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

Prepared for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research by the NOAA National Geophysical Data Center (NGDC)
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Carignan, K.S.[1], L.A. Taylor[2], B.W. Eakins[1], D.Z. Friday[1], P.R. Grothe[1], and M. Love[1]
1. Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder
2. NOAA, National Geophysical Data Center, Boulder, Colorado

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

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1. Introduction

On June 29th, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Adminstration (NOAA), developed an updated, version 2, bathymetric–topographic digital elevation model (DEM) of Craig, Alaska (Fig. 1). The 1/3 arc-second[1] DEM, referenced to Mean High Water (MHW), was developed and evaluated using diverse digital datasets available for the region (grid boundaries and sources shown in Fig. 4). The DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/) to simulate tsunami generation, propogation, and inundation as part of the tsunami forecast system Short-term Inundation Forecasting for Tsunamis (SIFT) currently being developed by PMEL for the NOAA Tsunami Warning Centers. This report provides and summary of the data sources and methodology used in developing the Craig DEM vers2.

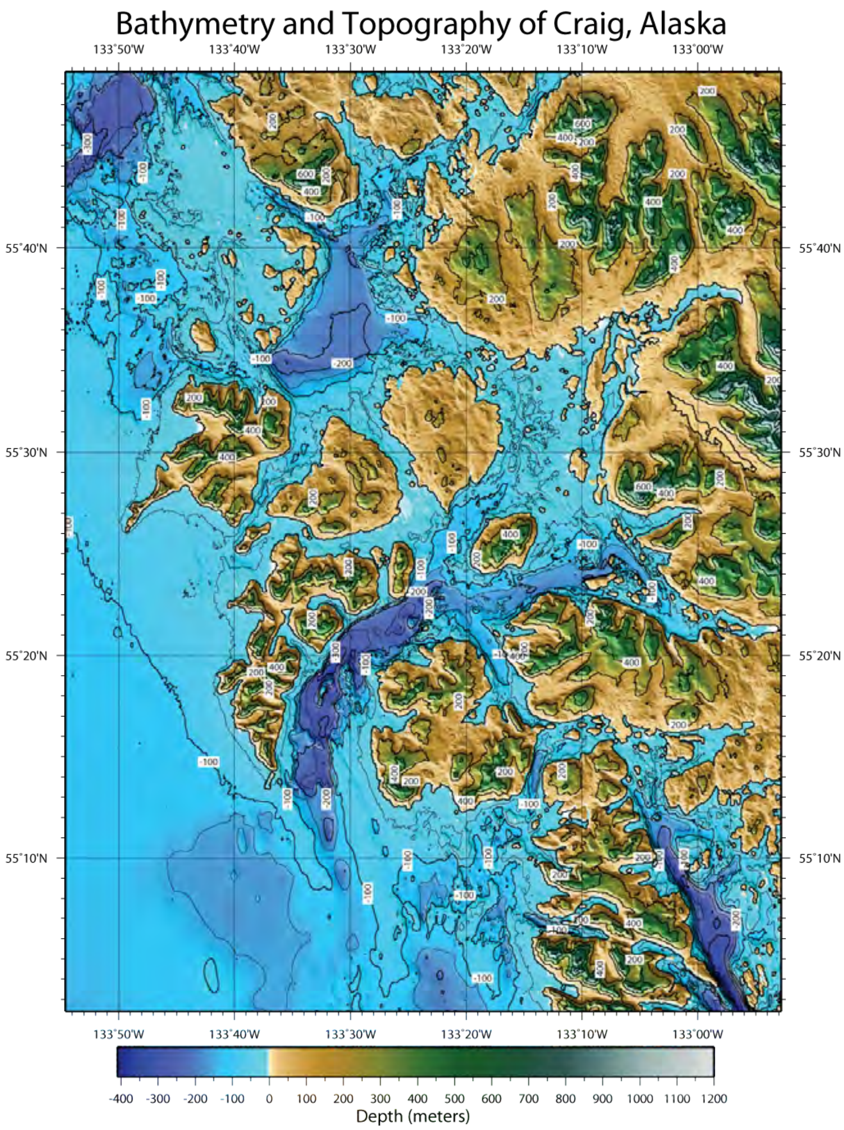

Figure 1. Shaded relief image of the Craig 1/3 arc-second DEM. Topographic contour intervals are 200 meters and bathymetric contour intervals are 50 meters.

1. The Craig DEM is built upon a grid of cells that are square in geographic coordinates (latitiude and longitude), however, the cells are not square when converted to projected coordinate systems such as UTM zones (in meters). At the latitude of Craig, Alaska, (55°28'35"N, 133°8'54"W) 1/3 arc-second of latitude is equivalent to 10.31 meters; 1/3 arc-second of longitude equals 5.85 meters.

2. Study Area

The Craig DEM provides coverage of the area surrounding Craig, Alaska, including the town of Klawock. The DEM area is located on the western coast of Prince of Wales Island in southeast Alaska, and approximately 200 miles southeast of Juneau, Alaska (Fig. 2). The town of Craig was founded in the late nineteenth century as a fishing town but has also developed a logging industry and a growing population currently of over 1,000 year-round residents.

The Fairweather and Denali/Chatham strike slip faults systems nearest to the DEM region may be less likely to cause a rupture induced tsunami but do have the potential for triggering landslides in the surrounding steep terrain (Hansen and Combellick, 1998, Fig. 3). Landslide generated waves have resulted in local damages as in Skagway in 1994 when a non-earthquake related wave caused damage to the harbor and docks.

Figure 2. Location of the Craig DEM. Red box indicates DEM boundary, green dots indicate local communities, yellow dot indicates the captial city of Juneau, AK.

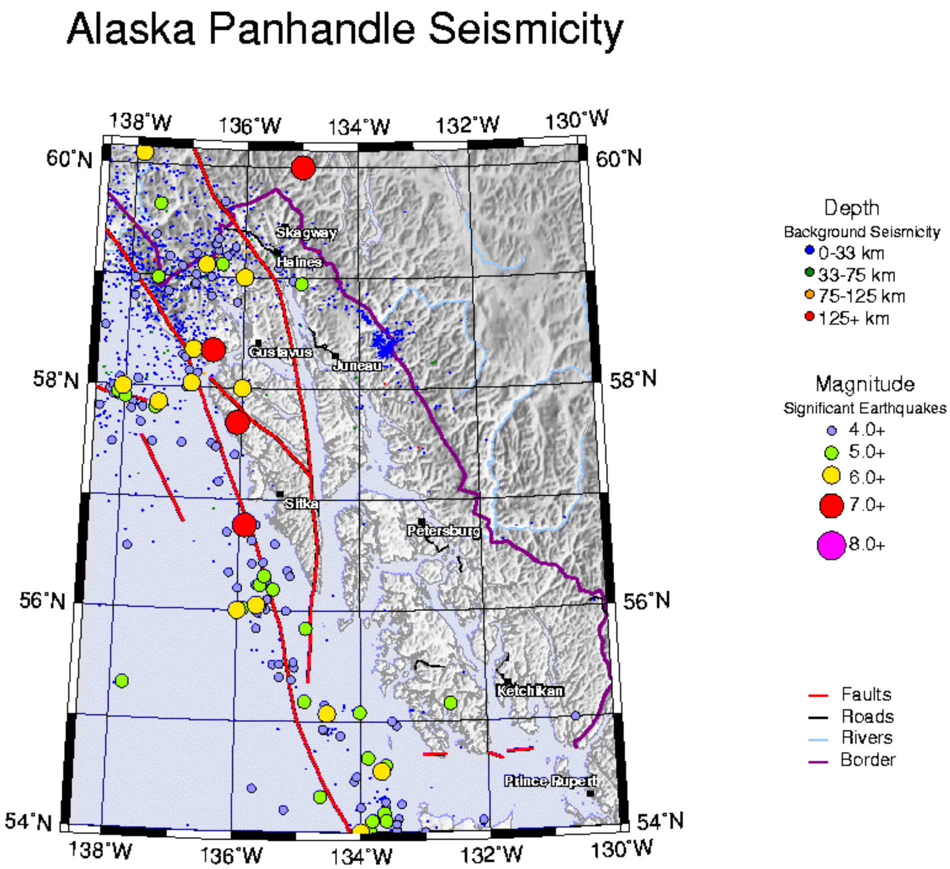

Figure 3. Alaska Panhandle seismicity. Image from Alaska Earthquake Information Center (www.aeic.alaska.edu/maps/southeast_panhandle_map.html).

