NOAA Technical Memorandum NESDIS NGDC-31

DIGITAL ELEVATION MODEL OF ADAK, ALASKA: PROCEDURES, DATA SOURCES AND ANALYSIS

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UNITED STATES DEPARTMENT OF COMMERCE

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Digital Elevation Model of Adak, Alaska: Procedures, Data Sources and Analysis

1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a bathymetric–topographic digital elevation model (DEM) of Adak (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1 arc-second[1] coastal DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 5). It will be used for tsunami forecasting 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. This report provides a summary of the data sources and methodology used in developing the Adak DEM.

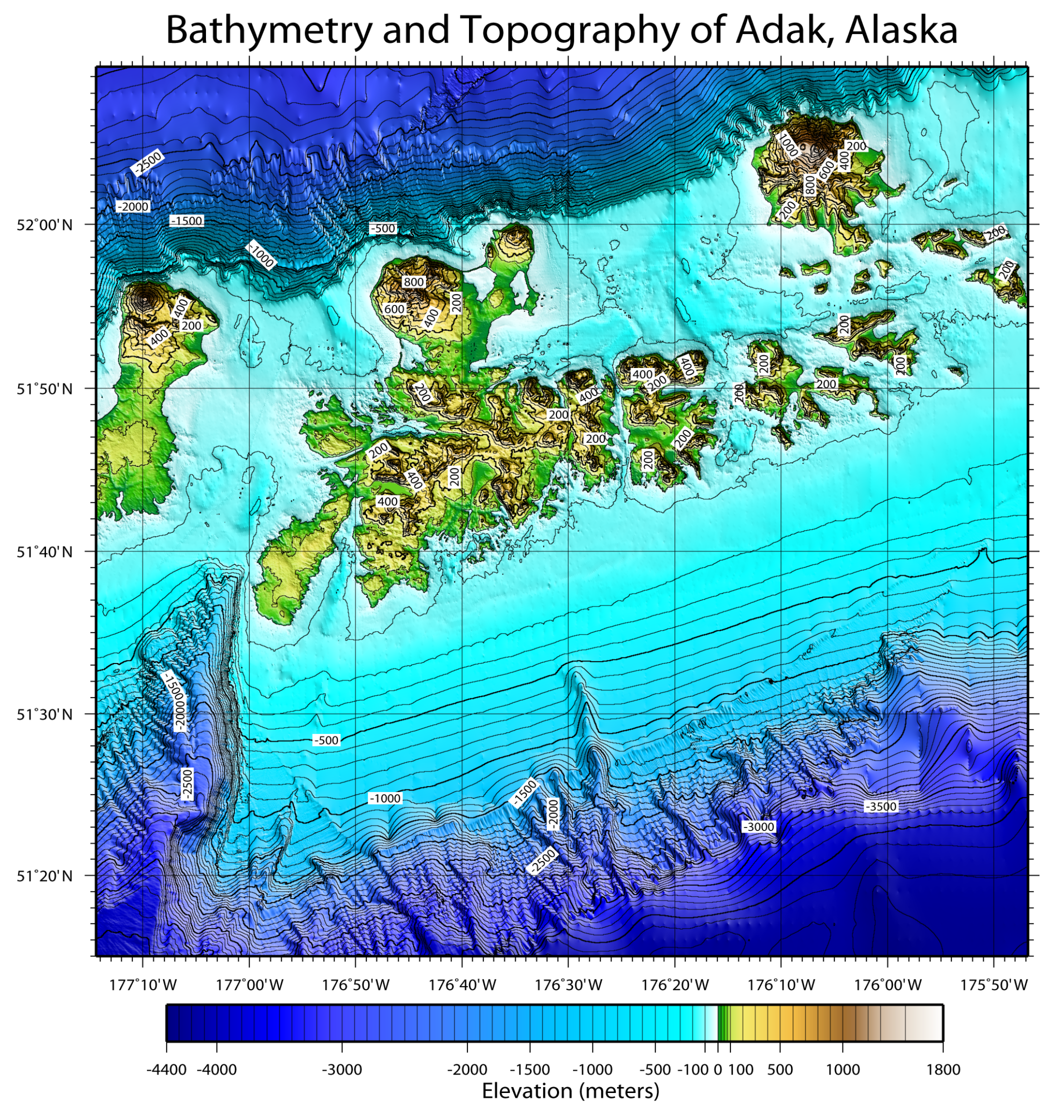

Figure 1. *Shaded-relief image of the Adak DEM. Contour interval is 100 meters.*

1. The Adak DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Adak, Alaska (51° 51′ 47.9″ N, 176° 37′ 55.2″ W) 1 arc-second of latitude is equivalent to 30.907 meters; 1 arc-second of longitude equals 19.137 meters.

2. Study Area

Adak, Alaska is located in the Andreanof Islands on the Aleutian Islands Chain of Alaska (Fig. 2). The Adak DEM encompasses the eastern half of Kanaga Island, Adak Island, Kagalaska Island, Little Tanaga Island, Umak Island, Great Sitkin Island, and Igitkin Island (Fig. 3). Adak Island was formed from tectonic plate interaction and resulting volcanic activity. The island consists of a thin sedimentary layer on top of volcanic rock. Tall coastal cliffs and mountains dominate the landscape with the steep slopes continuing offshore into deep water canyons.

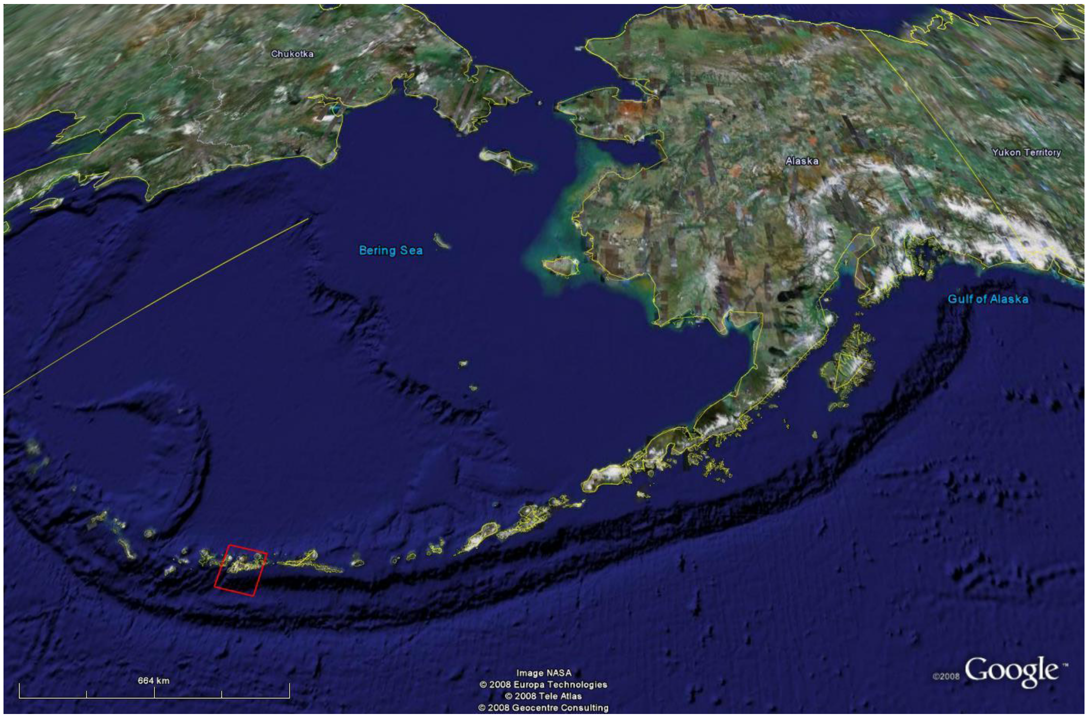

Figure 2. *Google Earth image of Alaska's Aleutian Island Chain and the location of the Adak DEM, as shown in the red box.*

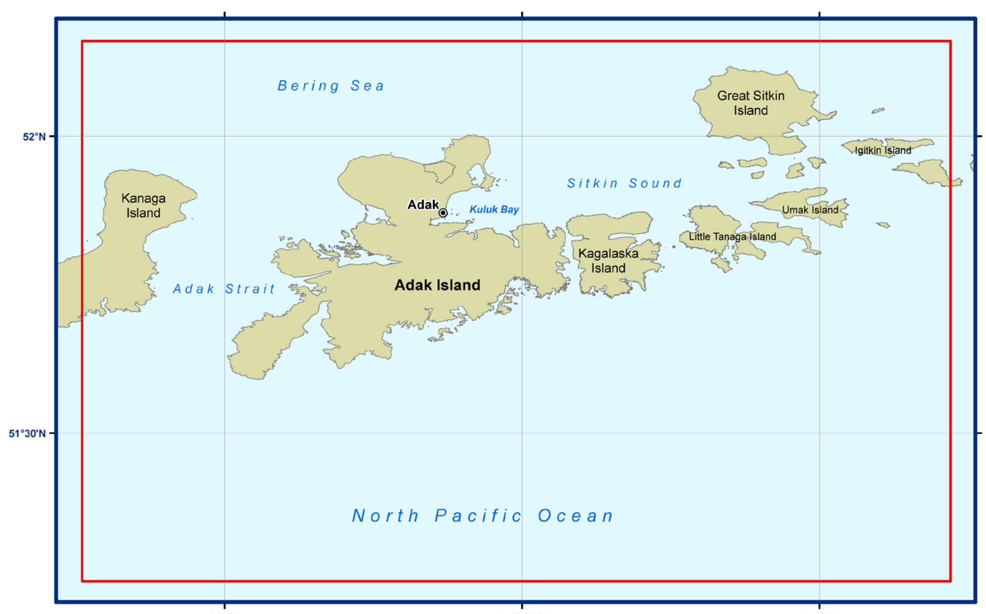

Figure 3. *Names and locations of islands within the Adak DEM boundary.*

The southernmost town in Alaska, Adak (Fig. 4) is located 350 miles west of Dutch Harbor, Alaska and has a population of less than 400. Adak served as a military base from the onset of World War II until the late 1990s. The current economy is based on the fishing and hunting industry and support for U.S. and foreign fishing fleets. A portion of the island lies within the National Maritime National Wildlife Refuge, managed by U.S. Fish and Wildlife Service.

Figure 4. *View of Adak from Bering Hill. Photo courtesy of Alaska Department of Commerce, Community, and Economic Development, Division of Community & Regional Affairs, Community Photo Library (http://www.commerce.state.ak.us/dca/photos/comm_list.cfm).*

3. Methodology

The Adak 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.

Table 1: PMEL specifications for the Adak DEM.

Grid Area	Adak, Alaska
Coverage Area	175.78º to 177.24º W; 51.25º to 52.16º 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 Arc ASCII 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. 5) were obtained from several U.S. federal agencies and academic institutions including: NOAA Office of Coast Survey (OCS) and NGDC; the U.S. Fish and Wildlife Service (USFWS); the U.S. Geological Survey (USGS); and the University of California, Scripps Institute of Oceanography (SIO). Safe Software's *FME* data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert them into ESRI *ArcGIS* shapefiles[3]. The shapefiles were then displayed with *ArcGIS* to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using *FME*, based upon data from the NOAA Adak tide station (http://tidesandcurrents.noaa.gov/). Applied Imagery's *Quick Terrain Modeler* software was used to evaluate processing and gridding techniques.

