NOAA Technical Memorandum NESDIS NGDC-5

DIGITAL ELEVATION MODELS OF SAND POINT, ALASKA: PROCEDURES, DATA SOURCES AND ANALYSIS

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1. Introduction

In September 2006, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed two bathymetric/topographic digital elevation models (DEMs) of Sand Point, Alaska (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The coastal DEMs will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. A 1/3 arc-second[1] DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 2) and will be used for tsunami inundation modeling. A 3 arc-second[1] DEM, which extends farther to the south, includes an additional dataset at lower resolution and is suitable for tsunami propagation modeling. This report provides a summary of the data sources and methodology used in developing the Sand Point DEMs.

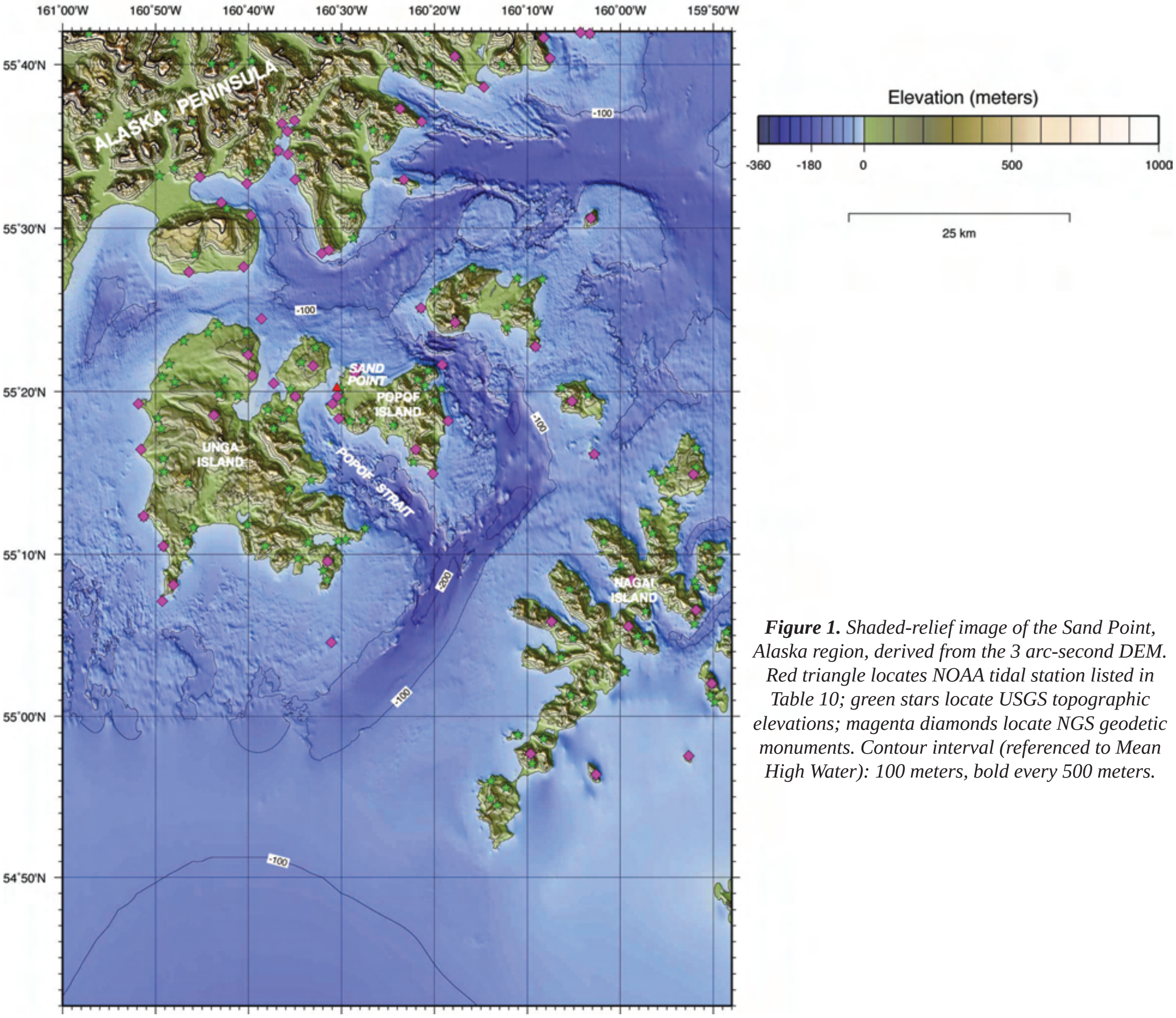

Figure 1. *Shaded-relief image of the Sand Point, Alaska region, derived from the 3 arc-second DEM. Red triangle locates NOAA tidal station listed in Table 10; green stars locate USGS topographic elevations; magenta diamonds locate NGS geodetic monuments. Contour interval (referenced to Mean High Water): 100 meters, bold every 500 meters.*

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[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 Sand Point, Alaska (55°20′ N, 160°30′ W) 1/3 arc-second of latitude is equivalent to 10.31 meters; 1/3 arc-second of longitude equals 5.88 meters. 3 arc-seconds of latitude is equivalent to 92.77 meters, while 3 arc-seconds of longitude equals 52.89 meters.

2. STUDY AREA

Sand Point is located in Humboldt Harbor at the northwestern end of Popof Island and adjacent to Popov Strait, which separates Popof and Unga islands (Fig. 1). Popof and Unga, along with Nagai and other smaller islands, make up the Shumagin Islands, a chain of volcanic islands southeast of the Alaska Peninsula that was once covered by a Pleistocene ice cap. Scouring and grinding of the ice fashioned a rugged landscape. Later weathering smoothed some of the ruggedness, especially on Popof Island, but the convoluted coastline remains today.

The Shumagin Islands are sited on the continental shelf 350 km southwest of Kodiak Island, along the chain of active and inactive volcanoes that make the Aleutian Islands. The Shumagins lie 40 to 120 km from the active Aleutian volcanic arc, toward the Aleutian trench, and are situated in what is called the “Shumagin Gap”, a region along the subduction zone that has not experienced a large seismic event in historical times.

The city of Sand Point was founded in 1898 by a San Francisco fishing company as a trading post and cod fishing station. Sand Point served as a repair and supply center for gold mining during the early 1900s, but fish processing became the dominant activity in the 1930s. Today, it is home to the largest fishing fleet in the Aleutian Chain.

3. METHODOLOGY

The Sand Point DEMs were developed to meet PMEL specifications (Table 1), based on input requirements for the MOST inundation model. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS84) and Mean High Water (MHW), for modeling of “worst-case scenario” flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections. Note that the 3 arc-second DEM fully encompasses the area of the 1/3 arc-second DEM but extends farther south for tsunami propagation modeling purposes.

Table 1a: PMEL specifications for the 1/3 arc-second Sand Point, Alaska DEM.

Grid Area	Sand Point, Alaska
Coverage Area	161.0 º to 159.8º W; 55.05º to 55.7º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI ASCII raster grid

Table 1b: PMEL specifications for the 3 arc-second Sand Point, Alaska DEM.

Grid Area	Sand Point, Alaska
Coverage Area	161.0 º to 159.8º W; 54.7º to 55.7º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	3 arc-seconds
Grid Format	ESRI ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, topographic and combined topographic/bathymetric digital datasets (Fig. 2) were obtained from several U.S. federal agencies, including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS), National Geodetic Survey (NGS), and NGDC; the U.S. Fish and Wildlife Service (FWS); and the U.S. Geological Survey (USGS). Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets; NGDC's GEODAS software (http://www.ngdc.noaa.gov/mgg/geodas/) was used to manually edit large xyz datasets. Vertical datum transformations to MHW were also accomplished using FME, based upon data from the NOAA Sand Point tidal station, as no VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was available for this area.

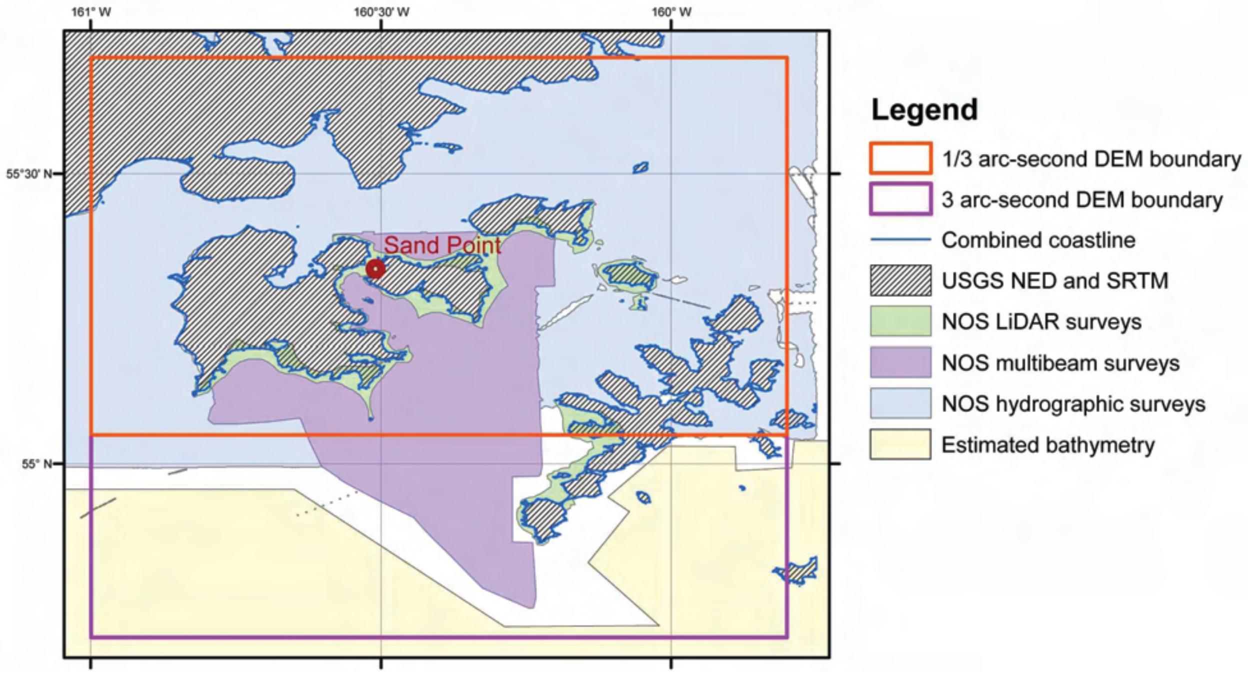

Figure 2. *Source and coverage of datasets used to compile the Sand Point, Alaska DEMs. White areas denote data gaps.*

3.1.1 Shoreline

Three digital coastline datasets of the Sand Point region were analyzed for inclusion in the Sand Point DEMs: Office of Coast Survey electronic navigational charts, National Geodetic Survey vector shoreline of the Shumagin Islands, and U.S. Fish and Wildlife Service statewide Alaska digital coastline (Table 2).

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

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS Electronic Navigational Chart #16553	1989	inferred MHW coastline	Digitized from 1:40,000 scale chart	WGS84 geographic	Inferred MHW	http://chartmaker.ncd.noaa.gov/
NGS vector shoreline	2003	MHW coastline	Digitized from island imagery and ENC #16553	NAD83 geographic	MHW	http://chartmaker.ncd.noaa.gov/
U.S. FWS	2006	compiled coastline	Various	WGS84 geographic	undefined	

1) **OCS electronic navigational charts**

One electronic navigational chart (ENC) was available for the Sand Point region (#16553; Table 3), which was downloaded from NOAA's Office of Coast Survey (OCS) website (http://chartmaker.ncd.noaa.gov/); the ENCs are digital versions of NOAA's published nautical charts. The NOAA Coastal Services Center's 'Electronic Navigational Chart Data Handler for ArcView' extension (http://www.csc.noaa.gov/products/enc/) was used to import the data into ArcGIS. The chart data include coastline data files (inferred MHW), which were compared with the other coastline datasets, high-resolution NOS coastal LiDAR data, topographic data, and NOS hydrographic soundings. They also include soundings (extracted from NOS hydrographic surveys) and land elevations.

