Digital Elevation Model of Grenada: Procedures, Data Sources, and Analysis

Prepared for NOAA's Pacific Marine Environmental Laboratory and the National Weather Service and the USAID Office of U.S. Foreign Disaster Assistance (OFDA) by the NOAA's National Centers for Environmental Information (NCEI) and the Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado at Boulder

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Summary

In April of 2017, NOAA's National Centers for Environmental Information (NCEI) developed an integrated bathymetric–topographic digital elevation model (DEM) of Grenada for NOAA's National Weather Service (NWS) and Pacific Marine Environmental Laboratory (PMEL). The DEM will be used to support modeling tsunami generation, propagation, and inundation as well as support a Tsunami Ready pilot project in Grenada funded by NOAA and USAID/OFDA. The 1 arc-second DEM of Grenada covers approximately 28,000 sq. km of the Windward Islands of the Lesser Antilles including St. Vincent, the Grenadines, Petite Martinique, Carriacou, and Grenada. Geographic extents of this DEM, procedures, data sources, and analysis are described below. The methodologies used by NCEI in developing DEM are described in the NOAA Technical Memorandum-52 for Central California and San Francisco Bay (Carignan et al., 2011).

DEM Specifications

The Grenada DEM were built to the specifications listed in Table 1. Figure 1 shows the 1 arc-second Grenada integrated topographic–bathymetric DEM boundary in red.

Table 1. Specifications for the Grenada DEM.

Cell Size	1 arc-second
Coverage	61.00° to 62.30° W, 11.70° to 13.50° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Instantaneous Water Level depth
Vertical Units	Meters
Grid Format	ASCII raster grid

