

Introduction

NOAA Coastal Mapping Program (CMP) Project FL1002 provides a highly accurate database of new digital shoreline data for the northern portion of Lake Worth, and includes Lake Worth Inlet, Palm Beach and West Palm Beach.

Successful completion of this project resulted in a densification of the National Spatial Reference System (NSRS), a set of controlled metric-quality aerial photographs, and digital feature data of the coastal zone which complements the Nautical Charting Program (NCP) as well as geographic information systems (GIS) for a variety of coastal zone management applications.

The project database consists of information measured and extracted from aerial photographs and metadata related to photogrammetric compilation. Base mapping was conducted in a digital environment using stereo softcopy photogrammetry and associated cartographic practices.

Project Design

The NOAA National Geodetic Survey (NGS) formulated the Project Instructions for this project following the guidelines of the "Scope of Work, Shoreline Mapping for the Coastal Mapping Program" (SOW), Version 13B, dated January 2008. The instructions discussed the project's purpose, geographic area of coverage, scope and priority; data acquisition, processing, accuracy, and compilation requirements; product delivery and reporting instructions; and contact and communication information.

All project digital imagery was acquired by NOAA using dual mounted Applanix DSS 439 medium format digital sensors. NOAA provided 287 Applanix DSS frames of RGB color imagery, 287 Applanix DSS frames of MLLW IR imagery, and 287 Applanix DSS frames of MHW IR imagery, two (2) DSS sensor calibration reports for each DDS sensor used, tide coordination data, photo center and photo frame outlines in ESRI shape file format and processed airborne GPS and IMU data in order to support photogrammetric processing and feature compilation. NOAA also provided shapefiles depicting the shoreline to be mapped, the boundaries of the project compilation areas, and flight lines and exposure centers of the imagery to be used for compilation.

Field Operations

The field survey operations were performed by Western Air Maps, Inc. /Wilson & Company, Engineers & Architects Inc. sub-contractor Land Point Survey. Following is a

brief summary of the field operations as described in the survey report.

The purpose of this Control Survey was to establish up to 24 points on the ground establish a ground control and check point network. The purpose of the field survey is to establish locations and coordinate values for ground points to be used as photo control for mapping the shoreline within the project limits.

The general location of the control points were provided in the files attached to the email entitled "Revised FL1002 control and check point network" sent by Mr. Barry Budzowski with Wilson & Company, Inc., Engineers & Architects on January 19, 2011. The files attached were entitled:

- FL1002SPBase_Control_V4.kmz
- FL1002SPBase_01192011.dgn
- FL1002SPBase_01192011control.dxf

All of the ground control points observed were photographically identifiable, consisting of an irregular feature easily observed from the pre-flown imagery. Please see the available photographs and field sketches for the exact location of the control and check points.

The Global Positioning System Sensors used to perform the field surveys was a Leica 1200 and a Leica 500 series.

Type	Serial Number
Leica AX1202	NVKO549OO15
Leica AT502	10401

During each survey session one of the receivers occupied each photo control point and or the check point location. Two hour static sessions were recorded at each point.

GPS Data Reduction

Upon return to Land Point Surveys office's the recorded Leica Raw Data files were downloaded and translated into RINEX file format using Leica's Geomatics Office Version 8.00 software. The RINEX files, and the antenna height utilized for each set of observations, were then submitted to the National Oceanic and Atmospheric Administration (NOAA) Online Positioning User Service (OPUS). Each file was processed along with the data collected simultaneously at the three closest Continually Operating Reference Stations (CORS) as determined by OPUS. The CORS served as base stations in this processing which effectively ties the surveyed points to the National Spatial Reference Systems (NSRS), NAD 83 and NAVD 88. Each of these five second collection rate CORS were used at least once in the photo control processing: ANPI, CORB, COVX, DEDT, DNRC, GLPT, REDI & VIMS. All pertinent information regarding each can be found at: http://geodesy.noaa.gov/CORS/cors-data.html

Final GCP coordinate values were determined utilizing precise point positioning techniques using Applanix TerraPOS (ver. 1.2) software and the NGS Online Positioning

User Service (OPUS). The minimum criteria used for acceptance of OPUS results for the photo control points are:

At least 90% of the observations are used.
At least 50% of ambiguities are used.
Overall RMS does not exceed 3 cm (0.03m)
Peak to Peak errors do not exceed 5 cm (0.05m)

Of the 24 control and check points collected during the original February 3, 2011 through February 6, 2011 ground survey, no point observed exceeded the minimum acceptance criteria for percentage of observations used, percentages of ambiguities used or the total root mean squares or RMS values. The data set did encounter Latitude, Longitude, Ellipsoid and Orthometric Accuracies exceeding the allowable amount. All of the supplied OPUS reports were prepared with the option of allowing the software to choose the 3 COR Stations for the post processing. We prepared additional OPUS reports selecting different COR stations and did not see any observable improvement with the peak to peak errors.