The ENC coastline for Chart #16553 generally corresponds well with the high-resolution NOS coastal LiDAR data (near-shore soundings and topography): the exception being occasional piers and docks that had to be deleted manually (Fig. 3 Panel A). It does not, however, provide complete coverage of the Sand Point region and was therefore used in conjunction with other datasets to build a 'combined coastline' (Fig. 4). It also does not capture all of the small, rocky islands that dot the near-shore environment, though many of these are resolved in the NOS coastal LiDAR data.

The other NOAA nautical charts in the Sand Point area (Table 3) do not exist in digital form, but were nevertheless useful in evaluating the accuracy and completeness of the coastline datasets.

Table 3. NOAA nautical charts in the Sand Point, Alaska region.

Chart #	*Descriptive Name*	*ENC?*	*Pub. date*	*Scale*
16540	Shumagin Is. To Sanak Is.	no	03-1989	1:300,000
16551	Unga Is. To Pavlof Is.	no	12-1990	1:80,000
16553	Shumagin Is.—Nagai Is. To Unga Is.	yes	09-1989	1:80,000
16556	Chaichi Is. To Nagai Is.	no	05-1996	1:80,000
16363	Port Moller & Herendeen Bay	no	07-2002	1:80,000

2) **NGS vector shoreline**

NOAA's National Geodetic Survey (NGS) has developed a high-resolution vector shoreline for the Shumagin Islands. The shoreline, complied from island imagery, was originally intended to support NOAA nautical chart production. It has since been cleaned and reformatted for GIS applications. Digital coastline data are in decimal degrees, NAD83 horizontal datum and are horizontally accurate to 12 meters at 95% confidence level. Vertical datum is Mean High Water.

This shoreline dataset is in many places identical to the ENC coastline and is generally consistent with the NOS coastal LiDAR data, topographic data, and NOS hydrographic soundings. It was also used in developing the combined coastline (Fig. 4), though it also contained manmade features (e.g., piers) and rivers that had to be deleted before gridding (e.g., Fig. 3 Panel B). The NGS coastline also contained the outlines of large coastal water bodies (e.g., sea-level lagoons separated from the ocean by coastal berms), which were included in the combined coastline (see Fig. 4).

3) 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. Though efforts were made to obtain the highest resolution coastlines available, their vertical datums were apparently not determined nor controlled in any way in compiling the FWS coastline; horizontal datum of the compiled FWS coastline is WGS84. This coastline is less consistent with the NOS coastal LiDAR data, topographic data, NOS hydrographic soundings, and the ENC and NGS coastlines (e.g., Fig 3 Panel C), but was nevertheless used in developing the combined coastline (Fig. 4). This dataset was graciously provided to NGDC by Bret Christensen, U.S. Fish and Wildlife Service.

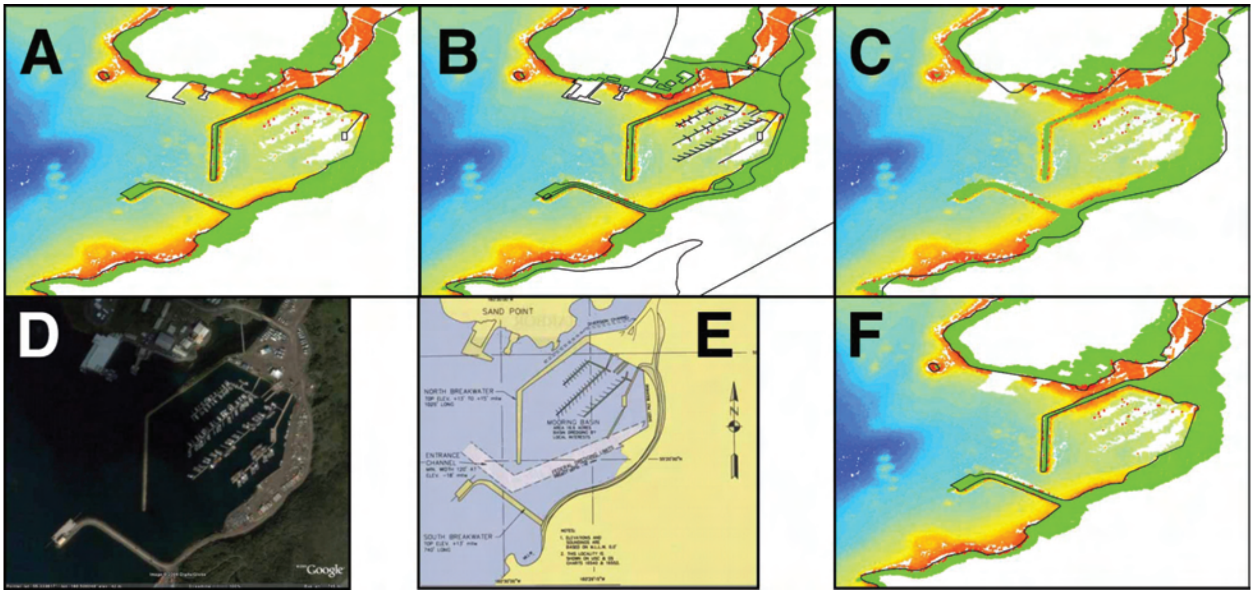

Figure 3. *Humboldt Harbor manmade features present in coastline datasets. A) ENC coastline (Chart #16553) with piers and docks included. B) NGS coastline, also with piers and docks. C) lower-resolution FWS coastline. D) Google Earth satellite image. E) harbor diagram. F) combined coastline, from ENC with pier structures removed, though the two breakwaters (solid constructs) have been retained. Panels A through C and F depict coastline shown against NOS high-resolution coastal LiDAR survey H11147a; green represents values above the MHW line. Note red points in Humboldt Harbor LiDAR data, where piers are identified on Panel E, that had to deleted.*

To obtain the best digital MHW coastline, NGDC combined the ENC, NGS and FWS coastlines. Where overlap occurred, the FWS coastline was excised, as the ENC and NGS coastlines were determined to more reliably define the MHW line and were more consistent with the high-resolution NOS coastal LiDAR data. This 'combined coastline' (Fig. 4) was manually adjusted in many places, using ArcGIS, to match the high-resolution coastal LiDAR data (Fig. 5). The combined coastline was subsampled to 10-meter spacing and converted to point data for use in the gridding process. It was also used as a coastal buffer for the NOS pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached "zero" at the coast. The combined coastline was also used to clip the topographic DEMs, which contained elevation values, typically zero, over the open ocean (Section 3.1.3).

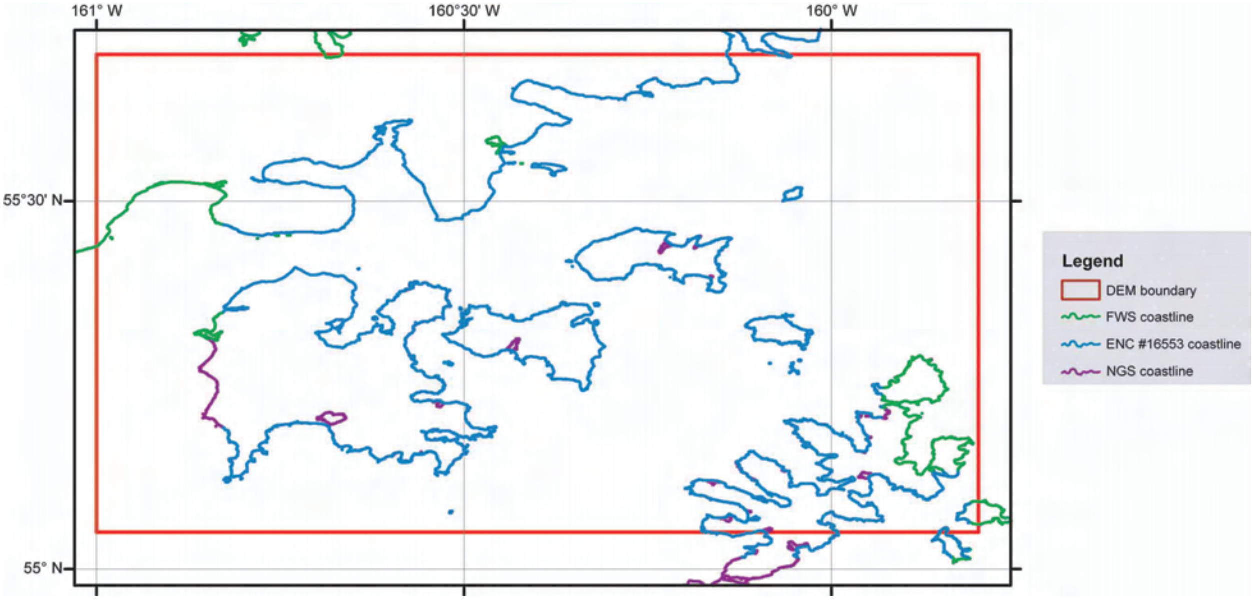

Figure 4. *Digital coastline segments combined for use in the Sand Point DEMs. Most segments are derived from digitized versions of NOAA nautical chart #16553.*

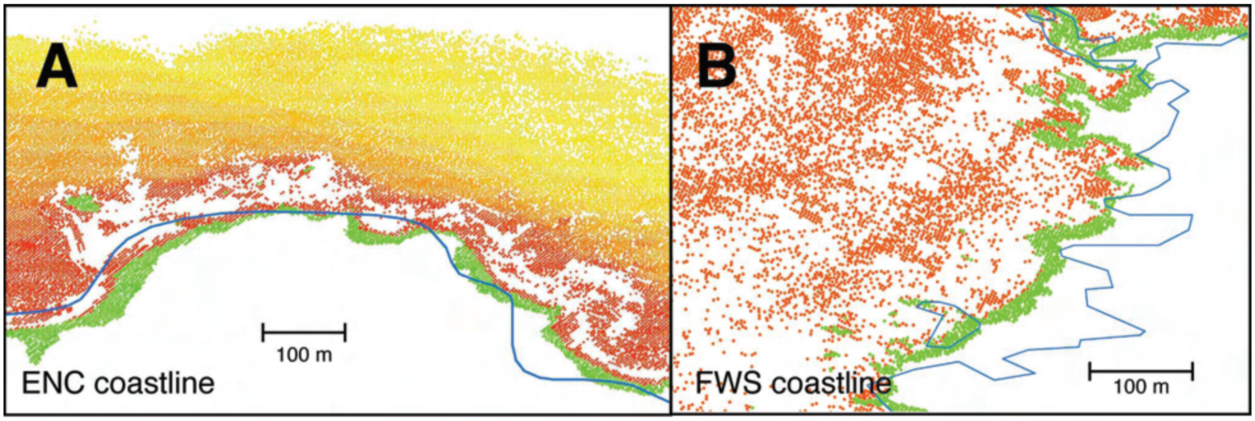

Figure 5. *Examples of misfit between coastline datasets and high-resolution NOS coastal LiDAR surveys. A) misfit between ENC chart #16553 coastline and NOS LiDAR survey H11147a along north side of Unga Island. B) misfit between FWS coastline and NOS LiDAR survey H11147n along southwest side of Nagai Island. The combined coastline (not shown) was manually adjusted in ArcGIS to coincide with the zero level in the high-resolution LiDAR data: green is above MHW, red and yellows below.*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Sand Point DEMs include 30 NOS hydrographic surveys, and 12 recent NOS multibeam swath sonar surveys (Table 4).

