NOAA Technical Memorandum NESDIS NGDC-15

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L.A.Taylor
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D.C. Schoolcraft

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Lisa A. Taylor[1]
Barry W. Eakins[2]
Kelly S. Carignan[2]
Robin R. Warnken[1]
Tatiana Sazonova[2]
David C. Schoolcraft[1]

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

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

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Corresponding author 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

In August 2007, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a bathymetric–topographic digital elevation model (DEM) of Kawaihae, Hawaii (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second[1] coastal DEM will be used as input for the MOST (Method of Splitting Tsunami) 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. 3) and will be used for tsunami inundation modeling, as part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) 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 Kawaihae DEM.

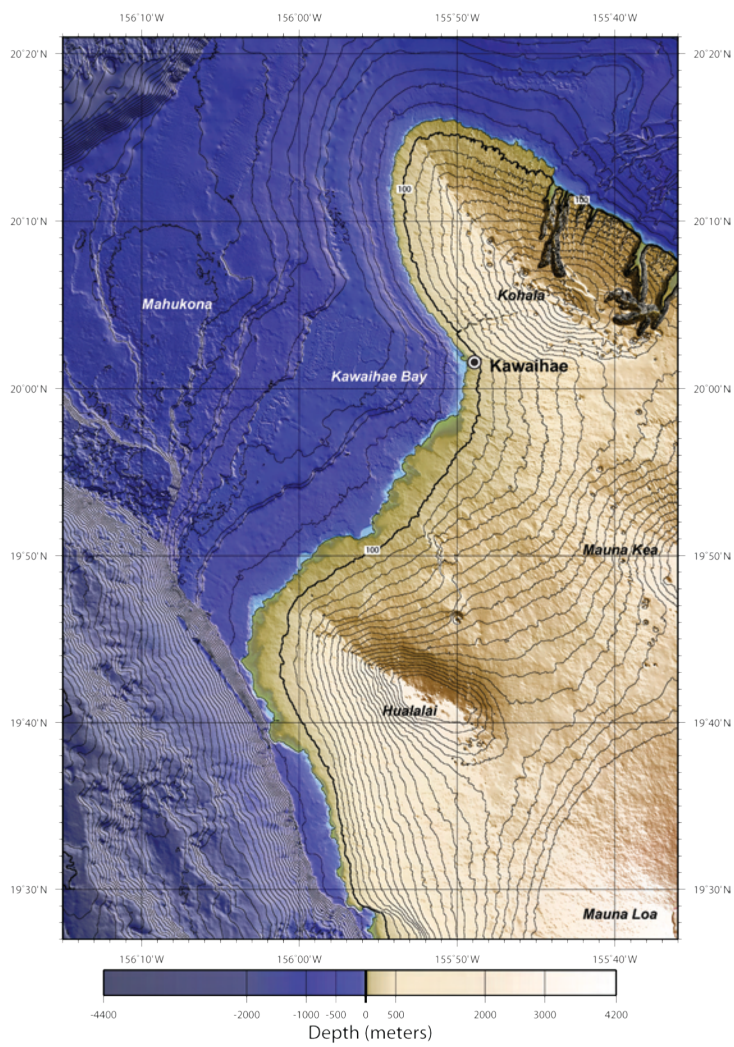

Figure 1. *Shaded relief image of the Kawaihae DEM. Contour interval is 100 meters.*

1. The Kawaihae 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 Kawaihae, Hawaii (20°2.4′ N, 155°49.9′ W) 1/3 arc-second of latitude is equivalent to 10.25 meters; 1/3 arc-second of longitude equals 9.69 meters.

2. Study Area

The Kawaihae DEM covers the northwestern coastal region centered on the western coast of the island of Hawaii, Hawaii. The islands of Hawaii have been created by shield-building volcanoes, whose low-viscosity lava flows often reach the coast. The Island of Hawaii lies over or just north of the Hawaiian hot spot and is composed of five volcanoes (Fig. 2): Kohala, Hualalai, Mauna Kea, Mauna Loa, and Kilauea; the extinct Mahukona Volcano (Fig. 1) lies west of Kawaihae and is completely submerged, Loihi, the youngest volcano, lies south of the island and has yet to reach the sea surface. The island has 428 km of general coastline and is known locally and abroad as the Big Island. The western side of the Big Island lies in the lee of Mauna Loa (4,205 m), the largest volcano on Earth (measuring from the sea floor), which has formed in the last 600,000–1,000,000 yrs, rising almost 9 km from the sea floor. The leeward climate is extraordinarily dry with 25 cm annual rainfall, resulting in minimal stream erosion on the Hawaii lavas of western Kohala, and on the lavas of Mauna Kea, Mauna Loa, and Hualalai, south along the coast respectively. Kawaihae Harbor is a deep draft harbor on the Big Island and is fronted by a system of offshore fringing reefs. Several sand beaches exist at the south end of Kawaihae Bay, derived from eroded coral that was dredged during construction of the harbor.

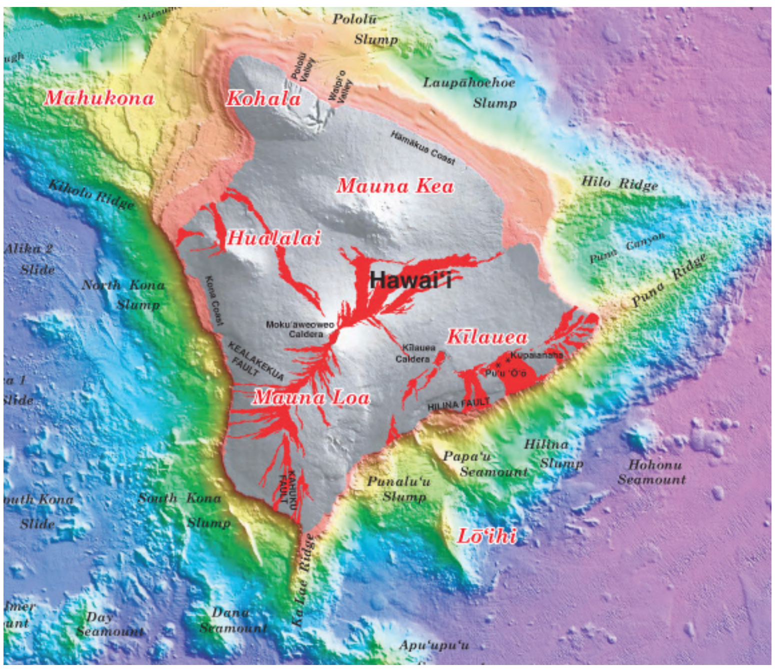

Figure 2. *The volcanoes of the Island of Hawaii (image from http://geopubs.wr.usgs.gov/i-map/i2809/).*

3. Methodology

The Kawaihae DEM was developed to meet PMEL specifications (Table 1), based on input requirements for the MOST inundation model. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS84) and Mean High Water (MHW), for modeling of "worst-case scenario" flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1. PMEL specifications for the Kawaihae, Hawaii DEM.