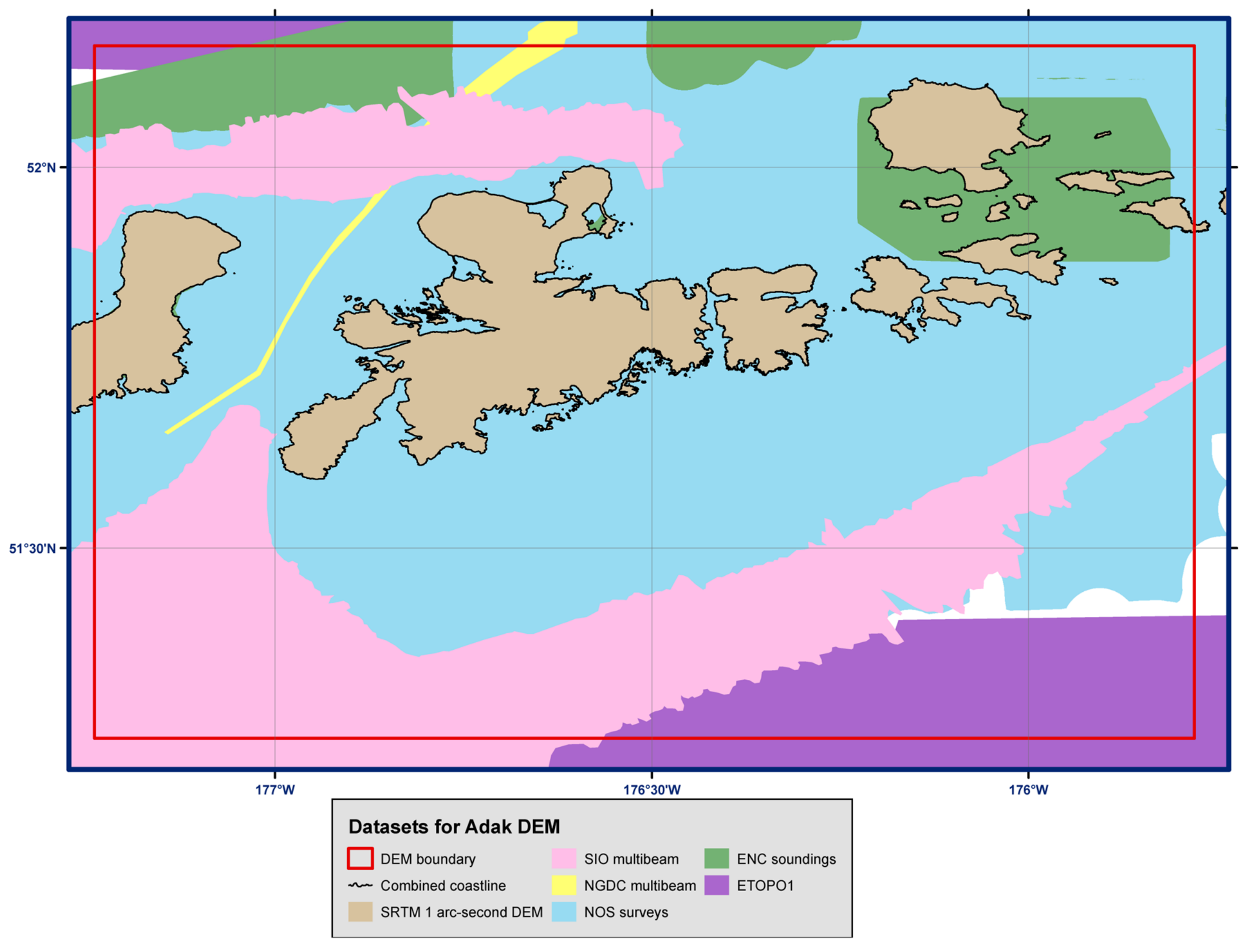

Figure 5. *Source and coverage of datasets used in compiling the Adak DEM.*

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

Coastline datasets of the Adak region were obtained from OCS and USFWS (Table 2; Fig. 6). NOAA Electronic Navigational Charts (ENCs)[4] and the USFWS coastline were used to develop a "combined coastline" for the Adak DEM.

Table 2: Shoreline datasets used in the Adak DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOAA ENCs	1990 to 2000	Digital nautical charts	Various	WGS 84 geographic	MHW	http://nauticalcharts.noaa.gov/mcd/enc/
USFWS	2006	Compiled coastline	Various	WGS 84 geographic	Unknown	

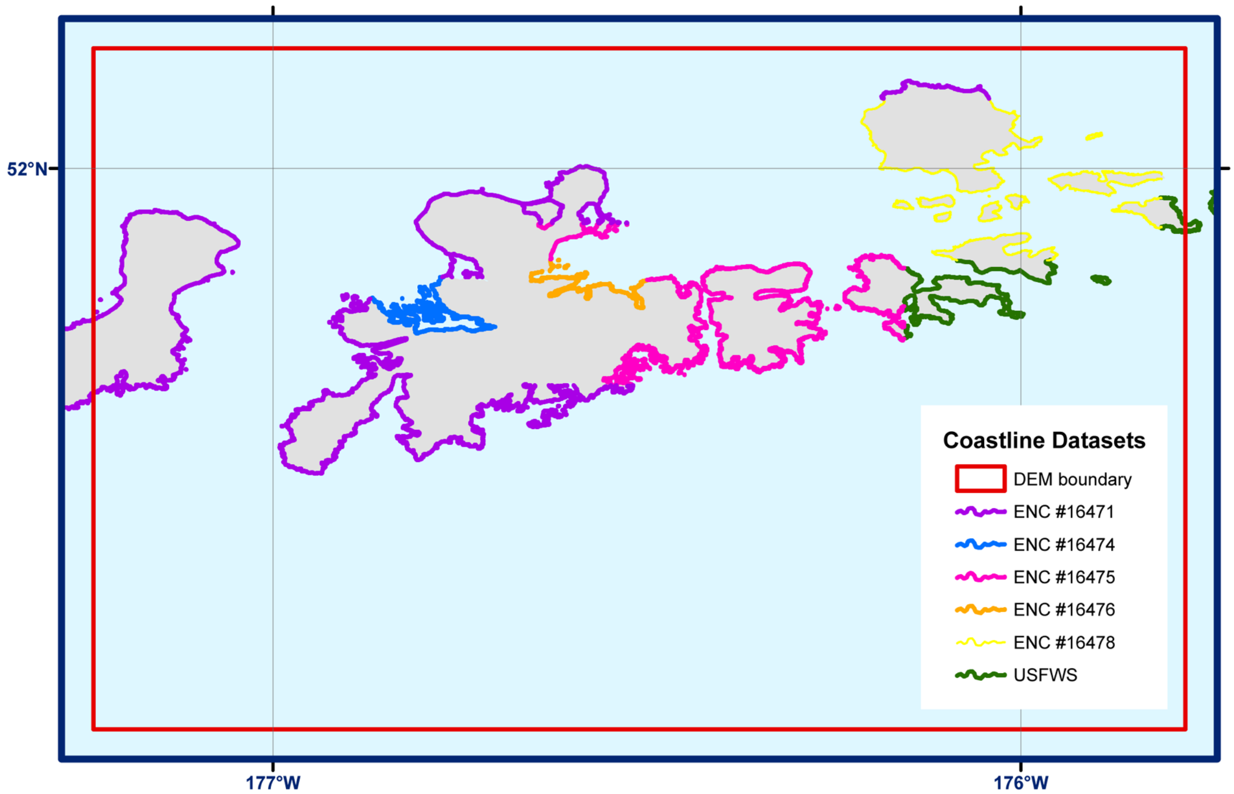

Figure 6. *Digital coastline datasets used in developing a "combined coastline" of the Adak region.*

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) NOAA Electronic Navigational Charts

Seven ENCs were available for the Adak area (Table 3) and downloaded from OCS (http://nauticalcharts.noaa.gov/mcd/enc/). The ENCs are in S-57 format and include coastline data files referenced to MHW. The extracted coastlines were merged using *ArcGIS* and used in the combined coastline for the Adak DEM.

Table 3: ENCs available in the Adak region.

Chart #	*Title*	*Edition*	*Year of Source data*	*Issue Date*	*Scale*
16012	Aleutian Islands, Amukta Island to Attu Island	5	1991	2008	1,126,321
16467	Adak Island to Tanaga Island	2	1994	2005	1:100,000
16471	Atka Pass to Adak Strait	3	2000	2007	1:120,000
16474	Bay of Islands, Adak Island	2	1990	2007	1:12,000
16475	Kuluk Bay and Approaches, Little Tanaga and Kagalaska Straits	3	1998	2008	1:50,000
16476	Adak Island Sweeper Cove Finger and Scabbard Bays	3	1997	2008	1:10,000
16478	Tagalak Island to Great Sitkin Island	2	1991	2007	1:30,000

2) U.S. Fish and Wildlife Service coastline

USFWS has compiled a seamless digital coastline of the State of Alaska from a variety of existing 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 graciously provided to NGDC by Bret Christensen, USFWS. Though efforts were made to obtain the highest resolution coastlines available, vertical datums were apparently not determined nor controlled in any way in compiling the USFWS coastline; horizontal datum of the compiled USFWS coastline is WGS 84.

The combined coastline was compared to the topographic datasets and modified to include large offshore rocks and small islets shown on NOAA Raster Navigational Charts (RNCs). The jetty at Adak was also added to the coastline. An xyz file of the combined coastline was generated using *GEODAS* for use in compiling the Adak DEM.

3.1.2 Bathymetry

Bathymetric datasets available for use in the compilation of the Adak DEM included 63 NOS hydrographic surveys; two multibeam surveys downloaded from the NGDC Multibeam Bathymetry Database; one SIO multibeam survey; soundings extracted from NOAA ENCs; and data points extracted from ETOPO1 (Table 4; Fig. 7). Datasets were originally referenced to mean lower low water (MLLW) or mean sea level (MSL).

