

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

Prepared for the Pacific Marine Environmental Laboratory (PMEL) by the NOAA National Centers for Environmental Information (NCEI)

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Summary

In December of 2016, NOAA's National Centers for Environmental Information (NCEI) developed an integrated bathymetric–topographic digital elevation model (DEM) of the island of Rarotonga of the archipelago nation of Cook Islands for the Pacific Marine Environmental Laboratory (PMEL). The DEM will be used to support modeling tsunami generation, propagation, and inundation. The DEM covers Rarotonga Island including the land districts of Avarua, Matavera, Ngatangila, Titikaveka and Arorangi. Extents of this DEM, procedures, data sources, and analysis are described below. The methodologies used by NCEI in developing DEMs are described in the NOAA Technical Memorandum-52 for Central California and San Francisco Bay (Carignan et al., 2011).

DEM Specifications

The Rarotonga DEM was built to the specifications listed in Table 1. Figure 1 shows this 1 arc-second Rarotonga integrated topographic–bathymetric DEM boundary in red, the 2009 Pago Pago, American Samoa 3 arc-second MHW DEM in green and the 2013 Tutuila, American Samoa 1/3 arc-second MHW DEM in yellow.

Table 1. Specifications for the Rarotonga DEM.

<i>Cell Size</i>	1 arc-second
<i>Coverage</i>	159.10° to 160.40° W, 20.70° to 21.85° S
<i>Coordinate System</i>	Geographic decimal degrees
<i>Horizontal Datum</i>	World Geodetic System 1984 (WGS 84)
<i>Vertical Datum</i>	Mean Sea Level (MSL)
<i>Vertical Units</i>	Meters
<i>Grid Format</i>	ASCII raster grid

