NOAA Technical Memorandum NESDIS NGDC-42

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

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Also available from the National Technical Information Service (NTIS)
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1. Introduction

In June of 2009, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a set of integrated bathymetric–topographic digital elevation models (DEMs) covering the Akutan, Alaska region (Fig. 1) for the Geophysical Institute at the University of Alaska at Fairbanks (UAF). These DEMs are nested at 8 arc-second[1], 8/3 arc-second and 8/15 arc-second, with the highest resolution grid centered on the harbor at Akutan, Alaska. The coastal DEMs will be used as input for the university-developed modeling system to simulate tsunami generation, propagation, and inundation (http://www.aeic.alaska.edu/tsunami/). The DEMs were generated from diverse digital datasets in the region (shown in Figure 4) and were designed to represent modern morphology. They will be used for tsunami inundation modeling by the Alaska Earthquake Information Center in support of the National Tsunami Hazard Mitigation Program (http://nthmp.tsunami.gov). This report provides a description of the data sources and methodology used to develop the Akutan DEMs.

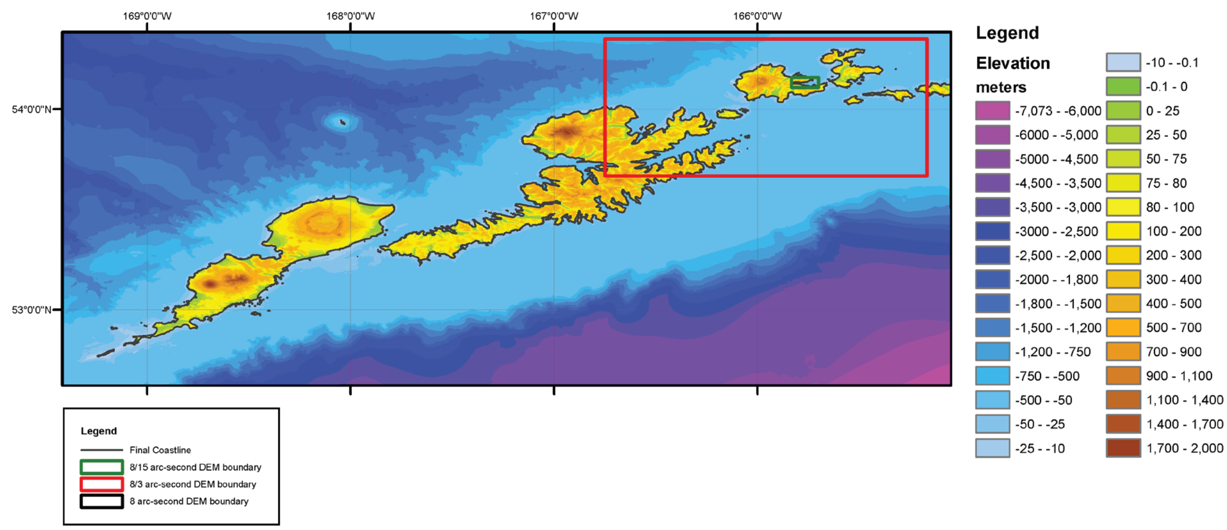

Figure 1. *Boundaries of the Akutan nested DEMs. Color image of the 8 arc-second DEM is in the background.*

1. In polar latitudes, longitude lines are spaced significantly closer together than latitude lines, approaching zero at the poles. While the DEMs are built upon grids of square cells in geographic coordinates, they are not square cells when converted to meters. At the latitude of Akutan, Alaska (54º 8' 42"N, 165º 48' 5"W) 1 arc-second of latitude is equal to 30.9 meters; 1 arc-second of longitude is 18.21 meters.

2. Study Area

Akutan is a community of 738 people located on Akutan Island in the Eastern Aleutians at approximately 167.77º W and 54.14º N (Fig. 2). It is one of the Krenitz Islands of the Fox Island group and lies 35 miles east of Unalaska and 765 miles southwest of Anchorage. The community encompasses 14 square miles of land and 5 square miles of water. It lies in the maritime climate zone, which has mild winters and cool summers. It receives an average annual precipitation of 28 inches and has a mean temperature range from 22 to 55 degrees Fahrenheit.

Figure 2. *Photograph of the community of Akutan. Source: http://static.panoramio.com/photos/original/16181482.jpg.*

At the heart of Akutan Island lies Mount Akutan, an active stratovolcano. It contains a 2 kilometer wide caldera with two post-caldera cones, Lava Point and Lava Peak. Lava Peak is of Pleistocene age, while Lava Point is of Holocene age (Fig. 3; *USGS: http://geopubs.wr.usgs.gov/open-file/of98-135/of98-135.pdf*). Recent eruptions produced small amounts of fine volcanic ash that fell primarily on the upper flanks of the volcano. Ash fell in and around the area of Akutan Harbor during eruptions in 1911, 1948, 1987, and 1989.

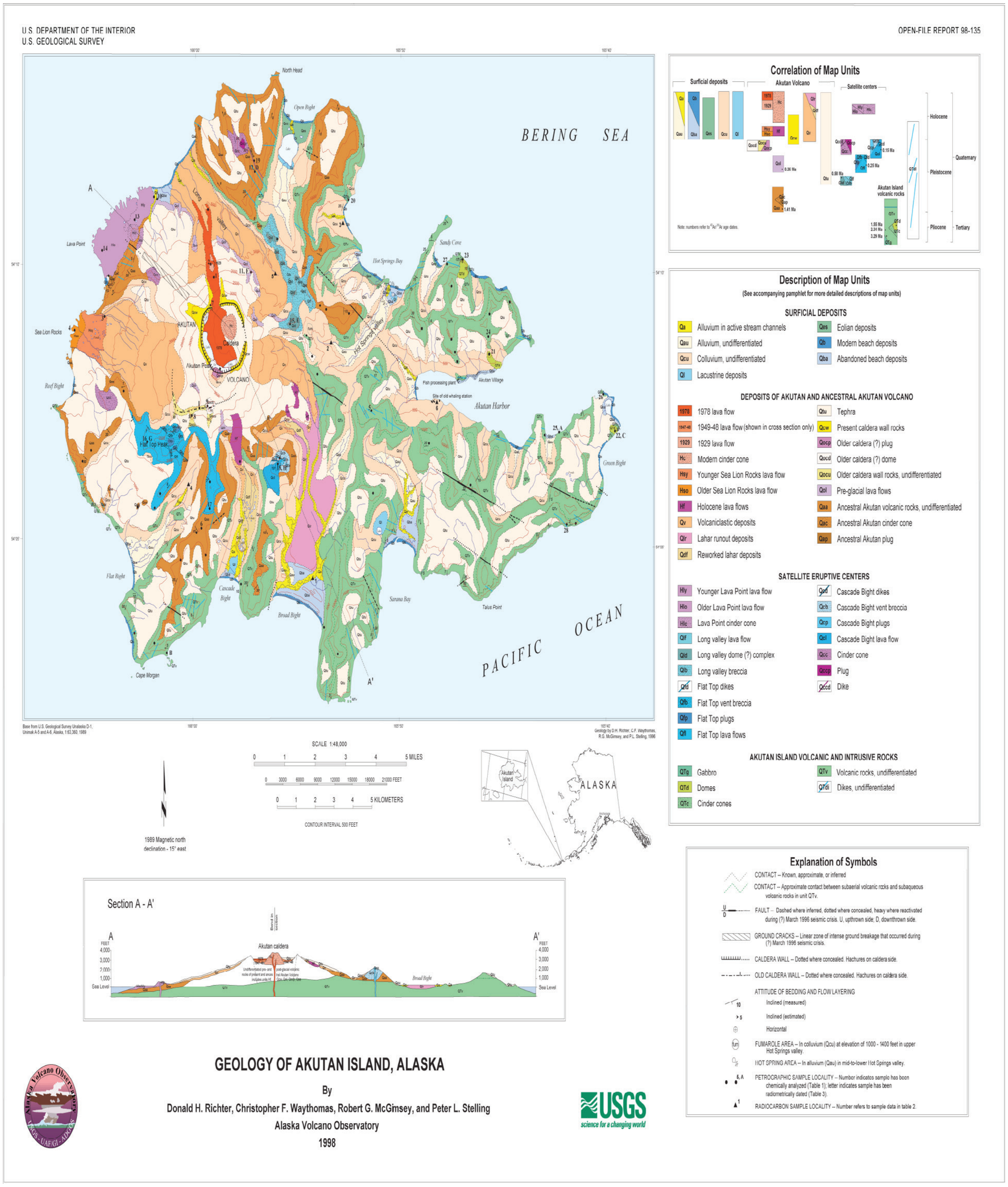

Figure 3. *Geologic map of Akutan Island. Source: USGS (http://geopubs.wr.usgs.gov/open-file/of98-135/of98-135.pdf)*

3. Methodology

The Akutan DEMs were developed to meet the specifications in Table 1, which have slightly larger extents than that required by UAF's tsunami modeling requirements. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS 84) geographic and Mean Higher High Water (MHHW), for modeling of maximum flooding, respectively[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1a: Specifications for the 8 arc-second Akutan, Alaska DEM.