Table 4: Bathymetric datasets used in compiling the Adak DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NGDC	1933 to 2005	NOS hydrographic survey soundings	Ranges from 1 meter to 1 kilometer (varies with scale of survey, depth, traffic, and probability of obstructions)	Early Alaska or NAD 83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
SIO	2004	Multibeam swath sonar		WGS 84 geographic	Assumed MSL	
NGDC	1989 to 1998	Multibeam swath sonar	5 meters	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NOAA ENCs	1954 to 2000	Extracted soundings	From several meters to hundreds of meters	WGS 84 geographic	MLLW	http://nauticalcharts.noaa.gov/mcd/enc/
NGDC ETOPO1	2008	Global Relief Model	1 arc-minute	WGS 84 geographic	MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html

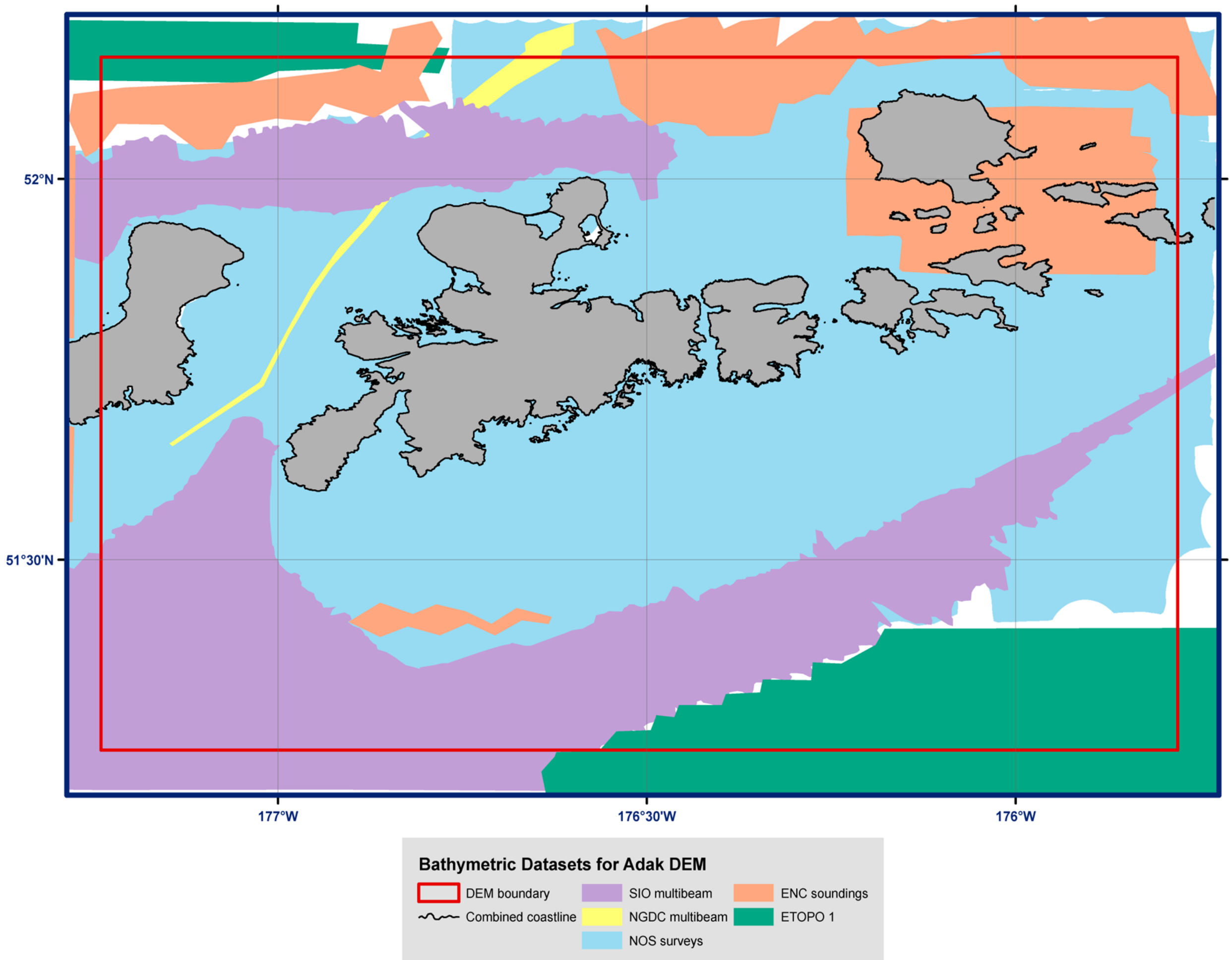

Figure 7. *Spatial coverage of the bathymetric datasets used in compiling the Adak DEM.*

1) National Ocean Service hydrographic survey data

A total of 63 NOS hydrographic surveys conducted between 1933 and 1988 were available for use in developing the Adak DEM. The hydrographic surveys were originally vertically referenced to MLLW and horizontally referenced to either NAD 83 or Early Alaskan Datum. Only 51 of the 63 surveys were used in building the Adak DEM, as some older surveys have been superseded (Table 5; Fig. 8).

Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys. Surveys were extracted from NGDC's NOS Hydrographic Survey Database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in NAD 83. The surveys were subsequently clipped to a polygon 0.05 degree (~5%) larger than the Adak DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW using a constant value based on the NOAA tide station (see Sec. 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to the topographic and bathymetric datasets, the combined coastline, and NOAA RNCs. The older surveys were clipped to remove soundings that have been superseded by more recent NOS surveys and multibeam data.

Some older survey data were offset from the combined coastline by nearly 1 km. These surveys were manually shifted in *ArcGIS* to align with the combined coastline. Figure 9 shows a scanned smooth sheet image overlaid with the combined coastline for survey H06896.

Table 5: Digital NOS hydrographic surveys available within the Adak DEM boundary.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H06881*	1933	40,000	MLLW	Early Alaska Datums
H06882*	1933	40,000	MLLW	Early Alaska Datums
H06883*	1933	10,000	MLLW	Early Alaska Datums
H06884*	1933	6,000	MLLW	Early Alaska Datums
H06886*	1933	6,000	MLLW	Early Alaska Datums
H06888	1933	10,000	MLLW	Early Alaska Datums
H06889*	1933	15,000	MLLW	Early Alaska Datums
H06890*	1933	15,000	MLLW	Early Alaska Datums
H06891	1933	5,000	MLLW	Early Alaska Datums
H06892*	1934	30,000	MLLW	Early Alaska Datums
H06893	1934	15,000	MLLW	Early Alaska Datums
H06894*	1934	15,000	MLLW	Early Alaska Datums
H06895	1934	15,000	MLLW	Early Alaska Datums
H06896*	1934	15,000	MLLW	Early Alaska Datums
H06897	1934	30,000	MLLW	Early Alaska Datums
H06898*	1934	60,000	MLLW	Early Alaska Datums
H06899*	1934	60,000	MLLW	Early Alaska Datums
H06920	1943	10,000	MLLW	Early Alaska Datums
H06971	1943	4,800	MLLW	Early Alaska Datums
H06778*	1943	120,000	MLLW	Early Alaska Datums
H06921*	1943	2,400	MLLW	Early Alaska Datums
H06913	1943	20,000	MLLW	Early Alaska Datums
H06915	1943	5,000	MLLW	Early Alaska Datums
H06916	1943	4,800	MLLW	Early Alaska Datums
H06917	1943	10,000	MLLW	Early Alaska Datums
H06918	1943	20,000	MLLW	Early Alaska Datums
H06919*	1943	20,000	MLLW	Early Alaska Datums
H06924	1943	5,000	MLLW	Early Alaska Datums
H06910	1943/44	10,000	MLLW	Early Alaska Datums
H07079	1944/55	10,000	MLLW	Early Alaska Datums

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H07084	1945	5,000	MLLW	Early Alaska Datums
H07049	1945	160,000	MLLW	Early Alaska Datums
H07078	1945/46	10,000	MLLW	Early Alaska Datums
H07182	1946	20,000	MLLW	Early Alaska Datums
H07183	1946	20,000	MLLW	Early Alaska Datums
H07605	1946	30,000	MLLW	Early Alaska Datums
H07825	1951	2,500	MLLW	Early Alaska Datums
H08055	1953	20,000	MLLW	Early Alaska Datums
H08056	1953	60,000	MLLW	Early Alaska Datums
H08070	1953	10,000	MLLW	Early Alaska Datums
H08057	1954	60,000	MLLW	Early Alaska Datums
H08139	1954	40,000	MLLW	Early Alaska Datums
H08140	1954	40,000	MLLW	Early Alaska Datums
H08142	1954	20,000	MLLW	Early Alaska Datums
H08143	1954	20,000	MLLW	Early Alaska Datums
H08145	1954	20,000	MLLW	Early Alaska Datums
H08146	1954	20,000	MLLW	Early Alaska Datums
H08147	1954	10,000	MLLW	Early Alaska Datums
H08144	1955	20,000	MLLW	Early Alaska Datums
H08233	1955	40,000	MLLW	Early Alaska Datums
H08234	1955	40,000	MLLW	Early Alaska Datums
H08235	1955	40,000	MLLW	Early Alaska Datums
H08236	1955	20,000	MLLW	Early Alaska Datums
H08237	1955	20,000	MLLW	Early Alaska Datums
H08238	1955	20,000	MLLW	Early Alaska Datums
H08239	1955	20,000	MLLW	Early Alaska Datums
H08240	1955	25,000	MLLW	Early Alaska Datums
H08306	1956	20,000	MLLW	Early Alaska Datums
H08307	1956	20,000	MLLW	Early Alaska Datums
H08309	1956	60,000	MLLW	Early Alaska Datums
H08071	1956	10,000	MLLW	Early Alaska Datums
H08454	1958	480	MLLW	Early Alaska Datums
H10282	1988	5,000	MLLW	NAD 83

* superseded survey not used in building the Adak DEM

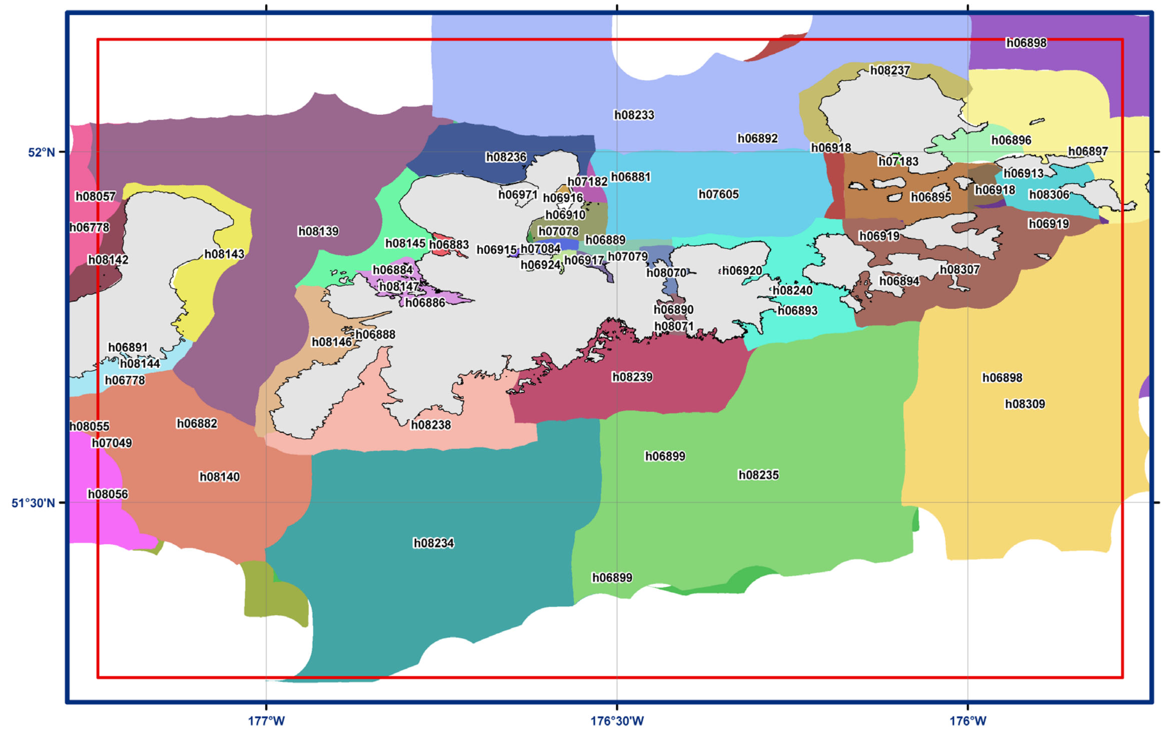

Figure 8. *Digital NOS hydrographic survey coverage in the Adak region. Some older surveys were not used as they have been superseded by more recent surveys. DEM boundary in red.*

