NOAA Technical Memorandum NESDIS NGDC-38

DIGITAL ELEVATION MODELS OF EUREKA, CALIFORNIA: PROCEDURES, DATA SOURCES AND ANALYSIS

K.S. Carignan
L.A. Taylor
B.W. Eakins
R.R. Warnken
R.J. Caldwell
D.Z. Friday
E. Lim
P.R. Grothe

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
July 2010

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite, Data, and Information Service

NOAA Technical Memorandum NESDIS NGDC-38

DIGITAL ELEVATION MODELS OF EUREKA, CALIFORNIA: PROCEDURES, DATA SOURCES AND ANALYSIS

Kelly S. Carignan[1]
Lisa A. Taylor[2]
Barry W. Eakins[1]
Robin R. Warnken[2]
R. Jason Caldwell[1]
Dorothy Z. Friday[1]
Elliot Lim[1]
Pamela R. Grothe[1]

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

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

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
July 2010



UNITED STATES DEPARTMENT OF COMMERCE

Gary Locke
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. Jane Lubchenco
Under Secretary for Oceans and Atmosphere/Administrator

National Environmental Satellite, Data, and Information Service

Mary E. Kicza
Assistant Administrator

NOTICE

Mention of a commercial company or product does not constitute an endorsement by the NOAA National Environmental Satellite, Data, and Information Service. Use of information from this publication concerning proprietary products or the test of such products for publicity or advertising purposes is not authorized.

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

---

Also available from the National Technical Information Service (NTIS)
(http://www.ntis.gov)

Contents

1. Introduction 1
2. Study Area 2
3. Methodology 4
   - 3.1 Data Sources and Processing 5
     - 3.1.1 Shoreline 6
     - 3.1.2 Bathymetry 8
     - 3.1.3 Topography 19
   - 3.2 Establishing Common Datums 27
     - 3.2.1 Vertical datum transformations 27
     - 3.2.2 Horizontal datum transformations 27
   - 3.3 Digital Elevation Model Development 28
     - 3.3.1 Verifying consistency between datasets 28
     - 3.3.2 Smoothing of bathymetric data 28
     - 3.3.3 Building the NAVD 88 DEM 30
     - 3.3.4 Developing the MHW DEM 30
   - 3.4 Quality Assessment of the DEMs 33
     - 3.4.1 Horizontal accuracy 33
     - 3.4.2 Vertical accuracy 33
     - 3.4.3 Onsite assessment of MHW DEM 33
     - 3.4.4 Slope map, 3-D perspective, and data contribution plot 34
     - 3.4.5 Comparison with NGS geodetic monuments 37
     - 3.4.6 NAVD 88 comparison with source data files 38
4. Summary and Conclusions 40
5. Acknowledgments 40
6. References 40
7. Data Processing Software 41

List of Figures

Figure 1. Shaded-relief image of the Eureka NAVD 88 DEM 1
Figure 2. Overview of the Eureka, California region 2
Figure 3. Shaded-relief map of the Gorda Plate region offshore of northern California and southern Oregon 3
Figure 4. Source and coverage of datasets used in compiling the Eureka NAVD 88 DEM 5
Figure 5. Digital coastline datasets used in developing a combined coastline of the Eureka region 6
Figure 6. Comparison of ESRI *World 2D* imagery of the mouth of the Eel River with available coastline datasets 7
Figure 7. Spatial coverage of the bathymetric datasets used in compiling the Eureka NAVD 88 DEM 9
Figure 8. Digital NOS hydrographic survey coverage in the Eureka region 11
Figure 9. Spatial coverage of NGDC multibeam swath sonar surveys available in the Eureka region 13
Figure 10. Mendocino Ridge bathymetry 14
Figure 11. Spatial coverage of USACE survey data used in compiling the Eureka NAVD 88 DEM 15
Figure 12. Spatial coverage of CSUMB bathymetric survey data used in compiling the Eureka NAVD 88 DEM 16
Figure 13. Perspective views of CSUMB bathymetric survey data 17
Figure 14. Location of extracted soundings from the 1:25,000 scale ENC #18622 18
Figure 15. Spatial coverage of the topographic datasets used in compiling the Eureka NAVD 88 DEM 20
Figure 16. Spatial coverage of the CRWQCB DEMs 21

