Digital Elevation Model of the Galapagos Islands, Ecuador: Procedures, Data Sources, and Analysis

Prepared for NOAA's Pacific Marine Environmental Laboratory and the National Weather Service by the NOAA's National Centers for Environmental Information (NCEI)
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Summary

In May of 2016, NOAA's National Centers for Environmental Information (NCEI) developed an integrated bathymetric–topographic digital elevation model (DEM) of the Galapagos Islands 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. The DEM covers Galapagos Islands (Archipelago de Colon) including Isla Fernandina, Isla Santa Maria, Isla Isabela, Isla Santa Cruz, Isla de San Cristobal, San Salvador, Isla Marchena, Isla Pinta, Isla Genovesa, Isla Floreana, Isla Espanola, and Wolf and Darwin Islands. 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 Galapagos Islands DEM was built to the specifications listed in Table 1. Figure 1 shows the 1 arc-second Galapagos Islands integrated topographic–bathymetric DEM boundary in red and the 3 arc-second DEM in yellow.

Table 1. Specifications for the Galapagos Islands, Ecuador DEM.

Cell Size	1 arc-second	3 arc-second
Coverage	87.20° to 92.32° W, 1.98°S to 1.95° N	83.81° to 93.18° W, 2.66°S to 3.81° N
Coordinate System	Geographic decimal degrees	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Sea Level	Mean Sea Level
Vertical Units	Meters	Meters
Grid Format	ASCII raster grid	ASCII raster grid

