NOAA Technical Memorandum NESDIS NGDC-48

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1. Introduction

In March of 2010, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed an integrated bathymetric–topographic digital elevation model (DEM) of Atka, Alaska (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1 arc-second[1] coastal DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 5) and will be used for tsunami inundation modeling as part of the tsunami forecast system Short-term Inundation Forecasting (SIFT) currently being developed by PMEL for the NOAA Tsunami Warning Centers. This report provides a summary of the data sources and methodology used in developing the Atka DEM.

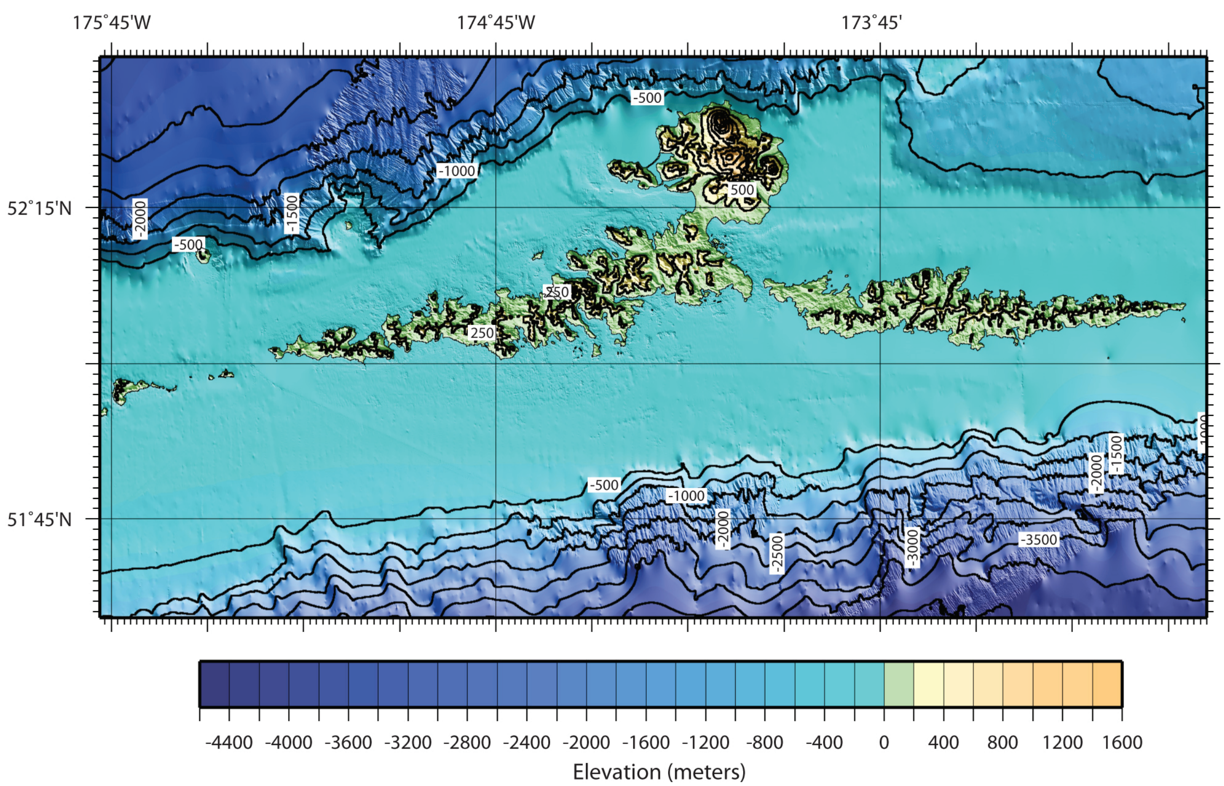

Figure 1. *Shaded-relief image of the Atka DEM.*

1. The Atka 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. At the latitude of Atka, Alaska, (52°11.6′ N, 174°12.5′ W) 1 arc-second of latitude is equivalent to 30.91 meters; 1 arc-second of longitude equals 18.99 meters.

2. Study Area

The Atka DEM covers two of the Andreanof Islands of Alaska, Atka and Amlia, which are part of the Aleutian archipelago (Fig. 2). The islands are mountainous, and were both formed by tectonic plate interaction and resulting volcanic activity. The town of Atka is located on the eastern side of Atka island (Fig. 2), and has a population of approximately 80 (Fig. 3).

The highest point on Atka island is the Korovin Volcano, part of the underlying Atka shield volcano system. The Korovin Volcano is located on the northernmost side of Atka Island, and exhibits small eruptions periodically through its summit vents (Fig. 4). The Atka shield volcano system spans most of the northern peninsula of Atka island, and small vents and thermal activities occur throughout the area.

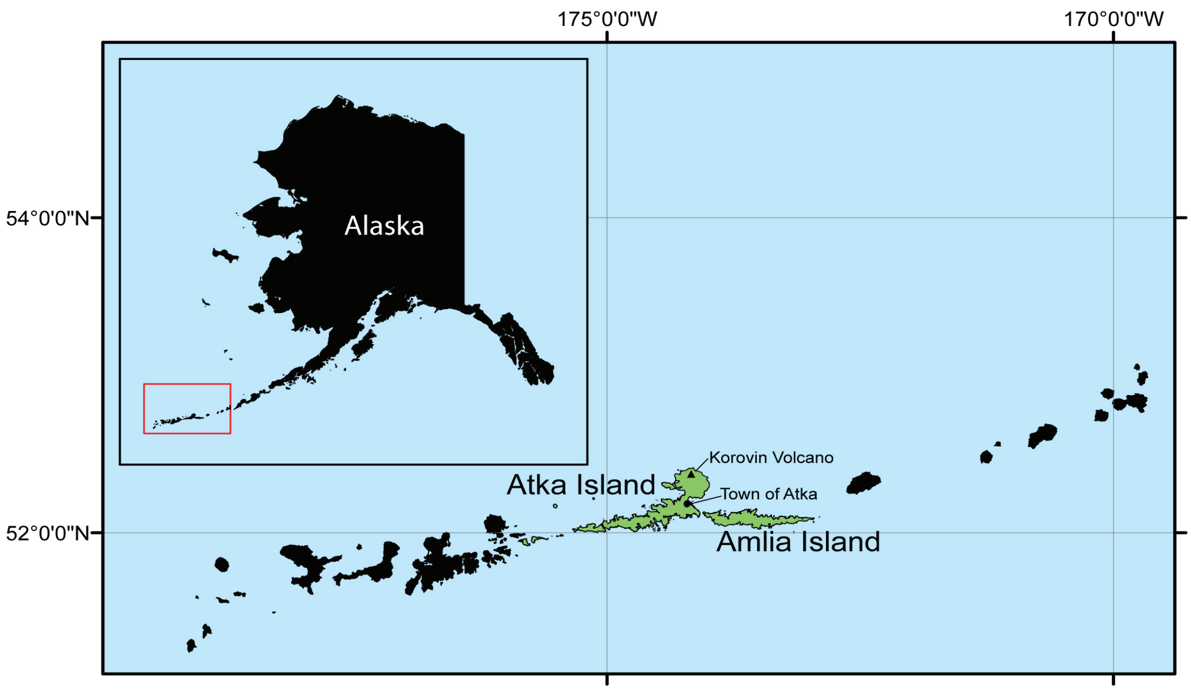

Figure 2. *Map showing the location of Atka island within the Aleutian archipelago.*

Figure 3. *Aerial photograph of the town of Atka, from the south.*
Image courtesy of Game McGimsey and the Alaska Volcano Observatory/USGS (http://www.avo.alaska.edu/image.php?id=12467).

