NOAA Technical Memorandum NESDIS NGDC-56

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R. Jason Caldwell[1]
Lisa A. Taylor[2]
Barry W. Eakins[1]
Kelly S. Carignan[1]

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

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

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## NOTICE



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

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# Digital Elevation Model of Chenega Bay, Alaska: Procedures, Data Sources and Analysis

## 1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a bathymetric–topographic digital elevation model (DEM) centered on Chenega Bay, Alaska (Fig. 1). 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 8/15 arc-second[1] DEM is nested within the extents of the previously developed Prince William Sound 8 arc-second and 8/3 arc-second DEMs (see Fig. 4; Caldwell et al., 2009). 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 and was designed to represent modern morphology. Primary data sources and grid development methodology are described in the technical report for the Prince William Sound DEMs (Caldwell et al., 2009; see link above). Additional datasets used in developing the Chenega Bay DEM are described in this report, which provides a summary of the supplemental data sources and quality control procedures used in developing the Chenega Bay DEM.

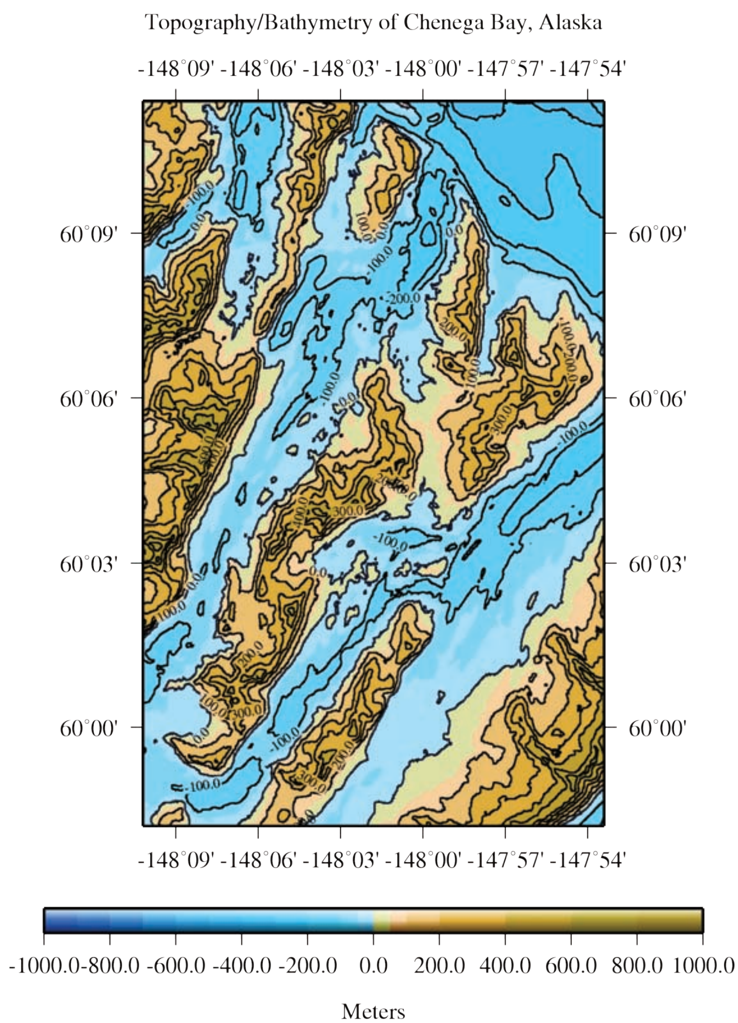


*Figure 1. Contour map of the Chenega Bay 8/15 arc-second DEM. Contour interval is 100 meters. Image is in Mercator projection.*

1. The Chenega Bay 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 Chenega Bay, Alaska, (60° 03' 59"N, 148° 00' 40"W) 1 arc-second of latitude is equivalent to 30.94 meters; 1 arc-second of longitude is equivalent to 15.47 meters.

## 2. Study Area

The community of Chenega Bay is currently located on Evans Island in the southwest portion of Prince William Sound. Chenega Bay is situated on a generally flat plain with the adjacent mountains climbing to over 300 meters (Figs. 2 and 3). Chenega Bay is located in the Chugach National Forest approximately 50 kilometers southeast of Whittier (Fig. 4). The population of Chenega Bay according to the U.S. Census Bureau in 2000 was 86, primarily Alaska Natives.

Chenega Bay is in an earthquake prone region, which makes the area highly vulnerable to tsunamis. The second most powerful earthquake in the twentieth century occurred on March 27, 1964. Its epicenter was located approximately 90 miles west of Valdez and measured 9.2 on the Richter scale (http://www.drgeorgepc.com/Earthquake1964Alaska.html). The town of Chenega was originally located on Chenega Island to the north, but was relocated and renamed to Chenega Bay after the village was destroyed by the tsunami from the 1964 earthquake. An estimated one-third to one-half of the population was killed and the remaining population migrated to the current location on Evans Island in the late 1970s and early 1980s.

*Figure 2. Photograph of Chenega Bay looking southwest (2006). Source: Alaska Division of Community and Regional Affairs (DCRA; http://www.commerce.state.ak.us/dca/photos/comm_list.cfm).*

*Figure 3. Photograph of Chenega Bay looking west-southwest (2006). Source: DCRA; http://www.commerce.state.ak.us/dca/photos/comm_list.cfm.*

