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

Prepared for the Pacific Marine Environmental Labratory (PMEL) and the National Tsunami Hazard Mitigation Program (NTHMP) by the NOAA National Geophysical Data Center (NGDC)
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1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a 1/3 arc-second[1] bathymetric–topographic digital elevation model (DEM) centered on Elfin Cove Alaska (Fig. 1). The DEM was developed for the Pacific Marine Environmental Labratory (PMEL) and will also be used for the National Tsunami Hazard Mitigation Program (NTHMP; http://nthmp.tsunami.gov/) in support of the State of Alaska's tsunami inundation modeling efforts led by the Geophysical Institute at the University of Alaska at Fairbanks (UAF). The DEM was built at 1/3 arc-second and an 8/15 arc-second empty xy ascii file was filled using the 1/3 arc-second DEM for use by UAF. The coastal DEM will be used as input for the university-developed modeling system to simulate tsunami generation, propagation, and inundation (http://www.aeic.alaska.edu/tsunami/). The DEM 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 Elfin Cove DEM.

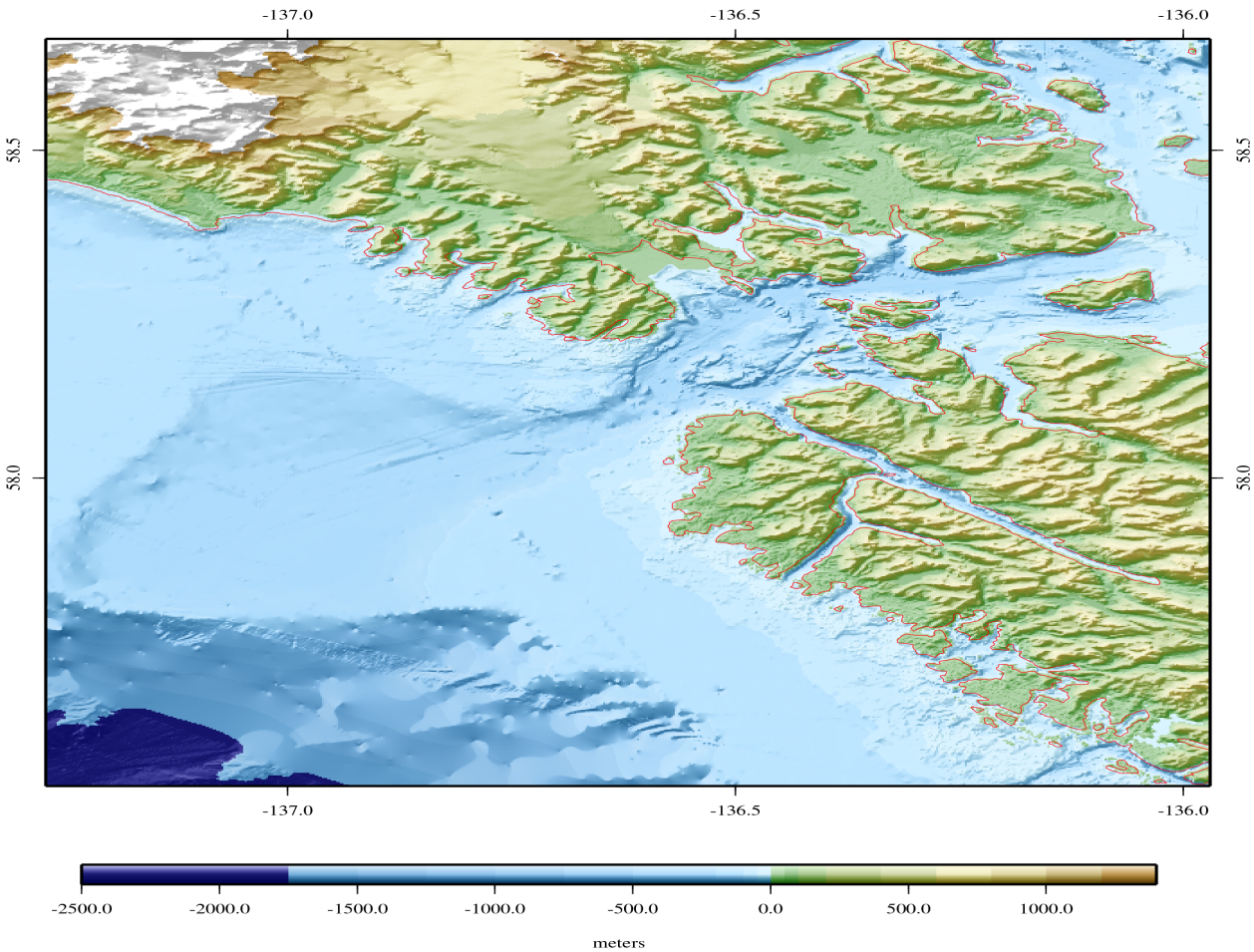

Figure 1. Shaded-relief image of the Elfin Cove 1/3 arc-second DEM.

1. The Elfin Cove 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 Elfin Cove, AK (58°11′56″N 136°21′19″W) 1/3 arc-second of latitude is equivalent to 10.31306513 meters; 1/3 arc-second of longitude equals 5.44487079 meters.

2. Study Area

Elfin Cove is a census-designated place (CDP) near the northwestern corner of Chichagof Island in Hoonah-Angoon Census Area, in the panhandle of southeast Alaska. The 1/3 arc-second DEM of the region encompasses the region around Elfin Cove (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 Elfin Cove 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 Elfin Cove 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 Elfin Cove, 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 Elfin Cove, South of Gustavas. Source: http://roundezvous.com/SubPages/PhotoSubPages/Alaska2006.htm. Taken by Rick Sood (http://roundezvous.com/)

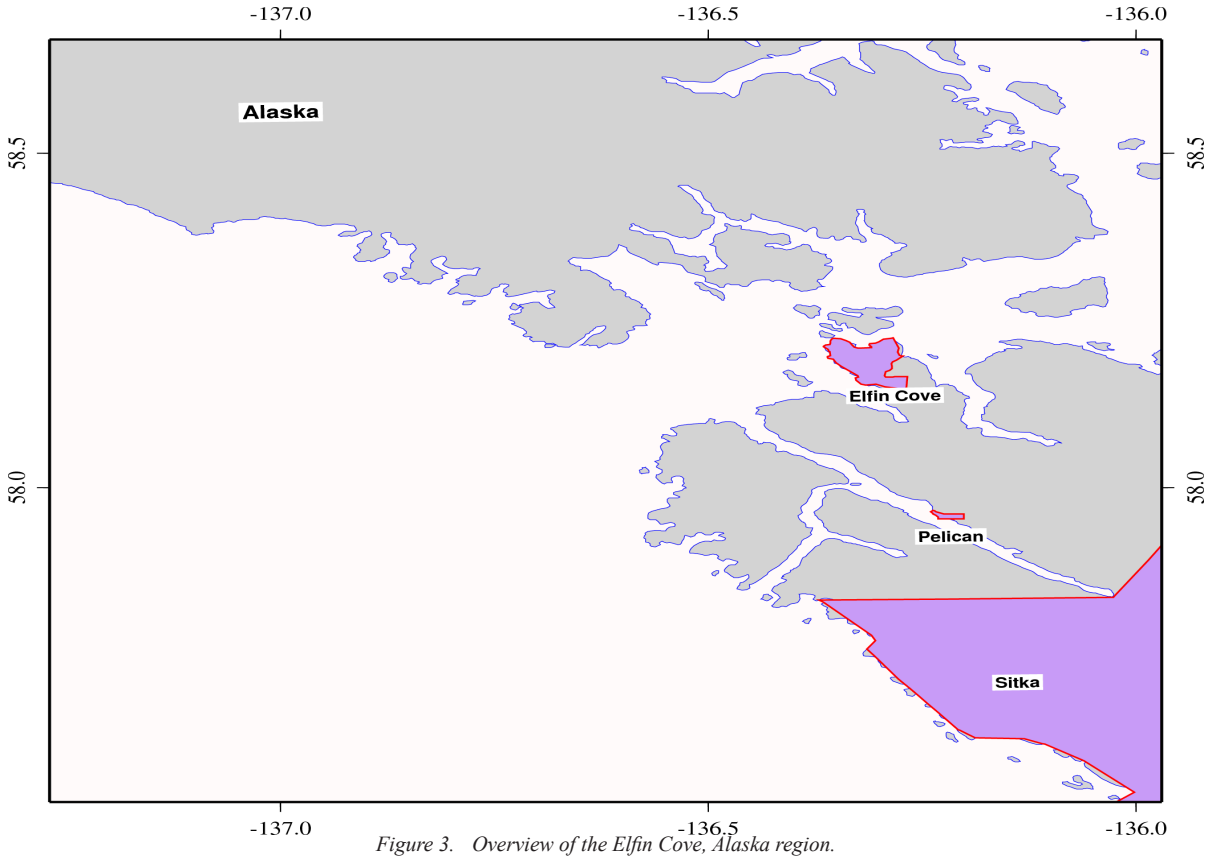

Figure 3. Overview of the Elfin Cove, Alaska region.

