NOAA Technical Memorandum NESDIS NGDC-63

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

M.R. Love
B.W. Eakins
L.A. Taylor
K.S. Carignan
D.Z. Friday
P.R. Grothe

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
August 2012

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite, Data, and Information Service

NOAA Technical Memorandum NESDIS NGDC-63

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

Matthew R. Love[1]
Barry W. Eakins[1]
Lisa A. Taylor[2]
Kelly S. Carignan[1]
Dorothy Z. Friday[1]
Pamela R. Grothe[1]

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

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

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
August 2012

UNITED STATES DEPARTMENT OF COMMERCE

Rebecca Blank
Acting Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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

National Environmental Satellite, Data, and Information Service

Mary E. Kicza
Assistant Administrator

NOTICE

Mention of a commercial company or product does not constitute an endorsement by the NOAA National Environmental Satellite, Data, and Information Service. Use of information from this publication concerning proprietary products or the test of such products for publicity or advertising purposes is not authorized.

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

Also available from the National Technical Information Service (NTIS)

Contents

List of Figures

List of Tables

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

1. Introduction

In April of 2011 the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a bathymetric–topographic digital elevation model (DEM) centered on Port Alexander, Alaska (Fig. 1) for the Pacific Marine Environmental Labratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second DEM[1] was generated from diverse digital datasets in the region (grid sources shown in Fig. 5) and was designed to represent modern morphology. This report provides a summary of the data sources and methodology used to develop the Port Alexander DEM.

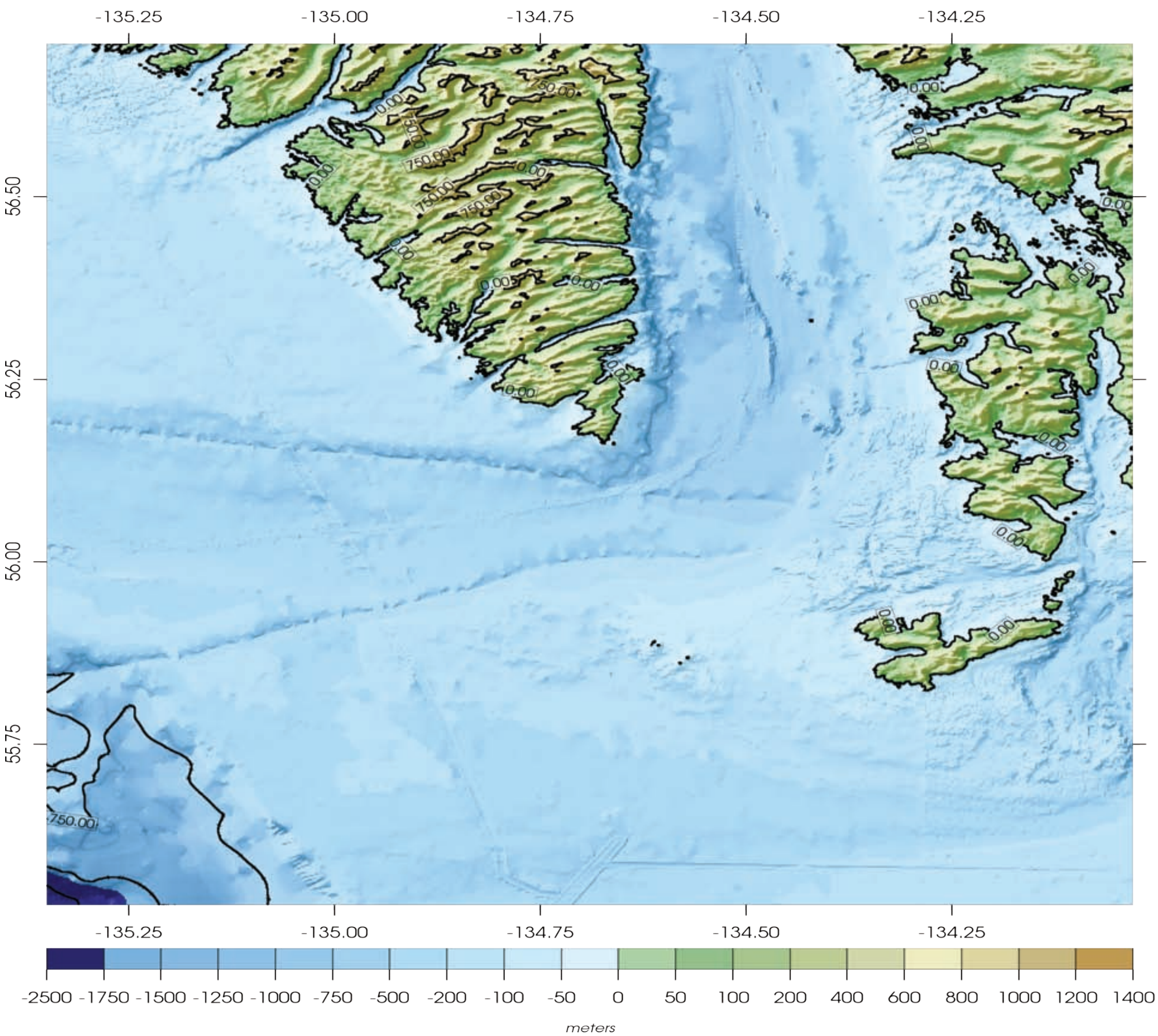

Figure 1. Shaded-relief image of the Port Alexander 1/3 arc-second DEM.

1. The Port Alexander DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Port Alexander, AK (56°14′24″N 134°39′26″W) 1/3 arc-second of latitude is equivalent to 10.30982775 meters; 1/3 arc-second of longitude equals 5.74125383 meters.

2. Study Area

Port Alexander is a city at the southeastern corner of Baranof Island in Petersburg Census Area, Alaska, in the panhandle of southeast Alaska. The 1/3 arc-second DEM of the region encompasses the region around Port Alexander (Fig. 3).

Southeast Alaska is a historically active earthquake region, which makes the area highly vulnerable to tsunamis (Fig. 4). Earthquakes are of concern in Port Alexander and the surrounding region because of the region's proximity to large fault systems, as well as the likelihood of landslides, avalanches and tsunamis resulting from a significant earthquake. Although most of Alaska's earthquakes occur in the south-central and southwest regions, southeastern Alaska experiences earthquakes from the Queen Charlotte-Fairweather fault, which runs from northwest to southeast in close proximity to the Port Alexander region. The Fairweather fault system has caused several recent moderate to large earthquakes: a magnitude 8.1 earthquake in 1949, a magnitude 7.9 event in 1958 that triggered the giant landslide-generated wave, a magnitude 7.6 quake in 1972, and a magnitude 6.8 event in 2004. Because of the steep slopes around Port Alexander, landslide-induced tsunamis are also possible if an earthquake triggers a large landslide into the channel (http://www.juneau.org/emergency/Earthquakes.php).

Figure 2. Photograph of Port Alexander. Source: http://icons-ecast.wunderground.com/data/wximagenew/f/FishermensInn/1.jpg

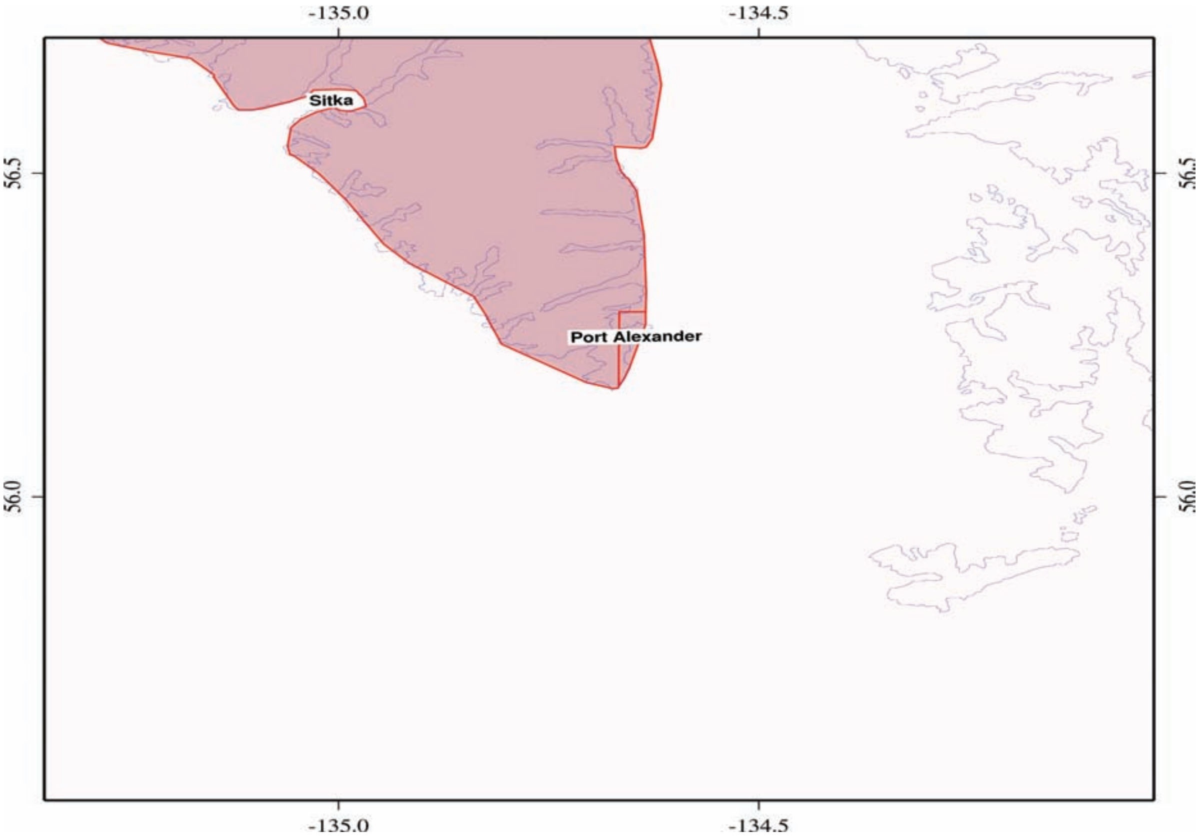

Figure 3. Overview of the Port Alexander, Alaska region.

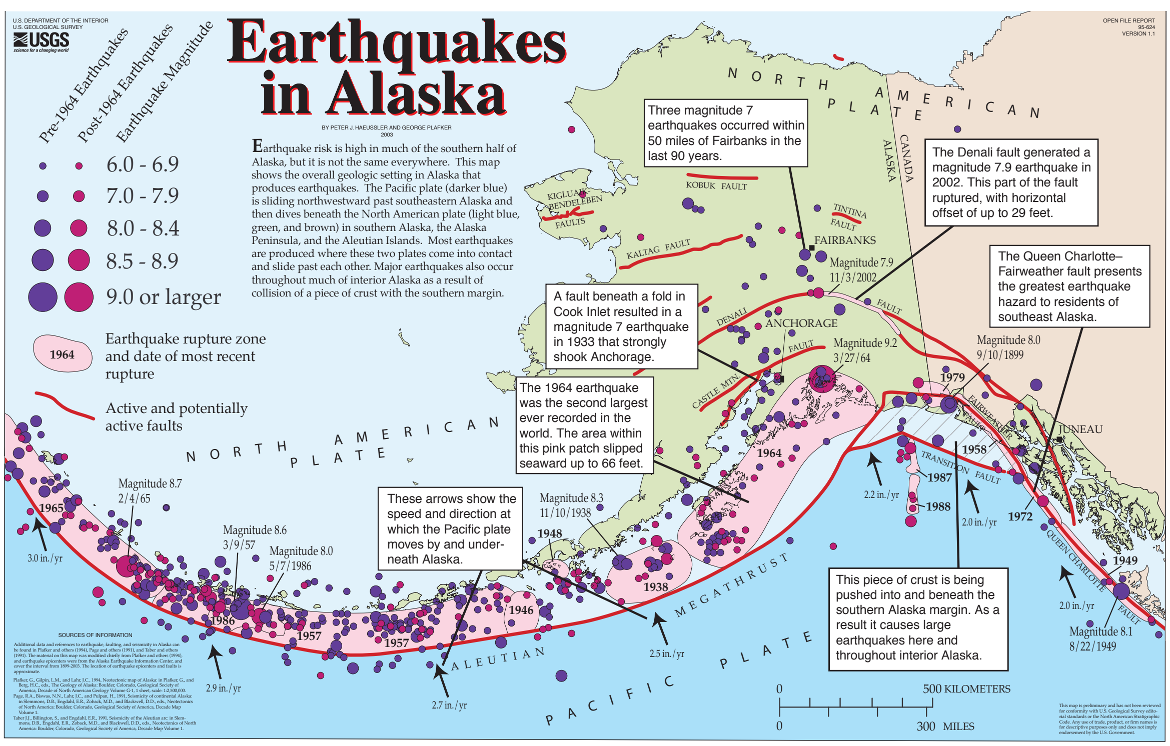

Figure 4. Earthquakes in Alaska. Sources: http://www.aeic.alaska.edu/html_docs/pdf_files/earthquakes_in_Alaska.pg.pdf; http://geopubs.wr.usgs.gov/open-file/of95-624/.

3. Methodology

The Port Alexander DEM was developed in the World Geodetic System 1984 (WGS 84) geographic horizontal datum and Mean High Water (MHW) vertical datum in vertical units of meters. The final grid format for the DEM is ESRI Arc Ascii Grid. The Port Alexander DEM was also developed to meet PMEL specifications listed in Table 1, based on input requirements for the development of Reference Innundation Models (RIMs) and Standby Inundation Models (SIMs) in support of NOAA's Tsunami Warning Centers use of SIFT to provide real-time tunami forecasts in an operational environment. The best available bathymetric and topographic digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North American Datum of 1983[2] (NAD 83) and MHW, for modeling of maximum flooding, respectively.

Table 1. Specifications for the Port Alexander DEM.