Grid Area	Akutan, Alaska
Coverage Area	169.63º to 164.97º W; 52.55º to 54.41º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8 arc-seconds
Grid Format	netCDF

Table 1b: Specifications for the 8/3 arc-second Akutan, Alaska DEM.

Grid Area	Akutan, Alaska
Coverage Area	166.89º to 165.67º W; 53.61º to 54.39º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8/3 arc-second
Grid Format	netCDF

Table 1c: Specifications for the 8/15 arc-second Akutan, Alaska DEM.

Grid Area	Akutan, Alaska
Coverage Area	165.85º to 165.67º W; 54.09º to 54.17º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8/15 arc-second
Grid Format	netCDF

2. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEMs. 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 the 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, for their DEMs so that they can model the wave's passage across ocean basins. These DEMs are identified as having a WGS 84 horizontal datum even though the underlying elevation data were typically transformed to NAD 83. At the scale of the DEMs, WGS 84 and NAD 83 are identical and may be used interchangeably.

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 4) were obtained from several U.S. federal and academic agencies, including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS), and NGDC; the U.S. Fish and Wildlife Service (FWS); the U.S. Geological Survey (USGS); and the National Aeronautics and Space Administration (NASA). Safe Software's (http://www.safe.com/) *FME* data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert into ESRI (http://www.esri.com/) *ArcGIS* shapefiles[3]. The shapefiles were then displayed with *ArcGIS* to assess data quality and manually edit datasets. The methodology used for vertical datum adjustments is described in Section 3.2.1.

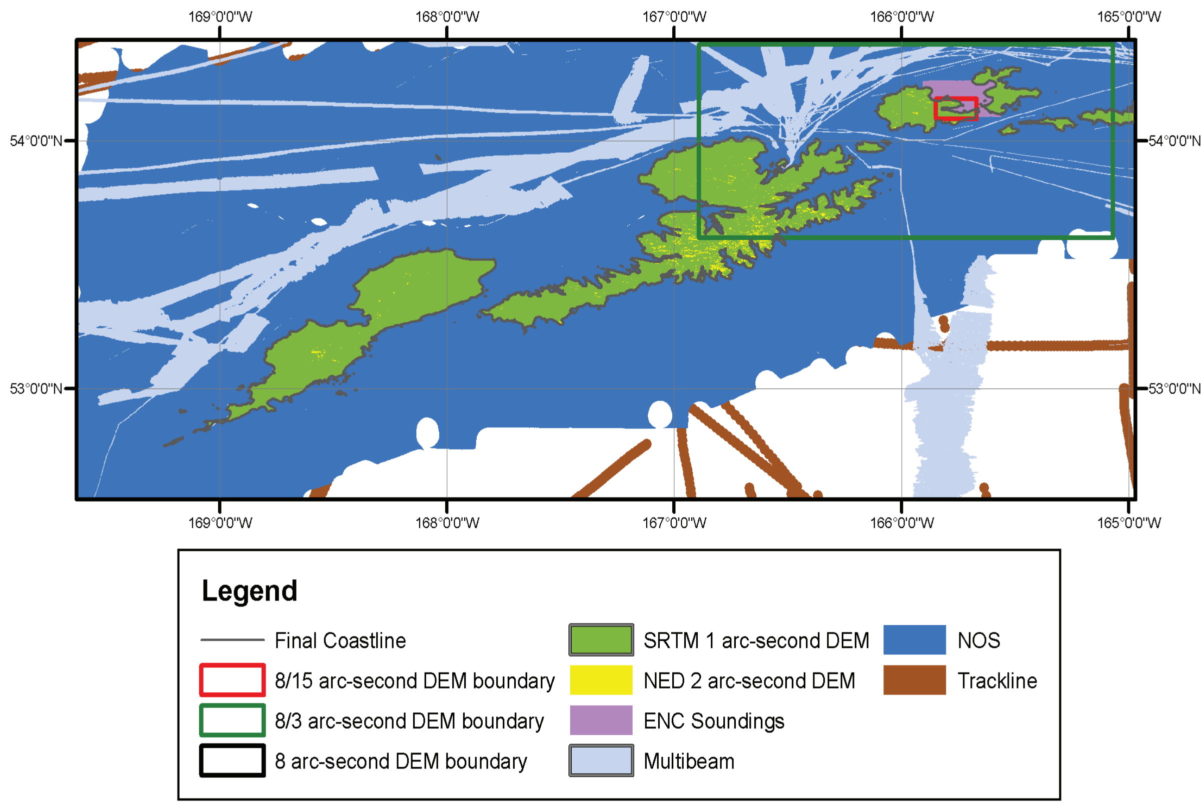

Figure 4. *Principal source dataset contributions to the Akutan, Alaska DEMs.*

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

Two digital coastline datasets of the Akutan region were analyzed for inclusion in the Akutan DEMs: NOAA ENCs (see Table 3) and U.S. Fish and Wildlife Service (FWS) statewide Alaska digital coastline (Table 2; Fig. 5). Comparisons between the two coastline datasets, NOS hydrographic surveys, and the National Elevation Dataset (NED) and the Shuttle Radar Topography Mission (SRTM) topographic DEMs showed that the FWS coastline best fit the topographic and bathymetric data.

Table 2. Shoreline datasets used in compiling the Akutan, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*
FWS	2006	Compiled coastline	Various	WGS 84 geographic	Undefined
NOAA nautical charts	2009	Mean High Water (MHW) coastline	Digitized from 1:10,000-1:300,000 scale charts	WGS 84 geographic	MHW

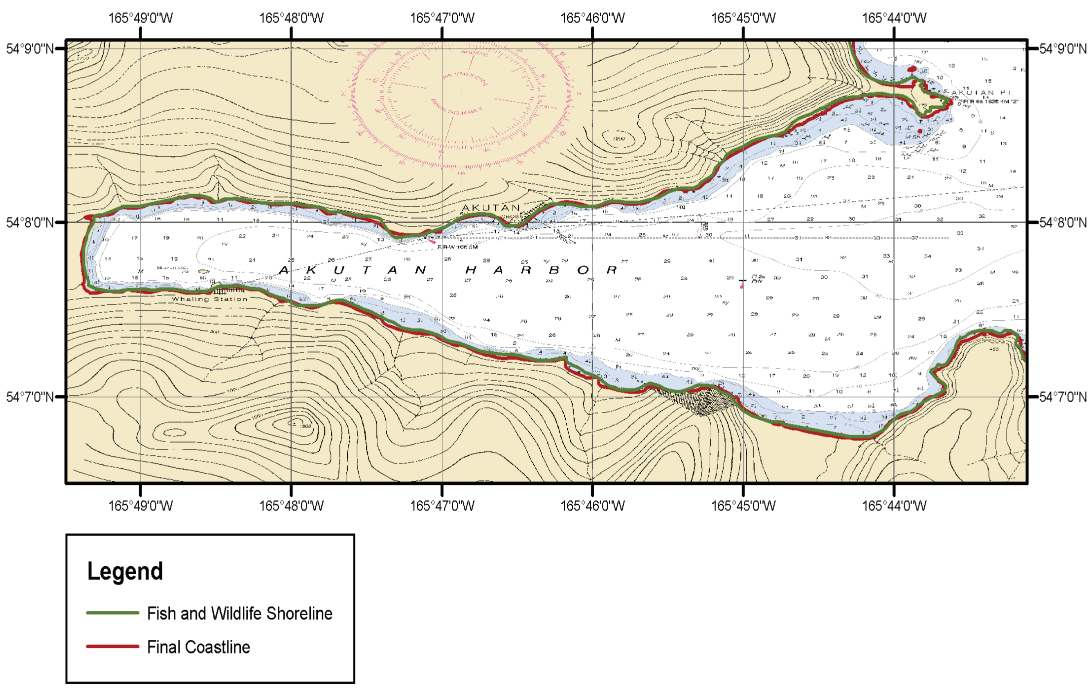

Figure 5. *The Fish and Wildlife Shoreline was manually digitized to be consistent with RNC #16532 to build the 'final coastline' in Akutan Harbor.*

1) U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS) has compiled a seamless digital coastline of the State of Alaska from a variety of sources, including: the National Hydrography Dataset, NOAA nautical charts, U.S. Fish and Wildlife Service, 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, U.S. Fish and Wildlife Service. 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 FWS coastline; the horizontal datum of the compiled FWS coastline is WGS 84. The FWS coastline provides complete coverage of the Akutan region.

2) NOAA nautical charts

Fifteen NOAA nautical charts were available for the Akutan area (Table 3), and were downloaded from NOAA's Office of Coast Survey web site (http://www.nauticalcharts.noaa.gov/mcd/enc/index.htm). All fifteen of the charts were available as georeferenced Raster Nautical Charts (RNCs; digitial images of the charts), which were used to assess the quality of bathymetric datasets. Eleven charts were also available as Electronic Navigational Charts (ENCs) that represent chart features as individual digital objects. The ENCs are in S-57 format and include coastline data files referenced to Mean High Water (MHW). The ENC coastlines were assumed to be essentially the same at MHHW once adjusted to fit the bathymetric datasets. The average vertical offset from MHW to MHHW based on the Unalaska tide station is approximately 0.087 meters.

