NOAA COASTAL MAPPING PROGRAM
PROJECT COMPLETION REPORT

PROJECT PR1401D-TB-N

Northern Puerto Rico, Arecibo to Isla de Culebra, Puerto Rico

Introduction

NOAA Coastal Mapping Program (CMP) Project PR1401D-TB-N provides a highly accurate database of new digital shoreline data for a portion of the northern shore of Puerto Rico, extending from Arecibo to Isla de Culebra. Project PR1401D-TB-N is a subproject of a larger project, PR1401-TB-N, which covers Puerto Rico nearly in its entirety. Project PR1401D-TB-N was conducted using stereo softcopy photogrammetry supplemented with Mean High Water (MHW) and Mean Lower Low Water (MLLW) data derived from topographic-bathymetric (topobathy) lidar sensor technology. The Geographic Cell (GC) may be used in support of the NOAA Nautical Charting Program (NCP) as well as geographic information systems (GIS) for a variety of coastal zone management applications.

Project Design

Project PR1401-TB-N was designed by personnel of NOAA's National Geodetic Survey (NGS) within the Requirements Branch (RB) of the Remote Sensing Division (RSD). RB formulated the Project Instructions for this project following the guidelines of the "Scope of Work, Shoreline Mapping for the Coastal Mapping Program" (SOW), Version 14A, dated October 24, 2012. 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.

NGS was responsible for the planning, acquisition, and processing of all aerial data in order to support photogrammetric and lidar processing for feature compilation. This includes the establishment of ground control, and the post-processing of airborne Global Positioning System (GPS) data. In addition, NGS provided shapefiles of the flight lines and exposure centers of the imagery to be used for compilation.

Subsequent to the completion of all project planning and data collection, Dewberry was contracted for additional processing and compilation activities.

Field Operations

NGS performed all field operations, which included the acquisition of aerial photographs and topobathy lidar, as well as the surveying of ground control points (GCPs) and accuracy assessment checkpoints (CPs), and the establishment of base stations to support aerial collection and survey operations.

Ground survey operations were conducted by NGS from October 2014 to May 2015 to support aerial imagery and lidar collections. Two aerial base stations per flight mission and 477 lidar GCPs were surveyed using a combination of traditional static, real-time kinematic, and post processed kinematic GPS techniques. From the above GCPs, a subset of 27 were utilized in an

accuracy assessment to compute a 95% confidence circle for PR1401-TB-N orthoimagery which was used for feature compilation in other subprojects.

Aerial survey operations for Project PR1401-TB-N were conducted by NGS in two phases. The first phase, from October 2014 to May 2015, included concurrent acquisition of lidar and imagery, utilizing a total of 630 passes with NOAA's DeHavilland Twin Otter aircraft at an altitude of 400 meters above ground level (AGL) to cover a 491 square mile area within the project. Topobathy lidar data was collected with a Riegl VQ-820-G system at an aggregate nominal point density of 18 pulses per square meter, with a nominal swath width of 234 meters and a 50% swath overlap. Additionally a total of 1,340 flight lines of color (RGB) imagery were acquired. Imagery was captured with an approximate nominal ground sample distance (GSD) of 0.035 meters through the use of an Applanix Digital Sensor System (DSS) 539 aerial camera. Imagery was collected in this phase of acquisition for the purpose of creating orthoimages.

The second phase of aerial survey operations was conducted from February through March 2016. Lidar acquisition consisted of a total of 163 passes using NOAA's DeHavilland Twin Otter aircraft at an altitude of 400 meters AGL to complete a 107 square mile area. Topobathy lidar data was collected with a Riegl VQ-880-G lidar system at an aggregate nominal point density of 18 pulses per square meter with a nominal swath width of 287 meters and a 50% swath overlap. Imagery was acquired separately from the lidar in this phase, using the NOAA King Air aircraft and an Applanix DSS 580/560 dual aerial camera system. A total of 49 flight lines of RGB and near-infrared (NIR) imagery were acquired over the project area at altitudes of 1,400 meters (34 lines) and 2,400 meters (15 lines), resulting in nominal GSDs of 0.14 meters and 0.24 meters respectively. Imagery collected in the second phase of acquisition was planned with 60% endlap specifically to support stereo photogrammetric feature compilation.