Grid Area	Port Alexander, AK
Coverage Area	-135.5, -134. 55.53, 56.71
Grid Spacing	1/3 arc-second
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Format	ESRI Arc ASCII

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

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 5) were obtained from several U.S. federal and local agencies, including: NGDC; NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS); the U.S. Fish and Wildlife Service (USFWS); the U.S. Forestry Service (USFS); the U.S. Army Corps of Engineers (USACE); the U.S. Geological Survey (USGS); the National Aeronautics and Space Administration (NASA). *Proj4*[3] was used to shift datasets to NAD 83 geographic horizontal datum. The Geographic Dataset Abstraction Layer (*GDAL)*[4] was used to convert the datasets into ESRI *ArcGIS* shapefiles and xyz format. The shapefiles and xyz files were then displayed with *ArcGIS* and Applied Imagery's *Quick Terrain Modeler* (*QT Modeler*) to assess data quality and manually edit datasets. The methodology used for vertical datum transformations is described in Section 3.2.1.

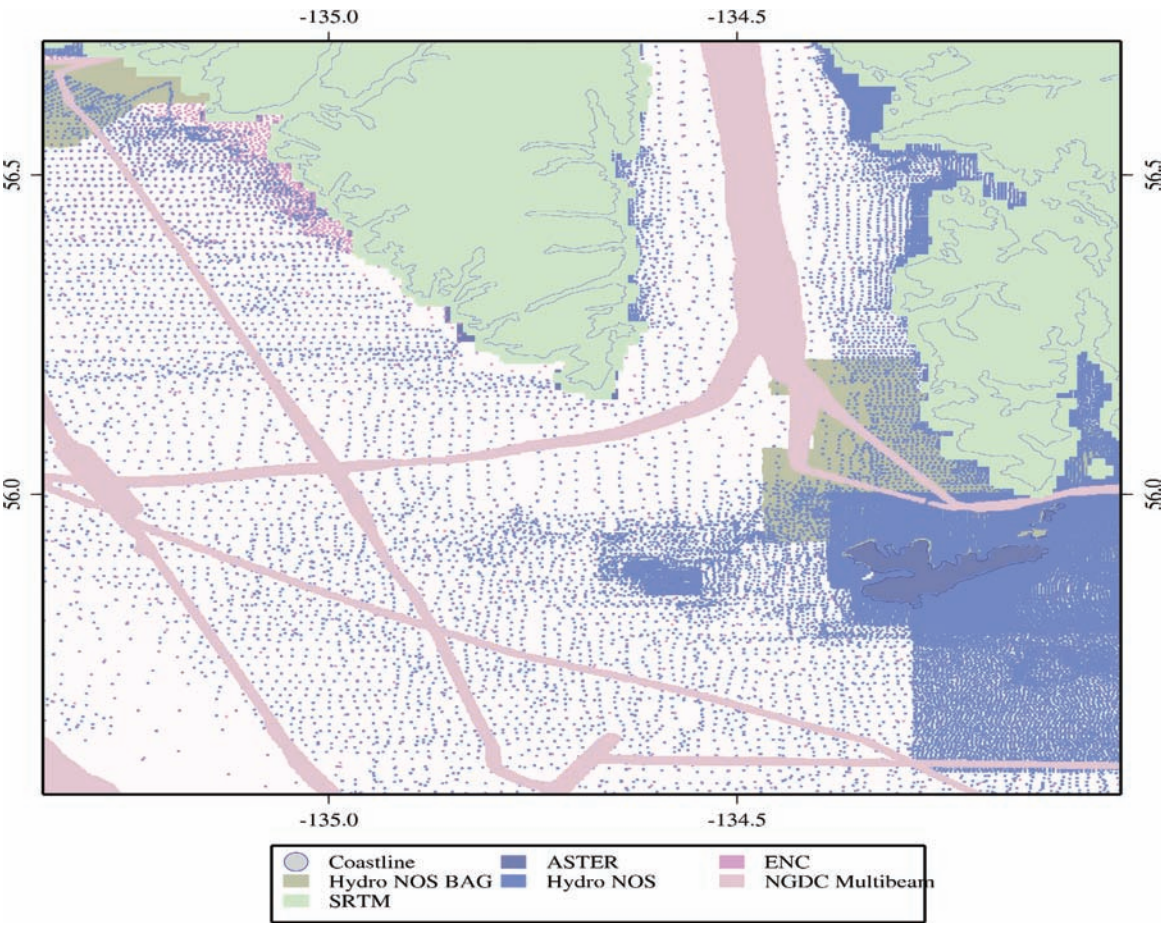

Figure 5. Source and coverage of datasets used in compiling the Port Alexander DEM.

3. *Proj4* is a cartographic projections library, originally written by Gerald Evenden, then of the USGS. The software is released under an MIT style Open Source license. *Proj4* was used to horizontally transform datasets that originated in State Plane datums before vertical transformations were performed .

4. *GDAL* is a translator library for raster geospatial data formats that is released under an X/MIT style Open Source license by the Open Source Geospatial Foundation. As a library, it presents a single abstract data model to the calling application for all supported formats. It also comes with a variety of useful commandline utilities for data translation and processing.

3.1.1 *Shoreline*

Two coastline datasets of the Port Alexander, Alaska region were analyzed for inclusion in the Port Alexander DEM: NOAA Electronic Navigational Charts (ENCs)[5] and the USFWS statewide Alaska digital coastline (Table 2). The USFWS coastline best fit the topographic and bathymetric data overall and was merged with higher resolution (e.g., at least 1:80,000 scale) ENC coastlines only within the immediate vicinity of Port Alexander. These datasets were used to develop a "final coastline" of the Port Alexander, Alaska region.

The final coastline was subsequently modified to include large offshore rocks and small islets shown on the larger-scale NOAA raster nautical charts (RNCs) and clipped to an area 0.05 degrees larger than the DEM boundary. Piers and docks were deleted from the coastline. The coastline was further modified based on *ESRI World 2D* imagery to reflect the most current coastal morphology.

Table 2. Shoreline datasets used in developing the Port Alexander DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
OCS	2009	ENC	1:20,000 to 1:80,000	WGS 84 geographic	MHW	http://w1.nauticalcharts.noaa.gov/staff/chartspubs.html
USFWS	2006	Compiled coastline	1:63,360	WGS 84 geographic	Undefined	ftp://ftp.dnr.state.ak.us/asgdc/adnr/alaska_63360.zip

1) **Office of Coast Survey extracted Electronic Navigational Chart coastlines**

Seven ENCs were available in the Port Alexander, Alaska region (Appendix B) and were downloaded from NOAA's Office of Coast Survey web site. The ENCs were in S-57 format and included coastline data referenced to MHW. The coastline shapefiles were extracted from the ENCs using *ArcCatalog* and compared to large-scale RNCs and ESRI's *World 2D* imagery. Only the ENCs with 1:80,000-scale or higher that were within the 8/15 arc-second DEM boundary were used.

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

The U.S. Fish and Wildlife Service (USFWS) has compiled a seamless digital coastline of the State of Alaska from a variety of sources, including: the National Hydrography Dataset, NOAA nautical charts, USFWS, National Geographic Topo Software, USACE, and Alaska Department of Natural Resources. This dataset was provided by Bret Christensen, USFWS. Though efforts were made to obtain the highest resolution coastlines available, vertical datums were not determined or controlled in the compilation of the USFWS coastline; the horizontal datum is WGS 84 geographic. The USFWS coastline provides complete coverage of the Southeast Alaska region.

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

3.1.2 Bathymetry

Bathymetric datasets available for use in the compilation of the Port Alexander DEM include 33 NOS hydrographic surveys; 9 multibeam surveys downloaded from the NGDC multibeam database; and soundings extracted from 7 ENCs. (Table 3; Fig. 6).

Table 3. Bathymetric datasets used in compiling the Port Alexander DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Downloaded Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NGDC	1883 to 2009	NOS hydrographic surveys	Ranges from less than 10 m to 600 m (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 83 geographic NAD 27 geographic NAD 83 UTM Zone 8 NAD 83 UTM Zone 9 Early Alaska Undetermined	MLW and MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC	1994 to 2009	Multibeam swath sonar	Gridded to 3 arc-seconds	WGS 84 geographic	Assumed Mean Sea Level (MSL)	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
OCS	1977 to 2009	ENC extracted soundings	Ranges from several meters to several kilometers (varies with scale of survey, depth, traffic, and probability of obstructions)	WGS 84 geographic	MLLW	http://w1.nauticalcharts.noaa.gov/staff/chartspubs.html

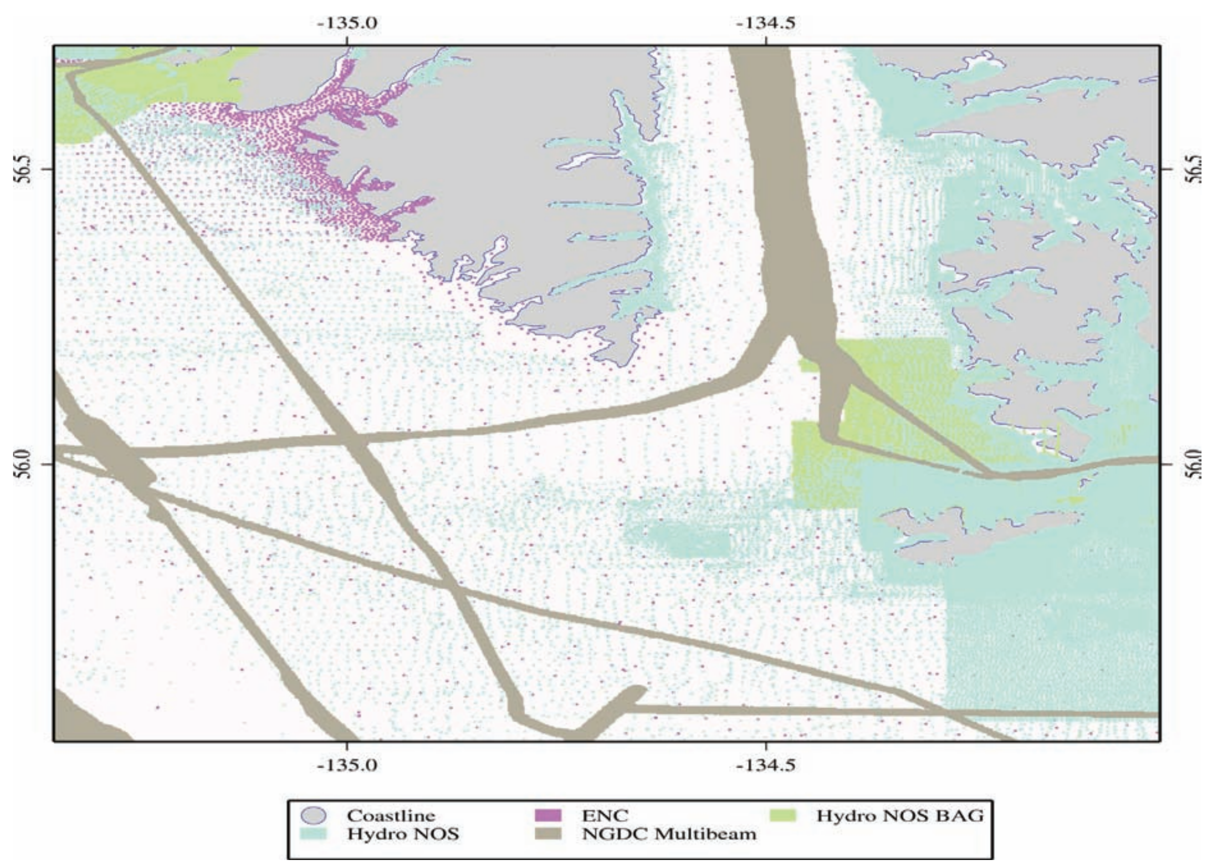

Figure 6. Spatial coverage of the bathymetric datasets used in compiling the Port Alexander DEM. Land areas shown in tan. Regions of no data shown in white.

1) National Ocean Service hydrographic survey data

A total of 33 NOS hydrographic surveys conducted between 1883 and 2009 were available for use in developing the Port Alexander DEM (Appendix A; Figs. 7 and 8). Surveys were extracted from NGDC's online NOS hydrographic database using *GEODAS*[6]. The surveys were downloaded in xyz format. The downloaded hydrographic survey data were vertically referenced to mean lower low water (MLLW) or mean low water (MLW) and horizontally referenced to NAD 27 or NAD 83 geographic, NAD 83 UTM Zone 8, NAD 83 UTM Zone 9, Early Alaska, or "undetermined" datums. NOS surveys in Early Alaska or "undetermined" datums were manually shifted in *ArcGIS* to fit the final coastline.

Data point spacing for the NOS surveys varied by scale. In general, small scale surveys had greater point spacing than large scale surveys. The data were converted to shapefiles using *Python* and *GDAL*. The surveys were subsequently clipped to a polygon 0.05 degree (~5%) larger than the Port Alexander DEM area to support data interpolation along grid edges.

After transforming all NOS survey data to MHW (see Sec. 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to other bathymetric datasets, the final coastline, and NOS RNCs (see Appendix A). Older surveys were clipped to remove soundings that have been superseded by more recent NOS surveys or multibeam data.