Grid Area	Kawaihae, Hawaii
Coverage Area	155.6º to 156.25º W; 19.4º to 20.4º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 3) were obtained from several U.S. federal agencies, including: NOAA's National Ocean Service (NOS), the U.S. Army Corps of Engineers (USACE); and the U.S. Geological Survey (USGS). The data were collected by numerous methods, in different terrestrial environments, and at various scales and resolutions. Datasets were assessed for quality and accuracy both within each dataset, and between datasets to ensure consistency and gradual topographic transitioning along the edges of datasets. Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets; NGDC's GEODAS software (http://www.ngdc.noaa.gov/mgg/geodas/) was used to manually edit large xyz datasets. Vertical datum transformations to MHW were accomplished using FME, based upon data from a NOAA tide station at Kawaihae Hawaii, as no VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was available for this area.

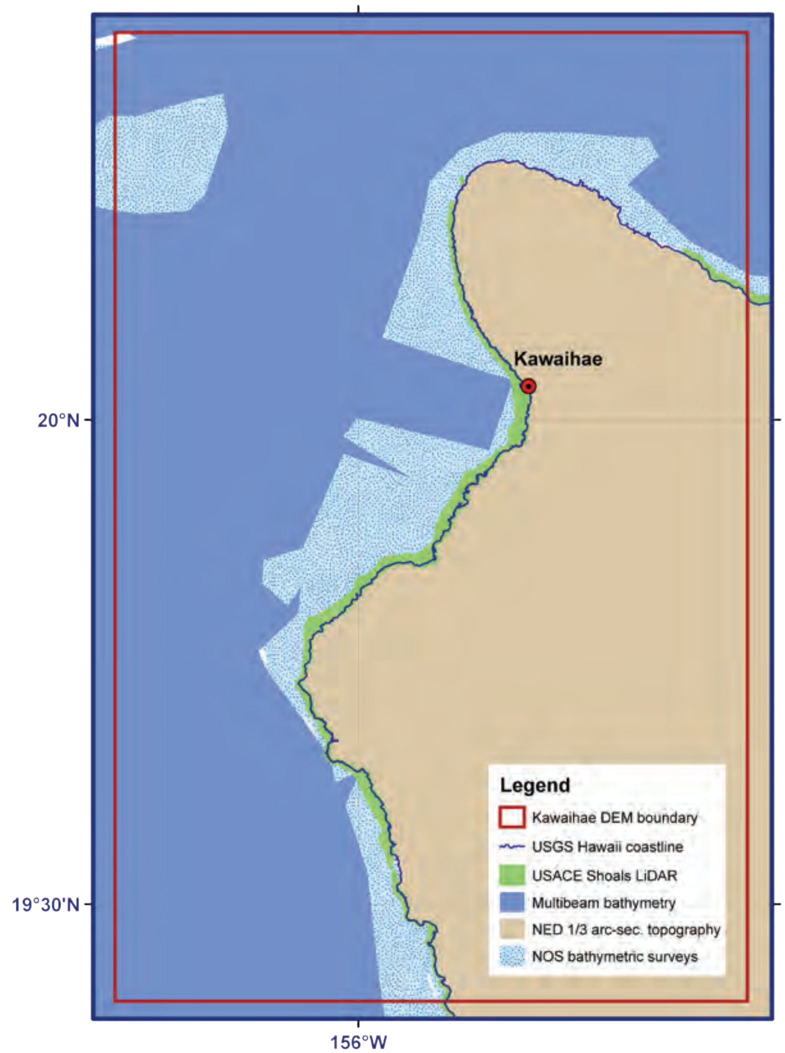

Figure 3. *Source and coverage of datasets used to compile the Kawaihae DEM.*

3.1.1 Shoreline

One digital coastline dataset of Hawaii Island was used in building the Kawaihae DEM: the United States Geological Survey Hawaii Island 7.5 minute Quads-Derived Shoreline (Table 2).

Table 2. Shoreline dataset used in compiling the Kawaihae DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*
USGS	2004	Vector shoreline derived from USGS quads	~ 1:24,000	NAD83 UTM Zone 5	Inferred MHW

1) USGS Hawaii Island 7.5 minute Quads-Derived Shoreline

The Hawaii (Big Island) coastline is an unclassified vector dataset generated by the United States Geological Survey in 1998. The shoreline is referenced to MHW and constructed from digitized 7.5 minutes USGS quads.

The Hawaii coastline is mostly consistent with the NED topographic data and JALBTCX SHOALS bathymetric LiDAR surveys. The coastline was converted to point data for use as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached “zero” at the coast. It was also used to clip USGS NED topographic DEMs, which contain elevation values, typically zero, over the open ocean (Section 3.1.3).

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Kawaihae DEM include 28 NOS hydrographic surveys, 13 multibeam sonar surveys, and JALBTCX SHOALS bathymetric LiDAR surveys along the coast (Table 3).

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

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1932 to 1987	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	Early Hawaiian Island, Old Hawaiian, or NAD83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC	1986 - 2002	Multibeam sonar	~ 3% of water depth	WGS84 geographic	MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
USACE	2001	SHOALS LiDAR	~ 5 to 10 meters	WGS84 geographic	MLLW	http://shoals.sam.usace.army.mil/hawaii/pages/Hawaii_Data.htm
NGDC	2006	Digitized soundings in Nonokohau and Kawaihae harbors	~5-10 meters	WGS84 geographic	MLLW	

1) NOS hydrographic survey data

A total of 28 NOS hydrographic surveys conducted between 1932 and 1987 were utilized in developing the Kawaihae DEM (Table 4; Fig. 5). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to Early Hawaiian Island, Old Hawaiian, or NAD83 geographic datums.

Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys. All surveys were extracted from NGDC’s online NOS hydrographic database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original, digitized vertical datum and NAD83 horizontal datum (Table 4). The data were then converted to WGS84 and MHW using FME software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com). The surveys were subsequently clipped to a polygon 0.05 degree (~10%) larger than the Kawaihae DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and compared to topographic NED data, JALBTCX SHOALS LiDAR bathymetric data, the Hawaii coastline, NOAA nautical charts, and *Google Earth* satellite imagery.

Table 4. Digital NOS hydrographic surveys used in compiling the Kawaihae DEM.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H05339	1932	100,000	mean lower low water	early Hawaiian island datum
H09017	1968	10,000	mean lower low water	early Hawaiian island datum
H09019	1968	10,000	mean lower low water	early Hawaiian island datum
H09015	1969	40,000	mean lower low water	early Hawaiian island datum
H09016	1969	80,000	mean lower low water	early Hawaiian island datum
H09129	1970	40,000	mean lower low water	early Hawaiian island datum
H09131	1970	10,000	mean lower low water	early Hawaiian island datum
H09132	1970	10,000	mean lower low water	old Hawaiian datum
H09234	1971	5,000	mean lower low water	old Hawaiian datum
H09235	1971	5,000	mean lower low water	old Hawaiian datum
H09308A	1972	5,000	mean lower low water	old Hawaiian datum
H09308B	1972	5,000	mean lower low water	old Hawaiian datum
H09334	1972	10,000	mean lower low water	old Hawaiian datum
H09335	1972	10,000	mean lower low water	early Hawaiian island datum
H09339	1972	80,000	mean lower low water	early Hawaiian island datum
H09346	1972	10,000	mean lower low water	old Hawaiian datum
H09361B	1973	5,000	mean lower low water	old Hawaiian datum
H09816	1979	10,000	mean lower low water	early Hawaiian island datum
H09974	1981	80,000	mean lower low water	old Hawaiian datum
H09975	1981	20,000	mean lower low water	old Hawaiian datum
H09983	1981	20,000	mean lower low water	old Hawaiian datum
H09985	1981	80,000	mean lower low water	early Hawaiian island datum
B00090	1986	50,000	mean lower low water	NAD83
B00101	1987	50,000	mean lower low water	NAD83
H09018	1968/70	10,000	mean lower low water	early Hawaiian island datum
H09237	1971/72	10,000	mean lower low water	old Hawaiian datum
H09336A	1972/73	5,000	mean lower low water	early Hawaiian island datum
H09307	1972/74	10,000	mean lower low water	early Hawaiian island datum

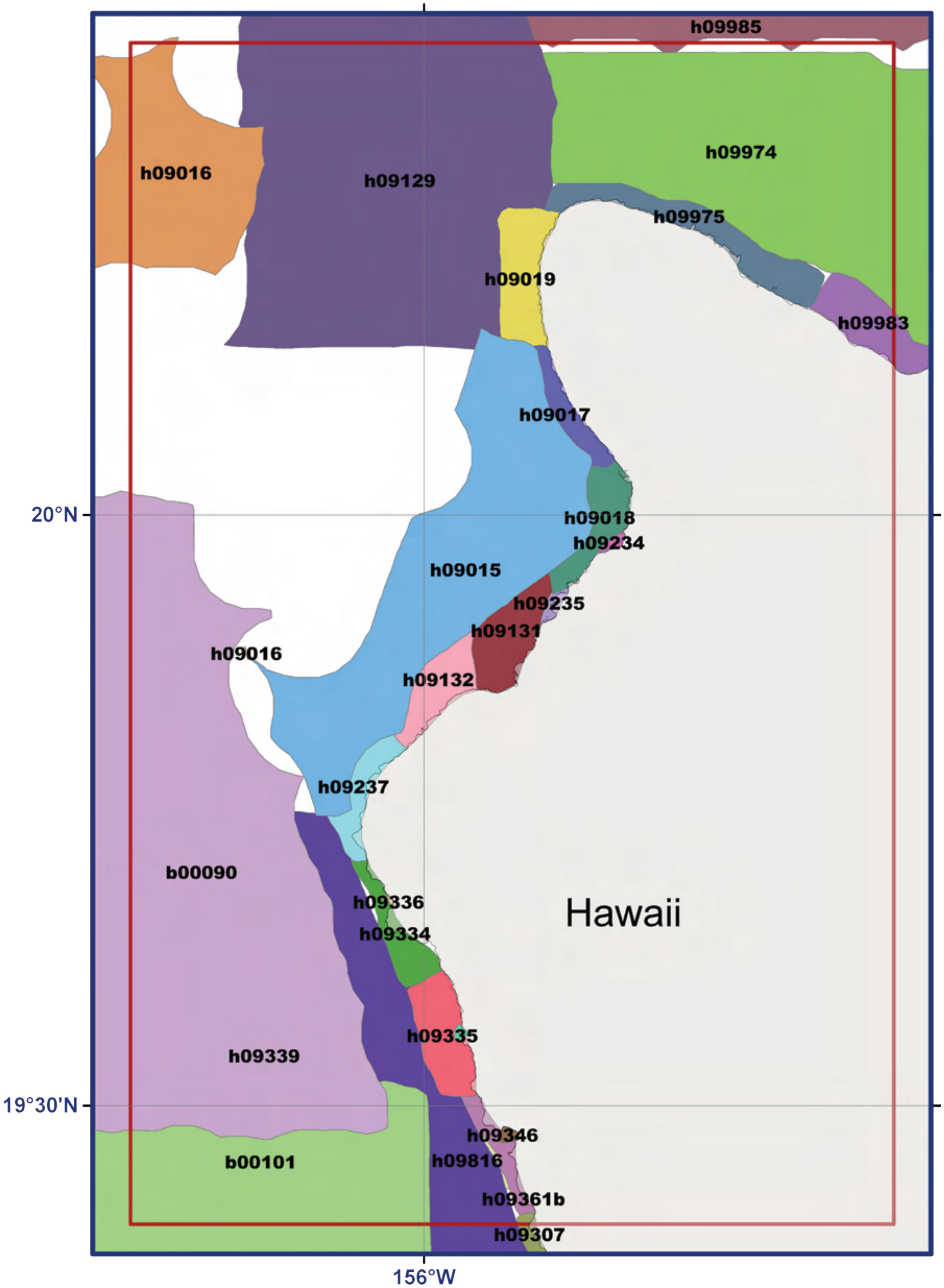

Figure 4. *Digital NOS hydrographic survey coverage in the Kawaihae region. DEM boundary in red, USGS coastline in gray.*