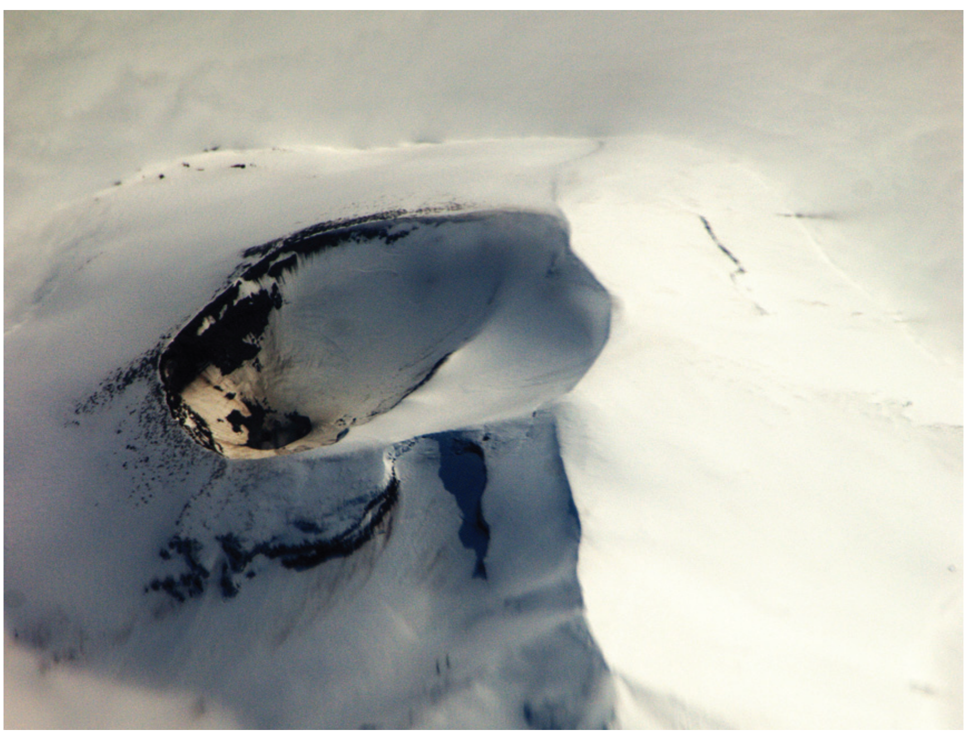

Figure 4. *Aerial photograph of the Korovin Volcano southeastern summit vent.*
Image courtesy of Cyrus Read and the Alaska Volcano Observatory/USGS (http://www.avo.alaska.edu/image.php?id=14266).

3. Methodology

The Atka 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 to provide real-time tsunami forecasts in an operational environment. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North American Datum of 1983 (NAD 83) geographic[2] and mean high water (MHW), for modeling of maximum flooding. Data were gathered in an area slightly larger than the DEM extents. This data "buffer" ensured that gridding occurred 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. PMEL specifications for the Atka DEM.

Grid Area	Atka, Alaska
Coverage Area	172.90º to 175.78º W; 51.59º to 52.49º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	MHW
Vertical Units	Meters
Cell Size	1 arc-second
Grid Format	ESRI Arc ASCII grid

3.1 Data Sources and Processing

Coastline, bathymetric, and topographic digital datasets (Fig. 5) were obtained from several U.S. federal agencies: NOAA's Office of Coast Survey (OCS) and NGDC; the U.S. Geological Survey (USGS); the U.S. Fish and Wildlife Service (USFWS); and the National Aeronautics and Space Administration (NASA). Safe Software's *Feature Manipulation Engine*[3] *(FME)* data translation tool package and ESRI's *ArcGIS* were used to horizontally shift datasets to NAD 83 geographic. The datasets were then displayed with ESRI's *ArcGIS,* ESRI's online *World 2D* imagery, and Applied Imagery's *Quick Terrain Modeler* software (*QT Modeler*) to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using *FME* and *ArcGIS*, based upon data from the Atka NOAA tide station (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 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. *FME* uses the North American Datum Conversion Utility (NADCON; http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html) 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.

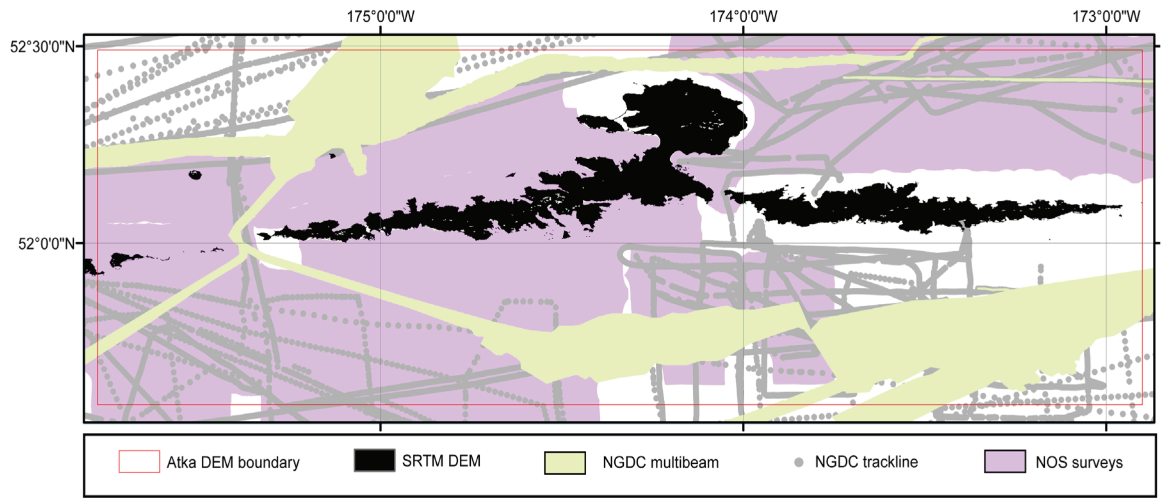

Figure 5. *Source and coverage of datasets used in compiling the Atka DEM.*

3.1.1 Coastline

A coastline dataset for the Atka region was obtained from the U.S. Fish and Wildlife Service (USFWS) (Table 2). The USFWS coastline combines the best available vector data from several other sources and organizations. The coastline closely matches existing topographic data, bathymetric data, and aerial imagery.

Table 2. Coastline dataset used in developing the Atka DEM.