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

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1913 to 1955	Hydrographic survey soundings	Ranges from 10 meters to 1.5 kilometers (varies with scale of survey, depth, traffic and probability of obstructions)	NAD27, NAD83, Unalaska	MLLW (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOS	2004	Multibeam swath sonar	5 meters	NAD83 geographic	MLLW (meters)	

1) **NOS hydrographic survey data**

A total of 30 NOS hydrographic surveys conducted between 1913 and 1955 were utilized in the Sand Point DEM development (Fig. 6; Table 5); one very sparse survey from 1910 was excluded (H03194), as were several that have been superceded by the recent, high-resolution NOS multibeam surveys. The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to either "Early Alaska," Unalaska, NAD27, or NAD83 datums. Many smooth sheets contain registration marks for both Unalaska and NAD27 datums, which necessitated careful assessment of the corresponding digital data to verify their datum.

Data point spacing for the surveys ranged from about 10 to 60 meters in shallow water 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 (Table 5). The data were then converted to WGS84 using FME software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com); the four NOS surveys that were digitized in Unalaska or "almost Unalaska" datum (see Table 4) were manually shifted in ArcGIS to fit the combined coastline. The surveys were subsequently clipped to a polygon 0.05 degrees (~5%) larger than the 3 arc-second gridding area to support data interpolation along grid edges.

After converting all NOS survey data to MHW (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 NOS multibeam and coastal LiDAR data, NED and SRTM topographic data, the combined coastline, and *Google Earth* satellite imagery.

Table 5. Digital NOS hydrographic surveys used in compiling the Sand Point, Alaska DEMs.

Survey ID	*Year*	*Survey Scale*	*Original Horizontal Datums*	*Digitized Horizontal Datum*	*Original Vertical Datum*
H03574*	1913	20,000	almost Unalaska	almost Unalaska	MLLW
H03578	1913	10,000	Early Alaska Datum	NAD 1927	MLLW
H03654	1913	100,000	Early Alaska Datum	NAD 1927	MLLW
H03706	1914	20,000	Early Alaska Datum	NAD 1927	MLLW
H03713	1914	20,000	Early Alaska Datum	NAD 1927	MLLW
H03714	1914	20,000	Early Alaska Datum	NAD 1927	MLLW
H03715	1914	10,000	Early Alaska Datum	NAD 1927	MLLW
H03722	1914	100,000	Unalaska	NAD 1927	MLLW
H03796	1915	100,000	Unalaska	NAD 1927	MLLW
H03806	1915	20,000	Early Alaska Datum	NAD 1927	MLLW
H03807*	1915	20,000	Early Alaska Datum	Unalaska	MLLW
H03808*	1915	5,000	Early Alaska Datum	Unalaska	MLLW
H03809*	1915	20,000	Approximate Unalaska	Unalaska	MLLW
H06774	1942	60,000	NAD 1927	NAD 1927	MLLW
H06927	1943	40,000	Unalaska	NAD 1927	MLLW
H07169	1946	80,000	NAD 1927	NAD 1927	MLLW
H07926	1952	20,000	NAD 1927	NAD 1927	MLLW
H07996	1953	20,000	Unalaska	NAD 1927	MLLW
H07998	1953	20,000	Unalaska	NAD 1927	MLLW

H07999	1952	40,000	Unalaska	NAD 1927	MLLW
H08000	1953	40,000	Unalaska	NAD 1927	MLLW
H08045	1953	20,000	NAD 1927	NAD 1927	MLLW
H08046	1953	20,000	NAD 1927	NAD 1927	MLLW
H08047	1953	20,000	NAD 1927	NAD 1927	MLLW
H08048	1953	20,000	NAD 1927	NAD 1927	MLLW
H08049	1953	20,000	NAD 1927	NAD83	MLLW
H08156	1954	20,000	NAD 1927	NAD83	MLLW
H08157	1954	25,000	NAD 1927	NAD83	MLLW
H08158	1954	25,000	NAD 1927	NAD83	MLLW
H08228	1955	20,000	NAD 1927	NAD 1927	MLLW

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

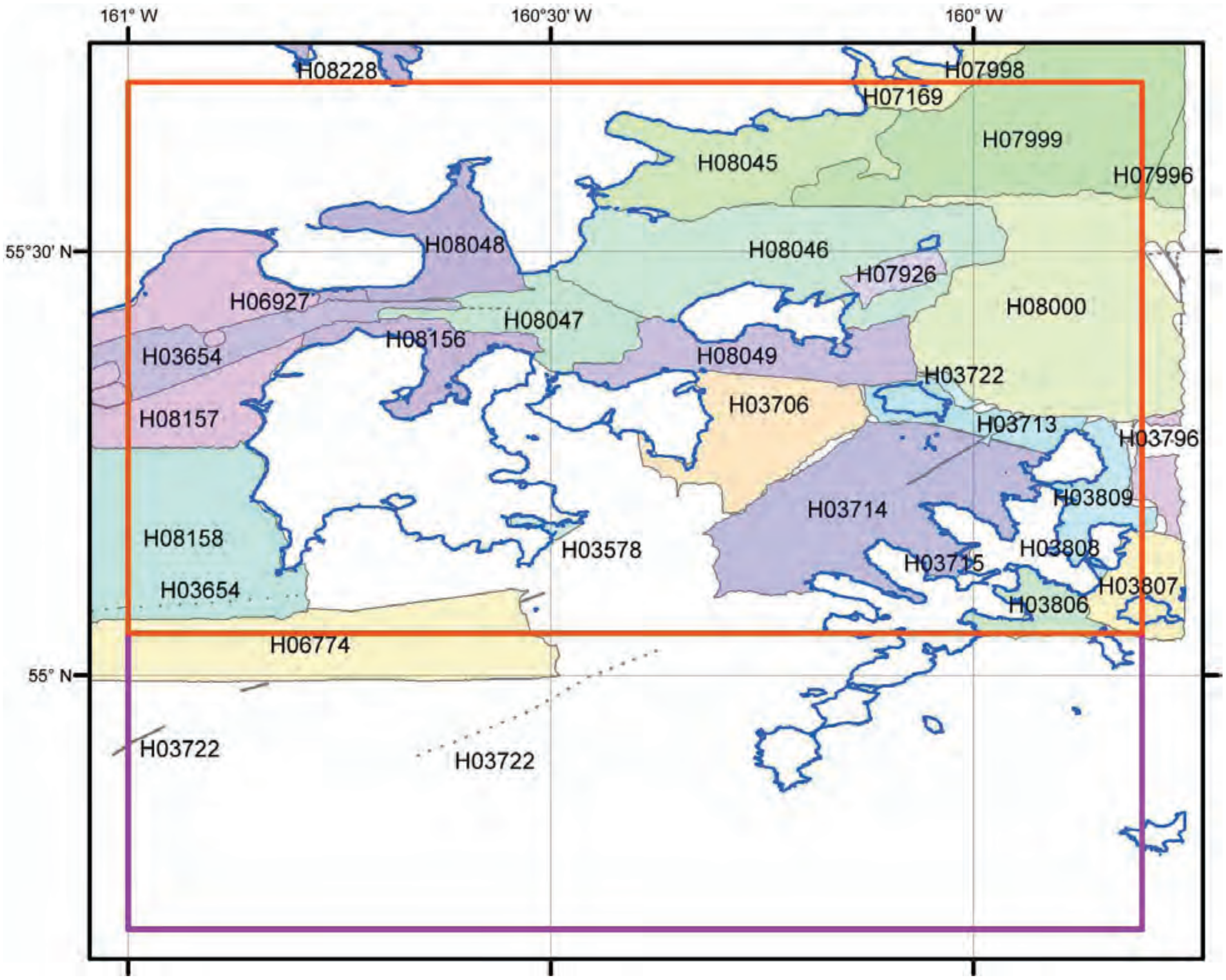

Figure 6. *Digital NOS hydrographic survey coverage in the Sand Point region. Red denotes boundary of 1/3 arc-second DEM; magenta denotes 3 arc-second DEM boundary; combined coastline in blue.*

2) NOS multibeam swath sonar surveys

NOS conducted or contracted 12 high-resolution multibeam swath sonar surveys in the vicinity of Sand Point in 2004 (Fig. 7). The survey data were supplied to NGDC by Gary Nelson at the NOS Pacific Hydrographic Branch of the Hydrographic Services Division. These data (~5-meter point spacing; e.g., Fig. 8) have not been fully evaluated by NOS and are therefore not yet available to the public. All multibeam data were originally in NAD83 geographic coordinates and MLLW vertical datum. NGDC carefully evaluated and, where necessary, edited the multibeam survey data prior to gridding.

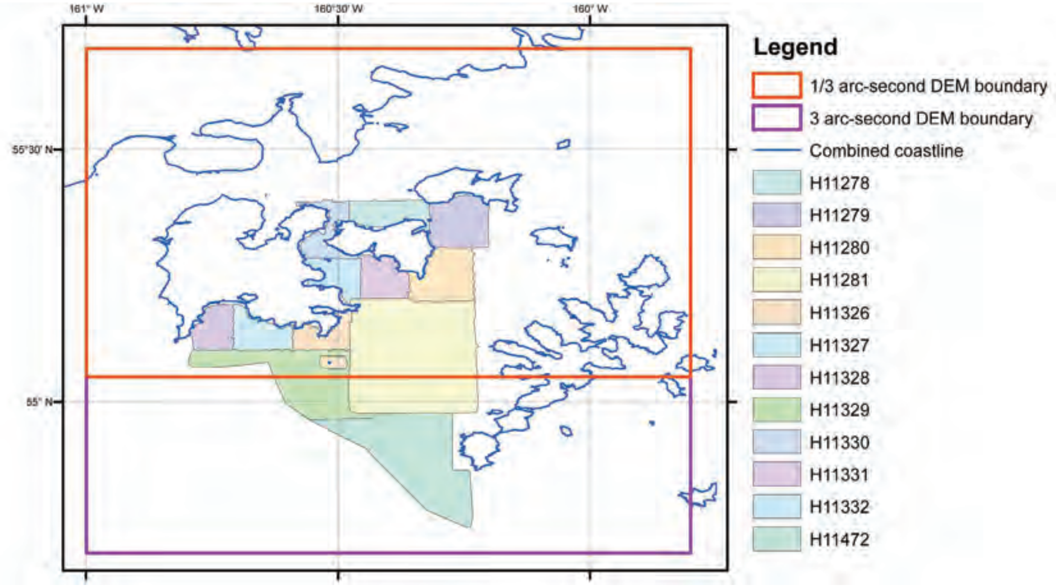

Figure 7. Spatial coverage of NOS high-resolution (5-meter point spacing) multibeam swath sonar surveys in the vicinity of Sand Point that were utilized in DEM development.