RNC #16532 was used to manually digitize the coastline for the area surrounding Akutan Harbor. Photographs obtained from various sources through the web were used to visually inspect the coastline in Akutan Harbor (e.g., Figs. 6 and 7).

Table 3. NOAA nautical charts in the Akutan region.

Chart	*Title*	*Edition*	*Edition Date*	*Format*	*Scale*
16500	Unalaska Island to Amukta Island	10th	2009	RNC	1:300,000
16501	Islands of Four Mountains	7th	2009	RNC	1:80,000
16511	Inanudak and Nikolski Bays	7th	2009	RNC	1:40,000
16513	Umnak Pass and Approaches	5th	2009	ENC and RNC	1:40,000
16514	Unalaska Island Kuliliak Bay to Surveyor Bay	4th	2009	ENC and RNC	1:40,000
16515	Unalaska Island Chernofski Harbor to Skan Bay	7th	2009	ENC and RNC	1:40,000
16517	Makushin Bay	6th	2009	ENC and RNC	1:40,000
16518	Cape Kovrizhka to Cape Cheerful	6th	2009	ENC and RNC	1:40,000
16521	Protection Bay to Eagle Bay	6th	2009	ENC and RNC	1:40,000
16522	Beaver Inlet	6th	2009	ENC and RNC	1:40,000
16528	Unalaska Bay and Akutan Pass	17th	2009	ENC and RNC	1:40,000
16529	Dutch Harbor	15th	2009	ENC and RNC	1:10,000
16530	Captains Bay	6th	2009	ENC and RNC	1:10,000
16531	Krenitzin Islands	7th	2009	RNC	1:40,000
16532	Akutan Bay	6th	2009	ENC and RNC	1:20,000

To obtain the best digital MHHW coastline of the Akutan region, NGDC merged the FWS coastline and manually digitized the coastline of Akutan Harbor. The final coastline was then edited to be consistent with the NOS hydrographic survey data. Piers and docks were also manually removed from the final coastline.

The final coastline was sub-sampled to 10-meter spacing using NGDC's *GEODAS* software and converted to point data for use as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached "zero" at the coast. The final coastline was used to clip the SRTM and NED topographic DEMs, which contained elevation values, typically zero, over the open ocean (Section 3.1.3).

Figure 6. *Aerial photograph of the cannery in Akutan Harbor.*
Source: http://deadliestreports.files.wordpress.com/2007/06/akutan-canery.jpg

Figure 7. *View from northeastern Akutan, across Hot Springs Bay and Ridge Point; on the horizon is Mount Gilbert and the western coast of Akun. Source: Alaska Volcano Observatory/U.S. Geological Survey*

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Akutan DEMs included NOS hydrographic surveys, NOAA ENC chart soundings, multibeam swath sonar surveys, and NGDC trackline surveys (Table 4).

Table 4. Bathymetric datasets used in compiling the Akutan, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1913- 1991	Hydrographic survey soundings	Ranges from 10 meters to 1.5 kilometers (varies with scale of survey, depth, traffic and probability of obstructions)	NAD 83, Early Alaskan Datum, Datum, Undefined Datum	Mean Lower Low Water (MLLW) (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOAA ENC	2009	NOAA digitized nautical chart soundings	~200 meters	WGS 84 geographic	MLLW (meters)	http://www.nauticalcharts.noaa.gov/mcd/enc/index.htm
NGDC	1999-2004	Multibeam	Raw MB files gridded to 6 arc-second	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NGDC	1953-Present	Trackline	Raw MB files gridded to 6 arc-second	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/geodas/trackline.html

1) NOS hydrographic survey data

A total of 87 NOS hydrographic surveys conducted between 1913 and 1991 were used in Akutan DEM development (Appendix A; Fig. 8). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to NAD 83 geographic, Early Alaska, or "undetermined" datums.

Data point spacing for the surveys ranged from about 10 to 60 meters in shallow water up to 1.5 kilometers in deep water. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original datums (Appendix A). The data were then transformed to NAD 83 geographic using *FME* software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com/). NOS surveys in Early Alaska or "undetermined" datums 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 8 arc-second gridding area to support data interpolation across DEM boundaries.

After transforming all NOS survey data to MHHW (see Section 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 NED and SRTM topographic data and the final coastline.

Older NOS surveys were clipped to remove soundings that overlap more recent, higher-resolution NOS bathymetric surveys.

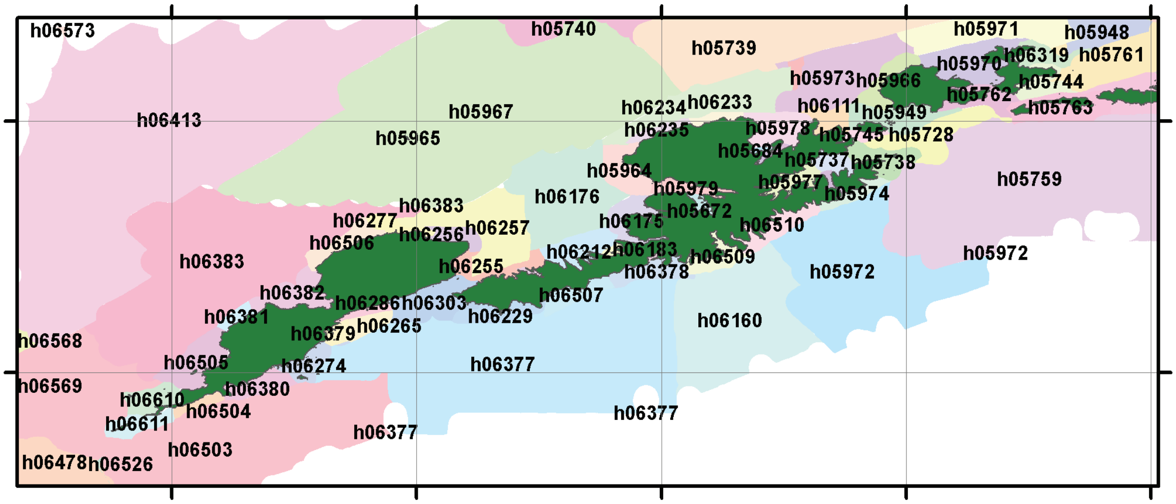

Figure 8. *Digital NOS hydrographic survey coverage in the Akutan region. Black denotes boundary of the 8 arc-second DEM. Areas without digital NOS hydrographic surveys depicted as white.*

2) OCS Electronic Navigational Chart soundings

Nautical chart #16532 for Akutan Harbor was available from NOAA's Office of Coast Survey in ENC format and, as sparse bathymetric survey data was available for this area, soundings were extracted from this chart using *FME* (see Table 3).

3) Multibeam swath sonar files

Thirty-five multibeam swath sonar surveys (Table 5, Fig. 4) were available from the NGDC multibeam sonar bathymetry database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) and the Bathymetric Data Center at the Bundesamt fur Seeschiffarhrt und Hydrographie (BSH; http://www.bsh.de/en/Marine_data/Hydrographic_surveys_and_wreck_search/Bathymetry/index.jsp) for use in building the Akutan DEMs. The NGDC and BSH databases are comprised of the original swath sonar files of surveys conducted mostly by U.S. and German fleets respectively. Most of the NGDC multibeam swath surveys were transits rather than dedicated seafloor surveys. All surveys have a horizontal datum of WGS 84/NAD 83 geographic and undefined vertical datum, assumed to be equivalent to mean sea level (MSL). The Sonne survey data were generously provided by Volkmar Leimer of BSH.

The downloaded data were gridded at 6 arc-seconds using the 'mbgrid' tool in *MB-System* to apply a tight spline tension. *MB-System* is an NSF-funded free software application specifically designed to manipulate multibeam swath sonar data (http://www.ldeo.columbia.edu/res/pi/MB-System/). The gridded data were converted to shapefiles and transformed to MHHW using *FME*.

Table 5. Multibeam swath sonar surveys used in compiling the Akutan, Alaska DEMs.