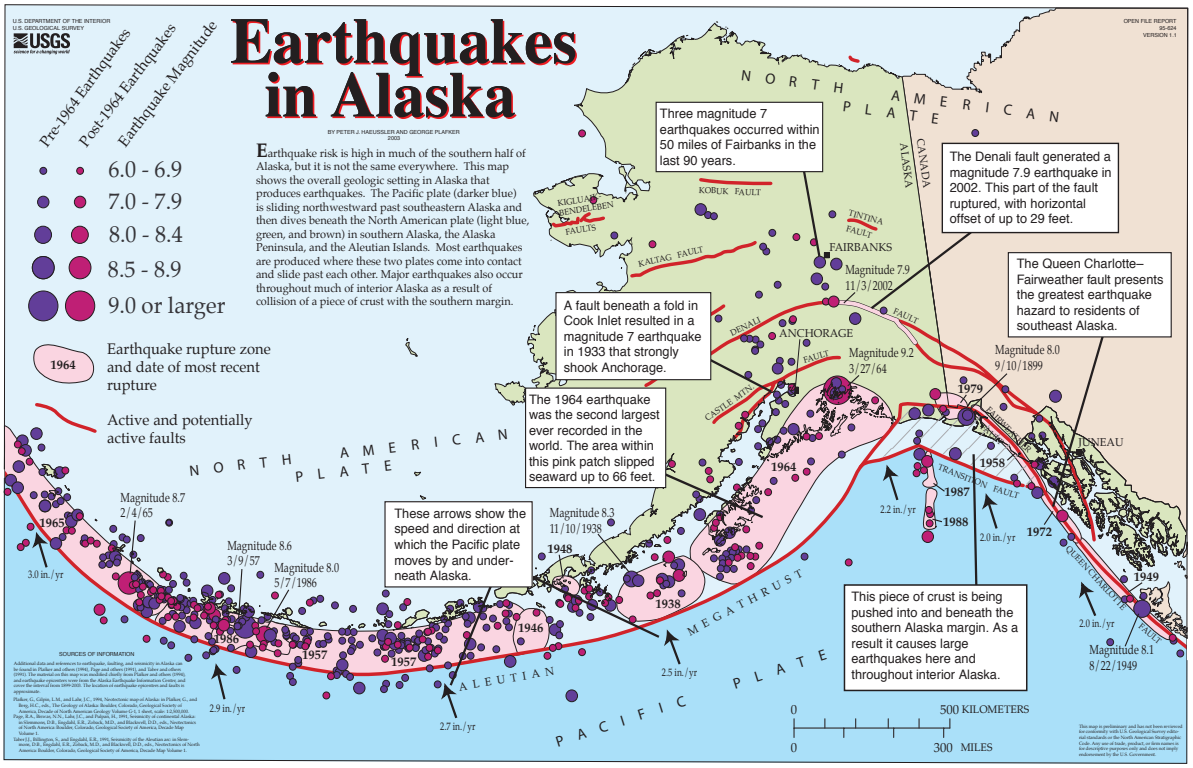

Figure 4. Earthquakes in Alaska. Sources: http://www.aeic.alaska.edu/html_docs/pdf_files/earthquakes_in_Alaska.pg.pdf; http://geopubs.wr.usgs.gov/open-file/of95-624/.

3. Methodology

The Elfin Cove DEM was developed in the World Geodetic System of 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 Elfin Cove DEM was also developed to meet the specifications listed in Table 1. 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 Elfin Cove DEM.

Grid Area	Elfin Cove, Alaska
Coverage Area	-137.27,-135.97,57.53,58.67
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

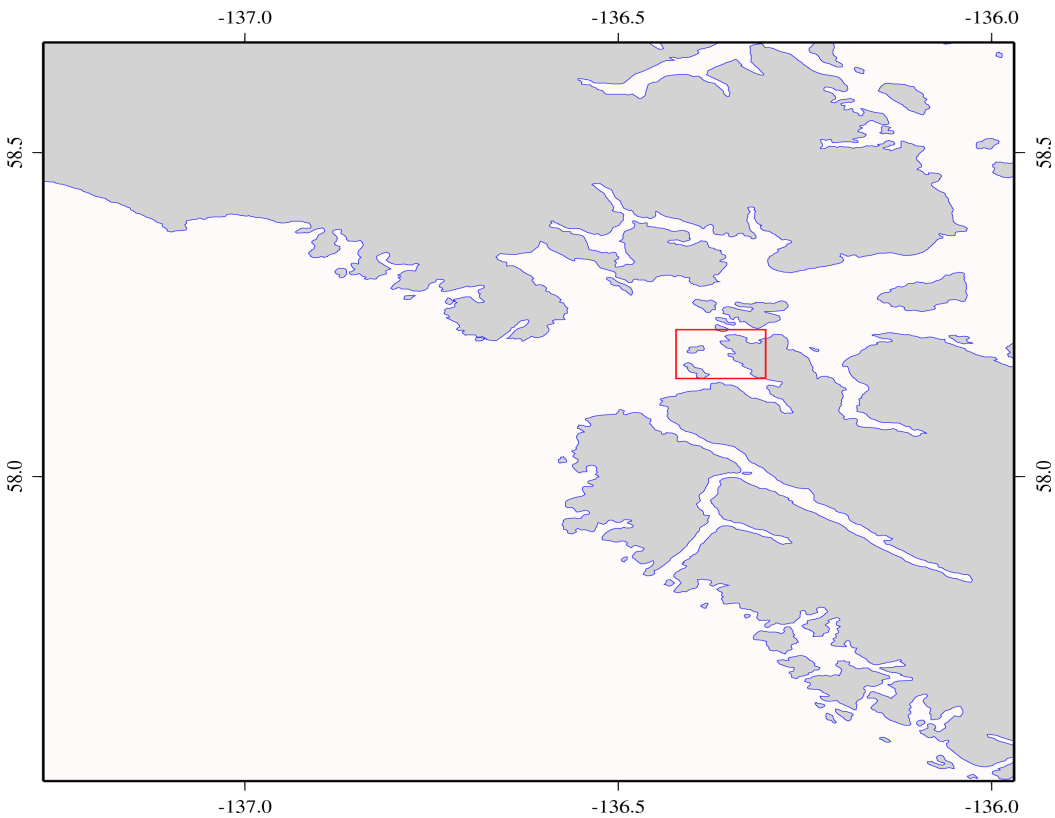

Figure 5. Comparison of NGDC and UAF extents in the Elfin Cove, Alaska region. Coastline shown in blue; land areas in grey; UAF boundary is shown in red.

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 DEMs. Most GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the wave's passage across ocean basins. These DEMs 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 DEMs, 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. 6) 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.

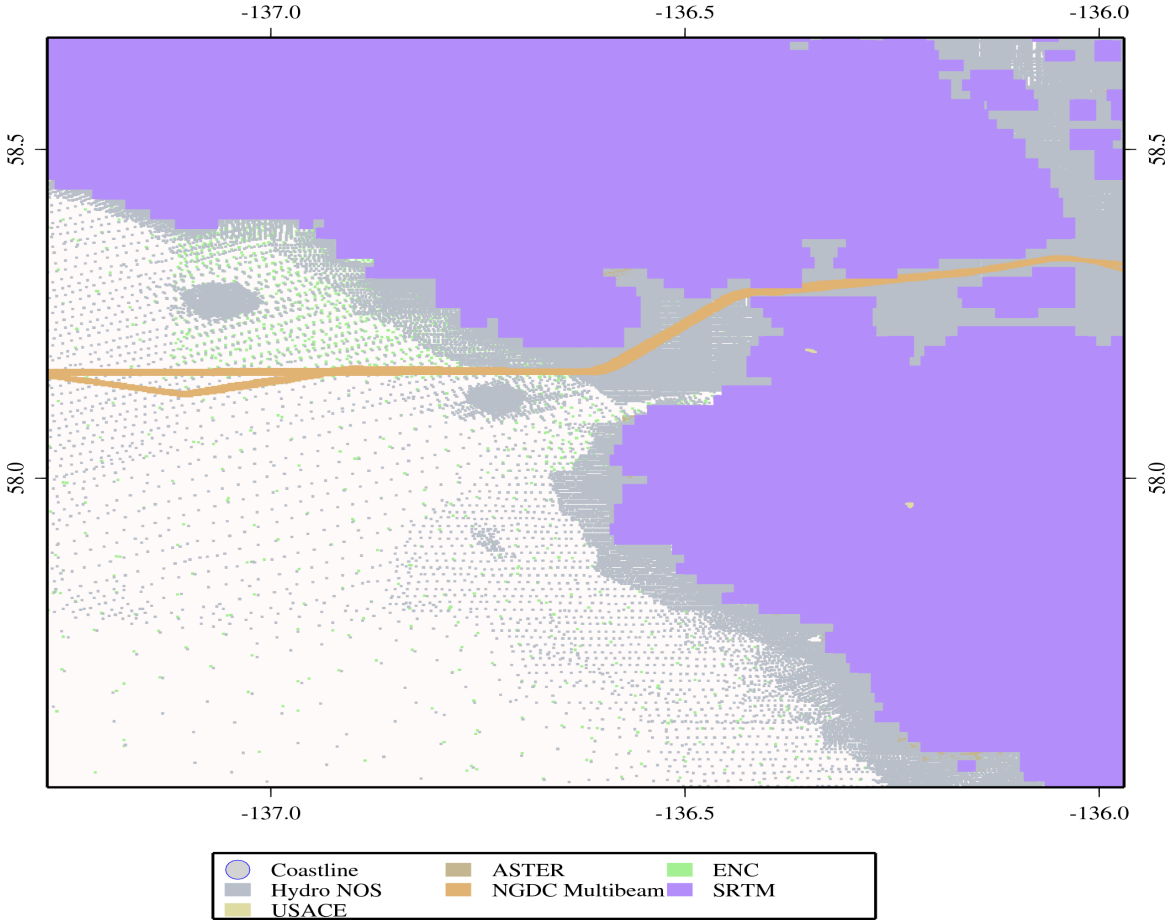

Figure 6. Source and coverage of datasets used in compiling the Elfin Cove DEM.

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 Elfin Cove, Alaska region were analyzed for inclusion in the Elfin Cove 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 8/15 arc-second UAF extents to improve representation of the coastline in the immediate vicinity of Elfin Cove. These datasets were used to develop a "final coastline" of the Elfin Cove, 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, particularly within the 8/15 arc-second extents.

Table 2. Shoreline datasets used in developing the Elfin Cove 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 Elfin Cove, 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 Elfin Cove DEM include 57 NOS hydrographic surveys; 9 multibeam surveys downloaded from the NGDC multibeam database; 5 hydrographic surveys from USACE; and soundings extracted from 7 ENCs. (Table 3; Fig. 7).