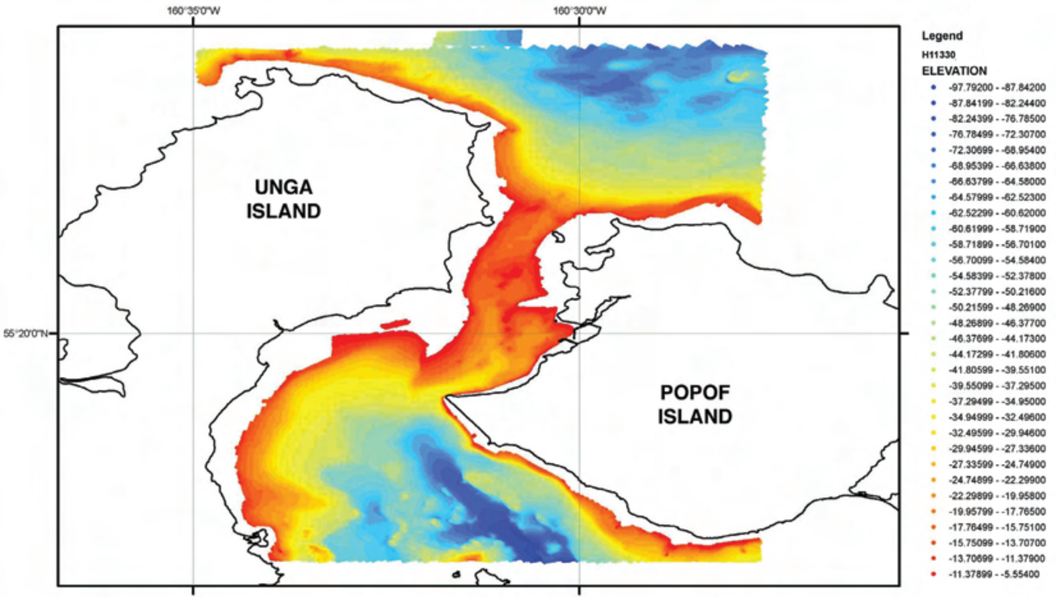

Figure 8. NOS multibeam swath sonar survey H11330 of the approaches to Humboldt Harbor and Sand Point. Data extends from 5 meters (red) to 98 meters water depth (blue). Combined coastline in black.

3.1.3 Topography

Topographic datasets were obtained from the U.S. Geological Survey: National Elevation Dataset 2 arc-second gridded topography, and 1 arc-second NASA space shuttle radar topography (Table 6).

Table 6. Topographic datasets used in compiling the Sand Point, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS NED	2006	Topographic DEM	2 arc-second grid	NAD27 geographic	NGVD29 (meters)	http://ned.usgs.gov/
NASA SRTM	2000	Topographic DEM	1 arc-second grid	WGS84 geographic	WGS84/EGM96 Geoid (meters)	http://srtm.usgs.gov/

1) **USGS NED topography**

The U.S. Geological Survey's (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 2 arc-second coverage of Alaska[2]. Data are in NAD27 Alaska geographic coordinates and NGVD29 vertical datum (meters), and are available for download as raster DEMs. The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quad maps and aerial photos based on surveys conducted in the 1970s and 1980s.

The NED data included "zero" elevation values over the open ocean (Fig. 9), which were removed from the dataset before gridding. Some anomalous values still remained over the open ocean, which were visually inspected and compared with NOAA nautical charts, the combined coastline, and *Google Earth* satellite imagery. These points were removed in ESRI ArcCatalog by clipping to the combined coastline.

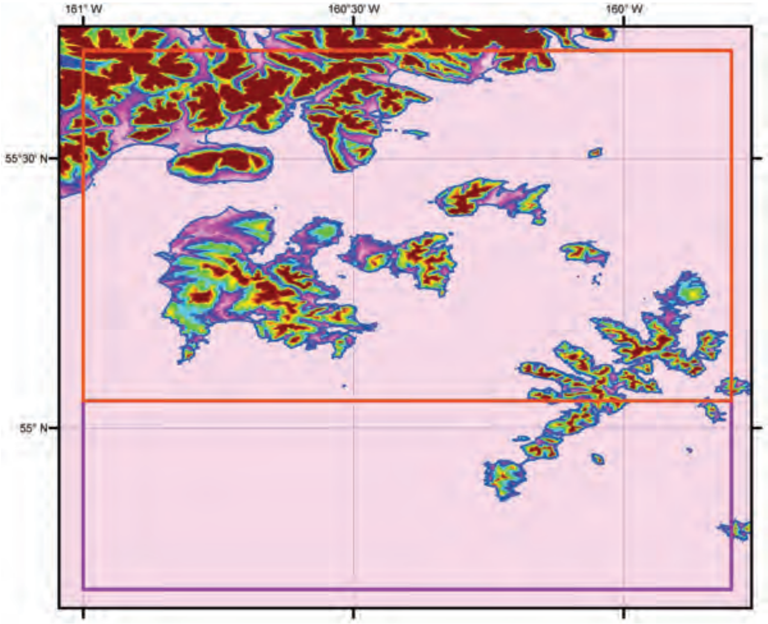

Figure 9. *Color image of the NED DEM extracted from the USGS web site. Note data values over the open ocean (light pink) that had to be excised prior to gridding. Red denotes boundary of 1/3 arc-second DEM; magenta denotes 3 arc-second DEM boundary; combined coastline in blue.*

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[2] 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 NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

2) NASA space shuttle radar topography

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[3]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Data from this mission have been processed into 1 degree × 1 degree tiles that have been edited to define the coastline, and are available from the USGS Seamless web site (http://seamless.usgs.gov/) as raster DEMs. The data have not been processed to bare earth, but meet the absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

For U.S. regions, the data have a 1 arc-second spacing and are referenced to the WGS84/EGM96 Geoid. While providing mostly complete coverage of the Aleutian Islands in the vicinity of Sand Point, there are numerous small areas with "no data" values (e.g., Fig. 10), necessitating use of the lower-resolution NED topographic data (see Section 3.3.3, Table 11). The SRTM DEM also contains "zero" values over the open ocean, which were deleted by clipping to the combined coastline.

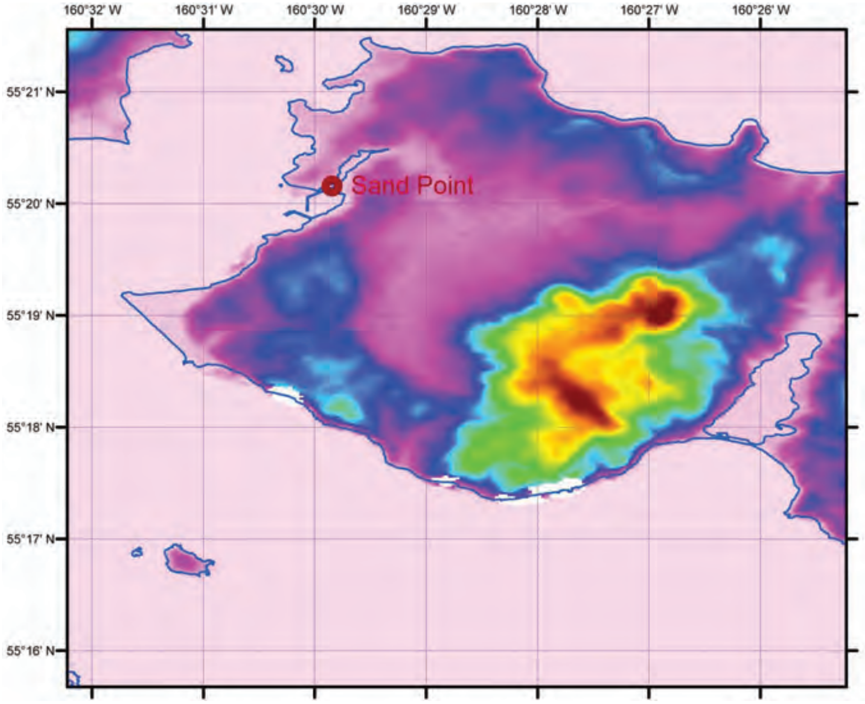

Figure 10. *Example of gaps in SRTM data coverage. Numerous gaps (white areas) exist over land areas in the SRTM DEM, which also includes "zero" values (light pink) over water that had to be excised. Gaps were filled with topographic data from the NED DEM. Combined coastline in blue.*

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[3] 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]

3.1.4 Topography/Bathymetry

Combined topographic/bathymetric datasets were obtained from two sources: NOS high-resolution coastal LiDAR surveys in the vicinity of Sand Point, and estimated global bathymetry (Table 7).

Table 7. Combined topographic/bathymetric datasets used in compiling the Sand Point, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	2003 to 2005	Coastal topography and bathymetry	~4-meter point data	NAD83 geographic	MLLW (meters)	
SIO	2000	Estimated global bathymetry and topography	1-minute grid	WGS84	undefined	http://topex.ucsd.edu/marine_topo/

1) **NOS coastal LiDAR data**

NOAA’s National Ocean Service (NOS) conducted high-resolution LiDAR surveys of part of the coastal flanks of Unga, Popof and Nagai Islands in 2003 and 2005 (Fig. 11)[4]. Data straddled the coastline, ranging from ~20 meter land elevations to ~40 meter water depths, and were instrumental in building an accurate combined coastline for the Sand Point region. Data were in NAD83 geographic and MLLW datum. Survey H11147 had been divided into smaller, more manageable pieces by NOS (see Fig. 11). The survey data were supplied to NGDC by Gary Nelson at the NOS Pacific Hydrographic Branch of the Hydrographic Services Division. These data (~4-meter point spacing; e.g., Fig. 12) have not been fully evaluated by NOS and are therefore not yet available to the public.

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4. LIDAR data collection was conducted using the LADS Mk II Airborne System, data processing using the LADS Mk II Ground System and data visualization, quality control and final products using Caris HIPS 5.3, GMT/VTK, Terramodel and MicroStation version 8. A prototype Digital Imagery capture system was installed at the commencement of this survey, which allowed digital images from the downward looking video to be captured. The LADS Mk II Airborne System (AS) consists of a Dash 8-200 series aircraft which has a transit speed of 250 knots at altitudes of up to 25,000 feet and an endurance of up to eight hours. Survey operations are conducted from heights between 1,200 and 2,200 feet at ground speeds between 140 and 175 knots. The aircraft is fitted with a Nd: YAG laser which is eye safe in accordance with ANSI Z136.1-2000, American National Standard for Safe Use of Lasers. The laser operates at 900 Hertz from a stabilized platform to provide 5x5 or 4x4 meter laser spot spacing in the main line sounding mode of operation. These two modes of data capture resolution require an over ground aircraft speed of 175 and 140 knots respectively. The electro-mechanical scanner also provides examination modes of sounding with laser spot spacings of 3x3 and 2x2 meters and swath widths of 100 and 50 meters respectively. Green laser pulses are scanned beneath the aircraft in a rectilinear pattern. The pulses are reflected from the land, sea surface, within the water column and from the seabed. The green returned laser energy is captured by the green receiver and then digitized and logged onto digital linear tape. An infra-red beam is also directed vertically beneath the aircraft. The height of the aircraft is determined by the infra-red laser return, which is supplemented by the inertial height from the Attitude and Heading Reference System and Global Positioning System (GPS) height. The LADS Mk II system can operate by day and night. The depth penetration of the system may be improved at night by removing the daylight filter from the receiving optics. Survey operations may be restricted at night by elevations in or near the survey area, which may invoke civil aviation lowest safe altitude rules. Real-time positioning is obtained by either an Ashtech GG24 GPS receiver providing autonomous GPS. Ashtech Z12 GPS receivers are also provided as part of the Airborne System and Ground Systems to log KGPS data on the aircraft and at a locally established GPS base station. The LADS Mk II Ground System (GS) ‘Forrest’ was used to conduct data processing in the field. Forrest consists of a portable Compaq Alpha ES40 Series 3 processor server with 1 GB EEC RAM, 764 GB disk space, digital linear tape (DLT) drives and magazines, digital audio tape (DAT) drive, CD ROM drive and is networked to up to 12 Compaq 1.5 GHz PCs and a HP 800ps Design Jet Plotter, printers and QC workstations. [Extracted from descriptive report accompanying the data.]