2) NGDC multibeam sonar surveys

Various oceanographic institutions have conducted high-resolution multibeam swath sonar surveys around the Hawaiian Islands in the period from 1987 through 2002 including NOAA, University of Rhode Island, Scripps Institute of Oceanography, Monterey Bay Aquarium Research Institute, and Japan Agency for Marine-Earth Science and Technology. The multibeam data are archived and disseminated by NGDC, with 13 surveys falling within the Kawaihae DEM boundary (Table 5, Fig. 6). Data were referenced to WGS84 and MSL and were gridded using MB-System [section 3.3.2].

Table 5. Multibeam sonar surveys used in compiling the Kawaihae DEM.

Survey ID	*Year*	*Source*
AII8L11	1987	U. of Rhode Island
B00090	1986	NOAA
B00101	1987	NOAA
CRGN04WT	1987	SIO
DRFT13RR	2002	SIO
KR2001	2001	JAMSTEC
Kohala	1998	MBARI
Mahukona	1998	MBARI
NECR05RR	2000	SIO
TUNE03WT	1991	SIO
TUNE04WT	1991	SIO
YK1999	2002	JAMSTEC
YK2002	2002	JAMSTEC

Figure 5. *Screen grab of multibeam sonar surveys in the Kawaihae region, from NGDC ArcIMS interface (http://map.ngdc.noaa.gov/website/mgg/multibeam/viewer.htm).*

3) JALBTX SHOALS LiDAR surveys

Near coastal bathymetric LiDAR data (Fig. 6) were collected by the U.S. Army Corps of Engineers Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX), using the SHOALS (Scanning Hydrographic Operational Airborne LiDAR Survey) system, which consists of an airborne laser transmitter/receiver capable of measuring 400 soundings per second. The system operates from a deHavilland DHC-6 Twin Otter flying at altitudes between 200 and 400 meters with a ground speed of about 100 knots. The SHOALS system also includes a ground-based data processing system for calculating accurate horizontal position and water depth. The positional accuracy of the data is $\pm$3 meters horizontally, and $\pm$0.15 meters vertically. The dataset was originally referenced to MLLW and WGS84 geographic.

Positive elevation values were present in the data, reflecting subaerial returns, and were excised by NGDC prior to building the Kawaihae DEM. Some anomalous values were also present in bathymetric regions, which were deleted.

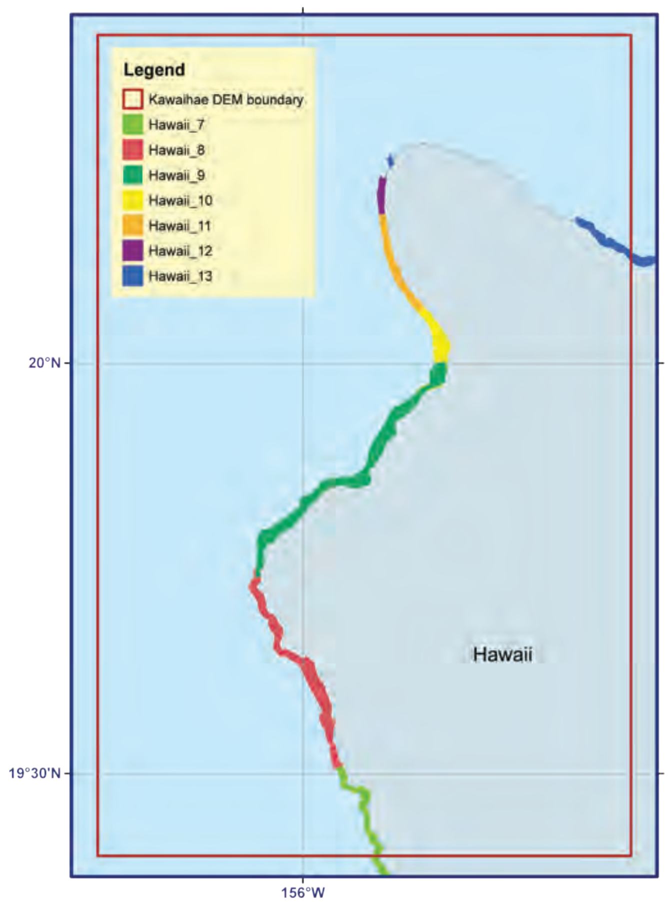

Figure 6. *Spatial coverage of JALBTCX SHOALS bathymetric LiDAR surveys in the Kawaihae region.*

4) NGDC Honokohau and Kawaihae harbors

As no bathymetry was available for Honokohau and Kawaihae harbors NGDC digitized soundings for the harbors from two NOAA Raster Nautical Charts (#19330 and #19327). Original soundings were in fathoms at MLLW.

3.1.3 Topography

One topographic dataset in the Kawaihae region was obtained from the U.S. Geological Survey and used in building the Kawaihae DEM (Table 6; Fig. 7).

Table 6. Topographic dataset used in compiling the Kawaihae DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS	2001	NED DEM	1/3 arc-second	NAD83 geographic	Inferred Mean Sea Level	http://ned.usgs.gov/

1) USGS NED topography

The U.S. Geological Survey (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provided complete 1/3 arc-second coverage of the Kawaihae region[2]. Data are in NAD83 geographic coordinates and NGVD88 vertical datum (meters), and are available for download as raster DEMs. The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quadrangle maps and aerial photographs based on topographic surveys; it was revised using data collected in 1999 and 2004.

The NED data included "zero" elevation values over the open ocean, which were removed from the dataset before gridding. Non-zero values still remained over the open ocean, which were visually inspected and compared with NOAA nautical charts, the USGS coastline, and *Google Earth* satellite imagery. ESRI Arc Catalog was used to clip the data to the USGS coastline.

