NOAA Technical Memorandum NESDIS NGDC-28

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P.R. Medley
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Boulder, Colorado
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Pamela R. Medley[1]
Lisa A. Taylor[2]
Barry W. Eakins[1]
Kelly S. Carignan[1]
Robin R. Warnken[2]
Elliot Lim[1]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder

[2]NOAA, National Geophysical Data Center, Boulder, Colorado

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UNITED STATES DEPARTMENT OF COMMERCE

Gary Locke
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. Jane Lubchenco
Under Secretary for Oceans and Atmosphere/Administrator

National Environmental Satellite, Data, and Information Service

Mary E. Kicza
Assistant Administrator

NOTICE

Corresponding project contact:
Lisa A. Taylor
NOAA National Geophysical Data Center
Marine Geology and Geophysics Division
325 Broadway, E/GC 3
Boulder, Colorado 80305
Phone: 303-497-6767
Fax: 303-497-6513
E-mail: Lisa.A.Taylor@noaa.gov
http://www.ngdc.noaa.gov/mgg/inundation/tsunami/inundation.html

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Digital Elevation Models of Chignik, Alaska: Procedures, Data Sources and Analysis

1. Introduction

In October 2008, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed two integrated bathymetric–topographic digital elevation models (DEMs) centered on Chignik, Alaska for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The coastal DEMs will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. A 1 arc-second[1] DEM (Fig. 1) was generated from diverse digital datasets in the region (see Fig. 3). It will be used for tsunami modeling as part of the tsunami forecast system Short-term Inundation Forecasting for Tsunamis (SIFT) currently being developed by PMEL for the NOAA Tsunami Warning Centers. A smaller 1/3 arc-second DEM (grid boundary shown in Fig. 3) was generated for the area surrounding Chignik Bay to increase forecasting accuracy around the harbor. This report provides a summary of the data sources and methodology used in developing the Chignik DEMs.

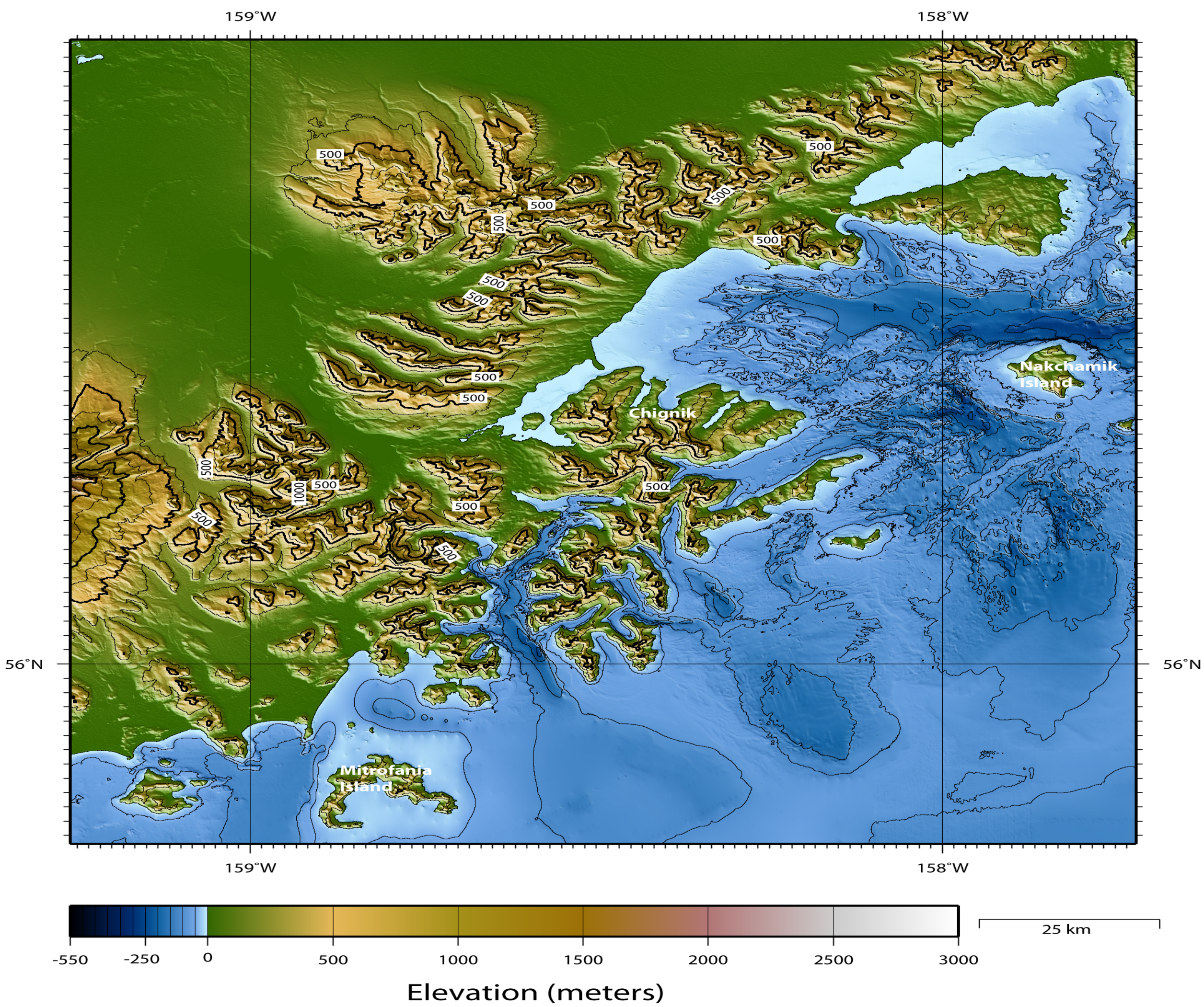


Figure 1. *Shaded-relief image of the Chignik region, derived from the 1 arc-second DEM. Contour interval is 500 meters.*

1. In polar latitudes, longitude lines are spaced significantly closer together than latitude lines, approaching zero at the poles. While the DEM is built upon grids of square cells in geographic coordinates, they are not square cells when converted to meters. At the latitude of Chignik, Alaska (56°17′43″ N, 158°24′08″ W) 1 arc-second of latitude is equivalent to 30.78 meters; 1 arc-second of longitude equals 17.60 meters.

2. Study Area

Chignik, Alaska (Fig. 2), population 80, is located approximately 450 miles southwest of Anchorage and 250 miles southwest of Kodiak Island at 56°17'42"N 158°24'7"W. Chignik is a fishing village where many residents have dual residency in either Kodiak or Anchorage and only live in Chignik during the summer for the salmon season (http://www.chignikbay.com/).

Chignik is approximately 40 miles east of Mt. Veniaminol and contains many deposits of volcanic ash and cinders. The geology is predominately brown to tan sandstone with coal seams and conglomerate. Rocks exposed in Chignik Bay are part of the Chignik Formation and are approximately 77 to 68 million years old. The Chignik Formation represents a cyclic sequence of predominately shallow to nearshore marine environments.

Chignik's land features are characterized by long mountain slopes with many streams. Mountain runoff from waterfalls occurs after heavy rains and floods the town's roads. The steep topography has well-drained soils on the slopes of loamy volcanic ash overlying sandy and cindery ash. The soil in the community of Chignik consists mostly of wetlands, pebble rock, and sand. The beach consists of rock, pebble, and sand, and the banks are mud, rock, and a sand mixture.

Figure 2. *Chignik Bay during the summer months. [Photo credit: U.S. Fish and Wildlife Service; http://images.fws.gov/]*

3. Methodology

The Chignik DEM was constructed to meet PMEL specifications (Table 1), based on input requirements for the development of reference inundation models (RIMs) and standby inundation models (SIMs) (*V. Titov, pers. comm.*) in support of NOAA's Tsunami Warning Centers use of SIFT to provide real-time tsunami forecasts in an operational environment. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North America Datum of 1983 (NAD 83) and mean high water (MHW), for modeling of maximum flooding, respectively[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections. The 1 arc-second DEM fully encompasses the 1/3 arc-second DEM, but extends out to a much broader boundary for tsunami propagation modeling (Fig. 3).

Table 1a: PMEL specifications for the 1 arc-second Chignik DEM.

Grid Area	Chignik, Alaska
Coverage Area	157.56º to 159.26º W; 55.79º to 56.72º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	MHW
Vertical Units	Meters
Cell Size	1 arc-second
Grid Format	ESRI ASCII raster grid

Table 1b: PMEL specifications for the 1/3 arc-second Chignik DEM.

Grid Area	Chignik, Alaska
Coverage Area	158.54º to 158.21º W; 56.23º to 56.49º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	MHW
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI ASCII raster grid

2. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) geographic horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEM. Most GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the wave's passage across ocean basins. This DEM is identified as having a WGS 84 geographic horizontal datum even though the underlying elevation data were typically transformed to NAD 83 geographic. At the scale of the DEM, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 3) were obtained from several U.S. federal agencies, including: NOAA's Office of Coast Survey (OCS) and NGDC; the National Geospatial-Intelligence Agency (NGA); the U.S. Fish and Wildlife Service (USFWS); and the U.S. Geological Survey (USGS). Safe Software's *FME* data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert into ESRI *ArcGIS* shapefiles[3]. The shapefiles were then displayed with *ArcGIS* to assess them and manually edit datasets. Vertical datum transformations to MHW were also accomplished using *FME*, based upon data from several NOAA tide stations in the Chignik region, as no *VDatum* model software was available for this area.