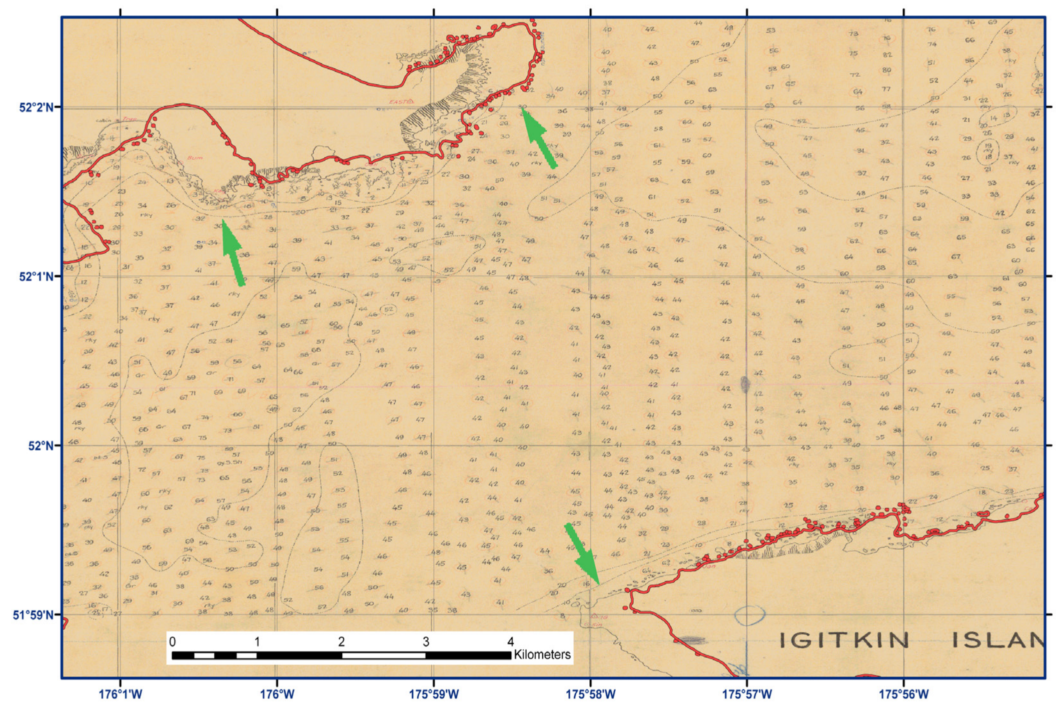

Figure 9. *Smooth sheet image of NOS hydrographic survey H06896 with the combined coastline shown in red. Differences between smooth sheet coastline in gray and combined coastline are up to one kilometer, marked by green arrows. This survey was not used in compiling the Adak DEM.*

2) University of California, Scripps Institute of Oceanography multibeam swath sonar survey

A 2004 multibeam swath sonar survey was provided to NGDC by SIO (Table 6). The survey is located in the southwest corner of the DEM boundary (Fig. 10). The data were gridded using *MB-System* into smaller sections and converted to point shapefile format, then transformed from MSL to MHW. The shapefile was displayed in *ArcMap* and edited removing spikes and anomalous values. The edited shapefile was converted to an xyz file for use in the final gridding process.

Table 6: SIO multibeam sonar survey available in the Adak DEM region.

Survey ID	*Year*	*Original Vertical Datum*	*Institute*	*Ship*
KRUS03RR leg 2	2004	Assumed MSL	SIO	Roger Revelle

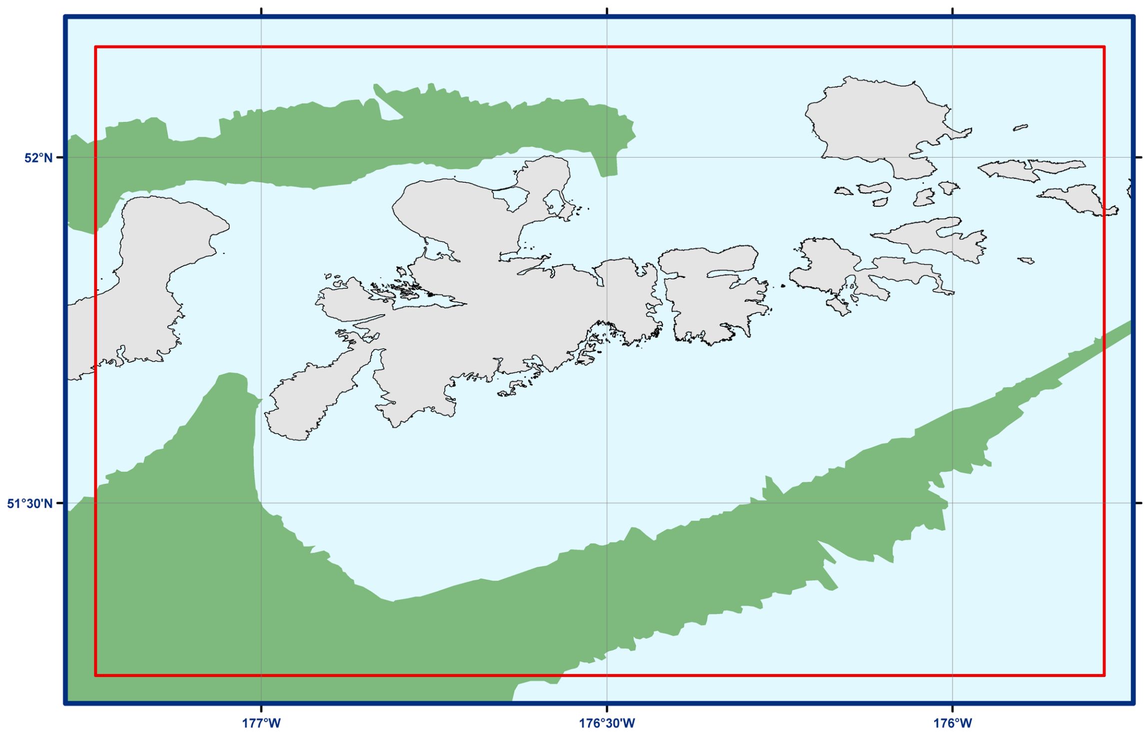

Figure 10. *Spatial coverage of the SIO multibeam swath sonar survey used in compiling the Adak DEM.*

3) NGDC multibeam swath sonar surveys

Two multibeam swath sonar surveys were downloaded from the NGDC Multibeam Bathymetry Database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html; Table 7). Both surveys are located in approximately the same area in the northwest corner of the DEM boundary (Fig. 11). The survey data were gridded using *MB-System* into smaller sections and converted to shapefile format, transformed from MSL to MHW, and clipped to the more recent SIO survey leaving a small portion of the *Thomas Washington* survey to be used in the final gridding process.

Table 7: NGDC multibeam sonar surveys available in the Adak DEM region.

Survey ID	***Year***	***Original Vertical Datum***	***Institute***	***Ship***
PPTU11WT	1986	Assumed MSL	SIO	Thomas Washington
FOCI93	1993	Assumed MSL	NOAA	Surveyor

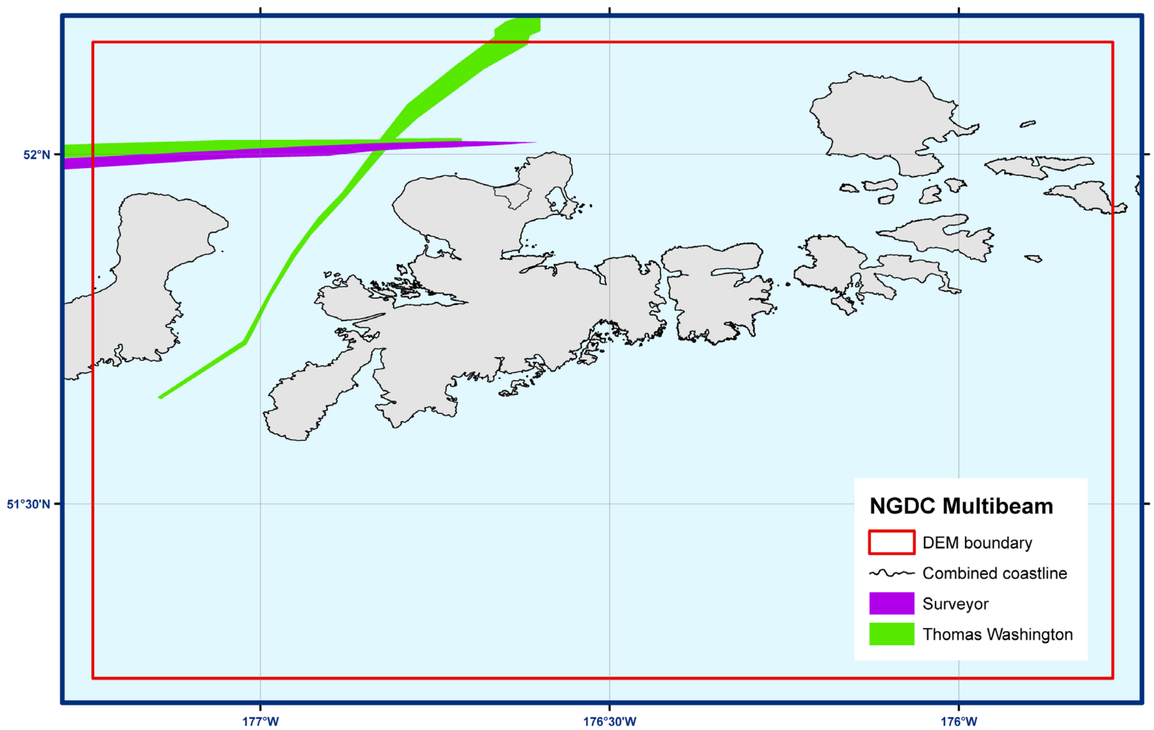

Figure 11. *Spatial coverage of NGDC multibeam bathymetric data available for use in the Adak DEM area.*

4) NOAA Electronic Navigational Chart soundings

In areas with little or no NOS data coverage, bathymetric soundings were extracted from the ENC datasets and converted to MHW using *FME* (Fig. 12). Soundings from ENC #16478 were used around Greater Sitkin Island to replace NOS survey H06896 which was not completely digitized. The ENC data were converted to shapefiles and displayed in *ArcMap* to compare to the RNCs and multibeam bathymetric data. Extracted points that do not reflect actual depth values, e.g., wrecks, were removed from the dataset before clipping to the SIO multibeam swath sonar survey and the most recent NOS surveys.