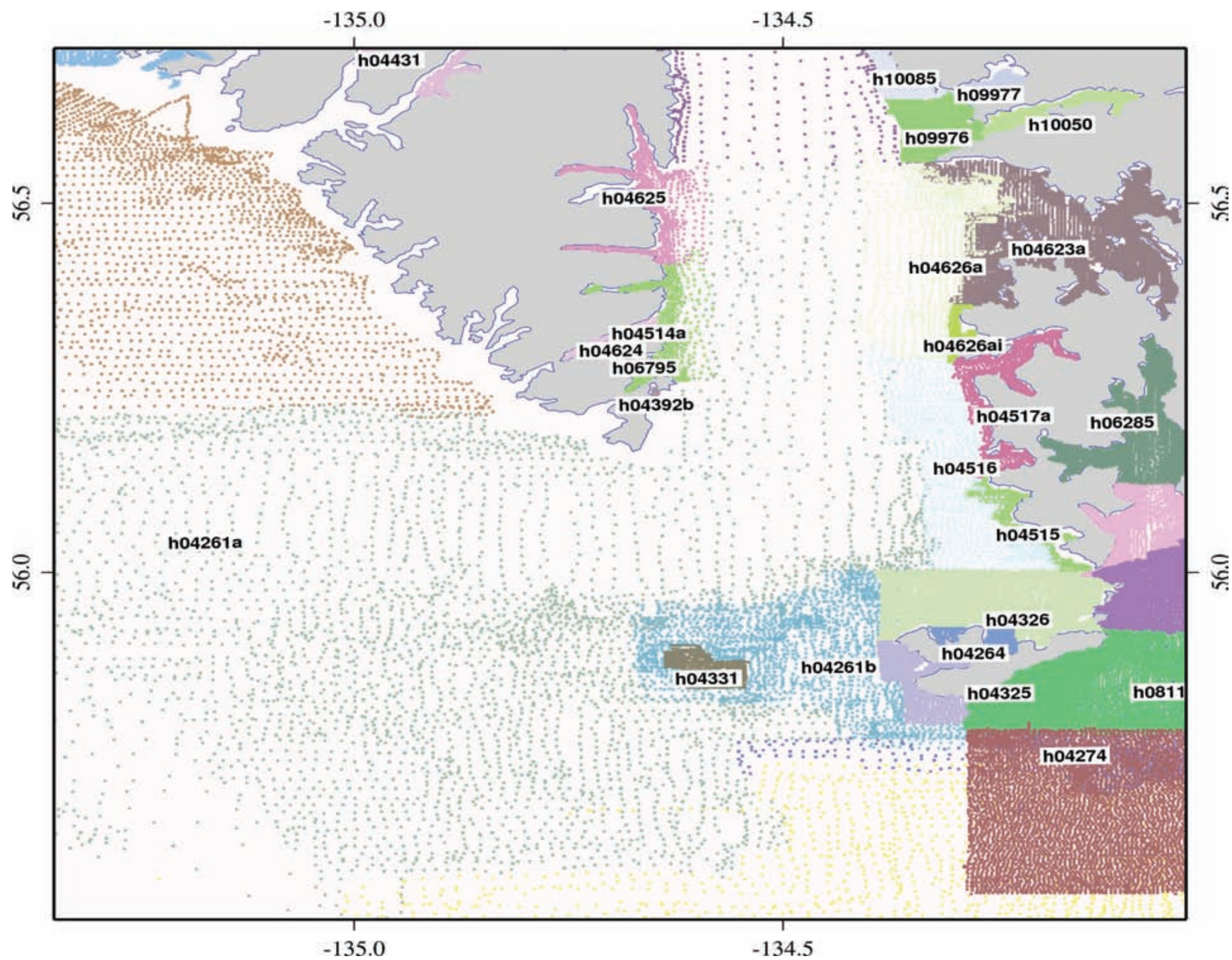

Figure 7. Digital NOS hydrographic survey coverage in the Port Alexander region. Several older surveys were not used as they have been superseded by more recent surveys. Land areas shown in tan. Regions where NOS data were not available are shown in white.

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

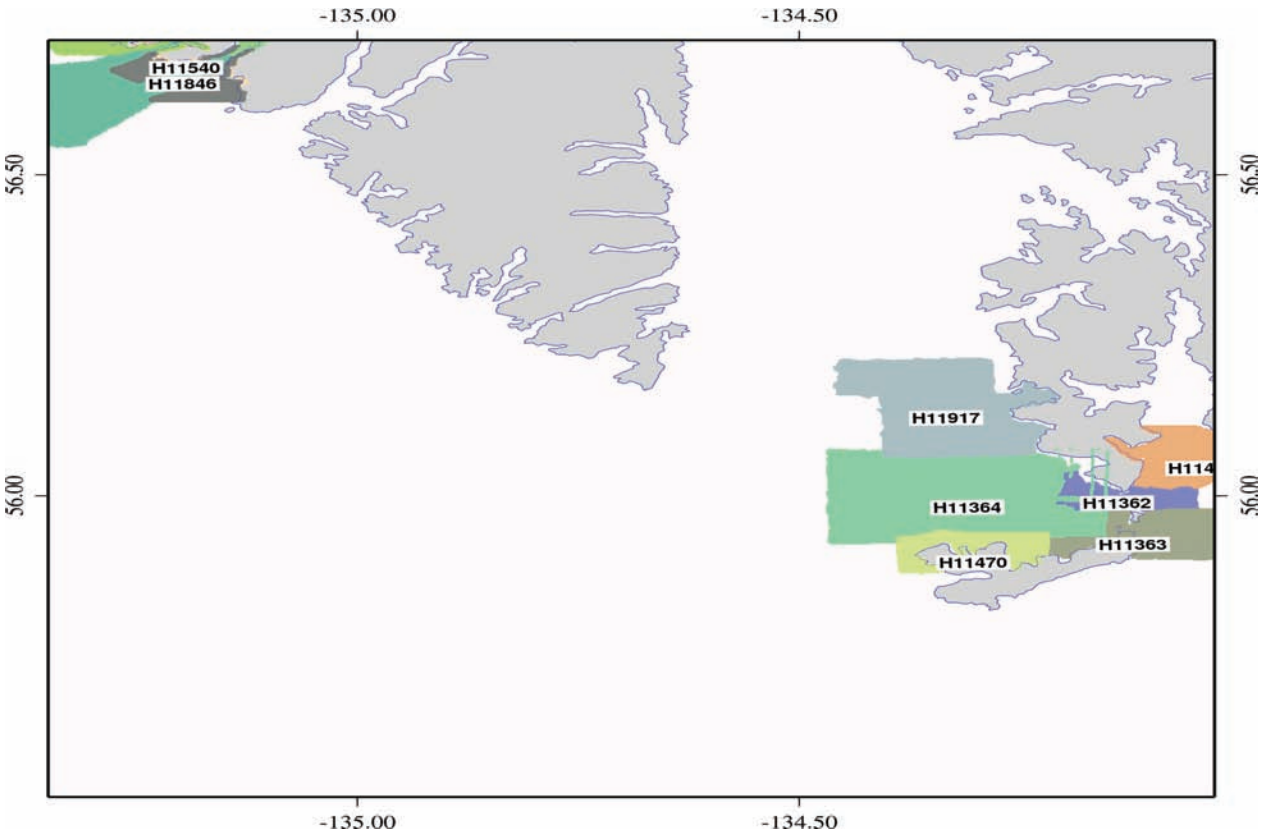

Figure 8. Spatial coverage of digital NOS hydrographic surveys in BAG format in the Port Alexander, Alaska region. Land areas shown in tan.

2) NGDC multibeam swath sonar surveys

Nine multibeam swath sonar surveys were available from the NGDC multibeam bathymetry database for use in building the Port Alexander DEM (Fig. 9). The data were referenced to WGS 84 geographic horizontal datum and were assumed to be referenced to MSL vertical datum. The data were gridded at 3 arc-seconds at extents approximately 5 percent (~0.10 degree) larger than the 8 arc-second DEM extents using *MB-System*[7] (http://www.ldeo.columbia.edu/res/pi/MB-System/). The grids were converted to xyz format and viewed in *QT Modeler* for quality analysis. Editing was done using *QT Modeler* and *ArcMap* to eliminate errors where survey data overlapped. The elevations were then transformed from MSL to MHW (see Sec. 3.2.1) for use in the final gridding process.

7. *MB-System* is an open source software package for the processing and display of bathymetry and backscatter imagery data derived from multibeam, interferometry, and sidescan sonars. The source code for *MB-System* is freely available (for free) by anonymous ftp (including "point and click" access through these web pages). A complete description is provided in web pages accessed through the web site. *MB-System* was originally developed at the Lamont-Doherty Earth Observatory of Columbia University (L-DEO) and is now a collaborative effort between the Monterey Bay Aquarium Research Institute (MBARI) and L-DEO. The National Science Foundation has provided the primary support for *MB-System* development since 1993. The Packard Foundation has provided significant support through MBARI since 1998. Additional support has derived from SeaBeam Instruments (1994-1997), NOAA (2002-2004), and others. URL: http://www.ldeo.columbia.edu/res/pi/MB-System/ [Extracted from *MB-System* web site.]

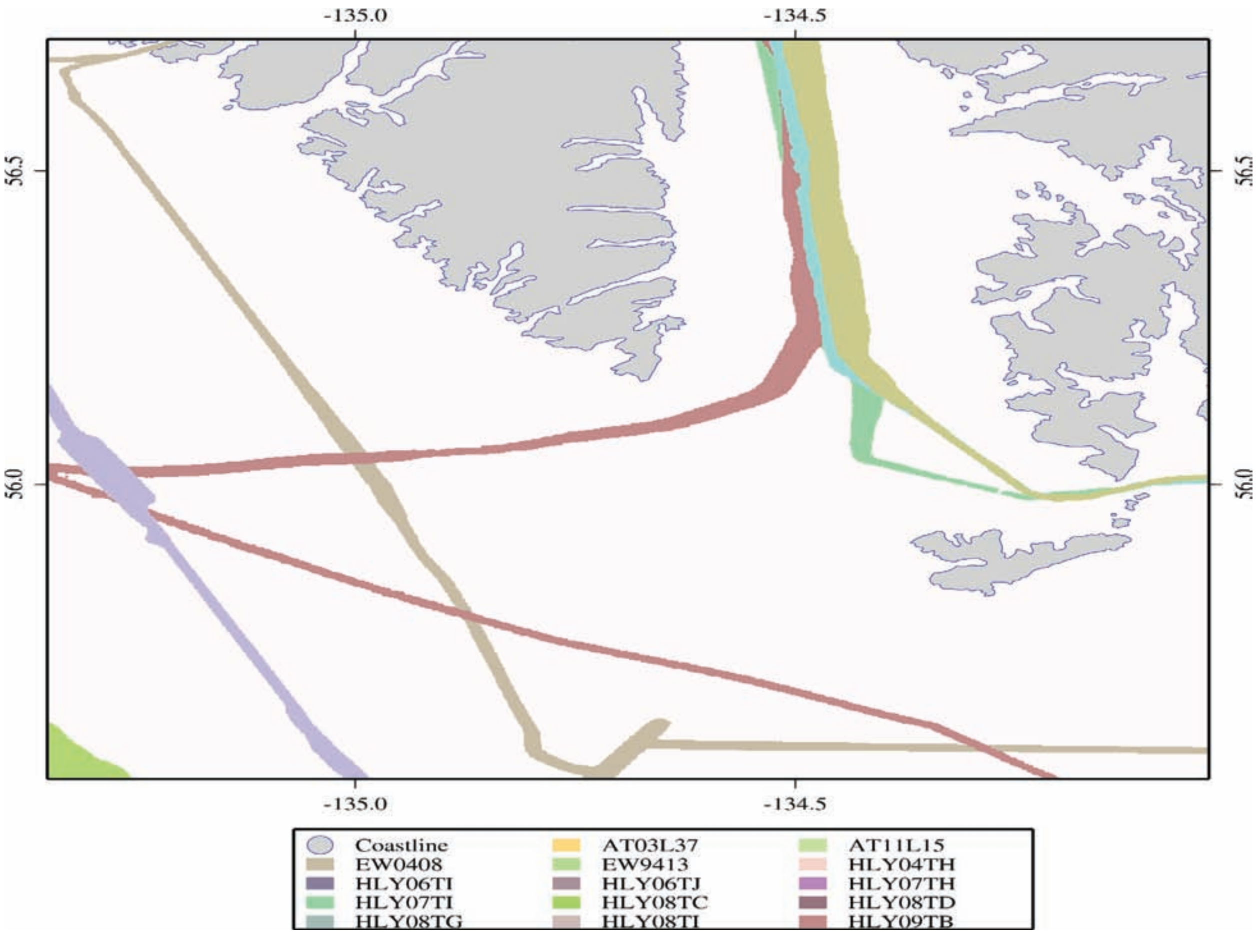

Figure 9. NGDC Multibeam survey coverage in the Port Alexander region.

3) Electronic navigation chart soundings

Soundings from seven ENCs were used to supplement other bathymetric data, particularly in the deep water (Fig. 10; Appendix B). The ENCs were downloaded from NOAA's Office of Coast Survey website and were horizontally referenced to WGS 84 geographic. ENC soundings were included in the gridding process only in regions where higher resolution and/or newer datasets were unavailable. The extracted soundings were transformed from a vertical datum of MLLW to MHW (see Section 3.2.1).