Figure 17. Perspective view of CSC lidar data looking south....22
Figure 18. Perspective view of northern portion of CSC lidar data....22
Figure 19. Perspective view of CSUMB lidar data at Humboldt Bay entrance....23
Figure 20. Perspective view of the GEON topographic lidar returns from water surface....24
Figure 21. Comparison of NED topographic DEM and satellite imagery....25
Figure 22. Location and ID of USACE control points....26
Figure 23. Spatial coverage of the *VDatum* transformation tool in the Eureka region....27
Figure 24. Histogram of the differences between pre-2008 NOS hydrographic surveys and the 1 arc-second pre-surfaced bathymetric grid....29
Figure 25. Histogram of the differences between the conversion grid and the xyz difference files using NOS hydrographic survey data....31
Figure 26. Histogram of the differences between the conversion grid and the xyz difference files using USACE hydrographic survey data....32
Figure 27. Image showing the water level differences at Fields Landing levee....33
Figure 28. Slope map of the Eureka NAVD 88 DEM....34
Figure 29. Perspective view from the southwest of the Eureka NAVD 88 DEM....35
Figure 30. Data contribution plot of the Eureka DEMs....36
Figure 31. Location of NGS geodetic monuments and NOAA tide stations....37
Figure 32. Histogram of the differences between NGS geodetic monument elevations and the Eureka NAVD 88 DEM....37
Figure 33. Histogram of the differences between pre-2008 NOS soundings and the Eureka NAVD 88 DEM....38
Figure 34. Histogram of the differences between all USACE survey elevations and the Eureka NAVD 88 DEM....38
Figure 35. Histogram of the differences between select CSUMB topographic lidar elevations and the Eureka NAVD 88 DEM....39
Figure 36. Histogram of the differences between select CSC topographic lidar elevations and the Eureka NAVD 88 DEM....39

List of Tables

Table 1. PMEL specifications for the Eureka DEMs....4
Table 2. Shoreline datasets used in developing the Eureka DEMs....6
Table 3. NOAA nautical charts available in the Eureka region....7
Table 4. Bathymetric datasets used in compiling the Eureka NAVD 88 DEM....8
Table 5. Digital NOS hydrographic surveys available in the Eureka region....10
Table 6. NGDC multibeam swath sonar surveys available in the Eureka region....12
Table 7. USACE bathymetric surveys used in compiling the Eureka NAVD 88 DEM....15
Table 8. Topographic datasets used in compiling the Eureka NAVD 88 DEM....19
Table 9. USACE control points for the Humboldt Bay jetties....26
Table 10. Relationship between NAVD 88 and other vertical tidal datums at North Spit, Humboldt Bay....27
Table 11. Data hierarchy used to assign gridding weight in *MB-System*....30

Digital Elevation Models of Eureka, California: Procedures, Data Sources and Analysis

1. Introduction

In November 2009, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed two integrated bathymetric–topographic digital elevation models (DEMs) of Eureka, California (Fig. 1). A 1/3 arc-second[1] DEM referenced to North American Vertical Datum of 1988 (NAVD 88) was carefully developed and evaluated. An NAVD 88 to mean high water (MHW) 1/3 arc-second conversion grid was then created to model the relationship between NAVD 88 and MHW in the Eureka region. A 1/3 arc-second MHW DEM, combining the NAVD 88 DEM and the conversion grid, will be used as input for the Method of Splitting Tsunami (MOST) model developed by Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov) to simulate tsunami generation, propagation and inundation. The NAVD 88 DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 4) and was shifted to MHW for tsunami inundation modeling, as part of the tsunami forecast system Short-term Inundation Forecasting for Tsunamis (SIFT) currently being developed by PMEL for the NOAA Tsunami Warning Centers. This report provides a summary of the data sources and methodology used in developing both Eureka DEMs.

