Southern Alaska Coastal Relief Model: Procedures, Data Sources and Analysis

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

Southern Alaska Coastal Relief Model: Procedures, Data Sources and Analysis

1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a 24 arc-second[1] integrated bathymetric–topographic digital elevation model (DEM) covering Southern Alaska (Fig. 1). This Southern Alaska Coastal Relief Model (CRM) was generated from diverse digital datasets in the region (grid sources shown in Fig. 2) and was designed to represent modern morphology. This report provides a summary of the data sources and methodology used in developing the Southern Alaska CRM.

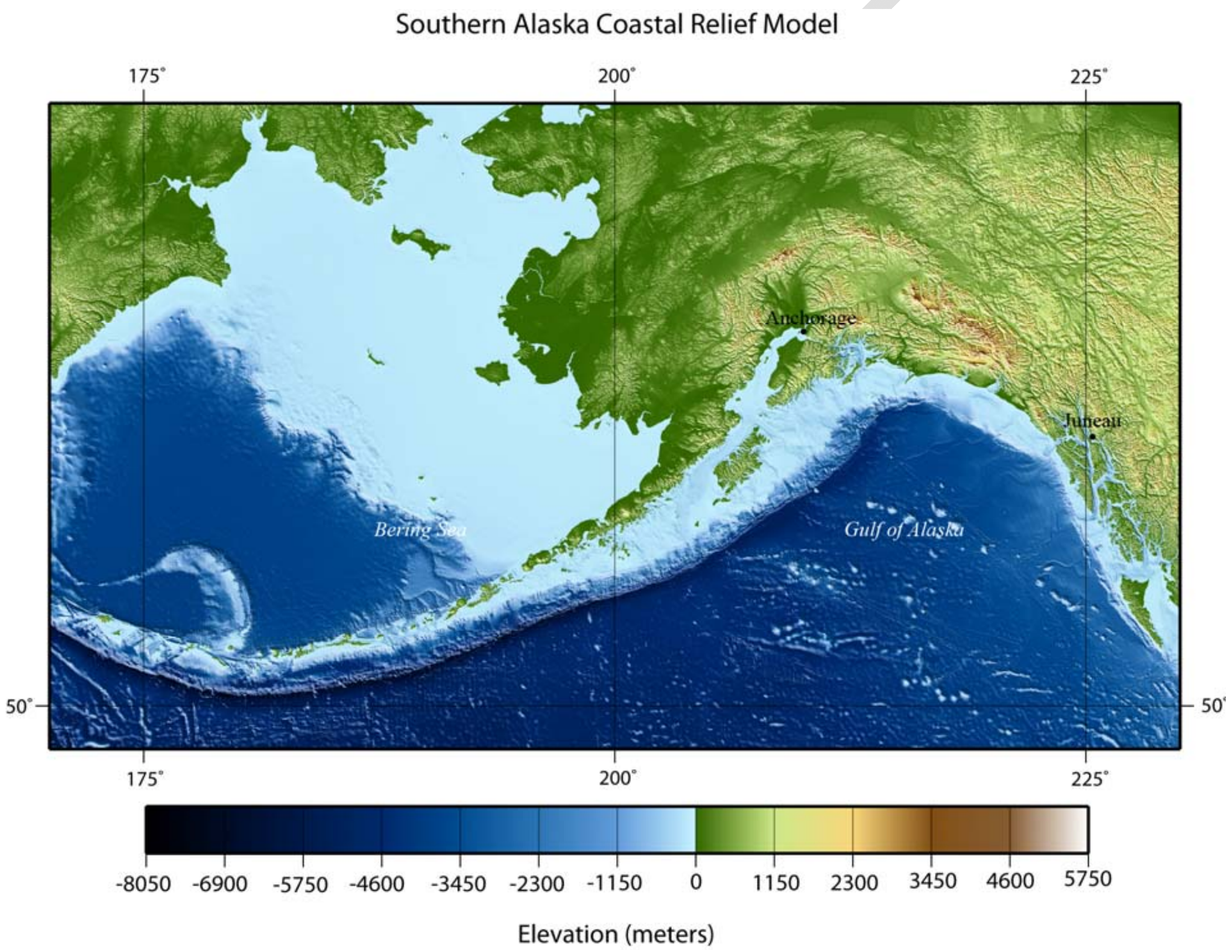

Figure 1. *Shaded-relief image of the Southern Alaska CRM. Image is in Mercator projection.*

1. In polar latitudes, longitude lines are spaced significantly closer together than latitude lines, approaching zero at the poles. The Southern Alaska CRM was built upon grids of square cells in geographic coordinates; they are not square cells when converted to meters. At the southern extent of the CRM (48.5º N) 24 arc-seconds of latitude is equal to 741 meters; 24 arc-seconds of longitude is 498 meters. At the northern extent of the CRM (66º N), 24 arc-seconds of latitude is equal to 743 meters; 24 arc-seconds of longitude is 303 meters.

2. STUDY AREA

The Southern Alaska CRM is a 24 arc-second digital elevation model that spans from 170° to 230° E and 48.5° to 66.5° N. The CRM integrates bathymetry and topography to represent Earth's surface and includes the Gulf of Alaska, Bering Sea, Aleutian Islands, and Alaska's largest communities: Anchorage, College, Fairbanks, and Juneau. The CRM was built from a variety of source datasets acquired from NGDC, NOAA's National Ocean Service (NOS), the United States Geological Survey (USGS), and other U.S. and international agencies.

The Southern Alaska CRM provides a framework to enable scientists to model tsunami propagation and ocean circulation. In addition, it may also be useful for benthic habitat research, weather forecasting, and environmental stewardship.

3. METHODOLOGY

The Southern Alaska CRM was developed to meet the specifications in Table 1. The best available digital data were obtained by NGDC and shifted to the global horizontal datum of World Geodetic System 1984 geographic (WGS 84)[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1: Specifications for the 24 arc-second Southern Alaska CRM.

Grid Area	Southern Alaska, USA
Coverage Area	170° E to 230° E; 48.5° to 66.5° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Sea Level
Vertical Units	Meters
Cell Size	24 arc-seconds
Grid Format	netCDF; binary float, geoTIFF; xyz

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

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 2) were obtained from several U.S. federal agencies, academic institutions, and international agencies including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS); Scripps Institute of Oceanography (SIO); the Bathymetric Data Center at the Bundesamt für Seeschiffarhrt und Hydrographie (BSH); and the National Geophysical Data Center (NGDC); the U.S. Fish and Wildlife Service (FWS); and the U.S. Geological Survey (USGS). Safe Software's (http://www.safe.com/) *FME* data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert into ESRI (http://www.esri.com/) *ArcGIS* shape files. The shape files were then displayed with *ArcGIS* to assess data quality and manually edit datasets.