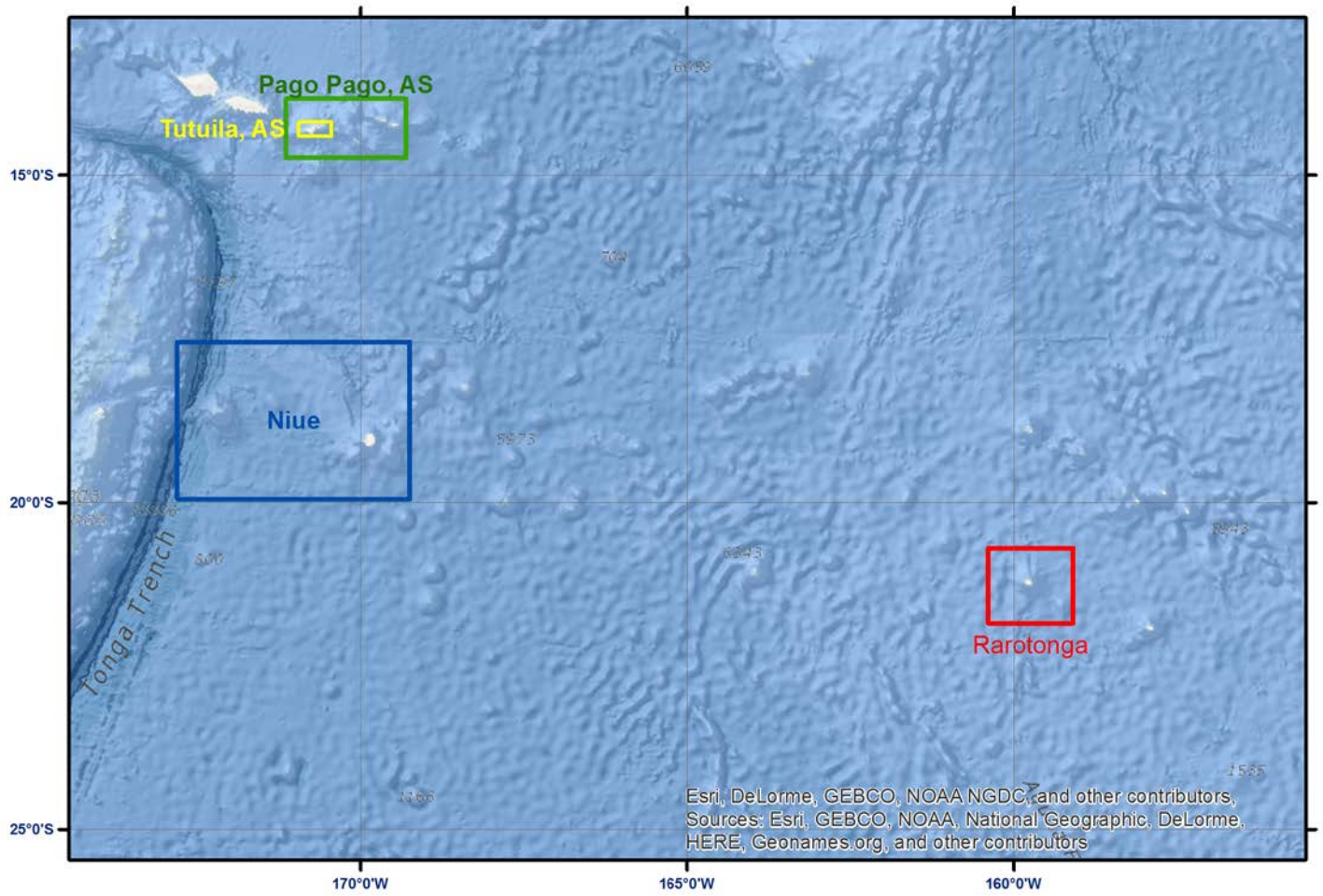


Figure 1. Map image of the boundaries for the 3 arc-second Rarotonga DEM in red and the previously developed DEMs of Niue in blue, Pago Pago, AS in green and Tutuila, AS in yellow.

Data Sources and Processing

Digital shoreline data were sourced from the Land Information New Zealand Data Service, (LINZ, 2014) and licensed by LINZ for reuse under the Creative Commons Attribution 4.0 International License; the data were transformed to WGS 84 geographic (latitude and longitude) coordinates using MB-System coordinate conversion controls. Digitized bathymetric chart data (points and contours) for Avarua and Avatiu harbors and their approaches were obtained from the National Geospatial-Intelligence Agency (NGA) as Digitized Nautical Charts originally published by LINZ (2014). Bathymetry data from a Real-Time Kinematic (RTK) GPS survey of lagoon depths and from a digitized survey of lagoon depths were obtained from the University of New South Wales' Water Research Laboratory while bathymetry data sets of Avatiu and Avarua harbors and the nearshore reef slope were obtained from Pacific Islands Applied Geoscience Commission (SOPAC); all were transformed to WGS 84 geographic coordinates using MB-System coordinate conversion controls. Single beam bathymetry data of nearshore environments were obtained from the Khaled bin Sultan Living Oceans Foundation (Bruckner, 2014). Trackline bathymetric data were downloaded from NOAA/NCEI. DEM data for the extent of

the study area were downloaded from the General Bathymetric Chart of the Oceans (GEBCO). Figures 2 and 3 shows the source and coverage of the datasets used in developing the Rarotonga DEM.