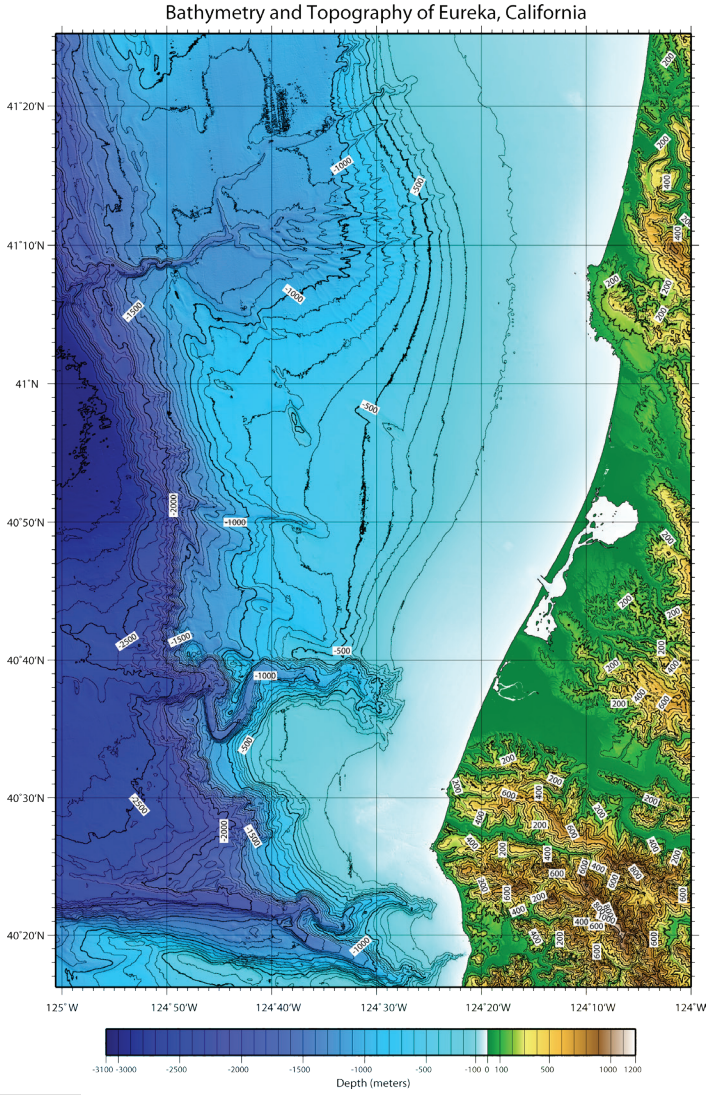


Figure 1. *Shaded-relief image of the Eureka NAVD 88 DEM. Contour interval is 100 meters.*

1. The Eureka DEMs are built upon a grid of cells that are square in geographic coordinates (latitiude and longitude), however, the cells are not square when converted to projected coordinate systems such as UTM zones (in meters). At the latitude of Eureka, California, (40°48' 07"N, 124°09'49"W) 1/3 arc-second of latitude is equivalent to 10.28 meters; 1/3 arc-second of longitude equals 7.81 meters.

2. Study Area

Eureka, California, is located in Humboldt County on the north coast of California between Cape Mendocino and south of the Oregon border. The DEM boundary encompasses the communities: Orick, Trinidad, McKinleyville, Arcata, and Eureka (Fig. 2). Eureka was originally established by gold miners in order to ship gold south to Sacramento. After the Gold Rush, Humboldt County's economy relied heavily on salmon fishing and the lumber industry. More recently, tourism has provided some economic recovery to the region. The Redwood National Park is located 40 miles north of Eureka along scenic Pacific Coast Highway 101. Humboldt State University, located in Arcata, hosts approximately 7,000 students yearly. The average resident population of Humboldt County is 26,000.

Located offshore on the western edge of the DEM is the southern end of the Cascadia Subduction Zone (CSZ). This region is where the Juan de Fuca plate to the north is subducted below the North American Plate to the east (Fig. 3). Plate movement here creates a highly seismic region putting the area at risk for not just earthquakes but for tsunamis or landslides. Closer to shore near the junction of the Gorda Plate and the Mendocino Ridge, steep submarine canyons have formed at the mouths of the Eel River and Mattole River and off Cape Mendocino.