Survey ID	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
EW0204	2002	Assumed MSL	WGS 84 geographic	Columbia University, Lamont Doherty Earth Observatory (LDEO)
EW9408	1994	Assumed MSL	WGS 84 geographic	LDEO
FOCI93	1993	Assumed MSL	WGS 84 geographic	NOAA
FOCI95	1995	Assumed MSL	WGS 84 geographic	NOAA

Survey ID	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
HLY0202	2002	Assumed MSL	WGS 84 geographic	LDEO
HLY0203	2002	Assumed MSL	WGS 84 geographic	LDEO
HLY0401	2004	Assumed MSL	WGS 84 geographic	LDEO
HLY04TA	2004	Assumed MSL	WGS 84 geographic	LDEO
HLY04TD	2004	Assumed MSL	WGS 84 geographic	LDEO
HLY04TG	2004	Assumed MSL	WGS 84 geographic	LDEO
HLY0503	2005	Assumed MSL	WGS 84 geographic	LDEO
HLY05TC	2005	Assumed MSL	WGS 84 geographic	LDEO
HLY05TD	2005	Assumed MSL	WGS 84 geographic	LDEO
HLY06TD	2006	Assumed MSL	WGS 84 geographic	LDEO
HLY06TG	2006	Assumed MSL	WGS 84 geographic	LDEO
HLY06TH	2006	Assumed MSL	WGS 84 geographic	LDEO
HLY0701	2007	Assumed MSL	WGS 84 geographic	LDEO
HLY07TC	2007	Assumed MSL	WGS 84 geographic	LDEO
HLY07TD	2007	Assumed MSL	WGS 84 geographic	LDEO
HLY07TG	2007	Assumed MSL	WGS 84 geographic	LDEO
HLY07TH	2007	Assumed MSL	WGS 84 geographic	LDEO
HLY0803	2008	Assumed MSL	WGS 84 geographic	LDEO
HLY08TC	2008	Assumed MSL	WGS 84 geographic	LDEO
HLY08TD	2008	Assumed MSL	WGS 84 geographic	LDEO
HLY08TG	2008	Assumed MSL	WGS 84 geographic	LDEO
HLY08TH	2008	Assumed MSL	WGS 84 geographic	LDEO
HLY08TI	2008	Assumed MSL	WGS 84 geographic	LDEO
KRUS02RR	2004	Assumed MSL	WGS 84 geographic	SIO
NBP0304	2003	Assumed MSL	WGS 84 geographic	National Science Foundation (NSF)
NBP0304B	2003	Assumed MSL	WGS 84 geographic	NSF
RNDB06WT	1988	Assumed MSL	WGS 84 geographic	Scripps Institution of Oceanography (SIO)
RNDB09WT	1988	Assumed MSL	WGS 84 geographic	SIO
TN182	2005	Assumed MSL	WGS 84 geographic	SIO
SO97-1	1997	Assumed MSL	WGS 84 geographic	Bundesamt fur Seeschiffarhrt und Hydrographie, Germany

4) Trackline data files

Twelve trackline surveys (Table 6) were available from the NGDC trackline survey database (http://www.ngdc.noaa.gov/mgg/geodas/trackline.html) for use in building the Akutan DEMs. The Marine Trackline Geophysics database contains bathymetry, magnetics, gravity, and seismic navigation data collected during marine cruises from 1953 to the present. All surveys have a horizontal datum of WGS 84 geographic and undefined vertical datum assumed to be equivalent to mean sea level (MSL). The downloaded data in xyz format were then converted to shapefiles and transformed to MHHW using *FME* software.

Table 6. Trackline surveys used in compiling the Akutan, Alaska DEMs.

Survey ID	*Institution*	*Year*
26180	Defense Mapping Agency	1987
BBAY212	NOAA	1985
CMAPSU4S	NOAA	1980
CMAPSU3N	NOAA	2006
FARN0888	Natural Environment Research Council	1994
FOCI93	NOAA	1993
RC1109	Lamont-Doherty Geological Observatory	1979
RC1407	Lamont-Doherty Geological Observatory	1971
SI343607	US Navy Naval Oceanographic Office	1980
SI933001	US Navy Naval Oceanographic Office	1980
V2112	Lamont-Doherty Geological Observatory	1974
ZTES2AAR	Scripps Institution of Oceanography	1980

3.1.3 Topography

Topographic datasets of the Akutan region were obtained from USGS and NASA. (Fig. 9; Table 7).

Table 7. Topographic datasets used in compiling the Akutan, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*	*URL*
USGS NED	2006	Topographic DEM	2 arc-second grid	NAD 27 geographic	NGVD 29 (meters)	http://ned.usgs.gov/
NASA SRTM	2000	Topographic DEM	1 arc-second grid	WGS 84 geographic	WGS 84/ EGM 96 Geoid (meters)	http://srtm.usgs.gov/

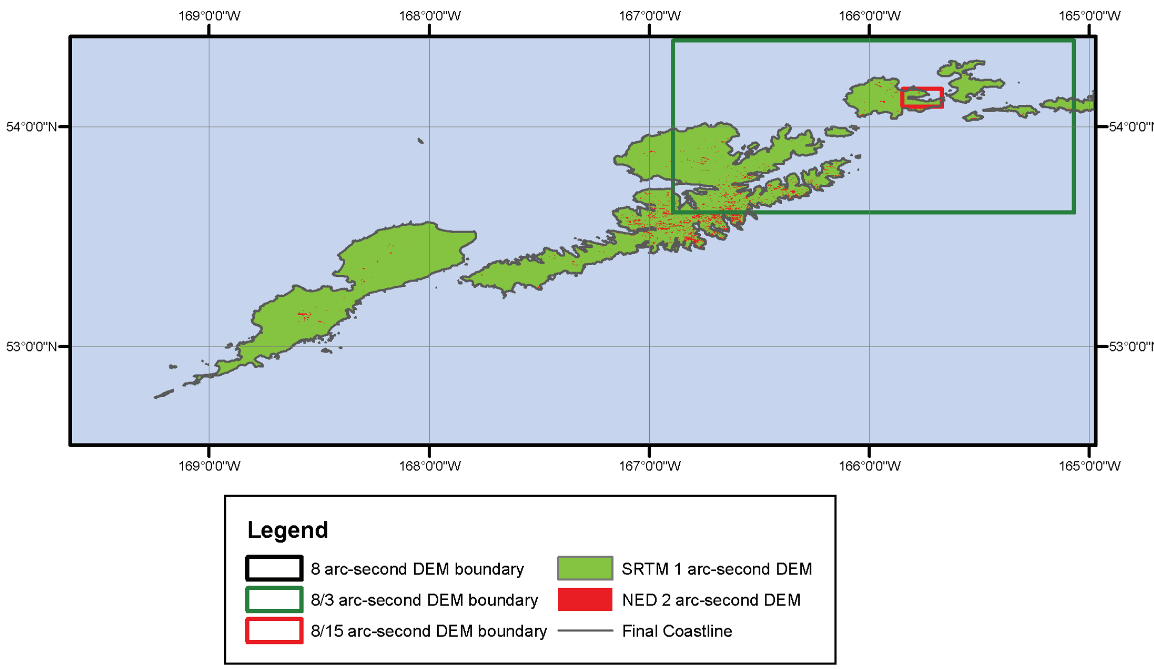

Figure 9. *Principal topographic datasets contribute to the Akutan DEMs.*

1) USGS NED topography

The USGS National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 2 arc-second coverage of Alaska[4]. Data are in NAD 27 Alaska geographic coordinates and National Geodetic Vertical Datum of 1929 (NGVD 29) 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 quadrangle maps and aerial photos based on surveys conducted in the 1970s and 1980s. The NED also contains values over the open ocean which were deleted by clipping to the final coastline.

2) NASA space shuttle radar topography

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale (60° S to 60° N) 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 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 the Akutan region, the data have 1 arc-second spacing and are referenced to the WGS 84/Earth Gravitational Model 1996 (EGM 96) Geoid. The SRTM provides coverage of most of the Akutan region, but exhibits numerous small areas with "no data" values necessitating the use of the lower-resolution NED topographic data in these areas (Fig. 10). The SRTM DEM also contains values over the open ocean which were deleted by clipping to the final coastline.

4. 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 NAVD 88, except for AK, which is NGVD 29. 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]

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]