Source	*Year*	*Data Type*	*Spatial Resolution or Scale*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Coordinate System*
USFWS	2006	Compiled vector coastline	Various	WGS 84 geographic	Undefined

1) United States Fish and Wildlife Service coastline

USFWS compiled a seamless digital vector coastline of the State of Alaska using USFWS data, and data from six other sources, including: the USGS National Hydrography Dataset, NOAA's Electronic Navigational Charts (ENCs), National Geographic Topographic Software (derived from USGS topographic quadrangle maps), the U.S. Army Corps of Engineers, and the Alaska Department of Natural Resources. This dataset was provided to NGDC by Bret Christensen of the USFSW.

In order to define a coastline for the Atka DEM, NGDC clipped the USFWS Alaska coastline to the Atka DEM extent and closely reviewed it. It was compared with USGS and NASA topographic digital elevation models, NOAA National Ocean Service (NOS) hydrographic soundings, NOAA Raster Nautical Charts (RNC's), and ESRI's *World 2D* online imagery. Small adjustments to the coastline were made as necessary. The comparison helped to ensure that features such as jetties and rocks were accurately reflected along the coastline. The final edited coastline was converted to xyz data with 10 meter point spacing, using NGDC's *GEODAS* software, for use in building a pre-surfaced bathymetric grid (see Sec. 3.3.2).

3.1.2 Bathymetry

Bathymetric data used in the compilation of the Atka DEM include 25 NOS hydrographic surveys, five multibeam swath sonar surveys from NGDC, and 14 trackline surveys from NGDC (Table 3).

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

Source	***Year***	***Data Type***	***Spatial Resolution or Scale***	***Original Horizontal Datum/ Coordinate System***	***Original Vertical Datum***	***URL***
NGDC	1910 to 1959	NOS hydrographic survey soundings	Ranges from 30 meters to 2 kilometers (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 27 or Early Alaska Datums	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC	1993 to 2006	Multibeam swath sonar surveys	1 arc-second	WGS 84 geographic	Assumed mean sea level (MSL)	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NGDC	1964-1988	Trackline data survey soundings	Ranges from 100 meters to 2 kilometers	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/geodas/trackline.html

1) NOS hydrographic survey data

A total of 25 digital NOS hydrographic surveys conducted between 1910 and 1959 were available for use in developing the Atka DEM (Table 4, Fig. 6). The hydrographic survey data were downloaded from NGDC's NOS Hydrographic Survey Database. In order to support data interpolation across grid edges, survey data were downloaded in an area 0.05 degrees larger than the Atka DEM extent.

The NOS data are horizontally referenced to NAD 27 or to the Early Alaska Datums, and are vertically referenced to the mean lower low water (MLLW) datum. All NOS survey data were converted to NAD 83 geographic during download using *GEODAS*[4], and to MHW (see Sec. 3.2.1) using *FME*.

The converted NOS survey data were displayed in ESRI *ArcMap*. The data were reviewed for digitizing errors against scanned original survey smooth sheets, and some were manually shifted in *ArcGIS* to fit the Atka coastline. The surveys were also compared to other bathymetric datasets, topographic datasets, and NOS RNCs. Soundings that overlapped more recent or more accurate NGDC multibeam datasets were removed. Data point spacing within the NOS surveys ranged from 30 meters in shallow water to approximately two kilometers in deeper water. The 1910 survey was not used because a more recent, higher resolution NOS survey existed at the same location (see Table 4). The data were converted into xyz format and used to create the gridded bathymetric surface (see Sec. 3.3.2) and the final DEM.

4. NGDC's *GEODAS* uses the North American Datum Conversion Utility (NADCON; http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html) developed by NOAA's National Geodetic Survey (NGS) to convert data from NAD 27 and NAD 13 to NAD 83 geographic. NADCON is the U.S. Federal Standard for NAD 27 to NAD 83 datum transformations.

Table 4. Digital NOS hydrographic surveys available in the Atka region.

Name	*Year*	*Scale or Resolution of Survey*	*Original Horizontal Datum*
H03194*	1910	Unknown	Undetermined
H05643	1934	5,000	Early Alaska Datums
H05644	1934	20,000	Early Alaska Datums
H06845	1943	20,000	Early Alaska Datums
H06846	1943	20,000	Early Alaska Datums
H06847	1943	20,000	Early Alaska Datums
H06848	1943	20,000	Early Alaska Datums
H06849	1943	20,000	Early Alaska Datums
H06850	1943	60,000	Early Alaska Datums
H06851	1943	20,000	Early Alaska Datums
H06852	1943	10,000	Early Alaska Datums
H06897	1932	30,000	Early Alaska Datums
H06898	1934	60,000	Early Alaska Datums
H06919	1943	20,000	Early Alaska Datums
H07995	1952	100,000	Early Alaska Datums
H08306	1956	20,000	Early Alaska Datums
H08307	1956	20,000	Early Alaska Datums
H08309	1956	60,000	Early Alaska Datums
H08437	1958	20,000	Early Alaska Datums
H08439	1958	20,000	NAD 27
H08473	1959	60,000	NAD 27
H08474	1959	20,000	NAD 27
H08475	1958	20,000	NAD 27
H08476	1957	10,000	NAD 27
H08823	1959	60,000	NAD 27

*Survey not used in the final DEM because it was superseded by newer surveys.

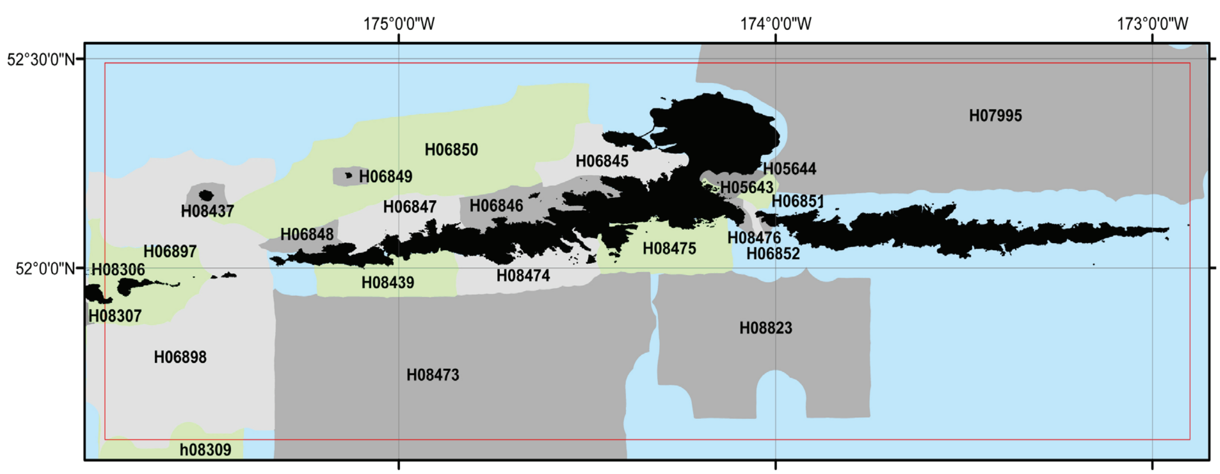

Figure 6. *Digital NOS hydrographic survey coverage in the Atka region. Blue areas represent areas with no NOS data coverage.*

2) NGDC multibeam swath sonar surveys

A total of five multibeam swath sonar surveys were available for use in developing the Atka DEM. The surveys were retrieved from the NGDC Multibeam Bathymetry Database (Table 5, Fig. 7) as xyz files, using *MB-System*[5]. The NGDC Multibeam Bathymetry Database is comprised of original swath sonar data from surveys conducted mostly by the U.S. academic fleet. Many of the multibeam swath sonar surveys were transits rather than dedicated sea-floor surveys.