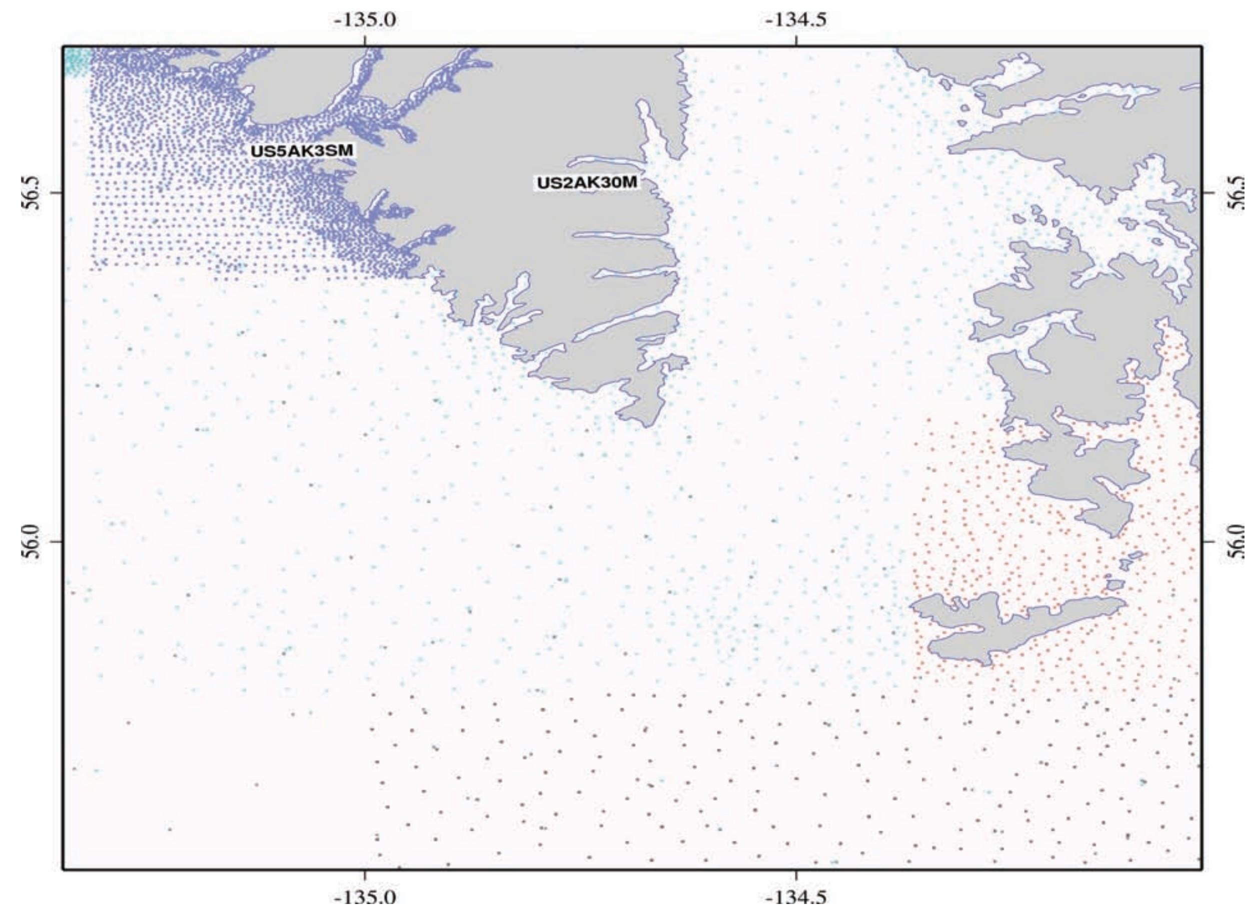

Figure 10. Spatial coverage of ENC soundings in the Port Alexander, Alaska region. Land areas shown in tan.

3.1.3 Topography

Topographic datasets of the Port Alexander, Alaska region were obtained from the USGS and the NASA Jet Propulsion Laboratory (Table 4; Fig. 11). In addition, NGDC digitized elevation points to better represent several breakwaters, jetties, and bridge pilings along Gastineau Channel in the vicinity of Juneau as they were not resolved completely in the other topographic datasets.

NGDC reviewed the USGS National Elevation Dataset (http://ned.usgs.gov/) 2 arc-second gridded topography. The dataset was derived from USGS quadrangle maps and aerial photographs based on topographic surveys conducted in the 1970s and 1980s. The NED data were not used in the development of the Port Alexander DEM due to the following: morphological changes in regions of rapid deglaciation across Alaska; lateral shifts in the NED discovered during prior DEM development in Alaska (see Caldwell et al., 2009 for further details); and lower resolution than other available topographic datasets.

Table 4. Topographic datasets used in compiling the Port Alexander DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*	*URL*
NASA SRTM	2000	Topographic DEM	1 arc-second	WGS 84 geographic	WGS 84/ EGM 96 Geoid (meters)	http://srtm.usgs.gov/
NASA ASTER	2009	Topographic DEM	1 arc-second	WGS 84 geographic	WGS 84/ EGM 96 Geoid (meters)	http://asterweb.jpl.nasa.gov/gdem.asp/
NGDC	2009	Digitized elevation points	~ 10 meters	WGS 84 geographic	MHW	

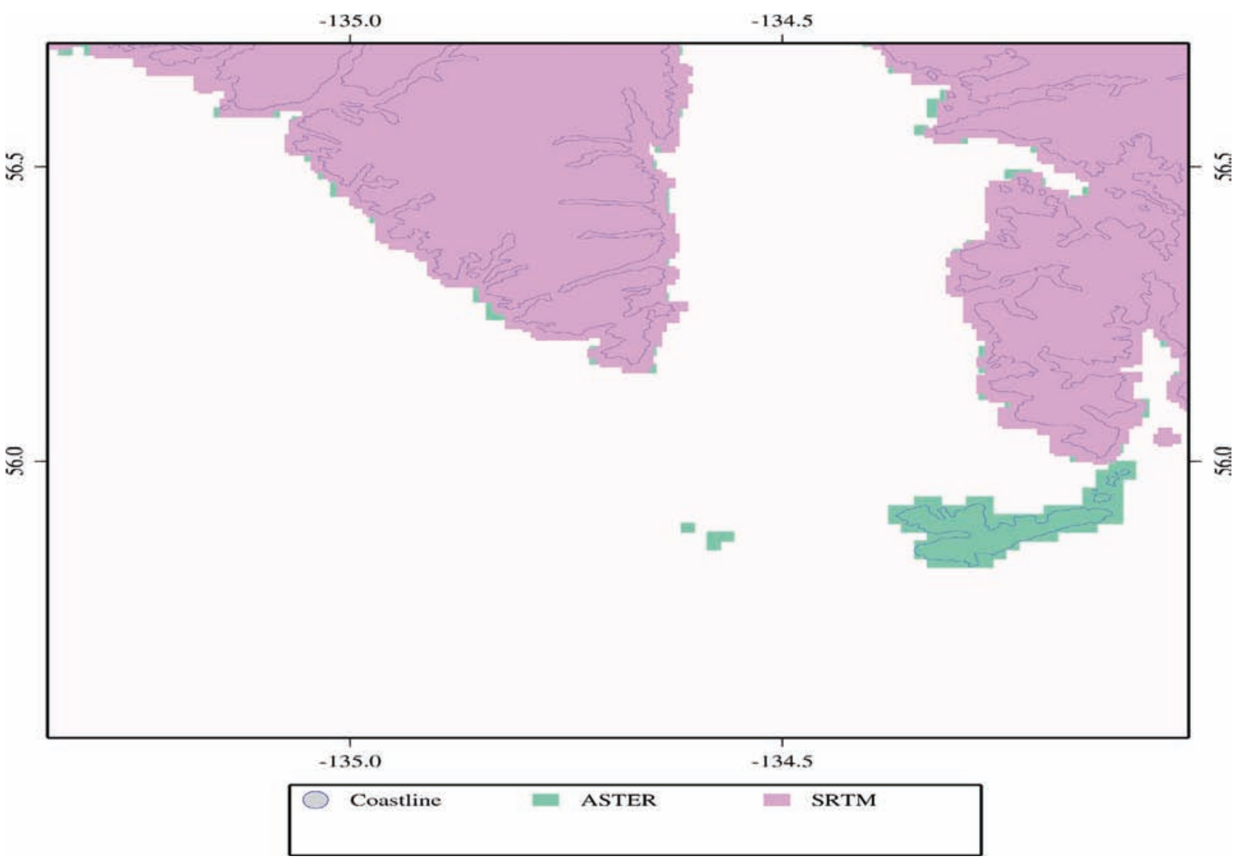

Figure 11. Source and coverage of topographic datasets used in compiling the Port Alexander DEM. Areas of water indicated in white.

1) 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 a complete high-resolution digital topographic database of Earth[8]. 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 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 Port Alexander, Alaska region, the data have 1 arc-second spacing and are referenced to the WGS 84/EGM 96 Geoid. The SRTM provides nearly complete coverage of Prince William Sound but exhibits numerous small areas with "no data" values necessitating the use of the ASTER data in these areas (see Fig. 11). The SRTM DEM also contains values over the open ocean, which were deleted by clipping the data to the final coastline.

2) NASA ASTER topography

ASTER provides complete 1 arc-second topographic data coverage of Alaska[9]. Data are in WGS 84 geographic coordinates and vertically referenced to the WGS 84/EGM 96 Geoid. The dataset is available for download as 1 degree x 1 degree raster files. The extracted non-bare-earth elevations have a vertical accuracy of +/- 20 meters and horizontal accuracy of +/- 30 meters, both at the 95 percent confidence level.

The ASTER data contain values over the open ocean, which were deleted by clipping the data to the final coastline. As discussed, the ASTER data was used to fill "no data" regions within the SRTM dataset (see Fig. 19). The ASTER data were not used as the primary topographic dataset due to the improper representation of areas along the immediate coastline. NGDC considered the SRTM to be most representative of the current coastal morphology, particularly in the immediate vicinity of Port Alexander.

3) NGDC digitized elevation points

Several jetties, breakwaters, and large bridge pilings were not resolved completely in the topographic datasets. Using the nearby elevations from SRTM and ASTER, a point shapefile was created using elevations of 1 or 1.5 meters at MHW to best represent these features in the final DEM.

8. 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]

9. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's Earth Remote Sensing Data Analysis Center (ERSDAC). ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. The three EOS platforms are part of NASA's Science Mission Directorate and the Earth-Sun System, whose goal is to observe, understand, and model the Earth system to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. METI and NASA announced the release of the ASTER Global Digital Elevation Model (GDEM) on June 29, 2009. The GDEM was created by stereo-correlating the 1.3 million scene ASTER visible and near-infrared (VNIR) archive, covering the Earth's land surface between 83N and 83S latitudes. The GDEM is produced with 30 meter postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files. Each GDEM file is accompanied by a Quality Assessment file, either giving the number of ASTER scenes used to calculate a pixel's value, or indicating the source of external DEM data used to fill the ASTER voids [Extracted from NASA JPL ASTER website]

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Port Alexander DEM was originally referenced to a number of vertical datums including MLLW (feet and meters), MLW, MSL, MHW, WGS 84/EGM 96 Geoid, and undefined (assumed to be MSL). All datasets were transformed to MHW for modeling of maximum flooding. Vertical datum transformations to MHW were accomplished using *Proj4* and *GDAL*, based upon data from tide stations, a DART buoy, and dominant tidal components (Brown et al., 1989) in the region.

NGDC created two offset grids approximating the relationship between MHW and MLLW, and MHW and MSL for the Southeast Alaska region. The grids were built in *ArcGIS* using the 'Kriging' tool and the differences, in meters, between the vertical datums as measured at 8 NOAA tide stations (http://tidesandcurrents.noaa.gov/), 10 tide prediction sites (http://co-ops.nos.noaa.gov/tides05/tab2wc2b.html), one deep-ocean DART buoy (http://www.ndbc.noaa.gov/dart.shtml), and 74 CHS tide stations (Appendix C; Figs. 12-14). In using the differences between the vertical datums, the final offsets grids contained negative values (Figs. 12-14).

1) **Bathymetric data**

   The NOS hydrographic surveys, multibeam swath sonar surveys, ENC soundings, and USACE surveys were transformed from either MSL to MHW or MLLW to MHW by adding the corresponding grid value to the point elevation value using *GDAL* . For the two remaining MLW surveys, NGDC first converted the surveys to MHW using the MLLW to MHW conversion grid and then adjusted the values by +0.41, the average difference between MLLW and MLW at the NOAA tide stations, tide prediction sites, and DART buoy.

2) **Topographic data**

   The topographic datasets were originally referenced to WGS 84/EGM 96 Geoid. There are no survey markers in Southeast Alaska that relate the geodetic datum to local tidal datums. Therefore, it was assumed that the datum is essentially equivalent to MSL in this area. Conversion to MHW, using *GDAL*, was accomplished by adding the MSL to MHW offset grid. Values less than 1 meter following the conversion were set equal to 1 meter, as both the SRTM and ASTER data are in integer format.

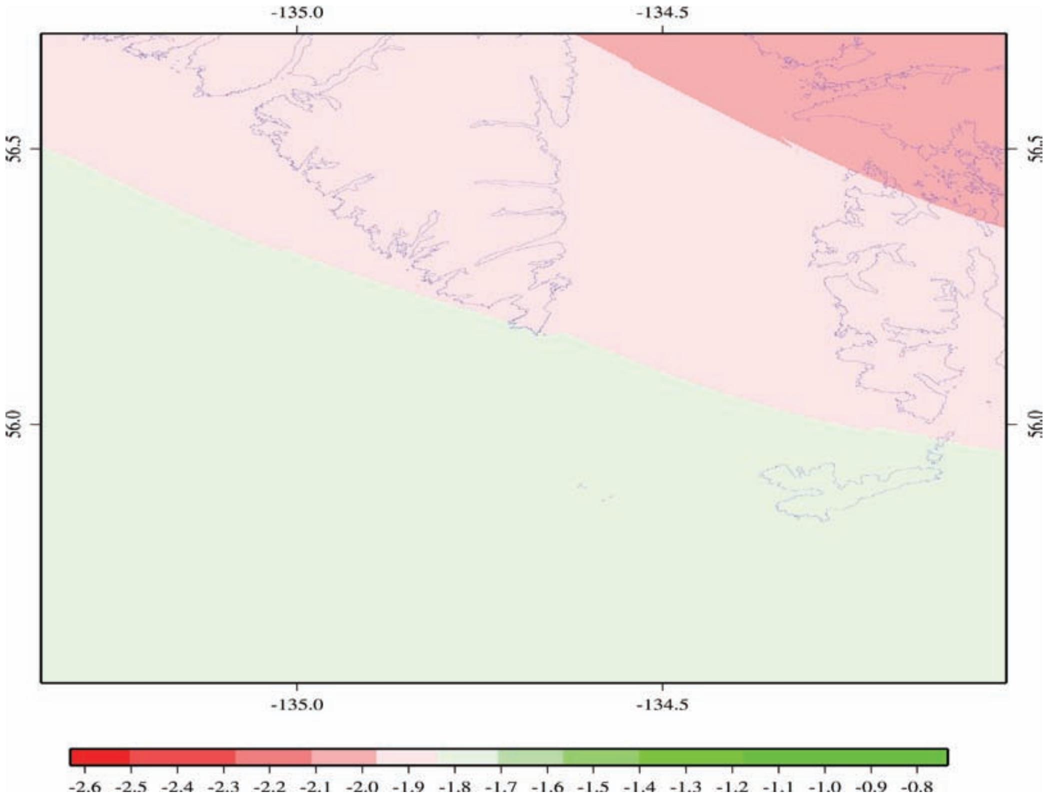

Figure 12. The MLLW to MSL regional offset grid used to convert between vertical datums. Tide stations, tide prediction sites, and DART buoy are shown in orange. Coastline is in blue.