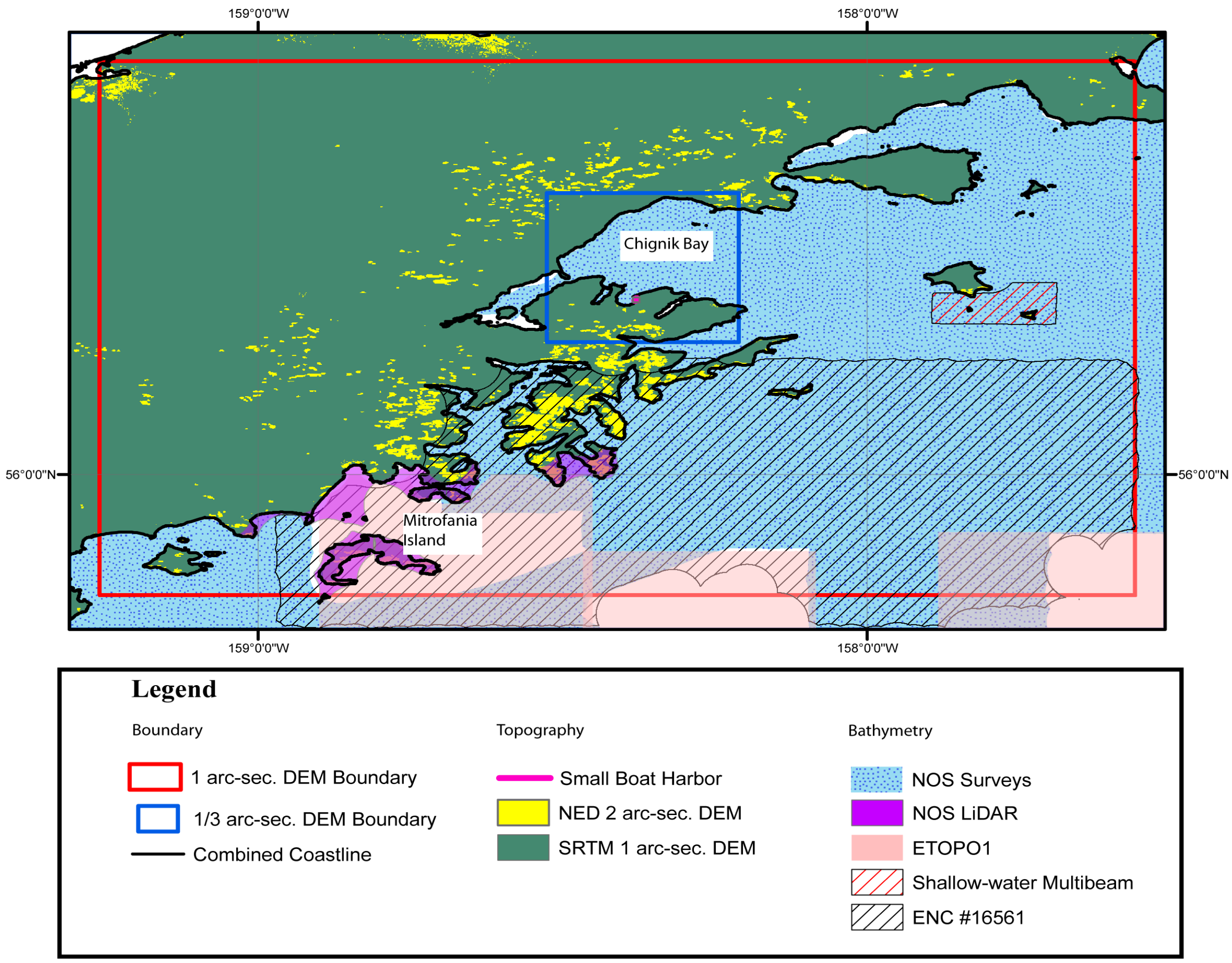


Figure 3. *Source and coverage of datasets used in compiling the Chignik DEMs. White areas denote data gaps.*

3. *FME* uses the North American Datum Conversion Utility (NADCON; http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html) developed by NOAA's National Geodetic Survey (NGS) to convert data from NAD 27 to NAD 83. NADCON is the U.S. Federal Standard for NAD 27 to NAD 83 datum transformations.

3.1.1 *Shoreline*

Three digital coastline datasets available for the Chignik region were analyzed for inclusion in the Chignik DEMs: NOAA Electronic Navigational Chart (ENC)[4] #16011; NGA High Water Line; and USFWS statewide Alaska digital coastline. Comparisons between the different coastline datasets, NOS hydrographic surveys, Space Shuttle Radar Topography (SRTM) topographic DEM, Raster Navigational Charts (RNCs), and *Google Earth* satellite imagery showed that the USFWS coastline (Table 2) best fit the topographic and bathymetric data (Figs. 4 and 5) and was used to create a "final coastline" for the Chignik DEMs.

Table 2. Shoreline datasets used in compiling the Chignik DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*
USFWS	2006	Compiled coastline	Various	WGS 84 geographic	Undefined

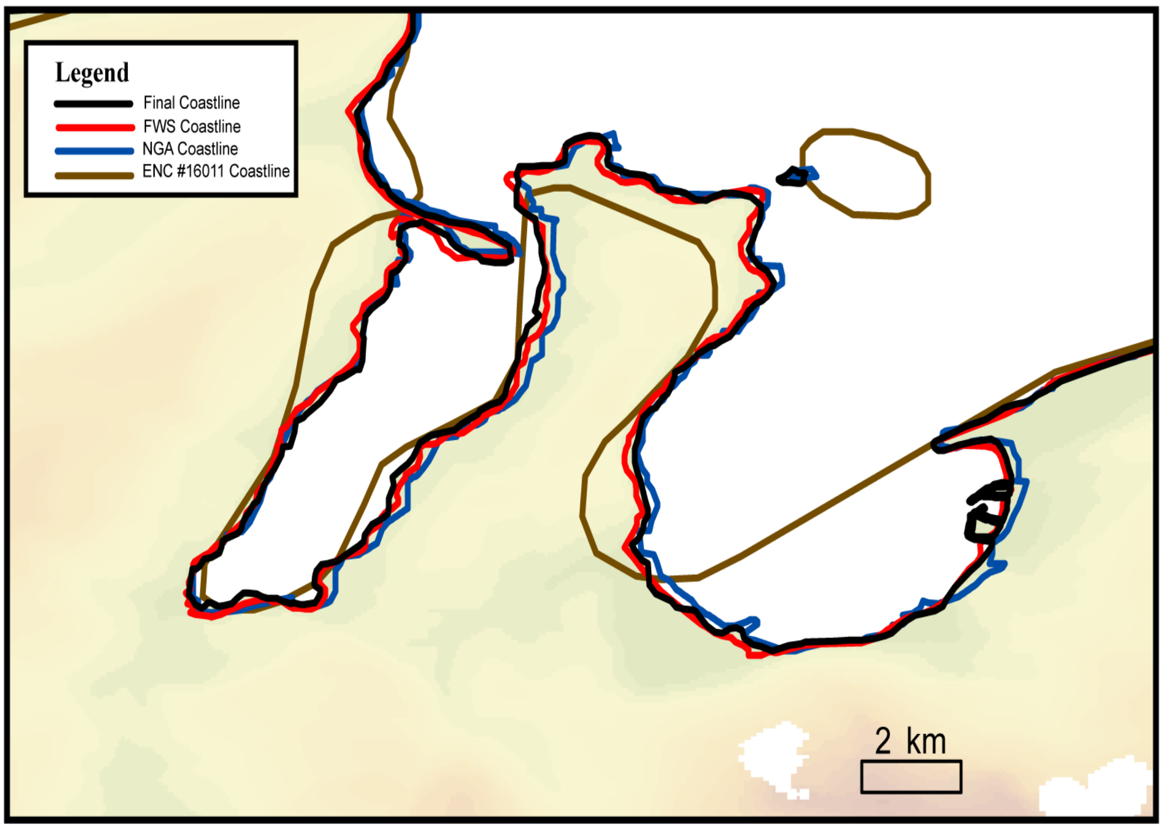


Figure 4. *Digital coastline datasets in the Chignik vicinity shown with SRTM topographic data.*

4. The Office of Coast Survey (OCS) produces NOAA Electronic Navigational Charts (NOAA ENC®) to support the marine transportation infrastructure and coastal management. NOAA ENC®s are in the International Hydrographic Office (IHO) S-57 international exchange format, comply with the IHO ENC Product Specification and are provided with incremental updates, which supply Notice to Mariners corrections and other critical changes. NOAA ENC®s are available for free download on the OCS web site. [Extracted from NOAA OCS web site: http://nauticalcharts.noaa.gov/mcd/enc/]

1) **National Geospatial-Intelligence Agency High Water Line**

The NGA[5] Office of Global Navigation, Maritime Division developed the Global Shoreline Data set from digitized orthorectified NASA, 2000 era, LANDSAT GeoCover (multi-spectral imagery). This new shoreline is an approximation of the High Water Line with a resolution of 1:75,000 or smaller. The NGA coastline provides complete coverage of the 1 arc-second DEM area but was not used in the final coastline, as the USFWS was more accurate.

2) **U.S. Fish and Wildlife Service**

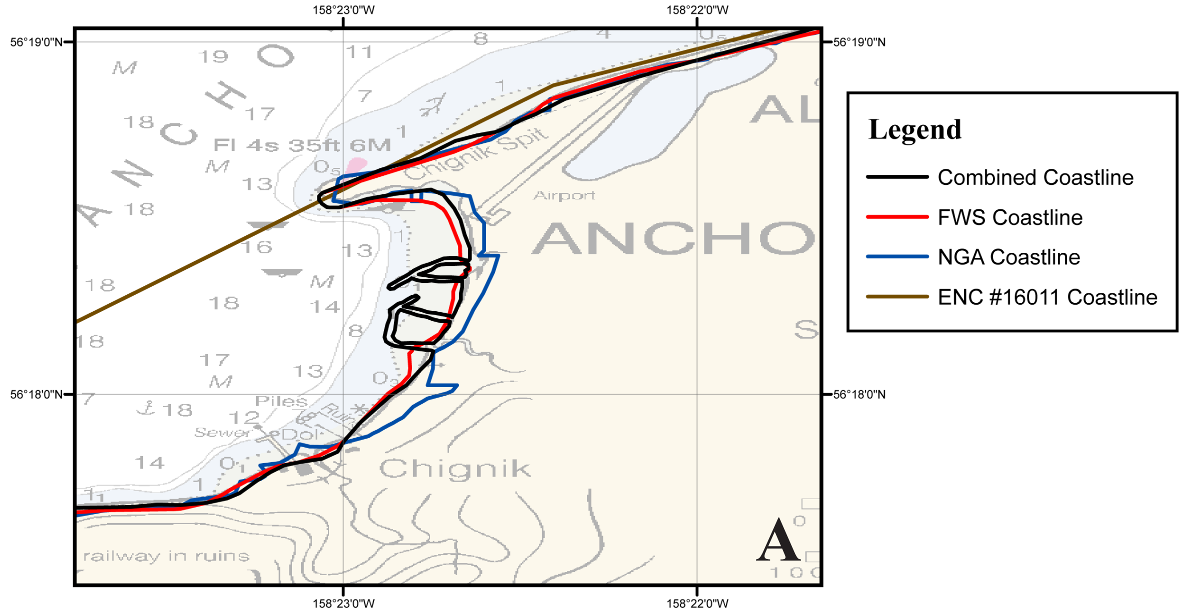
USFWS compiled a seamless digital coastline of the State of Alaska from a variety of sources, including: the National Hydrography Dataset, NOAA nautical charts, USFWS, National Geographic Topo Software, U.S. Army Corps of Engineers, and Alaska Department of Natural Resources. This dataset was provided to NGDC by Bret Christensen, USFWS. Though efforts were made to obtain the highest resolution coastlines available, vertical datums were not determined nor controlled in any way in compiling the USFWS coastline; the horizontal datum of the compiled USFWS coastline is WGS 84. The USFWS coastline provides complete coverage of the 1 arc-second Chignik DEM area and most closely matched the SRTM topographic data and raster nautical charts.