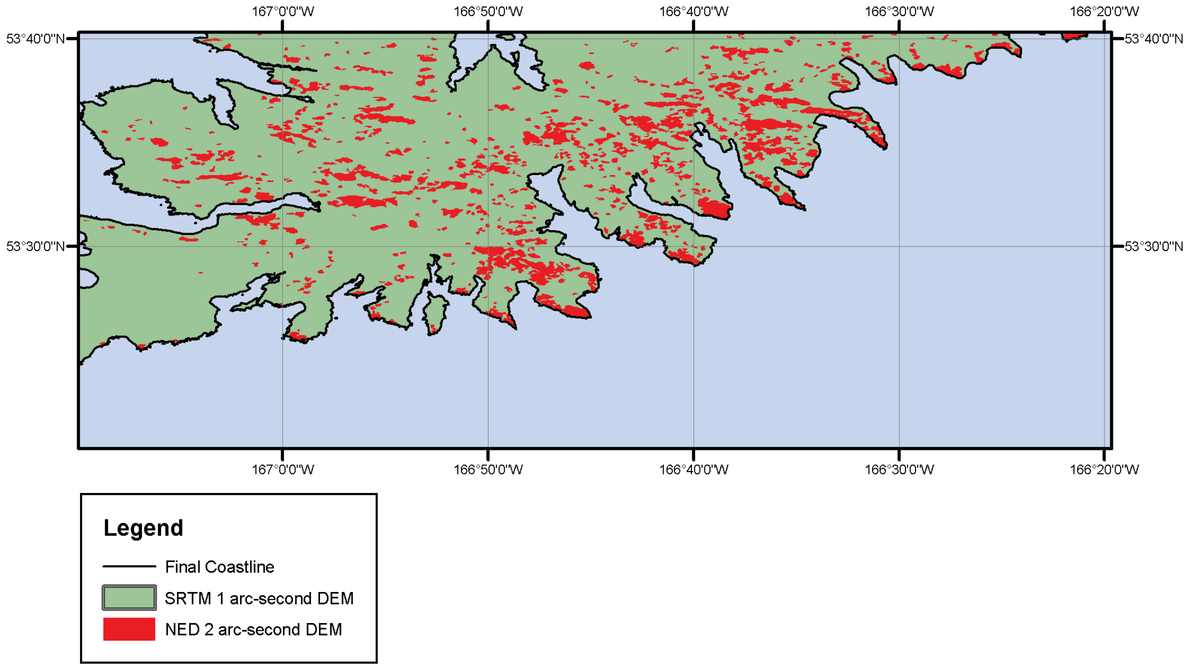

Figure 10. *Example of gaps (red areas) in the SRTM data coverage gaps were filled with topographic data from the NED DEM. Final coastline in black. Blue represents zero values over the open ocean.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Akutan DEMs were originally referenced to a number of vertical datums including: Mean Lower Low Water (MLLW), MSL, WGS 84/EGM 96 Geoid, and North American Vertical Datum of 1929 (NGVD 29). Measurements from NOAA's Unalaska tide station were used for converting datasets within the boundary of the 8 and 8/3 arc-second Akutan DEMs (Table 8;). Datasets within the 8/15 arc-second Akutan DEM boundary were transformed using NOAA's tide predictions (http://co-ops.nos.noaa.gov/tides05/tab2wc2c.html#157). All datasets were transformed to MHHW for modeling of maximum flooding.

1) **Bathymetric data**

   The NOS hydrographic surveys, multibeam swath sonar surveys, trackline surveys, and the nautical chart soundings within the Akutan 8 and 8/3 arc-second DEM boundaries were transformed from either MSL or MLLW to MHHW, using *FME* software, by subtracting a constant offset (0.463 and 1.098 meters, respectively) measured at the Unalaska tide station (Table 8).

   The NOS hydrographic surveys and the nautical chart soundings within the Akutan 8/15 arc-second DEM boundary were transformed from either MSL or MLLW to MHHW, using *FME* software, by subtracting a constant offset (0.426 and 1.188 meters, respectively) based on the NOAA tide prediction at Akutan Harbor (Table 8).

2) **Topographic data**

   The NED and SRTM DEMs were originally referenced to NGVD 29 and WGS 84/EGM 96 Geoid vertical datums, respectively. There are no survey markers in the vicinity of Akutan 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 8). Topographic data that were present within the 8 and 8/3 arc-second Akutan DEM boundaries were converted to MHHW using measurements from the Unalaska tide station. Topographic data present in the 8/15 arc-second Akutan DEM were transformed to MHHW in accordance with the NOAA tide prediction at Akutan Harbor.

Table 8. Relationship between Mean Higher High Water and other vertical datums at the Unalaska tide station and Akutan Harbor.

Name	*Id*	*Longitude*	*Latitude*	*MHHW*	*MHW*	*MSL*	*Mean Low Water (MLW)*	*MLLW*
Unalaska, AK	9462620	-166.54	53.88	1.098	1.011	0.635	0.283	0
Akutan Harbor Tide Prediction	n/a	-165.80	54.13	1.188	n/a	0.762	n/a	0

3.2.2 Horizontal datum transformations

Datasets used to compile the Akutan DEMs were originally referenced to Early Alaska, "undetermined", NAD 27, NAD 83, and WGS 84 geographic horizontal datums. The relationships and transformational equations between the geographic horizontal datums are well established. All of the data were converted to a horizontal datum of NAD 83/WGS 84 geographic using *FME* software. The NOS surveys referenced to Early Alaska and "undetermined" 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* and *Quick Terrain Modeler* 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.
- Sparse bathymetric data in deep water.
- Digital NOS surveys with Early Alaska or "undetermined" horizontal datums.
- Piers and docks in the coastline datasets that had to be removed.
- Only older 1930, bathymetric data in Akutan Harbor.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the Akutan DEMs. In both deep water and near shore, the NOS survey data have point spacing up to 1.5 kilometers apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEMs due to this low resolution dataset, and to provide effective interpolation into the coastal zone, bathymetric 'pre-surfaces' or grids were generated using *GMT*, an NSF-funded free software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The Akutan 8 and 8/3 arc-second, 'pre-surface' grids were compiled from NOS hydrographic point data, ENC soundings, trackline surveys, and NGDC multibeam swath sonar bathymetry data by converting the files to xyz format. These xyz files were combined into a single file, along with points extracted every 10 meters from the final coastline. To provide a slightly negative buffer along the entire coastline, the extracted points were reassigned values of -1 meter to make sure that the offshore elevations remained negative; this was necessary due to the sparseness of the bathymetric data near the coast. These point data were then smoothed using the *GMT* tool 'blockmedian' onto an 8 and 8/3 arc-second grid respectively. The *GMT* tool 'surface' was then applied to interpolate values for cells without data values. The netcdf grids created by 'surface' were converted into ESRI Arc ASCII grid files using the *MB-System* tool 'mbm_grd2arc'. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid with the final coastline (to eliminate data interpolation into land areas).

For the Akutan 8/15 arc-second, 'pre-surface', the data from NOS hydrographic surveys were more limited; and, the north-south linearity of the sounding resulted in lineations in the bathymetric 'pre-surface' grid. To alleviate the impact of the spline tension interpolation in regions of sparse data, the NOS survey point data and available ENC soundings were interpolated using the 'triangulation' tool in *GMT* to create a triangular irregular network (TIN) surface. The resultant TIN grid was used as a 'pre-pre-surface' grid and served as an additional input dataset using the methodology described above for the 8 and 8/3 arc-second Akutan grids.

The pre-surfaces were compared with the original soundings to ensure grid accuracy, converted to a shapefile, and then exported as an xyz file for use in the final gridding process (Table 9). The statistical analysis of the differences between the 8/15 arc-second bathymetric surface at Akutan and NOS survey H05762 showed that the majority of the NOS soundings are in good agreement (Fig. 11) with the bathymetric surface. The few exceptions where the differences reached up to 94.43 meters are attributed to rugged bathymetry where two or more closely positioned points were averaged to obtain the elevation of one grid cell.

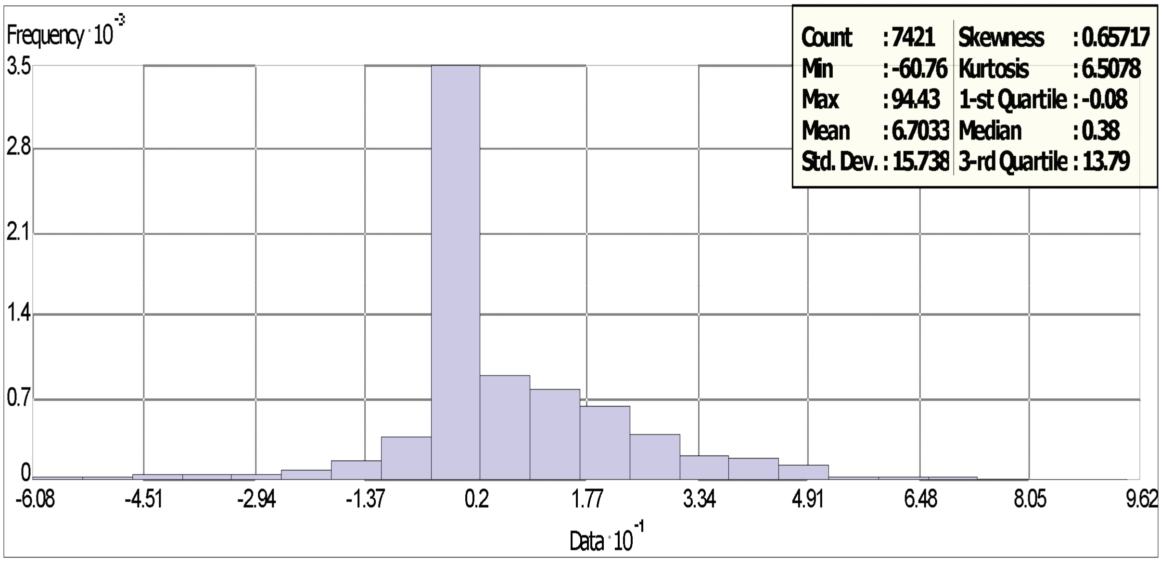

Figure 11. *Histogram of the differences between NOS hydrographic survey H05762 and the 8/15 arc-second pre-surfaced bathymetric grid of Akutan, Harbor. Large differences result from averaging of multiple, closely-spaced NOS soundings within regions of steep bathymetry.*

3.3.3 Building the DEMs with MB System

MB-System was used to create 8, 8/3, and 8/15 arc-second DEMs of Akutan, AK. 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 9. Greatest weight was given to the SRTM topographic DEM, higher resolution DEMs, and multibeam swath sonar. Least weight was given to the pre-surfaced bathymetric grids, coastline, and trackline soundings. As noted in the hierarchy, higher resolution DEMs generated by NGDC (8/15 and 8/3 arc-seconds) served as sources for the coarser 8/3 and 8 arc-second grids, respectively.