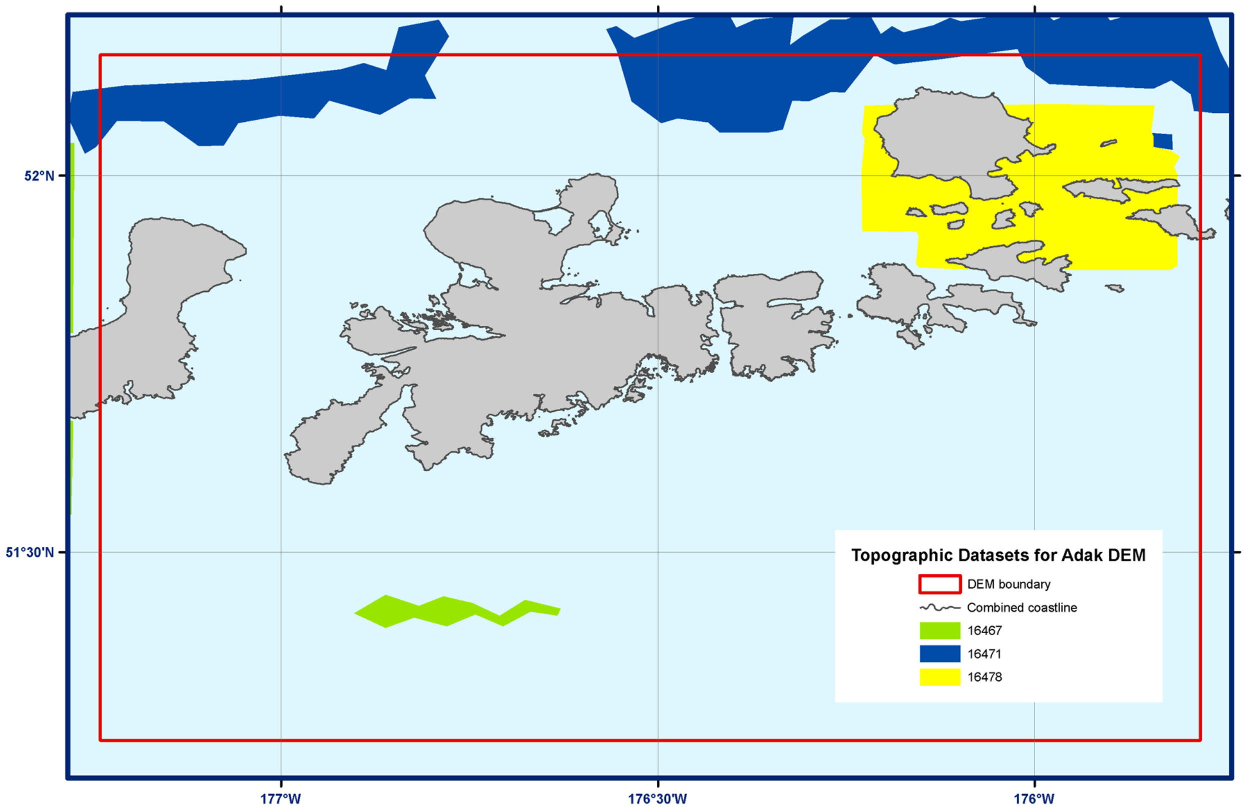

Figure 12. *Spatial coverage of ENC sounding data used in compiling the Adak DEM.*

5) ETOPO1 Global Relief Model

A portion of the 1 arc-minute (~2 kilometer cell size) ETOPO1 Global Relief Model was extracted using NGDC's *GEODAS* grid translator "Design-a-Grid" tool (http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html?dbase=grdet1). ETOPO1 is an integrated bathymetric–topographic grid, however only the bathymetric values were used in creating a bathymetric surface. Figure 13 shows the bathymetric portion of the ETOPO1 grid that was used in building the Adak DEM. *FME* was used to convert the grid to MHW and transform it to a point shapefile. It was then edited to retain points in areas without direct depth measurements.

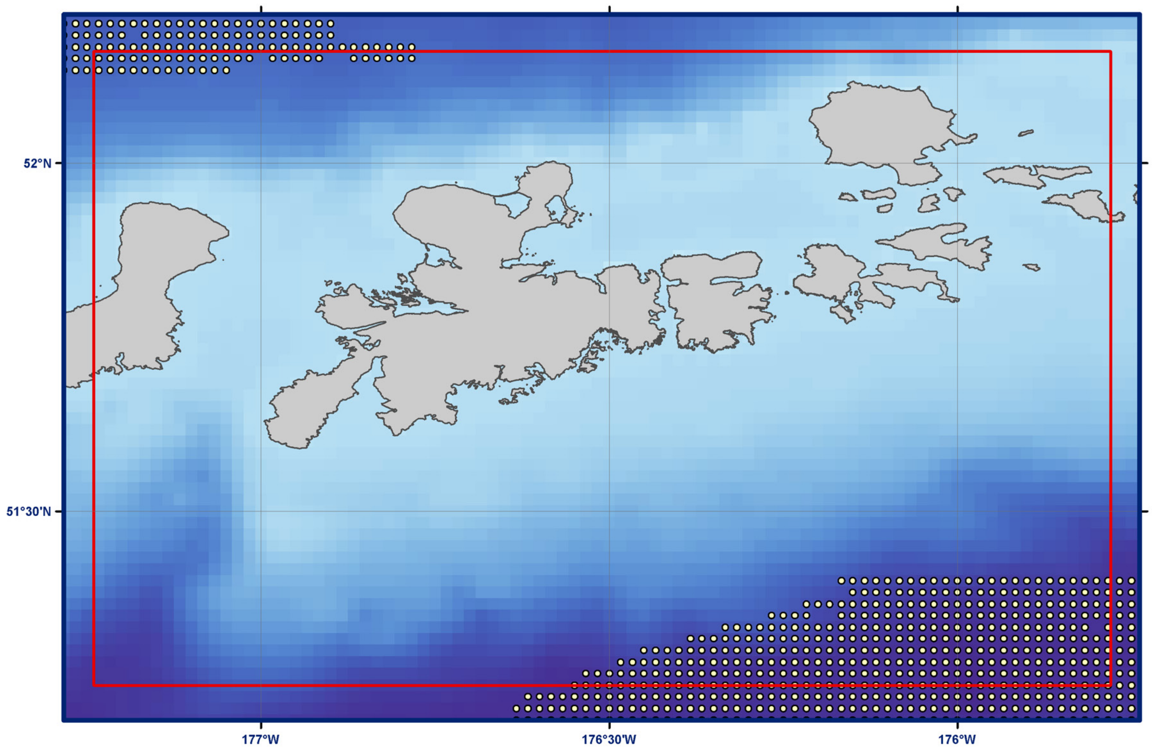

Figure 13. *Spatial coverage of ETOPO1 extracted points used in compiling the Adak DEM.*

3.1.3 *Topography*

Two topographic datasets in the Adak region were obtained from USGS and OCS and used to build the Adak DEM (Table 8; Fig. 14). NGDC evaluated but did not use the National Elevation Dataset (NED) 2 arc-second DEM available from USGS. NGDC digitized additional elevation points to supplement the available datasets on Adak and Umak Islands.

Table 8: Topographic datasets used in compiling the Adak DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NASA SRTM	2000	Global topography	1 arc-second	WGS 84 geographic	Assumed MSL	http://seamless.usgs.gov/
NOAA ENCs	1990 to 2000	Extracted elevation points	Varies	WGS 84 geographic	MHW	http://nauticalcharts.noaa.gov/mcd/enc/
NGDC		Digitized elevation points	< 10 meters	WGS 84 geographic		

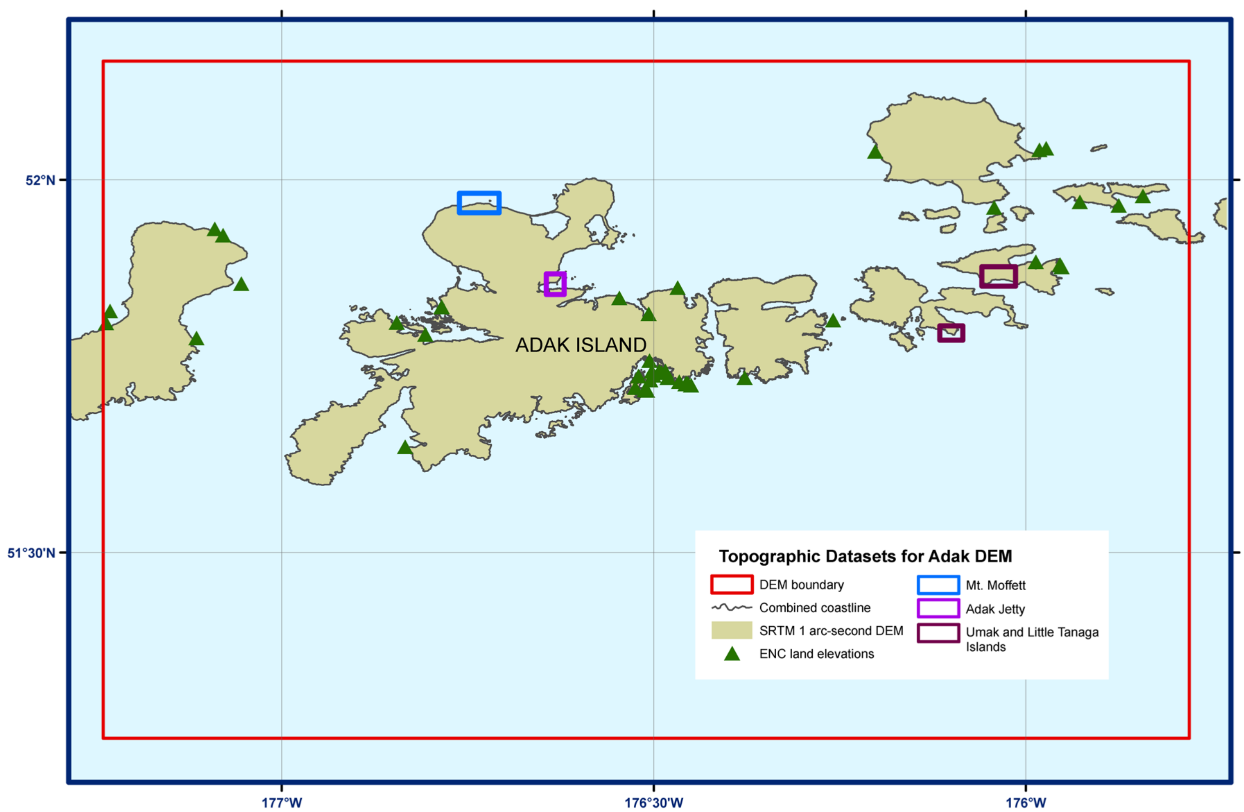

Figure 14. *Spatial coverage of the topographic datasets used in compiling the Adak DEM.*

1) NASA Shuttle Radar Topography Mission

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[5]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February, 2000. Data from this mission have been processed into 1 degree × 1 degree tiles and edited to define the coastline. Data 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 Adak, there are numerous small areas with "no data" values (Fig. 15). The SRTM DEM also contains values over the open ocean, which were deleted by clipping to the final coastline.

Points extracted from the NED 2 arc-second DEM were tested to fill holes in the SRTM data. However, analysis of the resulting gridded topography showed discrepancies in the data values creating uneven transitions between datasets. Leaving the holes unfilled created a smoother surface.