All multibeam swath sonar surveys have a horizontal datum of WGS 84 geographic and an undefined vertical datum, which was assumed to be MSL. The data were converted to MHW using *FME* (see Sec. 3.2.1). Data errors were common in the multibeam surveys due to noise along multibeam swath edges. In order to reduce the influence of these errors, the data were manually edited in *QT Modeler* before being used to create the gridded bathymetric surface (see Sec. 3.3.2) and the final DEM.

Table 5. Multibeam swath sonar surveys used in compiling the Atka DEM.

Cruise ID	***Ship***	***Year***	***Institution***
KRUS03RR	Roger Revelle	2004	Scripps Institute of Oceanography (SIO)
EW0204	Maurice Ewing	2002	SIO
FOCI93	Surveyor	1993	SIO
RNDB06WT	Thomas Washington	1988	SIO
TN182	Thomas Washington	2005	SIO

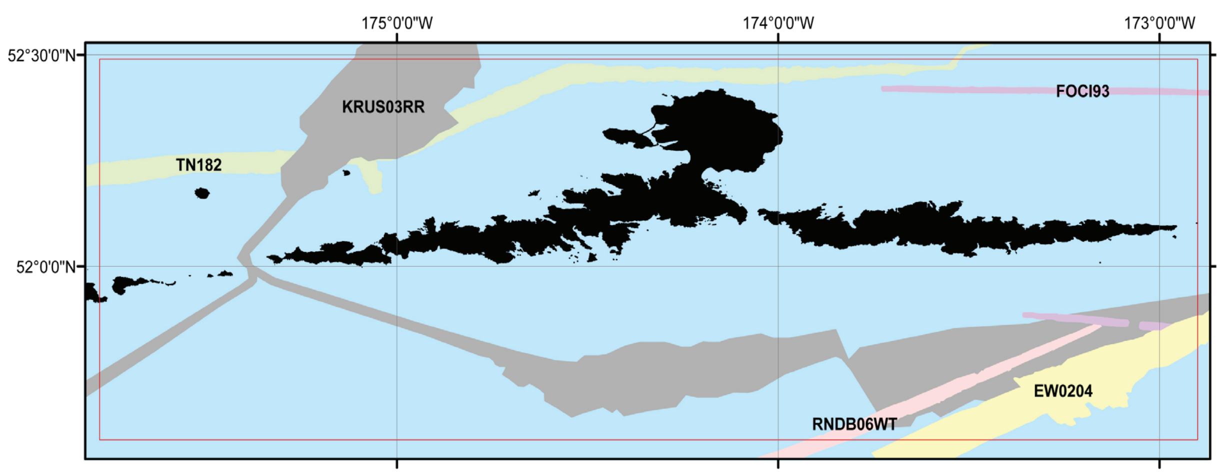

Figure 7. *Spatial coverage of the NGDC multibeam swath sonar surveys used in compiling the Atka DEM.*

5. *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) NGDC trackline bathymetric surveys

A total of 23 trackline bathymetric data surveys were available for use in developing the Atka DEM. The surveys were downloaded from the NGDC Marine Trackline Geophysics Database (Table 6, Fig. 8). All trackline surveys have a horizontal datum of WGS 84 and an undefined vertical datum, which was assumed to be MSL. The files were converted to MHW using *FME* (see Sec. 3.2.1). The surveys were reviewed and edited as shapefiles in *ArcGIS*, and converted into xyz format to be used in creating the gridded bathymetric surface (see Sec. 3.3.2) and the final DEM.

Table 6. Trackline data surveys used in compiling the Atka DEM.

Cruise ID	*Ship*	*Year*	*Institution*
ANTP02MV	Melville	1970	Scripps Institution of Oceanography (SIO)
CMAPSU4S	Surveyor	1964	NOAA NOS
DSDP19GC	Glomar Challenger	1971	SIO
F486BS	Farnella	1986	USGS Branch of Pacific Marine Geology (BPMG)
FARN0788	Farnella	1988	Natural Environment Research Council (NERC)
FARN0887	Farnella	1987	NERC
FOCI93	Surveyor	1993	NOAA
HU931005	Hunt	1970	US Navy Naval Oceanographic Office (NAVO)
KH7803	Hakuho Maru	1978	Ocean Research Institute, University of Tokyo
L580AA	Samuel P. Lee	1981	USGS BPMG
L679NP	Sea Sounder	1979	USGS BPMG
L981AA	Samuel P. Lee	1981	USGS BPMG
POL6829	Surveyor	1968	NOAA Pacific Oceanic Laboratory
RC1010	Robert Conrad	1966	Columbia University Lamont-Doherty Earth Observatory (CU LDEO)
RC1208	Robert Conrad	1968	CU LDEO
RC1406	Robert Conrad	1971	CU LDEO
RC1407	Robert Conrad	1971	CU LDEO
RNDB06WT	Thomas Washington	1988	SIO

Cruise ID	***Ship***	***Year***	***Institution***
SI343621	Silas Bent	1976	NAVO
SI931005	Silas Bent	1970	NAVO
YAQ66JL1	Yaquina	1966	Oregon State University (OSU)
YAQ66JUN	Yaquina	1966	OSU
YAQ702	Yaquina	1970	OSU

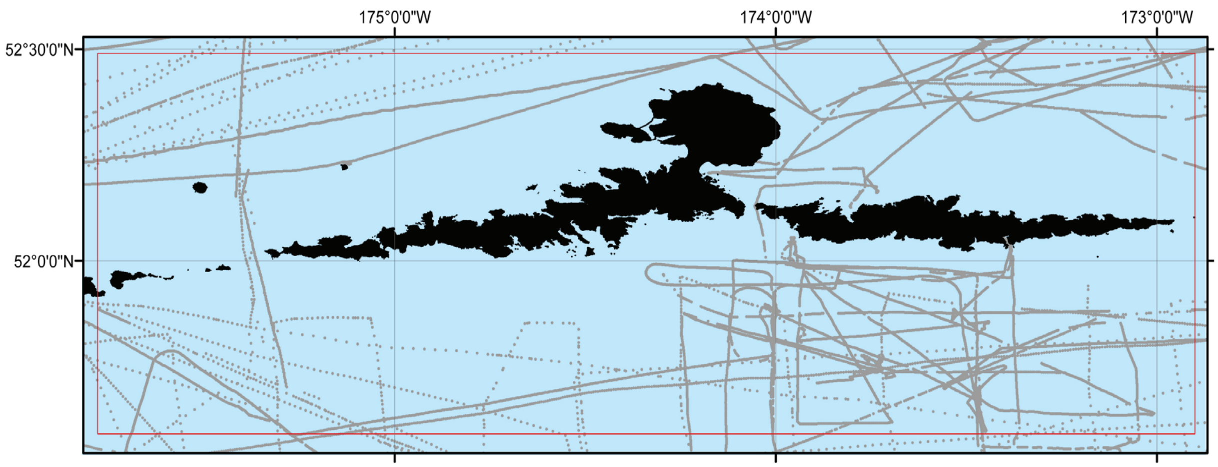

Figure 8. *Spatial coverage of the NGDC trackline surveys used in compiling the Atka DEM.*

3.1.3 Topography

A 1 arc-second topographic raster dataset was used in building the Atka DEM (Table 7; Fig. 5). The NASA Shuttle Radar Topography Mission (SRTM) 1 arc-second DEM provided full coverage for the Atka region, with the exception of some data gaps located at mostly at higher elevations (see Fig. 5). The Advanced Spaceborne Thermal Emission and Reflection (ASTER) 1 arc-second raster dataset was assessed, but was not used because it was unable to provide adequate coverage in coastal regions. NGDC also evaluated but did not use lower resolution topographic DEMs available from the USGS.