3) **NOAA Electronic Navigational Chart #16011 extracted coastlines**

ENC #16011 provides complete coverage of the 1 arc-second Chignik DEM, however, the coastline extracted from the chart is not as detailed as the NGA and the USFWS coastlines, so was not used in building the final coastline for the DEM.

To obtain the best digital MHW coastline, NGDC edited the USFWS coastline in *ArcGIS* to fit recent NOS hydrographic survey data, SRTM data and *Google Earth* satellite imagery. Recent breakwater construction for a small boat harbor in Chignik Bay is not represented in any of the three available coastlines. Therefore, an aerial image of the small boat harbor was georeferenced in *ArcGIS* and the breakwater was manually digitized by NGDC and added to the final coastline (Figs. 5 and 12). The final coastline was subsampled to 10-meter spacing and converted to point data for use in the gridding process. It was also used as a coastal buffer for the bathymetric pre-surfacing algorithm (see Sec. 3.3.2) to ensure that interpolated bathymetric values reached “zero” at the coast. The final coastline was also used to clip the SRTM and National Elevation Dataset (NED) topographic DEMs, which contained elevation values, typically zero, over the open ocean (Sec. 3.1.3).

5. The NGA Office of Global Navigation, Maritime Division is in the process of developing a new version of World Vector Shoreline (WVS®) and in support of this effort has acquired a prototype Global Shoreline Data set. This new shoreline is an approximation of the High Water Line; it is NOT a Mean High Water Line since the source data have not been tide coordinated (https://www1.nga.mil/Pages/Default.aspx). The prototype Global Shoreline Data set (satellite derived High Water Line) in work at NGA has been acquired from orthorectified NASA, 2000 era, LANDSAT GeoCover (multi-spectral imagery). [Extracted from metadata]



F[illegible]*de the boat harbor, and added 1 meter elevations approximately every 4 meters. The final coastline is in black. B) Aerial photo of the small boat harbor taken from a plane.*
[Photo credit: West Construction Company, Inc.; http://www.bwcc.us]

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Chignik DEMs include 60 NOS hydrographic surveys, a shallow-water multibeam swath sonar survey, hydrographic lidar surveys, ENC soundings, and subsets extracted from the ETOPO1 Global Relief Model (Table 3). Datasets were originally referenced to mean lower low water (MLLW) or mean sea level (MSL).

Table 3. Bathymetric datasets used in compiling the Chignik DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum (meters)*	*URL*
NGDC	1914 to 2005	NOS hydrographic survey soundings	1:10,00 to 1:120,000	Unalaska Datum, Early Alaskan Datum, Undefined Datum, NAD 83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOS	2001	Shallow-water multibeam sonar	10 meters	NAD 83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOS	2004	Hydrographic lidar surveys	1:10,000	NAD 83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOAA ENC #16561		Extracted ENC sounding data	1:80,000	WGS 84 geographic	MLLW	http://nauticalcharts.noaa.gov/mcd/enc
ETOPO1	2008	Global Relief Model	1 arc-minute	WGS 84 geographic	MSL	http://www.ngdc.noaa.gov/mgg/global/global.html

1) National Ocean Service hydrographic survey data

A total of 60 NOS hydrographic surveys conducted between 1914 and 2005 were used in the development of the Chignik DEMs (Fig. 6; Table 4); a survey containing sparse data from 1910 was excluded (H03194). The hydrographic survey data were originally vertically referenced to MLLW and horizontally referenced to either Early Alaska, Unalaska, Undetermined, or NAD 83 datums.

Data point spacing for the surveys ranged from about 10 meters in shallow water to 1.2 kilometers in deep water. All surveys were extracted from NGDC's NOS Hydrographic Survey Database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original datums (Table 4). The data were then converted to NAD 83 using *FME* software, an integrated collection of spatial extract, transform, and load tools for data transformation; some NOS surveys were manually shifted in *ArcGIS* to fit the final coastline. The surveys were subsequently clipped to a polygon 0.05 degrees (~5%) larger than the 1 arc-second gridding area to support data interpolation across DEM boundaries.

After converting all NOS survey data to MHW (see Sec. 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and compared to the SRTM and NED topographic data, the final coastline and *Google Earth* satellite imagery.

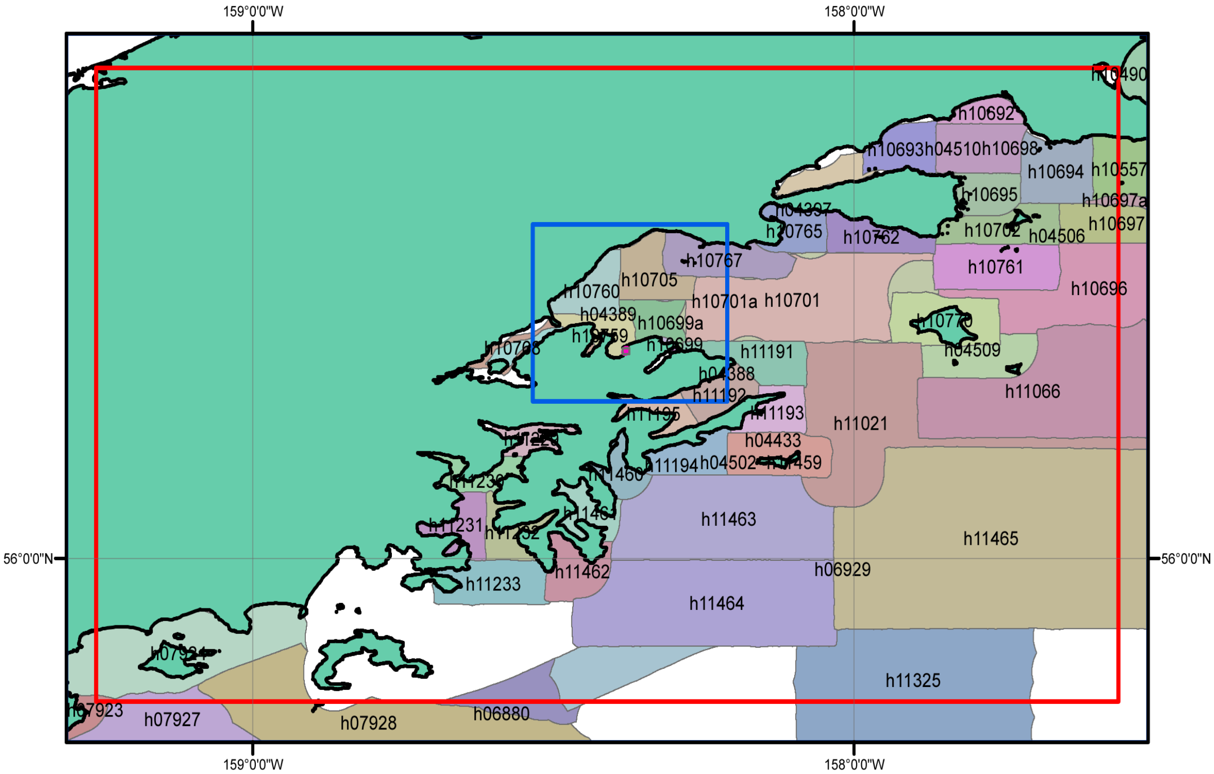


Figure 6. *Digital NOS hydrographic survey coverage in the Chignik region. Red denotes boundary of the 1 arc-second DEM, blue denotes boundary of the 1/3 arc-second DEM. The combined coastline is in black.*

Table 4. Digital NOS hydrographic surveys used in compiling the Chignik DEMs.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum of Digital Records*
H03722*	1914	100,000	MLLW	Unalaska Datum
H03796	1915	100,000	MLLW	Undetermined Horizontal Datum
H04388*	1924	20,000	MLLW	Undetermined Horizontal Datum
H04389*	1924	20,000	MLLW	Undetermined Horizontal Datum
H04397*	1924	20,000	MLLW	Undetermined Horizontal Datum
H04433*	1924	20,000	MLLW	Undetermined Horizontal Datum
H04502*	1925	20,000	MLLW	Undetermined Horizontal Datum
H04506	1925	60,000	MLLW	Undetermined Horizontal Datum
H04509	1925	60,000	MLLW	Undetermined Horizontal Datum
H04510*	1925	20,000	MLLW	Undetermined Horizontal Datum
H06880	1943	120,000	MLLW	Early Alaska Datums
H06929	1943	120,000	MLLW	Early Alaska Datums
H07923	1953	20,000	MLLW	Early Alaska Datums
H07924	1951	20,000	MLLW	Early Alaska Datums
H07927	1951	40,000	MLLW	Early Alaska Datums
H07928	1951	40,000	MLLW	Early Alaska Datums
H10490	1993	10,000	MLLW	NAD 83
H10557	1994	10,000	MLLW	NAD 83
H10692	1996	10,000	MLLW	NAD 83
H10693	1996	10,000	MLLW	NAD 83
H10694	1996	10,000	MLLW	NAD 83
H10695	1996	10,000	MLLW	NAD 83
H10696	1996	20,000	MLLW	NAD 83
H10697	1996	10,000	MLLW	NAD 83
H10697A	1997	10,000	MLLW	NAD 83
H10698	1996	10,000	MLLW	NAD 83
H10699	1996	10,000	MLLW	NAD 83
H10699A	1996	10,000	MLLW	NAD 83
H10701	1996	20,000	MLLW	NAD 83
H10701A	1997	20,000	MLLW	NAD 83
H10702	1996	10,000	MLLW	NAD 83
H10705	1996	10,000	MLLW	NAD 83
H10759	1997	10,000	MLLW	NAD 83
H10760	1997	10,000	MLLW	NAD 83
H10761	1997	10,000	MLLW	NAD 83
H10762	1997	10,000	MLLW	NAD 83
H10765	1997	10,000	MLLW	NAD 83
H10767	1997	10,000	MLLW	NAD 83
H10768	1997	10,000	MLLW	NAD 83
H10770	1997	10,000	MLLW	NAD 83
H11021	2002	40,000	MLLW	NAD 83
H11066	2001	40,000	MLLW	NAD 83
H11191	2003	10,000	MLLW	NAD 83
H11192	2003	10,000	MLLW	NAD 83
H11193	2003	10,000	MLLW	NAD 83