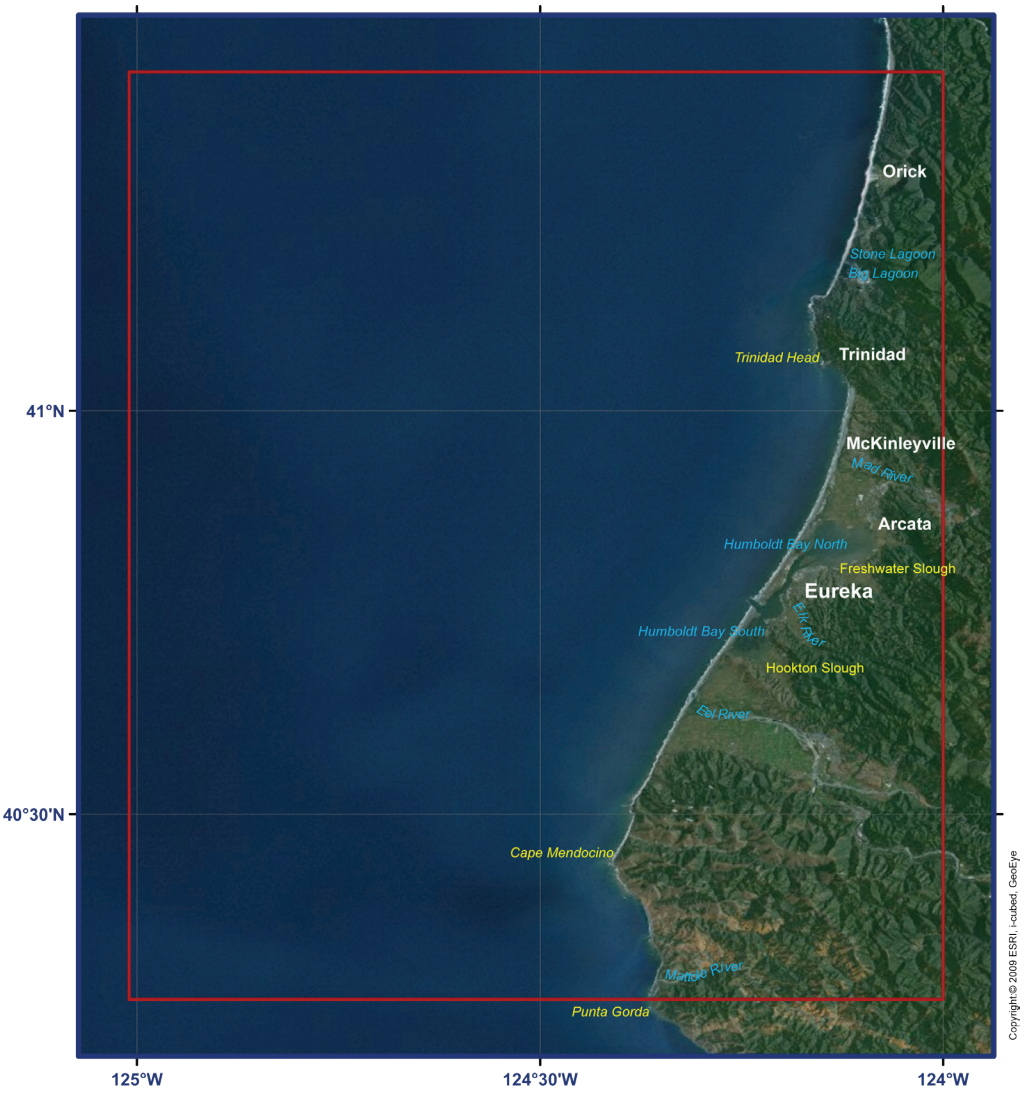


Figure 2. *Overview of the Eureka, California region. (Photo credit: ESRI, i-cubed, GeoEye)*