3. Methodology

The Craig DEM was constructed to meet PMEL specifications (Table 1), based on input requirements for the development of Reference Inundation Models (RIMs) and Standby Inundation Models (SIMs) (*V. Titov, pers. comm.*) in support of NOAA's Tsunami Warning Centers use of SIFT (Short-term Inundation Forecasting for Tsunamis) to provide real-time tsunami forecasts in an operational environment. This DEM for Craig, Alaska is a high resolution version of the 2008 Craig DEM developed by NGDC. Higher resolution bathymetry data and coastal lidar enables a 1/3 arc-second version to be developed. 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. Data were gathered in an area slightly larger than the DEM extents. This data "buffer" ensured that gridding occured across rather than along the DEM boundaries to prevent edge effects. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1. Specifications for the Craig DEM.

Grid Area	Craig, Alaska
Coverage Area	132.88° to 133.91° W; 55.04° to 55.81° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI Arc ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets were obtained from federal, state, and local agencies and institutions including: NGDC; NOAA's National Ocean Service (NOS), National Geodetic Survey (NGS), Office of Coast Survey (OCS); the State of Alaska's Department of Commerce, Community, and Economic Development, Division of Community and Regional Affairs (DCRA); the U.S. Army Corps of Engineers (USACE); the U.S. Geological Survey (USGS); the National Geospatial Intelligence Agency (NGA); and the National Aeronautics and Space Administration (NASA). Datasets were shifted to NAD 83 geographic horizontal datum using ESRI's ArcGIS and FME. Data were visually displayed with ArcGIS and Applied Imagery's Quick Terrain Modeler (QT Modeler), to assess quality and manually edit datasets. Vertical datum transformations were accomplished using a generated grid of offset values derived from regional tide stations and tidal information (see Sec. 3.2.1).

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.

3.1.1 Coastline

Alaska shoreline data were retrieved from the NGDC archive (Table 2). The vector coastline was developed by NGDC in 2008 based on the USFWS coastline for use in developing a DEM for Craig, Alaska.

Table 2. Shoreline dataset used in developing the Craig DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*
NGDC	2009	Vector Coastline	Various	WGS 84 Geographic	Undefined

1) **NGDC coastline**

For this updated DEM of Craig, Alaska, NGDC further defined the coastline developed for the vers.1 Craig DEM in 2008 by comparing it with lidar datasets, recent NOS hydrographic surveys and imagery from UAF's SDMI-GINA project. Small adjustments to the coastline were made as necessary. The comparison helped to ensure that features such as jetties and rocks were accurately reflected in the coastline. The final edited coastline was converted to xyz data with a ten meter point spacing, using NGDC's *GEODAS* software, for use in building a 'pre-surface' bathymetric grid (see Sec. 3.3.2).

3.1.2 Bathymetry

Four bathymetric datasets were used to build the Craig DEM (Table 3, Fig. 4). These included twelve recent high-resolution NOS bathymetric BAG[3] surveys, six early NOS hydrographic surveys; and one hydrographic survey from the USACE Alaska District, and soundings from nautical charts.

Table 3. Bathymetric datasets used in compiling the Craig DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1912 to 2009	Hydrographic survey xyz data or BAG data	Ranges from less than 2 m to 600 m (varies with scale of survey, recency of survey, and distance from shore)	Early Alaska Datums; NAD 27 geographic; Universal Transverse Mercator (UTM) NAD 83, Zone 8 North; or undetermined	Mean Lower Low Water (MLLW)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2003 and 2007	Hydrographic survey xyz data	1 to 30 meters	NAD 83 Alaska State Plane 1 (feet)	MLLW	http://www.poa.usace.army.mil/en/hydro/
ENC	2004 to 2011	extracted soundings	~ 40 to 900 meter point spacing	WGS 84 geographic	MLLW	http://www.nautical-charts.noaa.gov/staff/chartspubs.html
RNC	2012	digitized soundings	~ 75 to 400 meter point spacing	WGS 84 geographic	MLLW	http://www.nautical-charts.noaa.gov/staff/chartspubs.html

3. Bathymetric Attributed Grid (BAG) is a non-proprietary file format for storing and exchanging bathymetric data developed by the Open Navigation Surface Working Group. BAG files are gridded, multi-dimensional bathymetric data files and is the standard NOS hydrographic data file for public release. Current versions of the BAG file contain position and depth grid data, as well as position and uncertainty grid data, and the metadata specific to that BAG file, providing end users information about the source and contents of the BAG file. Please visit the Open Navigation Surface Working Group for additional information on BAG files.