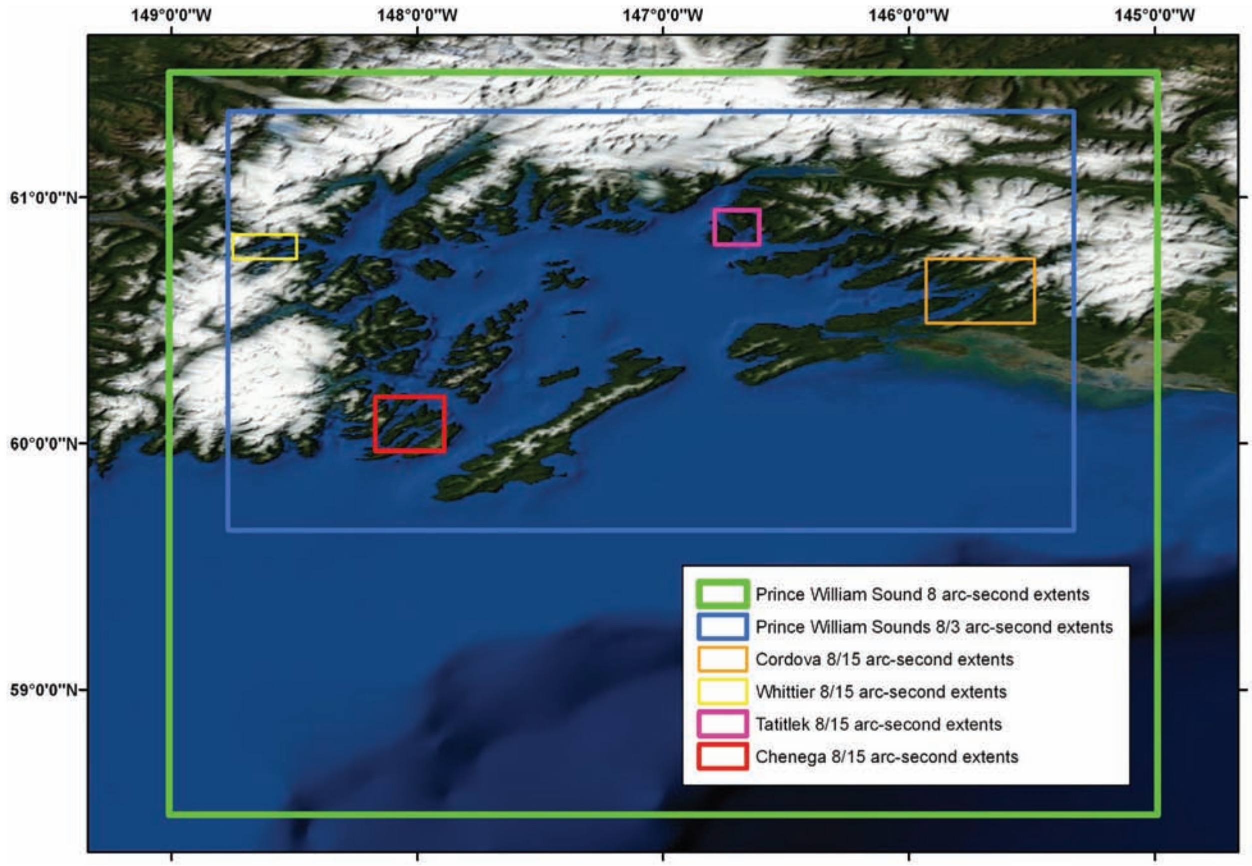


*Figure 4. Map of the Prince William Sound region with extents of the Chenega Bay DEM and previous Prince William Sound DEMs (e.g., Cordova , Whittier, and Tatitlek) shown. ESRI World 2D Imagery shown in the background.*

# 3. Methodology

The Chenega Bay DEM was developed in the World Geodetic System 1984 (WGS 84) geographic horizontal datum and Mean Higher High Water (MHHW) vertical datum in vertical units of meters. NGDC developed the DEM at extents slightly larger (~ 5 percent) than required by UAF. 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 MHHW, for modeling of maximum flooding, respectively.

**Table 1. Specifications for the Chenega Bay, Alaska DEM.**

| | |
|---|---|
| ***Grid Area*** | Chenega Bay, Alaska |
| ***Coverage Area*** | 148.17º to 147.89º W; 59.97º to 60.19º N |
| ***Grid Spacing*** | 8/15 arc-second |
| ***Coordinate System*** | Geographic decimal degrees |
| ***Horizontal Datum*** | World Geodetic System 1984 (WGS 84) |
| ***Vertical Datum*** | Mean Higher High Water (MHHW) |
| ***Vertical Units*** | Meters |
| ***Grid Format*** | netCDF |

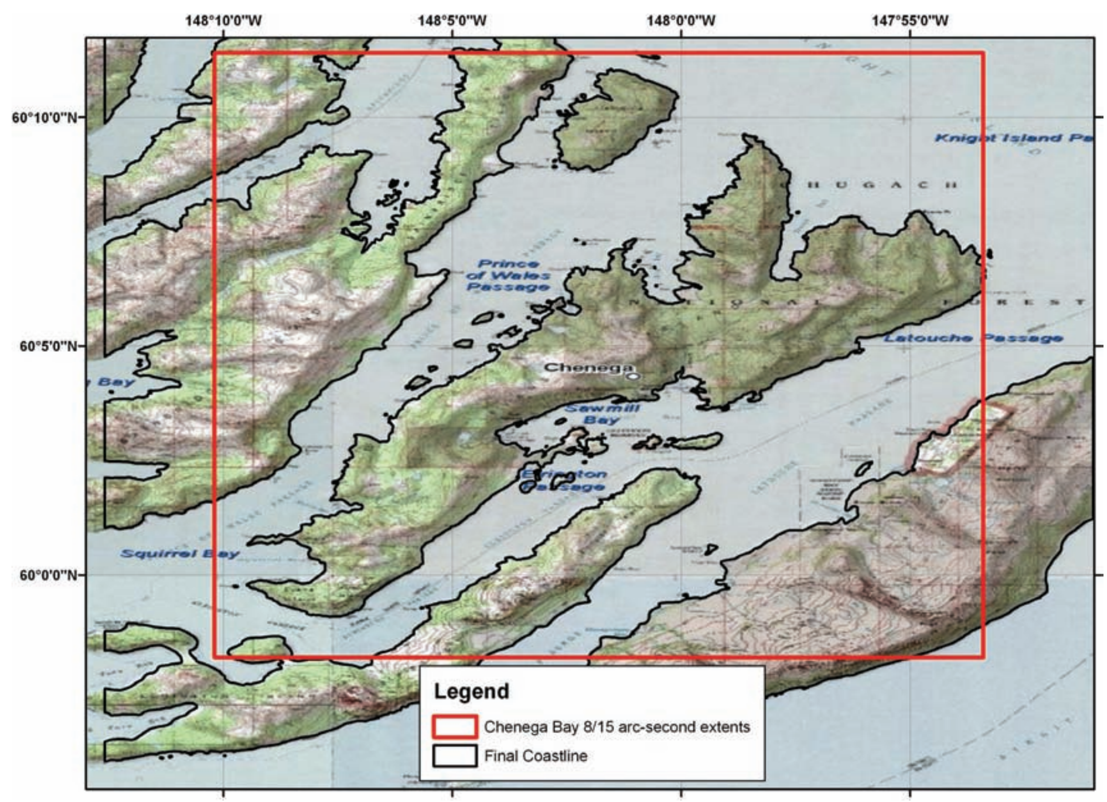


*Figure 5. Extents of the Chenega Bay 8/15 arc-second DEM. ESRI U.S. Topographic Maps layer in background.*

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

### 3.1 Supplemental Data Sources and Processing

Source datasets for the Chenega Bay DEM were comprised primarily of the datasets listed in the Prince William Sound technical report (Caldwell et al., 2009). Supplemental data included a recent U.S. Forestry Service (USFS) topographic DEM; point elevation measurements in the immediate vicinity of Chenega Bay from UAF that were used for quality assurance; and high-resolution aerial photographs of the Chenega Bay shoreline in 2005 from the State of Alaska's Division of Community and Regional Affairs (DCRA) that were used to digitize a final coastline (see Figs. 6 and 7).

Safe Software's *Feature Manipulation Engine* (*FME*)[3] data translation tool and *Proj4*[4] were used to shift datasets to NAD 83 geographic horizontal datum. *FME*, *GDAL*[5], and *OGR*[6] were 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. *QT Modeler* and Interactive Visualization System's *Fledermaus* software were used to evaluate processing and gridding techniques.