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum of Digital Records*
H11194	2003	10,000	MLLW	NAD 83
H11195	2003	10,000	MLLW	NAD 83
H11229	2003	10,000	MLLW	NAD 83
H11230	2003	10,000	MLLW	NAD 83
H11231	2003	10,000	MLLW	NAD 83
H11232	2003	10,000	MLLW	NAD 83
H11233	2003	10,000	MLLW	NAD 83
H11325	2004	40,000	MLLW	NAD 83
H11459	2005	10,000	MLLW	NAD 83
H11460	2005	10,000	MLLW	NAD 83
H11461	2005	10,000	MLLW	NAD 83
H11462	2005	10,000	MLLW	NAD 83
H11463	2005	20,000	MLLW	NAD 83
H11464	2005	10,000	MLLW	NAD 83
H11465	2005	40,000	MLLW	NAD 83

***** Geographic position manually adjusted in *ArcGIS* to fit combined coastline.

2) National Ocean Service shallow-water multibeam sonar

NOS conducted a shallow-water multibeam swath sonar survey just south of Nakchamik Island (Fig. 7). The survey was downloaded from NGDC's NOS Hydrographic Survey Database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in ASCII xyz gridded format in NAD 83 geographic at 10 meter resolution and referenced to MLLW. This dataset provided dense bathymetric coverage in the area south of Nakchamik Island.

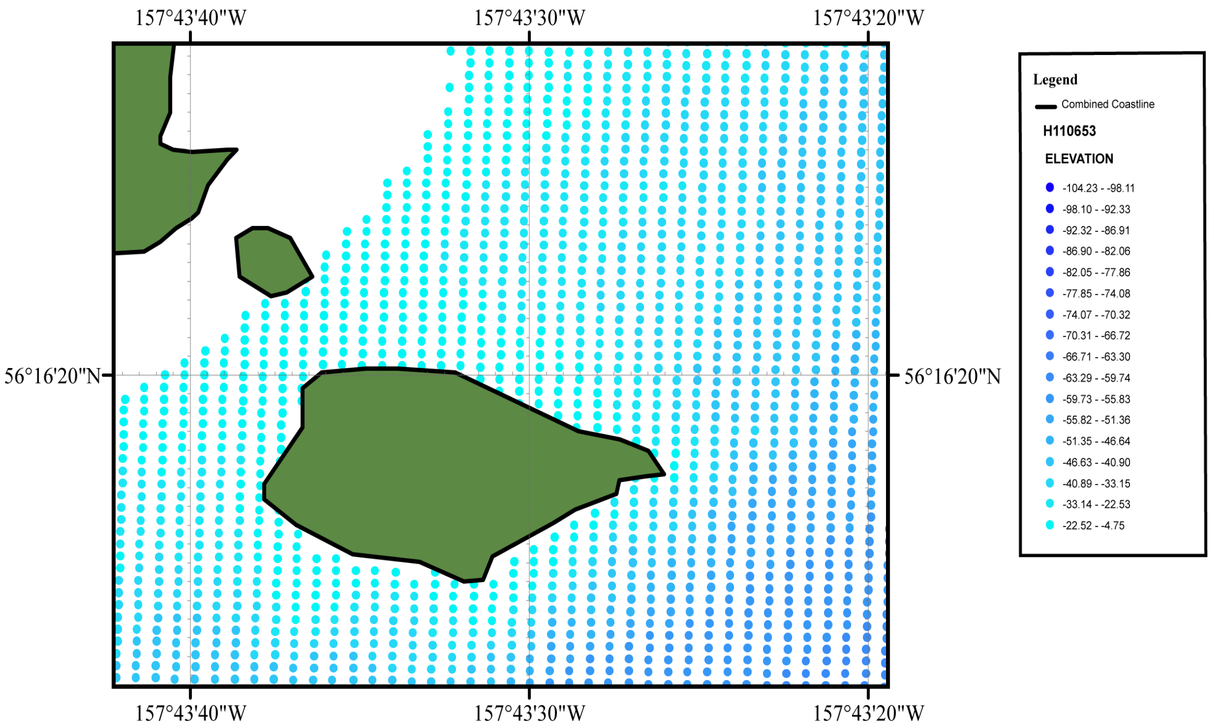


Figure 7. *NOS shallow-water multibeam swath sonar survey H11065. The high-resolution survey has soundings 10 meters apart and covers the near-shore region south of Nakchamik Island.*

3) National Ocean Service hydrographic lidar surveys

NOS's Pacific Hydrographic Branch provided NGDC with seven recent hydrographic lidar surveys located in the southwestern part of the 1 arc-second DEM (Fig. 8). The lidar surveys are referenced to NAD 83 and MLLW. These surveys range from -40 to 46 meters in elevation and have a point spacing of 5 meters. The elevations on and near the shoreline are generally consistent with the NOS and SRTM datasets; higher elevations are less consistent.

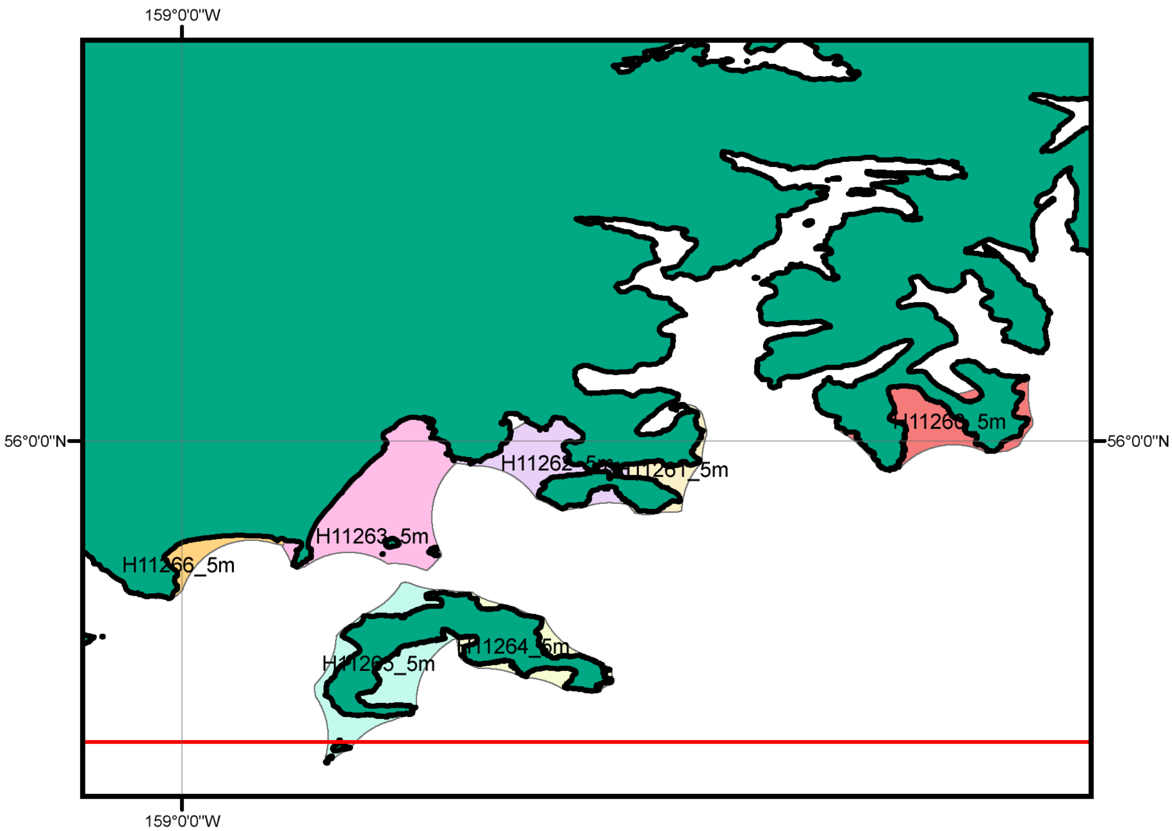


Figure 8: *Lidar survey data coverage in the southwestern portion of the 1 arc-second DEM. Final coastline is in black. Red line denotes the bottom of the DEM extent.*

4) NOAA Electronic Navigational Chart soundings

NOAA nautical charts #16011 and #16561 were available in ENC format and, as no bathymetric survey data were available for the area surrounding Mitrofania Island and other southern portions of the DEM, sounding data were extracted from these charts using *FME*. Chart #16011 covers the complete DEM but has a 1:1,023,188, resolution creating sparse soundings and was not used in the final gridding process. Chart #16561 covers most of the southern portion of the DEM and has a 1:80,000 resolution. Soundings were only used where no NOS data were available. Soundings range from ~0.5 kilometers to ~2 kilometers apart, and depths range from -2 meters to -150 meters at MHW. The "pimple" pattern evident in the 1 arc-second DEM between Mitrofania Island and the mainland is due to the low point density of these soundings. No other data were available in this area (Fig. 9).

5) ETOPO1 Global Relief Model

Three areas within the DEM boundary where no survey data were available are located in the southwestern section of the DEM around Mitrofania Island, the south central region, and the southeastern region (see Fig. 3; ETOPO1 source data). The 1 arc-minute ETOPO1 data were extracted from the NGDC web site (http://www.ngdc.noaa.gov/mgg/global) and converted to point shapefiles using *FME*.

The ETOPO1 grid (*Amante and Eakins, 2009*) has a 1 arc-minute cell size with data in WGS 84 geographic coordinates and MSL. These data are exceptionally coarse at the resolution of the 1 arc-second Chignik DEM, however, they provide the only digital constraints on the bathymetry in the three southern regions. Extracted bathymetric soundings are generally shallower than overlapping measured bathymetric values (e.g., NOS hydrographic soundings and ENC soundings). These values are considered to be of low accuracy and result in the expression of isolated highs in the vicinity of Mitrofania Island on the 1 arc-second DEM (Fig. 9).