GPS Data Processing

For both the lidar and image data acquisitions for PR1401-TB-N, airborne GPS data was collected using an Applanix POSAV IMU unit with a dual-frequency Trimble BD960 receiver. Airborne GPS data was processed using the Applanix POSPac MMS software with tightly coupled processing (IN-Fusion Single Base) to achieve the final image center locations and orientations. Base data, for all kinematic processing, consisted of GPS stations set-up in the survey area collecting at least four hours of static data with positions derived via the NGS Online Positioning Users Service (OPUS). Two base stations were utilized for the lidar acquisition for redundancy purposes. For further information refer to the Airborne Positioning and Orientation Reports (APOR) on file with other project data within the RSD Electronic Data Library.

Lidar Data Processing

Lidar point cloud data for both phases of acquisition was processed by October 2017. NGS personnel performed initial processing and quality control, including calibration, checks for data voids, relative swath accuracy, refraction correction, and preliminary vertical accuracy assessment before delivering calibrated lidar swath data to Dewberry for further processing.

Dewberry utilized a variety of software for lidar data processing, including Leica LP360, TerraScan, Esri ArcGIS, QT Modeler, GeoCue, Global Mapper, and Dewberry's proprietary LIDAR Processor tool. Data processing included additional quality checks and accuracy assessments of the preliminary swath data, breakline creation to define the land/water interface, point classification, automated and manual editing of the lidar tiles, QA/QC, and final formatting

of the LAS tiles. Final processed lidar products delivered to NOAA included raw point cloud data (swaths), breaklines, classified LAS tiles, topobathy digital elevation model (DEM) tiles, void polygon layer, intensity image tiles, confidence maps, and FGDC compliant metadata files.

NGS used NOAA VDatum software to convert the vertical datum of the classified lidar points from NAD83 ellipsoid to local MHW and MLLW tidal datums. QTModeler and custom ArcGIS scripts were used to produce bare-earth MHW and MLLW DEMs at a 1-meter grid resolution, and to create and format the MHW and MLLW vectors into shapefile format.

In order to determine the uncertainty of lidar-derived vectors, lidar point data was compared to CPs of higher accuracy to determine vertical uncertainties, and then further compared to the morphologic slope around the derived vectors at sample sites in the project area. Based on this assessment the MHW lidar-derived shoreline vectors for subproject PR1401D-TB-N meet a horizontal accuracy of 1.4 meters at the 95% confidence level, and the MLLW lidar-derived vectors meet a horizontal accuracy of 1.9 meters at the 95% confidence level. NOAA supplied the lidar-derived MHW and MLLW shapefiles to be segmented, edited, and attributed by Dewberry. For further information on lidar data processing and products refer to the Final Report of Survey on file within the RSD Electronic Data Library.

Aerotriangulation

The aerotriangulation (AT) phase of the project consisted exclusively of images acquired during the second phase of aerial survey operations, and was performed by Dewberry using digital AT methods to establish the network of photogrammetric control required for feature compilation. Inpho Match-AT software was used to perform automatic point measurements and interactive point measurements of tie points.

Due to the abundance of offshore islands within the imagery, the AT was subdivided into six independent blocks. The Root Mean Square (RMS) of the standard deviations in both X and Y directions were calculated and used to determine a predicted horizontal circular error at the 95% confidence level for each block, resulting in a predicted horizontal accuracy of 0.2 meters for all blocks except for one, covering Isla Palominos, which was calculated to be 0.1 meters. An AT Report is on file with other project data within the RSD Electronic Data Library.

There were 367 image frames within PR1401D-TB-N that were not adjusted in the AT because they were either open water frames or did not have enough land area to be measured in the adjustment. Therefore, these frames maintained the exterior orientation recorded by the airborne GPS/IMU during collection. The horizontal accuracy of these direct-georeferenced (DG) frames was calculated by NGS personnel. The Root Mean Square (RMS) of the standard deviations in both X and Y directions were calculated and used to determine a predicted horizontal circular error at the 95% confidence level. The predicted horizontal accuracy for these frames is 0.5 meters. All positional data is referenced to the North American Datum of 1983 (NAD 83).