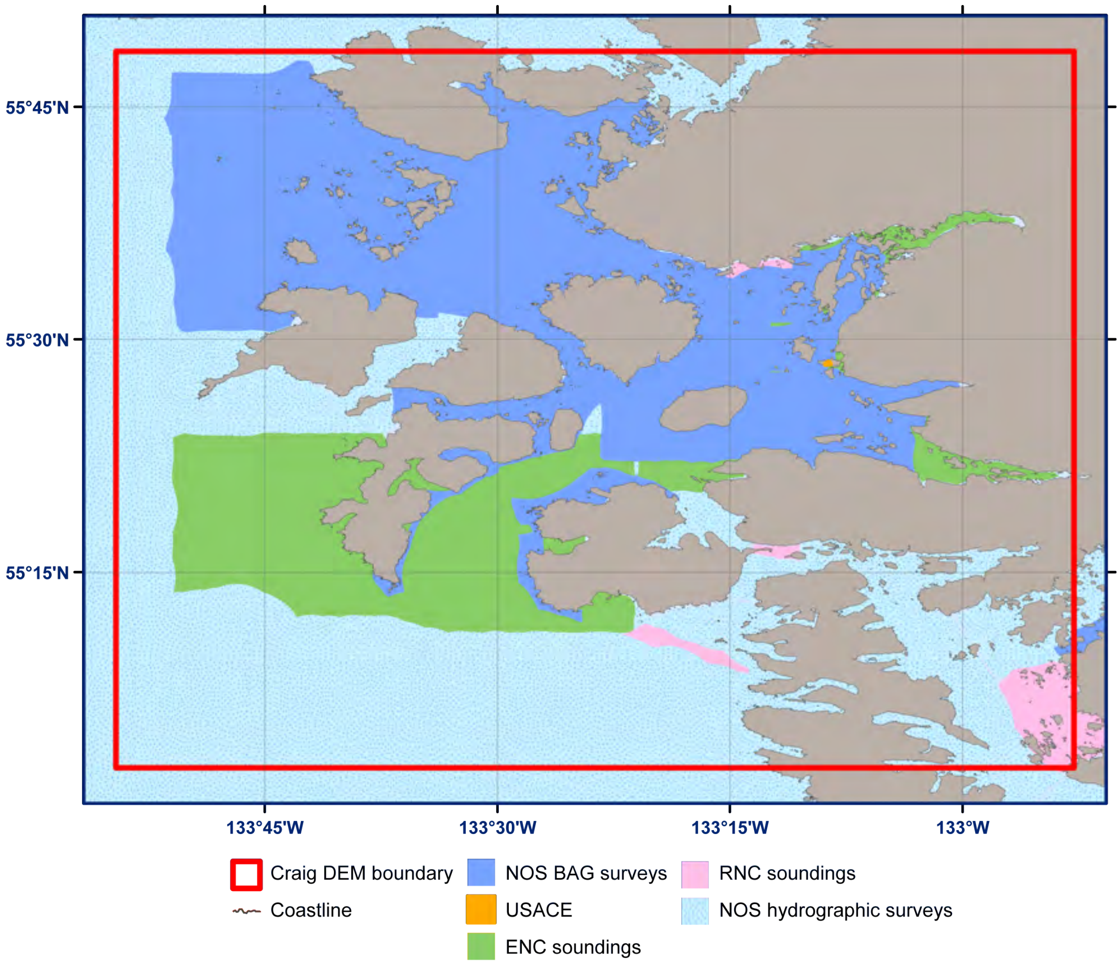

Figure 4. Spatial coverage of bathymetric data sources used in building the Craig DEM.

1) National Ocean Service hydrographic survey data

A total of 77 NOS hydrographic surveys conducted between 1912 and 2009 were used in building the Craig DEM (Table 4; Fig. 4). Older surveys, pre-1980, were extracted from NGDC's online NOS hydrographic database using *GEODAS*[4]. The hydrographic survey data were downloaded vertically referenced to mean lower low water (MLLW) and horizontally referenced to NAD 83 geographic. More recent surveys, post 2000, were downloaded individually as BAG files and converted to xyz format with *GDAL*. The data point spacing of the surveys varies by scale. In general, small scale surveys have greater point spacing than large scale surveys. The data were transformed to MHW and converted to shapefiles using *FME*, and were edited and clipped to the DEM buffer area in ESRI's *ArcGIS*. The surveys were compared to the original survey smooth sheets, other bathymetric datasets, the Craig coastline, topographic data, and NOS raster nautical charts (RNCs). Some surveys were manually shifted to fit the coastline. Older surveys were clipped or removed to eliminate data that were overlapped by more recent BAG data.

4. *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.

Table 4. Early digital NOS hydrographic surveys available for use in developing the Craig DEM.

Survey ID	*Date*	*Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*
D00143	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
D00144	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
D00145	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
D00146	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H03416*	1912/1913	1:20,000	Undetermined	MLLW
H03417*	1912	1:20,000	Undetermined	MLLW
H03427*	1912	1:10,000	Undetermined	MLLW
H03539*	1913	1:10,000	Undetermined	MLLW
H03540*	1913	1:20,000	Undetermined	MLLW
H03547*	1913	1:10,000	Undetermined	MLLW
H03666*	1914	1:10,000	Undetermined	MLLW
H03678*	1914	1:20,000	Undetermined	MLLW
H03679*	1914	1:10,000	Undetermined	MLLW
H03680*	1914	1:10,000	Undetermined	MLLW
H03691*	1914	1:20,000	Undetermined	MLLW
H03692*	1914	1:20,000	Undetermined	MLLW
H03692A*	1914/1925	1:20,000	Undetermined	MLLW
H03795*	1915	1:10,000	Undetermined	MLLW
H03818*	1915	1:20,000	Undetermined	MLLW
H03819B*	1920	1:120,000	Undetermined	MLLW
H03880*	1915	1:20,000	Undetermined	MLLW
H04191*	1920	1:20,000	Undetermined	MLLW
H04192*	1920	1:20,000	Undetermined	MLLW
H04203*	1921	1:20,000	Undetermined	MLLW
H04204*	1921	1:10,000	Undetermined	MLLW
H04208A*	1921	1:120,000	Undetermined	MLLW

Survey ID	*Date*	*Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*
H04208B*	1921	1:60,000	Undetermined	MLLW
H04209*	1921	1;20,000	Undetermined	MLLW
H04259*	1922	1;20,000	Undetermined	MLLW
H04260*	1922	1;20,000	Undetermined	MLLW
H04273*	1922	1;20,000	Undetermined	MLLW
H04274*	1922	1:50,000	Undetermined	MLLW
H04594*	1925	1:20,000	Undetermined	MLLW
H04761A*	1927	1:10,000	Undetermined	MLLW
H04773*	1927	1:10,000	Undetermined	MLLW
H04774*	1927	1:10,000	Undetermined	MLLW
H08036*	1953	1:10,000	Early Alaska Datums	MLLW
H08037*	1953	1:10,000	Early Alaska Datums	MLLW
H08038*	1953	1:10,000	Early Alaska Datums	MLLW
H08112	1960	1:20,000	NAD 27	MLLW
H08286	1956	1:10,000	Early Alaska Datums	MLLW
H08287	1956	1:10,000	Early Alaska Datums	MLLW
H08288*	1956	1:10,000	Early Alaska Datums	MLLW
H08325	1955	1:10,000	NAD 27	MLLW
H08326	1956/1958	1:5,000	Early Alaska Datums	MLLW
H08392*	1957	1:10,000	Early Alaska Datums	MLLW
H08393	1957	1:10,000	NAD 27	MLLW
H08443	1958	1:10,000	Early Alaska Datums	MLLW
H08444	1958	1:14,000	NAD 27	MLLW
H08455*	1958/1960	1:10,000	NAD 27	MLLW
H08456*	1958	1:10,000	NAD 27	MLLW
H08457	1958	1:10,000	NAD 27	MLLW

Survey ID	***Date***	***Resolution***	***Original Horizontal Datum***	***Original Vertical Datum***
H08458	1958	1:10,000	Early Alaska Datums	MLLW
H09309	1972	1:10,000	Early Alaska Datums	MLLW
H11208	2004	5 meter BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11574	2007	10 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11577	2006	20 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11688	2007	10 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11690	2007	5 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11691	2007	10 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11692	2007	10 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11694	2008	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11849	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11850	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11851	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11852	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11865	2009	3 meter BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11866	2008	3 meter BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11867	2008	3 meter BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H11993	2008	2 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12000	2008	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12026	2009	4 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12027	2009	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12029	2009	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12030	2009	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12031	2009	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW
H12032	2009	8 meter combined BAG	NAD 1983 UTM Zone 8 North (EPSG: 26908)	MLLW

* Denotes surveys that have been superseded by more recent data.

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

Two hydrographic survey datasets were available from the USACE Alaska District website. The surveys provided depth information near the town of Craig and were horizontally referenced to NAD 83 Alaska State Plane 1 (feet). The data were transformed to WGS 84 and MHW and converted to shapefiles using *FME* to review in *ArcMap*.

3) ENC extracted soundings

Navigational chart sounding data were extracted from Charts #17405, #17406, and #17407 (Table 5). These data were transformed from MLLW to MHW using *FME* to review in *ArcMap.*

Table 5. Navigational and Nautical Charts used in compiling the Craig DEM.