Table 3. Bathymetric datasets used in compiling the Elfin Cove 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	HUhttp://www.ngdc.noaa.gov/mgg/bathymetry/hydro.htmlUH
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
USACE	1999 to 2008	Hydrographic surveys	Ranges from less than 10 m to over 100 meters (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 83 Alaska State Plane Zone I (US survey feet)	MLLW (feet)	http://www.poa.usace.army.mil/en/hydro/
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/chart-spubs.html

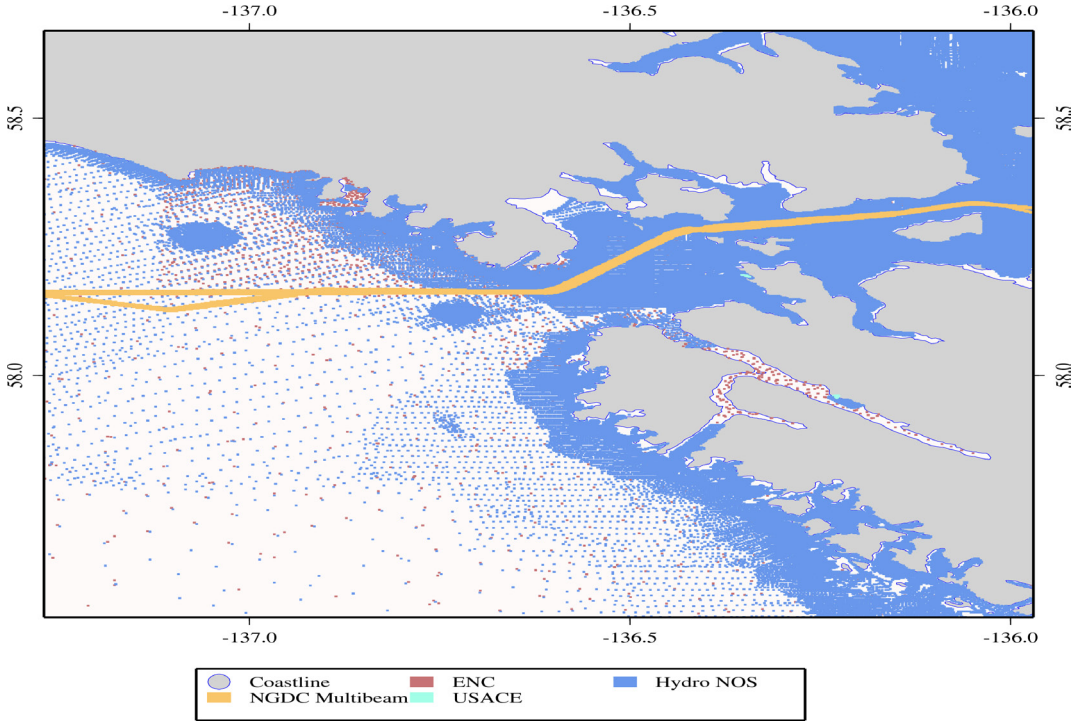

Figure 7. Spatial coverage of the bathymetric datasets used in compiling the Elfin Cove DEM. Land areas shown in tan. Regions of no data

shown in white.

1) National Ocean Service hydrographic survey data

A total of 57 NOS hydrographic surveys conducted between 1883 and 2009 were available for use in developing the Elfin Cove DEM (Appendix A; Fig. 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 Elfin Cove 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, USACE surveys, and multibeam data.

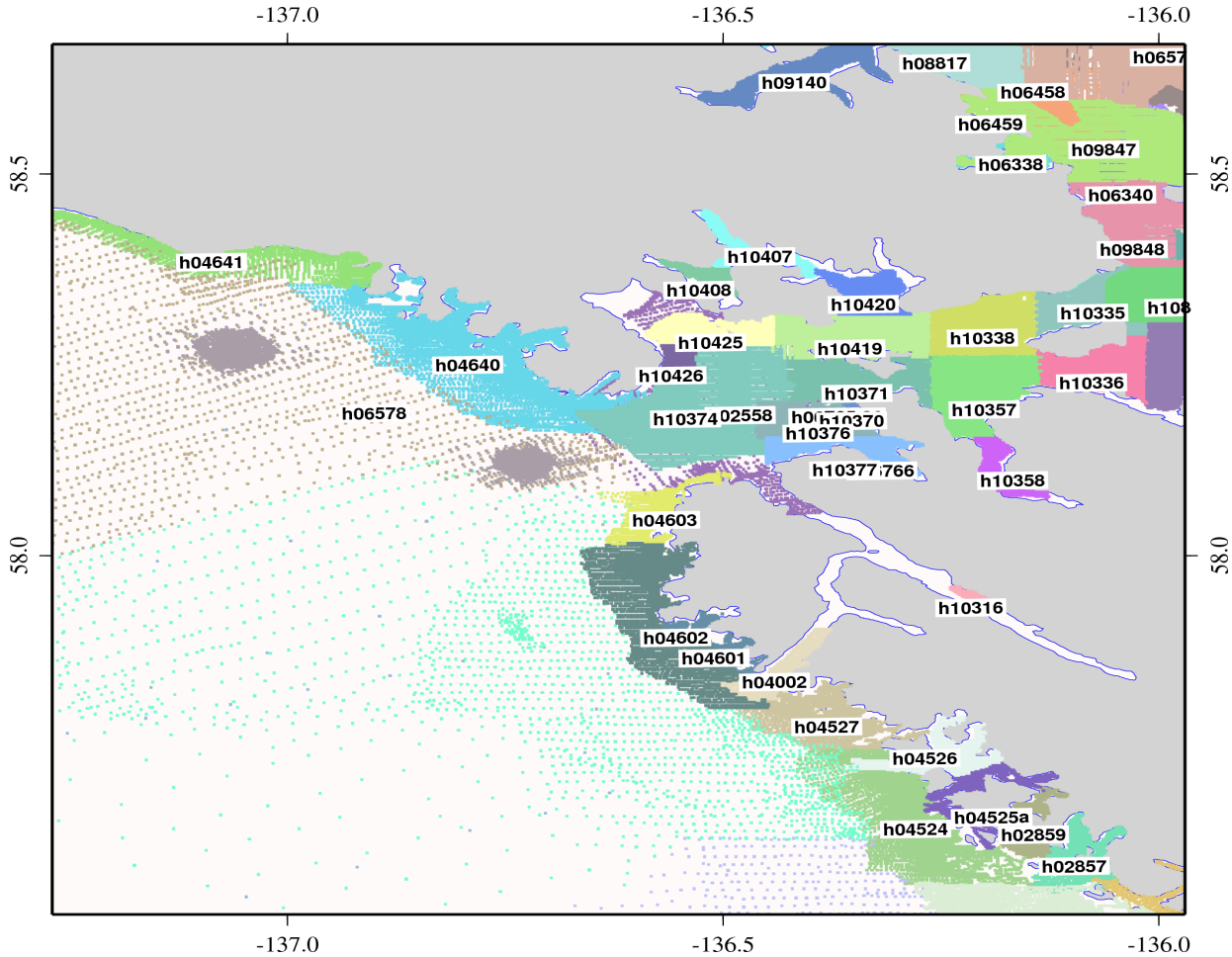

Figure 8. Digital NOS hydrographic survey coverage in the Elfin Cove region. Several older surveys were not used as they have been superseded by more recent surveys. Land areas shown in tan. Regions where NOS data were not available are shown in white.

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.

2) NGDC multibeam swath sonar surveys

Nine multibeam swath sonar surveys were available from the NGDC multibeam bathymetry database for use in building the Elfin Cove DEM (Fig. 7). 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.

3) U.S. Army Corps of Engineers hydrographic surveys

Five channel line survey datasets in xyz format were downloaded from the USACE Alaska District web site (Fig. 9). The surveys were horizontally referenced to NAD 83 Alaska State Plane Zone I (U.S. survey feet) and vertically referenced to MLLW (U.S. survey feet). Each survey was transformed to NAD 83 geographic using *Proj4* and transformed to MHW using the method described in Section 3.2.1. Older surveys were clipped to remove soundings that have been superseded by more recent NOS, multibeam, or USACE surveys.

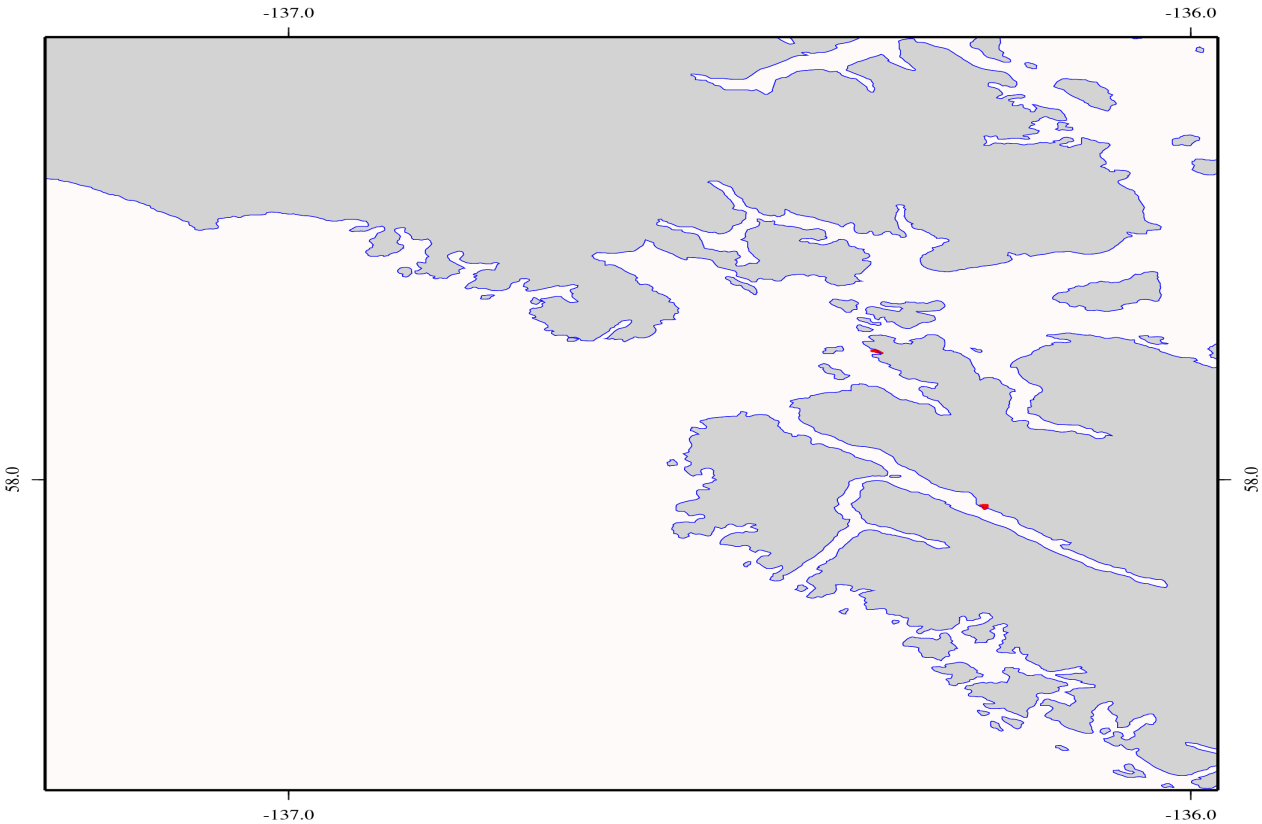

Figure 9. Spatial coverage of USACE hydrographic survey data in the Elfin Cove, Alaska region. Land areas shown in tan.