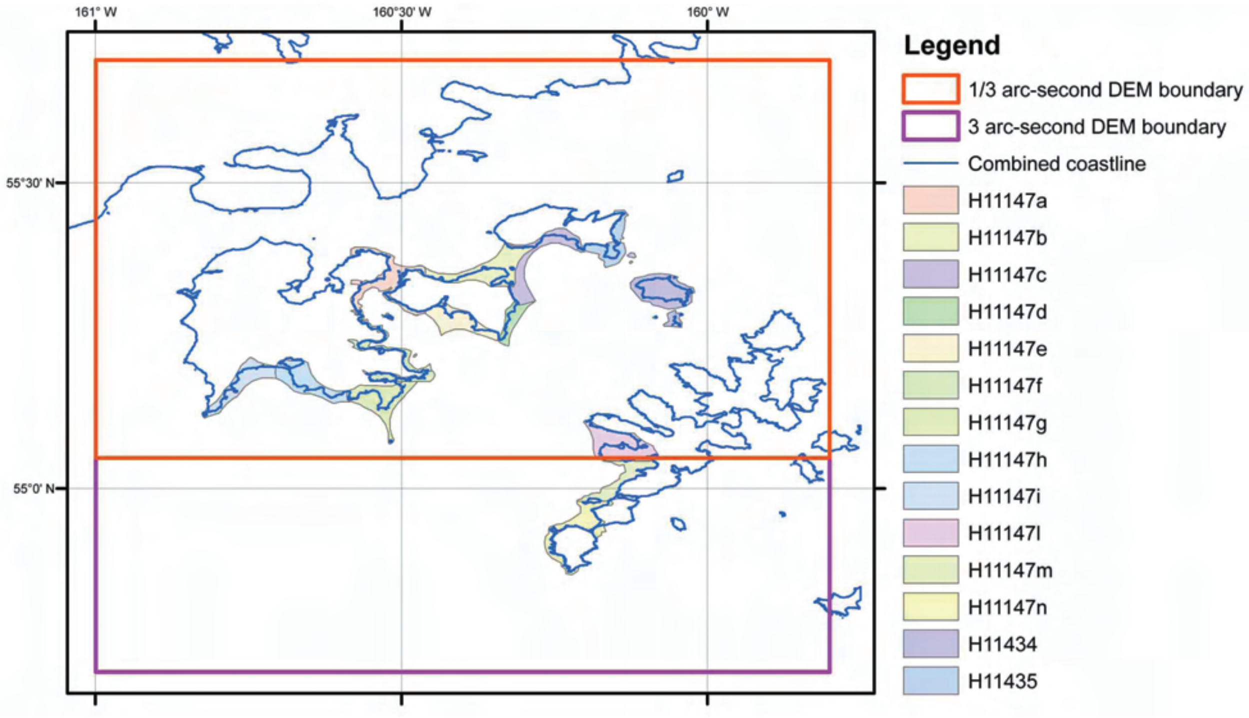

Figure 11. *Spatial coverage of NOS high-resolution (~4-meter point spacing) coastal LiDAR surveys in the vicinity of Sand Point that were utilized in DEM development.*

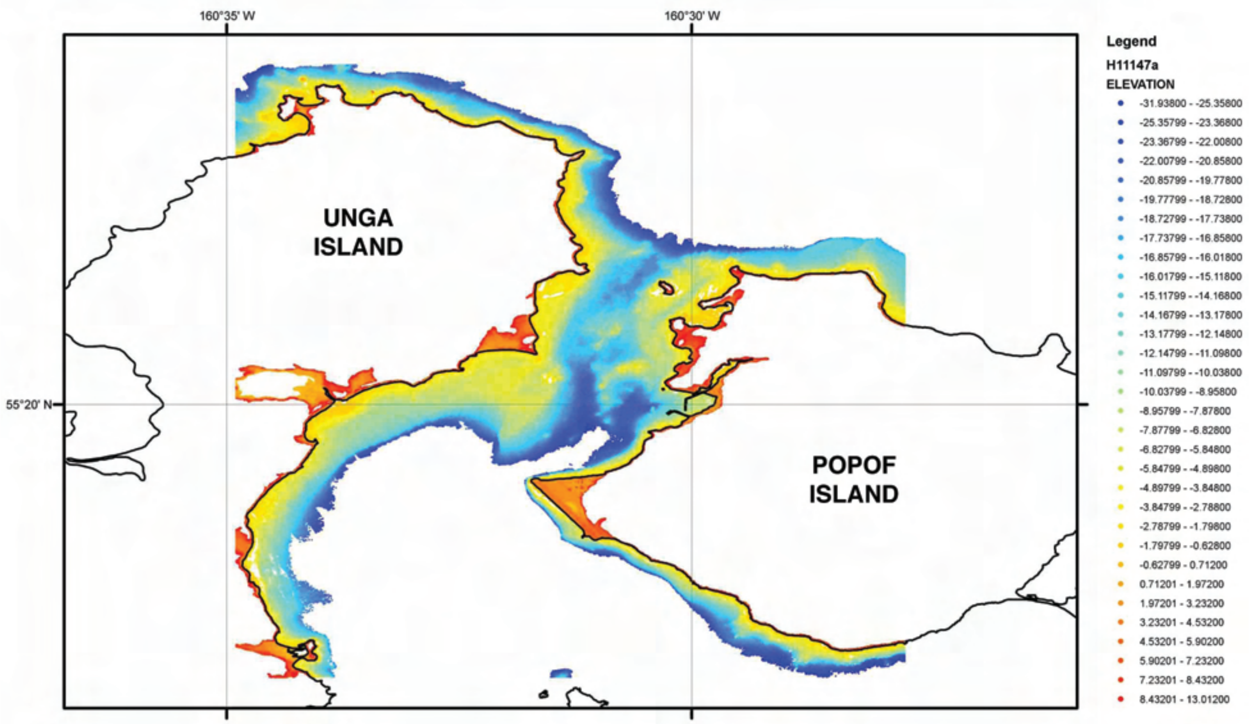

Figure 12. *NOS coastal LiDAR survey H11147a of the approaches to Humboldt Harbor and Sand Point. Data extends from 13 meters of land elevation (red) to 31 meters water depth (blue). Combined coastline in black.*

2) Measured and estimated global bathymetry and topography

Satellite altimetry is used to measure the height of the sea surface, from which estimates have been made of the coarse relief of the world's ocean floor[5] (http://topex.ucsd.edu/WWW_html/mar_topo.html). These data have been combined with measurements of land topography to develop a DEM of the world between 72° N and 72° S (e.g., Fig. 13). Data point spacing is 1 minute, with data in WGS84 geographic coordinates and undefined vertical datum. These data are exceptionally coarse at the resolution of the 3 arc-second Sand Point DEM, however, they provide the only digital constraints on the bathymetry in the southern part of that DEM's grid area. Extracted bathymetric data are generally shallower than overlapping measured bathymetric values (e.g., NOS hydrographic soundings and multibeam swath sonar survey data)—producing artificial bathymetric "steps" and "pimples" in preliminary DEMs—and are considered to be of low accuracy. Estimated bathymetric points were therefore deleted where they overlapped other datasets, and in an intervening "buffer zone" or data gap (see Fig. 2), which was introduced to generate a smoother DEM surface between the estimated bathymetry dataset and other datasets. The remaining estimated bathymetric points were utilized in generating the 3 arc-second DEM only (see Section 3.3.5).

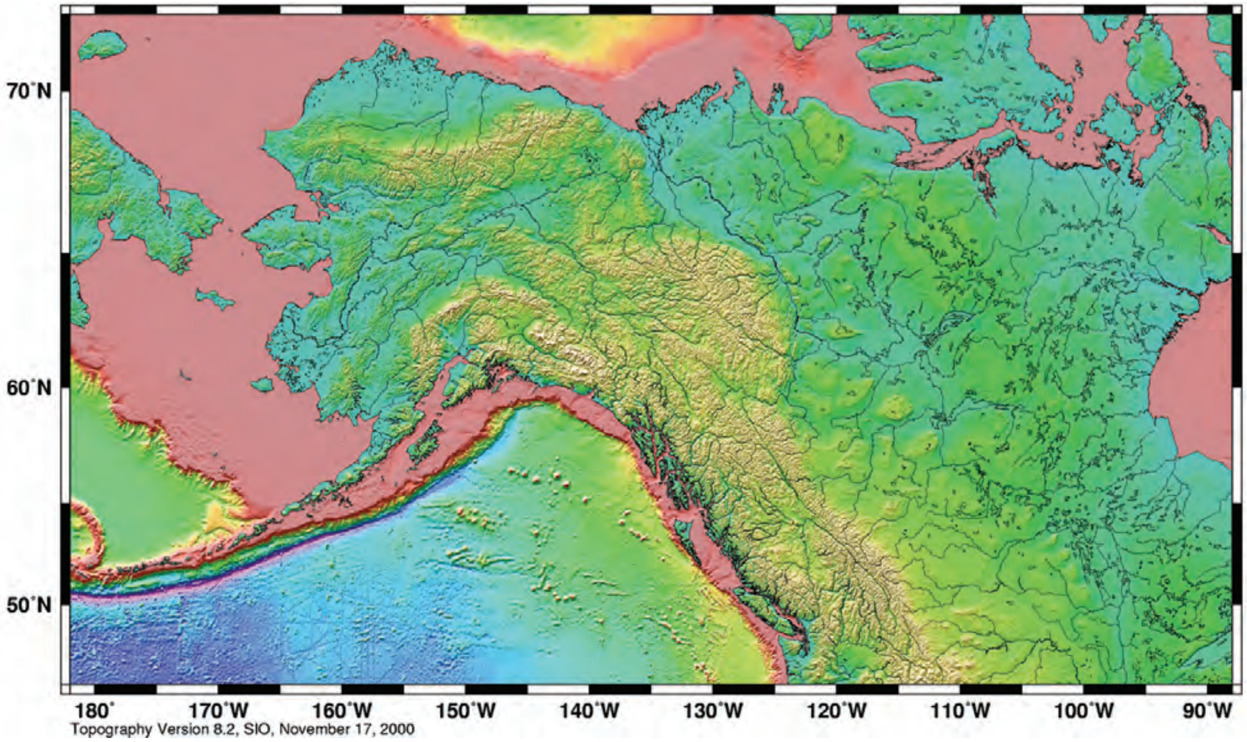

Figure 13. *Color relief image of estimated global bathymetry and topography in the Alaska region. Image taken from Satellite Geodesy web site: http://topex.ucsd.edu/WWW_html/mar_topo.html].*

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[5] A dense mapping of ocean surface topography from declassified Geosat altimeter data (U.S. Navy), ERS-1 altimeter data (European Space Agency), and repeat-track coverage from the Topex/Poseidon altimeter (NASA and CNES) has provided the first view of the ocean floor structures in many remote areas of the Earth. The spatial resolution of the derived gravity field is limited by travel-time noise from ocean waves and can be improved through additional dense measurements. Altimeter-derived gravity can be used to estimate seafloor topography but only over an intermediate wavelength band (200 < l < 20 km) and only in areas where sediment cover is thin. The longer wavelength variations in depth are constrained by depth soundings collected by research vessels over the past 30 years. Detailed bathymetry is essential for understanding physical oceanography, marine geophysics, and perhaps even biological oceanography. Currents and tides are controlled by the overall shapes of the ocean basins as well as the smaller sharp ocean ridges and seamounts. Because erosion rates are low in the deep oceans, detailed bathymetry reveals the mantle convection patterns, the plate boundaries, the cooling/subsidence of the oceanic lithosphere, the oceanic plateaus, and the distribution of off-ridge volcanoes. [Extracted from 'Satellite Geodesy' web site: http://topex.ucsd.edu/WWW_html/mar_topo.html]

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Sand Point DEMs were originally referenced to a number of vertical datums including: Mean Lower Low Water (MLLW), Mean Sea Level (MSL), WGS84/EGM96 Geoid, and North American Vertical Datum of 1929 (NGVD29). All datasets were transformed to MHW to provide the worst-case scenario for inundation modeling.