Chart	*Title*	*Format*	*Edition*	*Issue Date*	*Scale*
US5AK4BM / #17405	Ulloa Channel to San Christoval Channel;North Entrance, Big Salt Lake;Shelter Cove, Craig	ENC and RNC	14	4/2010	40,000
US5AK4CM-TM / #17406-7	Baker Island and Adjacent Waters - Northern Part of Tlevak Strait and Ulloa Channel	ENC and RNC	19/1	1/2012	40,000

4) RNC digitized soundings

Where no digital data existed, NGDC manually digitized nautical chart soundings (Table 5) using *ArcMap*. The data were digitized in original chart vertical datum and units and transformed to MHW and units of meters using *FME*.

3.1.3 *Topography*

Four topographic datasets were used in building the Craig DEM (Table 6; Fig. 5). The datasets included State of Alaska's Department of Commerce, Community, and Economic Development, Division of Community and Regional Affairs (DCRA) topography for Craig, USFS lidar data, NASA SRTM topographic DEMs, and USGS NED topographic DEMs. ASTER data were also assessed, but were not used in the final DEM because of data quality issues.

Table 6. Topographic datasets used in compiling the Craig DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NASA SRTM vers.2	2000	Topographic DEM	1 arc-second	WGS 84 geographic	WGS 84 / EPSG96	http://dds.cr.usgs.gov/srtm/
USFS	2000-2002	Bare-earth Lidar points	~ 1 to 25 meter point spacing	NAD 27 Alaska State Plane 1 (feet)	assumed MSL	
DCRA	2005	CAD DTM	~ 2 foot contour spacing	NAD 83 Alaska State Plane 1 (feet)	assumed MSL	
USGS NED	2001	Topographic DEM	2 arc-second	NAD 83 geographic	NGVD 29	http://ned.usgs.gov/

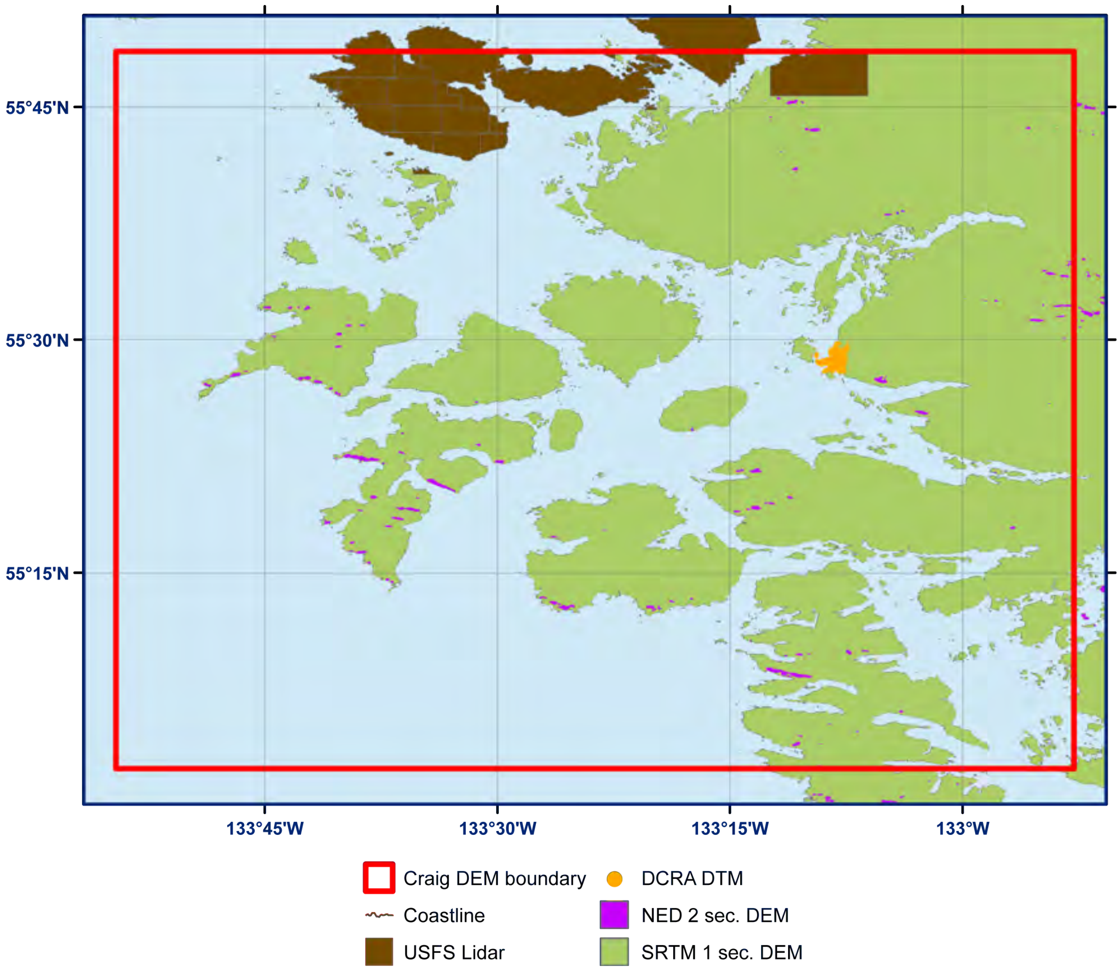

Figure 5. Spatial coverage of the topographic dataset used in developing the Craig DEM.

1) Shuttle Radar Topography Mission InSAR data

The SRTM was a joint international project run by the National Geospatial Intelligence Agency (NGA) and NASA[5]. In 2000, the SRTM project obtained global elevation data at 1 arc-second resolution using an interferometric synthetic aperture radar (InSAR) system. SRTM version 2 consists of the post processed data which includes editing, spike and well removal, water body leveling, and coastline definition. Two tiles were downloaded in .hgt format and converted to raster using ArcCatalog. The rasters were resampled to 1/3 arc-second to minimize artifacts during the final gridding process. The resampled data were transformed to MHW and converted to xyz format before gridding.

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

2) USFS Lidar

The USFS provided lidar data for several of the northern islands in the DEM region (Fig. 5). These data were transformed to NAD 83 and MHW and were converted to xyz format for incorporating in the gridding process.

3) DCRA topography

The DCRA provided NGDC with a topographic CAD dataset for the town of Craig. Elevation contour data were extracted from the CAD files provided and transformed to NAD 83 with *ArcGIS* and *FME*. The resulting shapefiles were transformed to MHW with *FME* and converted to xyz format for incorporating in the gridding process.

4) USGS NED topography

USGS NED 2 second DEMs were used only where SRTM data contained data voids. The DEM data were transformed to NAD 83 and MHW before clipping to the SRTM data using a data mask. The remaining elevations were converted to xyz format and used in the final gridding process.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation of the Craig DEM were originally referenced to a number of vertical datums including MLLW, WGS 84 / EPSG96, MSL, and NGVD 29. All datasets were transformed to MHW using conversion grids developed for the NGDC Southeast Alaska DEM (Caldwell et al., 2010). The grids were generated based on data from tide stations, a DART buoy, and dominate tidal components (Brown et al., 1989).

1) Bathymetric data

The early and recent NOS hydrographic surveys, chart data, and USACE hydrographic surveys were transformed from MLLW to MHW using the conversion grid.

2) Topographic data

The SRTM and NED topographic DEMs, the DCRA contour data, and the USFS lidar data were assumed to be referenced to MSL and were transformed to MHW using the conversion grid.