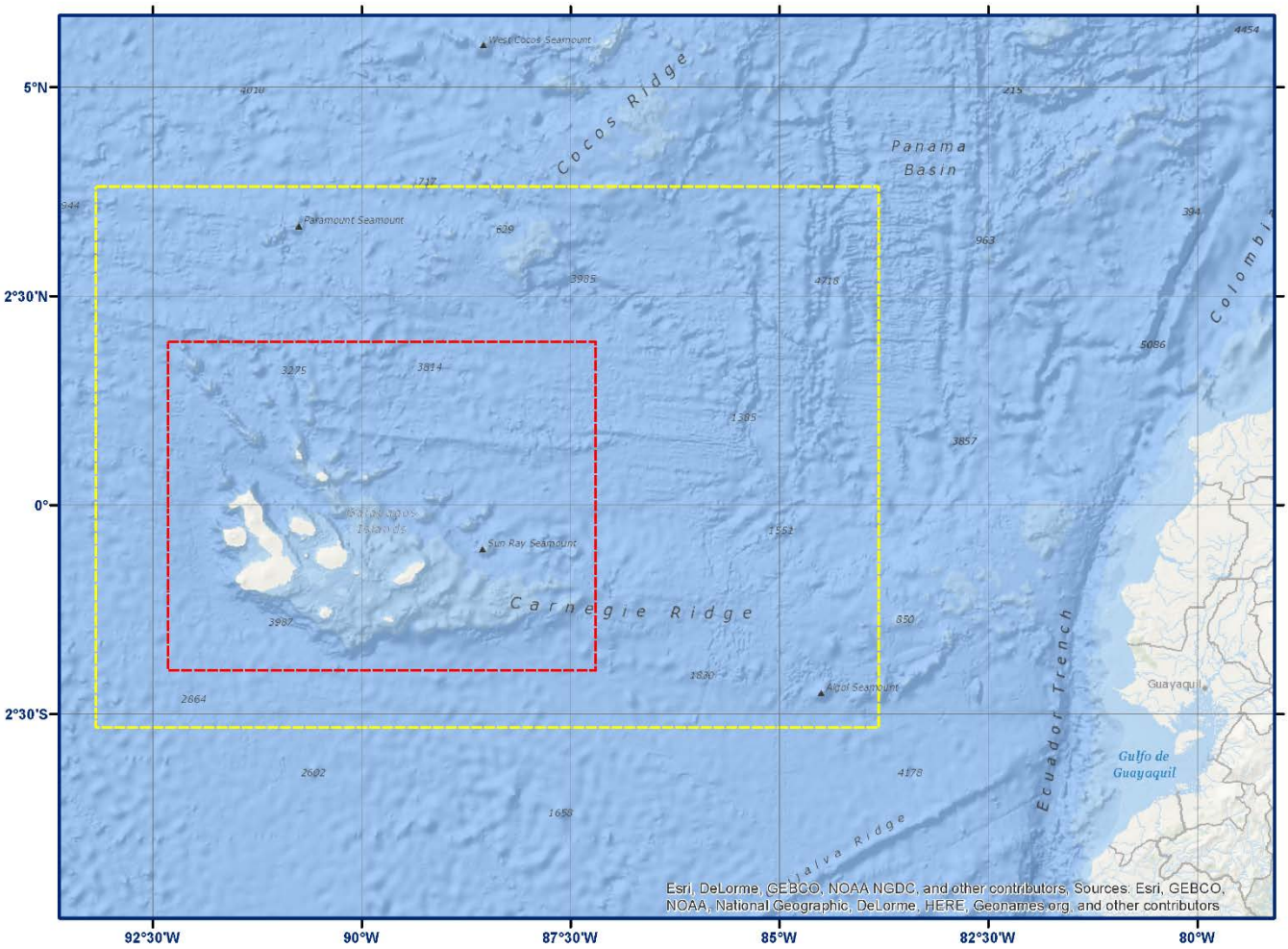

Figure 1. Map image of the boundaries for the 1 arc-second Galapagos Islands DEM in red and the 3 arc-second DEM in yellow.

Data Sources and Processing

Digital coastline data were extracted from Instituto Geográfico Militar, Gestión Geográfica – Gestión IDE web map service. These data were transformed to WGS 84 geographic in ArcCatalog and used as source data and to develop a clipping mask for the bathymetric surface. Bathymetric data were downloaded from NOAA's Pacific Marine Environmental Laboratory (PMEL), the Marine Geoscience Data System (MGDS), the General Bathymetric Chart of the Oceans (GEBCO), and NCEI. Bathymetric data were also provided to NCEI by Woods Hole Oceanographic Institute (WHOI), the Living Oceans Foundation (KSLOF), and Ecuador's Instituto Oceanográfico de la Armada (INOCAR). Figure 2 shows the source and coverage of the datasets used in developing the Galapagos Islands DEM.