The NAVD88 vertical datum is established only for the North American mainland and has not been surveyed for Hawaii. The NED DEMs are therefore inferred to represent elevations relative to Mean Sea Level.

2. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

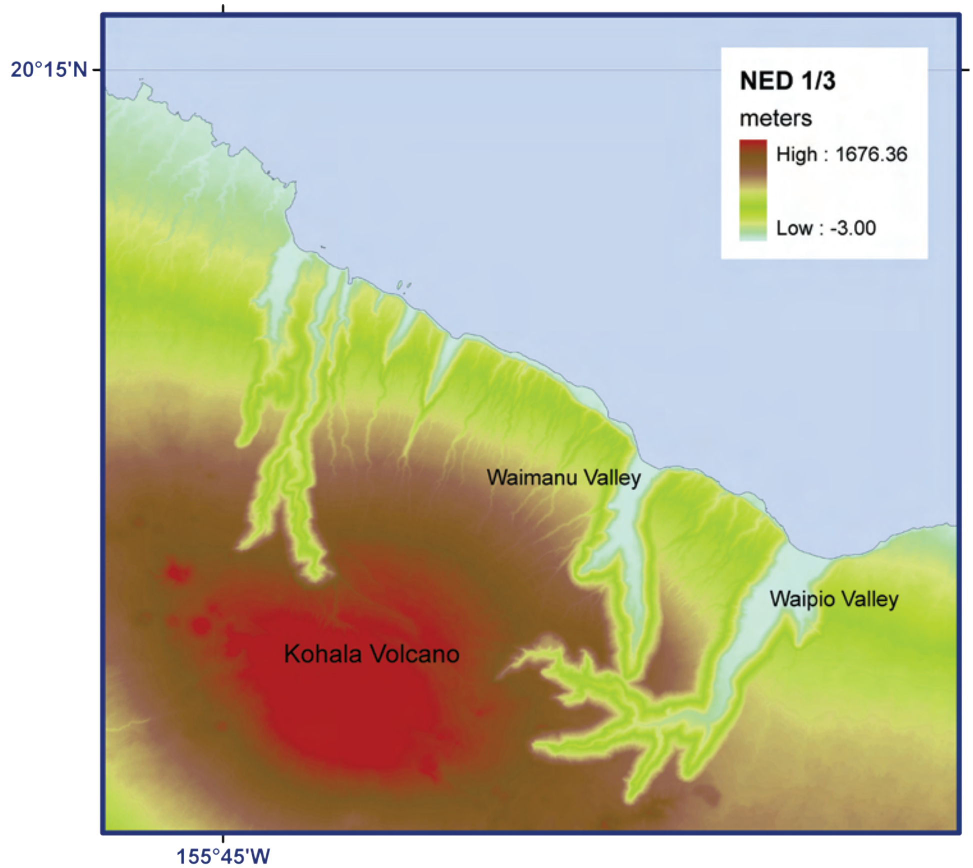

Figure 7. *Color image of the NED DEM in the vicinity of the Kohala Volcano.*

Figure 8. *Aerial photo of Waipio and Waimanu Valleys shown in Figure 7. The deeply incised canyons formed by erosion following landslide collapse [Smith et al., 2001]. (Photo was taken by P. Mouginis-Mark, http://satftp.soest.hawaii.edu/space/hawaii/nav/ap.kohala.html).*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Kawaihae DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Sea Level (MSL), and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW to provide the worst-case scenario for inundation modeling, using values measured at the NOAA tidal station at Kawaihae, Hawaii (#1617433; Table 7).

1) **Bathymetric data**

The NOS hydrographic and JALBTCX SHOALS LiDAR surveys were transformed from MLLW to MHW, using FME software, by adding a tide-station derived constant offset of -0.5 m (Table 7). The multibeam sonar data were referenced to MSL and were shifted by adding a constant offset of -0.217 m.

2) **Topographic data**

The USGS NED 1/3 arc-second DEM is referenced to NAVD88, which is not defined in Hawaii; this dataset was inferred to be referenced to MSL. Conversion to MHW, using FME software, was accomplished by adding a tide-station derived constant offset of -0.217 m (Table 7).

Table 7. Relationship between Mean High Water and other vertical datums in the Kawaihae region.*

Vertical datum	*Difference to MHW*
MSL+	-0.217
MLW	-0.446
MLLW	-0.5

* Datum relationships measured at tide station #1617433, Kawaihae, Hawaii.
+ Topographic data referenced to Local Tidal datum or NAVD88 inferred to be equivalent to MSL.

3.2.2 Horizontal datum transformations

Datasets used to compile the Kawaihae DEM were originally referenced to NAD83 geographic, NAD83 UTM Zone 5, or WGS84 geographic horizontal datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of WGS84 using FME software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

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

- Data values over the open ocean in the NED. The DEM required automated clipping to the USGS coastline.
- Noise present in the multibeam data which was resolved by eliminating data within survey.
- Offsets between older, low-resolution NOS surveys and newer recent high-resolution multibeam sonar data. NOS soundings in areas covered by multibeam sonar data were deleted.

3.3.2 Gridding of multibeam bathymetric data

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to grid the multibeam sonar data files. MB-System is an NSF-funded share-ware software application specifically designed to manipulate submarine multibeam sonar data. The MB-System tool 'mbgrid' applied a tight spline tension to the swath sonar data, and interpolated values for nearby cells without data. The resulting 1 arc-second ASCII grid was brought into ArcGIS for evaluation and conversion from MSL to MHW, and exported as xyz data for surfacing of all of the bathymetric data.

3.3.3 *Smoothing of bathymetric data*

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second Kawaihae DEM: in deep water, the NOS survey data have point spacings up to 900 m apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing 'pre-surface' or grid was generated using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The NOS hydrographic point data, in xyz format, were combined with the multibeam grid and JALBTCX SHOALS LiDAR survey data into a single file, along with points extracted from the Hawaii coastline to provide a "zero" buffer along the entire coastline. These point data were then median-averaged using the GMT tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~10%) larger than the Kawaihae DEM gridding region. The GMT tool 'surface' then applied a tight spline tension to interpolate cells without data values. The GMT grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the coastline (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy, converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 8).

