Digital Elevation Models of Bermuda: Data Sources, Processing and Analysis

Prepared for the NOAA Pacific Marine Environmental Laboratory (PMEL) by NOAA National Geophysical Data Center (NGDC)
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Summary

In the summer and fall of 2013, the NOAA National Geophysical Data Center (NGDC) developed two integrated topographic-bathymetric Digital Elevation Models (DEMs) of Bermuda for the NOAA Pacific Marine Environmental Laboratory (PMEL) to support tsunami inundation modeling in the region. The first DEM, centered on the Islands of Bermuda and the adjacent reef platform, was developed at a resolution of 1 arc-second. A larger-footprint, lower-resolution 3 arc-second DEM incorporates the extent of the 1 arc-second DEM and includes more of the Bermuda Rise and adjacent seafloor. The DEMs are referenced to the World Geodetic System of 1984 (WGS84) horizontally and vertically referenced to Mean Sea Level. The extent of the DEM, data sources, processing steps and a brief evaluation are described below.

DEM Specifications

The DEMs were created to the specifications listed in Table 1, as developed through discussion with PMEL.

Table 1. DEM Specifications for the Bermuda DEMs

Grid Area	Bermuda
Coverage Extent	65.06º to 64.51º W; 32.17º to 32.55º N (1 Arc-Second)
	65.50º to 64.00º W; 31.50º to 33.00º N (3 Arc-Second)
Coordinate System	Geographic Decimal Degrees
Horizontal Datum	World Geodetic System of 1984 (WGS84)
Vertical Datum	Assumed Mean Sea Level
Vertical Units	Meters
Cell Size	1 Arc-Second; 3 Arc-Second
Grid Format	ASCII raster grid

Figure 1 provides a graphic display of the extent of the DEMs. The source data were obtained and processed for an area slightly larger than illustrated in Figure 1 in order to minimize edge-effects during the gridding process.