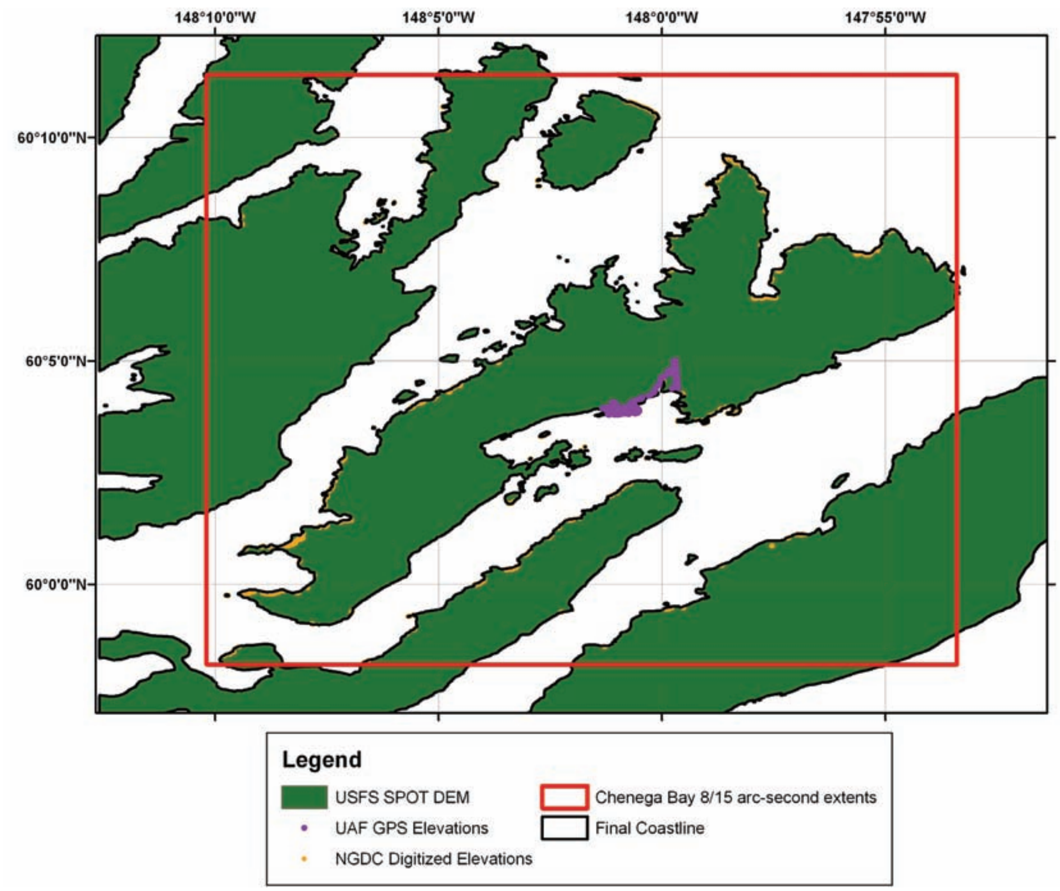


*Figure 6. Source and coverage of supplemental datasets used in compiling and evaluating the Chenega Bay DEM.*

3. *FME* 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 data from NAD 27 to NAD 83. NADCON is the U.S. Federal Standard for NAD 27 to NAD 83 datum transformations.
4. *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 .
5. *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.
6. The *OGR* Simple Features Library is a C++ open source library and commandline tools providing read and write access to a variety of vector file formats, including ESRI shapefiles. *OGR* is a part of the *GDAL* library.

### 3.1.1 Shoreline

Three high-resolution aerial photographs of Chenega Bay were downloaded from the DCRA (http://www.commerce.state.ak.us/dca/profiles/profile-maps.htm). These photographs were georeferenced to the Prince William Sound coastline using *ArcMap* (e.g., Fig 7). The Prince William Sound coastline was adjusted using the digital photographs as reference to produce a final coastline for Chenega Bay (see Fig. 6). 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 0.05 degrees larger than the 8/15 arc-second DEM boundary. Piers and docks were deleted from the coastline.


*Figure 7. Example of georeferenced DCRA aerial imagery used in developing the final coastline of the Chenega Bay region. Final coastline in blue.*

### 3.1.2 Bathymetry

No additional bathymetric surveys were available for use in the compilation of the Chenega Bay DEM.

### 3.1.3 Topography

A USFS high-resolution stereo digital elevation model (SPOT5) covering the Chugach National Forest area was downloaded from Alaska's Statewide Digital Mapping Initiative website (Fig. 8; http://www.alaskamapped.org). The non-bare-earth, Chugach SPOT5 DEM[7] was downloaded at 20 meter resolution with a vertical datum of altitude above Earth's Gravitational Model of 1996 (EGM 96) Geoid, and horizontal datum of WGS 84/UTM Zone 6 North. The vertical and horizontal accuracies of the DEM are 10 and 15 meters, respectively, at the 90 percent confidence level.

The Chugach SPOT5 DEM was shifted to WGS 84 and MHHW horizontal and vertical datums, respectively, before clipping to the final coastline and converting the grid to xyz using *GDAL*. Values less than 1 meter were then set to 1 meter to eliminate negative values on land. NGDC also reviewed the United States Geological Survey National Elevation Dataset (NED; http://ned.usgs.gov/) 2 arc-second gridded topography, the National Aeronautics and Space Administration (NASA) Shuttle Radar Topography Mission (SRTM; http://srtm.usgs.gov) 1 arc-second gridded topography, and the 1 arc-second NASA/Japan's Ministry of Economy, Trade, and Industry Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; http://asterweb.jpl.nasa.gov/gdem.asp/) global digital elevation model.

7. The SPOT5 (Satellite Pour l'Observation de la Terre) is a high-resolution, optical imaging Earth observation satellite system operating from space. SPOT5 was launched on May 4, 2002 and features a high-resolution stereo (HRS) imaging instrument operating in panchromatic mode. The HRS instrument points forward and backward of the satellite. Thus, it is able to take stereopair images almost simultaneously to map relief.

In addition, UAF provided GPS point elevation values from a field survey in Summer 2010 at MLLW vertical datum. These points were converted to MHHW using the 'MLLW to MHHW' vertical datum offset grid described in Caldwell et al. (2009). To select the most representative topographic dataset for the Chenega Bay DEM, NGDC performed an initial analysis to compare the GPS measurements to each topographic dataset. The quality check revealed biases in both the NED and ASTER datasets (Figs. 9 -10). Positive/negative values in Figures 9 -11 indicate under/over-estimated elevations in the topographic DEM.

The USGS NED 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 Chenega Bay DEM 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. The SRTM only provided coverage of a very small part of the Chenega Bay region; and, the ASTER data showed a distinct bias to under-estimate elevations along the coast. Figure 12 displays the different issues observed in the NED and ASTER datasets.

The quality assessment of the SPOT data indicated a near-normal distribution of differences in the histogram with clustering around zero and most errors +/- 4 meters (Fig. 11). Qualitative analysis of the SPOT data indicated gridding artifacts in the form of artificial steps in elevation that were oriented generally from north to south (see Caldwell et al., 2010). This did not appear to impact the quality of the DEM and most steps were on the order of several meters. The SPOT data fit the coastline well and did not exhibit any significant horizontal or vertical biases as did the ASTER and NED (Fig. 12c)