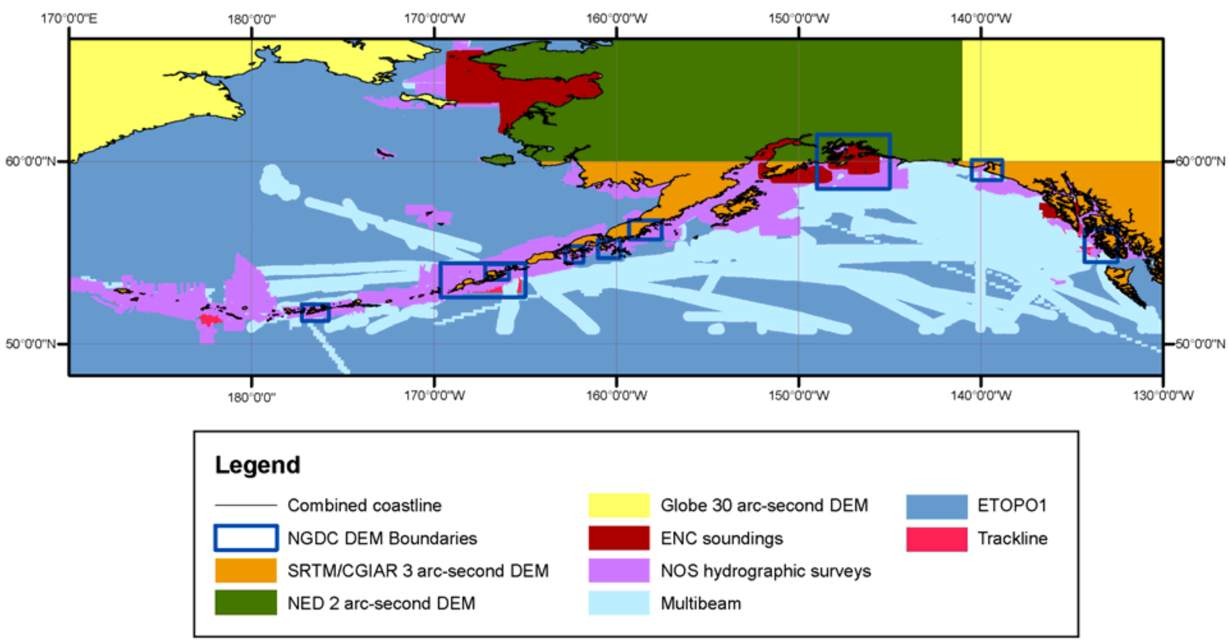

Figure 2. *Principal source dataset contributions to the Southern Alaska CRM.*

3.1.1 *Shoreline*

Three digital coastline datasets of the region were analyzed for inclusion in the Southern Alaska CRM: U.S. Fish and Wildlife Service (FWS) statewide Alaska digital coastline; National Geospatial-Intelligence Agency (NGA) global shoreline; and the Global Self-consistent, Hierarchical, High-resolution Shoreline (GSHHS) (Table 2, Fig. 3). Comparisons between the three coastline datasets with NOS hydrographic surveys, SRTM/CGIAR, NED, and GLOBE topographic DEMs, showed that all three coastline datasets fit the topographic and bathymetric data in their respective areas reasonably well. The coastlines were edited and integrated to create a ‘combined coastline’ of the Southern Alaska region.

Table 2. Shoreline datasets used in compiling the Southern Alaska CRM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
FWS	2006	Compiled coastline	Various	WGS 84 geographic	Undefined
NGA Global Shoreline	2000	Compiled coastline	Approximately 100 m	WGS 84 geographic	MHW
GSHHS Coastline	2003	Hierarchically arranged closed polygons	Approximately 100 m	WGS 84 geographic	MHW

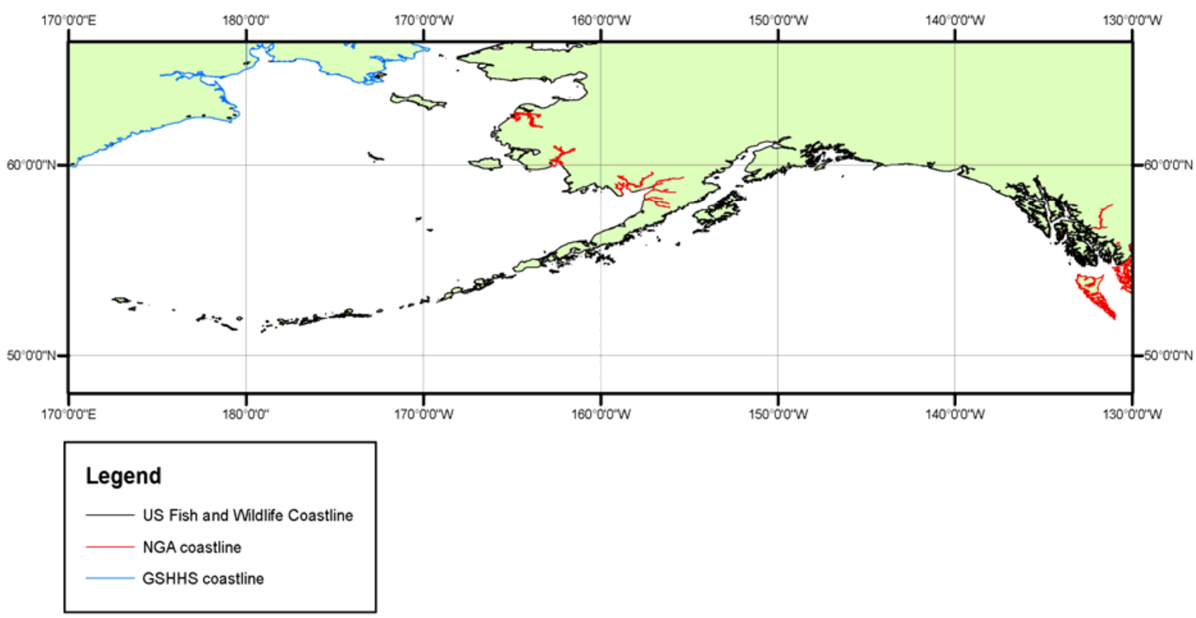

Figure 3. *Digital coastline datasets in the Southern Alaska region.*

1) U.S. Fish and Wildlife Service coastline

The U.S. Fish and Wildlife Service (FWS) has compiled a seamless digital coastline of the State of Alaska from a variety of sources, including: the National Hydrography Dataset, NOAA nautical charts, U.S. Fish and Wildlife Service, National Geographic Topo Software, U.S. Army Corps of Engineers, and Alaska Department of Natural Resources. This dataset was provided to NGDC by Bret Christensen, U.S. Fish and Wildlife Service. Though efforts were made to obtain the highest resolution coastlines available, vertical datums were apparently not determined nor controlled in any way in compiling the FWS coastline; the horizontal datum of the compiled FWS coastline is WGS 84.

2) NGA global shoreline

The National Geospatial-Intelligence Agency (NGA; http://www.nga.mil/) has developed a ‘Prototype Global Shoreline Data’ digital shoreline. The NGA Global Shoreline Data is an unclassified vector dataset generated by Earth Satellite Corporation (http://www.earthsat.com/) of Rockville, Maryland for NGA, under contract to Boeing in 2004. The shoreline is an approximation to the High Water Line and constructed from consistently orthorectified Landsat TM satellite imagery (GeoCover Ortho), acquired between 1998-2002 for NASA under the Global Land Mapping Program (GLMP). NDVI and SWIR models were used to define the landward extent of inundation (i.e., MHW). Independently verified positional accuracy for the source product (GeoCover Ortho) is consistently better than 50 meter root mean square (RMS) error. The NGA coastline matches the topographic data along island edges but is lacking the detail of the other coastline datasets, due principally to its lower resolution.

3) GSHHS Coastline

NGDC disseminates the GSHHS (Global Self-consistent, Hierarchical, High-resolution Shoreline) in ArcGIS format. GSHHS is a high-resolution shoreline data set created from two well-known, public domain data sets. World Data Bank II (WDB; also known as CIA Data Banks) contains the coastlines, lakes, political boundaries, and rivers at an approximate working scale of 1:3,000,000. The other data set is the World Vector Shoreline (WVS), which only contains shorelines along the ocean and land interface. The WVS data is superior in quality and resolution with a working scale of 1:100,000. Therefore, the GSHHS was created using the WVS dataset when possible and supplemented with WDB data. The data have undergone extensive processing and are free of internal inconsistencies such as erratic points and crossing coastline segments.

To obtain the best digital coastline, NGDC manually edited and merged the FWS, NGA, and GSHHS coastlines into a ‘combined coastline’. The ‘combined coastline’ was sampled to 500-meter spacing and converted to point data for use in the gridding process. It was also used as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached “zero” at the coast. The ‘combined coastline’ was used to clip the SRTM/CGIAR, NED, and GLOBE topographic DEMs, which contained elevation values, typically zero, over the open ocean (Section 3.1.3).

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Southern Alaska CRM include NOS hydrographic surveys, NOAA Electronic Navigation Chart (ENC) soundings, NGDC's ETOPO1 Global Relief Model, NGDC trackline surveys, and multibeam swath sonar surveys acquired from NGDC, Scripps Institution of Oceanography (SIO), and the Bathymetric Data Center at the Bundesamt für Seeschiffarht und Hydrographie (BSH) (Table 3).