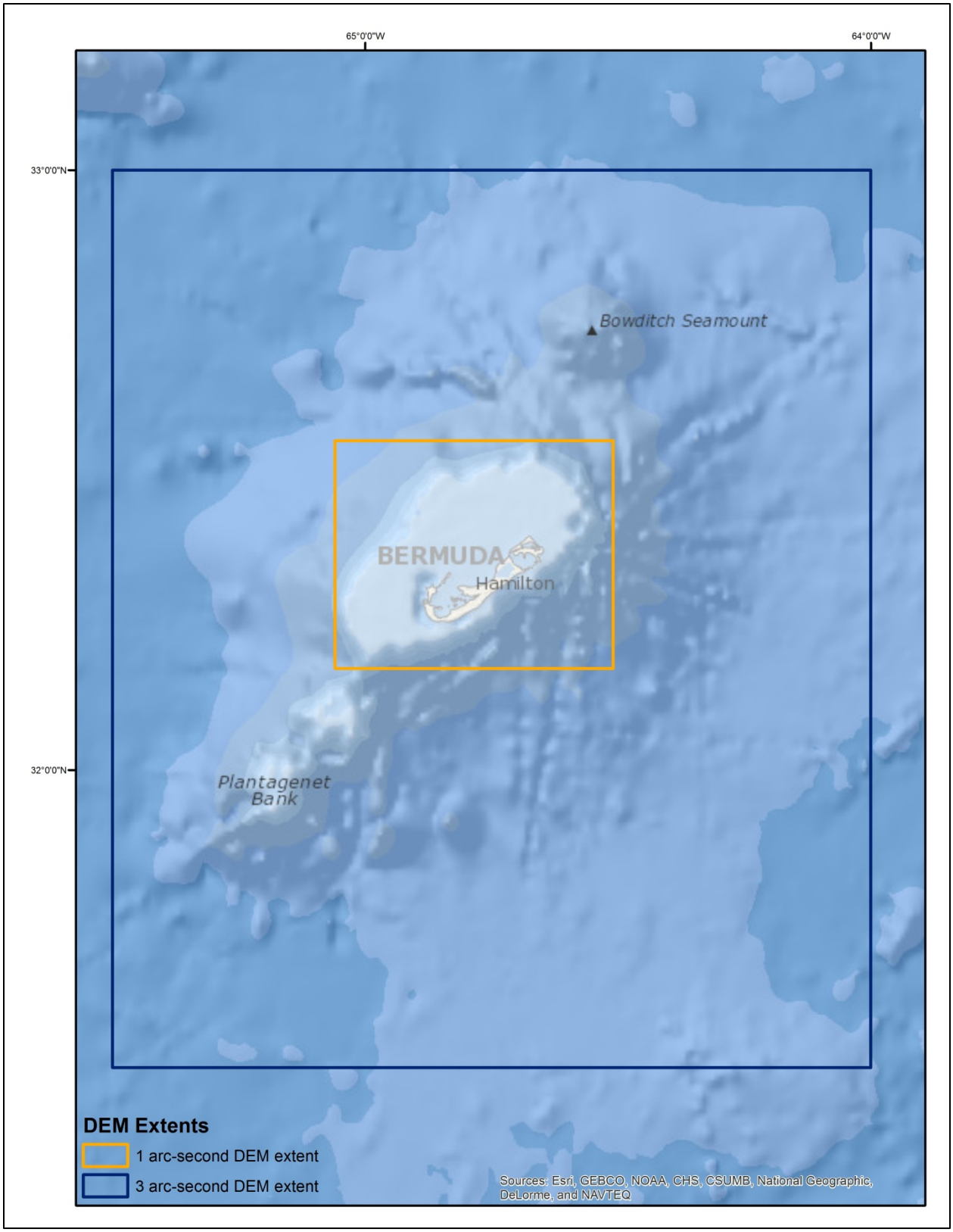

Figure 1. Map of the DEM extents, as indicated by bounding boxes.

Data Sources, Processing & Evaluation

The 'best available' bathymetric, topographic, and shoreline data were collected for the study area from a variety of sources, including the Government of Bermuda Department of Conservation Services, California State University Seafloor Mapping Lab and NOAA NGDC (See Appendices 1 and 2). The Generalized Bathymetric Chart of the Oceans (GEBCO08) was also used where no higher resolution data (e.g. multibeam bathymetry, lidar or hydrographic soundings) exist (Table 2).

Table 2. Data sources used in the development of the Bermuda DEMs

Source	Date	Data Type	Spatial Resolution	Original Horizontal Datum	Original Vertical Datum
Gov't of Bermuda	2012	Topographic surveyed spot heights (ESRI .GDB Feature Class)	Spatially variable across the island (~10-50m)	Bermuda 2000 National Grid	Bermuda Ordinance Datum
Gov't. of Bermuda	2004	Bathymetric lidar sounding depths (ESRI .SHP)	Collected at 4x4 m spot spacing	Bermuda 2000 National Grid	Lowest Astronomical Tide (LAT)
Gov't. of Bermuda	1993-1997	Nautical Chart Derived Sounding Depths (ESRI .SHP)	Scales of original charts range from 1:3k – 1:300k	Bermuda 2000 National Grid	Bermuda Chart Datum
California State Univ. Monterey Bay Seafloor Mapping Lab	2009	Gridded Multibeam Bathymetry (ESRI grid)	2m	WGS84 UTM Zone 20 N	MLLW
NOAA NGDC	1993-2003	Raw Multibeam Bathymetry (variable formats)	Variable among datasets	WGS84	Assumed MSL
GEBCO	2008	Gridded Global Relief (GEBCO_08;Arc ASCII Grid)	30 Arc-Seconds	WGS84	Sea level

All data were transformed to a common horizontal datum, WGS84, using the Proj4 Cartographic Projections Library. All bathymetric data were transformed to a common vertical datum, Mean Sea Level, using single value offsets established by the Government of Bermuda relating local tidal and surveyor datums to one another, as well as to the NOAA Bermuda Esso Pier (station ID: 2695540) tide gauge (See Appendix 1). The topographic data provided were left referenced to the Bermuda Ordinance Datum (OD), as it was assumed the magnitude of the offset between OD and MSL (~9 cm) is less than the vertical accuracy associated with the source data and spatial resolution of the grid (~30 and ~90 m, respectively; see Appendix 3).