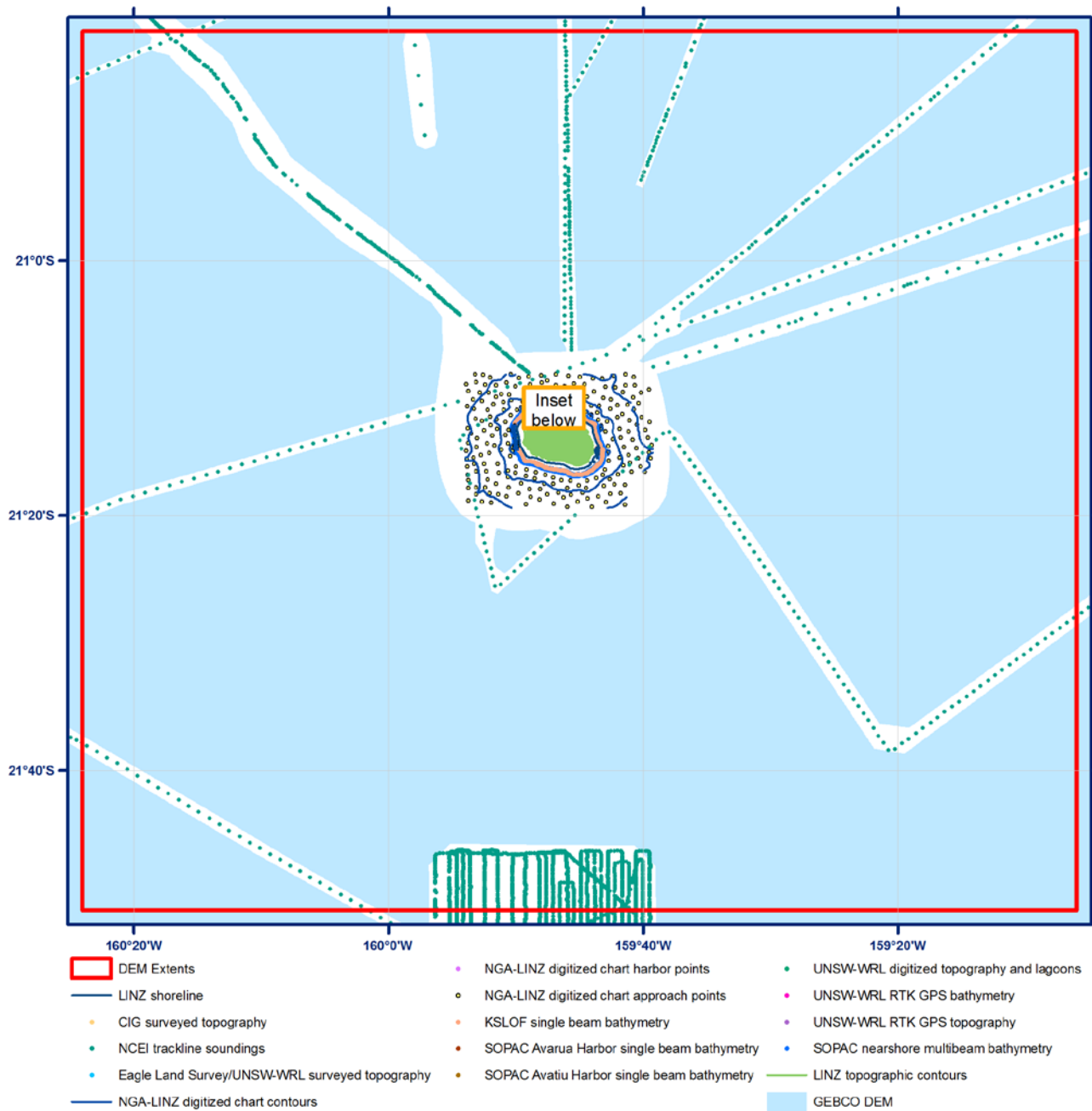


Figure 2. Source and coverage of the datasets used in compiling the Rarotonga DEM.