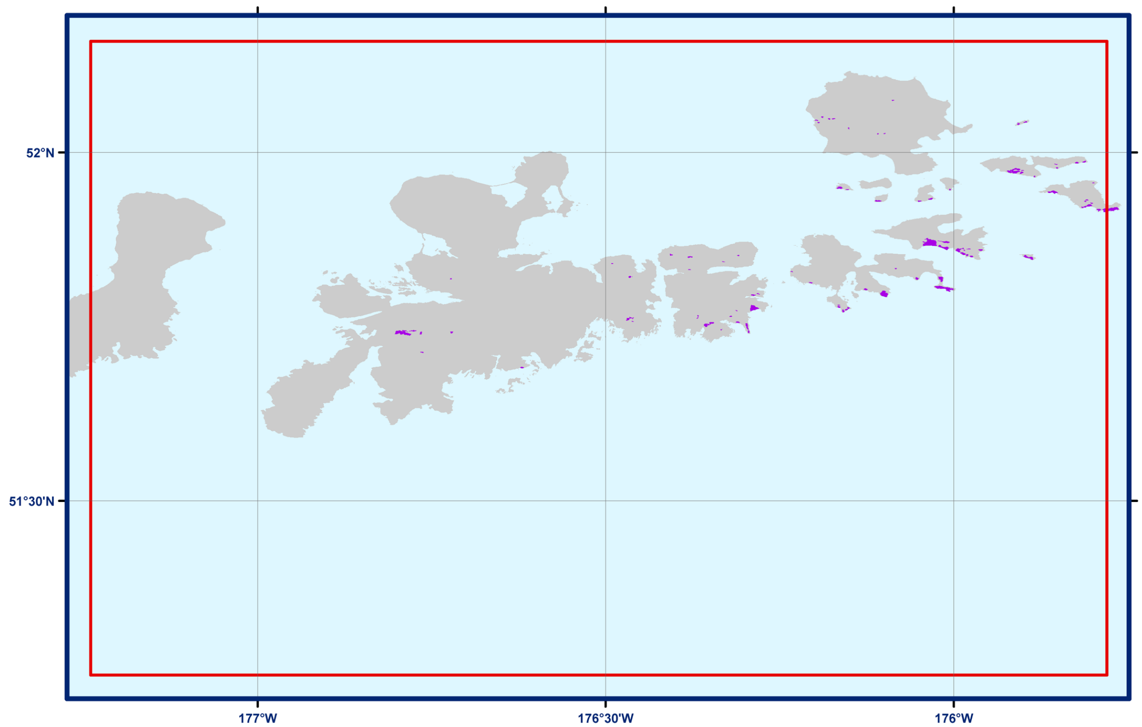

Figure 15. *Spatial coverage of the SRTM 1 arc-second DEM, shown in gray. No data areas are shown in purple. Open ocean values shown in light blue.*

5. 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]

2) NOAA Electronic Navigational Chart land elevation points

Many of the offshore rocks and islets were not fully resolved in the digital topographic elevation datasets. To include these features in the Adak DEM, land elevation points were extracted from ENCs #16471, 16474, 16475, 16476, and 16478 (Fig. 16). ENC land elevation data are referenced to MHW and WGS 84.

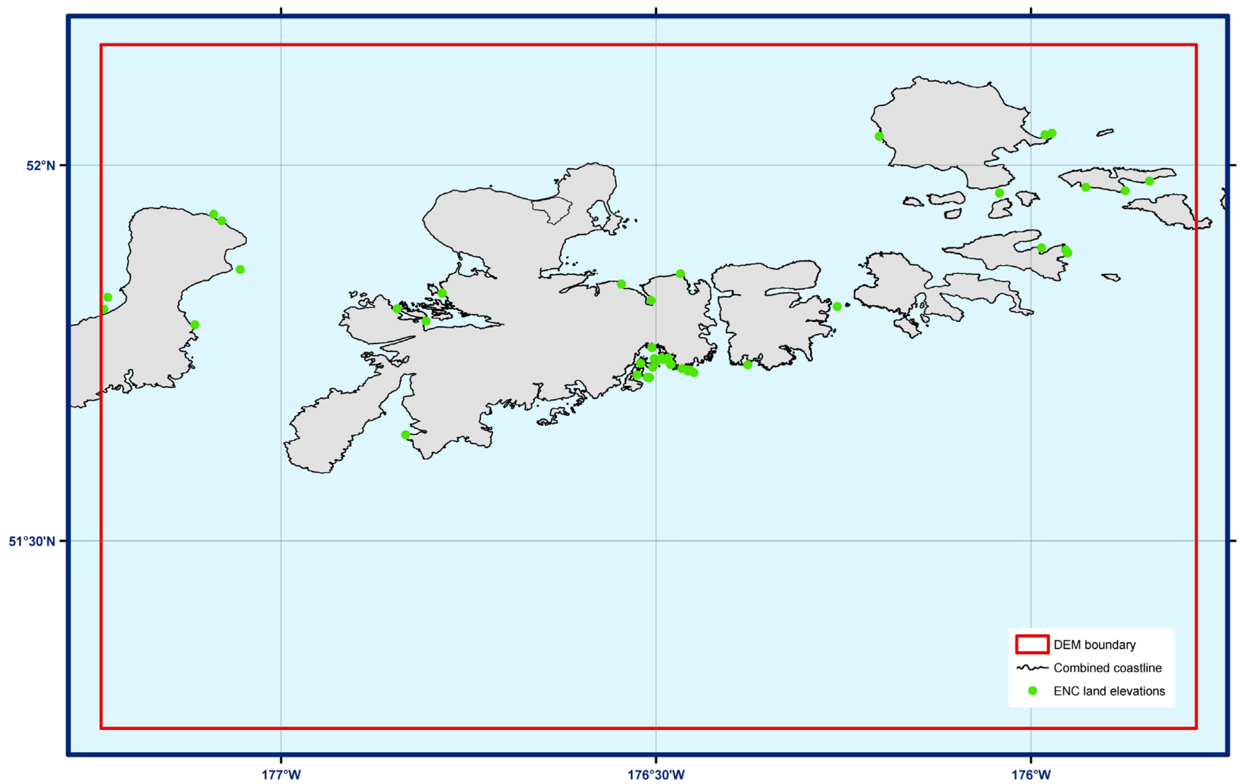

Figure 16. *Location of ENC extracted land elevations shown as green dots in the DEM region.*

3) NGDC digitized elevation points

NGDC added digitized elevation points to three areas where there are significant holes in the SRTM data (Fig. 17). Points were digitized along contour lines from USGS topographic maps. In the town of Adak, the airport runways were more accurately resolved using a constant elevation of 3 meters within the airstrip boundary shown in Figure 18. Elevation points of 1 meter were added to the jetty at Sweeper Cove to ensure positive values in the final grid, as SRTM topography did not fully resolve this feature.

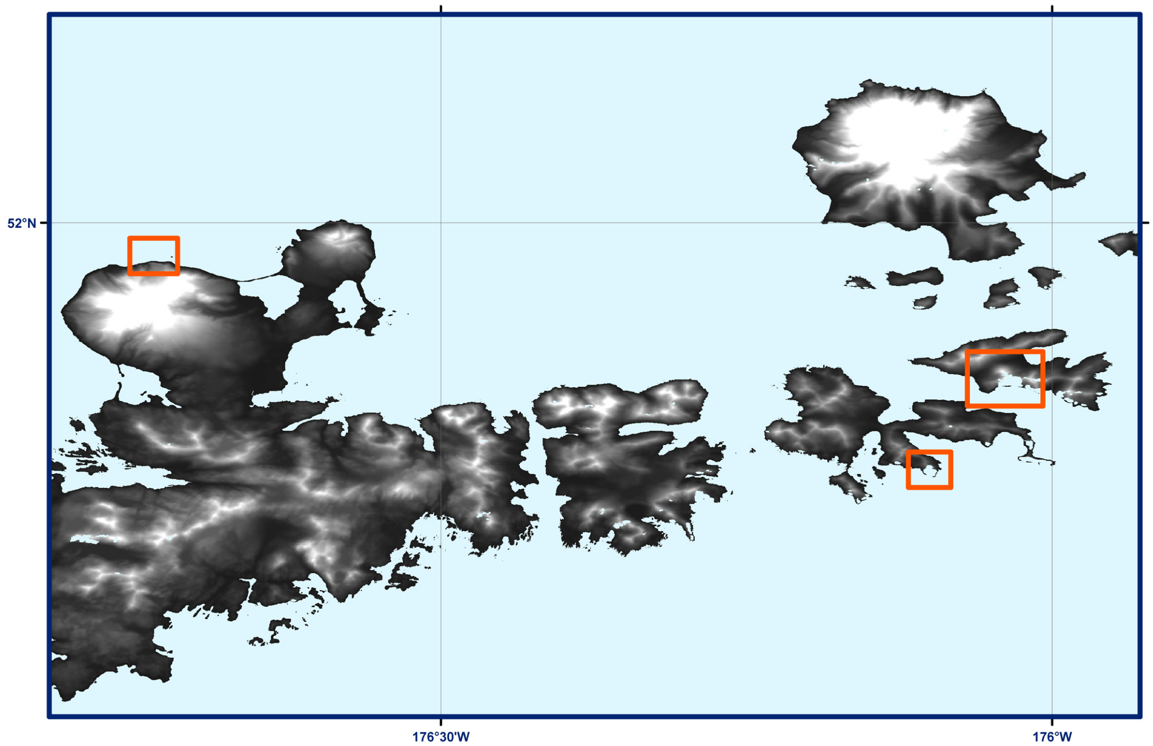

Figure 17. *Location of areas where NGDC digitized land elevations, shown as orange boxes, in the DEM region.*

Figure 18. *Aerial image of Adak from Google Earth. Elevation points were added to resolve the airstrip and the eastern jetty.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Adak DEM were originally referenced to a number of vertical datums including MLLW, MSL, and WGS 84/EGM96 Geoid. All datasets were transformed to MHW to provide the "worst-case scenario" for inundation modeling.

1) **Bathymetric data**

   The NOS hydrographic surveys, NGDC multibeam swath sonar surveys, and the SIO multibeam swath sonar survey were transformed from MLLW and MSL to MHW, using a constant based on the tide station on Adak Island.

2) **Topographic data**

   The USGS SRTM 1 arc-second DEM was originally referenced to WGS 84/EGM96 Geoid vertical datum. There are no survey markers in the vicinity of Adak that relate this geodetic datum to the local tidal datums. Thus, it was assumed that this datum is essentially equivalent to MSL in this area. Conversion to MHW, using *ArcCatalog* tools, was accomplished by adding a constant offset of -0.406 meters (Table 9), the difference between MSL and MHW at the Adak Island tide station (#9461380).

Table 9. Relationship between MHW and other vertical datums used in the Adak DEM.

MSL to MHW	-0.406 meters
MLLW to MHW	-1.055 meters

3.2.2 Horizontal datum transformations

Datasets used in compiling the Adak DEM were originally referenced to NAD 83 geographic, and WGS 84 geographic horizontal datums. Some NOS surveys were manually shifted in *ArcGIS* to fit the combined 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 *ArcMap* for consistency between datasets. 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:

- Gaps in SRTM topographic DEM.
- Data values over the ocean and rivers in the SRTM topographic dataset. The SRTM dataset required automated clipping to the combined coastline.
- Digital, measured bathymetric values from NOS surveys date back over 70 years. More recent data, such as the multibeam swath sonar surveys, differed from older NOS data by as much as 100 meters vertically. The older NOS survey data were excised where more recent bathymetric data exists.
- Some digital NOS survey data did not align with the combined coastline and were manually shifted in *ArcGIS.*

3.3.2 Smoothing of bathymetric data

The older NOS hydrographic survey data are generally sparse at the resolution of 1 arc-second in both deep water and in some areas close to shore. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing "pre-surface" bathymetric 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 clipped to remove overlap with the SIO and NGDC multibeam data and then combined with points extracted from the combined coastline—to provide a buffer along the entire coastline. The coastline elevation value was set to -1.0 meter to ensure a bathymetric surface below zero in areas where bathymetric data are sparse or nonexistent.

The point data were median-averaged using the *GMT* tool "blockmedian" to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Adak DEM gridding region. The *GMT* tool "surface" was then used to apply a tight spline tension to interpolate elevations for cells without data values. The *GMT* grid created by "surface" was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy and exported as an xyz file for use in the final gridding process (Table 10). Figure 19 shows a histogram of NOS survey H08240 compared to the 1 arc-second pre-surfaced bathymetric grid. Differences cluster around zero with only 11 out of 7483 points varying more than 5 meters from the DEM. These few points are located along the coastline and where this survey adjoins an older survey.

Some inconsistencies were identified while merging the bathymetric datasets due to the range in ages and resolutions of the NOS hydrographic surveys. In areas where more recent data were available, the older surveys were either edited or removed.