3.2.2 Horizontal datum transformations

Datasets used in the compilation of the Craig DEM were originally referenced to WGS 84 geographic, NAD 83 geographic, Universal Transverse Mercator (UTM) NAD 83 Zone 8 North, Early Alaska, NAD 83 Alaska State Plane Zone 1 (feet), NAD 27 geographic, and NAD 27 Alaska State Plane Zone 1 (feet). The relationships and transformational equations between these geographic horizontal datums are well established. Transformations to NAD 83 geographic were accomplished using *FME* and *ArcGIS* software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied to the source datasets, the resulting transformed data were viewed in *ArcMap* and *QT Modeler* for consistency. Any problems and errors were identified and resolved before proceeding with subsequent gridding steps. Once evaluated, compared, and corrected, the data were converted into final xyz files in preparation for the DEM gridding process. Problems included:

- Obvious small errors and anomalous points within datasets.
- Inconsistent overlapping NOS datasets. Earlier data were eliminated in these areas.
- Some topographic lidar data contained water-return values over the ocean, which needed to be clipped from the datasets using the Craig coastline.
- Inconsistencies between lidar data and SRTM data. The SRTM data are older and lower resolution data. Data overlaps were removed before gridding.

3.3.2 Smoothing of bathymetric data

The early NOS hydrographic survey data are generally sparse at the resolution of the Craig DEM, especially in the deep water areas near the mouth of Craig. To reduce the effect of artifacts due to this, a 1/3 arc-second 'pre-surface' bathymetric grid in MHW vertical datum was generated using *GMT*[6], an NSF-funded software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

To create the bathymetric surface, all bathymetric datasets were converted into xyz points, and were combined with points extracted from the Craig coastline—to provide a breakline along the entire coastline. The coastline elevation values were set to zero meters, to ensure the bathymetric surface approached zero relative to MHW in areas where bathymetric data are sparse or non-existent.

The point data were then median-averaged using the *GMT* tool 'blockmedian'. The *GMT* tool 'surface' was used to apply a tight spline tension to interpolate elevations for cells without data values, and to create 1/3 arc-second grid, 0.05 degrees (~5%) larger than the Craig DEM region. The *GMT* grid created by 'surface' was clipped to the Craig coastline, and the resulting surface was compared with original bathymetric soundings to ensure grid accuracy.

An example of the comparisons are shown in Figure 6, which shows a histogram of a recent NOS survey compared to the 1/3 arc-second pre-surfaced bathymetric grid. Differences cluster around zero with a range of -24.74 to +21.18 meters when compared to the bathymetric surface. Points with the largest differences are located in areas where dense data contain multiple elevation values per cell, which were averaged to create the bathymetric surface value. Eliminating overlapping dataset minimized this issue. The final bathymetric surface was converted into xyz files for use in building the Craig DEM (See Sec. 3.3.3).

9. *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.]

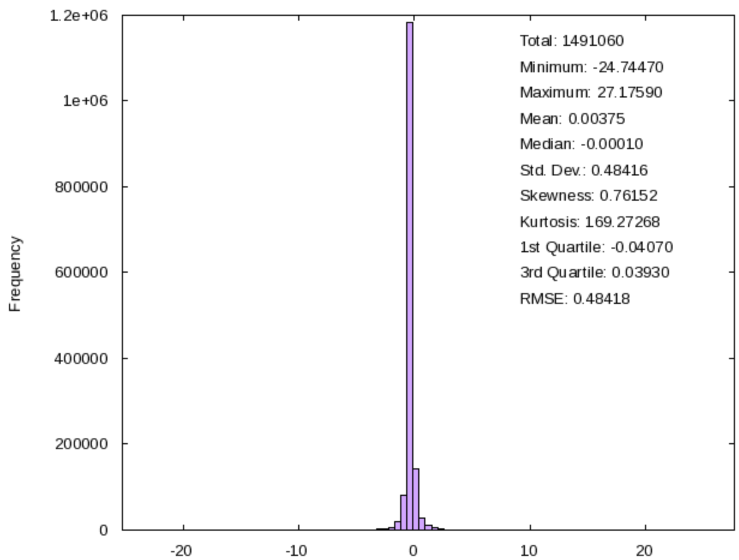

Figure 6. Histogram of the differences between NOS survey H12030 and the bathymetric pre-surface.

3.3.3 Building the DEM

MB-System[7] was used to create the 1/3 arc-second Craig 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 7. The greatest weights were assigned to the lidar datasets, digitized features, and the recent high-resolution NOS surveys. The least weight was given to the NED data and early NOS surveys.

Table 7. Data hierarchy used to assign gridding weight in *MB-System*.

Dataset	*Relative Gridding Weight*
USFS Lidar	100
Digitized breakwaters	100
Recent NOS Surveys	100
USACE	100
DCRA	10
ENCs and RNCs	10
SRTM vers.2	10
bathymetric pre-surface	1
Coastline	1
Early NOS Surveys	.1
USGS NED	.1

3.4 Quality Assessment of the Craig, Alaska DEM

3.4.1 Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Craig DEM is dependent upon the DEM cell size and the accuracy of source datasets. Topographic features have an estimated horizontal accuracy of 10-30 meters: lidar data have an accuracy of less than five meters, but DEM cell size is 10 meters; SRTM data are accurate to approximately 30 meters. Bathymetric features are resolved to only within a few tens of meters in deep-water areas.

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.]

Recent NOS surveys and shallow, near-coastal regions 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 Craig DEM is also dependent upon the source datasets contributing to DEM cell values. Topographic data have an estimated vertical accuracy less than 1 meter for bare-earth lidar data and up to 20 meters for non bare-earth SRTM DEMs. Bathymetric values have an estimated accuracy between 0.1 meters and 5% of water depth. The bathymetric depth values used in building the DEM were derived from a wide range of sounding measurements, from the early twentieth century NOS surveys to recent, high-resolution, GPS-navigated bathymetric surveys. Gridding interpolation— used to determine bathymetric values between sparse, poorly located NOS soundings— may degrade 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 Craig DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 7). The DEM was transformed to NAD 83 UTM Alaska Zone 1 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 *QT Modeler* and *Fledermaus* revealed suspect data points, which were corrected before recompiling the DEM. Figure 8 shows a data contribution plot of the Craig DEM. Figure 9 shows a color perspective image of the 1/3 arc-second Craig DEM in its final version.