Table 7. Topographic datasets used in compiling the Atka DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NASA	2000	DEM	1 arc-second	WGS 84 geographic	Assumed MSL	http://www2.jpl.nasa.gov/srtm/; http://seamless.usgs.gov/

1) Shuttle Radar Topography Mission

The SRTM was a joint international project run by the National Geospatial-Intelligence Agency (NGA) and NASA. In 2000, the SRTM project obtained global elevation data at 1-arc second resolution using an interferometric synthetic aperature radar (InSAR) system. Four SRTM raster grid data tiles were downloaded from the SRTM web site for use in the Atka DEM; the tiles provided 1 arc-second data coverage of most of the topography in the Atka DEM region.

The SRTM raster grid tiles used in compiling the Atka DEM contained some small data gaps (null grid cells) located mostly at higher elevations. NGDC attempted to fill the holes with lower resolution "filled" SRTM datasets and with ASTER data, but these datasets were inconsistent with the 1 arc-second SRTM data, and therefore caused erroneous steps and cliffs in the landscape near SRTM data hole boundaries. The SRTM data gaps were filled by allowing interpolation to assign values during gridding (see Sec. 3.3.3).

SRTM data are referenced to the WGS 84 horizontal datum. The vertical datum for the SRTM dataset was assumed to be MSL, and the data were transformed to MHW using *FME* (see Sec. 3.2.1). The tiles contained empty grid cells over the open ocean, which were clipped out of the dataset by NGDC. After datum transformation and clipping, topographic SRTM data for the Atka DEM were converted into xyz format to create the final DEM.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Atka DEM were originally referenced to MSL and MLLW vertical datums. The datasets were transformed to MHW to provide maximum flooding estimates for inundation modeling, and units were converted from feet to meters as appropriate.

1) **Bathymetric data**

   The NOS survey data, multibeam swath sonar surveys, and trackline survey data were transformed to MHW using *FME* software, which was accomplished by adding a constant offset, as measured at the Atka station (Table 8).

2) **Topographic data**

   The SRTM 1 arc-second DEM was transformed from MSL to MHW using *ArcGIS* software, which was accomplished by adding a constant offset of -0.372 meters, as measured at the Atka tide station (Table 8).

Table 8. Relationship between MHW and other vertical datums used in compiling the Atka DEM

Vertical datum	*Difference to MHW**
MSL	-0.372 meters
MLLW	-0.970 meters

*Data obtained from Atka tide station (#9461710)

3.2.2 Horizontal datum transformations

Datasets used to compile the Atka DEM were originally referenced to WGS 84 geographic and NAD 83 geographic. The relationships and transformational equations between these horizontal datums are well established. Data were converted to a horizontal datum of NAD 83 geographic using *GEODAS*, *FME* or *ArcGIS*.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting files were checked in ESRI *ArcMap* or *QT Modeler* for consistency between datasets. Problems and errors were identified and resolved before proceeding with final gridding steps. The evaluated and edited files were converted to xyz files in preparation for final DEM gridding. Problems included:

- Data gaps located at higher elevations in the SRTM dataset.
- Noise along edges of multibeam swath sonar surveys.
- Anomalous points and sparse soundings in the trackline data and NOS hydrographic surveys.
- Some near-shore rocks not represented in the available datasets.

3.3.2 Smoothing of bathymetric data

Bathymetric NOS hydrographic survey data and NGDC marine trackline geophysics data are generally sparse in the Atka area relative to the resolution of the 1 arc-second Atka DEM. This is especially true for deep-water surveys, where some survey data have point spacing up to three kilometers apart. In order to reduce the effect of artifacts created in the DEM by the low-resolution datasets, and to provide effective interpolation into the coastal zone, a 3 arc-second-spacing "pre-surface" bathymetric grid was generated using *GMT*[6].

The bathymetric point data were median-averaged using the *GMT* tool "blockmedian" to create a 3 arc-second grid 0.05 degrees larger than the Atka DEM gridding region. The *GMT* tool "surface" was then used to apply a tight spline tension to interpolate elevations for cells without data values. The resulting grid was converted into an ESRI Arc ASCII grid file, and clipped to the final coastline to eliminate values that were interpolated into land areas. The bathymetric surface was compared with original soundings to ensure grid accuracy (e.g., Fig. 9) and exported for use in the final gridding process (see Table 9). All large differences (greater than 200 meters) between the source bathymetric data and the bathymetric surface (Fig. 9) are caused by data points located in deep water (greater than 4000 meters deep).

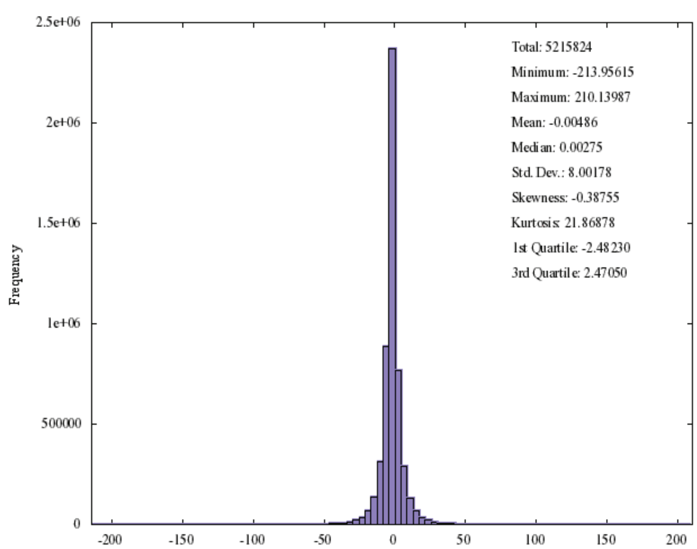

Figure 9. *Histogram of the differences between the source bathymetric data and the NGDC Atka bathymetric surface.*

6. 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.

3.3.3 Gridding the data with MB-System

MB-System was used to create the 1 arc-second Atka DEM. The *MB-System* tool 'mbgrid' was used to apply a tight spline tension to the Atka 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 9. Greatest weight was given to the topographic data, the pre-surfaced bathymetric grid, and the NGDC multibeam surveys. Least weight was given to the less dense bathymetric point data.