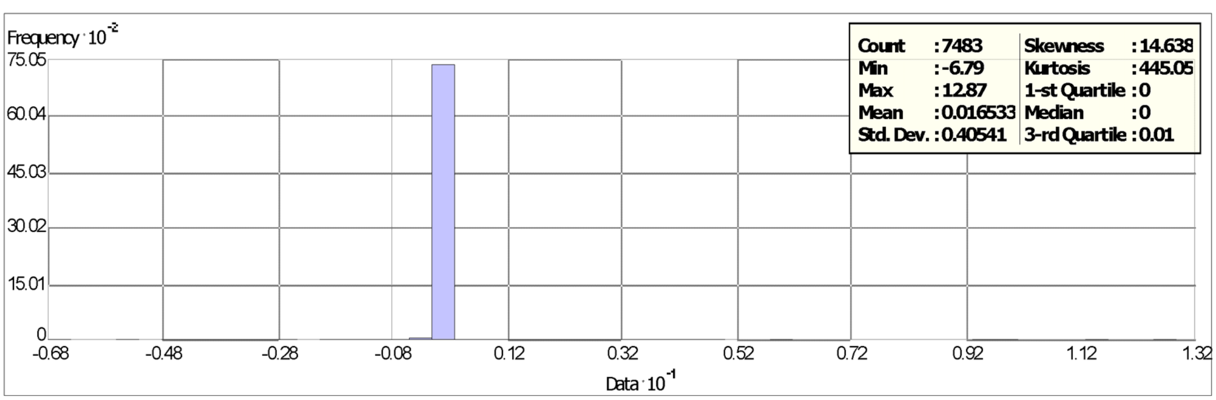

Figure 19. *Histogram of the differences between NOS hydrographic survey H08240 and the 1 arc-second pre-surfaced bathymetric grid.*

3.3.3 Gridding the data with MB-System

MB-System was used to create the 1 arc-second Adak DEM. *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. The *MB-System* tool "mbgrid" was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the "mbgrid" gridding algorithm, as relative gridding weights, is listed in Table 10. Greatest weight was given to the ENC land elevation data and NGDC digitized features. Least weight was given to the ENC soundings, ETOPO1 points, and pre-surfaced 1 arc-second bathymetric grid.

Table 10. Data hierarchy used to assign gridding weight in *MB-System*.

Dataset	*Relative Gridding Weight*
Combined coastline	1
Pre-surfaced bathymetric grid	1
ETOPO1 extracted grid points	1
ENC soundings	1
USGS STRM topographic DEM	1
NOS hydrographic surveys	10
NGDC multibeam survey	10
SIO multibeam survey	10
NGDC digitized elevations	100
ENC land elevations	100

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Adak DEM is dependent upon DEM cell size and the datasets used to determine corresponding DEM cell values. Topographic features have an estimated horizontal accuracy of 50 to 75 meters, based on the documented accuracy of the SRTM DEM. Bathymetric features are resolved only to within a few hundred meter in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of sub aerial topographic features. Positional accuracy is limited by: the sparseness of deep-water soundings; and potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Adak DEM is also highly dependent upon the source datasets contributing to DEM cell values. Elevation values, derived from the SRTM topographic data, have vertical accuracies of between 10 and 15 meters. Bathymetric values were derived from the wide range of sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine bathymetric values between sparse, poorly located NOS soundings degrades the vertical accuracy of elevations in deep water to about 5% of water depth.

3.4.3 Slope maps and 3-D perspectives

ESRI *ArcCatalog* was used to generate a slope grid from the Adak DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 20). The DEM was transformed to UTM zone 1 coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Analysis of preliminary grids using *Quick Terrain Modeler* revealed suspect data points, which were corrected before recompiling the DEM. Figure 1 shows a color image of the 1 arc-second Adak DEM in its final version. Figure 21 shows a perspective rendering of the final DEM.

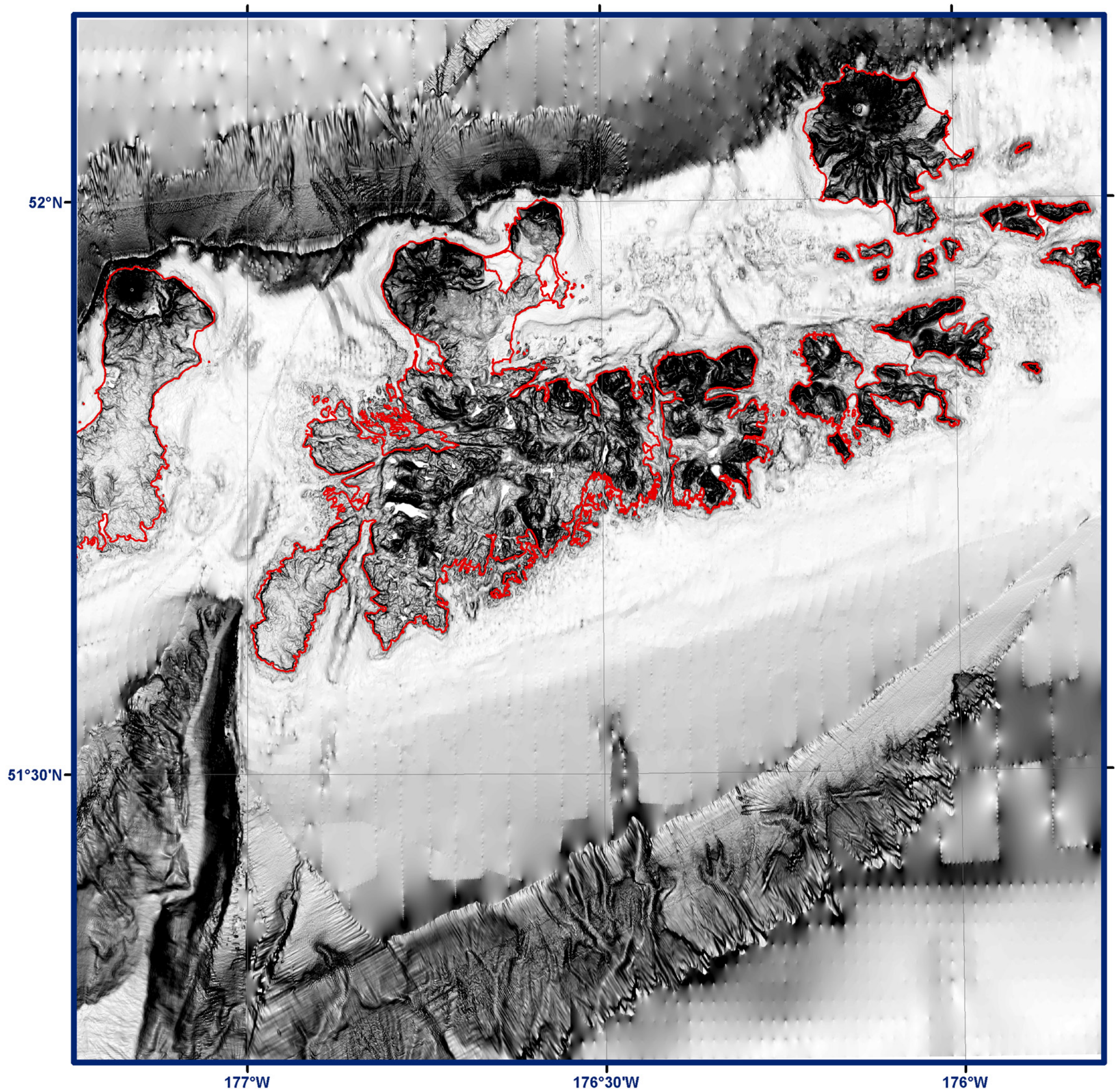

Figure 20. *Slope map of the Adak DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

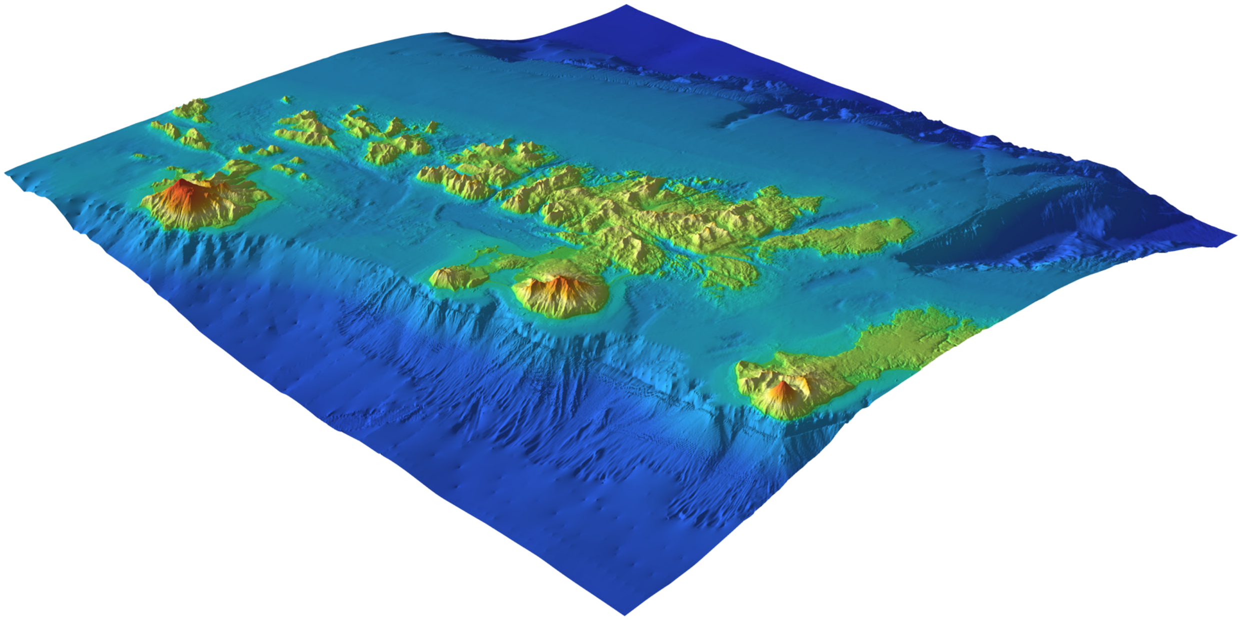

Figure 21. Perspective view from the northwest of the Adak DEM.
Vertical exaggeration–times 2.

3.4.4 Comparison with source data files

To ensure grid accuracy, the Adak 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 (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the differences between the SRTM 1 arc-second DEM and the completed Adak DEM is shown in Figure 22. Differences cluster around zero with elevation points with large difference values along the coastline and where ENC elevation points varied significantly from the SRTM elevation.

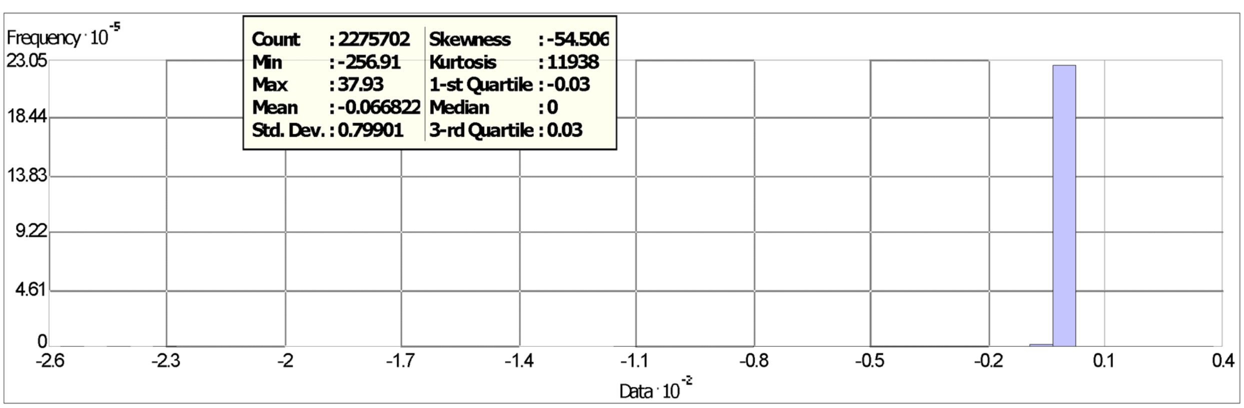

Figure 22. Histogram of the differences between the SRTM 1 arc-second topographic DEM and the Adak DEM.