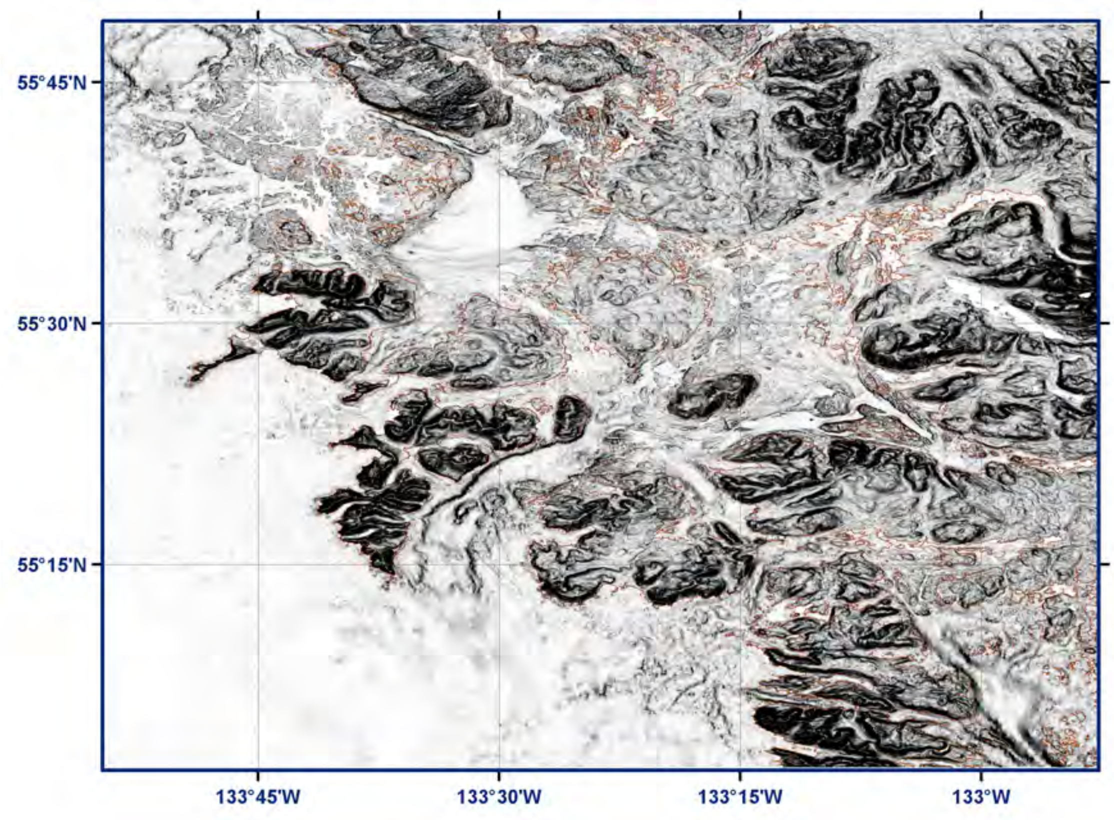

Figure 7. Slope map of the Craig DEM. Dark areas represent steeper terrain, light represents flat-lying regions. Coastline in orange.

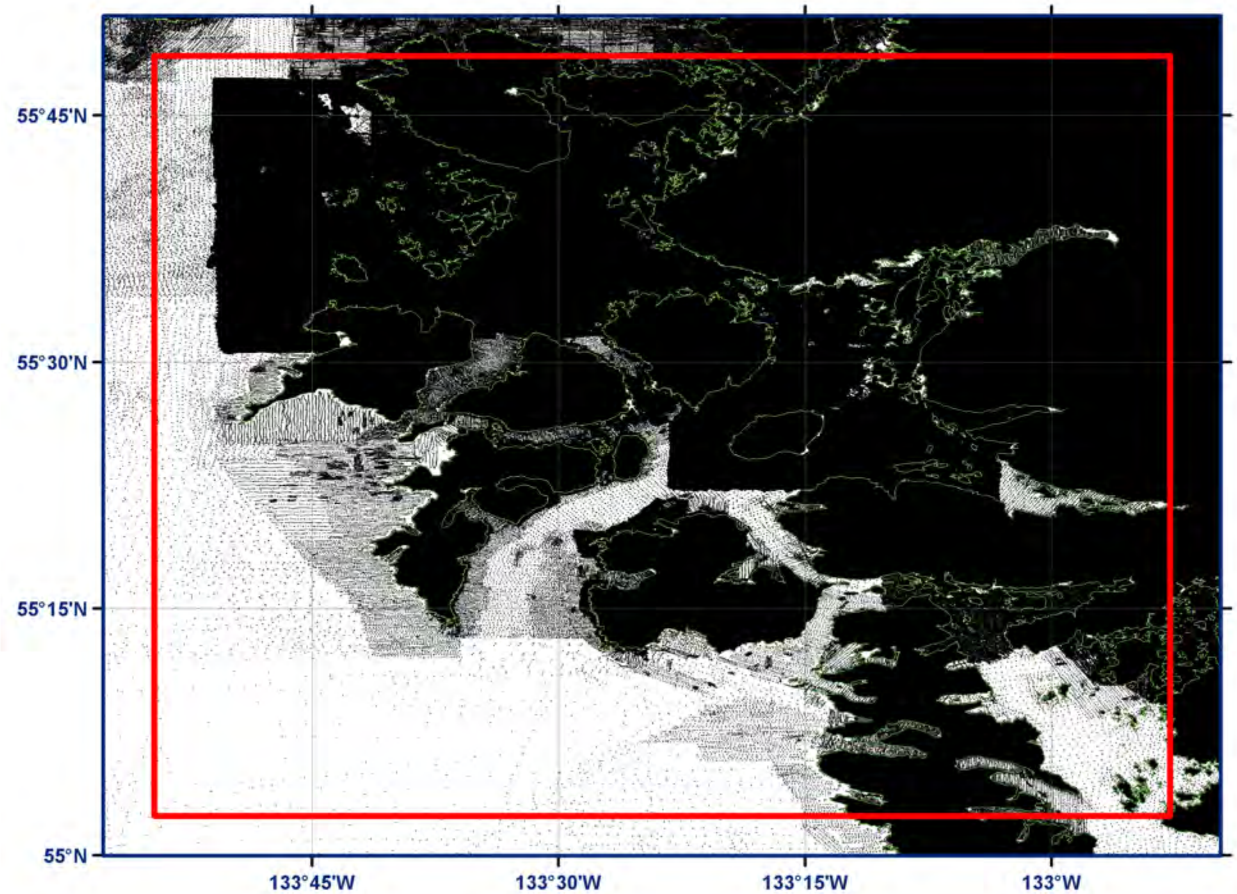

Figure 8. Data contrubution plot of the Craig DEM. Black depicts DEM cells constrained by source data, white depicts cells with elevaiton values dirived from interpolation. DEM boundary in red and coastline in green.

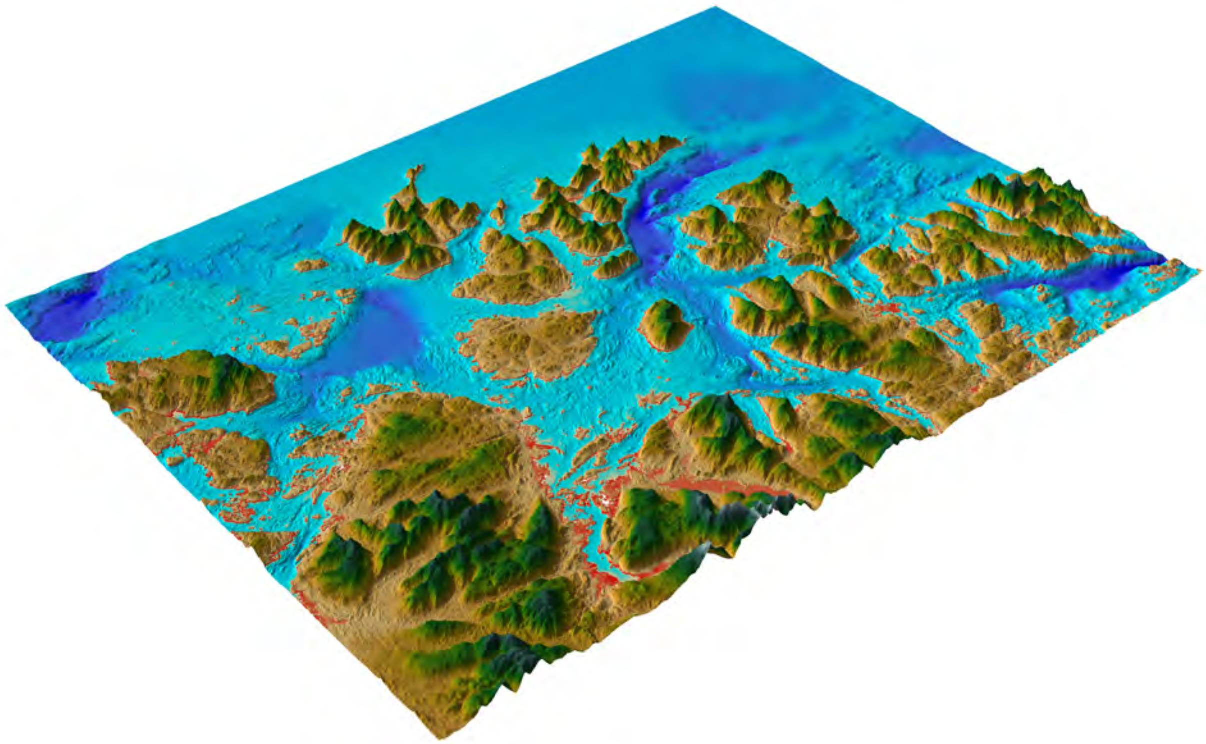

Figure 9. Perspective image of the Craig DEM from the southeast. Vertical exaggeration - times 2.