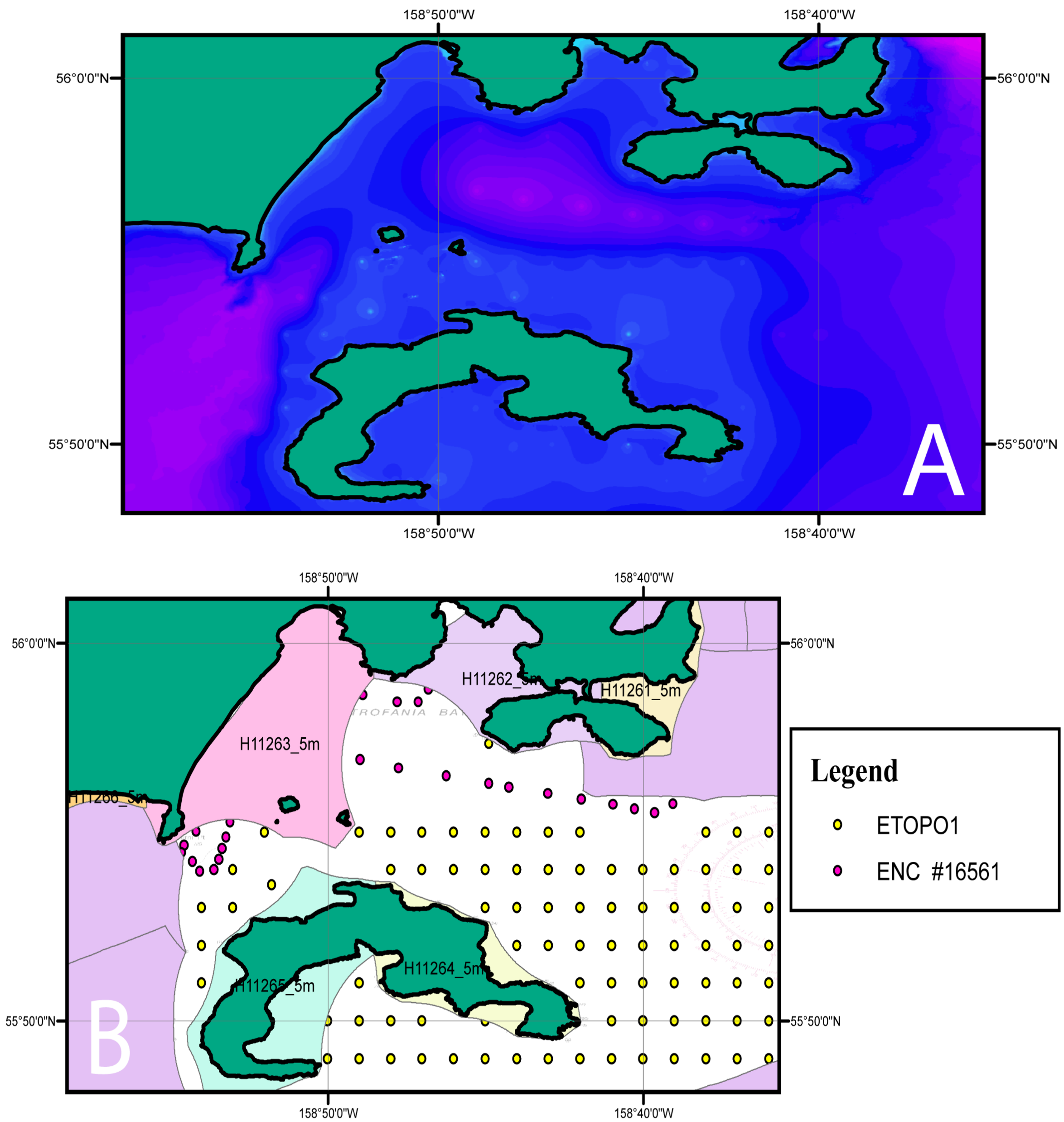


Figure 9. *Bathymetry surrounding Mitrofania Island. A) Pregridded bathysurface illustrating the expression of isolated highs due to sparse, low accuracy data in this region. B) ETOPO1 data and ENC data surrounded by NOS polygons overlying a raster nautical chart.*

3.1.3 Topography

Topographic datasets for Chignik were obtained from the USGS: NED 2 arc-second gridded topography and 1 arc-second NASA SRTM (Fig. 10; Table 5). NGDC also digitized harbor features not represented in either topographic dataset.

Table 5. Topographic datasets used in compiling the Chignik DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS NED	2006	Topographic DEM	2 arc-second grid	NAD 27 geographic	NGVD29 (meters)	http://ned.usgs.gov/
NASA SRTM	2000	Topographic DEM	1 arc-second grid	WGS 84 geographic	WGS 84/ EGM96 Geoid (meters)	http://srtm.usgs.gov/index.php
NGDC	2008	Digitized harbor features	5 meter point spacing	WGS 84 geographic	MHW	

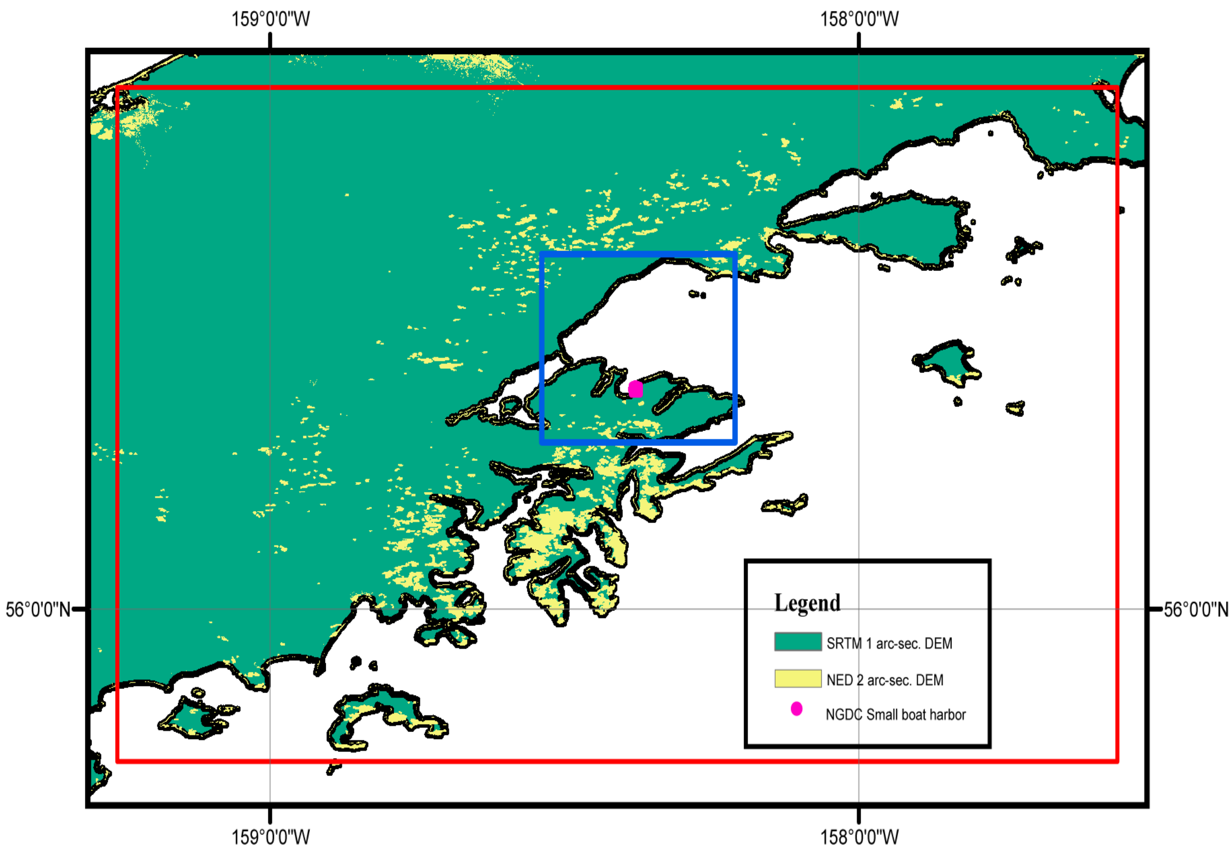


Figure 10. *Source and coverage of topographic datasets used in compiling the Chignik DEMs. 1 arc-second DEM boundary in red; 1/3 arc-second DEM boundary in blue; combined coastline in black.*

1) U.S. Geological Survey National Elevation Dataset topography

USGS's NED provides complete 2 arc-second coverage of Alaska[6]. Data are in NAD 27 Alaska geographic coordinates and North American Vertical Datum of 1929 (NGVD29) vertical datum (meters), and are available for download as raster DEMs. The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution (see the USGS Seamless web site for specific source information: http://seamless.usgs.gov). The dataset was derived from USGS quad maps and aerial photos based on surveys conducted in the 1970s and 1980s. The NED data were used only to fill in gaps within the SRTM data (e.g., Fig. 7).

2) NASA Space Shuttle Radar Topography Mission

NASA's SRTM obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[7]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Data from this mission have been processed into 1 degree × 1 degree tiles that have been edited to define the coastline, and are available from the USGS Seamless web site (http://seamless.usgs.gov) as raster DEMs. The data have not been processed to bare earth, but meet the absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

For U.S. regions, the data have 1 arc-second spacing and are referenced to the WGS 84/EGM96 Geoid. While providing near complete coverage of the Aleutian Islands in the vicinity of Chignik, there are numerous small areas with "no data" values (e.g., Fig. 11), necessitating use of the lower-resolution NED topographic data in these areas. The SRTM DEM also contains values over the open ocean, which were deleted by clipping to the final coastline. Negative SRTM values on land were converted to 0.9 meter elevation using *FME* to prevent terrestrial areas from being flooded at MHW.

6. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Alaska. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc-second), and elevation units (meters). The horizontal datum is NAD 83, except for AK, which is NAD 27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc-second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED web site, http://ned.usgs.gov/]

7. The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in Farr and Kobrick (2000). Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths range from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take." SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of Earth's total landmass. [Extracted from SRTM online documentation]

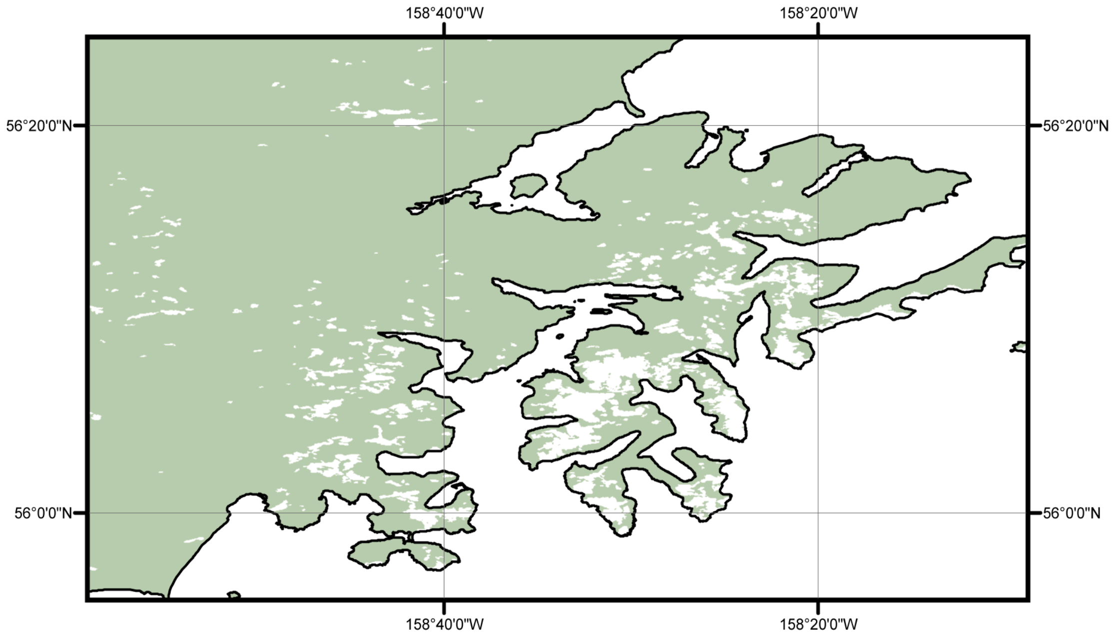


Figure 11. *Example of gaps (white areas) in SRTM data coverage. Gaps were filled with topographic values from the NED DEM. Final coastline in black.*

3) NGDC digitized harbor features

Using an aerial view image as a reference, NGDC digitized a point shapefile to represent the newly constructed small boat harbor in Chignik Bay. The breakwater is just south of the spit at the entrance to the harbor and was not represented in any available coastline or topographic data. Elevations applied to digitized points were one meter above MHW.

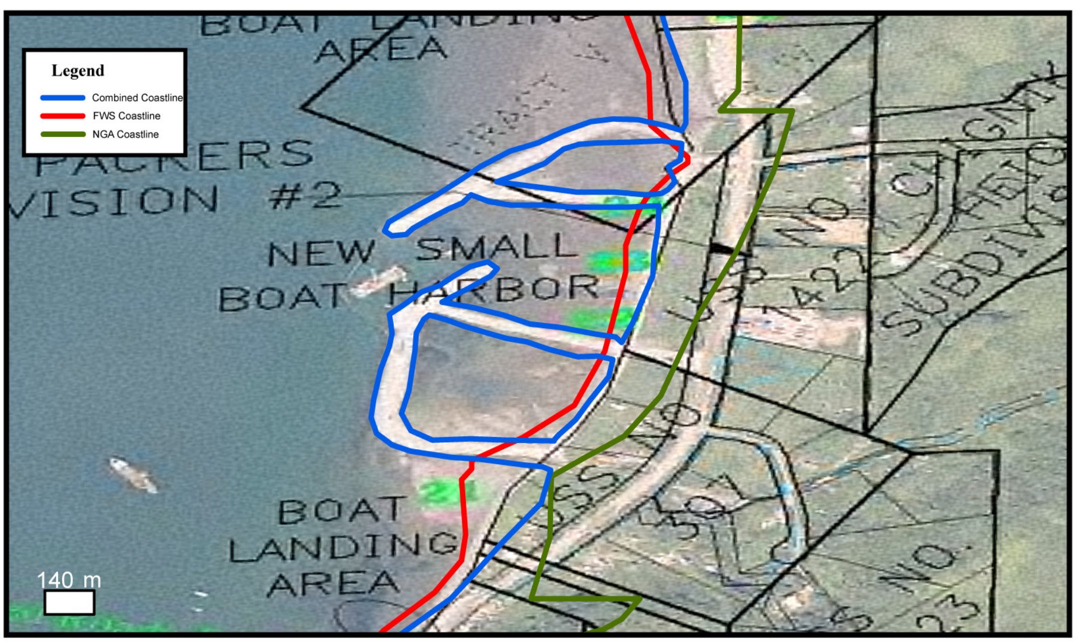


Figure 12. *Detail of Chignik small boat harbor with georeferenced aerial image underlying SRTM topographic data. (http://www.commerce.state.ak.us/dca/profiles/profile-maps.htm)*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Chignik DEMs were originally referenced to a number of vertical datums including: MLLW, MSL, WGS 84/EGM96 Geoid, and NGVD29. All datasets were transformed to MHW to provide the maximum flooding for inundation modeling. Conversions were accomplished by averaging the datum values of 8 NOAA tide stations in the region (Fig. 13).

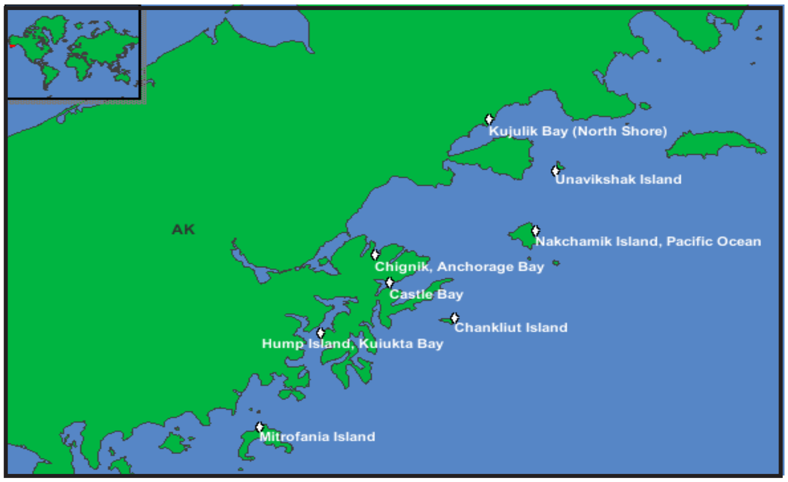


Figure 13. *Locations of the 8 NOAA tide stations used to average tidal datum relationships. (http://tidesandcurrents.noaa.gov/)*

1) **Bathymetric data**

The NOS hydrographic surveys, shallow-water multibeam swath sonar survey, and lidar surveys were transformed from MLLW to MHW, using *FME* software, by adding a constant offset measured at NOAA tide stations in the Chignik region (see Table 6). The 8 tide stations in the region used to calculate an average tidal measurement only had one, two, and four months of data records; there were no tide stations in the region with records that spanned multiple years.

2) **Topographic data**

The NED and SRTM DEMs were originally in NGVD29 and WGS 84/EGM96 Geoid vertical datums, respectively. There are no survey markers in the vicinity of Chignik that relate these two geodetic datums to the local tidal datums. Thus, it was assumed that both datums are essentially equivalent to MSL in this area (Table 6). Conversion to MHW was accomplished by adding a constant value of -1.061 meters.

Table 6. Relationship between MHW and other vertical datums in the Chignik region.*

Vertical datum	*Difference to MHW*
MTL	-0.983
NGVD29 +	-1.061
MSL	-1.061
MLW	-1.966
MLLW	-2.434

* Datum relationships determined by tidal station #9459881 at Chignik.
+ Assumed to be equivalent to MSL.

3.2.2 Horizontal datum transformations

Datasets used in compiling the Chignik DEMs were originally referenced to Early Alaska, “undetermined”, Unalaska, NAD 83, or WGS 84 horizontal datums. The NOS surveys referenced to Early Alaska, “undetermined” or Unalaska horizontal datums were manually shifted in *ArcGIS* to fit the final coastline.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shapefiles were checked in ESRI *ArcMap* for inter-dataset consistency. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shapefiles were then converted to xyz files in preparation for gridding. Problems included:

- Data values over the open ocean in the NED and SRTM topographic DEMs. Each dataset required automated clipping to the final coastline.
- Holes in the SRTM DEM which were filled in with lower-resolution data from the NED DEM.
- Lack of accurate bathymetric data in the southern region of the DEM, especially around Mitrofania Island.
- Lack of accurate bathymetric and topographic data near the coastline throughout the region.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic survey spacings generally depend on the collection year: older surveys (1914-1951) are more sparse with point spacing up to 1.2 kilometers in deep water; newer surveys (1993-2005) have point spacings generally less than 40 meters. ETOPO1 and ENC data used to fill gaps in the NOS data have a much lower resolution with spacing up to 2 kilometers apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the 1 arc-second DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second spacing "pre-surface" or grid was generated using *GMT*, an NSF-funded shareware software application designed to manipulate data for mapping purposes.

The NOS hydrographic point data, in xyz format, were combined with the shallow-water multibeam data, hydrographic coastal lidar surveys, ENC soundings, and the ETOPO1 data into a single file, along with points extracted every 10 meters from the final coastline. A -1 meter value was assigned to the coastline to make sure that the offshore elevations remained negative, which was necessary due to the sparseness of bathymetric data near the coast. These point data were then smoothed onto a 1 arc-second grid using the *GMT* tool "blockmedian". The *GMT* tool "surface" was then applied to interpolate values for cells without data. The *GMT* grid created by "surface" was converted into an ESRI Arc ASCII grid file using the *MB-System* tool "mbm_grd2arc". Conversion of this Arc ASCII grid file into an Arc raster format permitted clipping of the grid with the final coastline (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy (e.g., Fig. 14), converted to a shapefile, and exported as an xyz file for use in the final gridding process (see Table 7). The statistical analysis of the differences between the 1 arc-second bathymetric surface and one of the NOS surveys (see Fig. 14) showed that the majority of the NOS soundings are in a good agreement with the bathymetric surface. The few exceptions where the difference reached tens of meters are attributed to the rugged terrain when two or more closely positioned points were averaged to obtain the elevation of one grid cell.