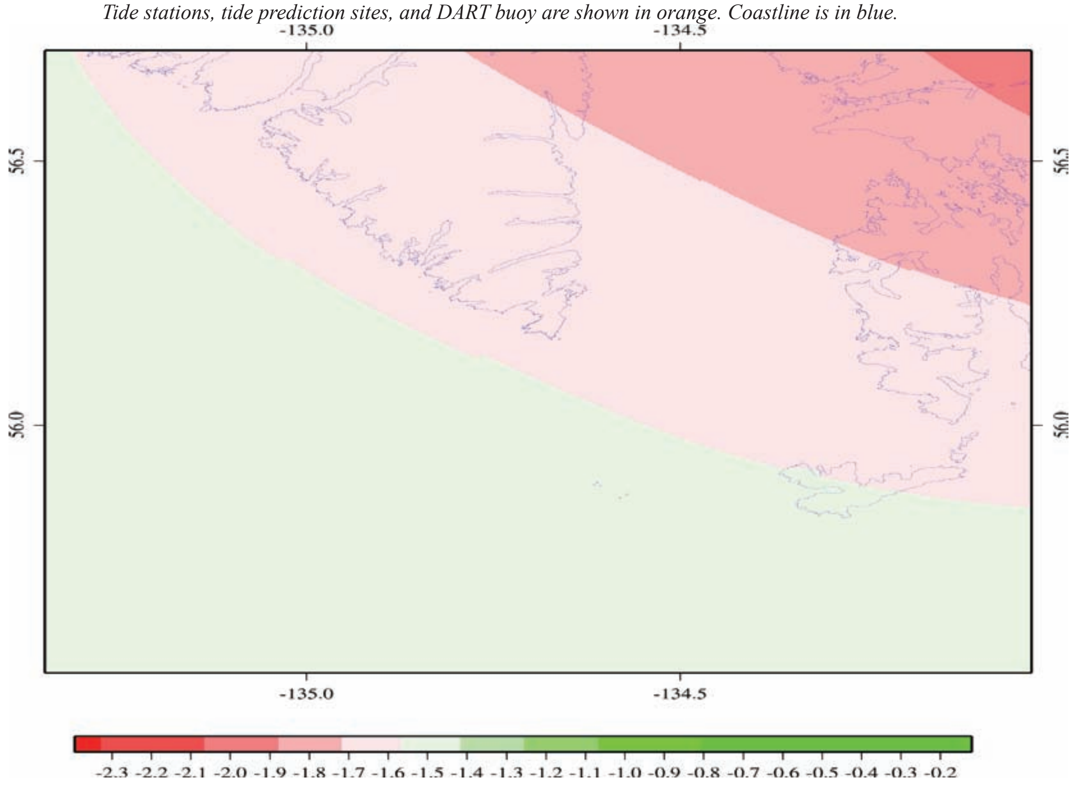

Figure 13. The MSL to MHHW offset grid used to convert between vertical datums. Tide stations, tide prediction sites, and DART buoy are shown. Coastline is in black.

3.2.2 Horizontal datum transformations

Datasets used to compile the Port Alexander DEM were originally referenced to WGS 84 geographic, NAD 83 geographic, NAD 83 UTM Zone 8 North, NAD 83 UTM Zone 9 North, NAD 83 Alaska State Plane Zone I (feet and meters). The relationships and transformational equations between the geographic horizontal datums are well established. Transformations to NAD 83 geographic were accomplished using *Proj4*.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shapefiles were checked in *ArcMap* and *QTModeler* 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:

- Inconsistent, overlapping high-resolution bathymetric datasets. Older datasets were clipped to newer datasets when possible. Datasets were weighted based on quality and year during the gridding process.
- Data values over the ocean in the SRTM and ASTER DEM datasets. These datasets required automated clipping to the final coastline or were edited manually.
- Digital, measured bathymetric values from NOS surveys date back over 100 years. More recent data, such as the multibeam surveys, differed from older NOS data by as much as 70 meters vertically. The older NOS survey data were removed where more recent bathymetric data exists.
- Lack of bathymetric data in the delta regions of the Mendenhall and Stikine Rivers. An upper limit was set during the generation of the bathymetric surface to ensure depths near -0.50 meter in those regions.

3.3.2 Smoothing of bathymetric data

The older NOS hydrographic survey data and extracted ENC soundings are generally sparse at the resolution of the Port Alexander DEM in both deep water and in some areas close to shore. In order to reduce the effect of artifacts in the form of lines or "pimples" in the DEM due to the low resolution datasets, and to provide effective interpolation into the coastal zone, 'pre-surface' bathymetric grids in MHW vertical datum were generated using *GMT*[10].

A Port Alexander 1 arc-second, 'pre-surface' grid was compiled from NOS hydrographic point data, USACE surveys, ENC soundings, 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 assigned values of -0.23 meter, the average difference between MHW and MHHW at the NOAA tide stations, 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 a 1 arc-second grid. The *GMT* tool 'surface' was then applied to interpolate values for 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' for viewing in ESRI *ArcMap*. *GDAL* software was used to clip the grid to the final coastline to eliminate data interpolation into land areas.

The 'pre-surface' grid was compared with the original soundings to ensure grid accuracy, and then exported as an xyz file for use in the final gridding process (Table 9; Figs. 15 and 16). The statistical analyses of the differences between the 1 arc-second bathymetric surface at Port Alexander with the NOS hydrographic surveys and NGDC multibeam swath sonar surveys show that the majority of the surveys are in good agreement (Figs. 23 and 24) with the bathymetric surface. The few exceptions where the differences reached up to 36.13 meters are attributed to rugged bathymetry or overlapping datasets, where two or more closely positioned points were averaged to obtain the elevation of one grid cell. Some inconsistencies were identified while merging the bathymetric datasets due to the range in ages and resolutions of the surveys. In areas where more recent data were available, the older surveys were either edited or not used. The gridded bathymetric surfaces were then converted to xyz files for use in building the final DEM.

10. GMT is an open source collection of ~60 tools for manipulating geographic and Cartesian data sets (including filtering, trend fitting, gridding, projecting, etc.) and producing Encapsulated PostScript File (EPS) illustrations ranging from simple x-y plots via contour maps to artificially illuminated surfaces and 3-D perspective views. GMT supports ~30 map projections and transformations and comes with support data such as GSHHS coastlines, rivers, and political boundaries. GMT is developed and maintained by Paul Wessel and Walter H. F. Smith with help from a global set of volunteers, and is supported by the National Science Foundation. It is released under the GNU General Public License. URL: http://gmt.soest.hawaii.edu/ [Extracted from GMT web site.]

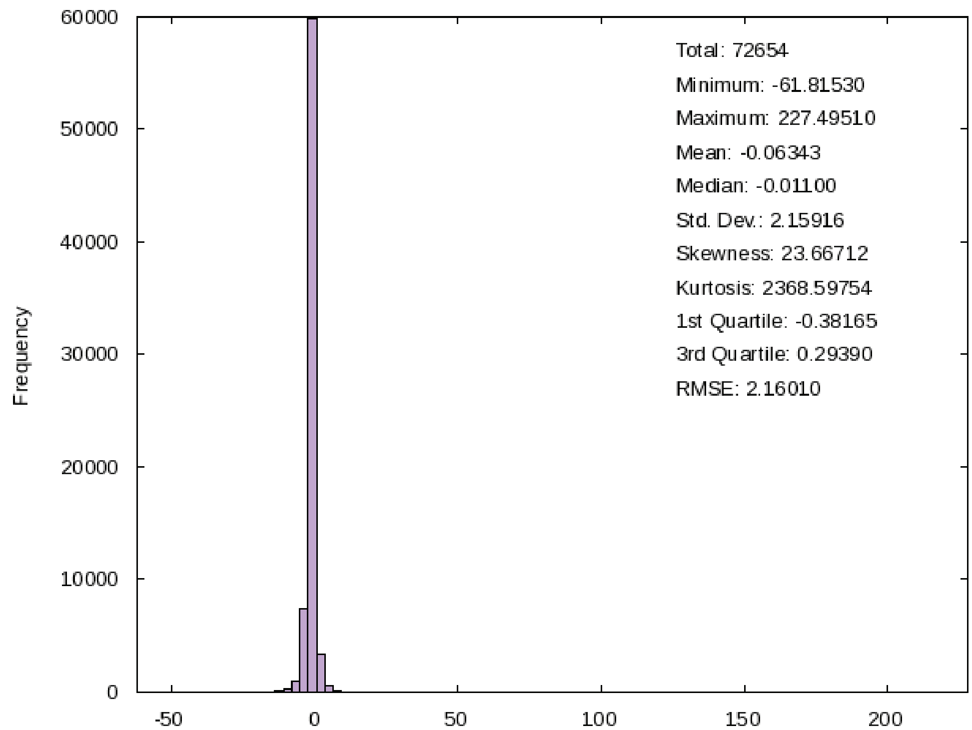

Figure 14. Histogram of the differences between NOS hydrographic surveys and the 1 arc-second pre-surfaced bathymetric grid.

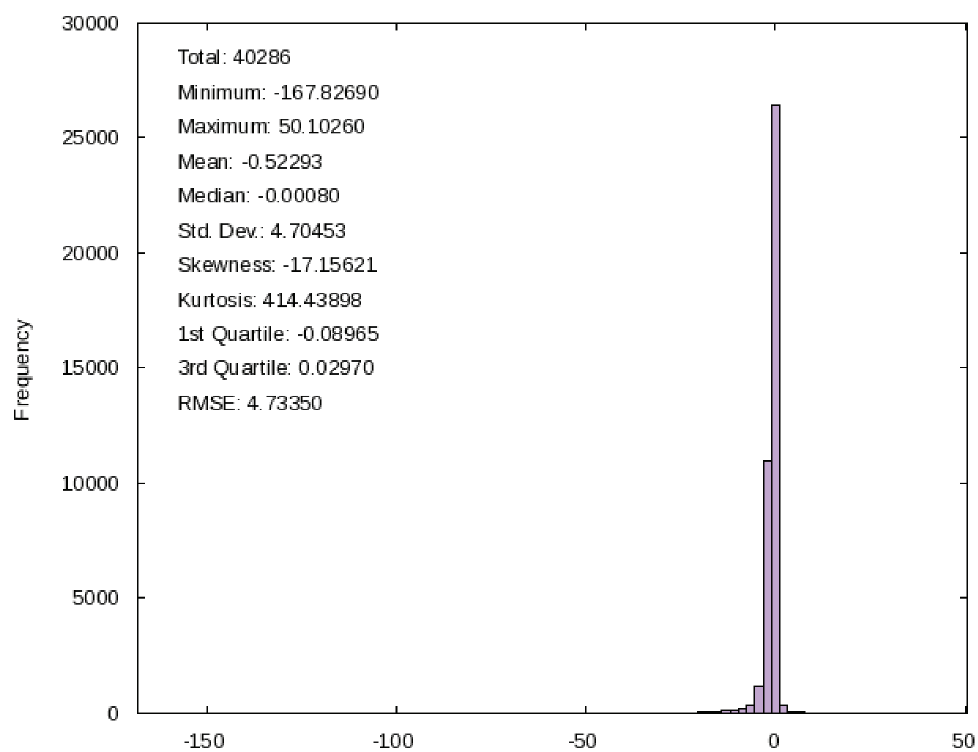

Figure 15. Histogram of the differences between NGDC multibeam swath sonar surveys and the 1 arc-second pre-surfaced bathymetric grid.

3.3.3 Building the DEM using MB-System

MB-System was used to create the Port Alexander DEM. The *MB-System* tool 'mbgrid' was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 6. Greatest weight was given to the high resolution multibeam surveys, NOS BAG data, USACE hydrographic surveys, and the NGDC digitized features. Least weight was given to the pre-surfaced bathymetric grid and ENC soundings.

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

Dataset	***Relative Gridding Weight***
NGDC multibeam	100
NGDC digitized features	100
NOS hydrographic surveys	10
ENC soundings	10
NASA SRTM	1
NASA ASTER	1
Pre-surfaced bathymetric grid	1

3.4 Quality Assessment of the DEM

3.4.1 *Horizontal accuracy*

The horizontal accuracy of topographic and bathymetric features in the Port Alexander DEM is dependent upon DEM cell size and source datasets. Topographic features have an estimated horizontal accuracy of 30 meters: SRTM has a horizontal accuracy of ~20 meters and ASTER, approximately 30 meters. Bathymetric features are resolved only to within a few hundreds of meters in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of sub-aerial topographic features. Positional accuracy is limited by the sparseness of deep-water soundings and potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 *Vertical accuracy*

Vertical accuracy of elevation values in the Port Alexander DEM is also dependent upon the source datasets contributing to DEM cell values. Topographic data have an estimated vertical accuracy between 16 meters for the SRTM DEM and 20 meters for the ASTER DEM. Bathymetric values have an estimated accuracy between 0.1 meters and 5% of water depth. Those values were derived from the wide range of sounding measurements from the early 20th century to recent, GPS-navigated multibeam swath sonar survey. Gridding interpolation to determine bathymetric values between sparse, poorly located NOS soundings degrades the vertical accuracy of elevations in deep water.

3.4.3 *Slope map and 3-D perspectives*

ESRI *ArcCatalog* was used to generate a slope grid from the 1/3 arc-second Port Alexander DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 17). The DEM was transformed to NAD 83 UTM Zone 8 North coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Analysis of preliminary grids using *QTModeler* revealed suspect data points, which were corrected before recompiling the DEM. Figure 1 shows a color image of the 1/3 arc-second Port Alexander DEM in its final version. Figure 18 shows a perspective rendering of the final 1/3 arc-second Port Alexander DEM. Figure 19 shows a data contribution plot of the Port Alexander DEM.

