NOAA COASTAL MAPPING PROGRAM
PROJECT COMPLETION REPORT

PROJECT GU1903-TB-C

Territory of Guam

Introduction
Coastal Mapping Program (CMP) Project GU1903-TB-C provides accurate digital shoreline data for the U.S. Territory of Guam, the southernmost of the Mariana Islands. The Geographic Cell (GC) may be used in support of the NOAA Nautical Charting Program (NCP) as well as geographic information systems (GIS) for coastal zone management applications.

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 14A, dated October 24, 2012. The project instructions discuss 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.

Quantum Spatial (QSI or Quantum) was provided satellite imagery and lidar data to support photogrammetric processing and feature compilation. Maxar/DigitalGlobe Worldview satellite imagery was provided by NOAA NGS for aerotriangulation (AT) and feature compilation by Quantum. NOAA NGS supplied the lidar-derived Mean High Water (MHW) and Mean Lower Low Water (MLLW) contours to be segmented, edited, and attributed by Quantum. NOAA NGS also provided shapefiles depicting the shoreline to be mapped and the boundaries of the main project area.

Field Operations
Woolpert, Inc. was contracted to perform field operations in support of the contract with the NOAA Office of Coastal Management (OCM). These field operations consisted of the surveying of ground control and check points (GCPs), precise point positioning (PPP), and the acquisition and processing of topographic-bathymetric (topobathy) lidar data. See the Topographic and Bathymetric Lidar Survey Report on file in the RSD Electronic Data Library for full details on lidar planning, acquisition and processing for GU1903-TB-C.

The ground control survey operations took place in February and March 2020, to establish three-dimensional coordinates for 24 photo control points, 8 bathymetry check points, 13 lidar control points, 30 non-vegetated check points, and 18 vegetated check points. The points were collected per the flight layout and were uniformly dispersed over the project area. In the establishment of the primary control network for the ground control for the island of Guam it was determined that NGS CORS station GUAM (PID AF9627) would be the primary control station to which the surveys would be referenced. The field crew utilized static ground and real-time kinematic GPS

surveying throughout the ground control and check point data collection process. The ground control data meet Geospatial Positioning Accuracy Standards. See the Ground Control Survey Report on file in the RSD Electronic Data Library for further details.

The lidar acquisition phase of the project was conducted by Woolpert with flights starting July 4, 2019 through July 14, 2020. A total of 61 missions were completed between two projects, MP1907-TB-C and GU1903-TB-C. Lidar data was acquired with a target pulse density ≥ 8 pulses/m^2 (topographic) and ≥ 2 pulses/m^2 (bathymetric) using a Leica Hawkeye 4X sensor.

The satellite imagery used by Quantum was supplied by NOAA. The multispectral satellite imagery was captured by DigitalGlobe Inc. The imagery was acquired at a nominal ground sample distance of 0.66 meters from WorldView Satellites. The imagery was acquired from May 2019 through October 2019.

GPS Data Processing

Position and orientation data were acquired in the aircraft using a NovAtel SPAN with LCI-100C IMU. All data were post-processed by Woolpert using NovAtel Inertial Explorer software with a multi-pass algorithm to provide a tightly coupled solution. GNSS base stations and precise point positioning were used for processing. Separation plots and additional statistics were reviewed for each flight trajectory processed. Average Forward and Reverse Separation RMS for the project was 0.013m in Easting, 0.014m in Northing, and 0.043m in Height for single base solutions.

Lidar Data Processing

The lidar processing phase of the project was performed by Woolpert following their established HE4X processing workflow: Leica's Lidar Survey Studio (LSS) was used to produce lidar point cloud data in LAS format, which were then reprojected using VDatum. Woopert's custom scripts within SAFE's FME software were used to in preparation for data editing, and later to apply geoid corrections. The LAS files were imported into a TerraScan project, where spatial algorithms were used to remove noise and classify bare earth/ground. Manual review and editing were conducted in both Terrascan and LP360. Digital Elevation Models (DEMs) were then created using TerraModel at 1-meter resolution. Quality control checks were applied throughout the lidar processing phase to ensure accuracy and consistency.

Aerotriangulation

The AT phase of the project was performed by Quantum using digital AT methods to establish the network of photogrammetric control required for the compilation phase. The images were bridged in a bundle adjustment that included 17 satellite images, divided into 49 tiles. This work was accomplished using a Digital Photogrammetric Workstation (DPW), which consists of a stereo-enabled PC-based graphics workstation running Socet GXP digital photogrammetric software. Socet GXP was used to perform automatic point measurements and interactive point measurements of tie points. The final adjustment of the block was accomplished by using a rigorous simultaneous least squares bundle adjustment. Analysis tools within Socet GXP were used to iteratively refine the AT solutions and to evaluate the accuracy of the final adjustment.

The 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 of 1.75 meters. This accuracy refers to the overall block, but in the bundle adjustment the errors were distributed such that the largest errors are associated with points around the edges of the project, as well as areas of vast water, where the strength of the solution is weakest.