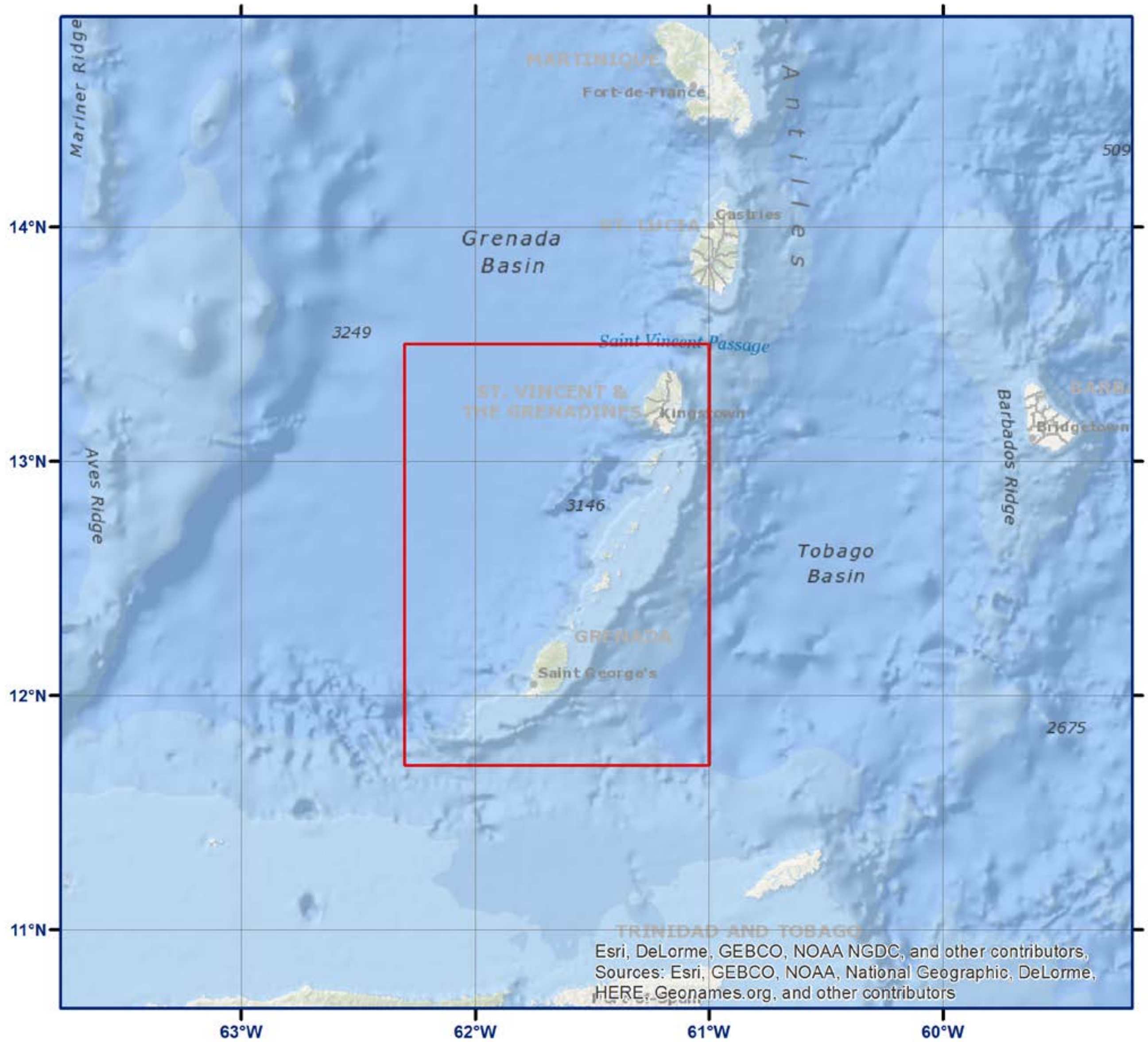

Figure 1. Map image of the boundary for the 1 arc-second Grenada DEM in red.

Data Sources and Processing

A coastline shapefile was developed by extracting the vector coastline data from both the UKHO ENCs and the NGA DNCs. This was merged, compared the lidar DEMs and to ESRI World Imagery basemap layer then edited to reflect the most recently available images. The shapefile was converted to xyz points with elevation set at zero and used as source dataset and converted to a raster mask for generating the bathymetric surface. Bathymetric data were downloaded from a number of online sources including: General Bathymetric Chart of the Oceans (GEBCO), SeaDataNet, and NCEI. Additional bathymetric data was provided by The Nature Conservancy (TNC) and Ocean Exploration Trust (OET). Sounding data was extracted from ENCs and DNCs provided by UKHO and NGA respectively. Topographic data consisted of a lidar DEM also provided by TNC and two DEMs based primarily on lidar downloaded from The Caribbean Handbook on Risk Information

Management (CHARIM) GeoNode. The SRTM topographic DEM was downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov). Figure 2 shows the source and coverage of the datasets used in developing the Grenada DEM.