Table 3. Bathymetric datasets used in compiling the Southern Alaska CRM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1888 to 2005	Hydrographic survey soundings	Ranges from 10 meters to 1.5 kilometers (varies with scale of survey, depth, traffic and probability of obstructions)	NAD 27, NAD 83, Early Alaskan Datum, Undetermined Datum	MLLW (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOAA ENCs	2008	NOAA digitized nautical chart soundings	~500 to 1200 meters	WGS 84 geographic	MLLW (meters)	http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm
NGDC, SIO, and BSH	1986-2005	Multibeam Swath Sonar	Raw MB files gridded to 10 arc-seconds	WGS 84 geographic	Sea level	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NGDC	1953-present	Trackline	Raw MB files gridded to 10 arc-seconds	WGS 84 geographic	Sea level	
NGDC ETOPO1	2008	Global Relief Model	1 arc-minute	WGS 84 geographic	Sea level	http://www.ngdc.noaa.gov/mgg/global/global.html
NGDC	2009	Digitized features	n/a	WGS 84 geographic	n/a	

1) NOS hydrographic survey data

A total of 1947 NOS hydrographic surveys conducted between 1888 and 2005 were used in building the Southern Alaska CRM (Fig. 4). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to Early Alaska, NAD 27, NAD 83 geographic, or "undetermined" datums.

Data point spacing for the surveys ranged from about 10 to 60 meters in shallow water to 1.5 kilometers in deep water. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original datums. The data were then converted to NAD 83 using *FME* software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com). NOS surveys in Early Alaska or undetermined datums were visually inspected and manually shifted in *ArcGIS* to fit the combined coastline. The surveys were subsequently clipped to a polygon 0.05 degrees (~5%) larger than the Southern Alaska CRM area to support data interpolation along grid edges.

After converting all NOS survey data to a common horizontal datum, the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and compared to the NED, SRTM/CGIAR, and GLOBE topographic data and the combined coastline.

Surveys #H11134 and #H11138 were found to have incorrect bathymetry values when compared to overlapping datasets. Further investigation revealed that original soundings had been converted from feet to meters twice. *FME* was used to correct the elevation values in each survey by multiplying the elevations by 3.28 (1 meter = 3.28 feet). NGDC notified NOS about this error and the surveys are being revised.

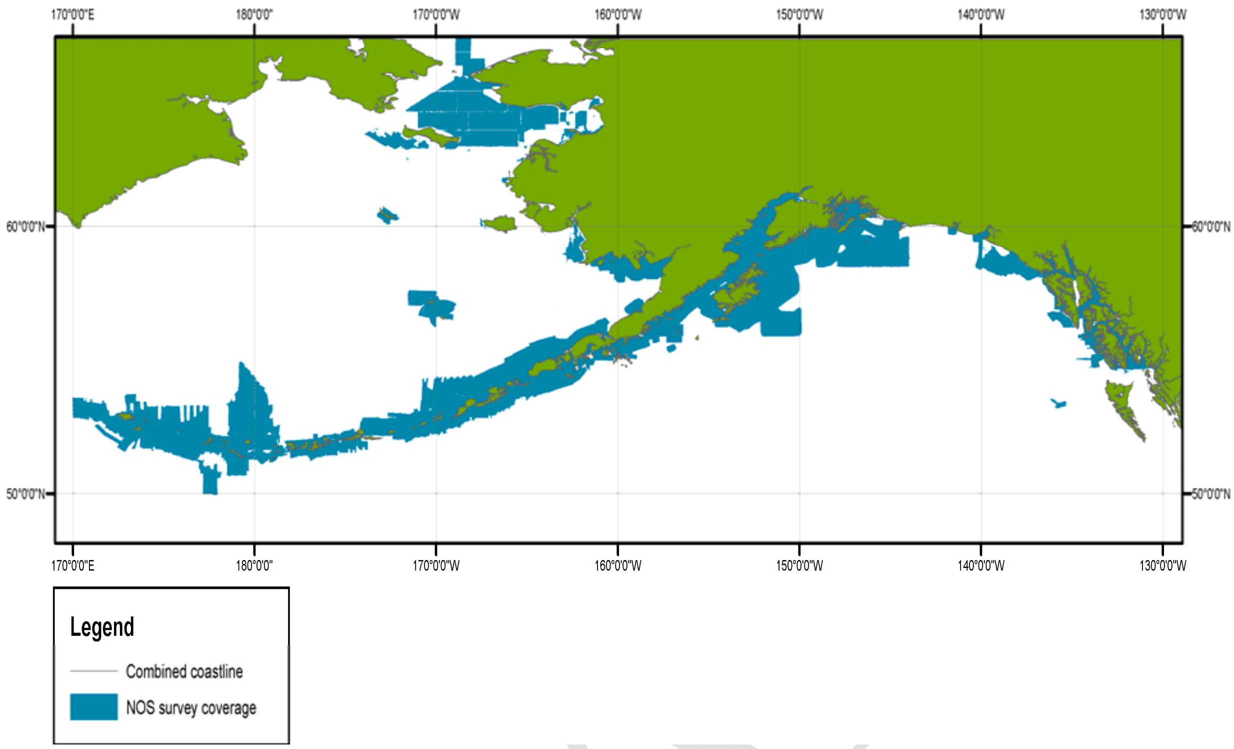

Figure 4. *Digital NOS hydrographic survey coverage in the Southern Alaska region.*

2) OCS ENC soundings

Numerous NOS nautical charts were available from NOAA's Office of Coast Survey in ENC format. NGDC extracted the digital soundings from ENCs in areas with sparse or no bathymetric soundings for use in building the Southern Alaska CRM (Table 4, Fig. 5).

Table 4. Electronic Nautical Charts used in compiling the Southern Alaska CRM.

Chart Number	*Region*	*Horizontal Spacing*	*Vertical Range*	*Scale*
16200	Norton Sound to Bering Strait	~1 to ~3 kilometers	-0.1 to -60.3 meters	1:400,000
16204	Port Clarence and Approaches	~800 m to ~2 km	-0.1 to -58.5 meters	1:100,000
16240	Cape Romanzof to St. Michael	~250 m to ~ 6.5 km	-0.1 to -29.5 meters	1:300,000
16645	Gore Point to Anchor Point	~500 m to ~1.5 km	-0.1 to -303.5 meters	1:82,662
16646	Port Chatham Kenai Peninsula	~100 to ~300 meters	-0.1 to -140.8 meters	1:20,000
16660	Cook Inlet Northern Part	~1 to ~3 kilometers	-0.1 to -140.8 meters	1:194,154
16662	Cook Inlet Kalgin Island to North Foreland	~100 m to ~1.5 km	-0.1 to -129.8 meters	1:194,154
16665	Cook Inlet Approaches to Anchorage	~100 m to ~1 km	-0.3 to -54.8 meters	1:50,000
16680	Point Elrington to East Chugach Island	~300 m to ~5.5 km	-2.7 to -294.4 meters	1:200,000
16700	Prince William Sound	~1 to ~2.5 kilometers	-0.3 to -1135.6 meters	1:200,000
16701	Prince William Sound Western Entrance	~200 m to 1.5 km	-0.3 to -473.6 meters	1:81,436
16709	Prince William Sound Eastern Entrance	~500 m to ~1.5 km	-0.3 to -499.8 meters	1:80,000
17320	Coronation Island to Lisianski	~1 to ~5.5 kilometers	-0.3 to -2368.2 meters	1:217,828

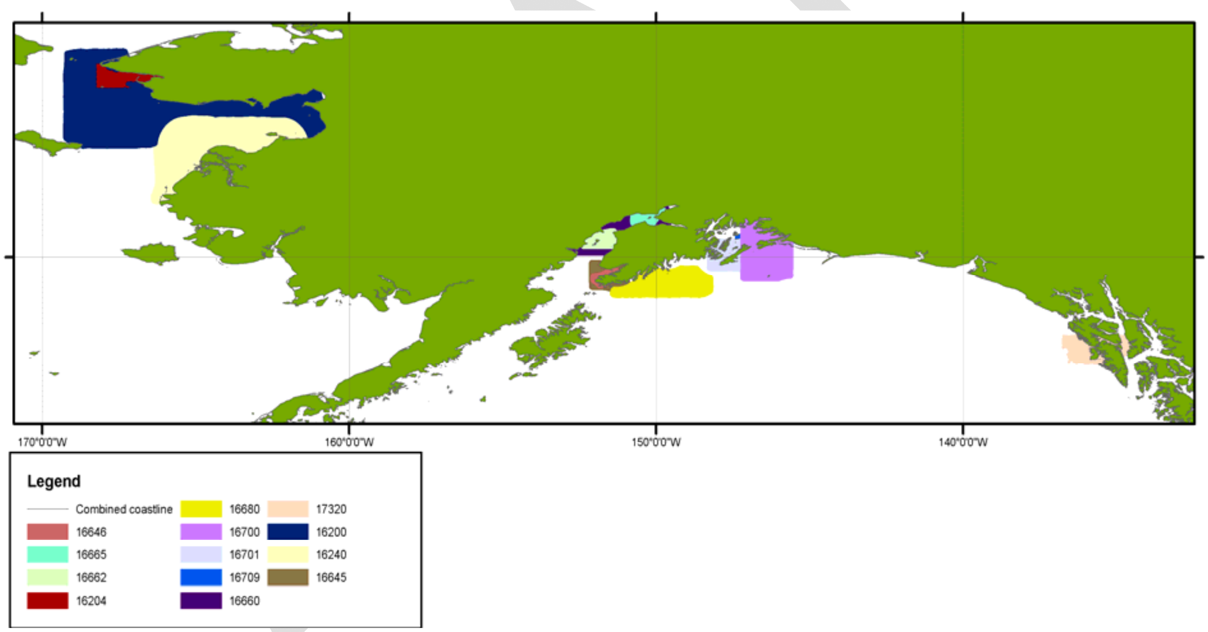

Figure 5. Coverage of extracted ENC soundings used in building the Southern Alaska CRM.