Table 9. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
SRTM topographic DEM	100
8/15 and 8/3 DEMs	100
Multibeam swath sonar	100
NOS hydrographic surveys	10
ENC soundings	10
USGS NED topographic DEM	10
Final coastline at 0 meters elevation	1
Pre-surfaced bathymetric grid	1
Trackline soundings	1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Akutan DEMs are dependent upon the DEM cell size and datasets used to determine corresponding DEM cell values. Topographic features have an estimated horizontal accuracy of approximately 50 to 75 meters, based on the documented accuracy of the NED and SRTM DEMs. Bathymetric features in areas covered by early 20th-century NOS hydrographic soundings—along the margins of the DEM—are resolved only to within a few tens of meters in shallow water, and to a few hundred meters in deep-water areas; their positional accuracy is limited by the sparseness of soundings, and potentially large positional accuracy of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the DEMs are also highly dependent upon the source datasets contributing to grid cell values. Topographic datasets have vertical accuracies of between 10 and 15 meters (NED: ~10 meters and SRTM: < 16 meters). Bathymetric values are derived from a wide range of input data, consisting of single and multibeam sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Modern NOS standards are 0.3 m in 0 to 20 m of water, 1.0 m in 20 to 100 m of water, and 1% of the water depth in 100 m of water. 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 map and 3-D perspectives

ESRI *ArcCatalog* was used to generate a slope grid from the 8/3 arc-second Akutan DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 12). The DEM was transformed to NAD 83/UTM Zone 3 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 all the DEMs (Fig. 13 through 15) was accomplished using *POV Ray,* a shareware tool for generating three-dimensional graphics (http://www.povray.org/). Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEMs.

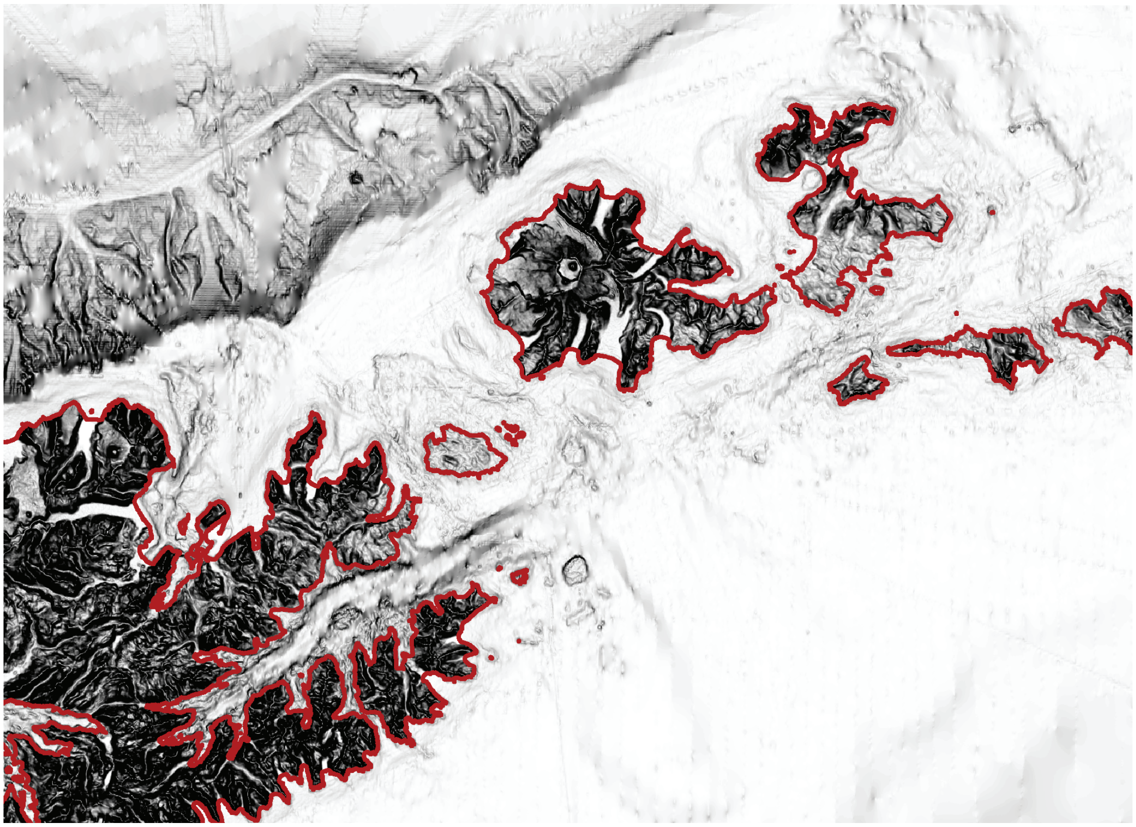

Figure 12. *Slope map of the 8/3 arc-second Akutan DEM. Flat-lying slopes are white; dark shading denotes steep slopes; final coastline in red.*

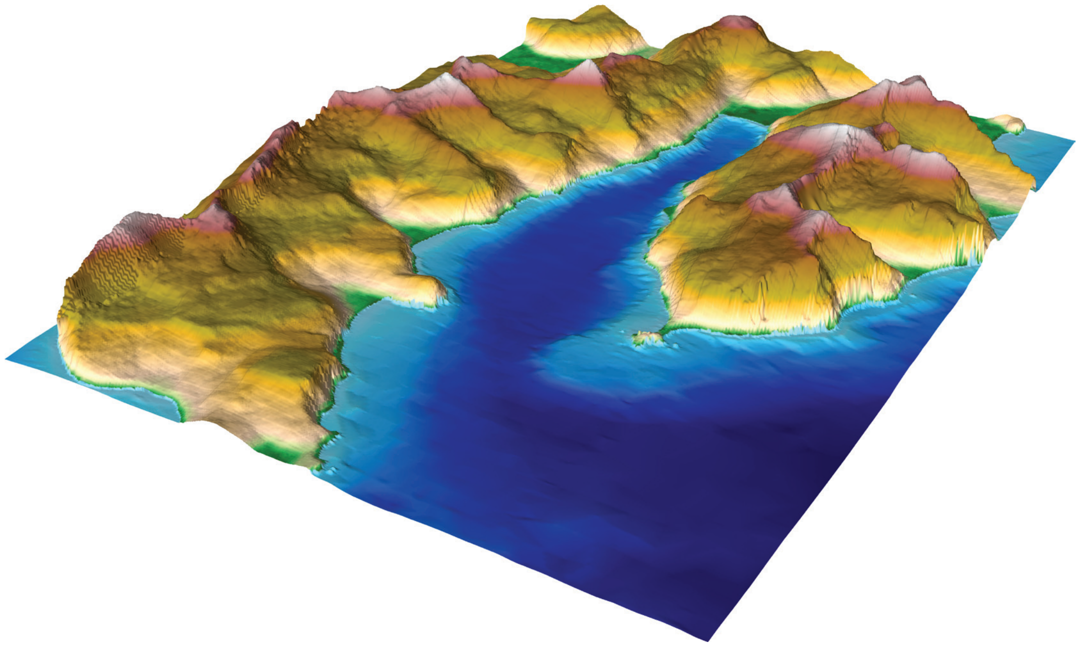

Figure 13. *Perspective view from the northeast of the 8/15 arc-second Akutan DEM.*
Vertical exaggeration–times 2.

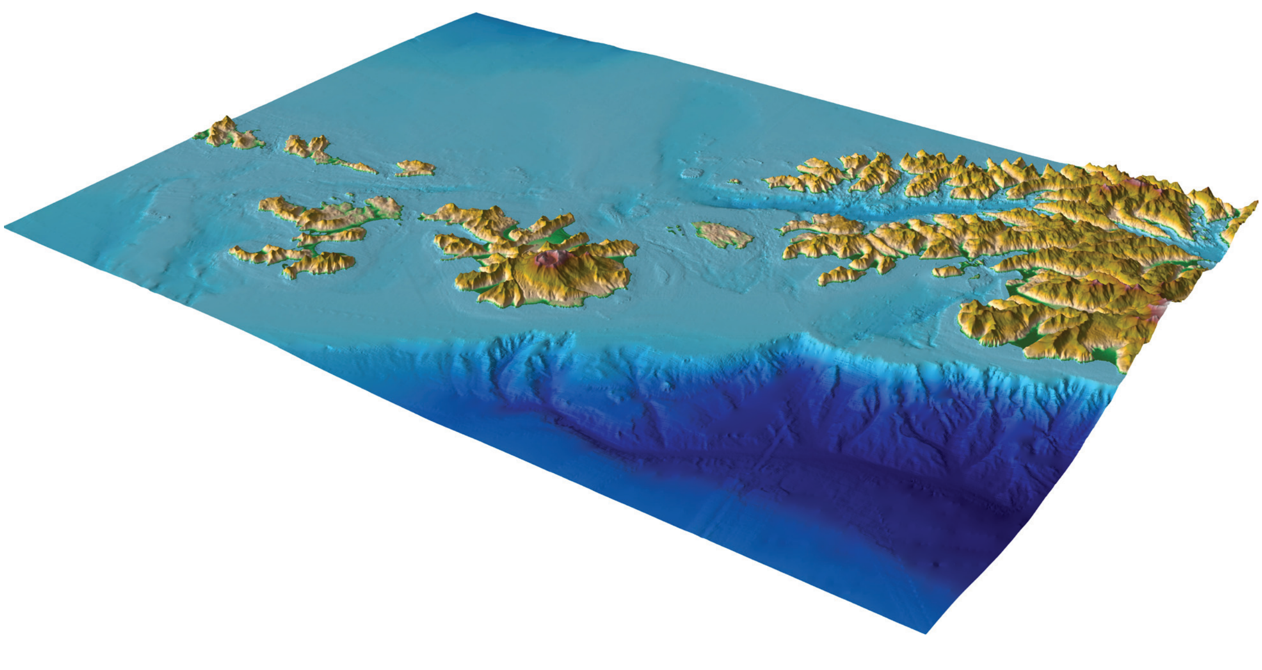

Figure 14. *Perspective view from the northwest of the 8/3 arc-second Akutan DEM.*
Vertical exaggeration–times 2.