3.3.4 *Gridding the data with MB-System*

MB-System was used to create the 1/3 arc-second Kawaihae DEM. The MB-System tool 'mbgrid' applied a tight spline tension to the xyz data, and interpolated values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 8. Greatest weight was given to the high-resolution topographic NED DEM. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid.

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

Dataset	*Relative Gridding Weight*
JALBTCX SHOALS coastal bathymetric LiDAR	100
Multibeam grid	100
USGS NED topographic DEM	1000
NOS hydrographic surveys: bathymetric soundings	100
Pre-surfaced bathymetric 1 arc-second grid	1

3.4 Quality Assessment of the DEM

3.4.1. *Horizontal accuracy*

The horizontal accuracy of topographic and bathymetric features in the Kawaihae DEM is dependent upon the datasets used to determine corresponding DEM cell values. NED topography is accurate to within about 15 meters. Bathymetric features are resolved only to within a few tens of meters in deep-water areas. Shallow, near-coastal regions have an accuracy approaching that of subaerial topographic features. Positional accuracy is limited by the sparseness of deep-water soundings and one potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 *Vertical accuracy*

Vertical accuracy of elevation values for the Kawaihae DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy to 7 meters (for NED topography). Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth (220 meters in the southwest corner of the DEM). Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep water.

3.4.3 Slope maps and 3-D perspectives

ESRI ArcCatalog was used to generate a slope grid from the Kawaihae DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 9). The DEM was transformed to UTM Zone 5 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM (Fig. 10) was accomplished using ESRI ArcScene. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 1 shows a color image of the 1/3 arc-second Kawaihae DEM in its final version.

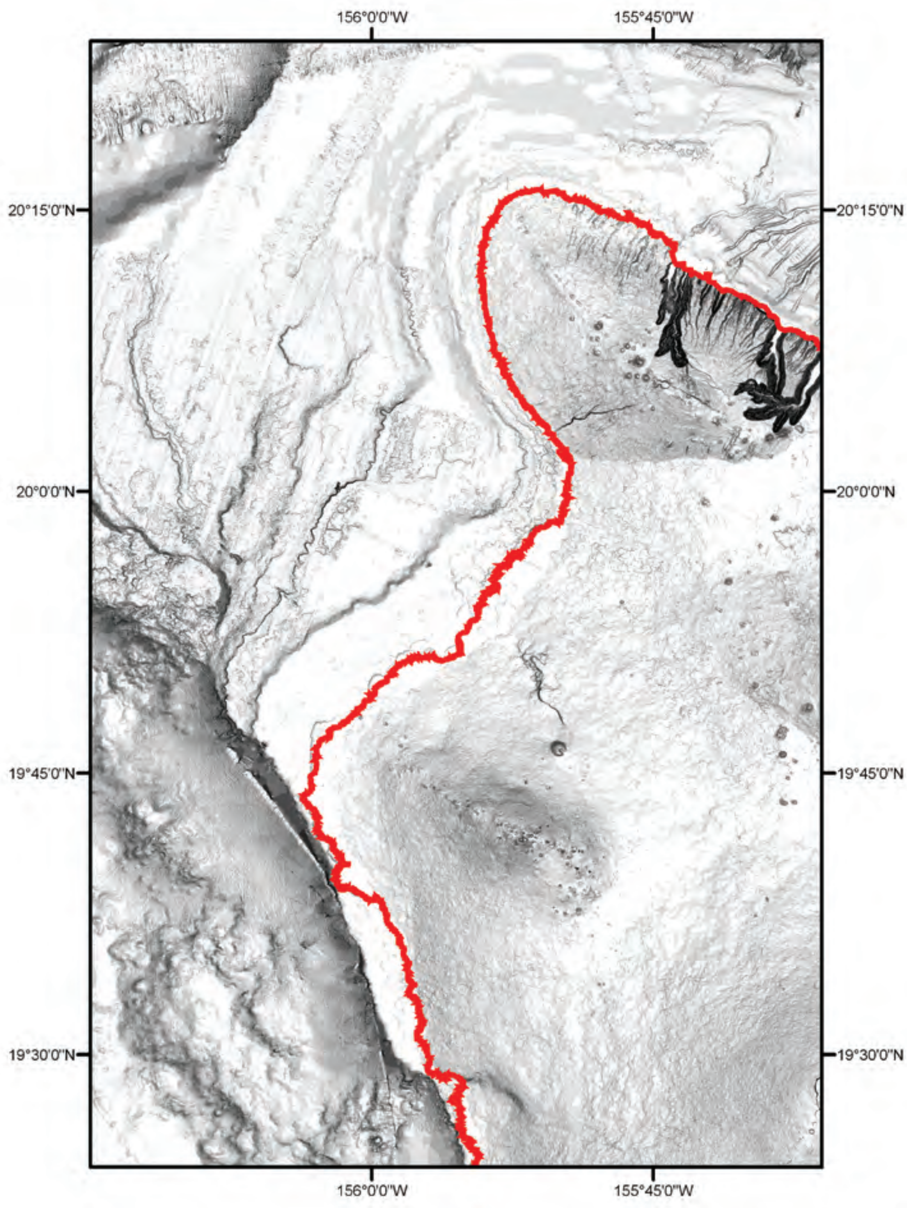

Figure 9. *Slope map of the Kawaihae DEM. Flat-lying slopes are white; dark shading denotes steep slopes; USGS coastline in red.*