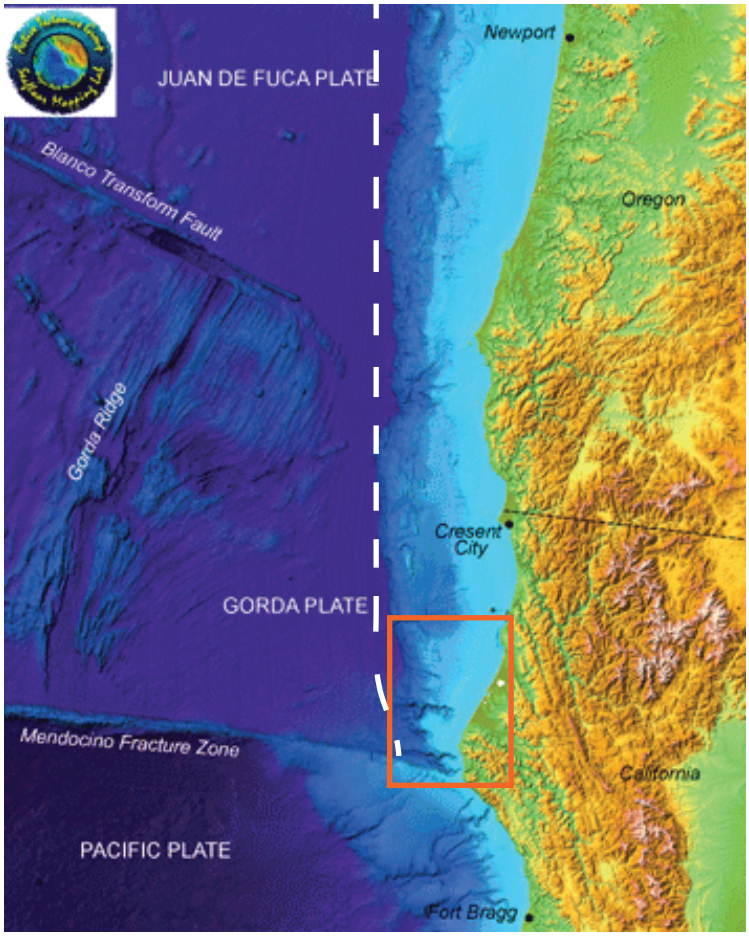


Figure 3. *Shaded-relief map of the Gorda plate region offshore of northern California and southern Oregon. Eureka DEM boundary shown as red box. Dashed white line is approximate location of Cascadia Subduction Zone. Map created by Jason Chaytor, OSU Active Tectonics Lab and Seafloor Mapping Lab, 2005.*

3. Methodology

The Eureka NAVD 88 and MHW DEMs were 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 Center use of SIFT to provide real-time tsunami forecasts in an operational environment. 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 geographic) and NAVD 88 then to MHW, for modeling of maximum flooding. Data were gathered in an area slightly larger (~5%) than the DEM extents. This data "buffer" ensures that gridding occurs 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 Eureka DEMs.

Eureka NAVD 88 DEM	
Grid Area	Eureka, California
Coverage Area	124.00º to 125.01º W; 40.27º to 41.42º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	North American Vertical Datum of 1988 (NAVD 88)
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

Eureka MHW DEM	
Grid Area	Eureka, California
Coverage Area	124.00º to 125.01º W; 40.27º to 41.42º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 1984 (WGS 84)
Vertical Datum	Mean high water (MHW)
Vertical Units	Meters
Cell Size	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

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

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 4) were obtained from several U.S. federal, state and local agencies, and academic institutions including: NGDC; NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) and Coastal Services Center (CSC); the California Department of Fish and Game (CDFG); the California State University Seafloor Mapping Laboratory (CSUMB); University of New Hampshire, Center for Coastal and Ocean Mapping, Joint Hydrographic Center (CCOM-JHC); the California Regional Water Quality Control Board North Coast Region (CRWQCB); the City of Arcata, California; the U.S. Army Corps of Engineers (USACE); the U.S. Geological Survey (USGS); and GEON's OpenTopography Portal. Safe Software's *FME* data translation tool package was used to shift datasets to NAD 83 geographic horizontal datum and to convert them into ESRI *ArcGIS* shapefiles[3]. The shapefiles were then displayed with *ArcGIS* and Applied Imagery's *Quick Terrain Modeler* (*QT Modeler*) to assess data quality and manually edit datasets. Vertical datum transformations to NAVD 88 were accomplished using the *VDatum* transformation tool. ESRI's online *World 2D* imagery was used to analyze and modify data. *QT Modeler* and Interactive Visualization System's *Fledermaus* software were used to evaluate processing and gridding techniques.