As a final check, select image pairs were examined in Socet Set to ensure horizontal and vertical integrity of the Socet GXP solution, and to verify the suitability of the database for use in compilation. Images were checked for proper parallax, and ground control tolerance. An AT Report is on file with other project data within the RSD Electronic Data Library.

The project database consists of project parameters and options, interior orientation parameters, ground control parameters, adjusted exterior orientation parameters, and positional listing of all measured points. Positional data is referenced to the North American Datum of 1983 (NAD 83) and is referenced to the Universal Transverse Mercator (UTM) Zone 55 coordinate system.

Compilation

The data compilation phase of the project was initiated by Quantum personnel in October 2021. This work was accomplished using a DPW running DAT/EM Summit Evolution (ver. 7.6) digital photogrammetric software. NOAA supplied the lidar-derived MHW and MLLW shapefiles to be segmented, edited, and attributed by Quantum Spatial. The MHW and MLLW lidar-derived shoreline vectors meet horizontal accuracies of 2.3 and 3.7 meters respectively at the 95% confidence level. Feature identification, segmentation, and attribution were based on imagery analysis of the processed digital images and information extracted from the appropriate NOAA Nautical Charts, U.S. 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.

Spatial data accuracies for project GU1903-TB-C were determined according to standard Federal Geographic Data Committee (FGDC) practices. Cartographic features extracted from the satellite imagery were compiled to meet a horizontal accuracy of 3.5 meters, at the 95% confidence level. This predicted accuracy of compiled, well defined points is derived by doubling the circular error calculated from the AT statistics. Lidar derived feature accuracies are indicated above. The following table provides information on the imagery used to complete this project:

Date	Time (UTC)	Source File Name	Tide Level*
05/25/2019	01:02:42	19MAY25010242-P1BS_R1C1-010821974010_01_P001	0.5 m
05/25/2019	01:02:42	19MAY25010242-P1BS_R2C1-010821974010_01_P001	0.5 m
05/25/2019	01:02:42	19MAY25010242-P1BS_R3C1-010821974010_01_P001	0.5 m
05/25/2019	01:02:42	19MAY25010242-P1BS_R4C1-010821974010_01_P001	0.7 m
05/25/2019	01:03:46	19MAY25010346-P1BS_R4C1-010821974010_01_P001	0.7 m

08/13/2019	04:07:28	19AUG13040728-P1BS_R7C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R1C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R2C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R3C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R4C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R5C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R6C1-010821972010_01_P001	0.1 m
08/13/2019	04:08:10	19AUG13040810-P1BS_R7C1-010821972010_01_P001	0.1 m
08/18/2019	03:50:58	19AUG18035058-P1BS_R1C1-010821973010_01_P001	0.2 m
08/18/2019	03:50:58	19AUG18035058-P1BS_R2C1-010821973010_01_P001	0.2 m
08/18/2019	03:50:58	19AUG18035058-P1BS_R3C1-010821973010_01_P001	0.2 m
08/18/2019	03:50:58	19AUG18035058-P1BS_R4C1-010821973010_01_P001	0.2 m
08/18/2019	03:51:47	19AUG18035147-P1BS_R4C1-010821973010_01_P001	0.2 m
09/24/2019	01:11:07	19SEP24011107-P1BS_R1C1-011555320010_01_P001	0.2 m
09/24/2019	01:11:07	19SEP24011107-P1BS_R2C1-011555320010_01_P001	0.2 m
10/05/2019	01:03:56	19OCT05010356-M1BS_R1C1-011555319010_01_P001	0.6 m
10/05/2019	01:03:56	19OCT05010356-M1BS_R2C1-011555319010_01_P001	0.6 m
10/05/2019	01:04:59	19OCT05010459-M1BS_R1C1-011555319010_01_P001	0.6 m
10/05/2019	01:04:59	19OCT05010459-M1BS_R2C1-011555319010_01_P001	0.6 m

* Tide levels given in meters above MLLW and are based on verified observations recorded by the NOS tide gauges at Apra Harbor (1630000) and at Pago Bay (1631428), Guam. The elevation of the MHW tidal datum at the Apra Harbor gauge is 0.678 meters, and at the Pago Bay gauge is 0.493 meters above MLLW.

Quality Control / Final Review

Quality control tasks were conducted during all phases of project completion by a Quantum senior mapping professional. The final QC review was completed in June 2021. The review process included analysis of AT results and assessment of the identification and attribution of digital feature data within the subproject according to image analysis and criteria defined in C-COAST. The quality control process concluded with an inspection of topological connectivity within the project using ArcGIS (ver. 10.8.1) software. All project data was evaluated for compliance to CMP requirements.