3) Multibeam swath sonar surveys

A total of 157 multibeam swath sonar surveys were available from NGDC's Multibeam Bathymetry Database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) in the Southern Alaska region (Table 5, Fig. 6). This database is comprised of the original swath sonar surveys conducted principally by the U.S. academic fleet. All surveys have a horizontal datum of WGS 84 geographic and an undefined vertical datum assumed to be equivalent to sea level.

Six multibeam swath sonar surveys were obtained from BSH. The data are comprised of the original swath sonar surveys conducted from 1994-1996 on the R/V Sonne. All surveys have a horizontal datum of WGS 84 geographic and a vertical datum of sea level. The Sonne survey data were generously provided by Volkmar Leimer of BSH.

One multibeam swath sonar survey conducted in 2004 on the R/V Roger Revelle was obtained from SIO. The survey has a horizontal datum of WGS 84 geographic and a vertical datum of sea level.

The multibeam bathymetry data were gridded at 10 to 12 arc-second cell size using *MB-System*. *MB-System* is an NSF-funded, free software application specifically designed to manipulate multibeam swath sonar data (http://www.ldeo.columbia.edu/res/pi/MB-System/). The gridded data were converted to shape-files and checked for erroneous soundings.

Table 5. Multibeam swath sonar surveys used in compiling the Southern Alaska CRM.

Survey ID	*Ship*	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
NGDC Multibeam	Multiple	1986-2005	Sea level	WGS 84 geographic	NOAA/NGDC
SO96-1	Sonne	1994	Sea level	WGS 84 geographic	BSH (Germany)
SO96-2	Sonne	1994	Sea level	WGS 84 geographic	BSH (Germany)
SO97-1	Sonne	1994	Sea level	WGS 84 geographic	BSH (Germany)
SO97-2	Sonne	1996	Sea level	WGS 84 geographic	BSH (Germany)
SO110-2	Sonne	1996	Sea level	WGS 84 geographic	BSH (Germany)
SO110-1b	Sonne	1996	Sea level	WGS 84 geographic	BSH (Germany)
KRUS03RR	Roger Revelle	1996	Sea level	WGS 84 geographic	SIO

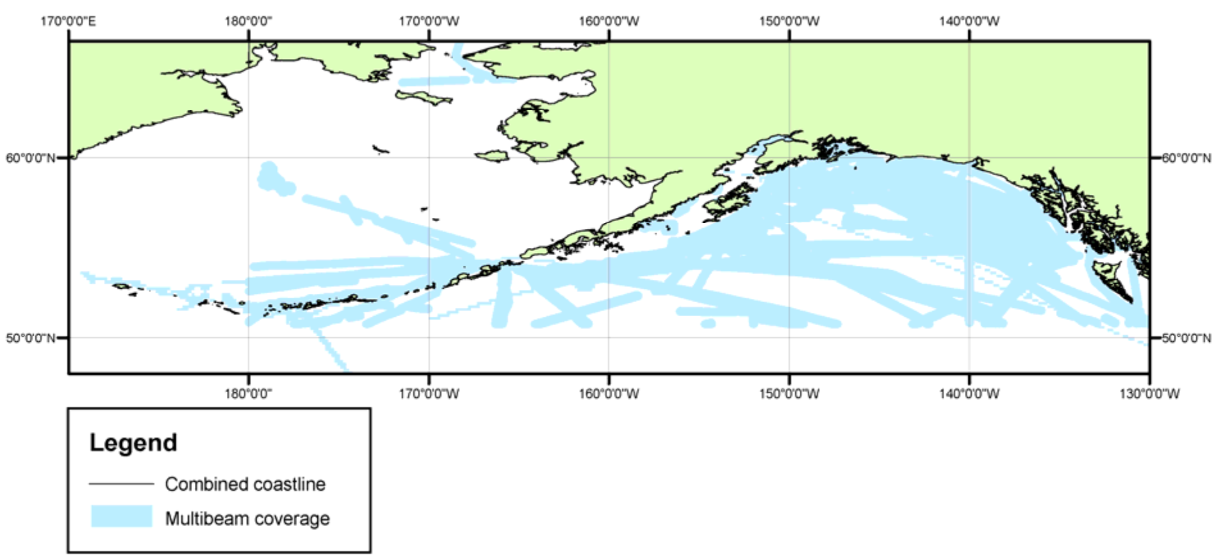

Figure 6. *Multibeam coverage for the Southern Alaska region.*

4) ETOPO1 Global Relief Model

Many areas of the Southern Alaska region contain sparse bathymetric measurements. NGDC's ETOPO1 Global Relief Model (http://www.ngdc.noaa.gov/mgg/global/global.html) has a 1 minute cell size and is referenced to WGS 84 geographic coordinates. This model is coarse at the resolution of the 24 arc second Southern Alaska CRM, however, it provides the only digital constraint over areas with sparse or no bathymetric data. Extracted bathymetric values are generally shallower than overlapping measured bathymetric values and are considered to be of low accuracy. NGDC clipped ETOPO1 where NOS hydrographic surveys and multibeam swath sonar data were present (Fig. 7).

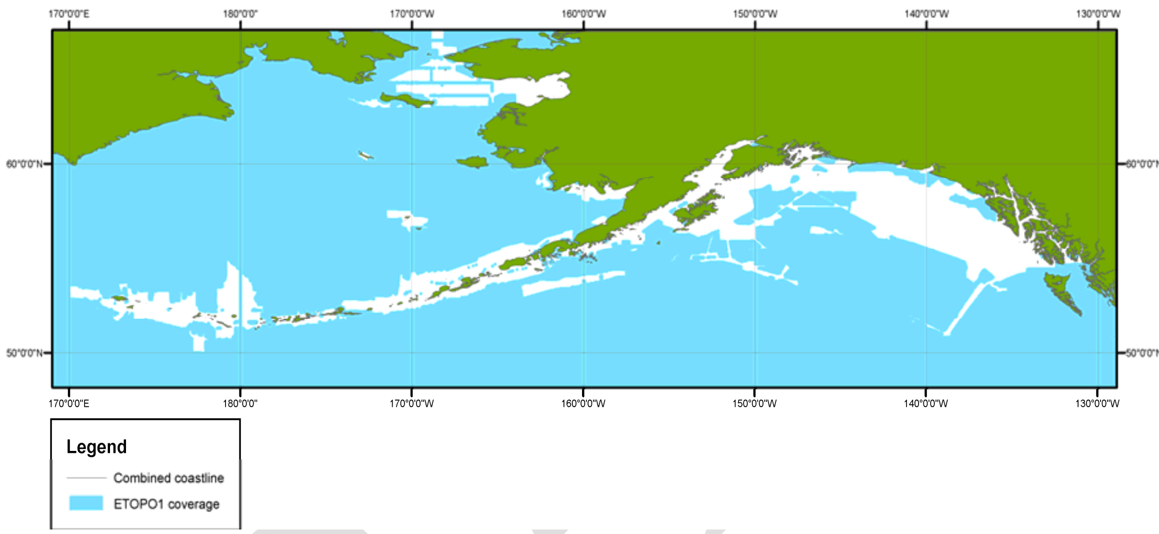

Figure 7. *Coverage of bathymetric data extracted from ETOPO1.*

5) Trackline surveys

A total of 313 trackline surveys were available from the NGDC trackline survey database (http://www.ngdc.noaa.gov/mgg/geodas/trackline.html) for use in building the Southern Alaska CRM (Fig. 2). The Marine Trackline Geophysics database contains bathymetry, magnetics, gravity and seismic navigation data collected during marine cruises from 1953 to the present. All surveys have a horizontal datum of WGS 84 geographic and an undefined vertical datum assumed to be equivalent to mean sea level (MSL). The data were downloaded in xyz format and converted to shapefiles using *FME* software.