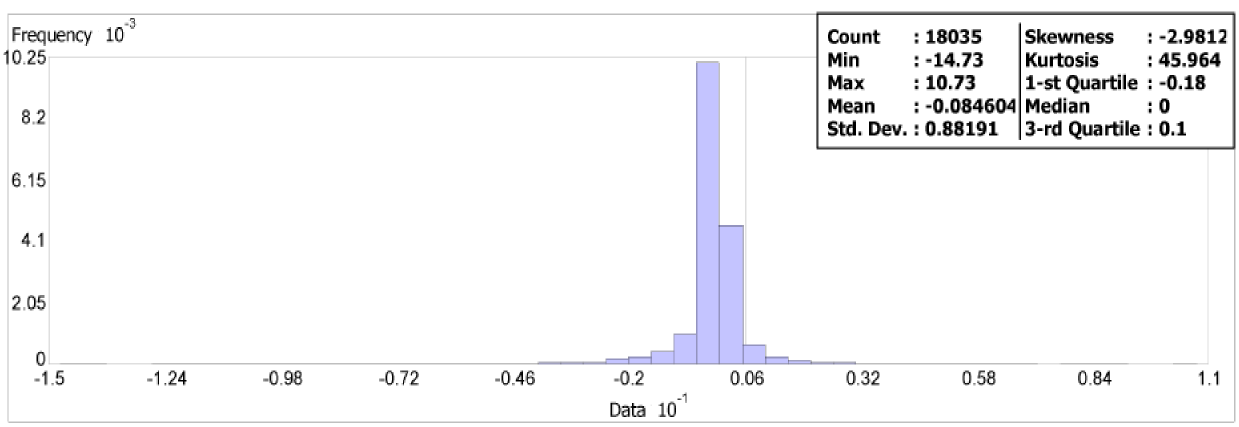


Figure 14. *Histogram of the differences between NOS hydrographic survey H10759 (a relatively dense survey near Chignik Harbor) and the 1 arc-second pre-surfaced bathymetric grid. The greatest differences resulted from averaging several closely spaced soundings from overlapping surveys.*

3.3.3 *Building the DEMs with MB-System*

MB-System was used to create a 1 arc-second Chignik DEM and a 1/3 arc-second DEM centered on Chignik Bay. *MB-System* is an NSF-funded shareware software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data, and interpolate values for cells without data. The *MB-System* tool "mbgrid" applied a tight spline tension to the xyz data, and interpolated values for cells without data. The data hierarchy used in the "mbgrid" gridding algorithm, as relative gridding weights, is listed in Table 7. Greatest weight was given to NGDC digitized harbor feature datasets. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid, ETOPO1 bathymetric grids, ENC #16561 soundings, final coastline, and USGS NED DEM.

Table 7. Data hierarchy used to assign gridding weight in *MB-System*.

Dataset	***Relative Gridding Weight***
NGDC digitized features	1,000
SRTM topographic DEM	100
Shallow-water multibeam survey	100
NOS lidar surveys	100
Recent NOS hydrographic surveys	100
Older NOS hydrographic surveys	10
USGS NED topographic DEM	1
Final coastline	1
ENC #16561 soundings	1
ETOPO1 bathymetric DEM	1
Pre-surfaced bathymetric grid	1

3.4 Quality Assessment of the DEMs

3.4.1. *Horizontal accuracy*

The horizontal accuracy of topographic and bathymetric features in the Chignik DEMs is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have a horizontal accuracy no better than 30 meters. Bathymetric features are resolved only to within a few tens of meters to a few hundred meters in deep-water areas; shallow, near-coastal regions have an accuracy approaching the sub aerial topographic features.

3.4.2 *Vertical accuracy*

Vertical accuracy of elevation values for the DEM is also highly dependent upon the source datasets contributing to grid cell values. Topographic values are derived from the SRTM DEM, which has a vertical accuracy typically better than 16 meters, and from the USGS NED DEM, which has an estimated vertical accuracy of 7 to 15 meters. Bathymetric values are derived from a wide range of input data. Modern NOS standards are 0.3 meters in 0 to 20 meters of water, 1.0 meters in 20 to 100 meters of water, and 1% of the water depth in 100 meters of water. The ENC soundings and ETOPO1 data have a very low resolution and vertical accuracy of 5% and 10% of water depth.

3.4.3 Slope map and 3-D perspective

ESRI *ArcCatalog* was used to generate a slope grid from the 1 arc-second Chignik DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 15). The DEM was transformed to UTM zone 4 coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM (e.g., Fig. 16) was accomplished using ESRI *ArcScene* and Applied Imagery's *Quick Terrain Modeler*. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM.

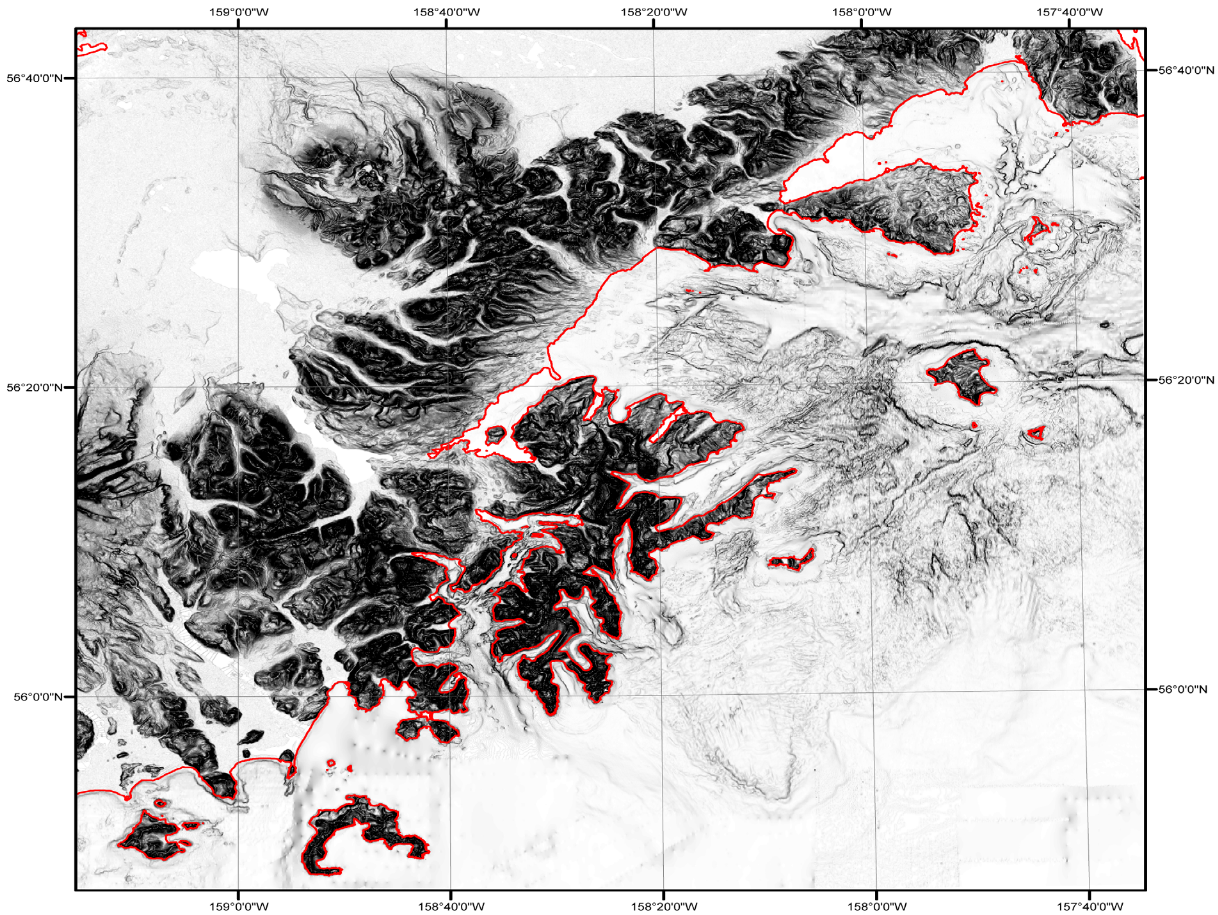


Figure 15. *Slope map of the 1 arc-second Chignik DEM.*
Flat-lying slopes are white; dark shading denotes steep slopes; final coastline in red.

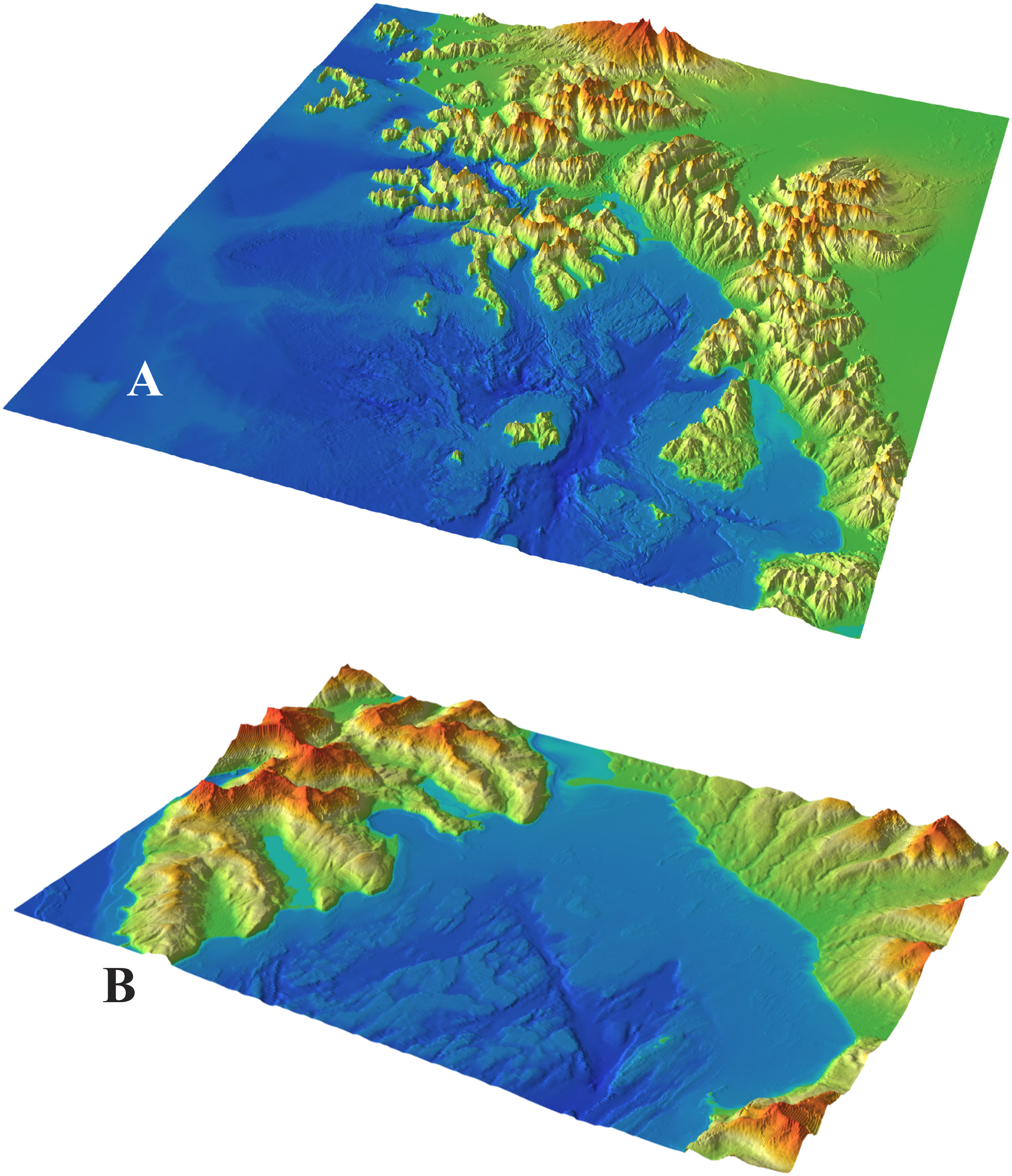


Figure 16. *Perspective views of the Chignik DEMs. A)1 arc-second Chignik DEM from the northeast. Vertical exaggeration–times 2. B) 1/3 arc-second Chignik DEM from the northeast. Vertical exaggeration–times 1.*

3.4.4 *Comparison with source data files*

To ensure grid accuracy, the 1/3 arc-second Chignik DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas. A histogram of the difference between the SRTM topographic data points and the 1/3 arc-second DEM is shown in Figure 17.