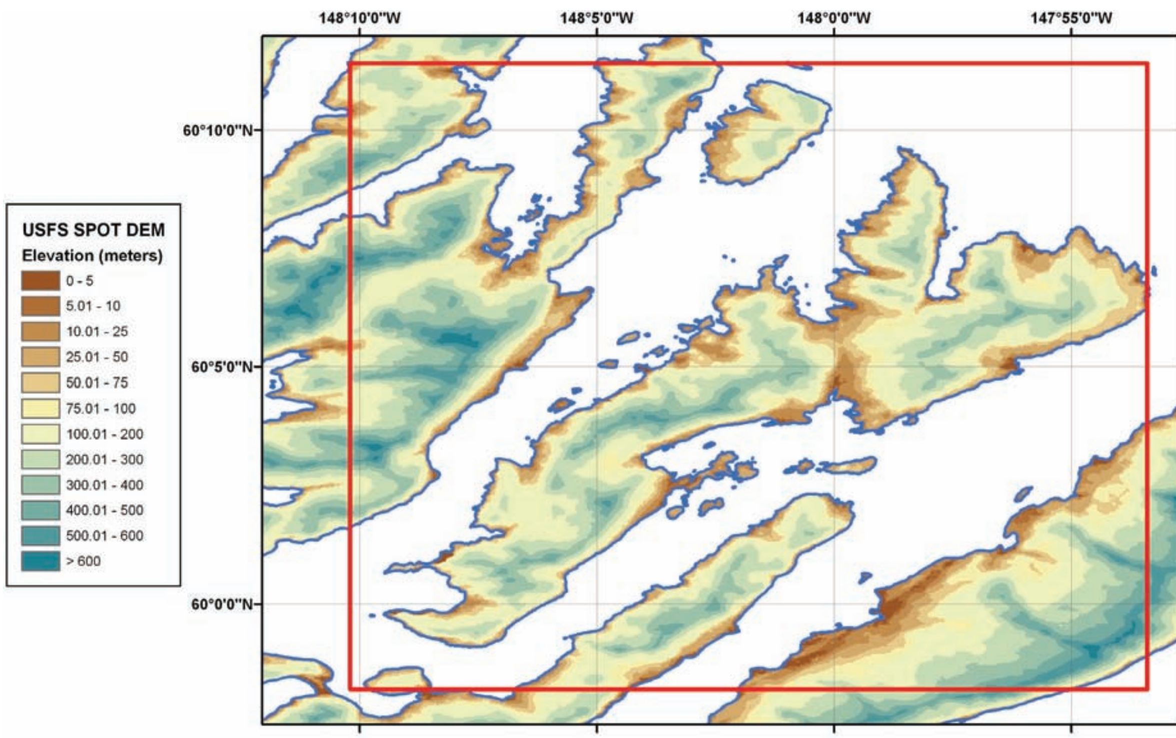


*Figure 8. USFS SPOT DEM coverage and elevations in the Chenega Bay region. Final coastline in blue. DEM extents in red.*

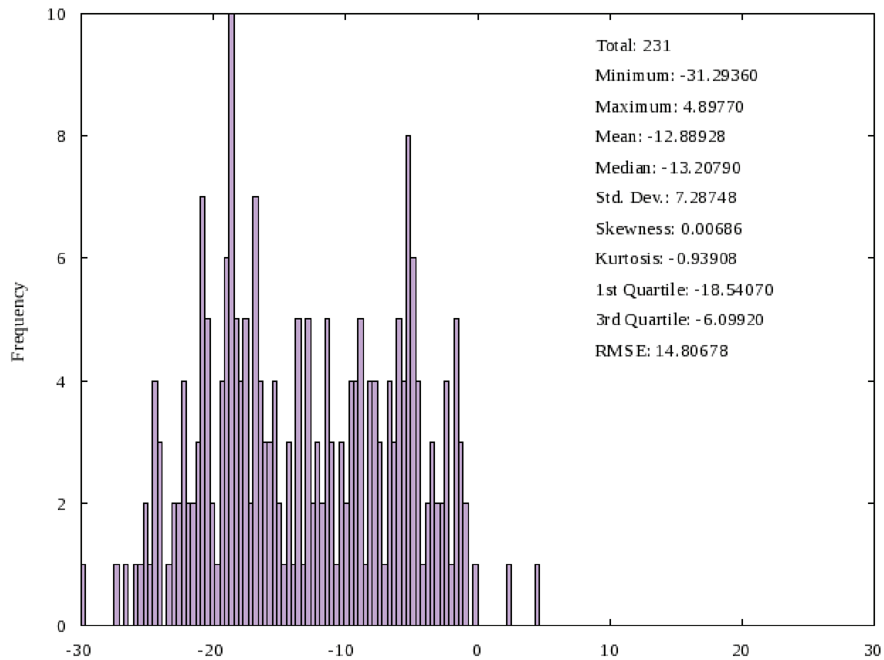


*Figure 9. Histogram of the differences between the UAF GPS elevation measurements and the NED topographic DEM. Positive/negative values indicate under/over-estimated elevations in the topographic DEM. The NED generally over-estimates elevations relative to the UAF GPS measurements.*

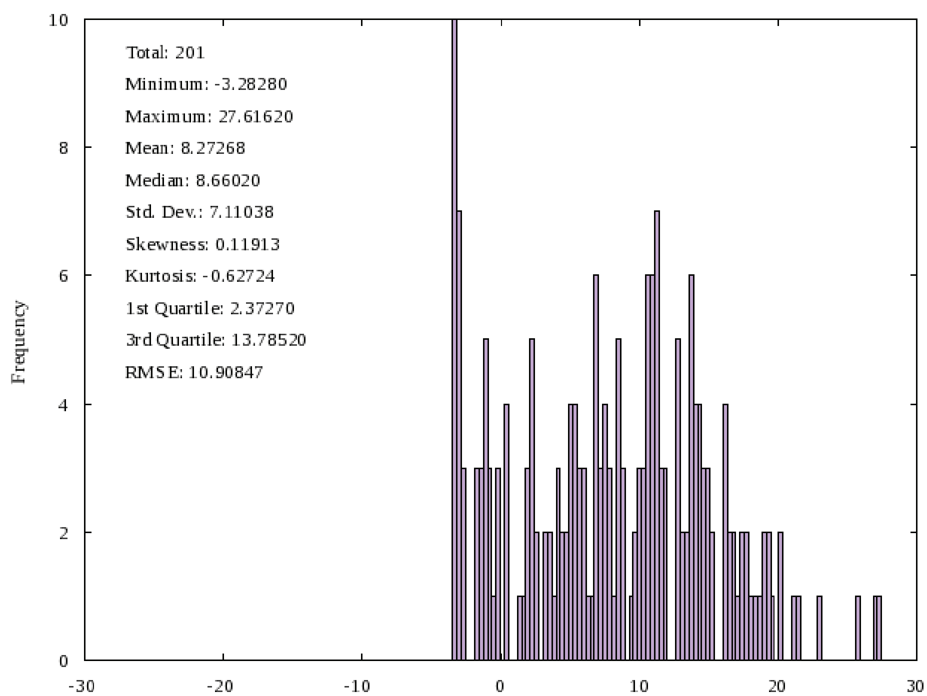


*Figure 10. Histogram of the differences between the UAF GPS elevation measurements and the ASTER topographic DEM. Positive/negative values indicate under/over-estimated elevations in the topographic DEM. The ASTER generally under-estimates elevations relative to the UAF GPS measurements.*

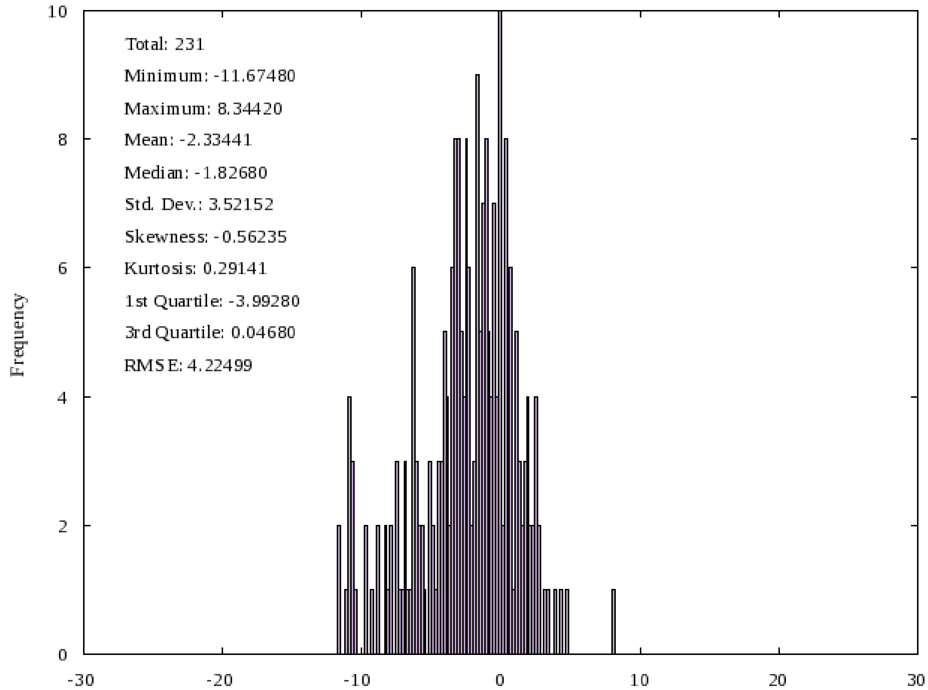


*Figure 11. Histogram of the differences between the UAF GPS elevation measurements and the SPOT topographic DEM. Positive/negative values indicate under/over-estimated elevations in the topographic DEM. Differences with the SPOT data cluster around zero with no obvious bias as in the NED and ASTER data.*