6) NGDC Digitized Features

In regions of poor data coverage, NGDC digitized depths from raster nautical charts into a point shapefile to represent shallow water regions along the coastline. The digitized points were given a value of -1 meter, with the majority of points added along the coast of Cook Inlet to represent mudflats (Fig. 8).

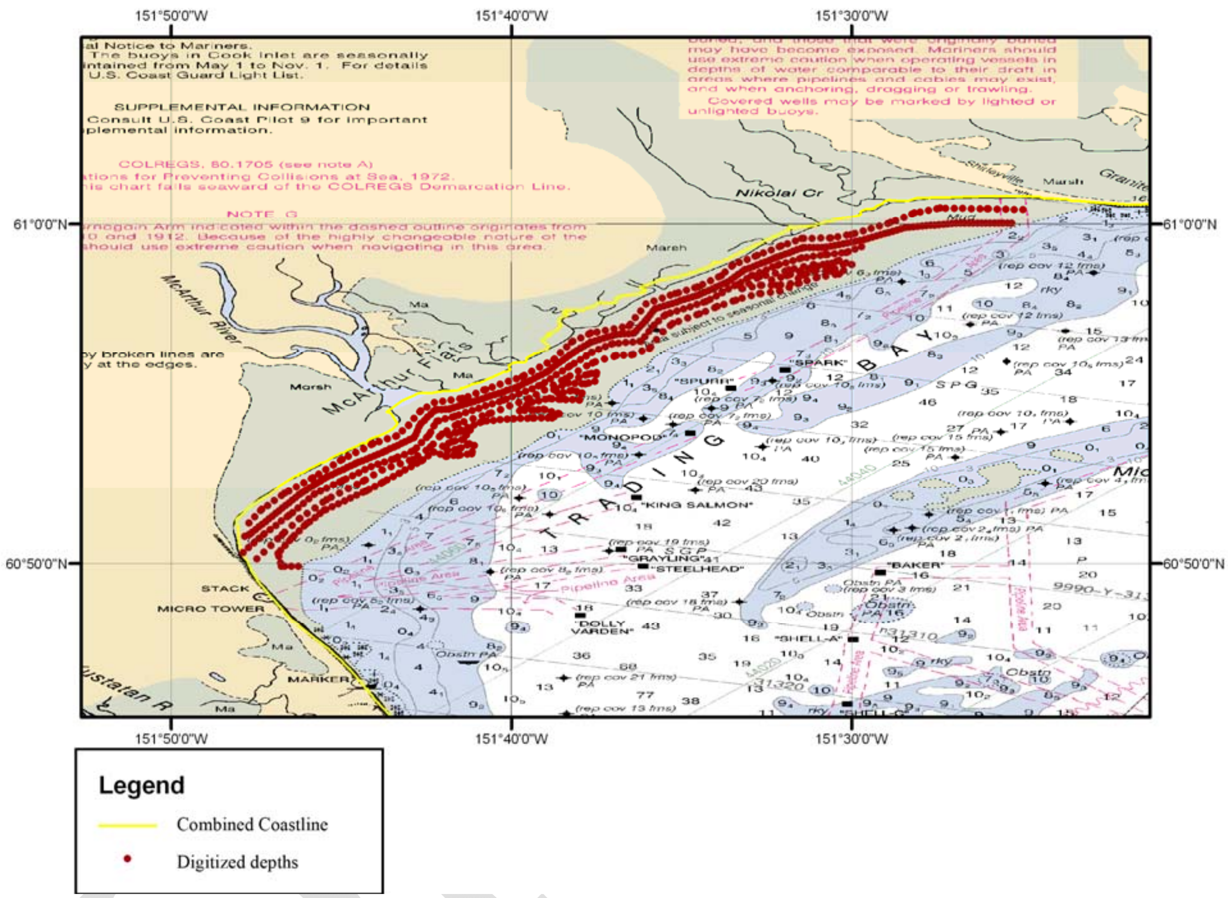

Figure 8. *NGDC digitized depths along the coast of Cook Inlet to represent mudflats shown in the RNC. Each point represents an elevation of -1 meter. Digitized features in red. Combined coastline in yellow.*

3.1.3 Topography

Topographic datasets for Southern Alaska were obtained from the U.S. Geological Survey: National Elevation Dataset 2 arc-second gridded topography (NED), 3 arc-second NASA space shuttle radar topography (SRTM) processed by the Consultative Group for International Agriculture Research (CGIAR), and NGDC's 30 arc-second GLOBE topography (Table 6, Fig. 9).

Table 6. Topographic datasets used in compiling the Southern Alaska CRM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*URL*
USGS NED	2006	Topographic DEM	2 arc-seconds	NAD 27 geographic	http://ned.usgs.gov/
SRTM/CGIAR	2000	Topographic DEM	3 arc-seconds	WGS 84 geographic	http://srtm.csi.cgiar.org/
NGDC GLOBE	1999	Grid derived from various data sets	30 arc-seconds	WGS 84 geographic	http://www.ngdc.noaa.gov/mgg/topo/globe.html

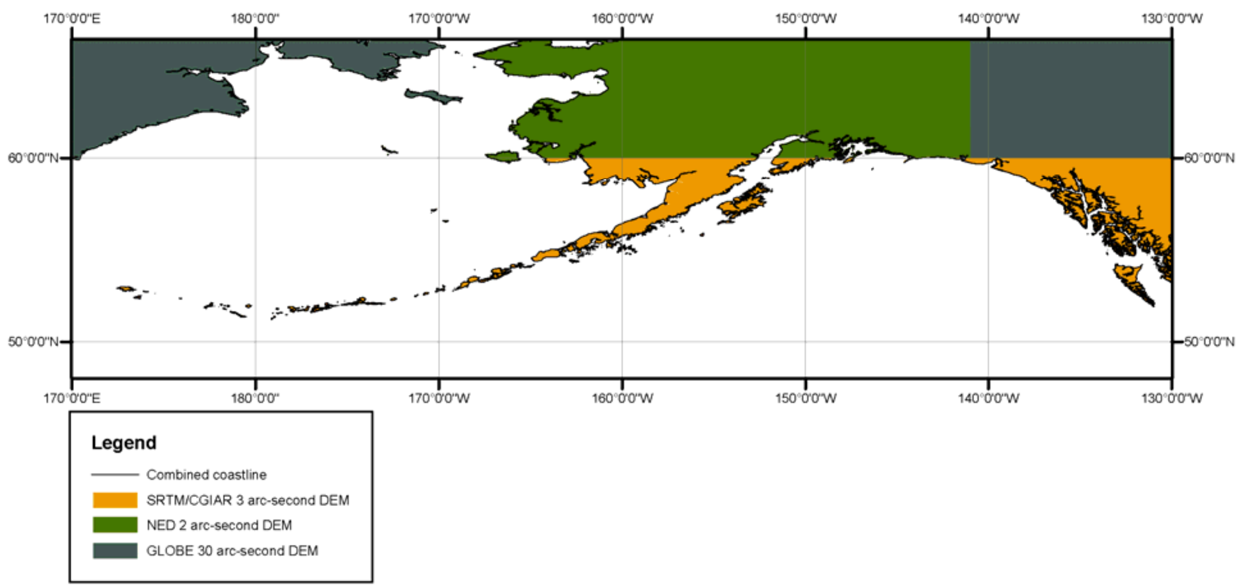

Figure 9. *Principal topographic dataset contributions to the Southern Alaska CRM.*

1) USGS NED topography

The U.S. Geological Survey's (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides 2 arc-second coverage of Alaska[3] (Fig. 10). Data are in NAD 27 Alaska geographic coordinates and NGVD29 vertical datum (meters), and are available for download as raster DEMs. The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quadrangles and aerial photographs based on surveys conducted in the 1970s and 1980s. Values over the open ocean required clipping to the combined coastline.