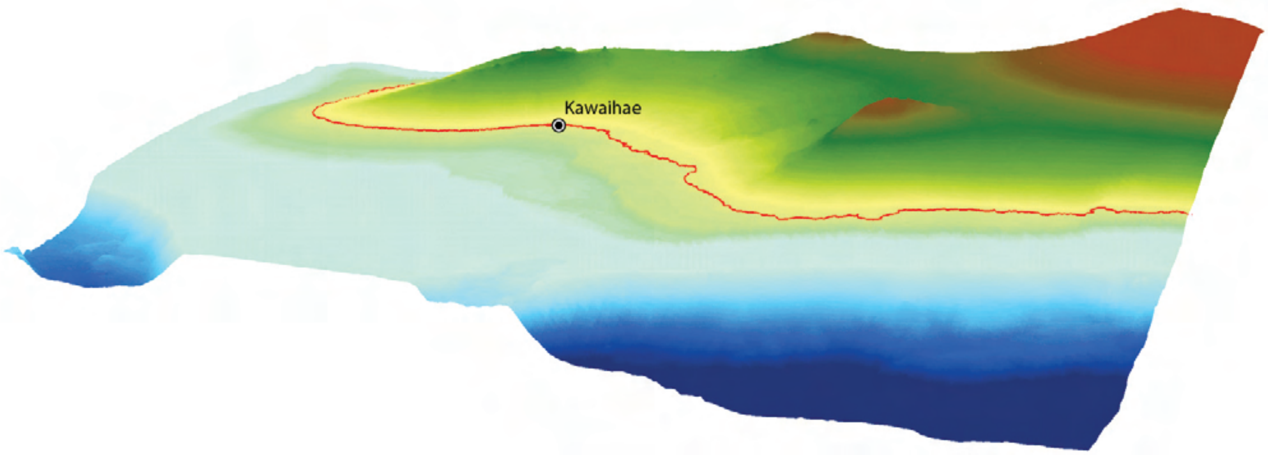

Figure 10. *Perspective view from the west of the Kawaihae DEM. USGS coastline in red; vertical exaggeration–times 3.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Kawaihae DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the difference between one NED file and the Kawaihae DEM is shown in Figure 11. Figure 12 shows a comparison between one NOS bathymetric survey and the Kawaihae DEM. Both show close agreement with the DEM, with the exception of areas where closely spaced values contribute to one elevation in the DEM. Significant discrepancies between some data values and the DEM resulted in reevaluation of the source data, further data editing and building of a revised DEM.

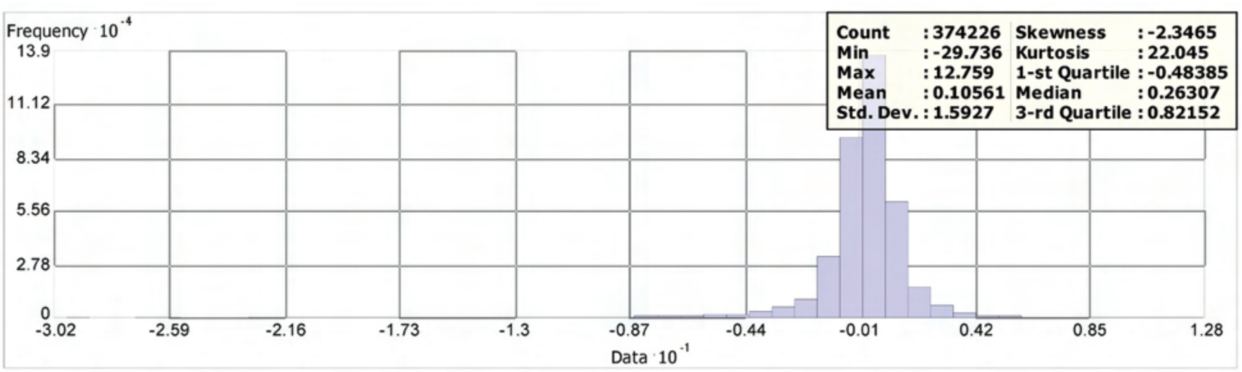

Figure 11. *Histogram of the differences between one file of the NED data and the Kawaihae DEM. The largest discrepancies resulted from the averaging of many closely spaced elevation values in regions of steep terrain.*

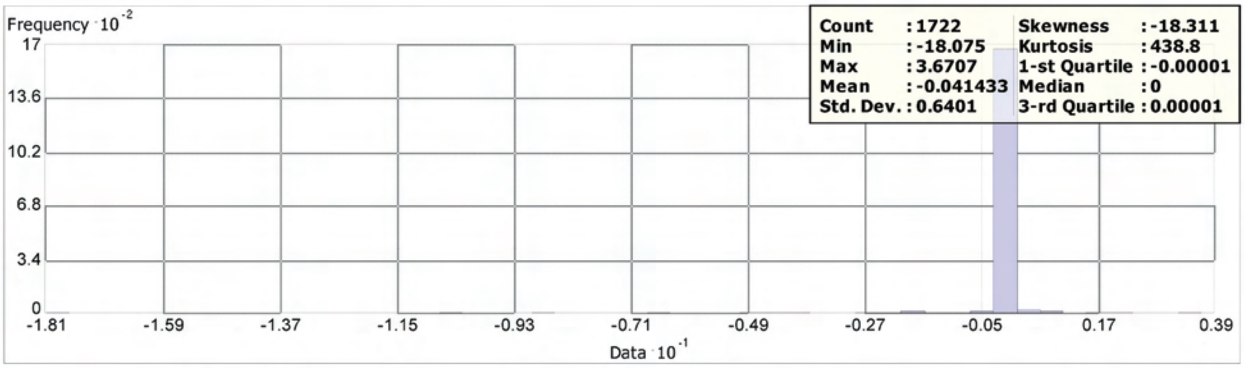

Figure 12. *Histogram of the differences between NOS survey #H09015 and the Kawaihae DEM.*

3.4.5 Comparison with NGS geodetic monuments

The elevations of 128 NOAA NGS geodetic monuments were extracted from online shape files of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD83 (sub-mm accuracy) and elevations in Local Tidal datums, which is assumed to be equivalent to MSL. Elevations were shifted to MHW vertical datum (see Table 6) for comparison with the Kawaihae DEM (see Fig. 14 for monument locations). Differences between the Kawaihae DEM and the NGS geodetic monument elevations range from -24 to 2,189 meters, with a positive value indicating that the DEM elevation value is greater than the monument elevation (Fig. 13). The largest offset of 2,189 meters corresponds to the NGS geodetic monument located on the western side of the summit of mount Hualalai. The corresponding datasheet of this monument provides an elevation of 311 meters (local tidal datum), and the coordinates indicate that the monument is only 600 meters away from the summit at 2,520 meters. Thus, the datasheet for this NGS monument gives an incorrect elevation. Further examination of the monuments with the largest offset revealed that these monuments were located along the coastline on man-made structures.