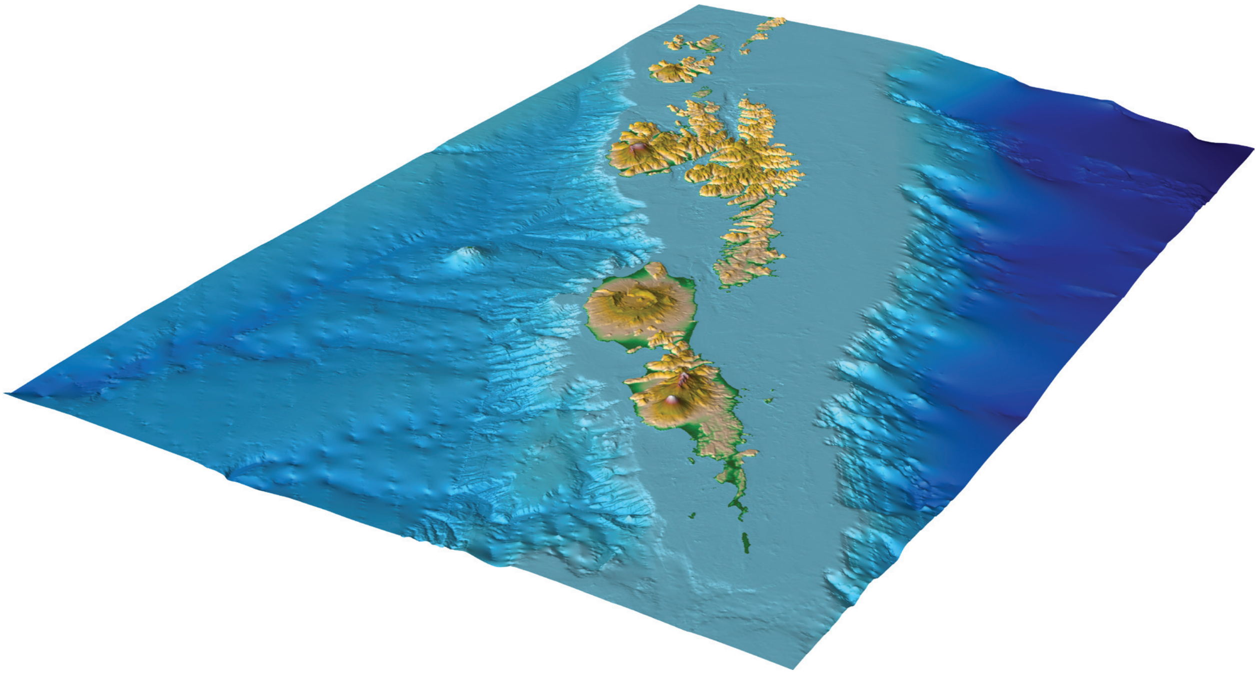

Figure 15. *Perspective view from the southwest of the 8 arc-second Akutan DEM. Vertical exaggeration–times 2.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the 8/15 arc-second Akutan 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 differences between selected SRTM data points and the 8/15 arc-second Akutan DEM is shown in Figure 16.

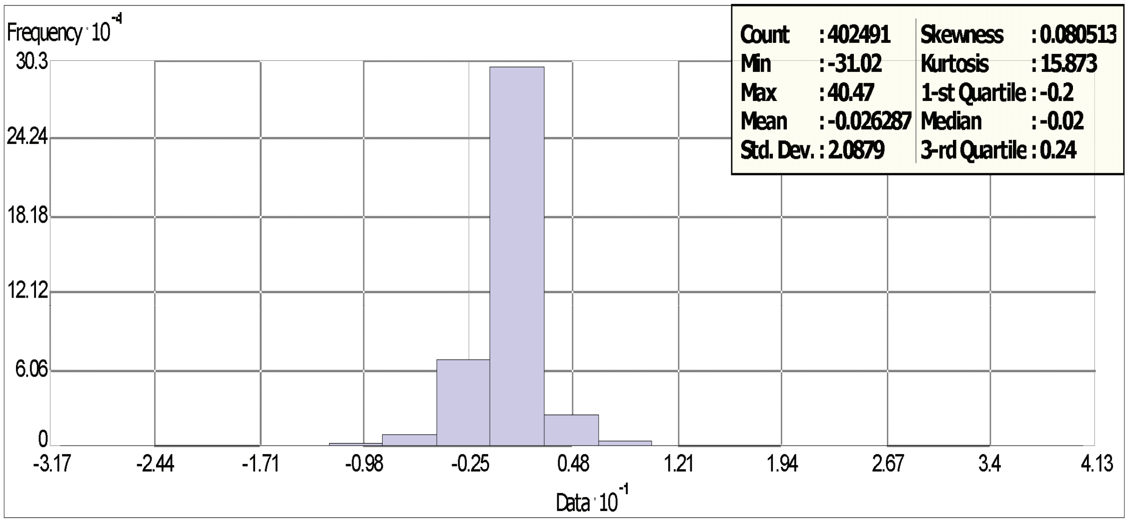

Figure 16. *Histogram of the differences between the SRTM topographic data and the 8/15 arc-second Akutan DEM.*

3.4.5 Comparison with USGS topographic contours

USGS topographic quadrangle, Unimak A-6 was downloaded in the vicinity of Akutan, AK. The Unimak A-6 quadrangle give positions and elevations in NAD 27/UTM Zone 3 and NGVD 29 vertical datum (in feet) and have a scale of 1:63,360 with a 100-foot contour interval.

A contour map with a 100-foot interval was created using the 8/15 arc-second DEM at Akutan Harbor. The contour map was then compared against the USGS topographic quadrangle (Fig. 17). Although the figures show that slight differences exist between the 8/15 arc-second DEM and the USGS topographic map contours, the morphology of the region surrounding Akutan Harbor is preserved.