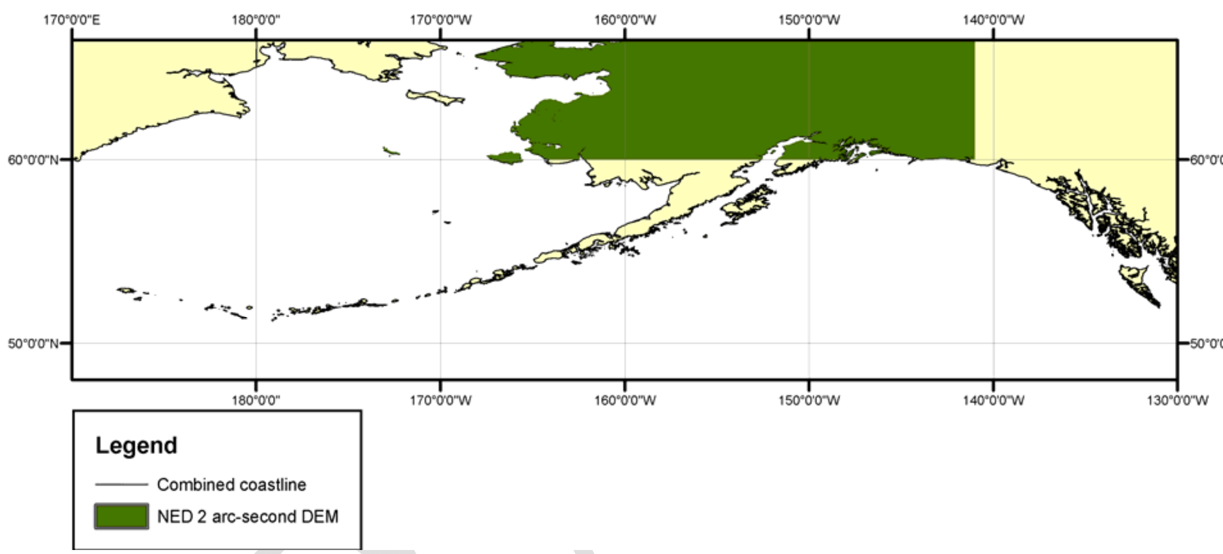

Figure 10. *The NED 2 arc-second topography used to build the Southern Alaska CRM. Combined coastline in black.*

3. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Alaska. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD 83, except for AK, which is NAD 27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

2) NASA space shuttle radar topography

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[4]. 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 was processed into 1 degree × 1 degree tiles and edited to define the coastline, and are available from the USGS Seamless web site (http://seamless.usgs.gov/) as raster DEMs. The data are not processed to bare earth, but meet the absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

For U.S. regions, the data has 1 arc-second spacing and are referenced to the WGS 84/EGM96 Geoid. While providing near complete coverage of the Aleutian Islands, the data does not extend beyond 60º N (Fig. 11) and there are numerous areas with “no data” values. CGIAR has processed the NASA/SRTM data to interpolate across data gaps. It is available for download at a global resolution of 3 arc-seconds (http://srtm.csi.cgiar.org/). The SRTM/CGIAR dataset contains values over the open oceans, which were deleted by clipping to the combined coastline.

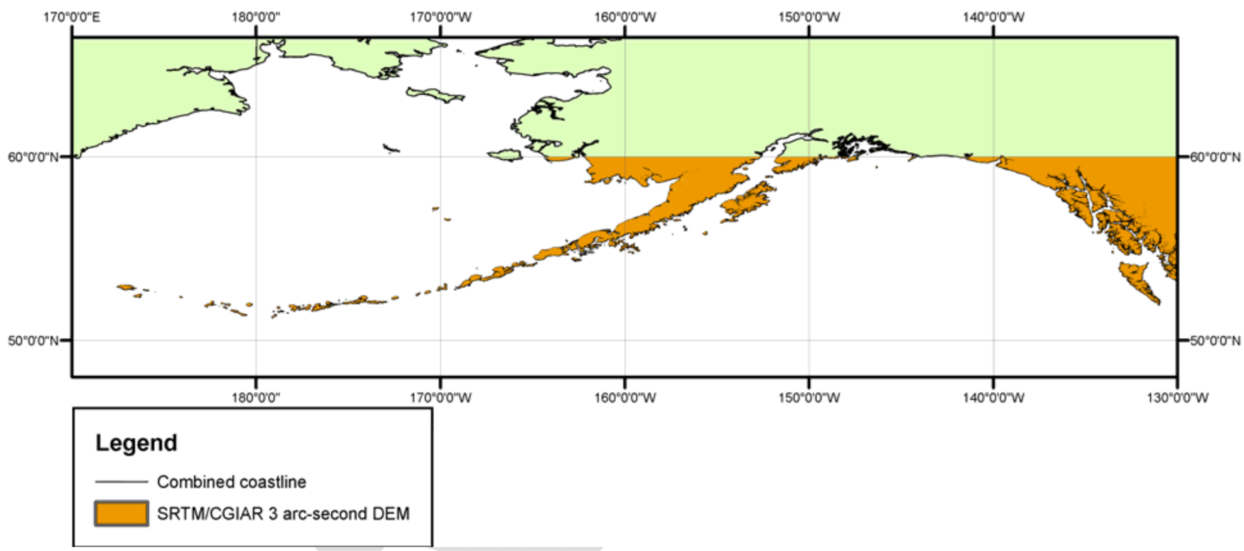

Figure 11. *The 3 arc-second SRTM/CGIAR topography used to build the Southern Alaska CRM. This dataset does not extend beyond 60º N and was processed by CGIAR to interpolate data gaps present in the original NASA/SRTM.*

4. The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in Farr and Kobrick (2000). Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths range from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take." SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of Earth’s total landmass. [Extracted from SRTM online documentation]

3) GLOBE topography

The NGDC GLOBE topography provides complete coverage of global topography and is available for download at a resolution of 30 arc-seconds (http://www.ngdc.noaa.gov/mgg/topo/globe.html). The data is in WGS 84 geographic coordinates and were referenced to sea level. GLOBE was created from both global and regional data sources in 1998; including Digital Terrain Elevation Data and Digital Chart of the World. Various regional data sources were also used and included DEMs of Australia, Japan, Italy, New Zealand, Greenland, Antarctica, and parts of South America and Asia. The Southern Alaska CRM incorporates GLOBE topographic data where NED and SRTM/CGIAR topography are not present, north of 60º N and in Canada and Russia (Fig. 12).

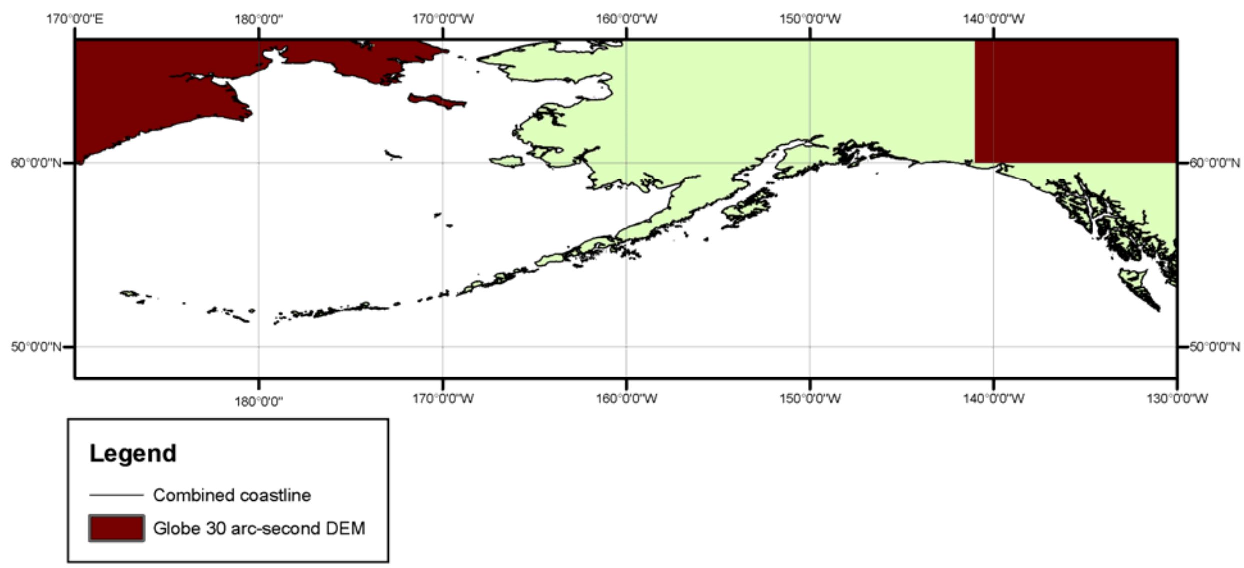

Figure 12. *The 30 arc-second GLOBE topography used in building the Southern Alaska CRM. GLOBE topography was used where NED topography is not present north of 60º N.*

3.1.4 *Bathymetry-Topography*

NGDC has built high-resolution integrated bathymetric-topographic DEMs for nine coastal regions within the bounds of the Southern Alaska CRM (Fig. 13). These DEMs are used to support tsunami forecasting and modeling efforts at the NOAA Center for Tsunami Research, Pacific Marine Environmental Laboratory (PMEL), and the state of Alaska (Table 7).