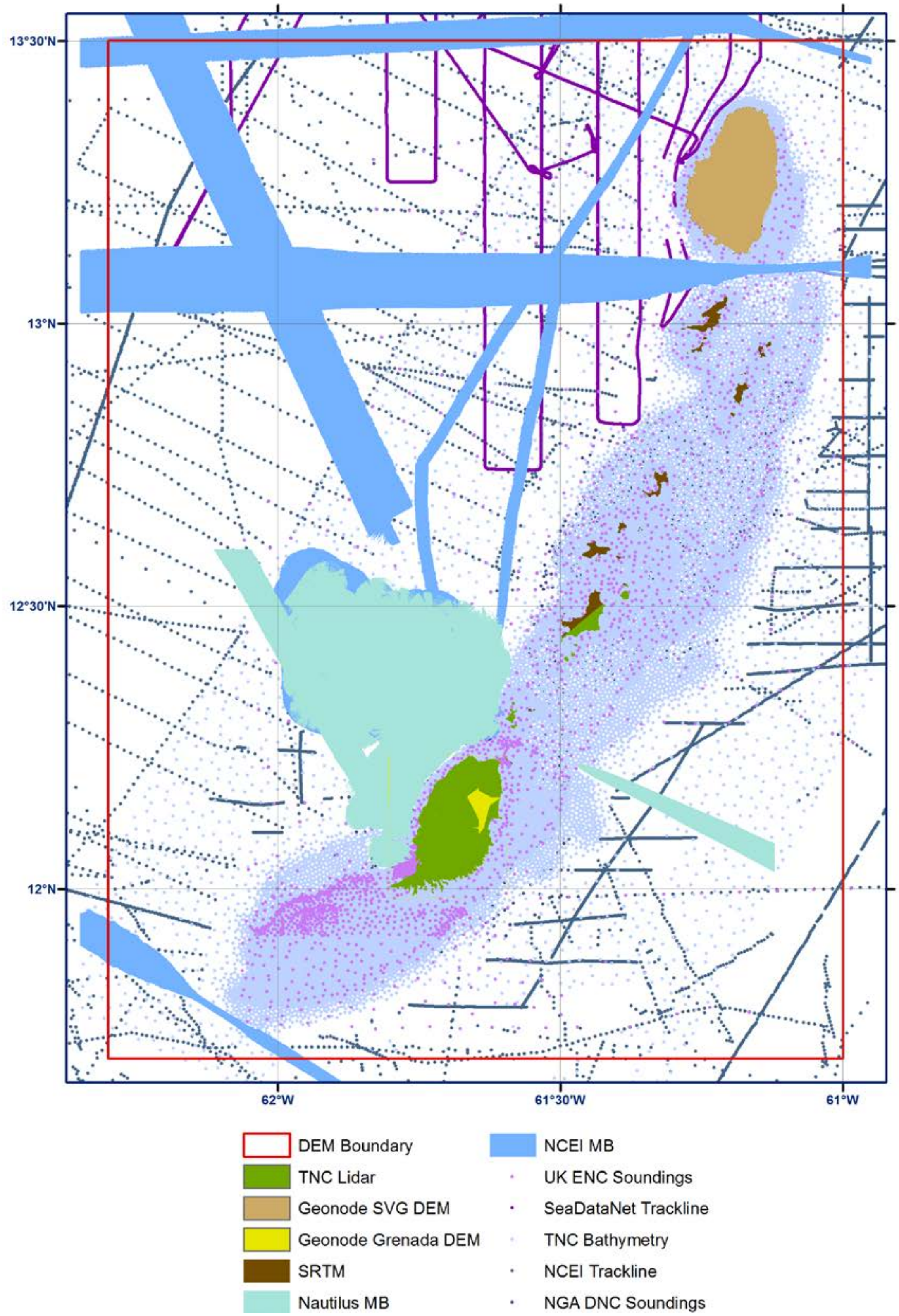

Figure 2. Source and coverage of the datasets used in compiling the Grenada DEM.

Table 2 lists the bathymetry data used in the compilation of the Grenada DEM including NCEI multibeam and trackline surveys (Appendix A and B), SeaDataNet bathymetric surveys (Appendix C).

Table 2: Bathymetric data sources used in compiling the Grenada DEM.

Source	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
OET E/V Nautilus	2013 and 2014	Multibeam Bathymetry	Gridded to 1 arc-second	Geographic	Assumed MSL
NCEI	1963 to 2000	Single-beam Trackline Bathymetry	~ 100 meters to > than 300 meters	NAD 83 geographic	Assumed MSL
NCEI	1985 to 2004	Multibeam bathymetry	30 meter grid	NAD 83 geographic	Assumed MSL
GEBCO	2014	Bathymetric DEM	30 arc-second	undefined	Assumed MSL
SeaDataNet	1985 to 2002	Single-beam Trackline Bathymetry	~ 100 to 200 meter point spacing	WGS 84 geographic and WGS 72 geographic	Assumed MSL
UKHO	2010 to 2017	ENC soundings	1:8,000 to 1:90,000	WGS 84 geographic	Chart datum
NGA	1995 to 1998	DNC soundings	1:10,000 to 1:72,560	WGS 84 geographic	Lowest Astronomical Tide (LAT)
TNC bathymetry	2013	Compilation of chart soundings, satellite derived bathymetry and high resolution near-shore surveys	~ 10 m to hundreds of meters	WGS 84 UTM Zone 20 North	MSL