Table 9: Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
SRTM topographic data	10
Pre-surfaced bathymetric grid	10
NGDC multibeam surveys	1
NGDC trackline surveys	0.1
NOS hydrographic surveys	0.1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Atka DEM is dependent upon the cell size of the DEM and the horizontal accuracy of source datasets. Topographic features, which were derived from the 1 arc-second SRTM DEM, have an estimated accuracy of thirty meters. Bathymetric features are resolved only to within two kilometers in deep-water areas. Shallow-water areas, near-coastal regions, and harbors have an accuracy between 30 and 100 meters. Positional accuracy is limited by the sparseness of soundings, the positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys, and the possibility of man-made morphologic change (i.e., channel dredging and building of jetties).

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Atka DEM is also dependent upon the accuracy of source datasets contributing to DEM cell values. Topographic data have an estimated vertical accuracy of up to 15 meters. Bathymetric source data have an estimated vertical accuracy between 0.1 meters and five percent of water depth, depending on the survey location and the survey date. Bathymetric data values are most accurate when derived from recent, highly detailed GPS-navigated multibeam sonar surveys, and least accurate when derived from surveys performed manually in the early twentieth century. Gridding interpolation to determine deep-water values between sparse, poorly-located soundings degrades the vertical accuracy of some elevations.

3.4.3 Slope map and 3-D perspective

ESRI *ArcCatalog* was used to generate a slope grid from the Atka DEM to allow for visual inspection and identification of artificial slopes. Artificial slopes are common along boundaries between datasets (Fig. 10). The DEM was transformed to UTM zone 2N 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 slope grids revealed suspect data points, which were corrected before recompiling the DEM. A source data contribution plot to the Atka DEM is shown in Figure 11. A perspective view of the 1 arc-second Atka DEM in its final version, from the northwest, is shown in Figure 12.

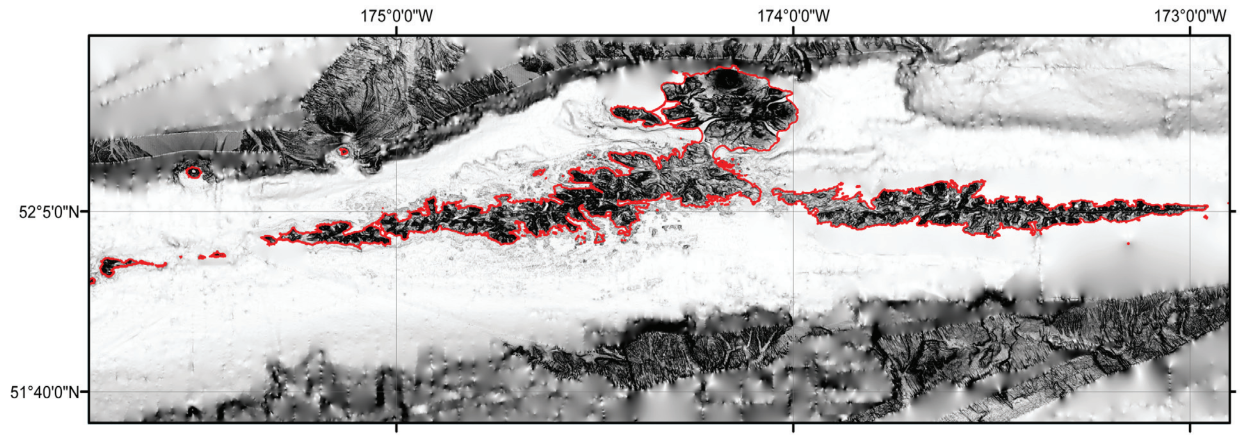

***Figure 10.** Slope map of the Atka DEM. Flat-lying slopes are white; dark shading denotes steep slopes; Atka DEM coastline in red.*

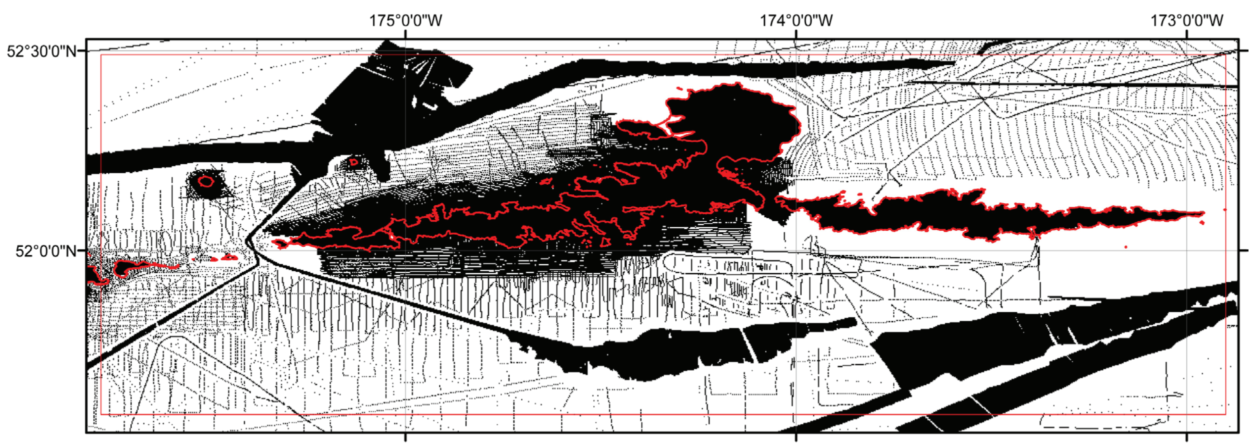

***Figure 11.** Data contribution plot to the Atka DEM. Black points depict DEM cells constrained by source data; white areas represent areas where grid elevations were derived from interpolation. Atka DEM coastline and Atka DEM boundary shown in red.*