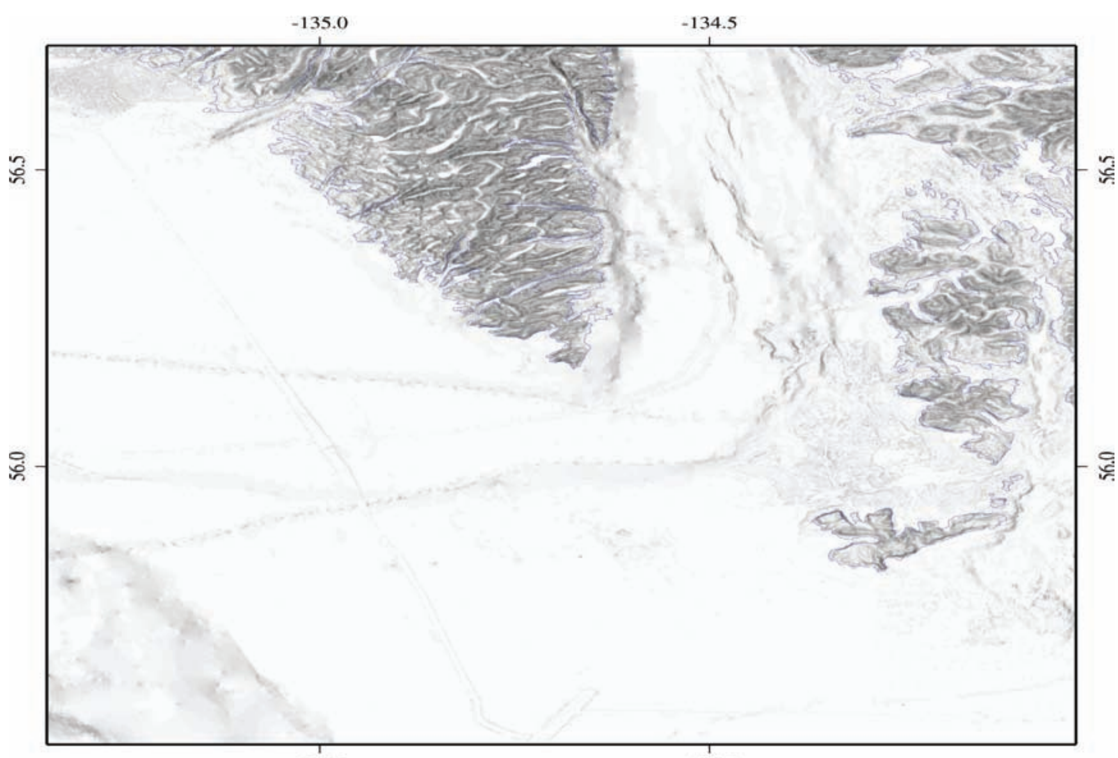

Figure 16. Slope map of the 1/3 arc-second Port Alexander DEM. Flat-lying slopes are shown in white; dark shading denotes steep slopes.

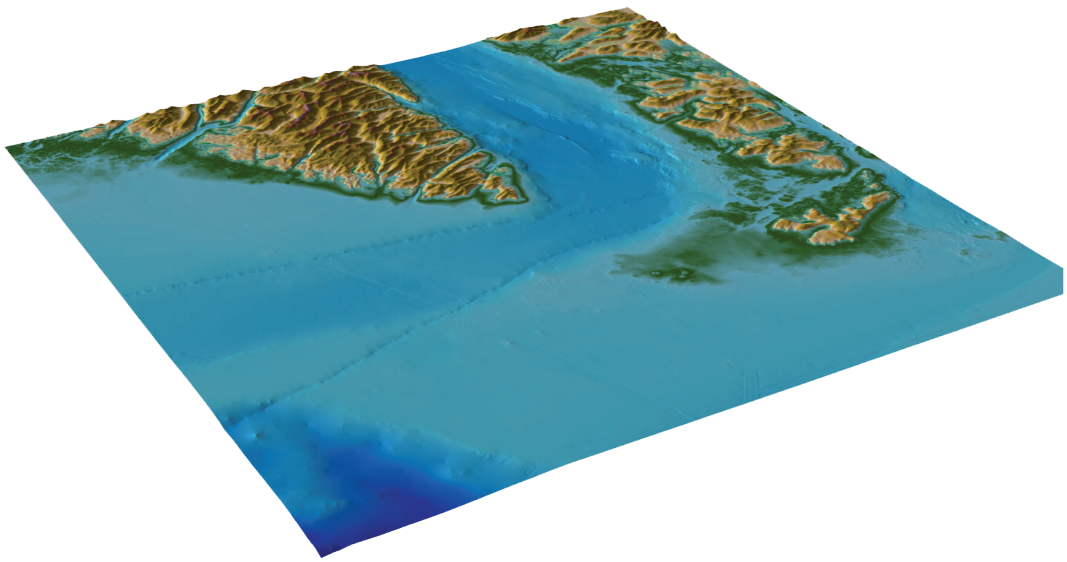

Figure 17. Perspective view from the southwest of the Port Alexander DEM. Vertical exaggeration–times 2.

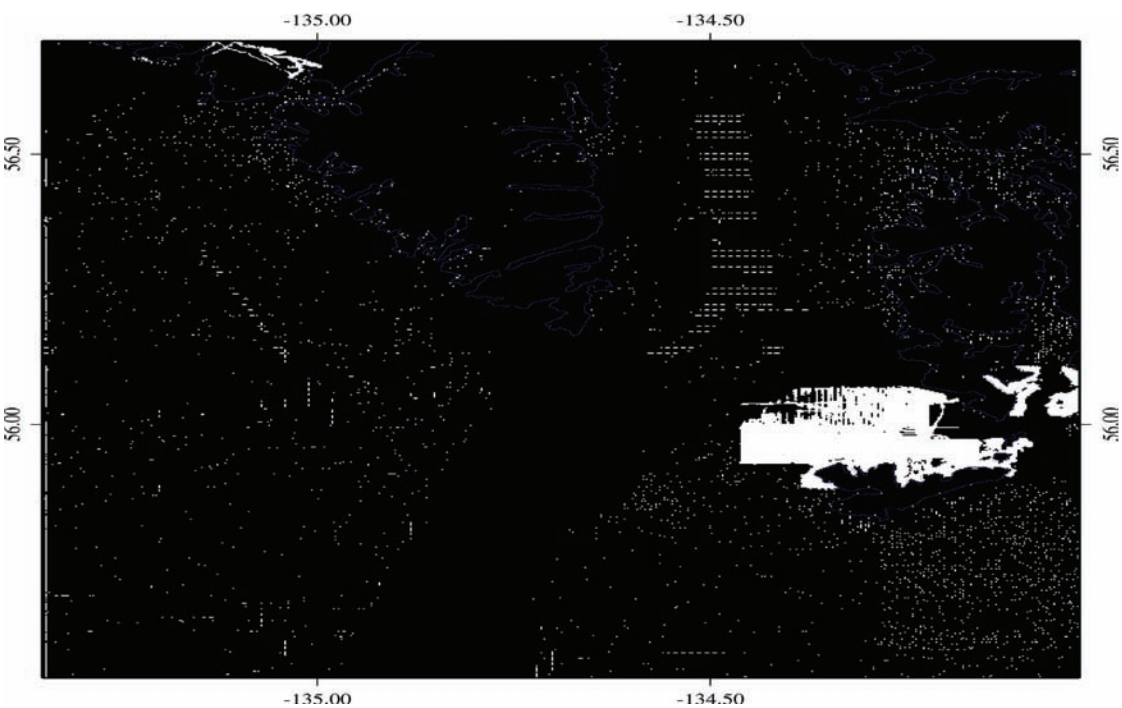

Figure 18. Data contribution plot of the Port Alexander DEM. Black depicts DEM cells constrained by source data; white depicts cells with elevation values derived from interpolation. Due to the scale of the image, sparse soundings may not be visible in the graphic. Coastline is shown in blue.

3.4.4 DEM comparison with source data files

To ensure grid accuracy, the Port Alexander DEM was compared to source data files. A histogram of the differences between the SRTM and ASTER topographic DEMs and the Port Alexander DEM are shown in Figures 20 and 21. Differences cluster around zero. The major differences in elevations in SRTM and ASTER data points with the grid (> 10 meters) are located in regions of steep slopes and forests, primarily along the coast.

Comparisons of the USACE hydrographic survey data and the Port Alexander DEM are shown in Figure 22. Largest differences occur where the USACE data overlap other higher resolution datasets, which may occur due to changes in dredged depths or sediment deposition in channels.

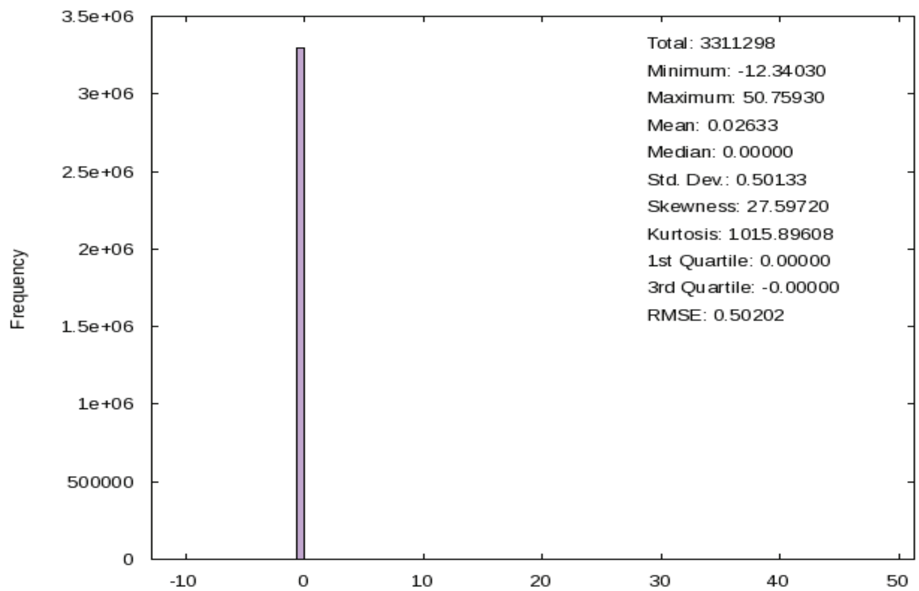

Figure 19. Histogram of the differences between the SRTM 1 arc-second topographic DEM data points and the Port Alexander DEM.

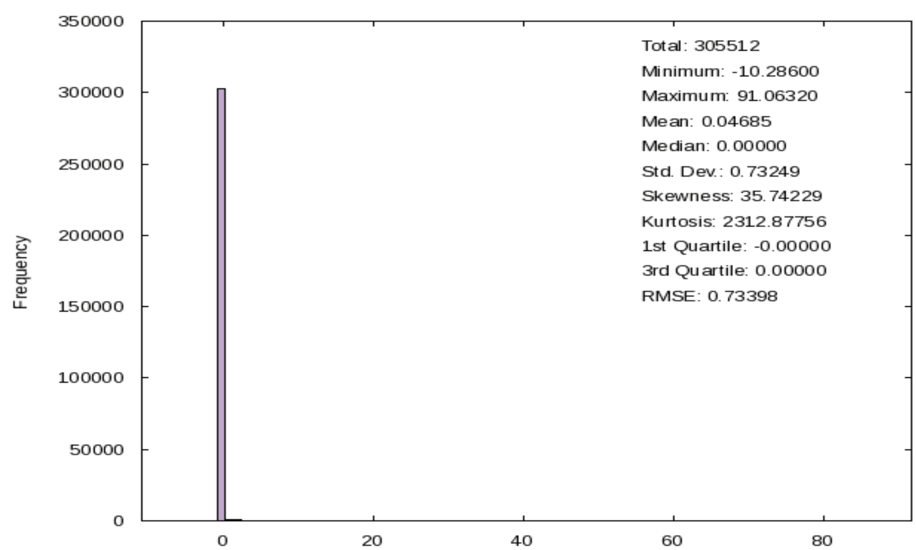

Figure 20. Histogram of the differences between the ASTER 1 arc-second DEM data points and the Port Alexander DEM.

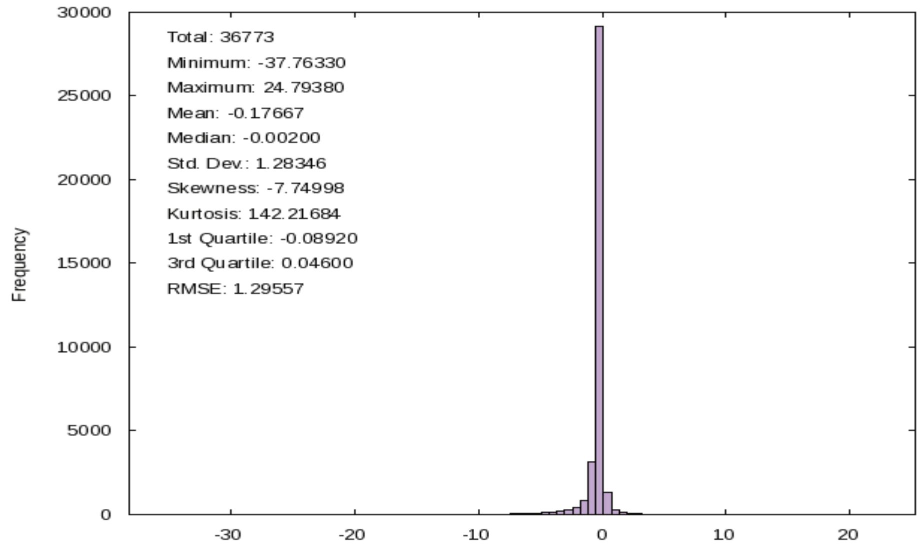

Figure 21. Histogram of the differences between the NGDC multibeam swath sonar surveys and the Port Alexander DEM.