The multibeam surveys from the Nautilus were gridded by at 1 arc-sec. using MB-System. The resulting data were reviewed and small artifacts were removed. The same process was used for the NCEI multibeam data. Trackline data from NCEI and from SeaDataNet were converted to shapefiles reviewed. The TNC bathymetry data were converted to a shapefile for reviewing in ArcMap along with the other datasets. Chart soundings from both UKHO and NGA were both extracted and converted to shapefiles. Bathymetric data were transformed to WGS 84 geographic using GDAL as needed and where recent, higher resolution data exists, older or lower resolution data were superseded. GEBCO 2014 data were used to fill in any areas missing data or with very little data points. These bathymetric data were converted to xyz format before combining with the coastline data to generate a bathymetric pre-surface at 1 arc-second with GMT surface command. This bathymetric surface grid was further processed by running ArcGIS focal statistics tool on the resulting gridded data. This smoothed surface was used as a single data source and reused along with only the higher resolution bathymetry data to create the 1 arc-second pre-surface used in the final gridding process.

Table 3: Topographic data source used in compiling the Grenada DEM.

Source - Title	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
GeoNode DEMs	Unknown	Lidar based DEM	5 meter	WGS 84 geographic	unknown
TNC Lidar DEM	Unknown	Lidar DEM	1 meter	WGS 84 UTM Zone 20 North	unknown
SRTM	2000	DEM	1 arc-second	WGS 84 geographic	EGM96 (Earth Gravitational Model 1996) ellipsoid

Topographic data for the Grenada DEM consisted of three topographic DEMs. The DEMs downloaded from the GeoNode portal have minimal documentation but are derived from a lidar data set, originator unknown, and filled in with a version of the SRTM. The TNC lidar file was converted from .img to .tif and re-projected and tiled using GDAL. The tiles were resampled to 5m to reduce file size and converted to xyz. The two GeoNode DEMs were converted to xyz format with the same process. Both DEM data files were manually edited to remove artifacts. The SRTM topographic DEM was clipped to the coast using a mask to remove values over water and converted to xyz format. Where the lidar based DEM data existed, SRTM data were removed.

DEM Development

Development of the Grenada DEM followed procedures documented in NOAA Technical Memorandum NGDC-52 for Central California and San Francisco Bay (Carignan et al., 2011). Exceptions being the bathymetric pre-surface was generated at 1 arc-second. Gridding weight was modified to Table 4.

Table 4: Data hierarchy used to assign gridding weight in MB-System for 3 arc-second DEM.

Dataset	*Relative Gridding Weight*
TNC Lidar DEM	1000
Bathymetric surface	100
Nautilus multibeam survey	100
SeaDataNet surveys	10
GeoNode DEMs	10
TNC bathymetry	10
NCEI multibeam surveys	1
SRTM DEM	1
Coastline	1
UK chart soundings	1

DEM Analysis

The completed Grenada DEM was compared to high resolution imagery and chart contours. Inconsistencies were evaluated and resolved based on most current or reliable data available.

Acknowledgement

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Reference

Bell, K.L.C., M.L. Brennan, and N.A. Raineault, eds. 2014. New frontiers in ocean exploration: The E/V Nautilus 2013 Gulf of Mexico and Caribbean field season. Oceanography 27(1), supplement, 52 pp, http://dx.doi.org/10.5670/oceanog.2014.supplement.01.

Bell, K.L.C., M.L. Brennan, and N.A. Raineault, eds. 2015. New frontiers in ocean exploration: The E/V Nautilus 2014 Gulf of Mexico and Caribbean field season. Oceanography 28(1), supplement, 60 pp., http://dx.doi.org/10.5670/oceanog.2015.supplement.01.

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ESRI World Imagery. Source: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS USER Community.

GEBCO_2014 Grid, version 20150318, http://www.gebco.net [accessed December 2016].