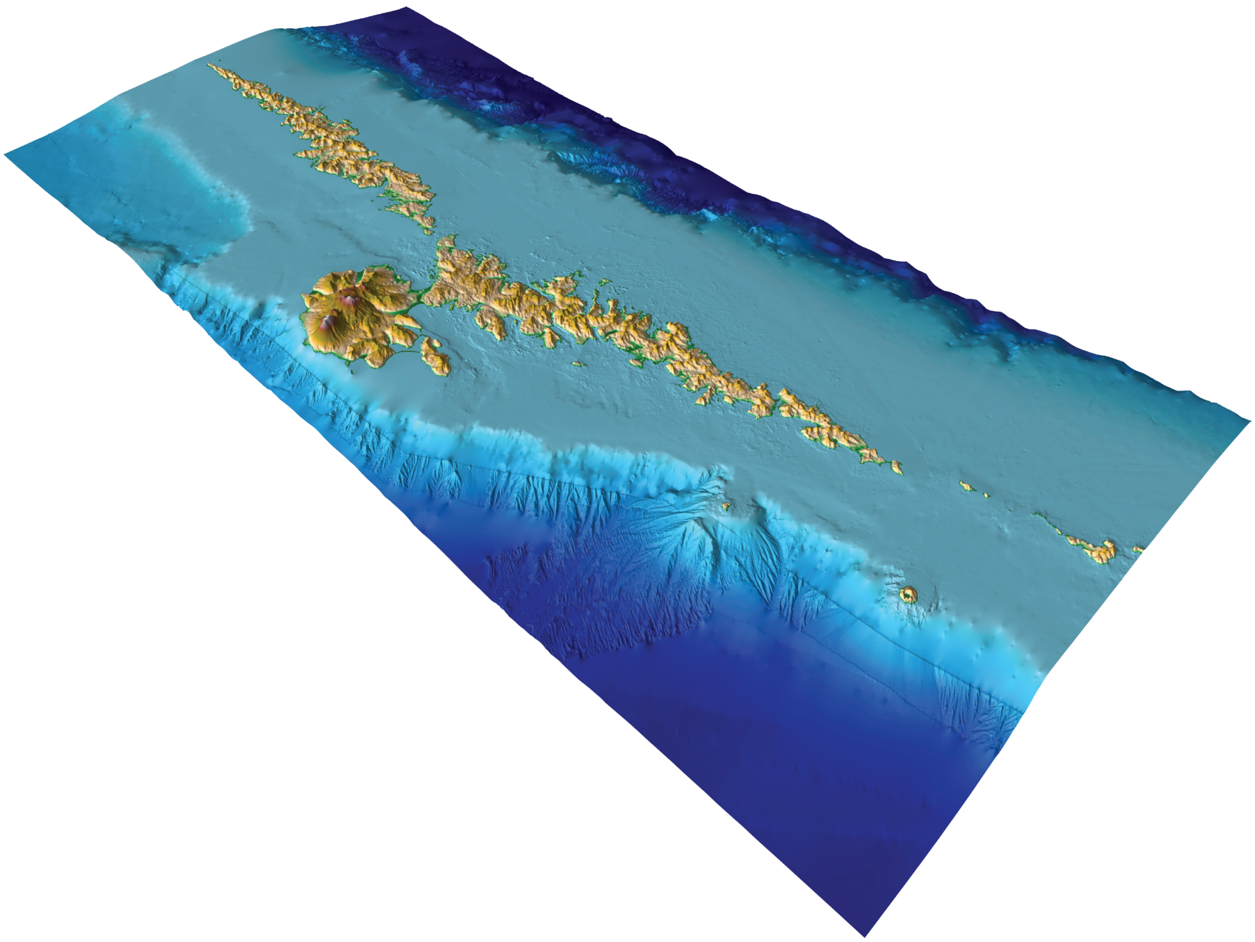

Figure 12. *Perspective view from the northwest of the Atka DEM. Three times vertical exaggeration.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Atka DEM was compared to all source data files. Comparisons are shown in Figures 13-16. Very few significant differences existed between the source data files and the DEM. The largest differences between source datasets and the DEM occured in regions of steep slope near the coastline (e.g., NOS soundings, Fig. 14) and in areas with depths greater than 3500 meters (e.g., NGDC multibeam data, Fig. 15; NGDC trackline data, Fig. 16). The NASA SRTM dataset contained few data points that showed significant differences from the DEM (Fig. 13); all SRTM differences greater than 20 meters occurred where the elevation was greater than 1000 meters.

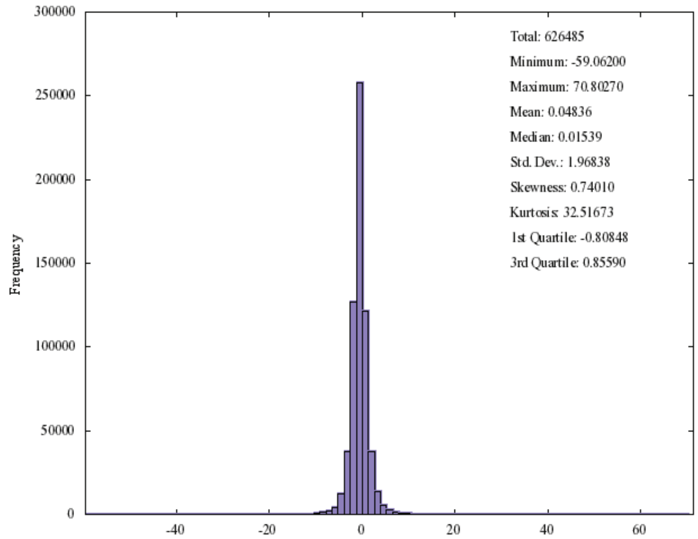

Figure 13. *Histogram of the differences between the SRTM topographic dataset and the Atka DEM.*

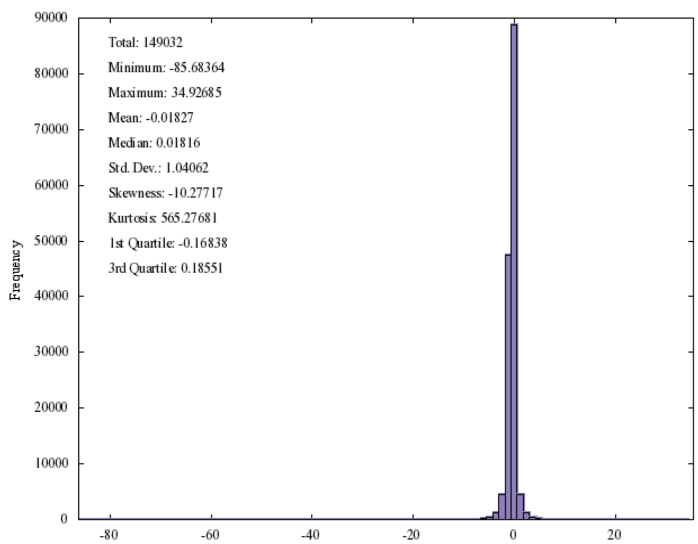

Figure 14. *Histogram of the differences between the NOS data and the Atka DEM.*

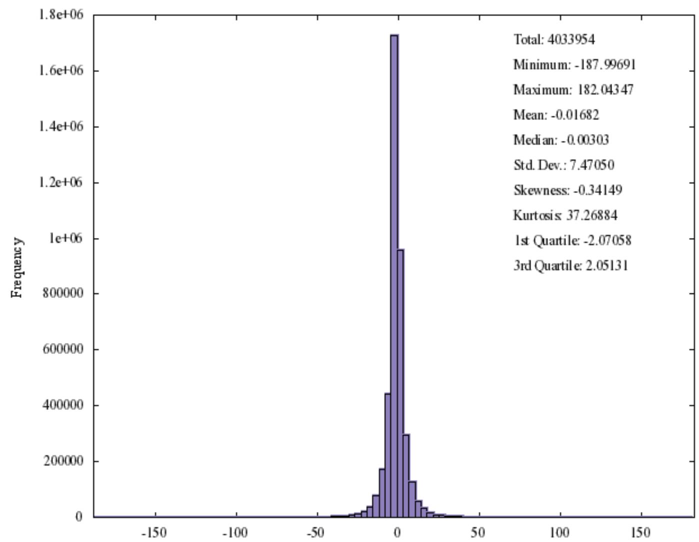

Figure 15. *Histogram of the differences between the NGDC multibeam data and the Atka DEM.*