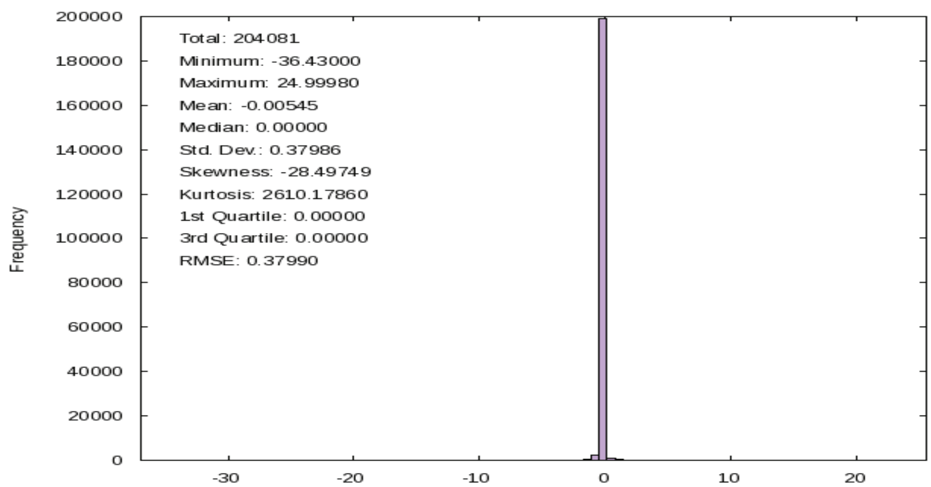

Figure 22. Histogram of the differences between the NOS Hydro data points and the Port Alexander DEM.

4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of Port Alexander, Alaska, with cell size of 1/3 arc-seconds, was developed for the Pacific Marine Environmental Labratory (PMEL) and the National Tsunami Hazard Mitigation Program in support of the State of Alaska's tsunami inundation modeling efforts led by the Geophysical Institute at the University of Alaska at Fairbanks. The best available digital data from U.S. federal, state, local, and academic 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*, ESRI *ArcGIS World Imagery 2-D*, *GMT*, *MB-System*, *QT Modeler*, *GDAL, Proj4,* and *VDatum* software.

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

- Conduct a high-resolution topographic lidar surveys near Port Alexander and Sitka.
- Establish, via survey, relationships between tidal and geodetic datums in the Southeast Alaska region.
- Determine the relationship between Early Alaska and NAD 83/WGS 84 geographic horizontal datums.

5. Acknowledgments

The creation of the Port Alexander DEM was funded by the Pacific Marine Environmental Labratory (PMEL). The authors thank Nazila Meratia and Vasily Titov (PMEL).

6. References

Brown, J., A. Colling, D. Park, J. Phillips, D. Rothery, and J. Wright, 1989. Waves, Tides, and Shallow-Water Processes, Pergamon Press, New York, USA, 187 pp.

Caldwell, R.J., B.W. Eakins, and E. Lim, 2009. Digital Elevation Models of Prince William Sound, Alaska: Procedures, Data Sources, and Analysis, U.S. Department of Commerce, NOAA, National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/inundation/nthmp/data/prince_william_sound_ak/prince_william_sound_ak.pdf.

Lim, E., L.A. Taylor, B.W. Eakins, K.S. Carignan, R.R. Warnken, and P.R. Grothe, 2009. Digital Elevation Models of Craig, Alaska: Procedures, Data Sources, and Analysis, U.S. Department of Commerce, NOAA Technical Memorandum NESDIS NGDC-27, March 2009, http://www.ngdc.noaa.gov/mgg/inundation/tigp/ngdc/data/craig_ak/craig_ak.pdf.

Nautical Chart #50 (ENC and RNC), 6th Edition, 2003. North Pacific Ocean (eastern part) Bering Sea Continuation. Scale 1:10,000,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #500 (ENC and RNC), 8th Edition, 2003. West Coast Of North America - Dixon Entrance To Unimak Pass. Scale 1:3,500,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #501 (ENC and RNC), 13th Edition, 2009. North Pacific Ocean West Coast Of North America - Mexican Border To Dixon Entrance. Scale 1:3,500,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #530 (ENC and RNC), 32nd Edition, 2007. North America West Coast - San Diego to Aleutian Islands and Hawaiian Islands. Scale 1:4,860,700. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #531 (ENC and RNC), 24th Edition, 2007. Gulf of Alaska - Strait of Juan de Fuca to Kodiak Island. Scale 1:2,100,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16016 (ENC and RNC), 21st Edition, 2007. Dixon Entrance to Cape St. Elias. Scale 1:969,756. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16760 (ENC and RNC), 10th Edition, 2000. Cross Sound to Yakutat Bay. Scale 1:300,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16762 (RNC), 9th Edition, 2002. Lituya Bay - Lituya Bay Entrance. Scale 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17300 (ENC and RNC), 31st Edition, 2005. Stephens Passage to Cross Sound, including Lynn Canal. Scale 1:100,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17301 (ENC and RNC), 8th Edition, 1998. Cape Spencer to Icy Point. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17302 (ENC and RNC), 18th Edition, 2002. Icy Strait and Cross Sound; Inian Cove; Port Alexander. Scale 1:80,000 with 1:20,000 and 1:10,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17303 (RNC), 10th Edition, 2004. Yakobi Island and Lisianski Inlet; Pelican Harbor. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17311 (RNC), 1st Edition, 2000. Holkham Bay and Tracy Arm - Stephens Passage. Scale 1:40,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17312 (RNC), 2nd Edition, 2005. Hawk Inlet, Chatham Strait. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17313 (RNC), 9th Edition, 2009. Port Snettisham. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17314 (RNC), 12th Edition, 1998. Slocum and Limestone Inlets and Taku Harbor. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17315 (ENC and RNC), 24th Edition, 2006. Gastineau Channel and Taku Inlet; Juneau Harbor. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17316 (ENC and RNC), 20th Edition, 2002. Lynn Canal-Icy Strait to Point Sherman;Funter Bay; Chatham Strait. Scale 1:80,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17317 (RNC), 20th Edition, 2004. Lynn Canal-Point Sherman to Skagway; Lutak Inlet; Skagway and Nahku Bay; Portage Cove, Chilkoot Inlet. Scale 1:77,812 with 1:20,000 and 1:10,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17318 (RNC), 1st Edition, 2009. Glacier Bay; Bartlett Cove. Scale 1:80,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17320 (ENC and RNC), 18th Edition, 2008. Coronation Island to Lisianski Strait. Scale 1:217,828. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17321 (RNC), 9th Edition, 2004. Cape Edward to Lisianski Strait, Chichagof Island. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17322 (RNC), 10th Edition, 2005. Khaz Bay, Chichagof Island Elbow Passage. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17323 (RNC), 12th Edition, 2006. Salisbury Sound, Peril Strait and Hoonah Sound. Scale 1:40,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17324 (RNC), 15th Edition, 2007. Sitka Sound to Salisbury Sound, Inside Passage; Neva Strait-Neva Point to Zeal Point. Scale 1:40,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17325 (RNC), 9th Edition, 2006. South and West Coasts of Kruzof Island. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17326 (ENC and RNC), 16th Edition, 2007. Crawfish Inlet to Sitka, Baranof Island; Sawmill Cove. Scale 1:40,000 with 1:5,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17327 (RNC), 23rd Edition, 2008. Sitka Harbor and approaches; Sitka Harbor. Scale 1:10,000 with 1:5,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17328 (ENC and RNC), 7th Edition, 2003. Snipe Bay to Crawfish Inlet, Baranof lsland. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17330 (RNC), 9th Edition, 2007. West Coast of Baranof Island - Cape Ommaney to Byron Bay. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17331 (RNC), 8th Edition, 2007. Chatham Strait - Ports Alexander, Conclusion, and Armstrong. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17333 (RNC), 9th Edition, 2007. Ports Herbert, Walter, Lucy and Armstrong. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17335 (RNC), 7th Edition, 2004. Patterson Bay and Deep Cove. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17336 (RNC), 9th Edition, 2007. Harbors in Chatham Strait and vicinity - Gut Bay, Chatham Strait; Hoggatt Bay, Chatham Strait; Red Bluff Bay, Chatham Strait; Herring Bay and Chapin Bay, Frederick Sound; Surprise Harbor, and Murder Cove, Frederick Sound. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17337 (RNC), 9th Edition, 2004. Harbors in Chatham Strait Kelp Bay;Warm Spring Bay; Takatz and Kasnyku Bays. Scale 1:40,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17338 (RNC), 14th Edition, 2005. Peril Strait - Hoonah Sound to Chatham Strait. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17339 (RNC), 12th Edition, 2007. Hood Bay and Kootznahoo Inlet. Scale 1:30,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17341 (RNC), 9th Edition, 2007. Whitewater Bay and Chaik Bay, Chatham Strait. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17360 (ENC and RNC), 35th Edition, 2008. Etolin Island to Midway Islands, including Sumner Strait; Holkham Bay; Big Castle Island. Scale 1:217,828 with 1:40,000 and 1:20,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17362 (RNC), 10th Edition, 1996. Gambier Bay, Stephens Passage. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17363 (RNC), 13th Edition, 1997. Pybus Bay, Frederick Sound; Hobart and Windham Bays, Stephens Passage. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17365 (RNC), 12th Edition, 1997. Woewodski and Eliza Harbors.; Fanshaw Bay and Cleveland Passage. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17367 (RNC), 11th Edition, 1998. Thomas, Farragut, and Portage Bays, Frederick Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17368 (ENC and RNC), 7th Edition, 2006. Keku Strait-northern part, including Saginaw and Security Bays and Port Camden; Kake Inset. Scale 1:40,000 with 1:15,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17370 (RNC), 11th Edition, 2006. Bay of Pillars and Rowan Bay, Chatham Strait; Washington Bay, Chatham Strait. Scale 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17372 (ENC and RNC), 11th Edition, 2003. Keku Strait-Monte Carlo Island to Entrance Island; The Summit; Devils Elbow. Scale 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17375 (ENC and RNC), 22nd Edition, 2009. Wrangell Narrows; Petersburg Harbor. Scale 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17376 (RNC), 8th Edition, 2008. Tebenkof Bay and Port Malmesbury. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17377 (RNC), 1st Edition, 1999. Le Conte Bay. Scale 1:25,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17378 (RNC), 14th Edition, 2004. Port Protection, Prince of Wales Island. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17379 (RNC), 1st Edition, 2002. Shakan Bay And Strait, Alaska. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17381 (RNC), 10th Edition, 2002. Red Bay, Prince of Wales Island. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17382 (ENC and RNC), 17th Edition, 2007. Zarembo Island and Approaches. Scale 1:80,000 with 1:40,000 and 1:20,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17383 (RNC), 3rd Edition, 2005. Snow Passage, Alaska. Scale 1:30,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17384 (ENC and RNC), 9th Edition, 2008. Wrangell Harbor and approaches. Scale 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17385 (ENC and RNC), 17th Edition, 2009. Ernest Sound-Eastern Passage and Zimovia Strait; Zimovia Strait. Scale 1:80,000 with 1:20,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17386 (RNC), 4th Edition, 2006. Sumner Strait-Southern part. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17387 (RNC), 13th Edition, 2001. Shakan and Shipley Bays and Part of El Capitan Passage; El Capitan Passage, Dry Pass to Shakan Strait. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17400 (ENC and RNC), 17th Edition, 2007. Dixon Entrance to Chatham Strait. Scale 1:229,376. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17401 (RNC), 12th Edition, 2006. Lake Bay and approaches, Clarence Strait. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17402 (RNC), 11th Edition, 2005. Southern Entrances to Sumner Strait. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17403 (RNC), 14th Edition, 2006. Davidson Inlet and Sea Otter Sound; Edna Bay. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17404 (ENC and RNC), 14th Edition, 2008. San Christoval Channel to Cape Lynch. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17405 (ENC and RNC), 16th Edition, 2008. Ulloa Channel to San Christoval Channel; North Entrance, Big Salt Lake; Shelter Cove, Craig. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17406 (ENC and RNC), 7th Edition, 2004. Baker, Noyes, and Lulu Islands and adjacent waters. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17407 (RNC), 15th Edition, 2003. Northern part of Tlevak Strait and Uloa Channel. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17408 (RNC), 8th Edition, 2004. Central Dall Island and vicinity. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17409 (RNC), 10th Edition, 2002. Southern Dall Island and vicinity. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17420 (ENC and RNC), 28th Edition, 2007. Hecate Strait to Etolin Island, including Behm and Portland Canals. Scale 1:229,376. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17422 (RNC), 9th Edition, 2006. Behm Canal-western part; Yes Bay. Scale 1:79,334 with 1:40,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17423 (RNC), 14th Edition, 2006. Harbor Charts-Clarence Strait and Behm Canal Dewey Anchorage, Etolin Island; Ratz Harbor, Prince of Wales Island; Naha Bay, Revillagigedo Island; Tolstoi and Thorne Bays, Prince of Wales lsland; Union Bay, Cleveland Peninsula. Scale 1:40,000, 1:20,000, and 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17424 (ENC and RNC), 9th Edition, 2009. Behm Canal-eastern part. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17425 (ENC and RNC), 6th Edition, 2002. Portland Canal-North of Hattie Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17426 (RNC), 15th Edition, 2006. Kasaan Bay, Clarence Strait; Hollis Anchorage, eastern part; Lyman Anchorage. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17427 (RNC), 7th Edition, 1998. Portland Canal - Dixon Entrance to Hattie Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17428 (ENC and RNC), 10th Edition, 2007. Revillagigedo Channel, Nichols Passage, and Tongass Narrows; Seal Cove; Ward Cove. Scale 1:40,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17430 (RNC), 11th Edition, 2005. Tongass Narrows. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17431 (RNC), 11th Edition, 2004. North End of Cordova Bay and Hetta Inlet. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17432 (RNC), 7th Edition, 2004. Clarence Strait and Moira Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17433 (RNC), 11th Edition, 2004. Kendrick Bay to Shipwreck Point, Prince of Wales Island. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17434 (RNC), 13th Edition, 2005. Revillagigedo Channel; Ryus Bay; Foggy Bay. Scale 1:80,000 with 1:40,000 and 1:20,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17435 (RNC), 16th Edition, 1999. Harbors in Clarence Strait Port Chester, Annette Island; Tamgas Harbor, Annette Island; Metlakatla Harbor. Scale 1:40,000 with 1:20,000 and 1:5,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17436 (RNC), 9th Edition, 2006. Clarence Strait, Cholmondeley Sound and Skowl Arm. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17437 (RNC), 9th Edition, 2004. Portland Inlet to Nakat Bay. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.3.1 – developed and licensed by ESRI, Redlands, California, http://www.esri.com/.