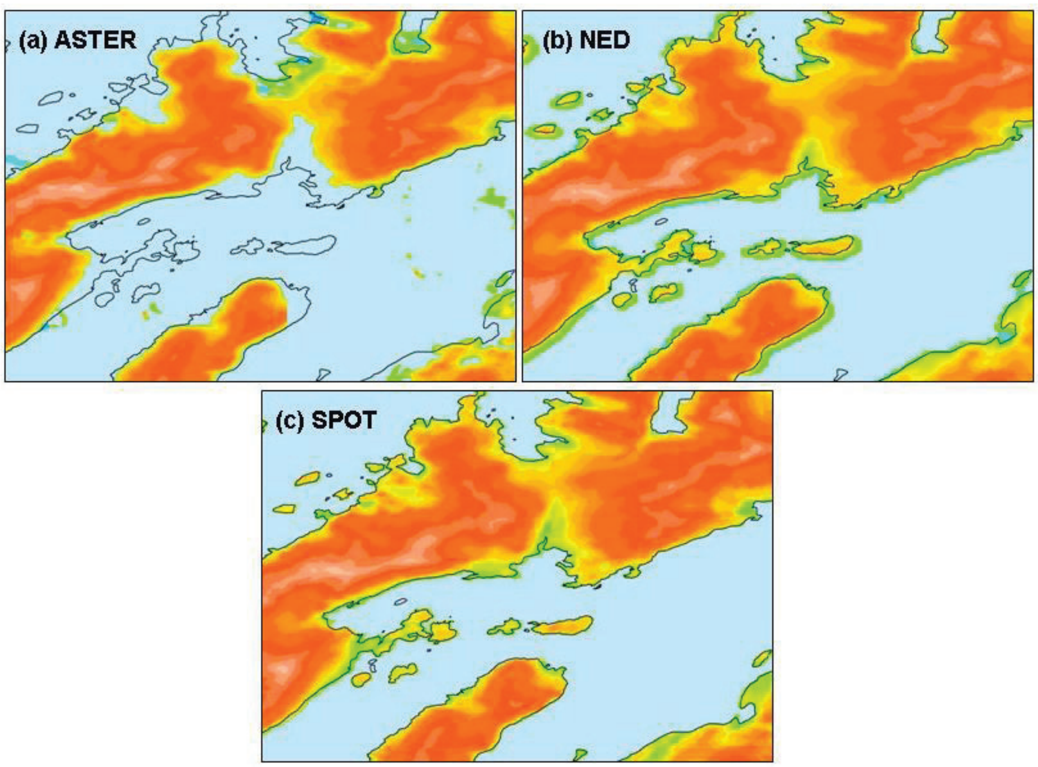


*Figure 12. Problems with available topographic datasets. (a) Coastal elevations in the ASTER data are regularly below zero (light blue shading). (b) Elevations in the NED appear to be shifted southward and smoothed horizontally, possibly due to interpolation. (c) The SPOT data best fits the final coastline (black line) with no obvious horizontal or vertical bias.*

Due to the steep slopes along the coastline in some regions of the Chenega Bay DEM, the spline interpolation generated small regions of negative elevations onshore. To correct this issue, NGDC digitized points (see Fig. 6) with elevation values of 1 meter to better represent the actual morphology in these locations by mitigating the introduction of interpolation artifacts in the grid.

NGDC also digitized points to represent the airport and a region near the ferry landing in Chenega Bay (Fig. 13). The GPS elevations provided by UAF were used to generate a 1 arc-second interpolation grid using the inverse distance weighting (IDW) tool in *ArcMap*. The IDW grid was converted to xyz format and then clipped to polygons representing the airport and ferry landing regions using *GDAL*. The SPOT data were subsequently removed from the same regions to avoid gridding artifacts due to overlapping datasets of different resolutions and quality.

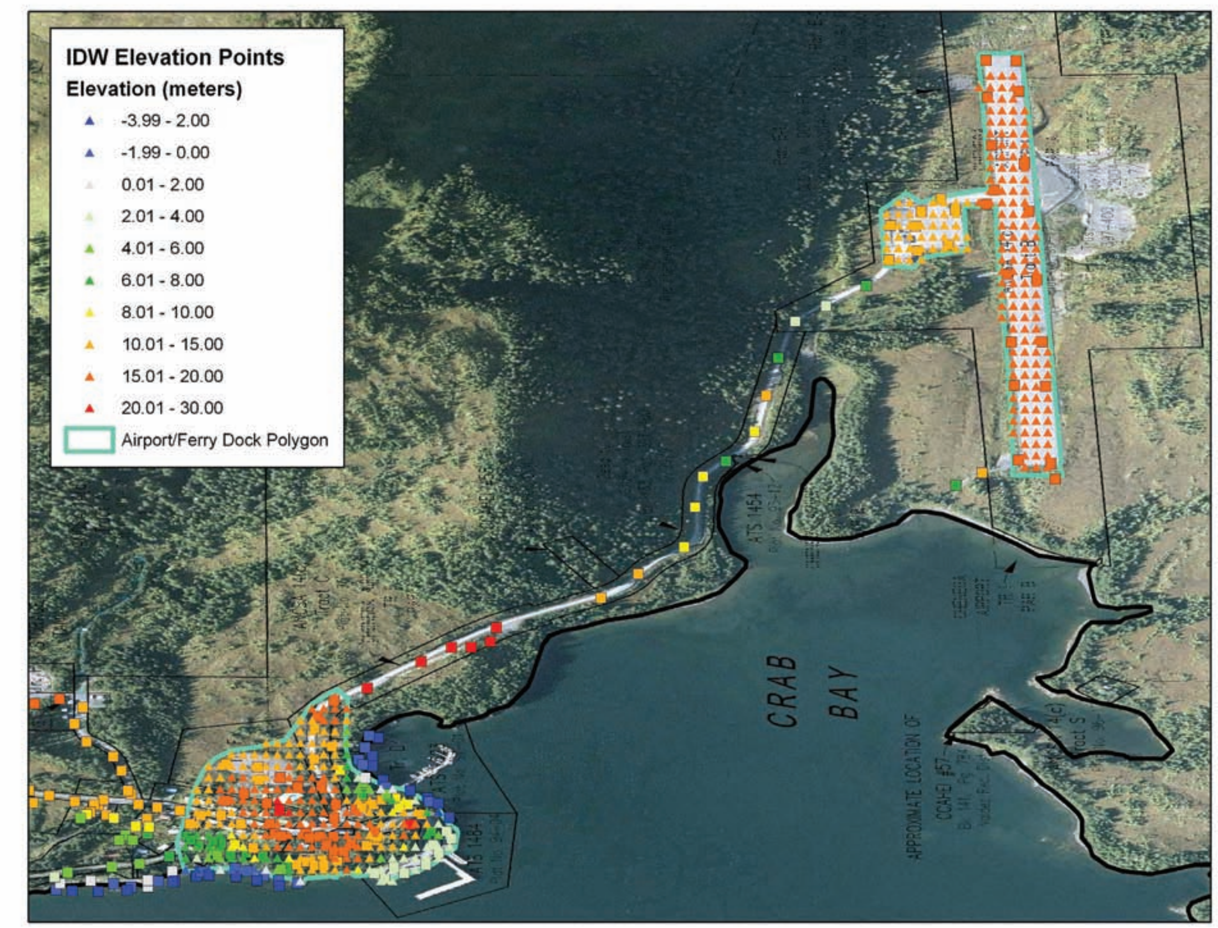


*Figure 13. Interpolated points at Chenega Bay. Elevation points from the inverse distance weighting (triangles) and UAF GPS measurements (squares) are shown in same color scale. The interpolated points have been clipped to the respective polygons (light blue). These polygons were also used to remove the SPOT data from the final gridding. DCRA imagery is in the background. Coastline is shown in black.*

## 3.2 Establishing Common Datums

### *3.2.1 Vertical datum transformations*

Datasets used in the compilation and evaluation of the Chenega Bay DEM were originally referenced to a number of vertical datums including MLLW (meters) and EGM 96 Geoid (assumed to be mean sea level (MSL)). All datasets were transformed to MHHW for modeling of maximum flooding. Vertical datum transformations to MHHW were accomplished using *FME* and *GDAL*, and the offset grids developed for the Prince William Sound DEMs.