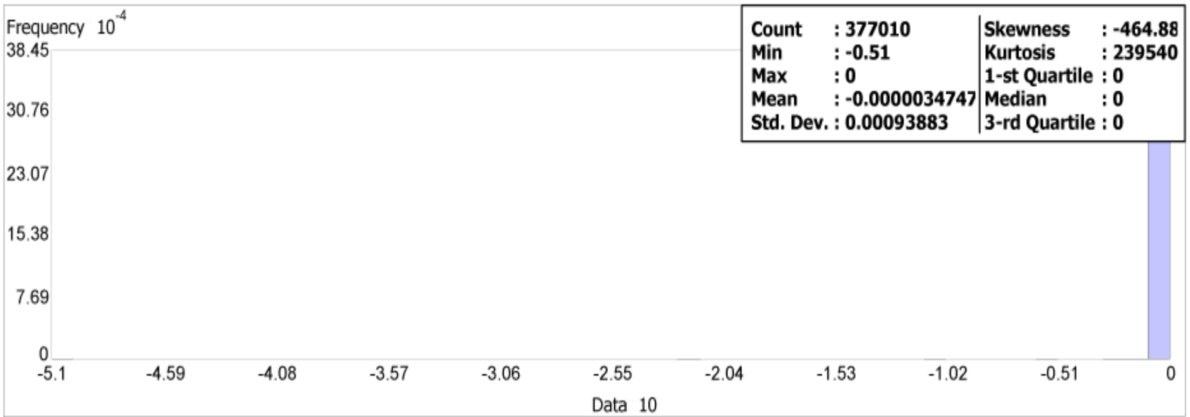


Figure 17. *Histogram of the differences between the SRTM topographic dataset and the 1/3 arc-second Chignik DEM.*

3.4.5 *Comparison with U.S. Geological Survey topographic elevations*

NGDC used USGS digital topographic quadrangles for qualitatively assessing the 1/3 arc-second Chignik DEM. Quadrangles were downloaded as georeferenced TIFFs from http://agdc.usgs.gov/data/usgs/ and loaded into *ArcMap*.

To be consistent with the USGS Chignik quadrangle, the 1/3 arc-second Chignik DEM was converted from meters to feet and 100 ft contours were created. Figure 17 displays the DEM contours on top of the USGS quadrangle for the populated regions around the town of Chignik and around Chignik Lake. The two sets of contour lines are in good agreement with each other, with only minor differences. Wavy areas in the DEM contours that do not match the USGS contours are from the lower resolution NED 2 arc-second DEM that was used to fill in holes from the SRTM 1 arc-second DEM.

Topographic elevations at localized high points in the DEM are lower than the USGS topographic quadrangle elevations (Fig. 18). These differences may be attributed to the fact that the SRTM and NED topographic data, used to constrain the sub aerial parts of the DEM, represent averages of land elevations over 30 x 30 meter and 60 x 60 meter square areas, respectively, while the topographic quadrangle elevations represent local maxima.

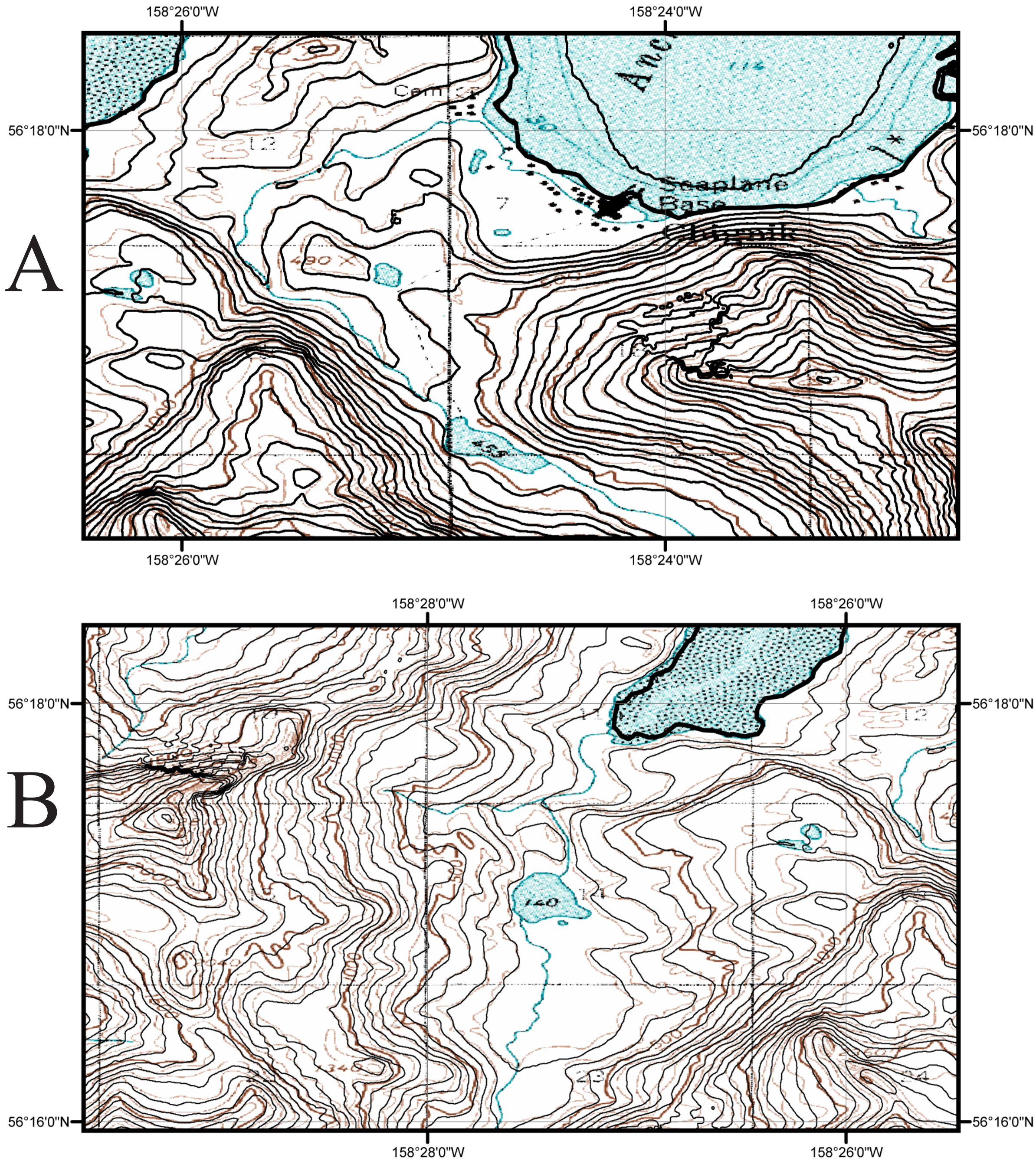


Figure 18. *Comparison between USGS topographic contours (brown lines) and the 1/3 arc-second Chignik DEM topographic contours (black lines). Contour lines are in 100 foot intervals. A) The town of Chignik. B) Chignik Lake. Areas were chosen based on population. (<http://agdc.usgs.gov/data/usgs/>)*

4. Summary and Conclusions

Two integrated topographic–bathymetric DEMs of the Chignik, Alaska area, with cell sizes of 1 arc-second and 1/3 arc-second, were developed for the PMEL NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using *ArcGIS*, *FME*, *GMT, Quick Terrain Modeler*, and *MB-System* software.

Recommendations to improve the DEMs, based on NGDC's research and analysis, are listed below:

- Conduct bathymetric surveys in the southern portion of the DEM that currently have sparse or no digital measured bathymetric data.
- Conduct additional lidar surveys along the coast to establish a more accurate coastline.
- Establish, via survey, the relationships between tidal and geodetic datums in the Chignik region.
- Complete survey work in Chignik Harbor to accurately reflect the small boat harbor.

5. Acknowledgments

The creation of the DEMs was funded by NOAA Center for Tsunami Research. The authors thank Nazila Meratia and Vasily Titov (PMEL), Bret Christensen (USFWS), Gary Nelson and Brooke McMahon (NOS Pacific Hydrographic Branch), David Scharff (NOS), Jeff Freymueller (University of Alaska, Fairbanks) and Greg Lee (USGS).

6. References

Electronic Navigational Chart #16011, 37th Edition, 2007. Alaska Peninsula and Aleutian Islands to Segum Pass. Scale 1:1,023,188. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16561, 3rd Edition, 2007. Mitrofania Bay and Kuiukta Bay. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16587, 1st Edition, 2006. Semidi Islands and Vicinity. Scale 1:135,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16566, 11th Edition, 2007. Chignik and Kujulik Bays. Scale 1:77,477. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16566, 11th Edition, 2007. Anchorage and Mud Bays. Scale 1:38,730. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis, NOAA Technical Memorandum NESDIS NGDC-24, 19 pp., March 2009.

7. Data Processing Software

ArcGIS v. 9.2, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

FME 2008 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, shareware developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/

GMT v. 4.3.0 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.1.0, shareware developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/

Quick Terrain Modeler v.6.0.1, developed by Johns Hopkins University Applied Physics Laboratory, licensed by Applied Imagery, Silver Spring, Maryland, http://www.appliedimagery.com/