1) **Bathymetric data**

   The NOS hydrographic and multibeam survey data were transformed from MLLW to MHW, using FME software, by adding a constant offset measured at the NOAA Sand Point tidal station (see Table 8).

2) **Topographic data**

   The NED and SRTM DEMs were originally in NGVD29 and WGS84/EGM96 Geoid vertical datums, respectively. There are no survey markers anywhere in the vicinity of Sand Point that relate these two geodetic datums to the local tidal datums. Thus, it was assumed out of necessity that both datums are essentially equivalent to MSL in this area (Table 8). Conversion to MHW, using FME software, was accomplished by adding a constant value of -0.807 meters.

3) **Topographic/bathymetric data**

   The NOS coastal LiDAR survey data were transformed from MLLW to MHW (Table 8) using FME. No vertical datum was defined for the estimated global bathymetric/topographic DEM. As this dataset is of very low resolution and accuracy, its elevation values were left unchanged.

Table 8. Relationship between Mean High Water and other vertical datums in the Sand Point region.*

Vertical datum	*Difference to MHW*
NAVD88[a]	-0.207
MTL	-0.791
MSL	-0.807
NGVD29	-0.807
WGS84 Geoid+	-0.807
MLW	-1.582
MLLW	-1.988

* Datum relationships determined by tidal station #9459450 at Sand Point, Alaska.
\+ Assumed to be equivalent to MSL.
a From Oswald and Associates.

3.2.2 Horizontal datum transformations

Datasets used to compile the Sand Point DEMs were originally referenced to Unalaska, NAD27, NAD83, and WGS84 horizontal datums. The relationships and transformational equations between these horizontal datums are well established, with the exception of the Unalaska datum. All data were converted to a horizontal datum of WGS84 using FME software, again with the exception of data in the Unalaska datum, which 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 shape files were checked in ESRI ArcMap for inter-dataset consistency. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files 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 combined coastline.
- Differences in topographic elevations between the high-resolution NOS coastal LiDAR survey data, the NED data and SRTM data. In most places, the coastal LiDAR data is lower in elevation than corresponding NED and SRTM data. This creates an unavoidable, artificial steep slope, at about 20 m above MHW, along the landward edge of areas covered by the coastal LiDAR data. The NED and SRTM data differ by up to about 30 m, often the result of horizontal offset of topographic features common to both datasets.
- Offsets between various incomplete coastline datasets and the high-resolution NOS coastal LiDAR data. Data from multiple sources were required to build a combined coastline, which was then manually adjusted to fit the coastal LiDAR data.
- Digital, measured bathymetric values do not exist for most of the southern region encompassed by the 3 arc-second DEM. This necessitated the development of two DEMs of differing resolution and spatial coverage: one for tsunami propagation modeling (3 arc-second) and one for tsunami inundation modeling (1/3 arc-second).
- Significant discrepancies between the estimated bathymetry in the southern part of the 3 arc-second DEM gridding region and other datasets. The low-resolution (1 minute) estimated bathymetric data were deleted wherever this dataset overlapped other datasets. In general, the estimated bathymetry dataset is significantly shallower than actual bathymetric data in the region.

3.3.2 Smoothing of NOS bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second grid: in deep water, the NOS survey data have point spacings up to 1.5 kilometers apart. In order to reduce the effect of artifacts in the form of lines of “pimples” in the 1/3 arc-second DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing ‘pre-surface’ or grid was generated using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The NOS hydrographic point data, in xyz format, were combined with the high-resolution NOS multibeam and coastal LiDAR survey data into a single file, along with points extracted every 10 meters from the combined coastline—to provide a “zero” buffer along the entire coastline. These point data were then smoothed using the GMT tool ‘blockmedian’ onto a 1 arc-second grid 0.05 degrees (~5%) larger than the 1/3 arc-second Sand Point DEM gridding region. The GMT tool ‘surface’ then applied a tight spline tension to interpolate cells without data values. The GMT grid created by ‘surface’ was converted into an ESRI Arc ASCII grid file using the MB-System tool ‘mbm_grd2arc’. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid by the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy (e.g., Fig. 14), converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 9).

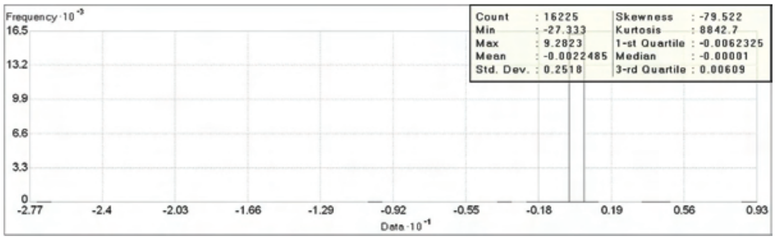


Figure 14. *Histogram of the difference between NOS hydrographic survey H08045 (relatively dense survey on flank of Alaska Peninsula) and the 1 arc-second NOS pre-surfaced bathymetric grid. The greatest differences derive from the averaging of several closely spaced soundings from overlapping surveys and with coastline data points.*

3.3.3 Resampling of 1 arc-second SRTM data

Both the 2 arc-second NED and 1 arc-second SRTM topographic DEMs are of lower resolution than that required for building the 1/3 arc-second Sand Point DEM. Preliminary gridding produced a ‘stippled-topography’ 1/3 arc-second DEM of interwoven NED and SRTM elevation values (i.e., every ninth cell had an SRTM data value, every 36th cell had a NED data value, and everything else was the result of interpolation between the two datasets). To overcome this stippled effect, the higher-resolution SRTM DEM was subsampled to 1/3 arc-second cell-size in ArcGIS, which provided an SRTM topographic value in each 1/3 arc-second Sand Point DEM cell, with the exception of regions within the SRTM DEM that did not have data values. In those regions, only the NED DEM contributed scattered topographic elevations, and interpolation was between NED data values.

3.3.4 Building the 1/3 arc-second DEM with MB-System

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the 1/3 arc-second Sand Point DEM. MB-System is an NSF-funded share-ware 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’ 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 high-resolution NOS multibeam and coastal LiDAR survey data. Least weight was given to the pre-surfaced 1 arc-second NOS bathymetric grid. Greater weight was given to the subsampled SRTM topographic data than the NED topographic data so that the 1/3 arc-second DEM principally reflects SRTM topography, while NED topographic data infills subaerial regions without SRTM data. Gridding was performed in quadrants, each with a 5% data overlap buffer. The resulting Arc ASCII grids were seamlessly merged in ArcCatalog to create the final 1/3 arc-second Sand Point DEM.

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

Dataset	*Relative Gridding Weight*
NOS coastal LiDAR bathymetry/topography	100
NOS multibeam swath sonar bathymetry	100
Combined coastline	10
NASA SRTM topographic DEM	10
NOS hydrographic surveys: bathymetric soundings	1
USGS NED topographic DEM	0.1
NOS surveys: gridded bathymetry	0.01

3.3.5 Building the 3 arc-second DEM with GMT

The GMT tools ‘blockmedian’ and ‘surface’ were used to create the 3 arc-second Sand Point DEM. NOS multibeam data were first smoothed using ‘blockmedian’ onto a 1 arc-second grid, to reduce file size. All point data, in xyz format, were then combined into a single file and smoothed using the GMT tool ‘blockmedian’ onto a 3 arc-second grid 0.05 degrees (~5%) larger than the 3 arc-second Sand Point DEM gridding region. The GMT tool ‘surface’ then applied a tight spline tension to interpolate cells without data values. The GMT grid created by ‘surface’ was converted into an Arc ASCII grid file—the 3 arc-second Sand Point DEM—using the MB-System tool ‘mbm_grd2arc’. The 3 arc-second DEM was compared with the 1/3 arc-second DEM to ensure elevation consistency.

3.4 Quality Assessment of the DEMs

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Sand Point DEMs is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features in island interiors have an estimated horizontal accuracy of 50 to 75 meters, based on the documented accuracy of the NED and SRTM DEMs, and discrepancies between these two datasets, as well as discrepancies with digital versions of USGS topographic quadrangles (see Section 3.4.6). Coastal topographic and bathymetric features surrounding Popof Island, in areas covered by high-resolution NOS coastal LiDAR and multibeam surveys (see Fig 2), have accuracies of about 10 meters. Bathymetric features in areas covered exclusively by early 20th-century NOS hydrographic soundings—along the margins of the DEMs—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. Bathymetric features in the southern region of the 3 arc-second DEM that are derived from the low-resolution estimated global bathymetry have a positional accuracy of a few kilometers.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the two DEMs are also highly dependent upon the source datasets contributing to grid cell values. Island interiors have vertical accuracies of between 10 and 15 meters, derived from: the NED topographic data, which have an estimated vertical accuracy between 7 and 15 meters; the SRTM topographic data, which have a vertical accuracy better than 16 meters but are typically about 10 meters; and discrepancies between the two datasets, which are up to about 30 meters. Coastal topography and bathymetry surrounding Popof Island, in areas covered by high-resolution, GPS-navigated NOS coastal LiDAR and multibeam surveys, meet modern NOS survey standards: 0.3 m in 0–20 m of water, 1.0 m in 20–100 m of water, and 1% of the water depth in >100 m of water. Gridding interpolation to determine bathymetric values between sparse, poorly located, early 20th-century NOS hydrographic soundings degrades the vertical accuracy of elevations in deep water, to about 5% of water depth. Bathymetry in the southern region of the 3 arc-second DEM is derived largely from the low-resolution estimated global bathymetry. This dataset is shoal biased by tens of meters in shallow water areas.

3.4.3 Slope maps and 3-D perspectives

ESRI ArcCatalog was used to generate a slope grid from the 1/3 arc-second Sand Point DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 15). The DEM was transformed to UTM Zone 4 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Of principal note is the creation of unavoidable, artificial steep slopes along the landward boundary of areas covered by the high-resolution NOS coastal LiDAR surveys. The neighboring SRTM and NED data have lower resolution and tend to have greater elevations than the more accurate coastal LiDAR data. Three-dimensional viewing of the UTM-transformed DEM (e.g., Fig. 16) was accomplished using ESRI ArcScene. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEMs.