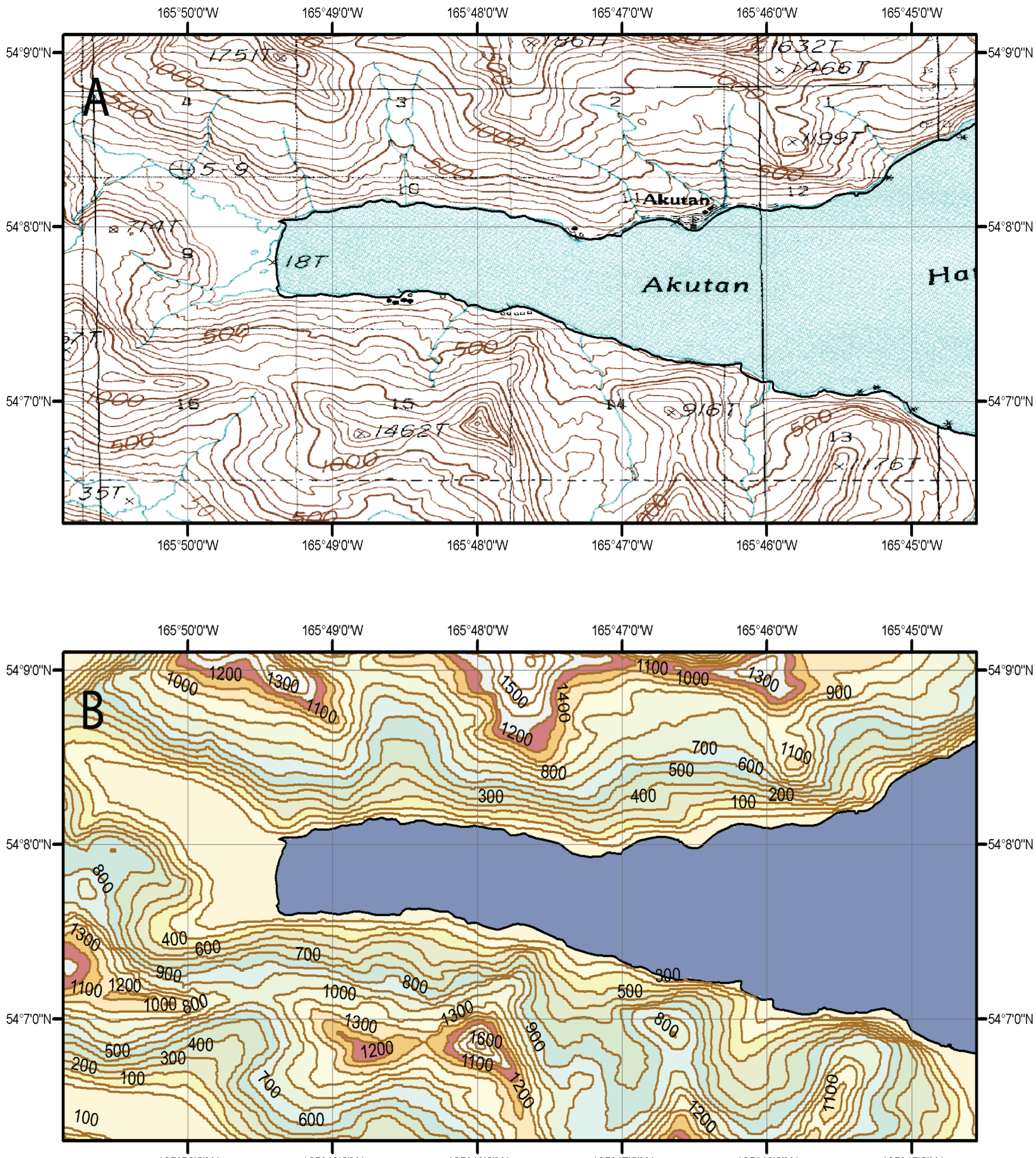

Figure 17. Comparison between USGS topographic contours and topographic contours from the 8/15 arc-second Akutan DEM.
A) Brown lines and numbers represent 100-foot contours from the USGS topographic map.
B) Brown lines and black numbers represent 100-foot contours derived from the 8/15 arc-second Akutan DEM.

4. Summary and Conclusions

Three nested, integrated topographic–bathymetric digital elevation models of the Akutan, Alaska area, with cell sizes of 8 arc-second, 8/3 arc-second, and 8/15 arc-second, were developed for the University of Alaska at Fairbanks' (UAF) Geophysical Institute. The best available digital data from 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 ESRI *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 deep water.
- Conduct surveys in the area of Akutan Harbor.
- Establish, via survey, the relationships between tidal and geodetic datums in Akutan Harbor.
- Determine the relationship between Early Alaska and NAD83/WGS 84 geographic horizontal datums.

5. Acknowledgments

The creation of the DEMs was funded by the University of Alaska at Fairbanks. The authors thank Elena Suleimani, Dave West, and Dmitry Nicolsky (UAF), Bret Christensen (U.S. Fish and Wildlife Service), and Gary Nelson and Brooke McMahon (NOS Pacific Hydrographic Branch). We would also like to extend our appreciation to Volkmar Leimer (BSH) for providing access to the Sonne multibeam dataset. In addition, photographs from several sources were especially helpful in the identification of structures in and surrounding Akutan Harbor.

6. References

Nautical Chart #16500 (RNC), 10th Edition, 2009. Unalaska Island to Amukta Island. 1:300,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16501 (RNC), 7th Edition, 2009. Islands of Four Mountains. 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16511 (RNC), 7th Edition, 2009. Inanudak and Nikolski Bays. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16513 (ENC and RNC), 5th Edition, 2009. Umnak Pass and Approaches. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

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Nautical Chart #16515 (ENC and RNC), 7th Edition, 2009. Unalaska Island Chernofski Harbor to Skan Bay. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16517 (ENC and RNC), 6th Edition, 2009. Lituya Bay. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16518 (ENC and RNC), 6th Edition, 2009. Cape Kovrizhka to Cape Cheerful. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16521 (ENC and RNC), 6th Edition, 2009. Protection Bay to Eagle Bay. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16532 (ENC and RNC), 6th Edition, 2009. Akutan Bay. 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

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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, free software 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, free software 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, free software 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/.

Persistence of Vision Pty. Ltd,. (2004), Persistence of Vision™ Raytracer.
Persistence of Vision Pty. Ltd., Williamstown, Victoria, Australia, http://www.povray.org/.

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/.

Appendix A. NOS Hydrographic Surveys

Table A-1. NOS Hydrographic Surveys used in compiling the Akutan, Alaska DEMs

Name	*Year*	*Scale of Survey*	*Original Horizontal Datum*	*Original Vertical Datum*
H03579	1913	80,000	Undetermined horizontal datum	Mean Lower Low Water
H05672	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05739	1934	80,000	Early Alaska Datums	Mean Lower Low Water
H05740	1934	60,000	Early Alaska Datums	Mean Lower Low Water
H05964	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05965	1935	10,000	Early Alaska Datums	Mean Lower Low Water
H05967	1935	60,000	Early Alaska Datums	Mean Lower Low Water
H05977	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05978	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05979	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05980	1935	55,000	Early Alaska Datums	Mean Lower Low Water
H05981	1935	55,000	Early Alaska Datums	Mean Lower Low Water
H06212	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06256	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06257	1937	40,000	Early Alaska Datums	Mean Lower Low Water
H06277	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H06278	1937	80,000	Early Alaska Datums	Mean Lower Low Water
H06288	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06388	1938	40,000	Early Alaska Datums	Mean Lower Low Water
H06389	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06527	1939	40,000	Early Alaska Datums	Mean Lower Low Water
H03194	1910	n/a	Unalaska Datum	Mean Lower Low Water
H06568	1940	80,000	Undetermined horizontal datum	Mean Lower Low Water
H06569	1940	20,000	Early Alaska Datums	Mean Lower Low Water
H06570	1940	20,000	Early Alaska Datums	Mean Lower Low Water
H06761	1941	20,000	Early Alaska Datums	Mean Lower Low Water
H06464	1939	80,000	Early Alaska Datums	Mean Lower Low Water
H06465	1939	40,000	Early Alaska Datums	Mean Lower Low Water
H06466	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06413	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06478	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06526	1939	200,000	Early Alaska Datums	Mean Lower Low Water
H06573	1940	60,000	Early Alaska Datums	Mean Lower Low Water
H10389	1991	5,000	NAD 83	Mean Lower Low Water
H10391	1991	5,000	NAD 83	Mean Lower Low Water
H05728	1934	40,000	Early Alaska Datums	Mean Lower Low Water
H05737	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05738	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05744	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05745	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05759	1934	80,000	Early Alaska Datums	Mean Lower Low Water
H05760	1934	80,000	Early Alaska Datums	Mean Lower Low Water
H05761	1935	40,000	Early Alaska Datums	Mean Lower Low Water
H05762	1934	20,000	Early Alaska Datums	Mean Lower Low Water

Name	*Year*	*Scale of Survey*	*Original Horizontal Datum*	*Original Vertical Datum*
H05763	1934	20,000	Early Alaska Datums	Mean Lower Low Water
H05948	1935	80,000	Early Alaska Datums	Mean Lower Low Water
H05949	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05966	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05970	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H05971	1935	40,000	Early Alaska Datums	Mean Lower Low Water
H05972	1935	80,000	Early Alaska Datums	Mean Lower Low Water
H05973	1935	40,000	Early Alaska Datums	Mean Lower Low Water
H05974	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H06109	1935	10,000	Early Alaska Datums	Mean Lower Low Water
H06110	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H06111	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H06112	1935	20,000	Early Alaska Datums	Mean Lower Low Water
H06160	1936	80,000	Early Alaska Datums	Mean Lower Low Water
H06175	1936	20,000	Early Alaska Datums	Mean Lower Low Water
H06176	1936	40,000	Early Alaska Datums	Mean Lower Low Water
H06183	1936	10,000	Early Alaska Datums	Mean Lower Low Water
H06229	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06233	1937	40,000	Early Alaska Datums	Mean Lower Low Water
H06234	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06235	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06241	1937	10,000	Early Alaska Datums	Mean Lower Low Water
H06255	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06265	1937	40,000	Early Alaska Datums	Mean Lower Low Water
H06274	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06286	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06303	1937	20,000	Early Alaska Datums	Mean Lower Low Water
H06319	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06377	1938	80,000	Early Alaska Datums	Mean Lower Low Water
H06378	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06379	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06380	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06381	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06382	1938	20,000	Early Alaska Datums	Mean Lower Low Water
H06383	1938	80,000	Early Alaska Datums	Mean Lower Low Water
H06414	1939	10,000	Early Alaska Datums	Mean Lower Low Water
H06503	1940	80,000	Early Alaska Datums	Mean Lower Low Water
H06504	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06505	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06506	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06507	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06508	1939	10,000	Early Alaska Datums	Mean Lower Low Water
H06509	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06510	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06610	1939	20,000	Early Alaska Datums	Mean Lower Low Water
H06611	1940	20,000	Early Alaska Datums	Mean Lower Low Water

Name	*Year*	*Scale of Survey*	*Original Horizontal Datum*	*Original Vertical Datum*
H05684	1934	45,000	Early Alaska Datums	Mean Lower Low Water