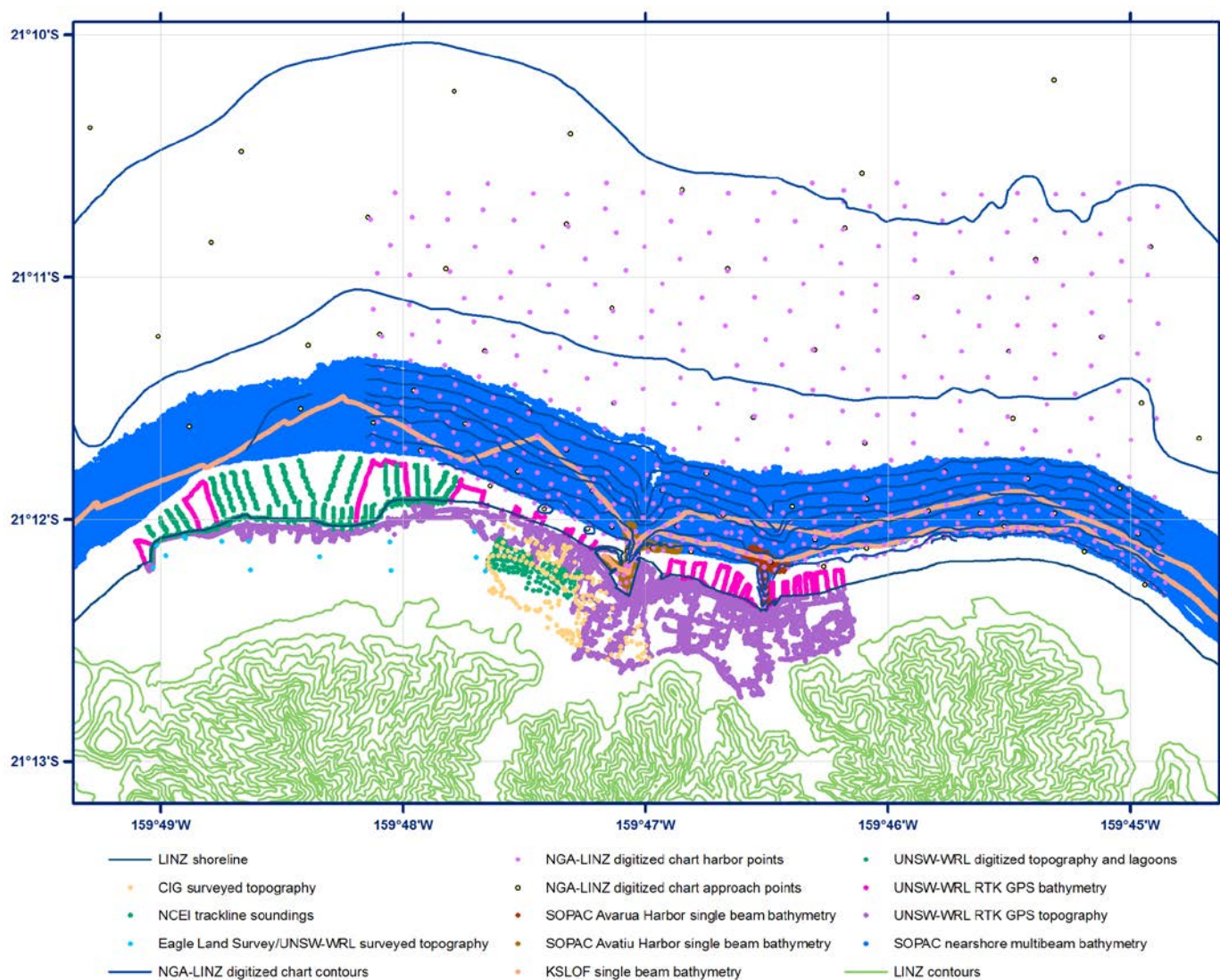


Figure 3. Source and coverage of the island harbor environment datasets used in compiling the Rarotonga DEM.

Table 2 lists the bathymetry data used in the compilation of the Rarotonga DEM including the SOPAC multibeam survey, SOPAC single beam surveys, KBSLOF single beam survey, and NOAA/NCEI trackline surveys (Appendix D).

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

<i>Source</i>	<i>Date</i>	<i>Data Type</i>	<i>Spatial Resolution</i>	<i>Horizontal Datum</i>	<i>Vertical Datum</i>
NGA/LINZ	1992	Digitized chart of approaches to Avatiu, Avarua harbors	1:40000	null	null
NGA/LINZ	1992	Digitized charts of Avatiu, Avarua harbors	1:9000	null	null
UNSW-WRL	2012	RTK GPS survey of north side lagoon bathymetry	0.1 meter	UTM Zone 4, South	MSL
UNSW-WRL	2013	Digitized north side lagoon bathymetry	n/a	UTM Zone 4, South	Assumed MSL
SOPAC	2004	Nearshore multibeam bathymetry	Assumed 1 meter	UTM Zone 4, South	NTF Tide Gauge Zero
SOPAC	2006	Single beam bathymetry, Avatiu Harbor	0.01 meter	UTM Zone 4, South	NTF Tide Gauge Zero
SOPAC	2006	Single beam bathymetry, Avarua Harbor	0.01 meter	UTM Zone 4, South	NTF Tide Gauge Zero
KBSLOF	2013	Single beam bathymetry; Survey ID: CIRR; Ship: M/Y Golden Shadow	+/-0.1 meter	WGS 84 geographic	Assumed Mean Sea Level (MSL)
NCEI	1964 to 1994	Trackline bathymetry	~ 25 meters to > 100 meters	WGS 84 geographic	Assumed Mean Sea Level (MSL)
GEBCO	2015	Bathymetric DEM	30 arc-second	undefined	Assumed Mean Sea Level (MSL)

Bathymetric depth values (in meters) in SOPAC nearshore bathymetry, Avatiu harbor and Avarua harbor data were reduced from Tide Gauge Zero to Mean Sea Level (MSL) by subtracting 0.6139 from all values, according to conversion information on vertical datums in SOPAC Technical Report 385 (Smith, 2006) before

transformation to WGS 84 geographic coordinates. A bathymetric contour of -0.3 meter (m) MSL was constructed nearly continuously around the island at the outside edge of the fringing reef, with gaps at Avatiu, Avarua and Avana harbors and Avaararoa Passage, to interpolate more accurately between SOPAC nearshore bathymetry and the 0.0 meter shoreline at MSL, using aerial imagery as a reference (Google, 2016). All bathymetric data were converted to xyz format to generate a bathymetric pre-surface grid at 1 arc-second which was subsequently converted to xyz format before incorporation into the final DEM.

Shoreline data (Table 3) was transformed to WGS 84 geographic coordinates using GDAL and also converted to xyz format.

Table 3: Shoreline data source used in compiling the Rarotonga DEM.