ESRI World Imagery (ESRI_Imagery_World_2D) – ESRI ArcGIS Resource Centers http://resources.esri.com/arcgisonlineservices/.

GDAL v. 1.7.1 – Geographic Data Abstraction Library is a translator library maintained by Frank Warmerdam, http://gdal.org/.

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

GMT v. 4.3.4 – Generic Mapping Tools, freeware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/.

Gnuplot v. 4.2, free software developed and maintained by Thomas Williams, Colin Kelley, Russell Lang, Dave Kotz, John Campbell, Gershon Elber, Alexander Woo, http://www.gnuplot.info/.

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

Proj4 v. 4.7.0, free software developed by Gerald Evenden and maintained by Frank Warmerdam, http://trac.osgeo.org/proj/.

Quick Terrain Modeler v. 7.0.0 – LiDAR processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/.

VDatum Transformation Tool, developed and maintained by NOAA's National Geodetic Survey (NGS), Office of CoastSurvey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/.

Appendix A. NOS Hydro Data Tables

Survey ID	Year	Scale/Vertical Accuracy	Original Vertical Datum	Provided Horizontal Datum
H02333	1897	1:80,000	Undetermined	Undetermined
H04264	1922	1:20,000	Undetermined	Undetermined
H04274	1922	1:50,000	Undetermined	Undetermined
H04325	1923	1:20,000	Undetermined	Undetermined
H04326	1923	1:20,000	Undetermined	Undetermined
H04331	1923	1:30,000	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
H04431	1924	1:20,000	Undetermined	Undetermined
H04432	1924	1:80,000	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
H04515	1925	1:20,000	Undetermined	Undetermined
H04516	1925	1:40,000	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
H04530	1925	1:20,000	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
H04624	1926	1:20,000	Undetermined	Undetermined
H04625	1926	1:20,000	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
	Undetermined	Undetermined	Undetermined	Undetermined
H06284	1937	20,000	Undetermined	Undetermined
H06285	1937	20,000	Undetermined	Undetermined
H06795	1942	1,000	Undetermined	Undetermined
H08112	1960	1:20,000	Undetermined	Undetermined
H08444	1958	1:40,000	Undetermined	Undetermined
H08604	1960	20,000	Undetermined	Undetermined
H09083	1969	10,000	MLLW	North American Datum 1927
H09976	1981	10000	MLLW	North American Datum 1927
H09977	1981	10000	MLLW	North American Datum 1927
H10050	1982	10,000	MLLW	North American Datum 1927
H10085	1983	10,000	MLLW	North American Datum 1927

Appendix B. ENC Data Tables

Chart	Title	Edition	Edition Date	Format	Scale
US1WC02M	Gulf of Alaska Strait of Juan de Fuca to Kodiak Island	20.1	10/8/2010	ENC	1:2100000
US2AK30M	Dixon Entrance to Cape St. Elias	12	1/6/2011	ENC	1:969756
US3AK3CM	Etolin Island to Midway Islands, including Sumner Strait;Holkham Bay;Big Castle Island	2	7/30/2010	ENC	1:217828
US3AK40M	Dixon Entrance to Chatham Strait	2	5/5/2010	ENC	1:229376
US3AK4PM	Coronation Island to Lisianski Strait	9	3/21/2011	ENC	1:217828
US5AK3GM	Crawfish Inlet to Sitka, Baranof I.;Sawmill Cove	8.1	3/25/2009	ENC	1:40000
US5AK3SM	Snipe Bay to Crawfish Inlet,Baranof l.	6	1/5/2009	ENC	1:40000

Appendix C. Vertical Datums in Southeast Alaska

Name	*ID*	*Type*	*Source*	*Longitude*	*Latitude*	*MLLW*	*MLW*	*MSL*	*MHW*	*MHHW*
Baranof Warm Spring	9451625	TPS	NOAA	-134.825000	57.088333	1.501	1.971	3.713	5.428	5.701
Big Salt Lake	9450623	TPS	NOAA	-132.950000	55.600000	17.437	17.466	17.904	18.363	18.601
Craig	9450551	TPS	NOAA	-133.141667	55.488333	1.606	2.024	3.233	4.448	4.707
DART 46410	46410	DART	NOAA	-143.804000	57.634000	0.000	---	1.554	---	2.950
Port Alexander	9452634	TS	NOAA	-136.346667	58.193333	2.878	3.326	4.635	5.977	6.251
Entrance Island	9451438	TPS	NOAA	-133.786667	56.811667	-1.022	-0.552	1.301	3.155	3.416
False Bay Chatham St	9452328	TPS	NOAA	-134.935000	57.966667	0.189	0.678	2.614	4.503	4.786
Juneau	9452210	TS	NOAA	-134.411667	58.298333	1.102	1.590	3.712	5.778	6.073
Ketchikan	9450460	TS	NOAA	-131.625000	55.331667	1.887	2.366	4.345	6.320	6.595
Magnetic Point Union	9450753	TPS	NOAA	-132.190000	55.788333	-2.349	-1.873	0.190	2.268	2.539
Monte Carlo Island	9451247	TPS	NOAA	-133.766667	56.535000	1.268	1.718	3.281	4.874	5.129
Port Alexander	9451054	TS	NOAA	-134.646667	56.246667	1.111	1.555	2.865	4.191	4.454
Sitka	9451600	TS	NOAA	-135.341667	57.051667	1.379	1.824	2.989	4.170	4.407
Skagway	9452400	TS	NOAA	-135.326667	59.450000	0.811	1.304	3.494	5.606	5.911
Target Island Mitche	9451953	TPS	NOAA	-134.416667	57.533333	15.559	15.881	17.302	18.697	18.975
The Summit	9451349	TPS	NOAA	-133.736667	56.681667	-0.992	-0.500	1.457	3.373	3.639
Trocadero Bay	9450463	TS	NOAA	-132.936667	55.351667	0.186	0.599	1.798	3.011	3.259
Turn Point	9451434	TPS	NOAA	-132.980000	56.800000	-1.152	-0.694	1.389	3.479	3.746
Yakutat	9453220	TS	NOAA	-139.733333	59.548333	0.550	0.975	2.159	3.357	3.620
Alice Arm	9448	TS	CHS	-129.483333	55.466667	1.270	---	3.954	---	6.290
Armentieres Channel	9605	TS	CHS	-132.383333	53.100000	0.960	---	2.526	---	3.770
Atli Inlet	9765	TS	CHS	-131.576667	52.713333	1.010	---	3.180	---	5.040
Barnard Harbour	9115	TS	CHS	-129.116667	53.083333	0.810	---	3.080	---	5.040
Beauchemin Channel	9082	TS	CHS	-129.298667	52.781333	0.960	---	3.050	---	4.850
Block Islands	9165	TS	CHS	-129.733333	53.150000	0.860	---	3.048	---	4.960
Borrowman Bay	9080	TS	CHS	-129.266667	52.733333	0.650	---	2.801	---	4.620
Brundige Inlet	9333	TS	CHS	-130.851817	54.614383	1.150	---	3.640	---	5.750
Butedale	9053	TS	CHS	-128.683333	53.150000	0.900	---	3.050	---	4.960
Casey Cove	9350	TS	CHS	-130.366667	54.266667	1.160	---	3.810	---	6.130
Claxton	9260	TS	CHS	-130.083333	54.066667	1.210	---	3.781	---	6.120
Dadens	9960	TS	CHS	-132.983333	54.183333	1.010	---	2.913	---	4.510
Davis River	9470	TS	CHS	-130.166667	55.766667	-0.170	---	2.621	---	5.030
Dawson Harbour	9635	TS	CHS	-132.459000	53.163000	0.740	---	2.370	---	3.680
Gillen Harbour	9105	TS	CHS	-129.600000	52.966667	0.970	---	3.103	---	4.950
Granby Bay	9443	TS	CHS	-129.816667	55.400000	1.170	---	3.834	---	6.120
Griffin Pass	9020	TS	CHS	-128.333333	52.766667	0.870	---	2.804	---	4.440
Griffith Harbour	9230	TS	CHS	-130.533333	53.583333	1.030	---	3.553	---	5.790
Hartley Bay	9130	TS	CHS	-129.233333	53.416667	0.900	---	3.170	---	5.140
Haysport	9266	TS	CHS	-130.000000	54.166667	1.230	---	3.840	---	6.150
Henslung Cove	9958	TS	CHS	-133.004167	54.191667	0.940	---	2.780	---	4.330
Higgins Passage	9056	TS	CHS	-128.750000	52.483333	1.040	---	2.930	---	4.540
Hudson Bay Passage	9329	TS	CHS	-130.850000	54.450000	0.980	---	3.460	---	5.580
Humpback Bay	9309	TS	CHS	-130.383333	54.083333	1.220	---	3.697	---	5.770
Hunger Harbour	9570	TS	CHS	-132.033333	52.750000	0.730	---	2.328	---	3.650
Hunt Inlet	9310	TS	CHS	-130.433333	54.066667	1.120	---	3.794	---	6.040

Name	*ID*	*Type*	*Source*	*Longitude*	*Latitude*	*MLLW*	*MLW*	*MSL*	*MHW*	*MHHW*
Juskatla	9927	TS	CHS	-132.316667	53.616667	0.070	---	0.610	---	1.290
Kemano Bay	9150	TS	CHS	-128.116667	53.466667	1.050	---	3.440	---	5.560
Khyex Point	9275	TS	CHS	-129.800000	54.233333	0.150	---	2.599	---	4.970
Kincolith	9422	TS	CHS	-129.966667	54.983333	0.980	---	3.691	---	6.000
Kitimat	9140	TS	CHS	-128.716667	53.983333	0.980	---	3.290	---	5.310
Kitkatla Islands	9242	TS	CHS	-130.350000	53.800000	1.040	---	3.660	---	5.930
Klemtu	9035	TS	CHS	-128.516667	52.583333	0.990	---	2.901	---	4.560
Kumeon Bay	9414	TS	CHS	-130.233333	54.700000	1.000	---	3.605	---	5.860
Kwinitsa River	9285	TS	CHS	-129.583333	54.216667	0.100	---	1.453	---	3.000
Langara Point	9964	TS	CHS	-133.033333	54.250000	0.850	---	2.770	---	4.360
Larsen Island	9232	TS	CHS	-130.566667	53.616667	1.370	---	3.780	---	5.980
Lawyer Island	9312	TS	CHS	-130.333333	54.100000	1.270	---	3.900	---	6.170
Lowe Inlet	9195	TS	CHS	-129.566667	53.550000	1.080	---	3.453	---	5.520
Masset	9910	TS	CHS	-132.149317	54.009683	0.480	---	2.040	---	3.420
McCoy Cove	9790	TS	CHS	-131.650000	53.033333	1.020	---	3.277	---	5.180
McKenney Island	9077	TS	CHS	-129.483333	52.650000	0.860	---	2.830	---	4.530
McPherson Point	9963	TS	CHS	-132.966667	54.233333	0.610	---	2.493	---	4.010
Meyers Narrows	9060	TS	CHS	-128.616667	52.600000	0.740	---	2.743	---	4.490
Mill Bay	9425	TS	CHS	-129.883333	54.983333	0.800	---	3.374	---	5.640
Milne Island	9063	TS	CHS	-128.766667	52.600000	0.920	---	2.910	---	4.640
Moffat Islands	9325	TS	CHS	-130.716667	54.433333	1.080	---	3.581	---	5.710
Morse Basin	9344	TS	CHS	-130.233333	54.250000	0.120	---	2.166	---	4.300
Pacofi Bay	9775	TS	CHS	-131.866667	52.816667	1.310	---	3.510	---	5.400
Port Clements	9920	TS	CHS	-132.183333	53.683333	0.200	---	1.311	---	2.370
Port Edward	9342	TS	CHS	-130.283333	54.216667	1.100	---	3.711	---	5.950
Port Louis	9671	TS	CHS	-132.950000	53.683333	0.840	---	2.530	---	3.880
Port Simpson	9390	TS	CHS	-130.416667	54.550000	1.220	---	3.851	---	6.070
Prince Rupert	9354	TS	CHS	-130.316667	54.316667	1.150	---	3.849	---	6.160
Qlawdzeet Anchorage	9315	TS	CHS	-130.766667	54.200000	1.130	---	3.690	---	5.860
Queen Charlotte	9850	TS	CHS	-132.066667	53.250000	1.170	---	3.992	---	6.320
Ranger Islet	9418	TS	CHS	-130.166667	54.833333	1.140	---	3.733	---	5.950
Refuge Bay	9306	TS	CHS	-130.533333	54.050000	1.150	---	3.753	---	6.000
Salmon Cove	9435	TS	CHS	-129.833333	55.250000	1.040	---	3.666	---	5.970
Seabreeze Point	9250	TS	CHS	-130.166667	53.983333	1.220	---	3.731	---	6.020
Seal Cove	9360	TS	CHS	-130.266667	54.316667	1.140	---	3.780	---	6.090
Sedgwick Bay	9753	TS	CHS	-131.583333	52.633333	0.770	---	2.798	---	4.520
Shields Bay	9650	TS	CHS	-132.416667	53.300000	0.900	---	2.560	---	3.880
Shingle Bay	9808	TS	CHS	-131.816667	53.250000	1.190	---	4.008	---	6.390
Skidegate Channel East	9823	TS	CHS	-132.233333	53.150000	1.170	---	3.942	---	6.390
Skidegate Channel West	9830	TS	CHS	-132.266667	53.150000	0.370	---	2.084	---	3.650
Stewart	9475	TS	CHS	-130.000000	55.916667	1.170	---	3.947	---	6.420
Surf Inlet	9090	TS	CHS	-128.900000	53.016667	0.900	---	2.944	---	4.710
Trail Bay	9406	TS	CHS	-130.350000	54.583333	0.990	---	3.636	---	5.880
Trounce Inlet	9625	TS	CHS	-132.316667	53.133333	0.480	---	2.017	---	3.480
Wainright Basin	9343	TS	CHS	-130.250000	54.250000	0.230	---	2.218	---	4.380
Wiah Point	9940	TS	CHS	-132.300000	54.100000	0.960	---	3.078	---	4.880

[Page left intentionally blank]