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.]

4) 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 NAD 83 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).

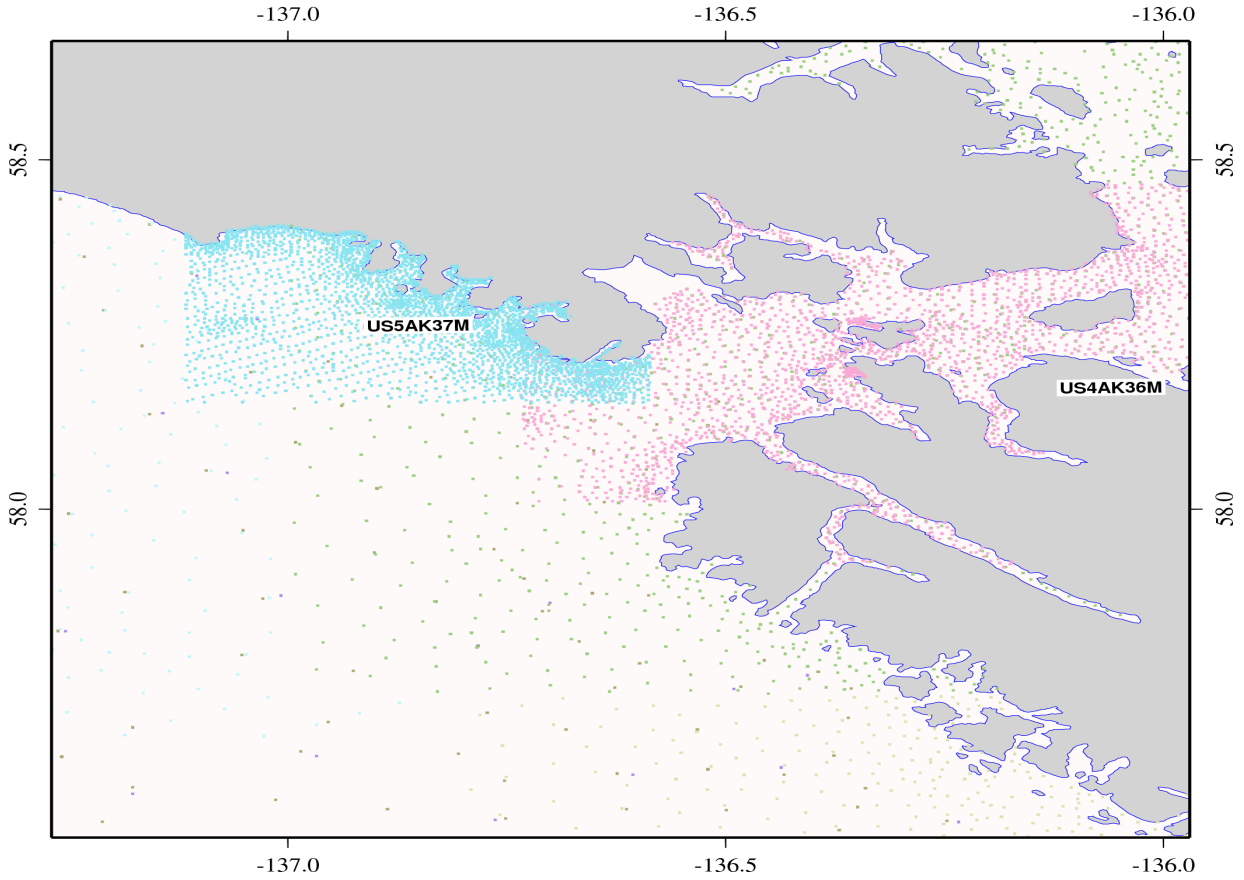

Figure 10. Spatial coverage of ENC soundings in the Elfin Cove, Alaska region. Land areas shown in tan.

3.1.3 Topography

Topographic datasets of the Elfin Cove, 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 Southeast Alaska DEMs due to: 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 Elfin Cove DEMs.

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	

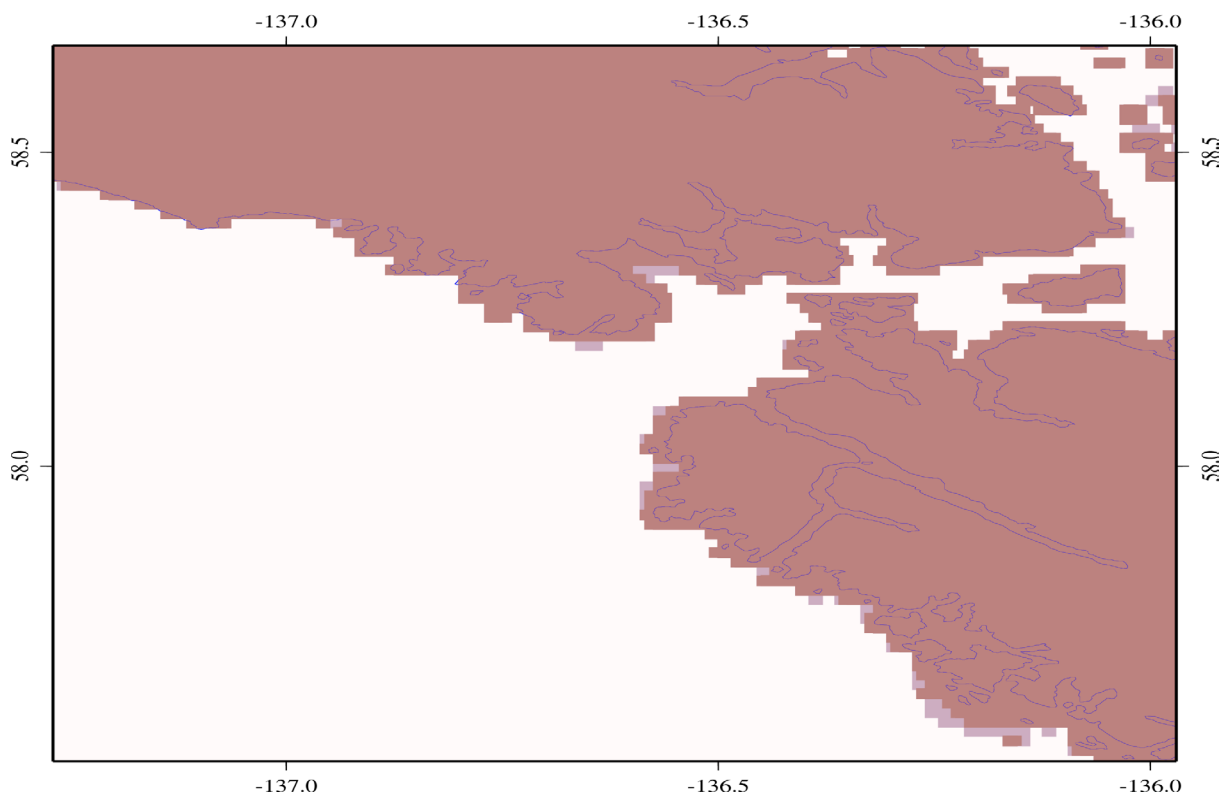

Figure 11. Source and coverage of topographic datasets used in compiling the Elfin Cove DEM. Areas of water indicated in white.

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 Elfin Cove, 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 Elfin Cove.

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 Elfin Cove 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.

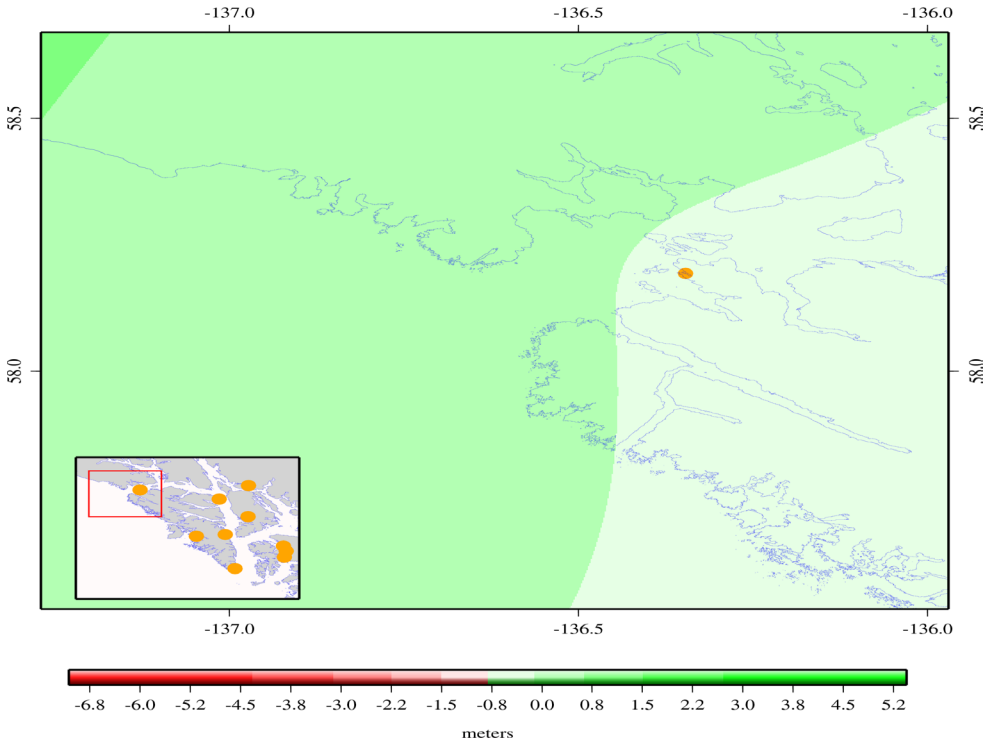

Figure 12. The MHW to MHHW offset grid used to convert between vertical datums. Tide stations, tide prediction sites, and DART buoy are shown in orange. Coastline is in blue.