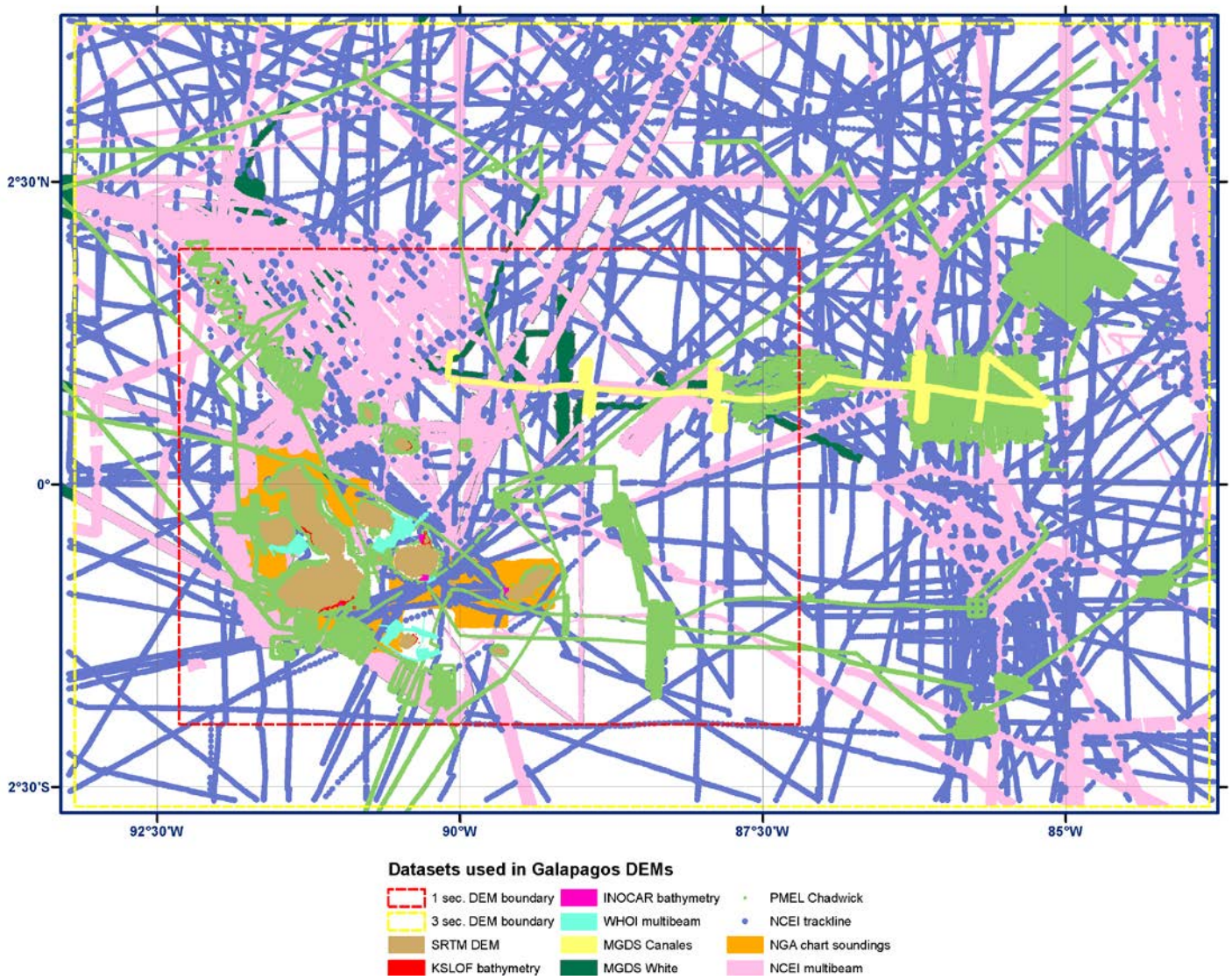

Figure 2. Source and coverage of the datasets used in compiling the Galapagos Islands DEM.

Table 2 lists the bathymetry data used in the compilation of the Galapagos Islands DEM including NCEI multibeam surveys (Appendix A), multibeam data from several organizations, INOCAR survey data, gridded multibeam compilations, AUV data, and optically derived bathymetry.

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

Source	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
INOCAR/SHOA	2015	Nautical chart sounding point data	~ 2 meters to 20 meters	UTM Zone 15 or Zone 16	Mean Low Water Springs (MLWS)
PMEL/OSU – Chadwick	2002	Gridded multibeam bathymetry	1 km grid	undefined	undefined
MGDS – Sentry AUV	2010	Processed Gridded submersible Multibeam Sonar Data	1 meter grid	WGS 84 geographic	undefined
MGDS – White	2015	Processed multibeam bathymetry compilation grid	100 meter grid	WGS 84 geographic	undefined
MGDS – Canalas	2005	Processed multibeam bathymetry grid	180 meter grid	WGS 84 geographic	undefined
KSLOF	2014	Optically derived bathymetry	2 meters	WGS 84 Web Mercator	undefined
WHOI	2015	Multibeam bathymetry grid	10 meters	WGS 84 Web Mercator	undefined
NCEI	1958 to 2002	Single-beam Trackline Bathymetry	~ 25 meters to > 100 meters	NAD 83 geographic	Assumed MSL
NCEI	1997 to 2010	Multibeam bathymetry	10 to 30 meter grid	NAD 83 geographic	Assumed MSL
GEBCO	2014	Bathymetric DEM	30 arc-second	undefined	Assumed MSL
NGA	1985 and 1994	Digitized nautical chart soundings	1:60,000	Georeferenced to WGS 84 geographic	Mean Low Water Springs (MLWS)

Bathymetric data were transformed to WGS 84 geographic using GDAL and where recent, higher resolution data exists, older data were superseded. Vertical datum conversion from MLWS to MSL was done using a constant value of 1.06 meters (González Paredes, 2012).

The bathymetric data were converted to xyz format before combining with the coastline data to generate a bathymetric pre-surface at 1/3 arc-second. This bathymetric surface grid was converted to xyz format before incorporating in the final DEM.
The SRTM topographic data (Table 5) were transformed to WGS 84 geographic using GDAL and converted to xyz format. The converted xyz data files were filtered to remove NoData values and returns over water.

Table 5: Topographic data source used in compiling the Galapagos Islands DEM.

Source - Title	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
SRTM	2000	DEM	1 arc-second	WGS 84 geographic	EGM96 (Earth Gravitational Model 1996) ellipsoid

DEM Development

Development of the Galapagos Islands 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 1/3 arc-second. Gridding weight was modified to Table 6.

Table 6: Data hierarchy used to assign gridding weight in MB-System for 1 arc-second DEM.

Dataset	*Relative Gridding Weight*
KSLOF	1000
INOCAR	1000
AUV	1000
WHOI	1000
Bathy surface	10
SRTM	10

Table 7: Data hierarchy used to assign gridding weight in MB-System for 3 arc-second DEM.