**1) Bathymetric data**

No additional bathymetric datasets were used in the compilation of the Chenega Bay DEM.

**2) Topographic data**

The SPOT topographic dataset was originally referenced to the EGM 96 Geoid. There are no survey markers in the vicinity of Chenega Bay 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 MHHW, using *GDAL*, was accomplished by adding the 'MSL to MHHW' offset grid. Values less than 1 meter following the conversion were set equal to 1 meter, as the SPOT data are in integer format.

The UAF GPS measurements were converted from MLLW to MHHW using the 'MLLW to MHHW' offset grid and *GDAL*.

### *3.2.2 Horizontal datum transformations*

Supplemental datasets used to compile the Chenega Bay DEM were originally referenced to WGS 84/UTM Zone 6 North. The relationships and transformational equations between the 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 *QT Modeler* 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 SPOT DEM dataset. The dataset required automated clipping to the final coastline or were edited manually.
- Steep slopes in the SPOT DEM along coastal areas led to interpolation artifacts in the DEM. NGDC digitized elevation points to provide additional control to mitigate negative values in onshore locations.

### *3.3.2 Smoothing of bathymetric data*

The older hydrographic survey data are generally sparse at the resolution of the 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 MHHW vertical datum were generated using *GMT*[8], an NSF-funded software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/). Additional information on the methodology to develop a pre-surface bathymetric grid can be found in Caldwell et al. (2009).

### *3.3.3 Quality Assessment of the Bathymetric Surface*

The bathymetric surface was compared with the original soundings to ensure grid accuracy, and then exported as an xyz file for use in the final gridding process. The statistical analyses of the differences between the 8/15 arc-second bathymetric surface at Chenega Bay with the NOS hydrographic surveys show that the majority of the surveys are in good agreement (Fig. 14) with the bathymetric surface. The few exceptions where the differences reached up to 113.30 meters are attributed primarily to overlapping datasets. These differences are fairly consistent with the chart comparison in the NOS descriptive report for survey H11387 (http://surveys.ngdc.noaa.gov/mgg/NOS/coast/H10001-H12000/H11387/DR/H11387.pdf), which indicates differences up to 29 fathoms (~54 meters) between older and newer surveys. In addition, large differences also occurred 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 surface was then converted to an xyz file for use in building the final DEM.

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

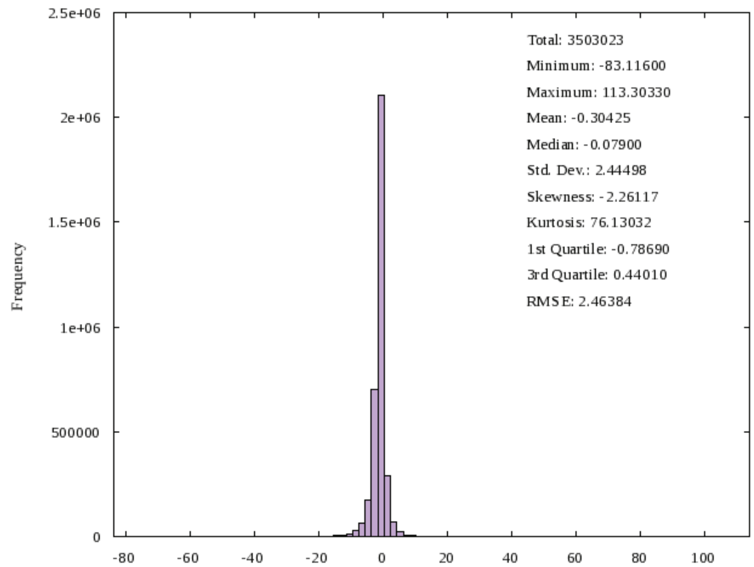


*Figure 14. Histogram of the differences between NOS hydrographic surveys and the 8/15 arc-second pre-surfaced bathymetric grid.*

### *3.3.4 Building the DEM using MB-System*

*MB-System*[9] was used to create the Chenega Bay 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 'mb-grid' gridding algorithm, as relative gridding weights, is listed in Table 2. For supplemental data of Chenega Bay, the greatest weight was given to the NGDC digitized features. Least weight was given to the pre-surfaced bathymetric grid. Only those datasets denoted with an '*' were used to compile the Chenega Bay DEM.

**Table 2. Data hierarchy used to assign gridding weight in *MB-System*.**

| Dataset | Relative Gridding Weight |
|---|---|
| USACE surveys | 100 |
| USGS NED topographic DEM | 100 |
| ENC soundings | 100 |
| NGDC digitized features * | 100 |
| UAF Valdez DEM | 100 |
| NOS BAG H11743 | 100 |
| SPOT topographic DEM * | 10 |
| SRTM topographic DEM | 10 |
| NOS hydrographic surveys * | 10 |
| Final coastline * | 10 |
| Higher resolution DEMs | 10 |
| NGDC hydrographic sonar multibeam | 10 |
| Pre-surfaced bathymetric grid * | 1 |
| Trackline soundings | 0.1 |

* indicates supplemental datasets used in compiling the Chenega Bay DEM.

9. *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.]

## 3.4 Quality Assessment of the DEM

### *3.4.1 Horizontal accuracy*

The horizontal accuracy of topographic and bathymetric features in the Chenega Bay DEM is dependent upon DEM cell size and source datasets. Topographic features have an estimated horizontal accuracy equivalent to that of the SPOT data, ~15 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 Chenega Bay DEM is also dependent upon the source datasets contributing to DEM cell values. Topographic data have a stated vertical accuracy of approximately 10 meters for the SPOT DEM, though a comparison with the UAF GPS elevations indicated an accuracy of 1-2 meters. 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 20$^{th}$ 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 8/15 arc-second Chenega Bay DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 15). The DEM was transformed to NAD 83 UTM Zone 6 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 *QT Modeler* and *Fledermaus* revealed suspect data points, which were corrected before recompiling the DEM. Again, the north-south oriented, artificial steps in the SPOT data are clearly visible in the slope analysis. Figure 1 shows a color image of the 8/15 arc-second Chenega Bay DEM in its final version. Figure 16 shows a perspective rendering of the final 8/15 arc-second Chenega Bay DEM.