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

- 81048, Mariana Islands, Island of Guam; 10th Ed., Feb. 2006
- 81054, Mariana Islands, Apra Harbor, Guam; 16th Ed., Sept. 2008

End Products and Deliverables

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

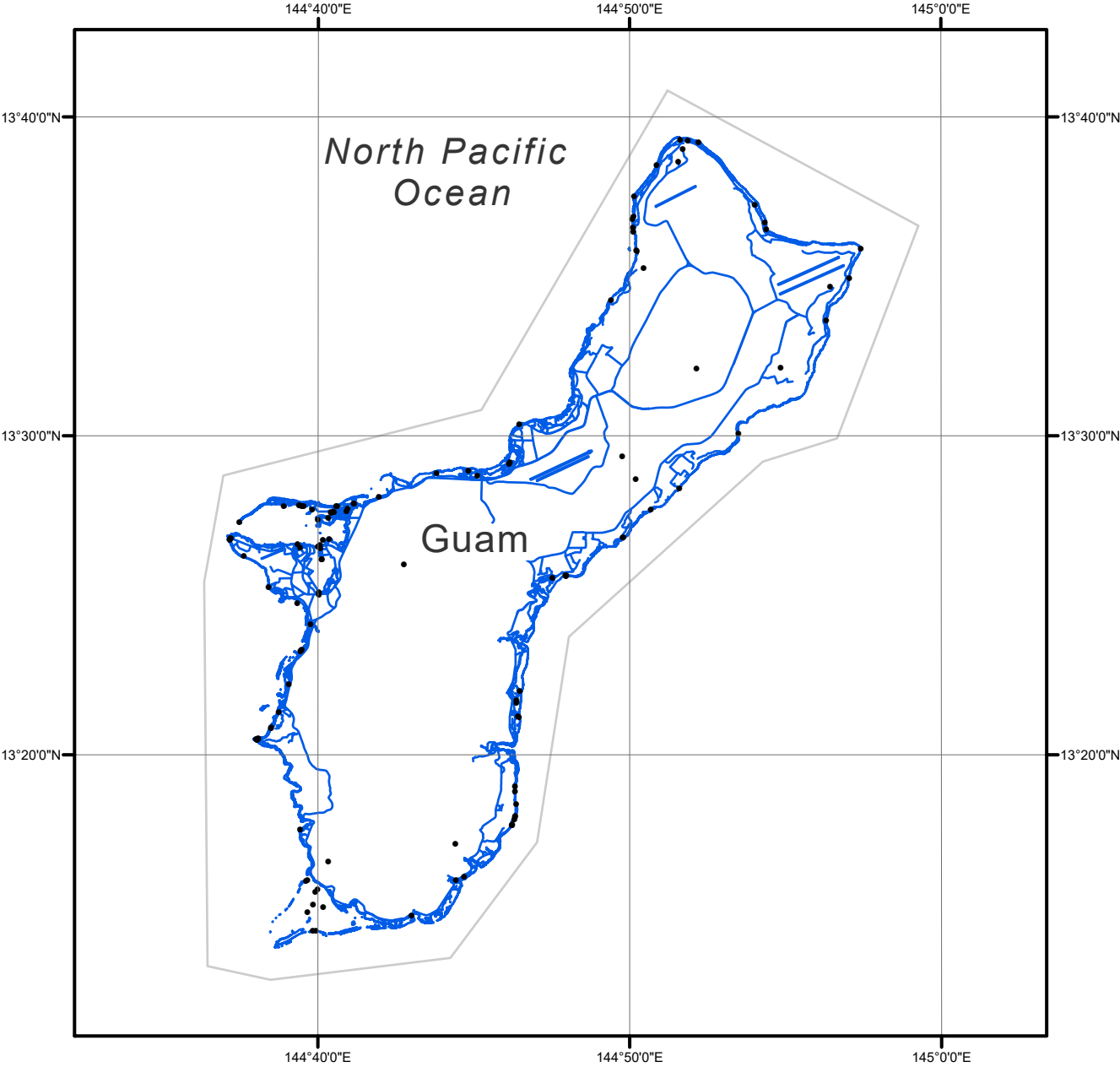### Remote Sensing Division Electronic Data Library

- Project database
- Ground Survey Report
- Aerotriangulation Report
- Topographic and Bathymetric Lidar Survey Report
- GC11636 in shapefile format
- Project Completion Report (PCR)
- CEF in shapefile format
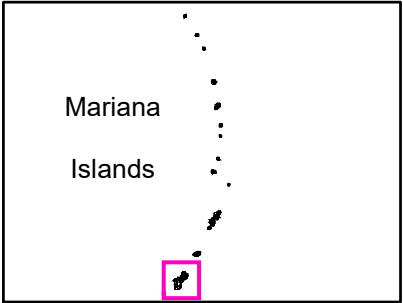
NOAA Shoreline Data Explorer

- GC11636 in shapefile format
- Metadata file for GC11636
- PCR in Adobe PDF format

End of Report

TERRITORY OF GUAM

144°40'0"E   144°50'0"E   145°0'0"E

13°40'0"N

North Pacific Ocean

13°30'0"N

Guam

13°20'0"N

144°40'0"E   144°50'0"E   145°0'0"E

13°40'0"N

13°30'0"N

13°20'0"N

Overview

Mariana

Islands

GU1903-TB-C

GC11636