Dataset	*Relative Gridding Weight*
KSLOF	1000
INOCAR	1000
AUV	1000
WHOI	1000
Bathy surface	10
SRTM	10
MGDS	1

DEM Analysis

The completed Galapagos Islands DEMs were compared to chart contour data and high resolution imagery. Inconsistencies were evaluated and resolved based on most current or reliable data available.

Acknowledgement

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Appendix A: NCEI Multibeam surveys

Survey ID	*Date*	*Ship*	*Institution*	*Original Horizontal Datum*	*Original Vertical Datum*
AII2L31	1985	Atlantis II	University of Rhode Island (URI)	NAD 83 geographic	assumed MSL
AMLR92T	1991-1992	Surveyor	NOAA	NAD 83 geographic	assumed MSL
ARIA02WT	1982	Thomas Washington	University of California, Scripps Institution of Oceanography (UC/SIO)	NAD 83 geographic	assumed MSL
AT07L12	2002	Atlantis	Woods Hole Oceanographic Institution (WHOI)	NAD 83 geographic	assumed MSL
AT07L13	2002	Atlantis	WHOI	NAD 83 geographic	assumed MSL
AT07L25	2002	Atlantis	WHOI	NAD 83 geographic	assumed MSL
AT11L27	2005	Atlantis	WHOI	NAD 83 geographic	assumed MSL
AT15-63	2010	Atlantis	UNOLS R2R	NAD 83 geographic	assumed MSL
CERE03WT	1982	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
CERE04WT	1982	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
COOK01MV	2000	Melville	UC/SIO	NAD 83 geographic	assumed MSL
DANA03RR	2003	Roger Revelle	UC/SIO	NAD 83 geographic	assumed MSL
DRFT02RR	2001	Roger Revelle	UC/SIO	NAD 83 geographic	assumed MSL
DRFT03RR	2001	Roger Revelle	UC/SIO	NAD 83 geographic	assumed MSL
DRFT04RR	2001	Roger Revelle	UC/SIO	NAD 83 geographic	assumed MSL
DRFT05RR	2001	Roger Revelle	UC/SIO	NAD 83 geographic	assumed MSL
EW0003	2000	Maurice Ewing	Marine Geoscience Data System (MGDS)	NAD 83 geographic	assumed MSL
EW0004	2000	Maurice Ewing	MGDS	NAD 83 geographic	assumed MSL
EW9205	1992	Maurice Ewing	MGDS	NAD 83 geographic	assumed MSL
EW9416	1994	Maurice Ewing	MGDS	NAD 83 geographic	assumed MSL
EW9603	1996	Maurice Ewing	MGDS	NAD 83 geographic	assumed MSL
EX1103*	2011	Okeanos Explorer	NOAA	NAD 83 geographic	assumed MSL
KN182L09	2005	Knorr	WHOI	NAD 83 geographic	assumed MSL
KN182L12	2006	Knorr	WHOI	NAD 83 geographic	assumed MSL
KN195-03	2009	Knorr	UNOLS R2R	NAD 83 geographic	assumed MSL
KN195L03	2009	Knorr	URI	NAD 83 geographic	assumed MSL
MGL0808	2008	Marcus G. Langseth	UNOLS R2R	NAD 83 geographic	assumed MSL
MV1007	2010	Melville	UNOLS R2R	NAD 83 geographic	assumed MSL
MV1014	2010	Melville	UNOLS R2R	NAD 83 geographic	assumed MSL
MV1207	2012	Melville	UNOLS R2R	NAD 83 geographic	assumed MSL
MV1208	2012	Melville	UNOLS R2R	NAD 83 geographic	assumed MSL

NEMO02MV	2000	Melville	UC/SIO	NAD 83 geographic	assumed MSL
NEMO03MV	2000	Melville	UC/SIO	NAD 83 geographic	assumed MSL
PLUM01WT	1990	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
PLUM02WT	1990	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
PLUM03WT	1990	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
RC2606	1985	Robert Conrad	MGDS	NAD 83 geographic	assumed MSL
RITS93A	1992-1993	Surveyor	NOAA	NAD 83 geographic	assumed MSL
TN188	2005	Thomas G. Thompson	MGDS	NAD 83 geographic	assumed MSL
TN189	2006	Thomas G. Thompson	MGDS	NAD 83 geographic	assumed MSL
TUGA02WT	1987	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL
VANC03MV	2002	Melville	UC/SIO	NAD 83 geographic	assumed MSL
VNTR01WT	1989	Thomas Washington	UC/SIO	NAD 83 geographic	assumed MSL

** Derived multibeam products were used instead of raw mb files.*