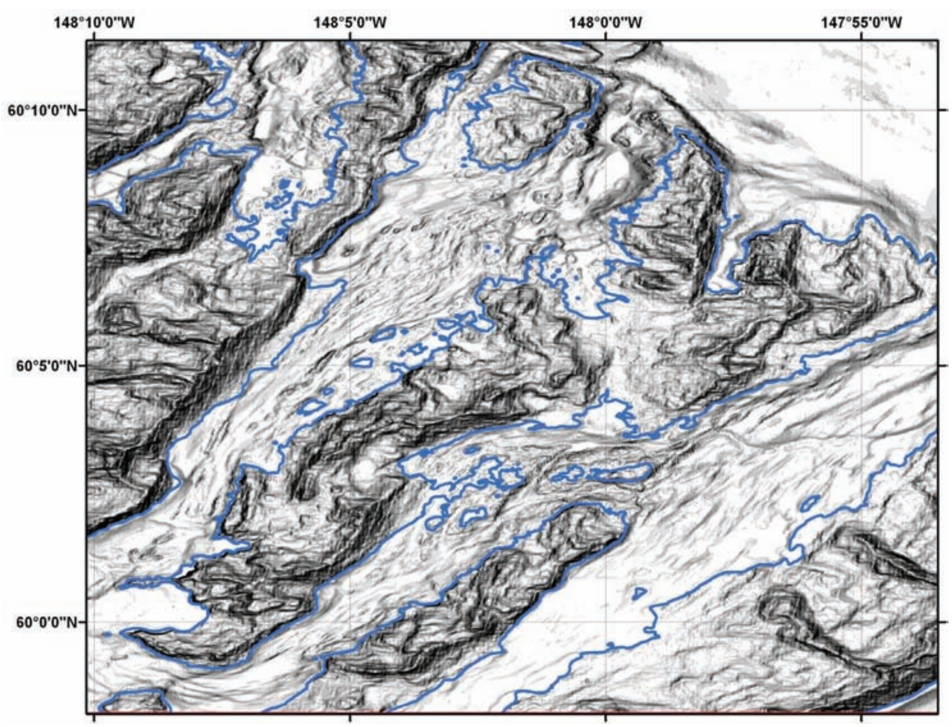


*Figure 15. Slope map of the 8/15 arc-second Chenega Bay DEM. Flat-lying slopes are shown in white; dark shading denotes steep slopes; final coastline indicated in blue. Steepest slopes exist over land.*

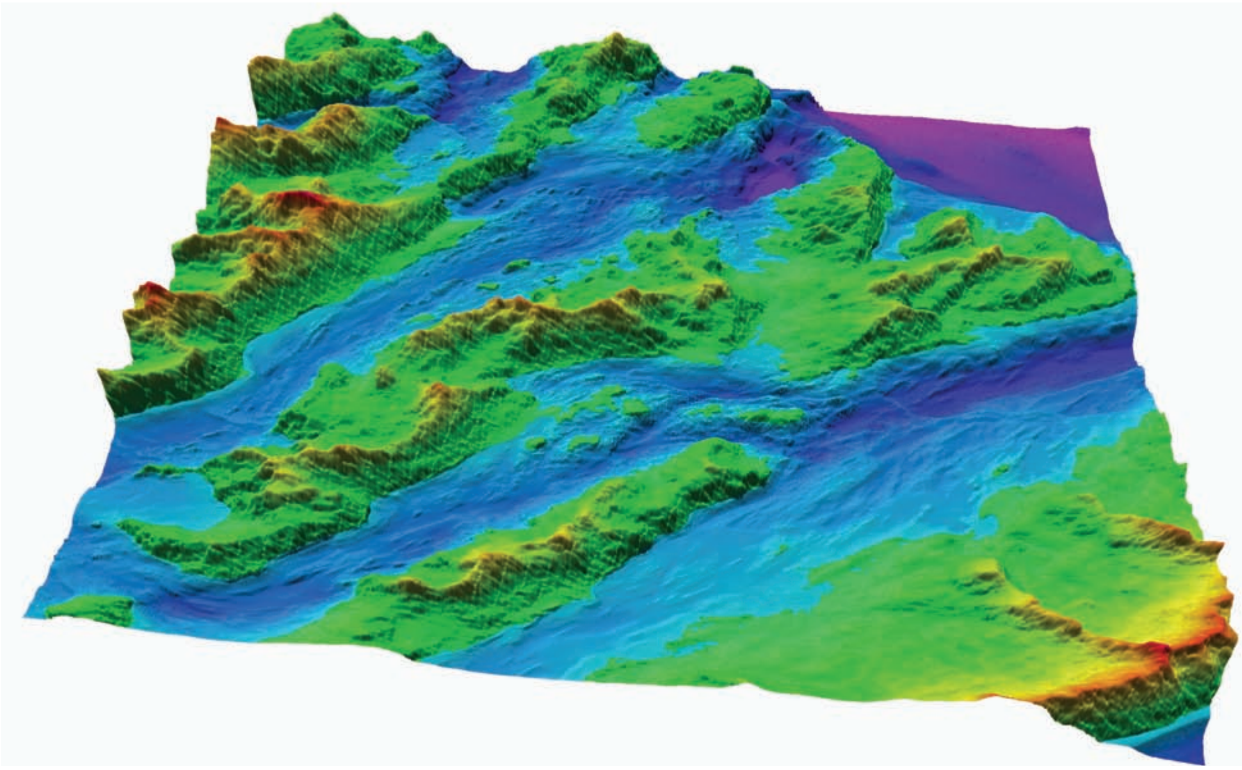

*Figure 16. Perspective view from the northeast of the 8/15 arc-second Chenega Bay DEM. Vertical exaggeration times four.*

### 3.4.4 *Comparison with UAF GPS measurements*

The locations of 230 GPS-collected elevation measurements were provided to NGDC by UAF (Fig. 17). Elevations were given relative to MLLW, but were converted using the 'MLLW to MHHW' offset grid from the Prince William Sound report (Caldwell et al., 2009). Elevations were compared to the 8/15 arc-second Chenega Bay DEM (Fig. 18). Differences between the DEM and the UAF GPS elevations range from -10.02 to 9.21 meters, with half of the differences between -1.28 and 1.96 meters. Large differences in elevations occurred where measurements were taken on piers and docks or in regions of steep topography. In addition, the SPOT topographic data used in the Chenega Bay DEM are not bare earth, which contributes to large differences in forested regions.