Compilation

The data compilation phase of the project was initiated by Dewberry personnel in December 2018. NGS supplied the lidar-derived MHW and MLLW shapefiles to be edited, attributed and generalized by Dewberry. Additional features were then manually compiled using the stereo imagery. Feature compilation was based on the lidar shoreline and features compiled using digital mapping methods within the SOCET for ArcGIS module of BAE's SOCET SET (ver.

5.6). This enabled compilation of features into an Esri Geodatabase where topological and attribution relationships could be enforced. Once compilation was complete, the geodatabase features were exported to shapefile format. 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 subproject PR1401D-TB-N were determined according to standard Federal Geographic Data Committee (FGDC) practices. Cartographic features compiled from all blocks adjusted via AT, except for the Isla Palominos block, were compiled to meet a horizontal accuracy of 0.4 meters at the 95% confidence level. Cartographic features compiled from the Isla Palominos block were compiled to meet a horizontal accuracy of 0.2 meters at the 95% confidence level. Cartographic features compiled from the DG images were compiled to meet a horizontal accuracy of 1.0 meter at the 95% confidence level. These predicted accuracies of compiled, well defined points are derived by doubling the circular error calculated from the AT and airborne GPS statistics. Lidar-derived features had horizontal accuracies that varied from 1.4 meters to 1.9 meters, as described above.

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

Date	Time (UTC)	Roll ID	Flight Line	Photo ID	GSD	Tide Level*
2/23/2016	17:23 – 17:25	16VC19	27-001	5328 – 5348	0.14 m	0.3 m
2/23/2016	17:27 – 17:30	16VC19	27-005	5349 – 5381	0.14 m	0.3 m
2/23/2016	17:45 – 17:48	16VC19	27-006	5382 – 5414	0.14 m	0.3 m
2/23/2016	17:50 – 17:51	16VC19	27-002	5415 – 5435	0.14 m	0.3 m
2/23/2016	17:56 – 18:18	16VC19	27-003	5436 – 5467	0.14 m	0.3 – 0.2 m
2/23/2016	18:23 – 18:25	16VC19	27-004	5468 – 5498	0.14 m	0.2 m
2/23/2016	18:32 – 18:35	16VC19	27-007	5499 – 5530	0.14 m	0.2 m
2/23/2016	18:44 – 18:45	16VC19	27-021	5575 – 5592	0.14 m	0.2 m
2/23/2016	19:04 – 19:07	16VC19	27-008	5625 – 5656	0.14 m	0.2 m
2/23/2016	19:23 – 19:25	16VC19	27-023	5688 – 5717	0.14 m	0.2 m
2/23/2016	19:35 – 19:37	16VC19	27-029	5735 – 5748	0.14 m	0.2 m
2/23/2016	19:37 – 19:39	16VC19	27-035	5749 – 5763	0.14 m	0.2 m
2/23/2016	19:44 – 19:45	16VC19	27-039	5764 – 5773	0.14 m	0.2 m
2/23/2016	19:48 – 19:49	16VC19	27-038	5774 – 5783	0.14 m	0.2 m
2/23/2016	19:51 – 19:52	16VC19	27-037	5784 – 5793	0.14 m	0.2 m
2/23/2016	19:57 – 19:58	16VC19	27-028	5794 – 5807	0.14 m	0.2 m
2/23/2016	20:00 – 20:02	16VC19	27-036	5808 – 5835	0.14 m	0.2 m
2/23/2016	20:06 – 20:09	16VC19	27-033	5836 – 5868	0.14 m	0.2 m
2/23/2016	20:13 – 20:15	16VC19	27-034	5869 – 5894	0.14 m	0.2 m
2/23/2016	20:18 – 20:20	16VC19	27-511	5895 – 5917	0.14 m	0.2 m
2/23/2016	20:25 – 20:29	16VC19	27-510	5918 – 5957	0.14 m	0.2 m
2/23/2016	20:33 – 20:36	16VC19	27-509	5958 – 5990	0.14 m	0.2 – 0.1 m
2/24/2016	20:10 – 20:11	16VC99	27-032	22519 – 22531	0.14 m	0.1 m