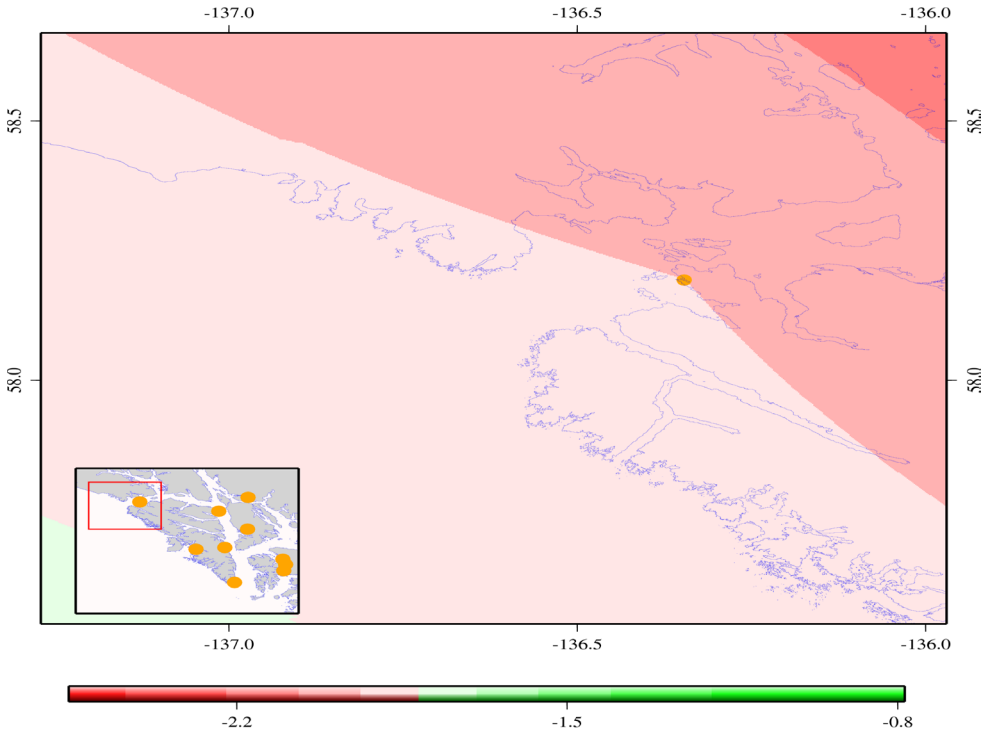

Figure 13. The MLLW to MSL regional offset grid used to convert between vertical datums. Tide stations, tide prediction sites, and DART buoy are shown in orange. Coastline is in blue.

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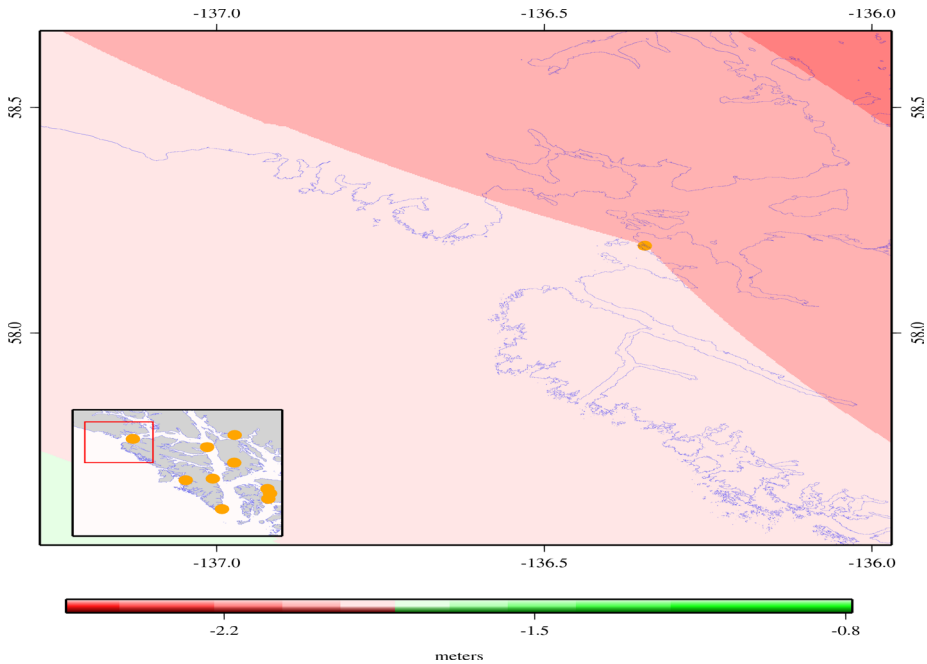

Figure 14. The MSL to MHW offset grid used to convert between vertical datums. Tide stations, tide prediction sites, and DART buoy are shown. Coastline is in blue.

3.2.2 Horizontal datum transformations

Datasets used to compile the Elfin Cove 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 excised where more recent bathymetric data exists.

3.3.2 Smoothing of bathymetric data

The older NOS hydrographic survey data, extracted ENC soundings, and NGDC trackine surveys are generally sparse at the resolution of the Elfin Cove 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].

An Elfin Cove 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 Elfin Cove 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 DEMs.

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.]

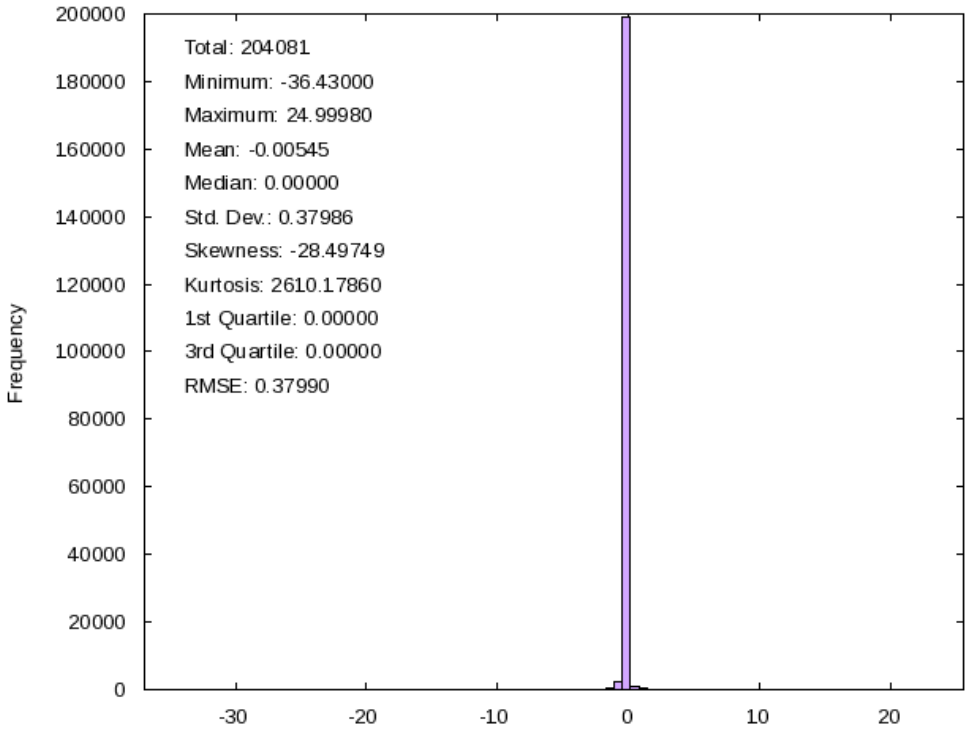

Figure 15. Histogram of the differences between NOS hydrographic surveys and the 1 arc-second pre-surfaced bathymetric grid.

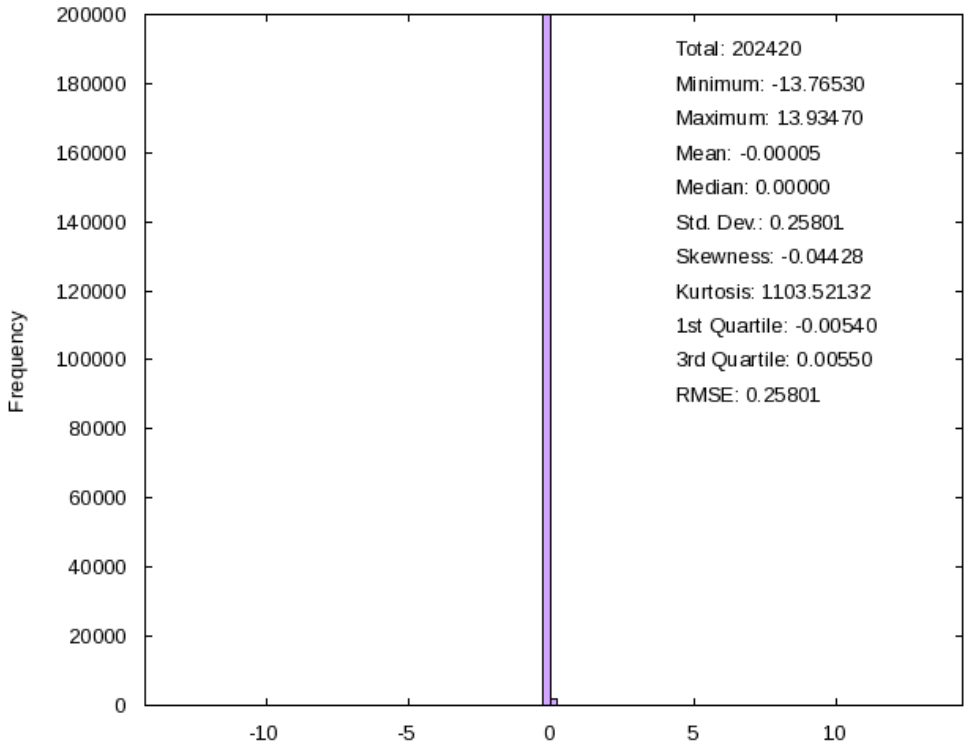

Figure 16. Histogram of the differences between NGDC multibeam swath sonar surveys and the 1 arc-second pre-surfaced bathymetric grid.