Aerotriangulation

All project digital imagery was acquired by NOAA using dual mounted Applanix DSS 439 medium format digital sensors.

- Sensor serial #SN0144 - DSS 439, 60 mm VIS lens (calibration date 2/12/2009) was used to collect all the color (RGB) images.
- Sensor serial #SN0131 – DSS 439, 60 mm NIR lens (calibration date 12/02/2009) was used to collect all the NIR MLLW and MHW images.

The flight plan used was comprised of 9 flight lines covering the FL1002 project area. The RGB and infrared Mean Lower Low Water (MLLW) imagery was collected simultaneously, with strips 4-9 being flown on March 4, 2010 and the remainder of the RGB and MLLW IR, strips 1-3, were acquired on March 19, 2010. Nine (9) strips of Mean High Water (MHW) infrared imagery were acquired on March 4, 2010.

Each of the three sets of images covers the entire FL1002 project area and the flight line configuration is identical for each image set. Each set of imagery (RGB, MLLW and MHW) is made up of 287 exposures, for a total of 861 images.

A combination of photo identifiable ground control points, Airborne Kinematic GPS (ABGPS) and IMU data was used control the imagery for aerial triangulation. Airborne Global Positioning System (ABGPS) and Inertial Measurement Unit (IMU) data was collected and processed to determine the exterior orientation of the image centers so they could be used as photogrammetric control during the aerotriangulation process in preparation for mapping the shoreline in the FL1002 project.

Airborne GPS: An airborne GPS receiver (a Trimble BD960) and an Applanix POS/AV510 GPS/IMU System in the NOAA King Air 350ER (N68RF) aircraft were used to collect airborne kinematic data and collected dual frequency phase data

simultaneously with a static ground base station receiver, a Trimble R7 dual frequency GPS receiver with an antenna (Model TRM55971.00) set on a 2 meter fixed height tripod, located at the Palm Beach International (KPBI) Airport. The base station geodetic position was derived using the NGS's Online Positioning Users Service (OPUS). Additionally NGS Continuously Operating Reference Stations (CORS) served as the ground reference stations during acquisition missions. These reference CORS stations were ZMA1, PBCH and LAUD.

After the acquisition missions, the raw kinematic GPS data from the ABGPS receiver was processed using POSPAC 4.4.0 GPS/IMU processing software. The processed GPS data was integrated with the IMU data to produce a Smoothed Best Estimate Trajectory (SBET) FILE. NOAA extracted Exterior Orientation (EO) from the SBET files and supplied a generic text file containing the EO information for use with ISAT and SOCET SET digital photogrammetric software.

Ground Points: The Consolidated AT block was based on 18 photo-identifiable ground control points with 6 check points. The control network was well distributed and proved to be adequate for an acceptable AT solution and for shoreline compilation. Refer to the Ground Control Location Diagram (Annex1) for a visual reference of the density and distribution of the ground control and check points used within the project area. Refer to the separate document Ground Survey Report for additional information regarding the field surveys done to obtain the ground control and check points. All of the photo identifiable locations were visible in both the color and infrared imagery, but one of the control points was relocated to another suitable photo identifiable feature due to property accessibility issues at the original planned location of the point.

The AT for the consolidated block was performed using digital images from the two Applanix DSS sensors, and controlled with ABGPS/IMU and 18 ground surveyed points. Z/I Imaging's ISAT digital AT software (version 6.6.1.0) operating on an Imagestation Workstation was used for the automatic tie point generation, manual measurements of additional tie points, ground control point measurements, and bundle adjustment. A project folder was set up, two sensor calibration definitions were created, and the images and NOAA provided EO were ingested, as well as the ground control network results. The automatic tie point generation between image types yielded large amounts of error, and necessitated that most if not all of the tie points be manually identified and measured. The photography was aerotriangulated as one consolidated block – the final block adjustment contained the color, the MHW and the MLLW BWIR photos.