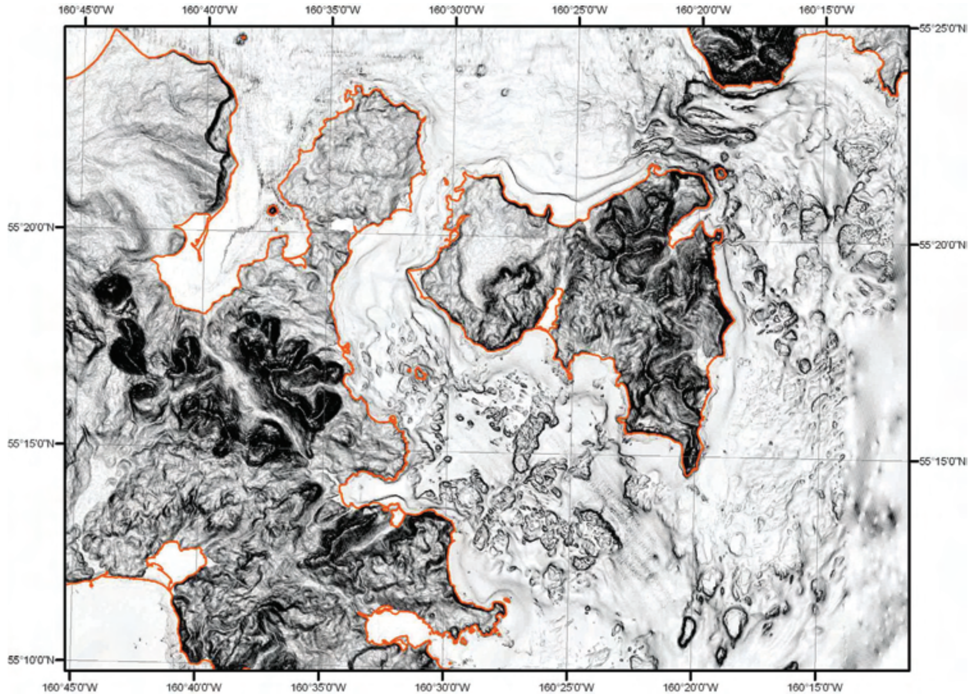


Figure 15. *Slope map of the 1/3 arc-second Sand Point DEM in the vicinity of Sand Point, Alaska. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

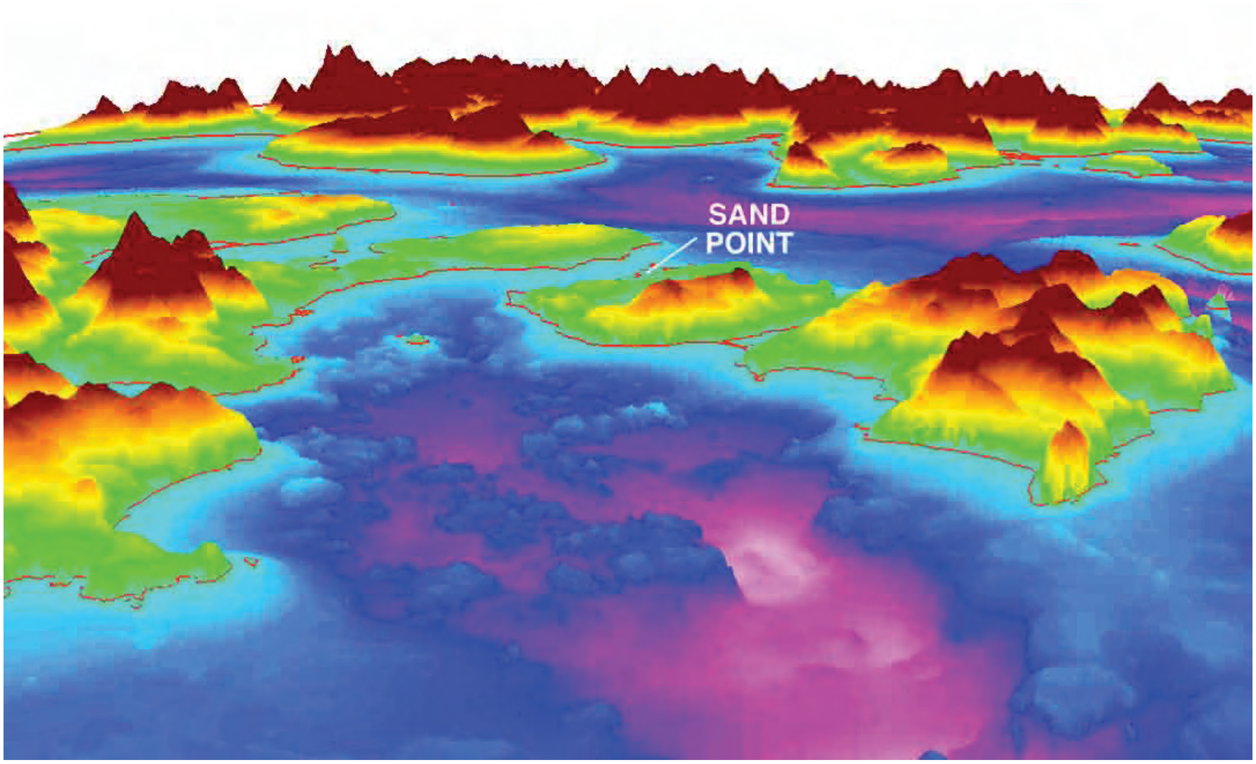


Figure 16. *Perspective view from the southeast of the 1/3 arc-second Sand Point DEM. Combined coastline in red; vertical exaggeration–times 3. Popof Strait in foreground, Alaska Peninsula in background.*

Figure 17 shows color images of the two Sand Point DEMs in their final versions. A pronounced, isolated bathymetric trough lies between Unga, Popof and Nagai islands (Panel B), which is inferred to result from crustal shortening and/or local extension in the Aleutian arc's accretionary prism. A neighboring trough to the north, separating the Shumagin Islands from the Alaska Peninsula, likely shares a similar tectonic origin.

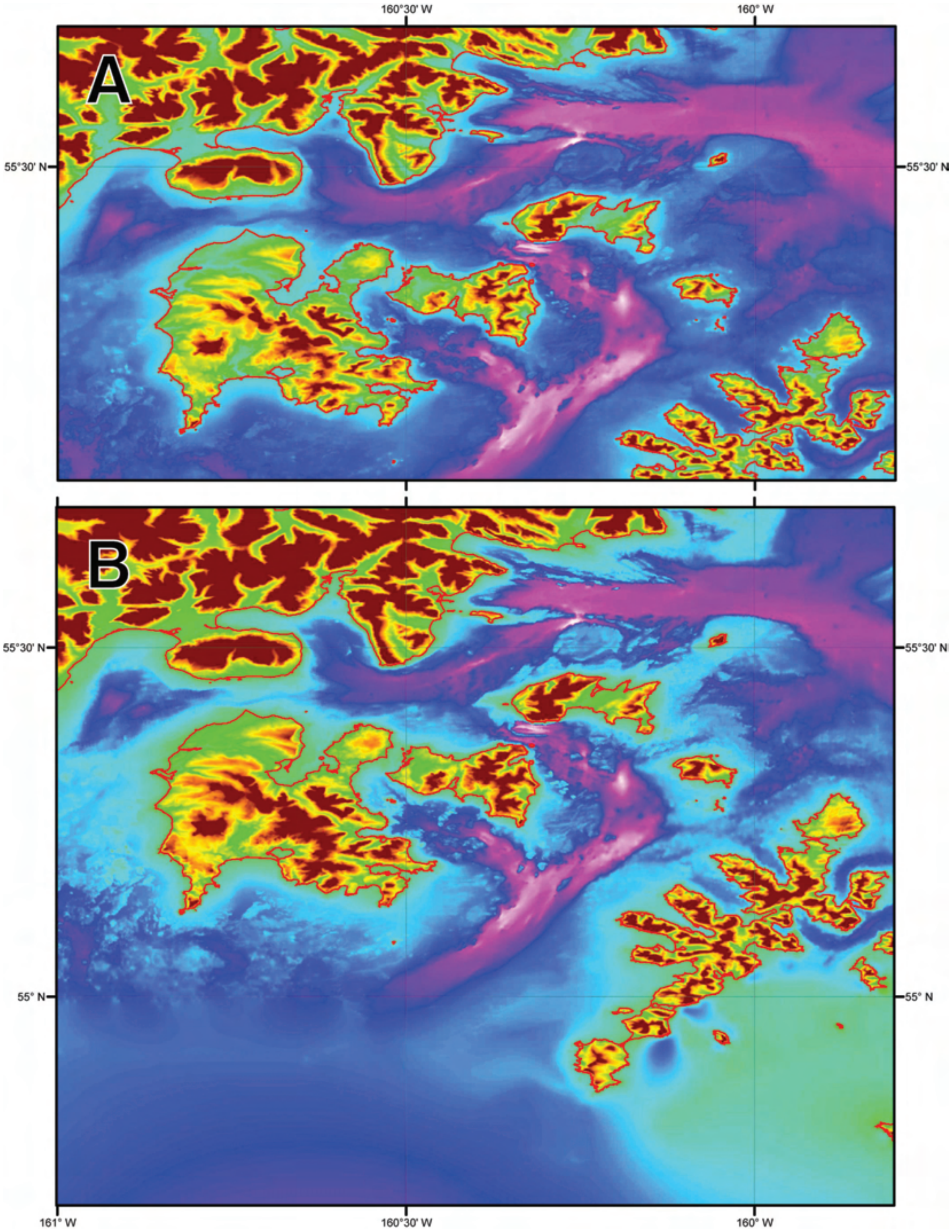


Figure 17. *Color images of the Sand Point DEMs. A) 1/3 arc-second Sand Point DEM. B) 3 arc-second Sand Point DEM. Values range from ~1000 meters above MHW (dark red) to ~250 meters below MHW (light pink). Note that the coloring between panels A and B is slightly different due to differing minimum and maximum DEM values. Combined coastline in red.*

3.4.4 *Comparison with source data files*

To ensure grid accuracy, the 1/3 arc-second Sand Point 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 difference between NOS coastal LiDAR survey H11147d data points and the Sand Point DEM is shown in Fig. 18. The largest differences occur in regions of highly variable, steep coastal relief where multiple, closely spaced points were averaged to a single cell value.

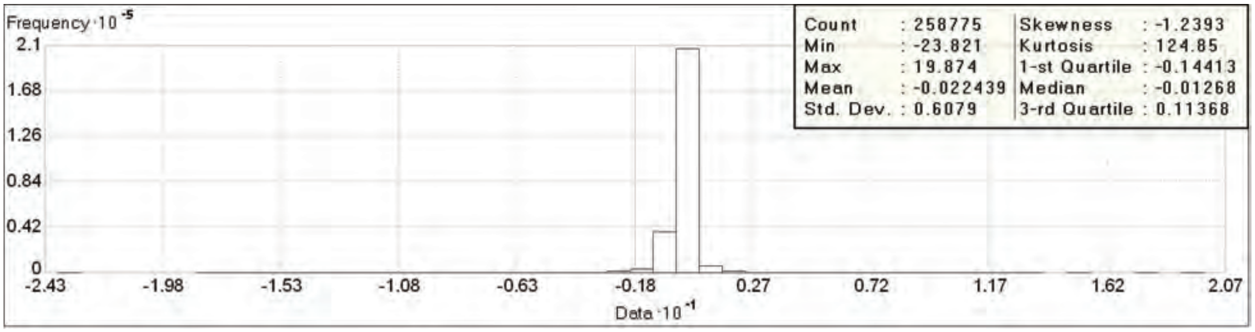


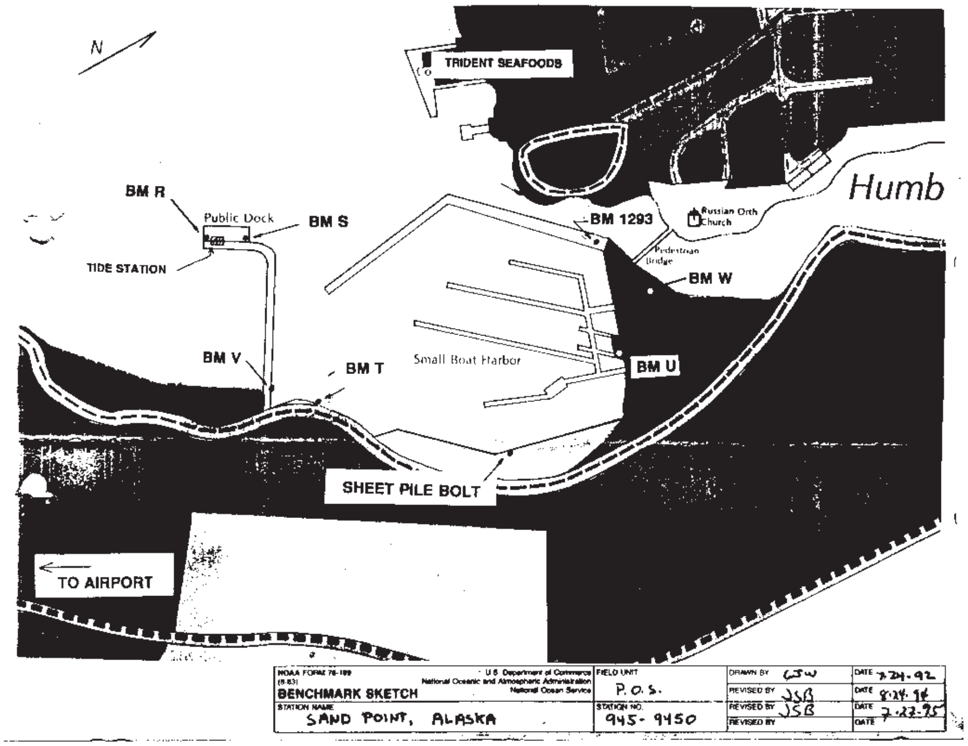
Figure 18. *Histogram of the difference between NOS coastal LiDAR survey H11147d (258,775 points) and the 1/3 arc-second Sand Point DEM. The largest differences occur in regions of highly variable, steep coastal relief where multiple, closely spaced points were averaged to a single cell value.*

3.4.5 *Comparison with NOAA tidal stations*

The National Geodetic Survey (NGS) data sheets for U.S. tidal stations (http://tidesandcurrents.noaa.gov/) document benchmark elevations, in meters above MHW, allowing for direct comparison with DEM values at those locations. There is only one tidal station within the Sand Point study area, which was compared with the value taken at the same locale from the 1/3 arc-second Sand Point DEM (see Fig. 19 and Table 10 for station location). The station has multiple benchmark stampings, all of which have the same geographic position, recorded to within 6 arc-seconds (160°30.1′ W, 55°20.2′ N). Stamping 'W' is located on the spit of land at the north end of the northern harbor breakwater. The 1/3 arc-second DEM value of 1.474 meters for that location compares favorably with the stamping's elevation of 1.565 meters (Table 10).