2/24/2016	20:16 – 20:17	16VC99	27-031	22539 – 22550	0.14 m	0.1 m
2/24/2016	20:41 – 20:43	16VC99	27-022	22638 – 22669	0.14 m	0.1 m
2/29/2016	12:17 – 12:19	16VC21	45-005	6376 – 6390	0.24 m	0.2 m
3/1/2016	14:19 – 14:22	16VC23	45-006	6533 – 6554	0.24 m	0.3 m
3/1/2016	14:27 – 14:30	16VC23	45-007	6559 – 6576	0.24 m	0.3 m
3/1/2016	14:34 – 14:38	16VC23	45-009	6577 – 6602	0.24 m	0.3 m
3/4/2016	13:15 – 13:16	16VC25	45-019	6800 – 6809	0.24 m	0.3 m
3/4/2016	13:21 – 13:23	16VC25	45-018	6810 – 6828	0.24 m	0.3 m
3/4/2016	13:30 – 13:33	16VC25	45-016	6830 – 6849	0.24 m	0.3 m
3/4/2016	13:38 – 13:41	16VC25	45-015	6850 – 6870	0.24 m	0.3 m
3/5/2016	12:31 – 12:34	16VC26	45-505	6964 – 6985	0.24 m	0.4 m
3/5/2016	12:39 – 12:43	16VC26	45-504	6986 – 7013	0.24 m	0.4 m
3/5/2016	12:48 – 12:51	16VC26	45-503	7014 – 7035	0.24 m	0.4 m
3/5/2016	12:56 – 12:58	16VC26	45-502	7037 – 7047	0.24 m	0.4 – 0.3 m
3/5/2016	13:03 – 13:04	16VC26	45-501	7057 – 7065	0.24 m	0.3 m
3/5/2016	13:52 – 13:54	16VC26	27-013	7135 – 7156	0.14 m	0.4 m
3/5/2016	14:00 – 14:03	16VC26	27-014	7179 – 7208	0.14 m	0.4 m
3/5/2016	14:08 – 14:10	16VC26	27-015	7225 – 7238	0.14 m	0.4 m
3/7/2016	12:35 – 12:37	16VC27	27-016	7387 – 7408	0.14 m	0.6 m
3/7/2016	12:42 – 12:43	16VC27	27-015	7409 – 7424	0.14 m	0.6 m
3/9/2016	12:32 – 12:33	16VC28	45-012	7434 – 7445	0.24 m	0.5 m
3/9/2016	12:39 – 12:41	16VC28	45-010	7446 – 7461	0.24 m	0.5 m

* Tide levels are given in meters above MLLW and calculated using the Pydro software tool with TCARI grids referenced to verified water level observations from various NOS gauges in the vicinity of the project. The elevation of the MHW tidal datum in the project area ranges between 0.28 – 0.40 meters above MLLW.

Quality Control / Final Review

Quality control tasks were conducted during all phases of project completion by a senior member of Dewberry. The final QC review was completed in June 2019. The review process included analysis of AT 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 (ver. 10.7.1) software. All project data was evaluated for compliance to CMP requirements.

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

25650, Virgin Passage and Sonda de Vieques, 37th Ed., Feb. 2014
25653, Isla de Culebra and Approaches, 13th Ed., Dec. 2002
25654, Ensenada Honda Isla de Culebra, 13th Ed., Jun. 2000
25655, Ensenada Honda to Canal de Luis Pena, 12th Ed., Jul. 2004
25663, Pasaje de San Juan to Puerto de Humacao, 29th Ed., Mar. 2014
25667, Bahia de Fajardo and Approaches, 21st Ed., Sep. 2014
25668, Northern Coast of Puerto Rico, 21st Ed., Nov. 2012
25669, Approaches to San Juan Harbor, 1st Ed., Oct. 2011
25670, Bahia de San Juan, 44th Ed., Jun. 2011

End Products and Deliverables

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

RSD Electronic Data Library

- Airborne Positioning and Orientation Report (APOR)
- Final Report of Survey
- AT Report
- Project Completion Report (PCR)
- Project database
- GC11465 in shapefile format
- CEF in shapefile format