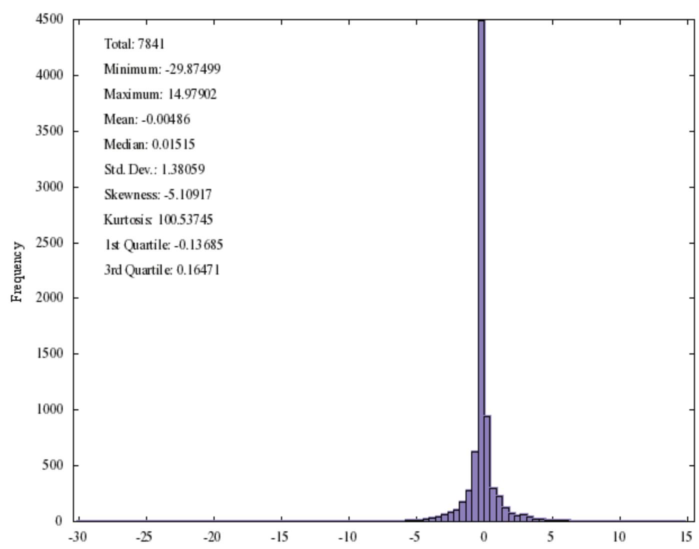

Figure 16. *Histogram of the differences between the NGDC trackline data and the Atka DEM.*

3.4.5 *Comparison with USGS topographic contours*

Topographic elevations were obtained from the USGS *Atka* quadrangle (http://agdc.usgs.gov/data/usgs/to_geo.html). The quadrangle provides positions and elevations in NAD 83 and the National Geodetic Vertical Datum (NGVD, in feet), and has a scale of 1:250,000 with a 200-foot contour interval.

To be consistent with the USGS *Atka* quadrangle, the Atka DEM was converted from meters into feet. A contour map of the DEM area surrounding the city of Atka with a 200-foot contour interval was created and compared against the USGS topographic quadrangle (Fig. 17). The results show that the Atka DEM provides a good representation of the terrain on Atka island.

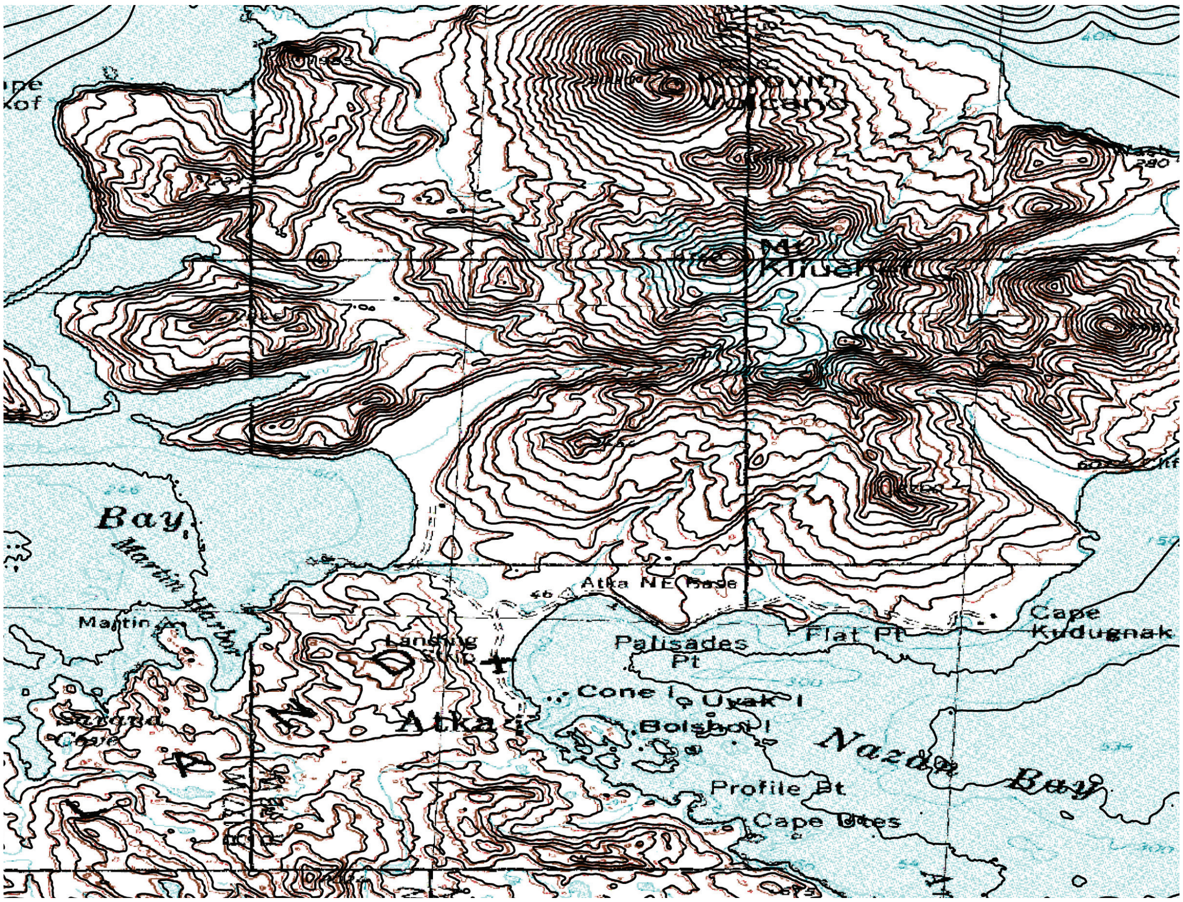

Figure 17. *Comparison between USGS topographic contours and the Atka DEM contours. Black lines represent NGDC Atka DEM contours, underlying red lines represent contours on USGS topographic map.*

4. Summary and Conclusions

An integrated bathymetric–topographic DEM of the Atka, Alaska region, with a cell size of 1 arc-second, was developed for NOAA/PMEL Center for Tsunami Research. The best available digital data from U.S. federal 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, FME, GMT, MB-System*, and *Quick Terrain Modeler* software.

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

- Conduct high-resolution bathymetric surveys in areas where bathymetric data does not currently exist.
- Conduct bathymetric–topographic lidar surveys of the entire coast.
- Survey and map rocks along the coastline.
- Improve topographic data coverage at high elevations.

5. Acknowledgments

The creation of the Atka DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Nazila Merati and Vasily Titov (PMEL).

6. References

Nautical Chart #16480 (ENC and RNC), 11th Edition, 2004. Atka Island- Western Part. Scale 1: 300,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #16486 (ENC and RNC), 7th Edition, 2004. Atka Island- Western Part. Scale 1: 40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #16487 (ENC and RNC), 6th Edition, 2004. Korovin Bay to Wall Bay. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #16490 (ENC and RNC), 8th Edition, 2003. Nazan Bay and Amlia Pass. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

7. Data Processing Software

ArcGIS v. 9.3, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

ESRI World Imagery, ESRI ArcGIS Resource Centers, http://resources.esri.com/arcgisonlineservices/

Fledermaus v. 7.0, developed and licensed by Interactive Visualization Systems (IVS 3D), Fredericton, New Brunswick, Canada, http://www.ivs3d.com/.

FME 2009 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, free software 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, free software developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.1.1, free software 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. 6.0.6, Lidar processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/