3.4.4 Comparison with older DEM

In 2008, NGDC created two DEMs of the Craig area for tsunami research purposes. These DEMs are available from NGDC at http://www.ngdc.noaa.gov/dem/. The 2008 DEMs provided 1 arc-second regional coverage and 1/3 arc-second local coverage Craig. Figure 10 shows the boundaries of the three DEMs.

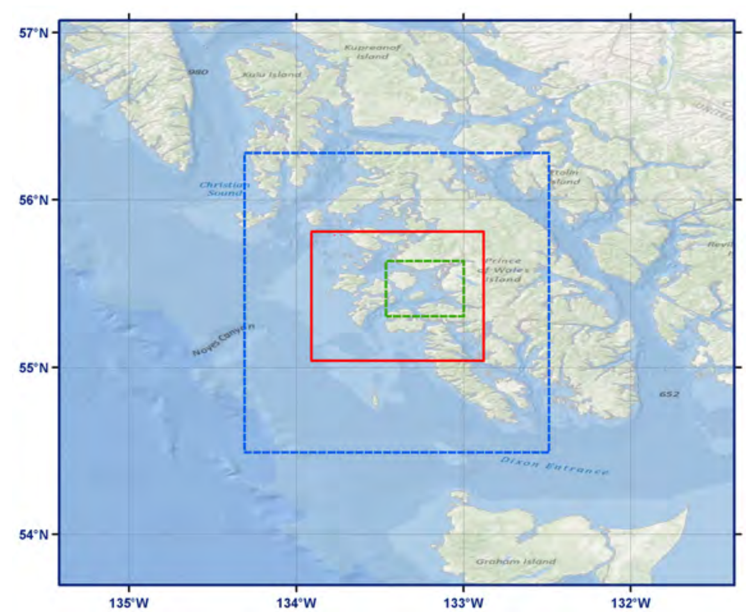

Figure 10. Spatial coverage of DEMs of Craig, Alaska. Green and blue dashed lines represent the 1/3 and 1 arc-second DEMs from 2008 and red solid line, the new 1/3 arc-second DEM.

A difference grid of the two 1/3 arc-second DEMs was generated using raster math to visualize improvement in the bathymetric elevation values. Much of the area surrounding Craig and Klawock were recently re-surveyed by NOS and the higher resolution data replaced hydrographic survey data dating as far back as the early 1900's. Figure 11 shows the difference grid with large improvements in cell elevation values for most bathymetric area.

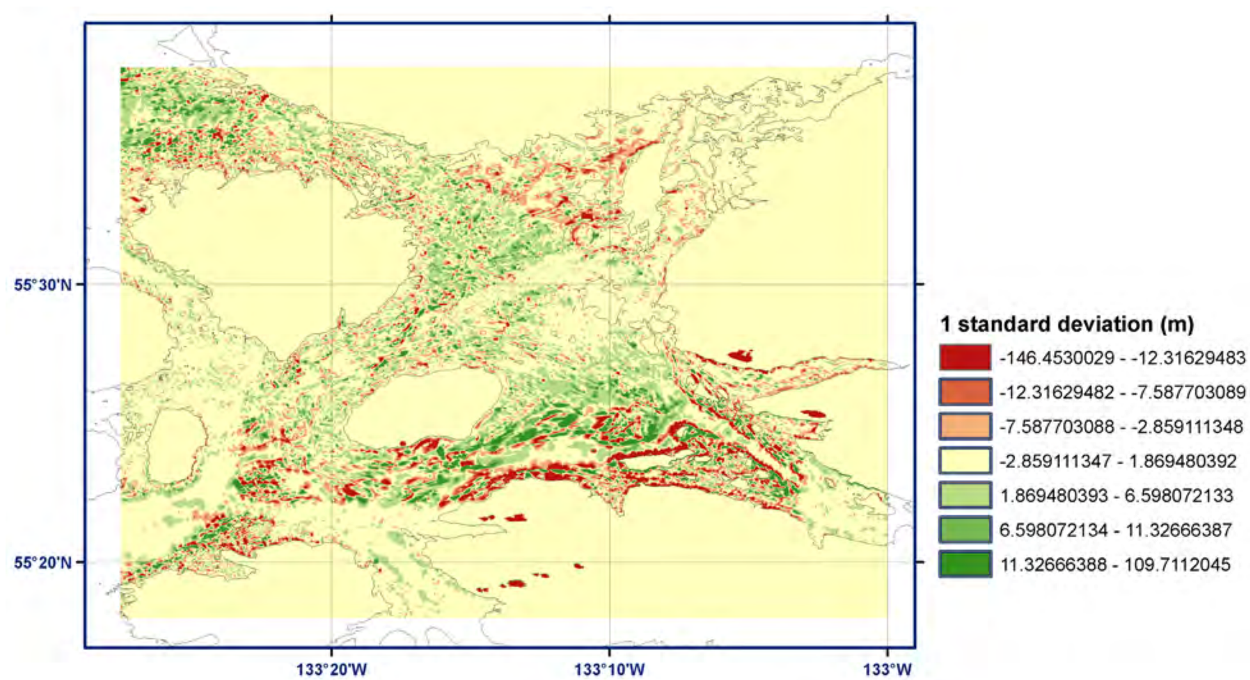

Figure 11. Difference grid of the 1/3 second Craig DEM from 2008 and the new 1/3 arc-second Craig DEM. Cell values represent the differnce between the tow grids.

3.4.5 DEM comparison with source data files

To ensure grid accuracy, the Craig DEM was compared to several source datasets. Histograms are shown in figures 12 through 15.

The USFS lidar dataset (Fig. 12) varied from the Craig DEM by a median of zero meters, ranging from a minimum difference of -45.87 meters to a maximum difference of 38.31 meters. These minimum and maximum differences occurred in heavily forested areas and in steep terrain.

The USACE hydrographic survey data (Fig. 13) varied from the Craig DEM by a median of -0.0039 meters, with a minimum difference of -2.85 meters and a maximum difference of 2.56 meters. The SRTM data (Fig. 14) varied from the Craig DEM by a median of 0.00 meters with a minimum difference of -5.29 meters and a maximum of 76.09 meters. The largest differences in the SRTM data occur along the shoreline. The DCRA contour data (Fig. 15) varied from the Craig DEM by a median of -0.67 meters with a minimum difference of -16.05 and a maximum difference of 5.88 meters. Much of the larger differences occur in more forested areas and along the steep shoreline.