Once the photogrammetrist had ascertained that the bundle adjustment results met the specified accuracy criteria, the adjusted EO results were exported into a generic text file format suitable for importation into SOCET SET. The SOCET SET project was setup and defined with the proper coordinate system, datum and units of measure. NOAA provided sensor calibration reports for the sensor definitions and these were incorporated into the project. The bundle adjusted EO data was ingested into the project, but upon visual inspection of the stereo models it was discovered that one of the IR datasets appeared to be shifted in the y axis. This shift was consistent throughout one set of IR images across

the project extent when viewed in SOCET SET, yet is was not evident at all when the same image sets were viewed together in the Imagestation ISSD software. Further testing eliminated the possibility of scaling issues. During a teleconference with the NOAA AT expert, it was determined that the sensor definitions could be the culprit, it was discovered that WAM/WCEA had a bench calibration report for just the RGB sensor in the dual sensor arrangement and did not have a bench calibration report for the IR sensor. NOAA officials promptly e-mailed a copy of the IR sensor's bench calibration report and inspection of the sensor definition files in the Imagestation software revealed that an erroneous value existed in the sensor definition. This value was corrected, the bundle adjustment was re-run and the results were ingested into SOCET SET. All image datasets were in alignment and compilation was ready to begin.

Approximately 10% of selected stereo models evenly distributed within each strip were reviewed by a senior photogrammetrist to ensure the horizontal and vertical integrity of the ISAT solution, and to verify the suitability of the database for use in the compilation phase. The final bundle adjustment for the consolidated image block was computed in ISAT as a full-covariance simultaneous solution, allowing for the output of standard deviation values for all triangulated points. The RMS of the standard deviations in both X and Y directions were calculated and used to determine the radius of the 95% confidence circle for each image block. The predicted horizontal accuracy of the final adjustments for the consolidated block adjustment at the 95% confidence level is 0.3 meters.

Compilation

The data compilation phase of this project was initiated by Western Air Maps, Inc. /Wilson & Company in July, 2011 and completed in October, 2011. Digital mapping was performed using SOCET for ArcGIS (Version 9.3.1) and SOCET SET (Version 5.5.0) software. Feature identification and attribution within the Geographic Cell (GC) was based on image analysis of digital images acquired from an altitude of approximately 4500 feet above mean terrain and information extracted from the appropriate NOAA nautical charts, US Coast Guard Light List and other ancillary sources. Feature attribution was assigned in compliance with the Coastal Cartographic Object Attribute Source Table (C-COAST), which provides the definition and attribution scheme for the full range of cartographic features pertinent to the CMP. Selected features were further modified with additional descriptive information to refine general classification.

Spatial data accuracies for Project FL1002 were determined according to standard Federal Geographic Data Committee (FGDC) practices. Cartographic features were compiled to meet a horizontal accuracy of 0.6 meters at the 95% confidence level. This predicted accuracy of compiled, well defined points is derived by doubling the circular error calculated from the aerotriangulation statistics.

The following table provides information on the aerial photographs used to complete this project:

Date	Time (UTC)	Roll #s	Photo #s	GSD	Tide Level*
3/4/2010	20:02:12 – 20:04:26	10NC06	1251 – 1284	0.15 m	0.0
3/4/2010	20:32:37 – 20:35:25	10NC06	1318 – 1351	0.15 m	-0.1 – 0.0
3/4/2010	20:39:52 – 20:42:10	10NC06	1352 – 1386	0.15 m	-0.1 – 0.0
3/4/2010	20:47:25 – 20:50:15	10NC06	1387 – 1420	0.15 m	-0.1 – 0.1
3/4/2010	20:54:44 – 20:56:46	10NC06	1421 – 1451	0.15 m	-0.1 – 0.1
3/4/2010	21:02:08 – 21:03:49	10NC06	1452 – 1471	0.15 m	0.0
3/19/2010	21:10:59 – 21:13:28	10NC12	4962 – 4994	0.15 m	0.1
3/19/2010	21:20:12 – 21:22:27	10NC12	4995 – 5027	0.15 m	0.1
3/19/2010	21:28:55 – 21:31:23	10NC12	5028 – 5060	0.15 m	0.0 – 0.1
3/4/2010	15:01:20 – 15:03:39	10NR04	688 – 720	0.15 m	0.8 – 0.9
3/4/2010	15:10:16 – 15:11:50	10NR04	721 – 740	0.15 m	0.8 – 0.7 †
3/4/2010	15:16:51 – 15:17:12	10NR04	741 – 746	0.15 m	0.7 †
3/4/2010	15:17:17 – 15:18:59	10NR04	747 – 771	0.15 m	0.8
3/4/2010	15:24:38 – 15:27:01	10NR04	772 – 802	0.15 m	0.8
3/4/2010	15:27:06 – 15:27:15	10NR04	803 – 805	0.15 m	0.7 †
3/4/2010	15:31:46 – 15:34:04	10NR04	806 – 840	0.15 m	0.8 – 0.9
3/4/2010	15:40:04 – 15:42:48	10NR04	841 – 874	0.15 m	0.9
3/4/2010	15:47:12 – 15:49:28	10NR04	875 – 908	0.15 m	0.9
3/4/2010	15:57:23 – 15:59:28	10NR04	909 – 941	0.15 m	0.9 – 0.7
3/4/2010	16:05:50 – 16:08:26	10NR04	942 – 974	0.15 m	0.7 – 0.8
3/4/2010	20:02:17 – 20:04:27	10NR05	975 – 1008	0.15 m	0.0
3/4/2010	20:32:37 – 20:35:30	10NR05	1042 – 1075	0.15 m	-0.1 – 0.0
3/4/2010	20:39:52 – 20:42:10	10NR05	1076 – 1110	0.15 m	-0.1 – 0.0
3/4/2010	20:47:25 – 20:50:15	10NR05	1111 – 1144	0.15 m	-0.1 – 0.1
3/4/2010	20:54:44 – 20:56:46	10NR05	1145 – 1175	0.15 m	-0.1 – 0.1
3/4/2010	21:02:08 – 21:03:49	10NR05	1176 – 1195	0.15 m	0.0
3/19/2010	21:10:59 – 21:13:28	10NR11	4686 – 4718	0.15 m	0.1
3/19/2010	21:20:12 – 21:22:27	10NR11	4719 – 4751	0.15 m	0.1
3/19/2010	21:28:55 – 21:31:23	10NR11	4752 – 4784	0.15 m	0.0 – 0.1

* Tide levels are given in meters above MLLW and were calculated using Tidal Constituent And Residual Interpolation (TCARI) with reference to verified water level observations at NOS gauges within the project area. The mean tide range is 0.8 meters.

† The tide levels for these photos are slightly outside the standard tolerance for tide coordination.

To expedite delivery and to assure quality, Western Air Maps/Wilson & Company delivered a pilot area for review and comment. Upon receiving NOAA review comments, the pilot area shapefile was finalized and then used as template for the remaining compilation of shoreline in the project area. This quality assurance step was felt to be necessary to ensure that there would be no confusion regarding how the FL1002 shoreline needed to be compiled and this particular production step was clearly defined in the project instructions as well as in the quality assurance/quality control plan submitted by Western Air Maps/Wilson & Co. and approved by NOAA at the start of the project.

Quality Control / Final Review

Western Air Maps, Inc. personnel conducted quality assurance (QA) reviews during all phases of project completion. The final QC review was completed in November, 2011. The review process included analysis of aerotriangulation results and assessment of the identification and attribution of digital feature data within the GC according to image analysis and criteria defined in C-COAST. The quality control process concluded with an inspection of topological connectivity within the GC using ArcGIS 9.3.1 software. All project data was evaluated for compliance to CMP requirements.

Comparisons of the largest scale NOAA nautical charts with the project photographs and compiled project data resulted in creation of the Chart Evaluation File (CEF). The following nautical charts were used in the comparison process:

11466, Lake Worth Inlet, FL, 1:80,000 scale, 38th edition, Jun/08
11472, Palm Shores to West Palm Beach, 1:40,000 scale, 34th edition, Jul/09

End Products and Deliverables

The following specifies the location and identification of the products generated during the completion of this project:

RSD Applications Branch Archive

- Hardcopy of the Field Survey Report
- Hardcopy of the Aerotriangulation Report
- Hardcopy of the Project Completion Report (PCR)
- Page-size graphic plot of GC10910 file contents, attached to PCR

Remote Sensing Division Electronic Data Library

- Project database
- GC10910 in shapefile format
- Digital copy of the PCR in Adobe PDF format
- Chart Evaluation File in shapefile format