3.3.3 Building the DEM using MB-System

MB-System was used to create the Elfin Cove 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
USACE hydrographic surveys	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 Elfin Cove 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 Elfin Cove 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 Elfin Cove 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 Elfin Cove DEM in its final version. Figure 18 shows a perspective rendering of the final 1/3 arc-second Elfin Cove DEM. Figure 19 shows a data contribution plot of the Elfin Cove DEM.

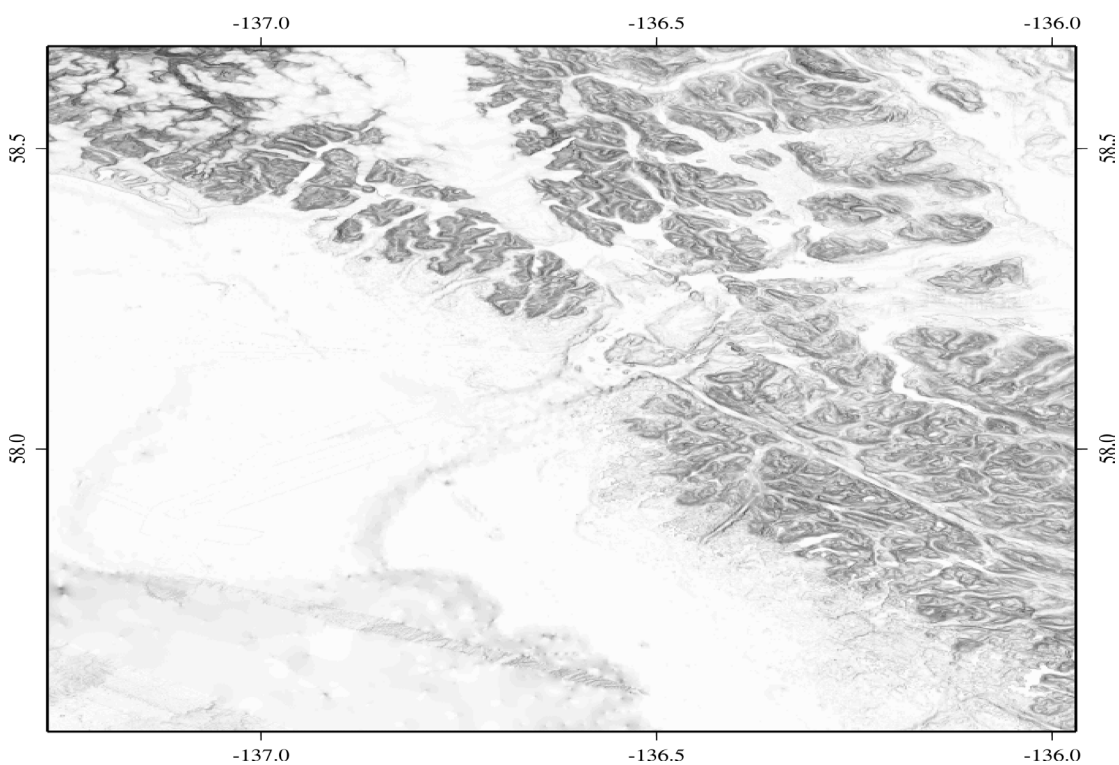

Figure 17. Slope map of the 1/3 arc-second Elfin Cove DEM. Flat-lying slopes are shown in white; dark shading denotes steep slopes; final coastline indicated in red.

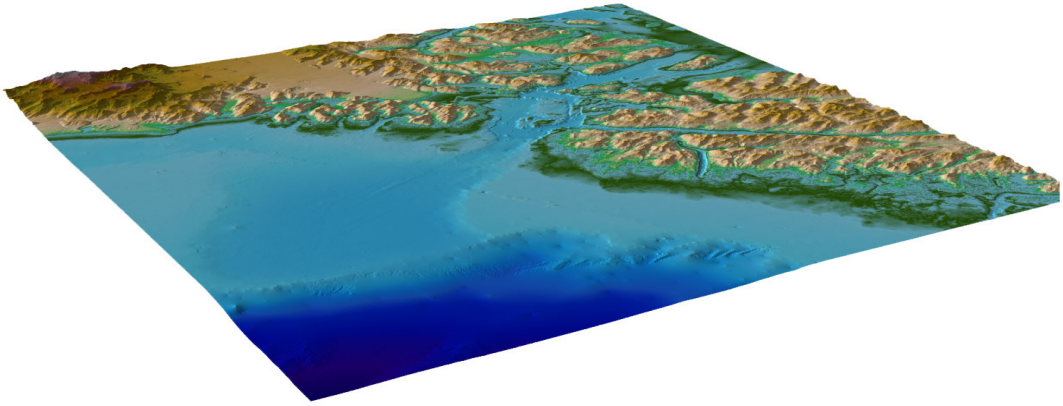

Figure 18. Perspective view from the southwest of the Elfin Cove DEM. Vertical exaggeration–times 2.

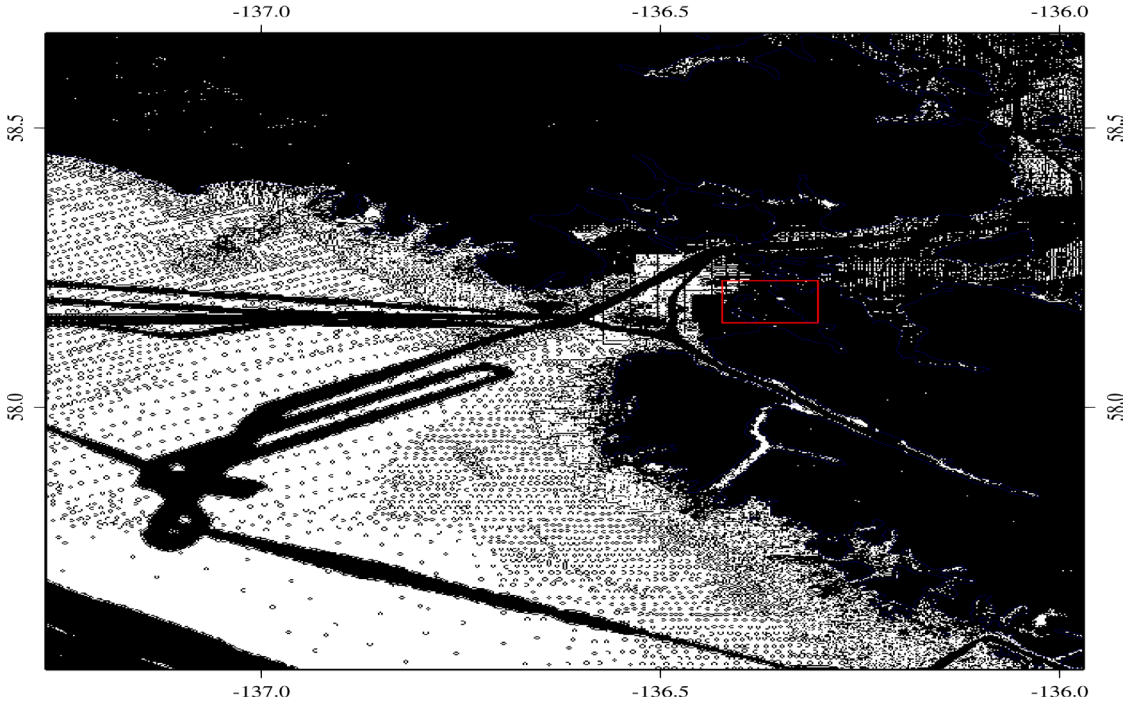

Figure 19. Data contribution plot of the Elfin Cove DEM. Black depicts DEM cells constrained by source data; white depicts cells with elevation values derived from interpolation. Due to the scale of the image, sparse soundings may not be visible in the graphic. Coastline is shown in blue. Extents of the 8/15 arc-second UAF boundary is shown in red.

3.4.4 DEM comparison with source data files

To ensure grid accuracy, the Elfin Cove DEM was compared to source data files. A histogram of the differences between the SRTM and ASTER topographic DEMs and the Elfin Cove 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 Elfin Cove 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.

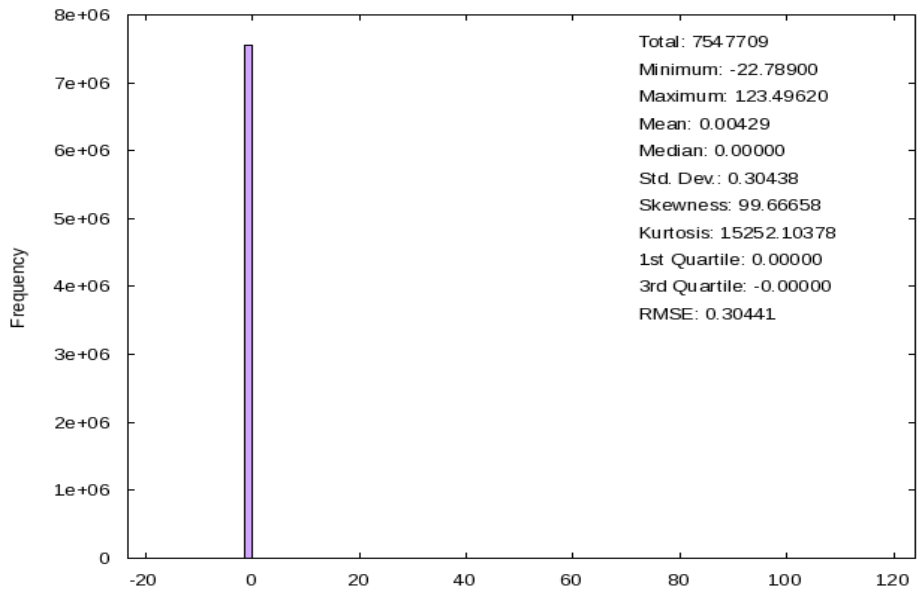

Figure 20. Histogram of the differences between the SRTM 1 arc-second topographic DEM data points and the Elfin Cove DEM.