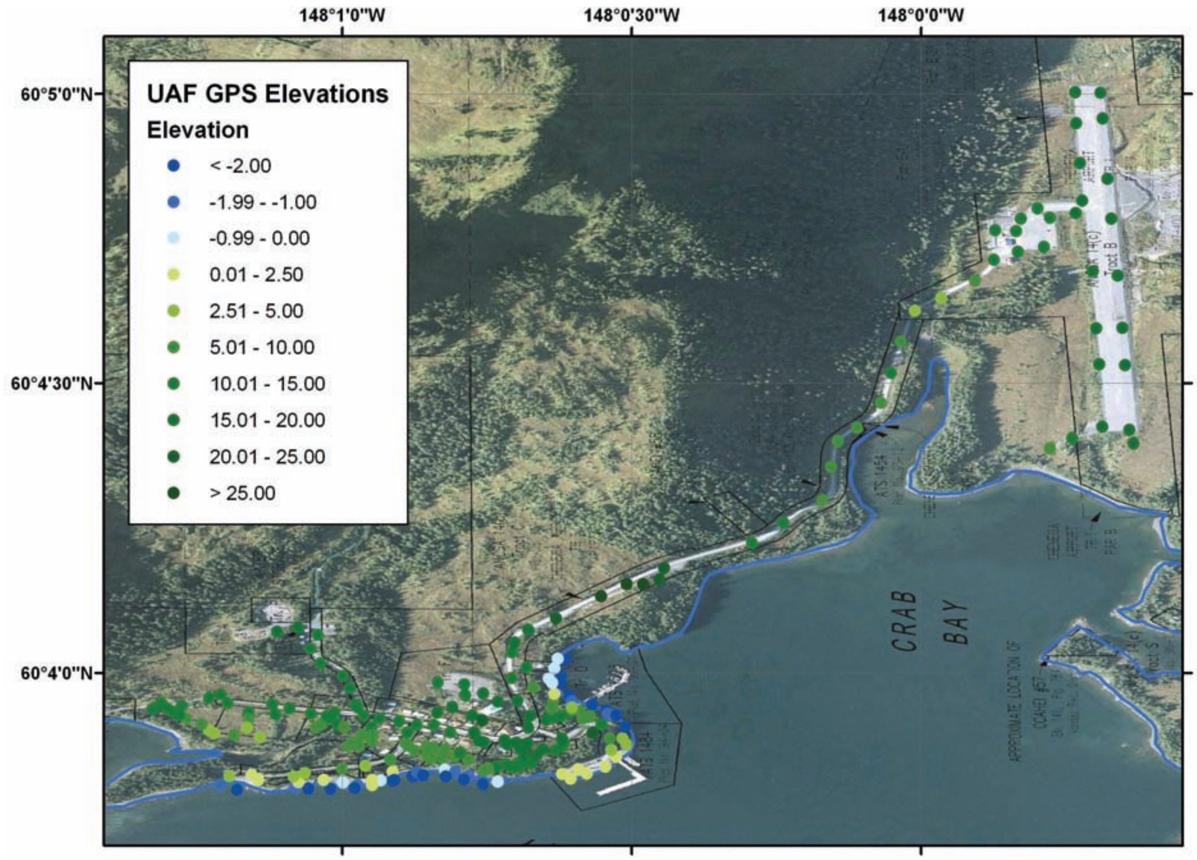


*Figure 17. Location of UAF GPS elevation measurements near Chenega Bay. Aerial imagery from DCRA is in the background. Coastline is in blue.*

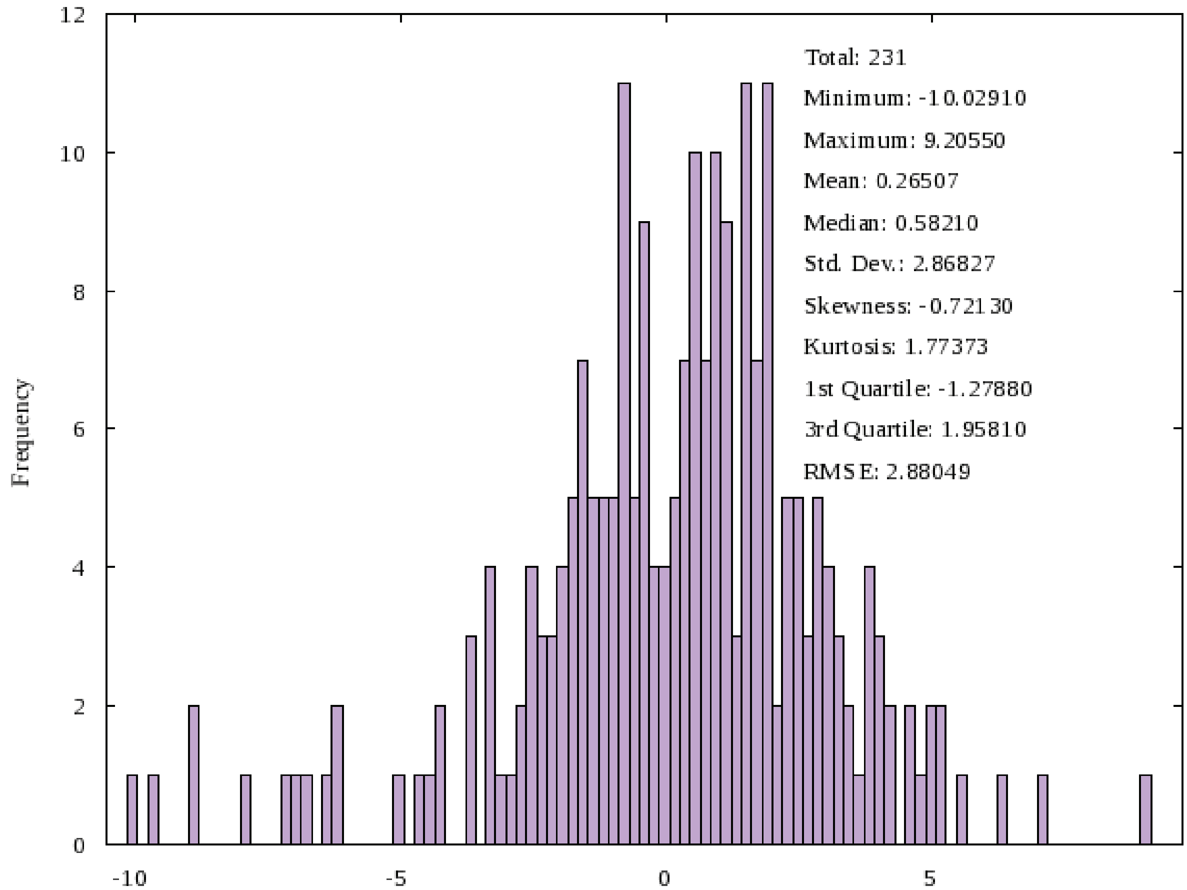


*Figure 18. Histogram of the differences between UAF GPS elevations and the 8/15 arc-second Chenega Bay DEM.*

### *3.4.5 Comparison with NOAA Raster Nautical Charts*

Elevations were also compared against five raster nautical charts (RNCs) in the area, including: 531, 16013, 16700, 16701, and 16702. Manual inspection of the DEM elevations revealed only small differences from elevations indicated on the RNCs. For complete reference information on these RNCs, see the Caldwell et al. (2009) report on the Prince William Sound DEMs.

## 4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of the Chenega Bay, Alaska region, with a cell size of 8/15 arc-second, was developed for 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*, *FME*, *Fledermaus*, *GMT*, *MB-System*, *QT Modeler*, *GDAL, OGR, Proj4,* and *VDatum* software.

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

- Conduct high-resolution topographic surveys, including lidar, of the Chenega Bay region.
- Establish, via survey, relationships between tidal and geodetic datums in the Chenega Bay region.
- Correct horizontal shift evident in the NED data and process SPOT data to bare earth.

## 5. Acknowledgments

The creation of the Chenega Bay DEM was funded by the National Tsunami Hazard Mitigation Program. The authors thank Elena Sulemani and Dmitry Nikolski (UAF); Bret Christensen (USFWS); and, Hans Andersen and Mark Riley (U.S. Forest Service).

## 6. References

Caldwell, R.J., B.W. Eakins, and E. Lim, 2011. Digital Elevation Models of Prince William Sound, Alaska: Procedures, Data Sources, and Analysis, U.S. Department of Commerce, NOAA Technical Memorandum, NESDIS, NGDC-40.

Caldwell, R.J., B.W. Eakins, L.A. Taylor, and K.S. Carignan, 2010. Digital Elevation Model of Tatitlek, Alaska: Procedures, Data Sources, and Analysis, U.S. Department of Commerce, NOAA, National Geophysical Data Center.

Descriptive Report to Accompany Hydrographic Survey H11387, 2004. Northern Prince of Wales Passage. Scale 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Project OPR-P139-TC-04, http://surveys.ngdc.noaa.gov/mgg/NOS/coast/H10001-H12000/H11351/DR/H11387.pdf.

## 7. Data Processing Software

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

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

FME 2010 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/.

Fledermaus v. 7.0.0 – developed and licensed by Interactive Visualization Systems (IVS 3D), Fredericton, New Brunswick, Canada, http://www.ivs3d.com/products/fledermaus/

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

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

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

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

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

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

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

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

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