3.4.5 *Comparison with National Geodetic Survey geodetic monuments*

NGS datasheets were downloaded in shapefile format from the NOAA NGS web site (http://www.ngs.noaa.gov/) in shapefile format, attributes generally providing monument positions in NAD 83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Datasheets for the Adak DEM region did not include this elevation data, however they did include superseded elevation information referenced to NGVD29 (Table 11). NGDC used 9 of the 271 datasheet points to qualitatively assess the DEM accuracy surrounding the town of Adak. Figure 23 shows the location and permanent ID (PID) for the selected points.

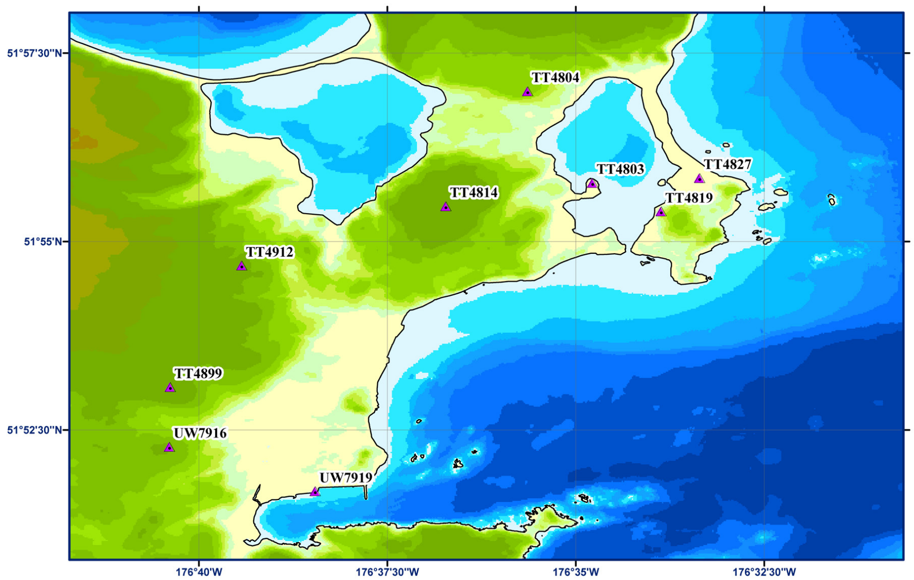

Figure 23. *Location and PID for selected NGS datasheet points near the town of Adak.*

Table 11. NGS datasheet NGVD29 heights (meters) compared to Adak DEM elevation.

PID	*NGVD29 Height*	*DEM elevation*	*Difference*
TT4803	11.2	4.5	6.7
TT4804	58.9	57.6	1.3
TT4814	187.8	183.5	4.3
TT4819	34.2	25.6	8.6
TT4827	5.6	6.6	-1.0
TT4899	156.0	155.5	0.5
TT4912	120.8	117.6	3.2
UW7916	116.6	111.5	5.1
UW7919	5.1	4.5	0.6

3.4.6 Comparison with topographic and bathymetric contours

Contours generated from the Adak DEM were compared to topographic contours from the USGS 1:250,000 topographic map in several locations. Figure 24 shows the area of northern Adak Island and Mt. Moffett on the topographic map displayed with the Adak DEM topographic contours overlaid. Land features on the map are well represented in the contour data. This technique was also used to qualitatively assess the bathymetric values of the DEM. Bathymetric contours were compared to contour lines on the NOAA nautical charts (e.g., Fig. 25).

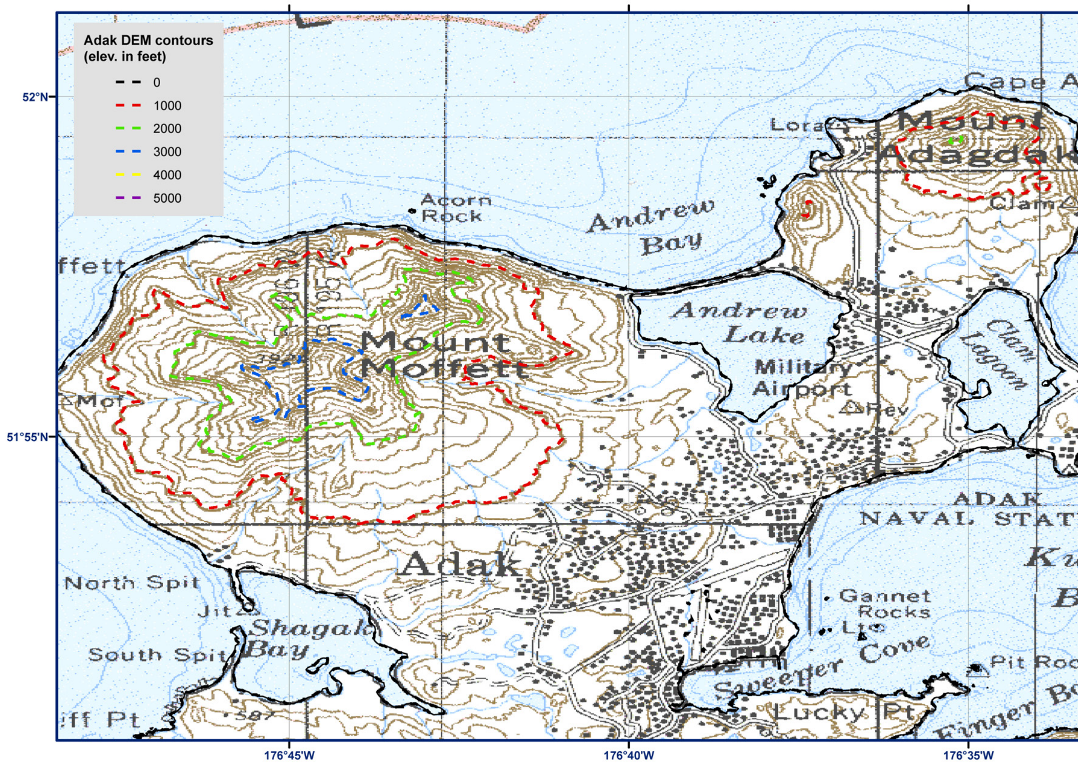

Figure 24. Comparison of USGS Adak topographic map to Adak DEM topographic contours.

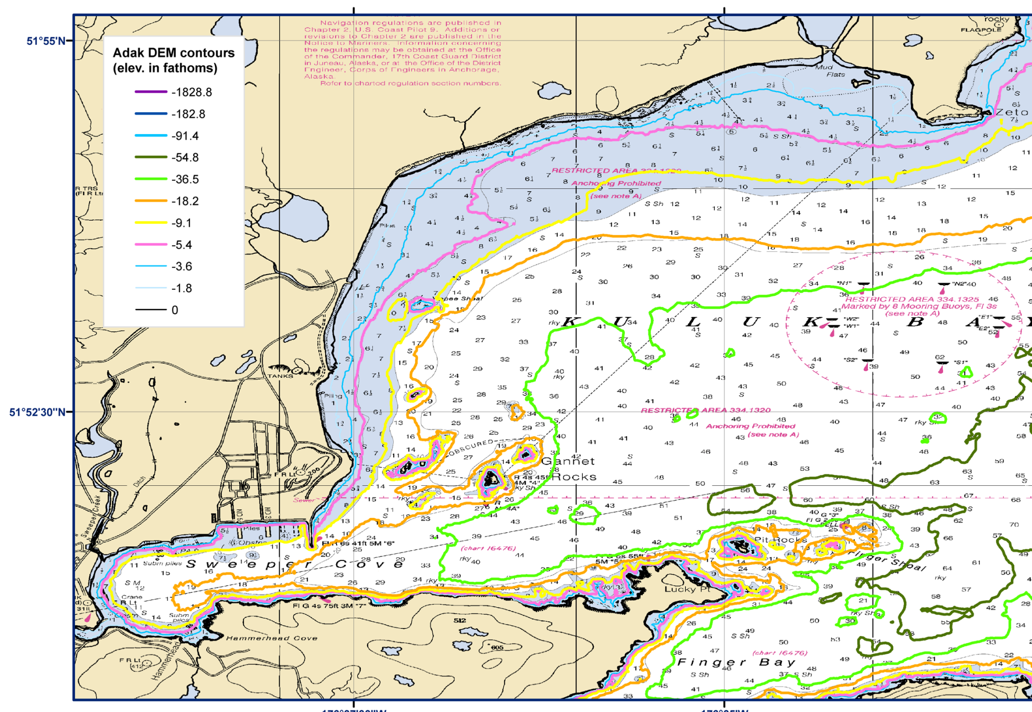

Figure 25. Comparison of NOAA ENC #16475 to Adak DEM bathymetric contours.

4. Summary and Conclusions

A bathymetric–topographic DEM of the Adak, Alaska region, with cell size of 1 arc-second, was developed for the PMEL NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies and academic institutions 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*, *MB-System* and *Quick Terrain Modeler* software.

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

- Conduct hydrographic surveys in near-shore areas, especially in harbors.
- Conduct bathymetric–topographic lidar survey of Adak Island.
- Conduct deep water multibeam surveys for regions north and south of Andreanof Islands.

5. Acknowledgments

The creation of the Adak DEM was funded by NOAA PMEL. The authors thank Nazila Meratia and Vasily Titov (PMEL), Patrick Barnard (USGS), Bret Christensen (USFWS), and Scott White and Gene Yogodzinski (Department of Geological Studies, University of South Carolina).

6. References

Nautical Chart #16012 (ENC and RNC), 5th Edition, 2008. Aleutian Islands, Amukta Island to Attu Island. Scale 1: 1,126,321. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16467 (ENC and RNC), 2nd Edition, 2005. Adak Island to Tanaga Island. Scale 1:100,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16471 (ENC and RNC), 3rd Edition, 2007. Atka Pass to Adak Strait. Scale 1:120,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16474 (ENC and RNC), 2nd Edition, 2007. Bay of Islands, Adak Island. Scale 1:12,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16475 (ENC and RNC), 3rd Edition, 2008. Kuluk Bay and Approaches, Little Tanaga and Kagalaska Straits. Scale 1:50,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16476 (ENC and RNC), 3rd Edition, 2008. Adak Island, Sweeper Cove, Finger and Scabbard Bays. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16477 (RNC), 7th Edition, 2008. Tagalak Island to Little Tanaga Island. Scale 1:30,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16478 (RNC and ENC), 2nd Edition, 2007. Tagalak Island to Great Sitkin Island. Scale 1:30,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

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

FME 2009 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

GMT v. 4.1.4 – Generic Mapping Tools, freeware 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 – lidar processing software developed by John Hopkins University's Applied Physics Laboratory and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/