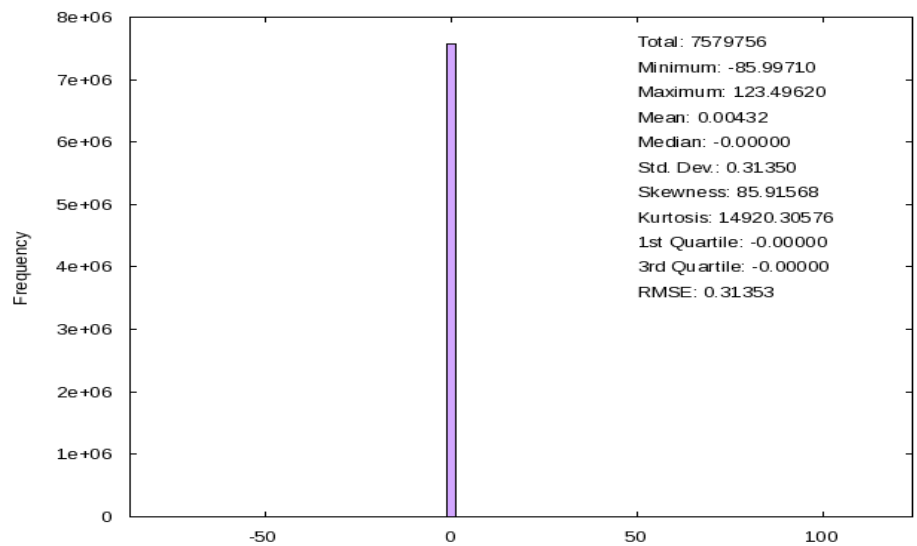

Figure 21. Histogram of the differences between the ASTER 1 arc-second DEM data points and the Elfin Cove DEM.

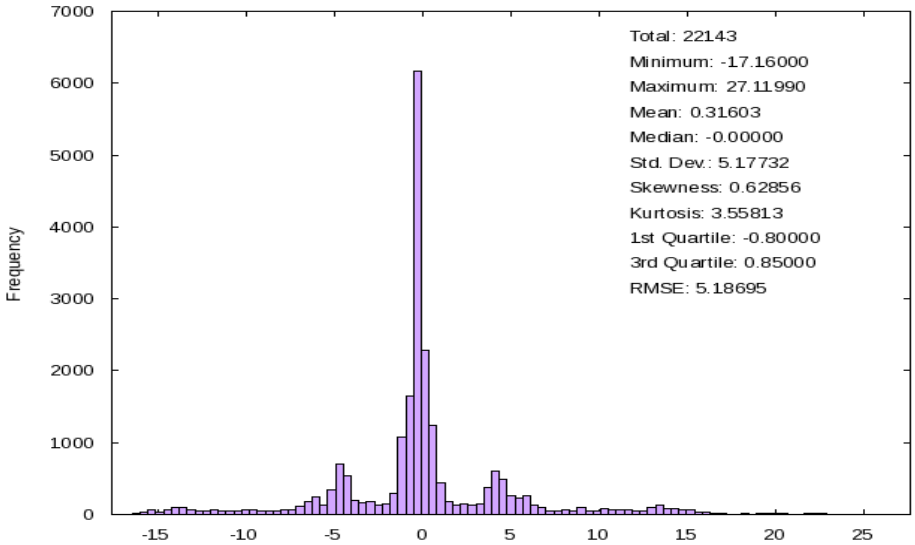

Figure 22. Histogram of the differences between the USACE hydrographic survey data points and the Elfin Cove DEM.

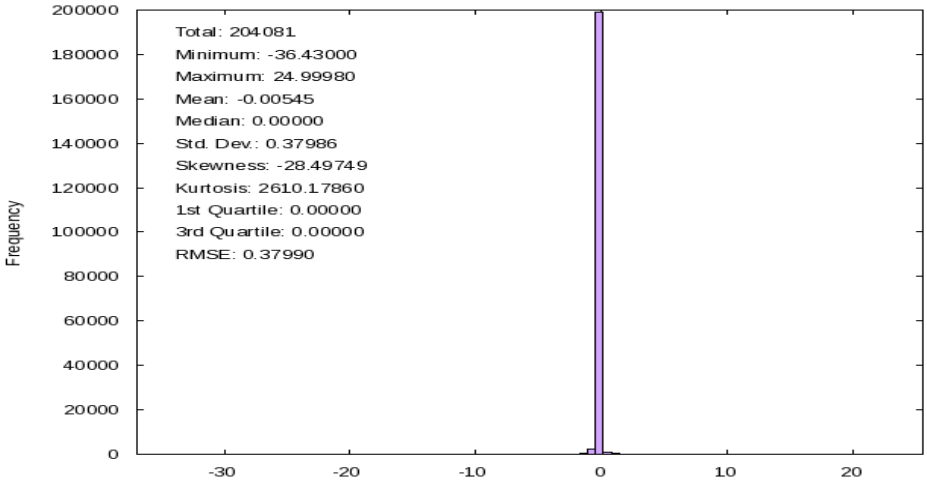

Figure 23. Histogram of the differences between the NOS Hydro data points and the Elfin Cove DEM.

4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of Elfin Cove, 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 Elfin Cove DEM, based on NGDC's research and analysis, are listed below:

- Conduct bathymetric surveys in the southwestern quarter of the 8 arc-second DEM region.
- Conduct a high-resolution topographic lidar surveys near the City of Juneau
- 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

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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.

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Nautical Chart #17302 (ENC and RNC), 18th Edition, 2002. Icy Strait and Cross Sound; Inian Cove; Elfin Cove. 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.

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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.

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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, HUhttp://www.esri.com/UH

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, HUhttp://www.ngdc.noaa.gov/mgg/geodas/UH

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

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, HUhttp://www.ldeo.columbia.edu/res/pi/MB-System/UH
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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, HUhttp://www.appliedimagery.com/UH

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/.

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Appendix A. NOS Hydro Data Tables

Survey ID	Year	Scale/Vertical Accuracy	Original Vertical Datum	Provided Horizontal Datum
H02558	1901	1:40,000	Undetermined	Undetermined
H02665	1903	1:600,000	Undetermined	Undetermined
H02857	1906	1:10,000	Undetermined	Undetermined
H02858	1906	1:20,000	Undetermined	Undetermined
H02859	1906	1:10,000	Undetermined	Undetermined
H04002	1917	1:20,000	Undetermined	Undetermined
H04524	1925	1:20,000	Undetermined	Undetermined
H04526	1925	1:10,000	Undetermined	Undetermined
H04527	1925	1:10,000	Undetermined	Undetermined
H04528	1925	1:80,000	Undetermined	Undetermined
H04529	1925	1:100,000	Undetermined	Undetermined
H04539	1925	1:20,000	Undetermined	Undetermined
H04601	1926	1:10,000	Undetermined	Undetermined
H04602	1926	1:20,000	Undetermined	Undetermined
H04603	1926	1:20,000	Undetermined	Undetermined
H04640	1926	1:20,000	Undetermined	Undetermined
H04641	1926	1:20,000	Undetermined	Undetermined
H04648	1926	1:100,000	Undetermined	Undetermined
H06336	1938	5,000	Undetermined	Undetermined
H06338	1938	10,000	Undetermined	Undetermined
H06339	1938	20,000	Undetermined	Undetermined
H06340	1938	20,000	Undetermined	Undetermined
H06457	1939	20,000	Undetermined	Undetermined
H06458	1940	20,000	Undetermined	Undetermined
H06459	1939	10,000	Undetermined	Undetermined
H06575	1940	20,000	Undetermined	Undetermined
H06578	1940	40,000	Undetermined	Undetermined
H06765	1942	5,000	Undetermined	Undetermined
H06766	1942	5,000	Undetermined	Undetermined
H08815	1964	1:10,000	MLLW	North American Datum 1927
H08817	1964	20,000	Undetermined	Undetermined
H09140	1970	20,000	MLLW	North American Datum 1927
H09143	1970	10,000	MLLW	North American Datum 1927
H09405	1973	20,000	MLLW	North American Datum 1927
H09847	1979	20,000	MLLW	North American Datum 1927
H09848	1979	20,000	MLLW	North American Datum 1927
H10316	1989	5000	MLLW	North American Datum 1927
H10333	1990	10000	MLLW	North American Datum 1983
H10334	1990	20000	MLLW	North American Datum 1983
H10335	1990	10000	MLLW	North American Datum 1983

H10336	1990	10000	MLLW	North American Datum 1983
H10338	1990	10000	MLLW	North American Datum 1983
H10357	1990	10000	MLLW	North American Datum 1983
H10358	1990	10000	MLLW	North American Datum 1983
H10370	1991	5000	MLLW	North American Datum 1983
H10371	1991	10000	MLLW	North American Datum 1983
H10374	1991	20000	MLLW	North American Datum 1983
H10376	1991	10000	MLLW	North American Datum 1983
H10377	1991	10000	MLLW	North American Datum 1983
H10407	1991	10000	MLLW	North American Datum 1983
H10408	1991	10000	MLLW	North American Datum 1983
H10419	1992	10000	MLLW	North American Datum 1983
H10420	1992	10000	MLLW	North American Datum 1983
H10425	1992	10000	MLLW	North American Datum 1983
H10426	1992	10000	MLLW	North American Datum 1983
H10883	1999	10000	MLLW	North American Datum 1983

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
US3AK38M	Cross Sound to Yakutat Bay	8	7/1/2010	ENC	1:300000
US3AK3AM	Stephens Passage to Cross Sound, including Lynn Canal	8.1	1/20/2011	ENC	1:209978
US3AK3BM	Coronation Island to Lisianski Strait	7	2/1/2011	ENC	1:217828
US4AK36M	Icy Strait and Cross Sound;Inian Cove;Elfin Cove	1.1	5/25/2010	ENC	1:80000
US5AK37M	Cape Spencer to Icy Point	5	11/30/2010	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
Elfin Cove	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

Appendix D. Mean Higher High Water Update, 2012

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a 1/3 arc-second bathymetric–topographic digital elevation model (DEM) centered on Elfin Cove Alaska (Fig. D-1) using a vertical datum of Mean Higher High Water (MHHW). The DEM was developed for the National Tsunami Hazard Mitigation Program (NTHMP; http://nthmp.tsunami.gov/) in support of the State of Alaska's tsunami inundation modeling efforts led by the Geophysical Institute at the University of Alaska at Fairbanks (UAF). The DEM was built at 1/3 arc-second and an 8/15 arc-second empty xy ascii file was filled using the 1/3 arc-second DEM for use by UAF. The coastal DEM will be used as input for the university-developed modeling system to simulate tsunami generation, propagation, and inundation (http://www.aeic.alaska.edu/tsunami/). The DEM was generated from diverse digital datasets in the region (grid sources shown in Fig. 5) and was designed to represent modern morphology. The Elfin Cove MHHW DEM was developed as a subset of the Elfin Cove MHW DEM, focusing on the area immediately surrounding the town of Elfin Cove, Alsaska (Figure D-2).