Table 7. Bathymetric-topographic DEMs used in compiling the Southern Alaska CRM.

Source	*DEM Area*	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOAA/ NGDC	Adak	2009	Bathymetric/ Topographic DEM	1 arc-second	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Chignik	2008	Bathymetric/ Topographic DEM	1 arc-second	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Craig	2008	Bathymetric/ Topographic DEM	1 arc-second	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Dutch Harbor	2006	Bathymetric/ Topographic DEM	1 arc-second	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	King Cove	2008	Bathymetric/ Topographic DEM	1 arc-second	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Sand Point	2006	Bathymetric/ Topographic DEM	3 arc-seconds	WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Akutan	2009	Bathymetric/ Topographic DEM	8 arc-seconds	WGS 84 geographic	Mean Higher High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Yakutat	2009	Bathymetric/ Topographic DEM	8 arc-seconds	WGS 84 geographic	Mean Higher High Water	http://www.ngdc.noaa.gov/dem/
NOAA/ NGDC	Prince William Sound	2009	Bathymetric/ Topographic DEM	8 arc-seconds	WGS 84 geographic	Mean Higher High Water	http://www.ngdc.noaa.gov/dem/

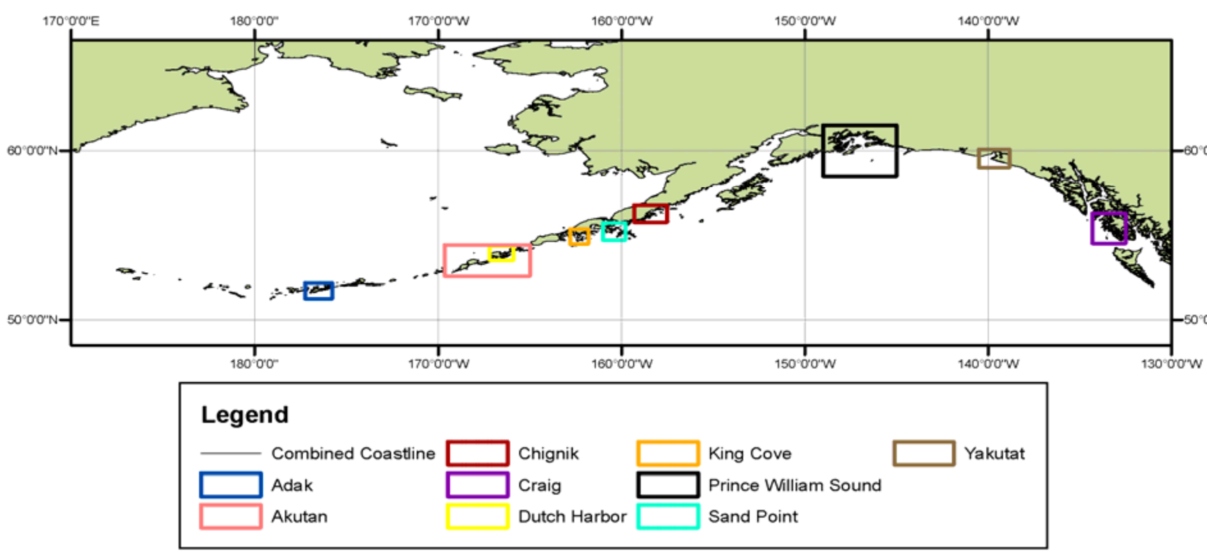

Figure 13. *Coverage of high resolution integrated bathymetric and topographic DEMs developed by NGDC. Combined coastline in black.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Source datasets used in the compilation and evaluation of the Southern Alaska CRM were originally referenced to a number of vertical datums including: Mean Lower Low Water (MLLW), Mean High Water (MHW), Mean Higher High Water (MHHW), WGS 84/EGM96 Geoid, North American Vertical Datum of 1929 (NGVD29), and North American Vertical Datum of 1988 (NGVD88). No common vertical datum was established for the Southern Alaska CRM due to its coarse (24 arc-second; ~700m) cell size; the vertical datum is assumed to be sea level.

3.2.2 Horizontal datum transformations

Source datasets used to compile the Southern Alaska CRM were originally referenced to Early Alaska, "undetermined", NAD 27, NAD 83, and WGS 84 geographic horizontal datums. The relationships and transformational equations between the horizontal datums are well established. All data were converted to a horizontal datum of either NAD 83 or WGS 84 geographic using *FME* software, with the exception of some of the older NOS surveys, which were manually shifted in *ArcGIS* to fit the combined coastline.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal transformations were applied, the resulting ESRI shape files were checked in ESRI *ArcMap* and Applied Imagery's *Quick Terrain Modeler* for inter-dataset consistency. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files were then converted to xyz files in preparation for gridding. Problems included:

- Data values over the open ocean in the NED, SRTM/CGIAR, and GLOBE topographic DEMs. Each dataset required automated clipping to the combined coastline.
- Sparse bathymetric data in the deep ocean
- Sparse bathymetric data at the coastline
- Scattered inaccurate soundings in some older NOS hydrographic surveys
- Incorrect units of measurement in two NOS hydrographic surveys

3.3.2 Smoothing of bathymetric data

The ETOPO1 Global Relief Model is sparse at the resolution of the 24 arc-second grid: in both deep water and near shore, the ETOPO1 survey data have point spacing up to 1.8 kilometers apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the 24 arc-second DEM, the ETOPO1 bathymetric data was clipped to the NOS hydrographic surveys and sections of the multibeam swath sonar to provide effective interpolation into the coastal zone. A 24 arc-second-spacing 'pre-surface' or grid was generated using *GMT*, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The ETOPO1 bathymetric point data, in xyz format, were combined with NOS hydrographic soundings, ENC soundings, and multibeam swath sonar soundings into a single file, along with points extracted every 300 meters from the combined coastline. To provide a slightly negative buffer along the entire coastline, the extracted points were assigned a value of -1 meter to make sure that the offshore elevations remained negative; this was necessary due to the sparseness of the bathymetric data near the coast. These point data were then smoothed using the *GMT* tool 'blockmedian' onto a 24 arc-second grid. The *GMT* tool 'surface' was then applied to interpolate values for cells without data. The *GMT* grid created by 'surface' was converted into an ESRI Arc ASCII grid file using the *MB-System* tool 'mbm_grd2arc'. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid with the combined coastline (to eliminate data interpolation into land areas). The pre-surface was compared with the original soundings to ensure grid accuracy (e.g., Fig. 14), converted to a shape file and then exported as a xyz file for use in the final gridding process (see Table 8).

The statistical analysis of the differences between the 24 arc-second bathymetric surface and one of the NOS surveys (see Fig. 14) showed that the majority of the NOS soundings are in a good agreement with the bathymetric surface. The few exceptions where the difference reached tens of meters are attributed to the rugged terrain where two or more closely positioned points were averaged to obtain the elevation of the one grid cell.