Table 10. Comparison of NOAA tidal benchmark elevation, in meters above MHW, with the 1/3 arc-second Sand Point DEM.

Station number	*Station name*	*Year*	*Longitude*	*Latitude*	*Bench mark*	*DEM*	*Difference*
9459450	SAND POINT	1992	160.508056° W	55.336667° N	1.565	1.472	-0.093



NOAA FORM 76-189 (8-83)
U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service
BENCHMARK SKETCH
FIELD UNIT P.O.S.
DRAWN BY GJW DATE 7-24-92
REVISED BY JSB DATE 8-24-94
REVISED BY JSB DATE 7-27-95
REVISED BY DATE
STATION NAME SAND POINT, ALASKA
STATION NO. 945-9450

Figure 19. *Location of benchmark stampings for NOAA tidal station #9450450, Sand Point, Alaska. Bench mark 'W' was compared with the 1/3 arc-second DEM (see Table 12).*

3.4.6 Comparison with USGS topographic elevations

Topographic elevations were extracted from online digital images of USGS topographic quadrangles at TopoZone (http://www.topozone.com), which give position and elevation in WGS84 and NGVD29 vertical datum (in feet). Elevations were converted to meters and shifted to MHW vertical datum (see Table 8) for comparison with the 1/3 arc-second and 3 arc-second Sand Point DEMs (see Fig. 1 for station locations). Significant differences exist between the Sand Point DEMs and the USGS topographic elevations: from -103 to 32 meters, with a negative value indicating that the DEM is less than the topographic quadrangle elevation (Figs. 20, 21). Much of the difference results from horizontal offsets between the positional information taken from the online quadrangles, and the corresponding feature in the DEMs. Such offsets range up to 75 meters, though not in any consistent direction.

Downloading and viewing of USGS 'Digital Raster Graphics' images of the quadrangles, after translation from NAD27 UTM Zone 4 to WGS84 horizontal datum with FME, yielded different locations for the topographic elevations, typically offset by 30 to 50 meters from the TopoZone-derived locations. The transformed DRGs are also offset some 50 meters to the northeast of the combined coastline. Land elevations extracted from the ENC for NOAA nautical chart #16553, downloaded in WGS84 datum, produced yet another geographic position for the same topographic elevations; land elevations on NOAA nautical charts are typically taken from USGS quadrangles. Because the same point from one dataset—the original USGS paper topographic quadrangle—has been shifted to multiple locations in WGS84 geographic coordinates by different means, the simplest conclusion is that the transformational equations to shift horizontal datums have not been properly applied. NGDC has not been able to deduce the proper WGS84 coordinates for these topographic elevations but infer that much of the discrepancy between the DEMs and the USGS topographic elevations extracted from TopoZone is the result of incorrect transformation of the quadrangles to WGS84 geographic coordinates.

From a vertical perspective, the topographic elevations and their corresponding DEM feature, typically local highs, are often within about 10 meters, though the DEM values are generally lower (Figs. 20, 21). These differences may be attributable to the fact that the SRTM and NED topographic data, used to constrain the subaerial parts of the DEMs, represent averages of land elevations over 30 × 30 meter, and 60 × 60 meter square areas, respectively, while the topographic quadrangle elevations represent maximum heights.

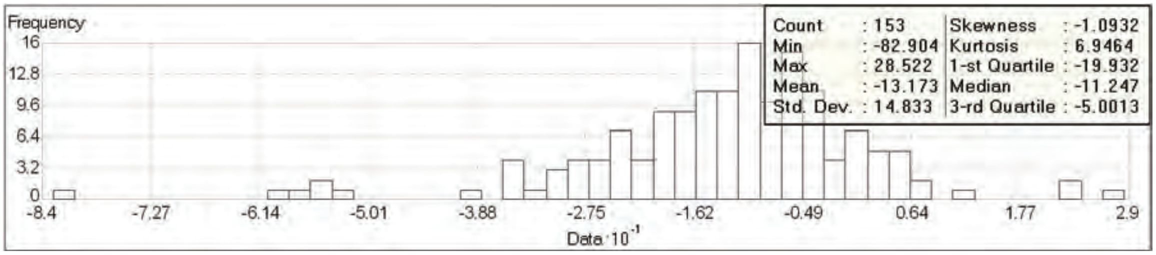


Figure 20. *Histogram of the differences between the USGS topographic quadrangle elevations and the 1/3 arc-second Sand Point DEM. The pronounced negative values (DEM less than topographic elevations) result partly from horizontal offsets of features, typically local highs, but may also result from comparing average elevation over an area with a local maximum.*

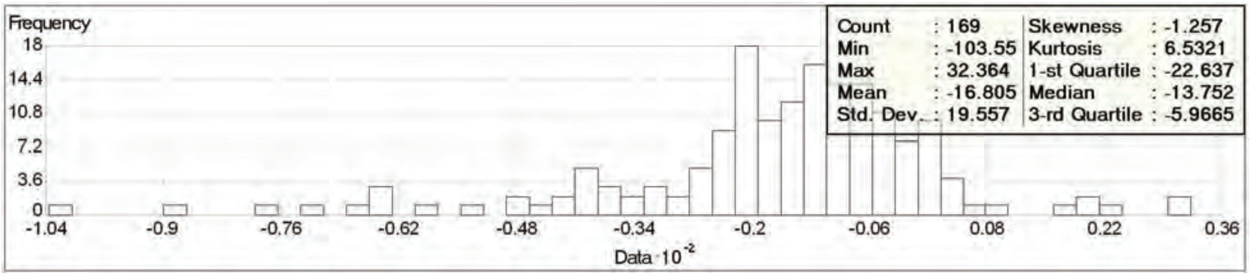


Figure 21. *Histogram of the differences between the USGS topographic quadrangle elevations and the 3 arc-second Sand Point DEM. The pronounced negative values (DEM less than topographic elevations) result partly from horizontal offsets of features, typically local highs, but may also result from comparing average elevation over an area with a local maximum.*

3.4.7 Comparison with NGS geodetic monuments

The elevations of NOAA NGS geodetic monuments were extracted from online monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give position in NAD83 (sub-mm accuracy) and elevation in NGVD29 (in meters). Elevations were shifted to MHW vertical datum (see Table 8) for comparison with the 1/3 arc-second and 3 arc-second Sand Point DEMs (see Fig. 1 for monument locations). Differences between the Sand Point DEMs and the NGS geodetic monument elevations range from -53 to 15 meters, with a negative value indicating that the DEM is less than the monument elevation (e.g., Fig. 22). Part of this difference results from the monuments having typically been anchored on local highs (e.g., large boulders). The remaining differences may be attributable to the fact that the SRTM and NED topographic data, used to constrain the subaerial parts of the DEMs, represent averages of land elevations over 30 × 30 meter, and 60 × 60 meter square areas, respectively. The monuments that differ the most from the 1/3 arc-second Sand Point DEM lie in areas where the USGS NED DEM contributed to the corresponding 1/3 arc-second Sand Point DEM. Descriptions and elevations of monuments near the coast support the assumption that the NGVD29 vertical datum roughly corresponds with mean sea level (see Table 8).

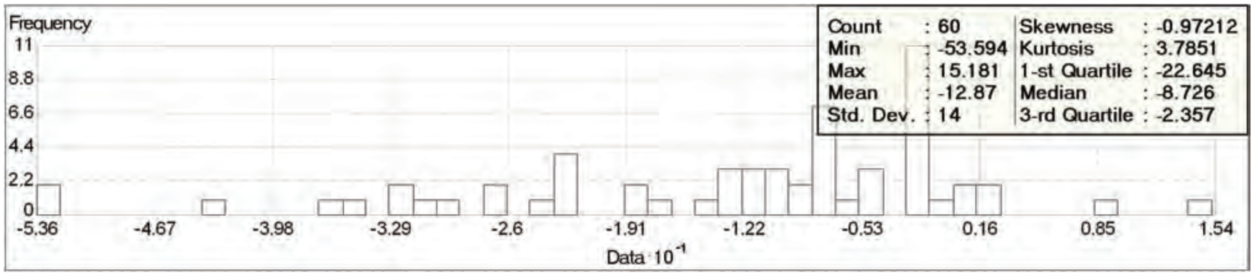


Figure 22. *Histogram of the differences between NGS geodetic monument elevations and the 1/3 arc-second Sand Point DEM. The pronounced negative values (DEM less than topographic elevations) may result from comparing average elevation over an area with a local high.*

4. SUMMARY AND CONCLUSIONS

Two topographic/bathymetric digital elevation models of the Sand Point, Alaska area, with cell spacings of 1/3 arc-second and 3 arc-seconds, were developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT, and MB-System software.

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

- Conduct bathymetric surveys in the region to the south of the Shumagin Islands, which currently has no digital measured bathymetric data.
- Obtain digital versions of several NOAA nautical charts (#16540, 16551, 16556, 16363) that have not yet been digitized.
- Establishment, via survey, of the relationships between tidal and geodetic datums in the Sand Point region.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Nautical Chart #16540, 11th Edition, 1989. Shumagin Islands to Sanak Islands. Scale 1:300,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16551, 12th Edition, 1990. Unga Island to Pavlof Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16553, 3rd Edition, 1989. Shumagin Islands—Nagai Island to Unga Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16556, 5th Edition, 1996. Chaichi Island to Nagai Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16363, 7th Edition, 2002. Port Moller and Herendeen Bay. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Oswald, John and Associates, LLC, Determination of the Separation between the ellipsoid and MLLW in the Shumigan Islands, Alaska. Delivered to NOAA – National Ocean Service, Office of Coast Survey.

U.S. Geological Survey, Alaska topographic quadrangles. Scale 1:63,360. TopoZone, http://www.topozone.com

7. DATA PROCESSING SOFTWARE

ArcGIS v. 9.1, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

Electronic Navigational Chart Data Handler for ArcView, developed by NOAA Coastal Services Center, http://www.csc.noaa.gov/products/enc/

FME 2006 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

GMT v. 4.1.1 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.0.9, 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/