Appendix A: NCEI Multibeam surveys

Survey ID	*Date*	*Ship*	*Institution*	*Original Horizontal Datum*	*Original Vertical Datum*
EW0404	2004	Maurice Ewing	Marine Geoscience Data System (MGDS)	NAD 83 geographic	Assumed MSL
EW9404	1994	Maurice Ewing	Marine Geoscience Data System (MGDS)	NAD 83 geographic	Assumed MSL
EW9802	1998	Maurice Ewing	Marine Geoscience Data System (MGDS)	NAD 83 geographic	Assumed MSL
EW9902	1999	Maurice Ewing	Marine Geoscience Data System (MGDS)	NAD 83 geographic	Assumed MSL
KN176L03	2004	Knorr	Woods Hole Oceanographic Institution (WHOI)	NAD 83 geographic	Assumed MSL
RB0303	2003	Ronald H. Brown	NOAA Office of Ocean Exploration and Research (OER)	NAD 83 geographic	Assumed MSL
RC2605	1985	Robert D. Conrad	Marine Geoscience Data System (MGDS)	NAD 83 geographic	Assumed MSL

Appendix B: NCEI Trackline surveys

Survey ID	*Date*	*Vessel*	*Institution*
19920018	1988	Britannia	UK Hydrographic Office
19930058	1986	Arrow	UK Hydrographic Office
19960005	1985	Brazen	UK Hydrographic Office
20000141	2000	Manchester	UK Hydrographic Office
BA70002	1970	Baffin	Canadian Hydrographic Service (CHS)
CATO07MV	1972	Melville	Scripps Institution of Oceanography (SIO)
CD7593	1993	Charles Darwin	UK Natural Environmental Research Council
CH075L03	1967	Chain	Woods Hole Oceanographic Institution
DI109L2	1980	Discovery	UK Institute of Oceanographic Sciences
DILANTLS	1970	Discoverer	NOAA ESSA
EW9206	1992	Maurice Ewing	Lamont-Doherty Earth Observatory
H00799	1986	Arrow	UK Hydrographic Office
H0549A	1972	Luymes	Royal Netherlands Navy Hydrographic Office
HU70002	1970	Hudson	Canadian Hydrographic Service (CHS)
IG1504	1975	Ida Green	University of Texas Institute for Geophysics
KA344602	1976	Kane	US Navy Naval Oceanographic Office
KA932008	1972	Kane	US Navy Naval Oceanographic Office
OPR-4841	1968	Discoverer	NOAA
OPR-4843	1968	Discoverer	NOAA
OPR425M1	1969	Mt. Mitchell	NOAA
OPR425R1	1969	Rainier	NOAA
OPR425RB	1969	Rainier	NOAA
OPR425RC	1969	Rainier	NOAA
RC0707	1963	Robert D. Conrad	Lamont-Doherty Earth Observatory
RC0708	1963	Robert D. Conrad	Lamont-Doherty Earth Observatory
RC1310	1970	Robert D. Conrad	Lamont-Doherty Earth Observatory
RC2103	1977	Robert D. Conrad	Lamont-Doherty Earth Observatory
RC2605	1985	Robert D. Conrad	Lamont-Doherty Earth Observatory
S486CB	1986	Starella	USGS Pacific Coastal and Marine Science Center
S586CB	1986	Starella	USGS Pacific Coastal and Marine Science Center
V2002	1964	Vema	Lamont-Doherty Earth Observatory
WI932010	1972	Wilkes	US Navy Naval Oceanographic Office

Appendix C: SeaDataNet surveys

Survey ID	*Date*	*Cruise Name*	*Institution*	*Original Horizontal Datum*	*Original Vertical Datum*
2010030	2002	Caravel	IFREMER / IDM / SISMER - Scientific Information Systems for the SEA (486);Institute of Earth Physics of Paris (519)	WGS 84 geographic	Assumed MSL
85001411	1985	Seacarib	IFREMER / IDM / SISMER - Scientific Information Systems for the SEA (486);LABORATOIRE DE TECTONIQUE (UNIVERSITE DE PARIS VI) (184)	WGS 72 geographic	Assumed MSL