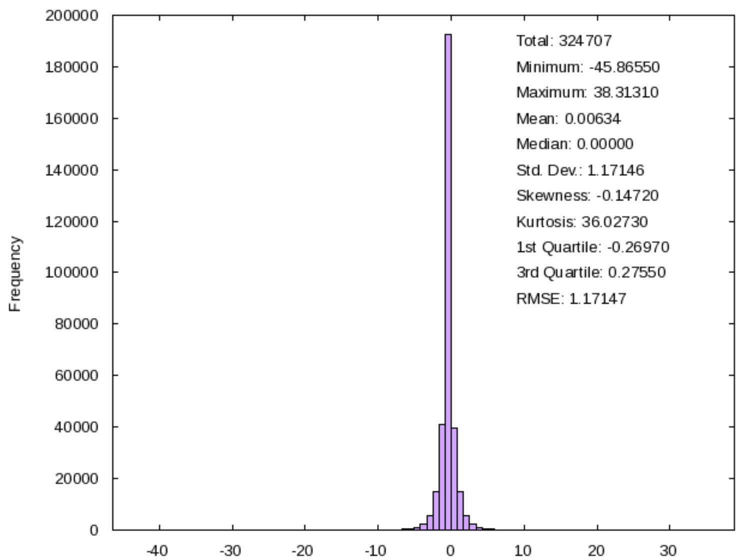

Figure 12. Histogram of the differences between a selection of the USFS lidar dataset and the Craig DEM.

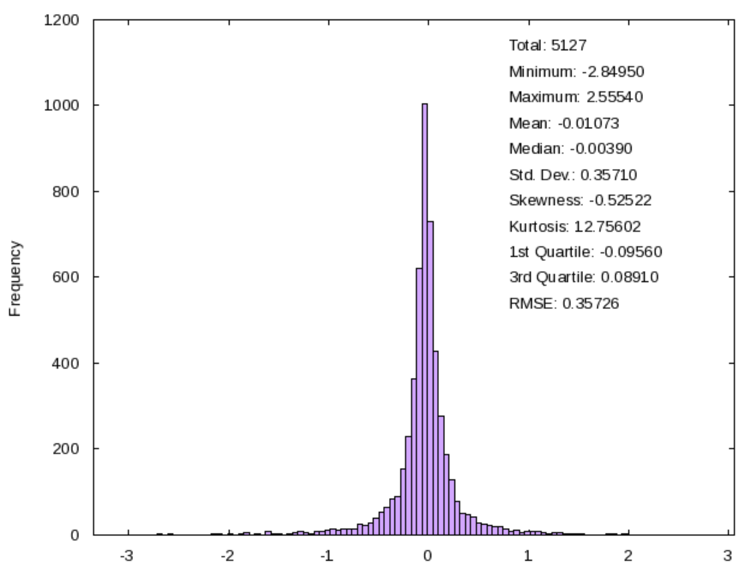

Figure 13. Histogram of the differences between a selection of the USACE dataset and the Craig DEM.

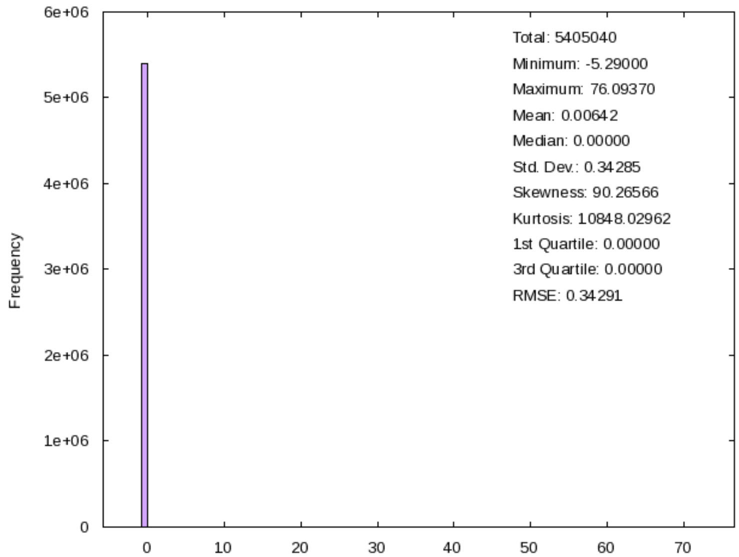

Figure 14. Histogram of the differences between a selection of the SRTM dataset and the Craig DEM.

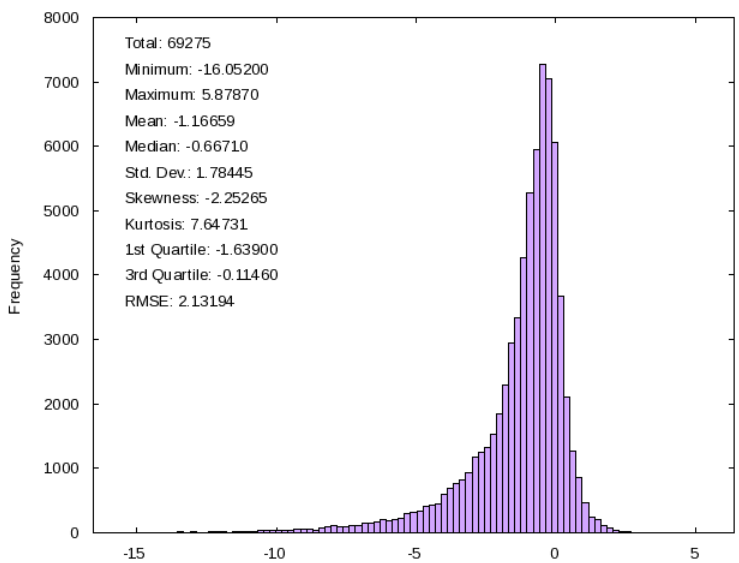

Figure 15. Histogram of the differences between the DCRA contour data and the Craig DEM.

4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of the Craig, Alaska region, with a cell size of 1/3 arc-second, was developed for the Pacific Marine Environmental Laboratory (PMEL), NOAA Center for Tsunami Research. 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*, *Fledermaus*, *GMT*, *MB-System*, *QT Modeler*, and *VDatum* software.

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

- Conduct topographic lidar surveys around Craig and Klawock.
- Conduct bathymetric surveys in deep water areas west of Prince of Wales Island.
- Extend the NED 1/3 dataset to include Alaska.
- Extend *VDatum* tidal conversion coverage to include Alaska.

5. Acknowledgments

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Lim, E., L.A. Taylor, B.W. Eakins, K.S. Carignan, R.R. Warnken, P.R. Medley, 2009: Digital Elevation Models of Craig, Alaska: Procedures, Data Sources, and Analysis. NOAA Technical Memorandum NESDIS NGDC-27, 27 pp.

Nautical Chart # 17405 (ENC and RNC), 14th Edition, 2010. Ulloa Channel to San Christoval Channel; North Entrance, Big Salt Lake; Shelter Cove, Craig. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #17406-7 (ENC and RNC), 19th - 1st Editions, 2012. Baker Island and Adjacent Waters - Northern Part of Tlevak Strait and Ulloa Channel. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Zilkoski, D.B., J.H. Richards, and G.M. Young, 1992: Results of the general adjustment of the North American Vertical Datum of 1988. Surv. and Land Info. Sys., 52(3), 133-149.

7. Data Processing Software

ArcGIS v. 10 – developed and licensed by ESRI, Redlands, California, http://www.esri.com/

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

FME 2011 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/.

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

GEODAS v. 5.0.11 – Geophysical Data System, freeware developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/.

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

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

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

Persistence of Vision Pty. Ltd (POV Ray) v. 3.6 – Persistence of VisionTM Raytracer. Persistence of Vision Pty., Williamstown, Victoria, Australia, http://www.povray.org/

Quick Terrain Modeler v. 7.1.1 – Lidar processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/.

VDatum Transformation Tool, Version 2.3.2— developed and maintained by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/welcome.html.