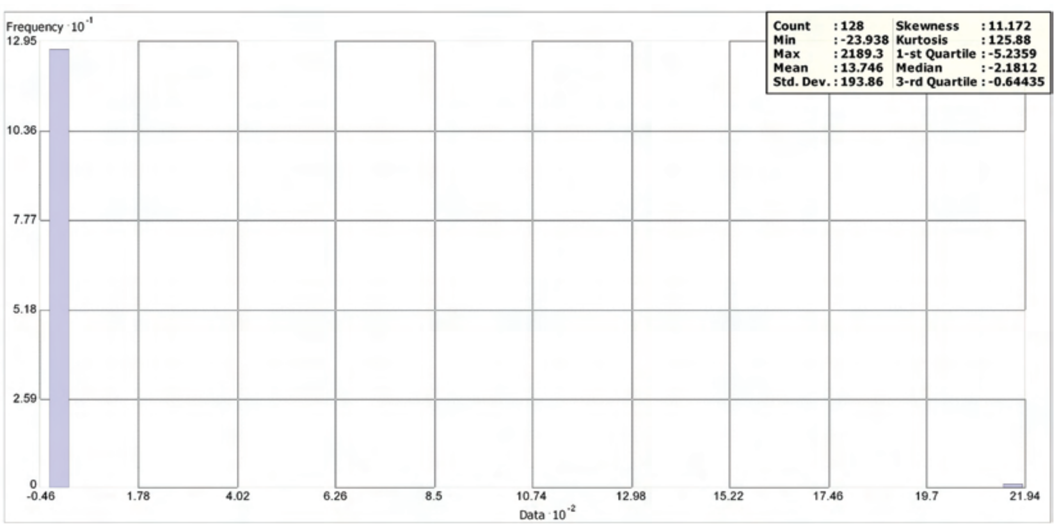

Figure 13. *Histogram of the differences between NGS geodetic monument elevations and the Kawaihae DEM.*

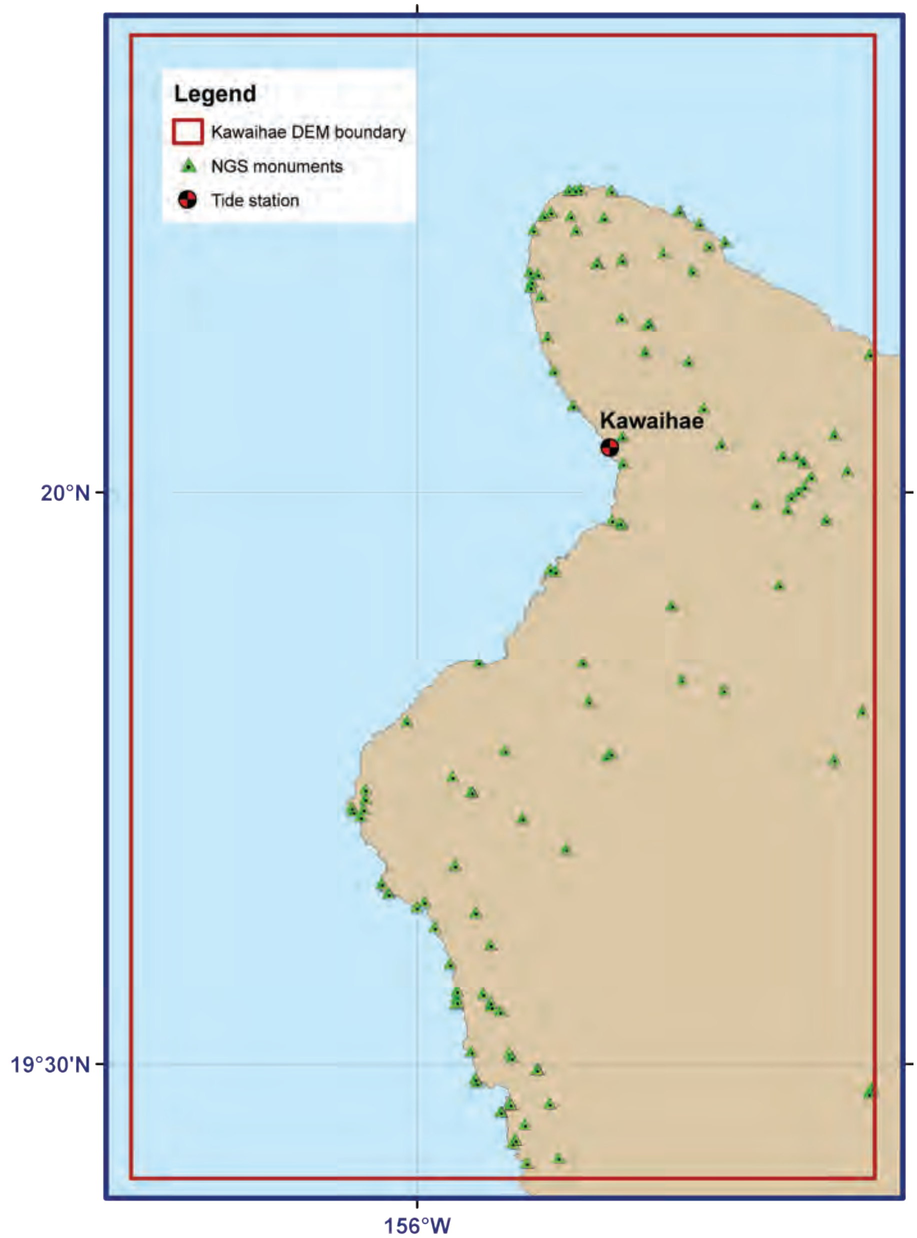

Figure 14. *Location of NGS monuments and NOAA tide station in the Kawaihae region. Tide station #1617433 was used to convert between vertical datums; NGS monument elevations were used to evaluate the Kawaihae DEM.*

4. Summary and Conclusions

A topographic–bathymetric digital elevation model of the Kawaihae, Hawaii region, with cell spacing 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 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, and MB-System software.

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

- Conduct topographic LiDAR surveys along the western coast of Hawaii.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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7. DATA PROCESSING SOFTWARE

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

Electronic Navigational Chart Data Handler for ArcView, developed by NOAA Coastal Services Center, http://www.csc.noaa.gov/products/enc/

FME 2006 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

GMT v. 4.1.4 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.1.0, 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/