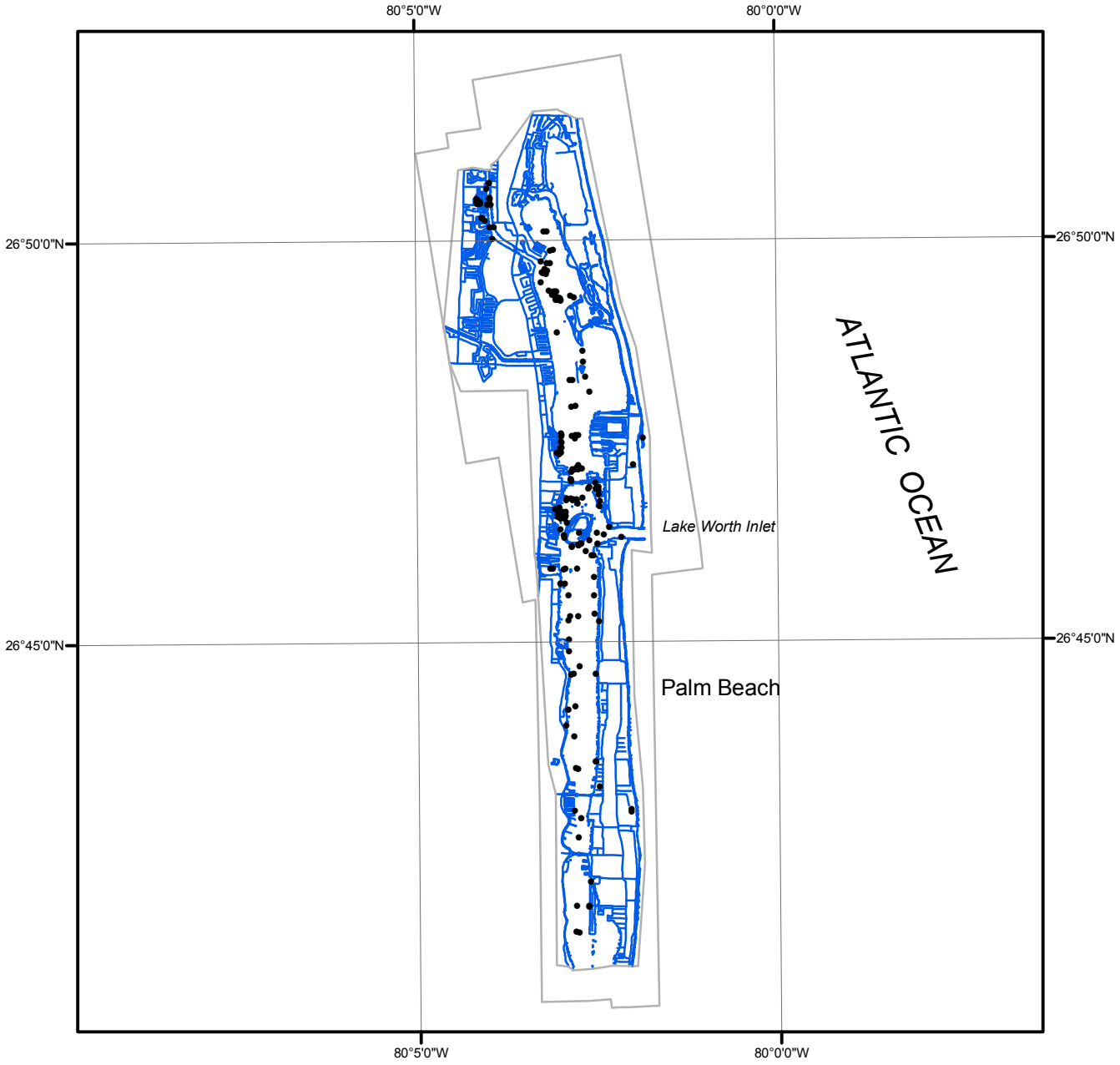
NOAA Shoreline Data Explorer

- GC10910 in shapefile format
- Metadata file for GC10910
- Digital copy of the PCR in Adobe PDF format

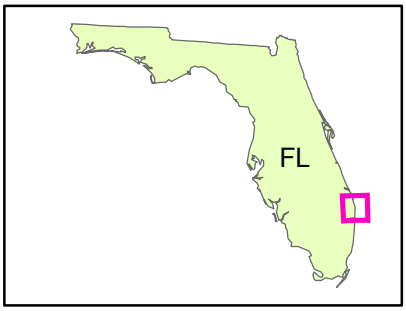
End of Report

PALM BEACH AND NORTH LAKE WORTH

FLORIDA



Overview



FL1002

GC10910