<i>Source</i>	<i>Date</i>	<i>Data Type</i>	<i>Spatial Resolution</i>	<i>Horizontal Datum</i>	<i>Vertical Datum</i>
LINZ	2016	Shoreline shapefile	1:25000	UTM Zone 4, South	MSL

Digital topographic data were sourced from LINZ Data Service, (LINZ, 2014) and licensed by LINZ for reuse under the Creative Commons Attribution 3.0 New Zealand License. Airport topographic survey data were provided by Eagle Land Survey and UNSW-WRL. UNSW-WRL also provided RTK GPS topographic survey data and digitized topographic data of different portions of the north side of the island. The LINZ, Eagle Land Survey and UNSW-WRL data were each transformed to WGS 84 geographic coordinates using MB-System coordinate conversion controls. The Cook Islands Government (CIG) provided topographic survey data for the vicinity of the swamplands at the east end of the international airport. In similar fashion and with similar purpose to the -0.3 m bathymetric contour, a nearly continuous 2 m MSL contour was constructed at the landward edge of the beach, except for the northern coastline between Avarua Harbor and the west end of the international airport, to more accurately interpolate the landform between the 0.0 m shoreline at MSL and the lowest contour at 20 m, based upon aerial imagery (Google, 2016). Topographic data (Table 4) were converted to xyz format and clipped to the shoreline to remove NoData values and returns over water.

Table 4: Topographic data sources used in compiling the Rarotonga DEM.

<i>Source</i>	<i>Location</i>	<i>Date</i>	<i>Data Type</i>	<i>Spatial Resolution</i>	<i>Horizontal Datum</i>	<i>Vertical Datum</i>
LINZ	Entire island	2014	Satellite imagery-derived survey	20m	UTM Zone 4, South	MSL
Eagle Land Survey/ UNSW-WRL	Airport	2013	Total station survey	assumed 0.1 meter	UTM Zone 4, South	MSL
UNSW-WRL	Island north side foreshore	2012	RTK GPS topographic survey	0.1 meter	UTM Zone 4, South	MSL
UNSW-WRL	Island north side foreshore swamplands	2012	Digitized topography	n/a	UTM Zone 4, South	MSL
CIG	Avatiu swamp	2004	GPS topographic survey	assumed < 1.0 m	WGS 84 geographic	MSL

DEM Development

Development of the Rarotonga DEM followed procedures documented in NOAA Technical Memorandum NGDC-52 for Central California and San Francisco Bay (Carignan et al., 2011). Gridding weight was modified to Table 5.

Table 5: Data hierarchy used to assign gridding weight in MB-System.

<i>Dataset</i>	<i>Relative Gridding Weight</i>
UNSW surveyed topography	1000
SOPAC nearshore multibeam bathymetry	1000
SOPAC single beam bathymetry, Avatiu Harbor	1000
SOPAC single beam bathymetry, Avarua Harbor	1000
KBSLOF single beam bathymetry	1000
NCEI trackline data	100
Bathymetric pre-surface grid	100
Airport topography	100
CIG topography	100
LINZ topographic data	100
GEBCO grid	50
Constructed 2 m contour line	50
Constructed -0.3 m contour line	50
UNSW-WRL digitized topography & bathymetry	10

DEM Analysis

The completed Rarotonga DEM was 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: NOAA/NCEI Trackline surveys

<i>Survey ID</i>	<i>Ship</i>	<i>Date</i>	<i>Institution</i>	<i>Original Horizontal Datum</i>	<i>Original Vertical Datum</i>
AMPH02AR	Argo	1964	University of California, Scripps Institution of Oceanography (UC/SIO)	NAD 83 geographic	assumed MSL
BNTH04MV	Melville	1983	University of California, Scripps Institution of Oceanography (UC/SIO)	NAD 83 geographic	assumed MSL
CK76-1	Ravakai	1976	University of Hawaii	NAD 83 geographic	assumed MSL
CK77-1	Acheron	1977	University of Hawaii	NAD 83 geographic	assumed MSL
CK782	Machias	1978	University of Hawaii	NAD 83 geographic	assumed MSL
DME05-B	Dmitry Mendeleev	1971	Russia IFZ AN SSSR	NAD 83 geographic	assumed MSL
DSDP91GC	Glomar Challenger	1983	University of California, Scripps Institution of Oceanography (UC/SIO)	NAD 83 geographic	assumed MSL
RC1713	Robert D. Conrad	1974	Lamont-Doherty Earth Obs	NAD 83 geographic	assumed MSL
RT8601	Tui II	1986	New Zealand GNS Science	NAD 83 geographic	assumed MSL
SOPAC94	Monowai	1994	New Zealand Navy	NAD 83 geographic	assumed MSL