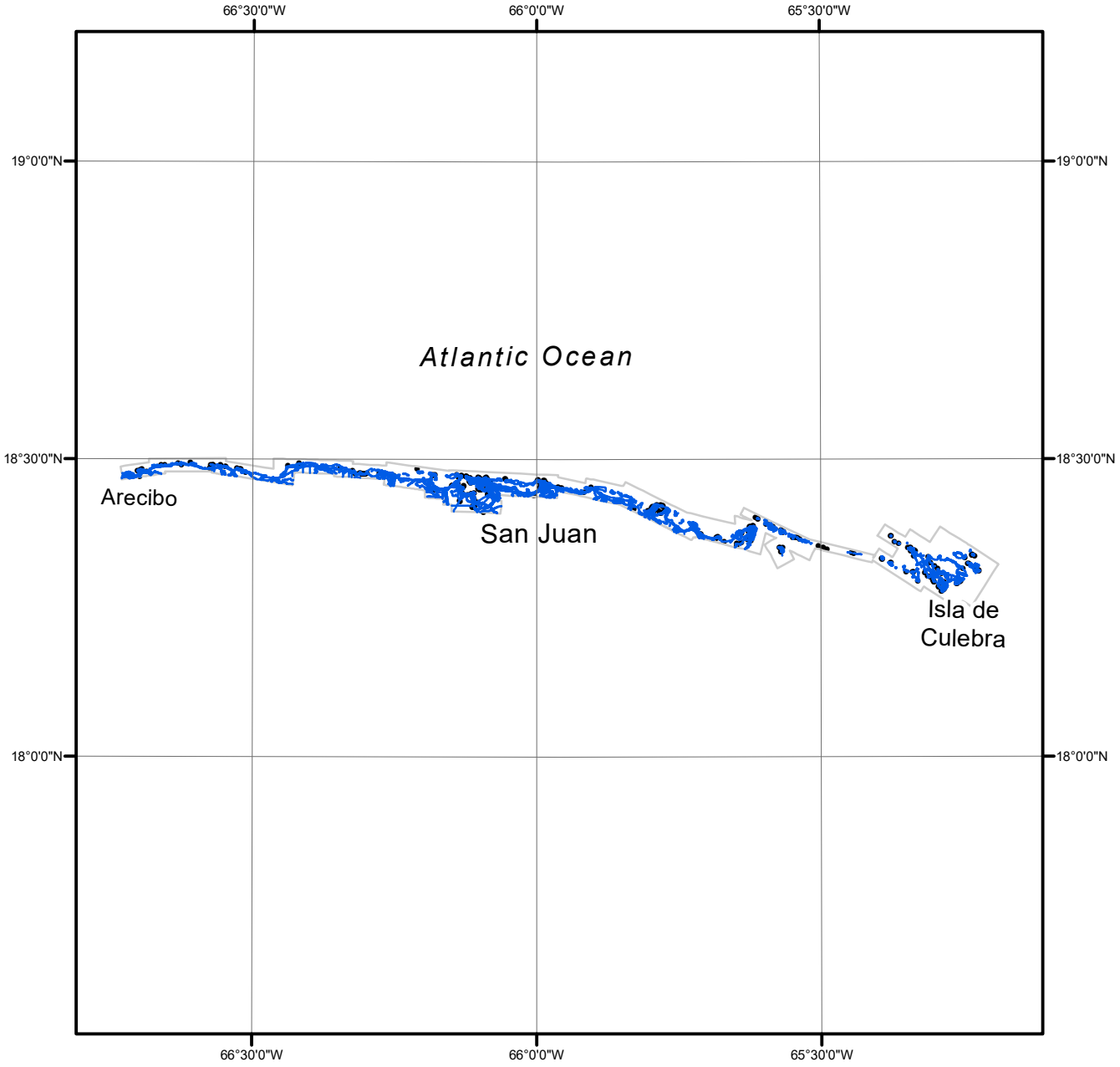
NOAA Shoreline Data Explorer

- GC11465 in shapefile format
- Metadata file for GC11465
- PCR in Adobe PDF format

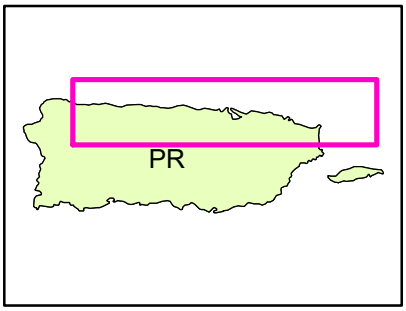
End of Report

NORTHERN PUERTO RICO, ARECIBO TO ISLA DE CULEBRA

PUERTO RICO



Overview



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GC11465