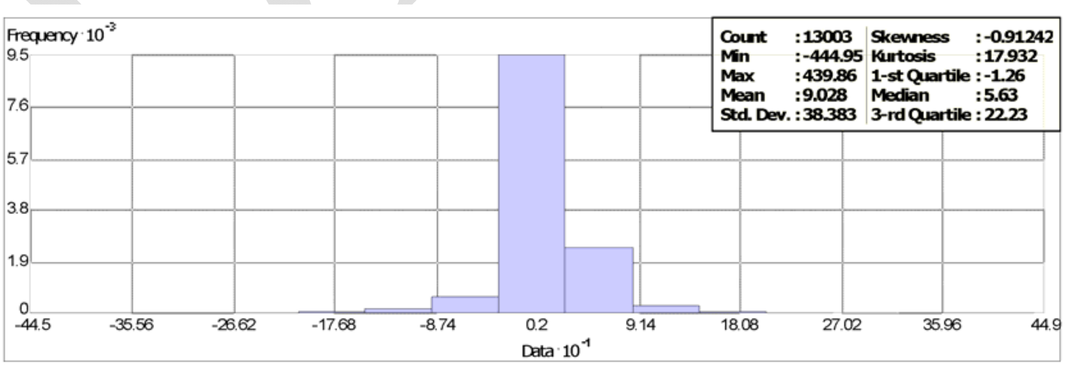

Figure 14. *Histogram of the difference between NOS hydrographic survey H07995 and the 24 arc-second pre-surfaced bathymetric grid.*

3.3.3 Building the Southern Alaska CRM with MB-System

MB-System was used to create the 24 arc-second Southern Alaska CRM. The *MB-System* tool 'mbgrid' applied a tight spline tension to the xyz data, and interpolated values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 8. Greatest weight was given to the high-resolution multibeam swath sonar surveys, NGDC's high-resolution DEMs, and NGDC digitized features. Least weight was given to the pre-surfaced bathymetric grid, trackline, and bathymetry from the ETOPO1 Global Relief Model.

Table 8. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
Mulitbeam swath sonar surveys	100
NGDC DEMs	100
NGDC digitized features	100
NOS hydrographic surveys	10
USGS NED topographic DEM	10
SRTM/CGIAR topographic DEM	10
ENC soundings	10
GLOBE topographic DEM	1
Combined coastline	1
ETOPO1 bathymetry	0.1
Trackline	0.1
Pre-surfaced bathymetric grid	0.1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Southern Alaska CRM is dependent upon the DEM cell size and the datasets used to determine corresponding DEM cell values. Topographic features have an estimated horizontal accuracy of ~700 meters, based on the cell size of the Southern Alaska CRM. Bathymetric features in areas covered by early 20th-century NOS hydrographic soundings are resolved only to within a few tens of meters in shallow water, and to a few hundred meters in deep-water areas; their positional accuracy is limited by the sparseness of soundings, and potentially large positional accuracy of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Southern Alaska CRM is also dependent upon DEM cell size and the source datasets contributing to grid cell values. Island interiors have vertical accuracies of between 10 and 15 meters, (NED: ~10 meters; SRTM: < 16 meters; and Globe: 10-500 meters). Gridding interpolation to determine bathymetric values between sparse, poorly located, early 20th-century NOS hydrographic soundings degrades the vertical accuracy of elevations in deep water, to about 5% of the water depth.

3.4.3 3-D orthographic image

Generic Mapping Tools (*GMT*) and *Persistence of Vision Raytracer* (*POV-Ray*) were used to generate an orthographic image of the Southern Alaska CRM. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM (Fig. 15).

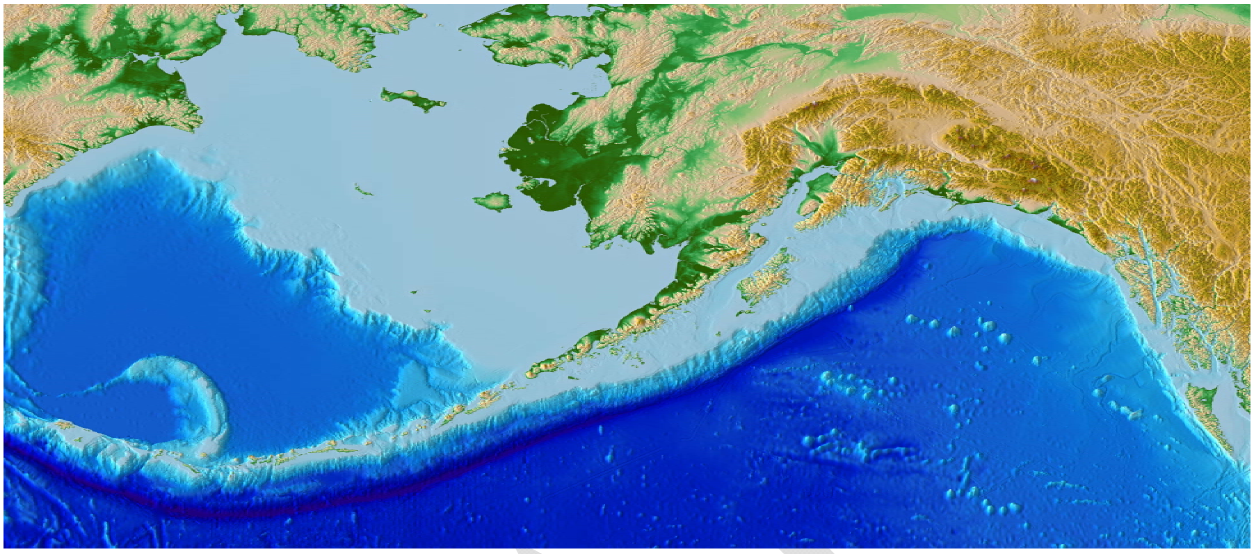

Figure 15. *An orthographic image of the Southern Alaska CRM.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the 24 arc-second Southern Alaska CRM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas. A histogram of the differences between selected SRTM/CGIAR data points and the 24 arc-second Southern Alaska CRM is shown in Figure 16.

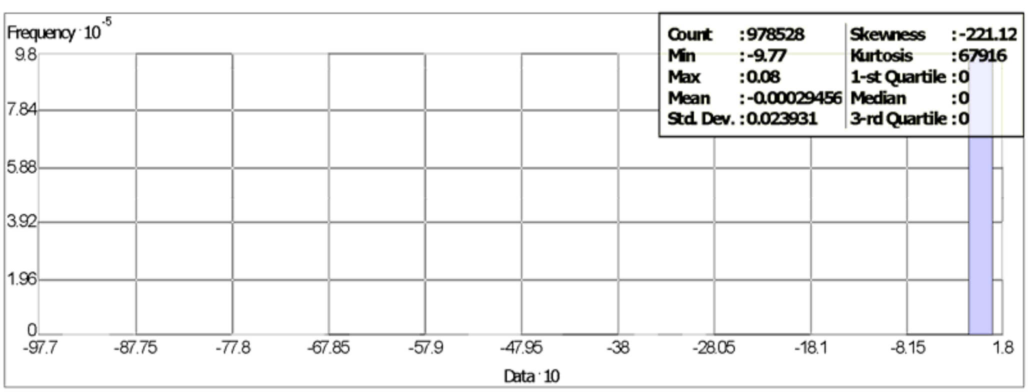

Figure 16. *Histogram of the difference between the SRTM/CGIAR topographic dataset and the Southern Alaska CRM. The largest differences occur in regions of highly variable, steep coastal relief where multiple, closely spaced points were averaged to a single cell value.*

4. Summary and Conclusions

An integrated bathymetric-topographic digital elevation model of the Southern Alaska region, with cell spacing of 24 arc-seconds, was developed by NOAA's National Geophysical Data Center (NGDC). The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to a common horizontal datum, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using *ESRI ArcGIS, FME, GMT, Quick Terrain Modeler*, *POV-Ray* and *MB-System* software.

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

- Conduct bathymetric coastal surveys.
- Conduct bathymetric deep-water multibeam surveys.
- Establish, via survey, the relationships between tidal and geodetic datums in the Southern Alaska region.
- Determine the relationship between Early Alaska and NAD83/WGS 84 geographic horizontal datums.
- Obtain bathymetric data along the coast of Russia.

5. Acknowledgments

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Nautical Chart #17320, 3rd Edition, 2008. Coronation Island to Lisianski Strait. Scale 1:217,828. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

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

FME 2008 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

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

MB-System v. 5.0.9, shareware developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/

Quick Terrain Modeler v.6.0.1, developed by Johns Hopkins University Applied Physics Laboratory, licensed by Applied Imagery, Silver Spring, Maryland, http://www.appliedimagery.com/index.html

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