Once common reference frames were established, the data were evaluated and in some cases edited using ESRI ArcGIS and MB-System software packages. Editing occurred primarily in areas exhibiting large vertical discrepancies between adjacent or overlapping data, or where there was obvious 'noisy' data (e.g. edges of multibeam swaths). Once the data were cleaned, a bathymetric 'pre-surface' was generated for the 1 arc-second DEM using Generic Mapping Tools (GMT) 'Surface' utility in order to interpolate/extrapolate values where data coverage was sparse or non-existent. Generally speaking, more recent data (usually the highest resolution) superseded older, lower resolution data in the creation of the bathymetric surface. In order to exclude extrapolated values in 'upland' areas, the 'pre-surface' was clipped using a shoreline obtained from the Bermuda Government. The 'Surface' utility was also used to derive the final integrated topo-bathy DEM 1 arc-second grid, using the bathymetric 'pre-surface' and the topographic spot heights as the input data. The final integrated DEM was then converted from a raster to points for use in constructing the 3 arc-second DEM.

The 3 arc-second second DEM was generated using MB-System's 'mbgrid' utility. Like the GMT 'Surface' utility, it uses a tensioned spline interpolation algorithm for grid creation. Unlike the GMT 'Surface' utility, MB-System's 'mbgrid' allows the user to define a relative weighting value to each input dataset for consideration during the gridding process. Generally speaking, datasets qualitatively deemed as higher quality were assigned a higher relative weighting value, whereas 'poor quality' data (containing noise/artifacts or covering a small spatial extent) were given less influence. Once the integrated 3 arc-second DEM was generated using MB-system, a low-pass filter (3X3 kernal) was applied in ArcGIS in order to minimize artifacts introduced during the gridding process as well as minimize any offsets among adjacent or overlapping datasets.

While no quantitative assessments were performed on either the 1 or 3 arc-second DEMs, each grid was visually inspected for significant artifacts and compared to nautical charts in order to identified issues not previously detected.

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Appendix 1- Admiralty Charts used for DEM creation

Chart Number	Original Publishing Date	Name	Scale
332"A"	1993	Ireland Island; North and South Basins incl. Bermuda Freeport	1:3000
332	1993	Grassy Bay and Great Sound incl. Little Sound	1:12500
1073	1993	Dundonald Channel to Hamilton Harbor	1:6000
867	1995	North and South Channels to Great Sound	1:17500
868	1995	Eastern and Western Approaches to The Narrows incl. Murray's Anchorage	1:17500
1315	1995	Five Fathom Hole, The Narrows and St. George's Harbour	1:7500
334	1997	North Atlantic Ocean; Bermuda	1:75000
360	1997	North Atlantic Ocean; Approaches to Bermuda	1:300000

Appendix 2- NOAA multibeam bathymetry used in the Bermuda DEM creation

Survey ID	Ship	Date
EW9304	R/V Ewing	1993
EW9309	R/V Ewing	1996
EW0006	R/V Ewing	2000
KN161L08	R/V Knorr	2000
AT05L03	R/V Atlantis	2001
AT05L04a	R/V Atlantis	2001
EW0102	R/V Ewing	2001
EW0106	R/V Ewing	2001
AT07L35	R/V Atlantis	2003
AT07L36	R/V Atlantis	2003
EW0306	R/V Ewing	2003
EW0309	R/V Ewing	2003
KN173L02	R/V Knorr	2003
KN200-06	R/V Knorr	2011
KN204-01	R/V Knorr	2011
AT20	R/V Atlantis	2012

Appendix 3- Established relationships between various vertical datums in Bermuda