NGDC transformed all previous Elfin Cove data (Section 3.1) to MHHW using a constant offset for use in the development of the updated MHHW DEM. The UAF provided NGDC with GPS data points collected around the town of Elfin Cove in MHHW in *xyz* format (Figure D-3). The data was transformed from Alaska State Plane Zone 1 to WGS 84 using *proj4*, and from elevation units of feet to elevation units of meters, using *GNU awk*. The USACE provided NGDC with bathymetry elevations of channels leading into and around Elfin Cove.

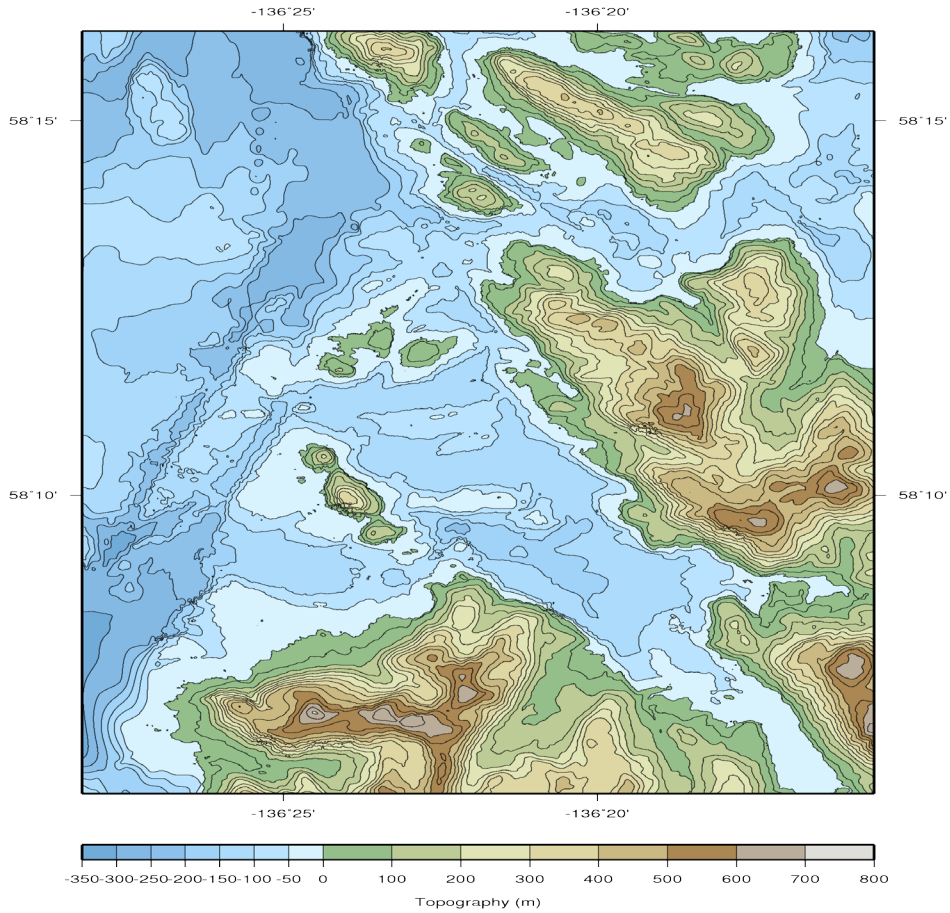

Figure D-1. Shaded releif image of the Elfin Cove MHHW subset DEM.

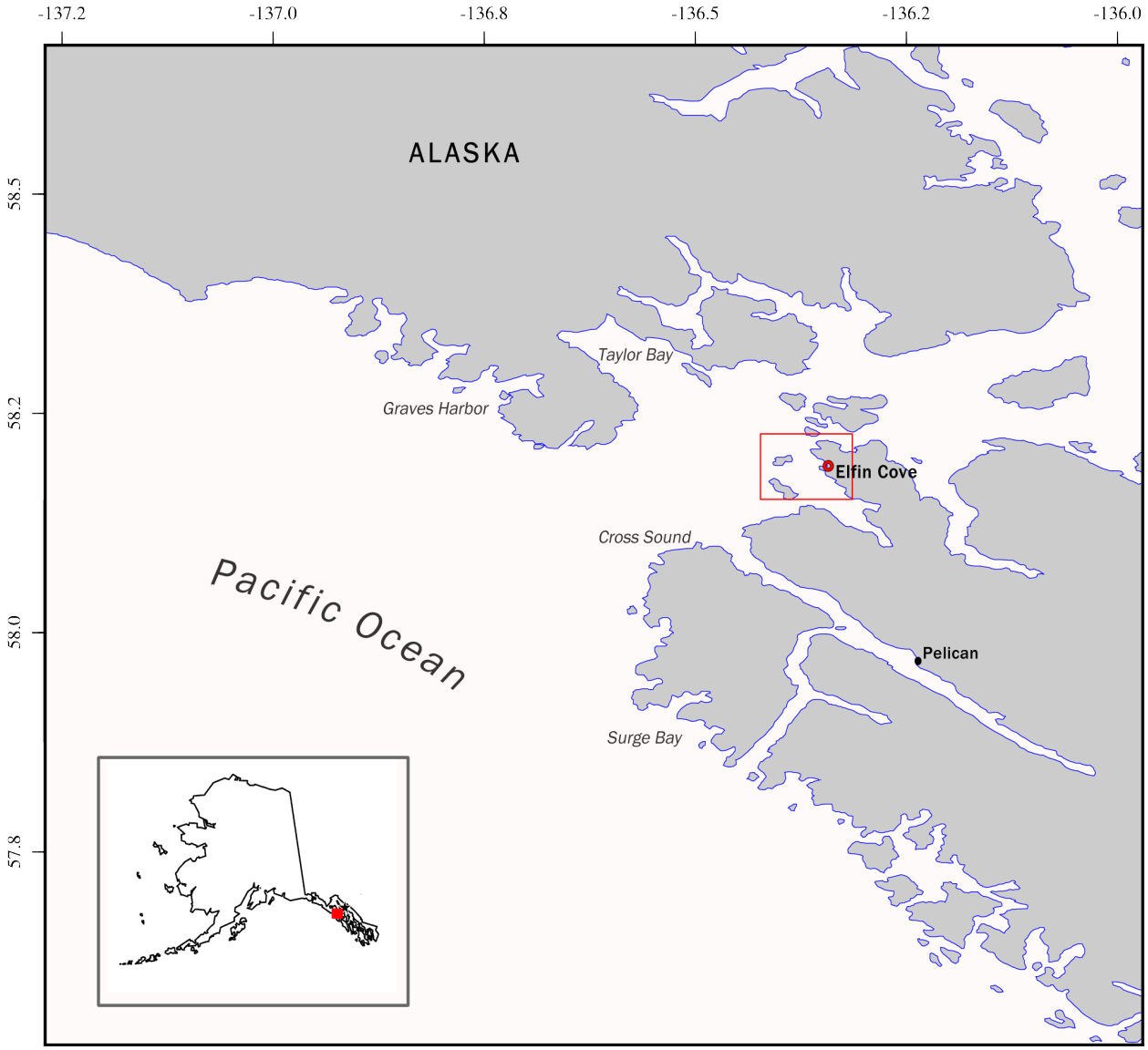

Figure D-2. Overview of Elfin Cove DEM MHHW project area, shown in red.

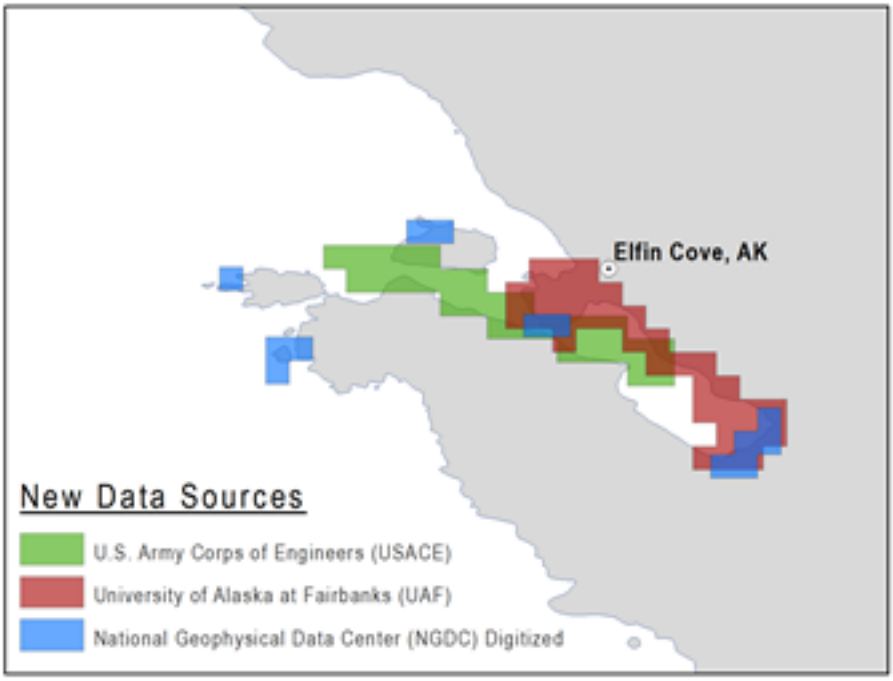

Figure D-3. Source and coverage of datasets used in compiling the updated Elfin Cove DEM. Areas of water indicated in white.