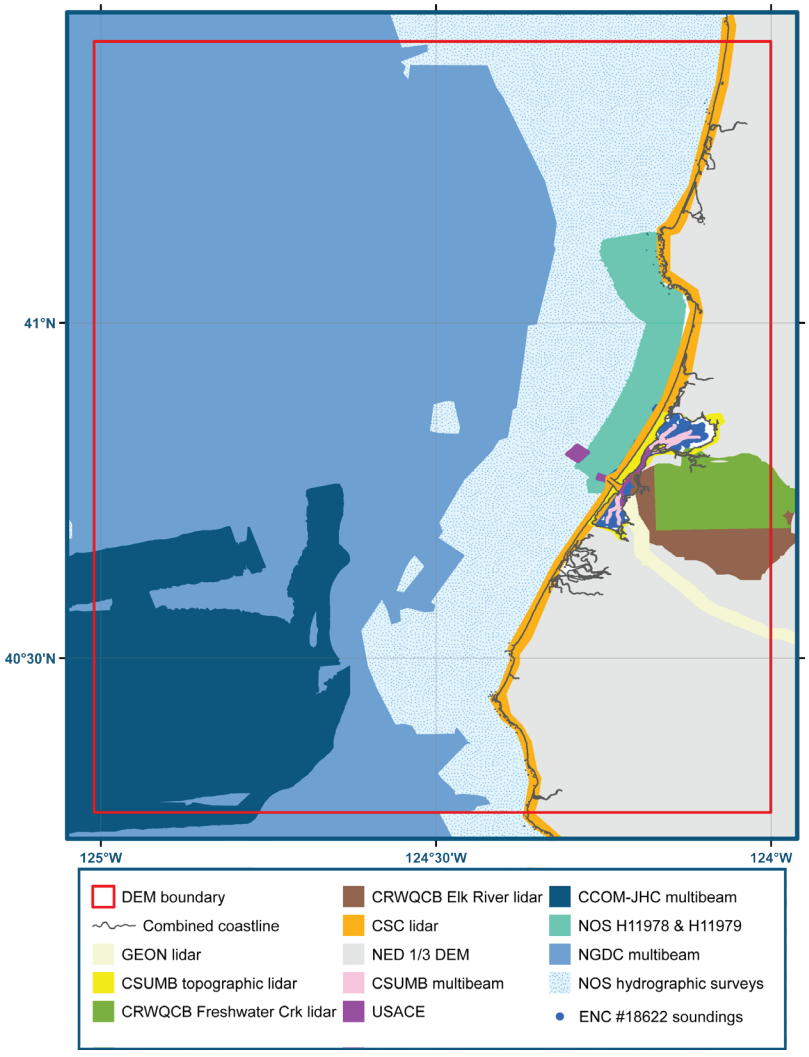


Figure 4. *Source and coverage of datasets used in compiling the Eureka NAVD 88 DEM.*

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 geographic to NAD 83 geographic. NADCON is the U.S. Federal Standard for NAD 27 geographic to NAD 83 geographic datum transformations.

3.1.1 Shoreline

Coastline datasets of the Eureka region were obtained from NOAA's OCS as Electronic Navigational Charts (ENCs)[4] and from CDFG's Marine Region GIS Unit (Table 2; Fig. 5). These two datasets were used to develop a "combined coastline" of the Eureka region.

Table 2: Shoreline datasets used in developing the Eureka DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS	2009	ENC	1:25,000	WGS 84 geographic	MHW	http://w1.nauticalcharts.noaa.gov/mcd/enc
CDFG	1996	Digitzed 1:24,000 USGS quads	1:24,000	NAD 83 geographic	Mean high tide	http://bios.dfg.ca.gov

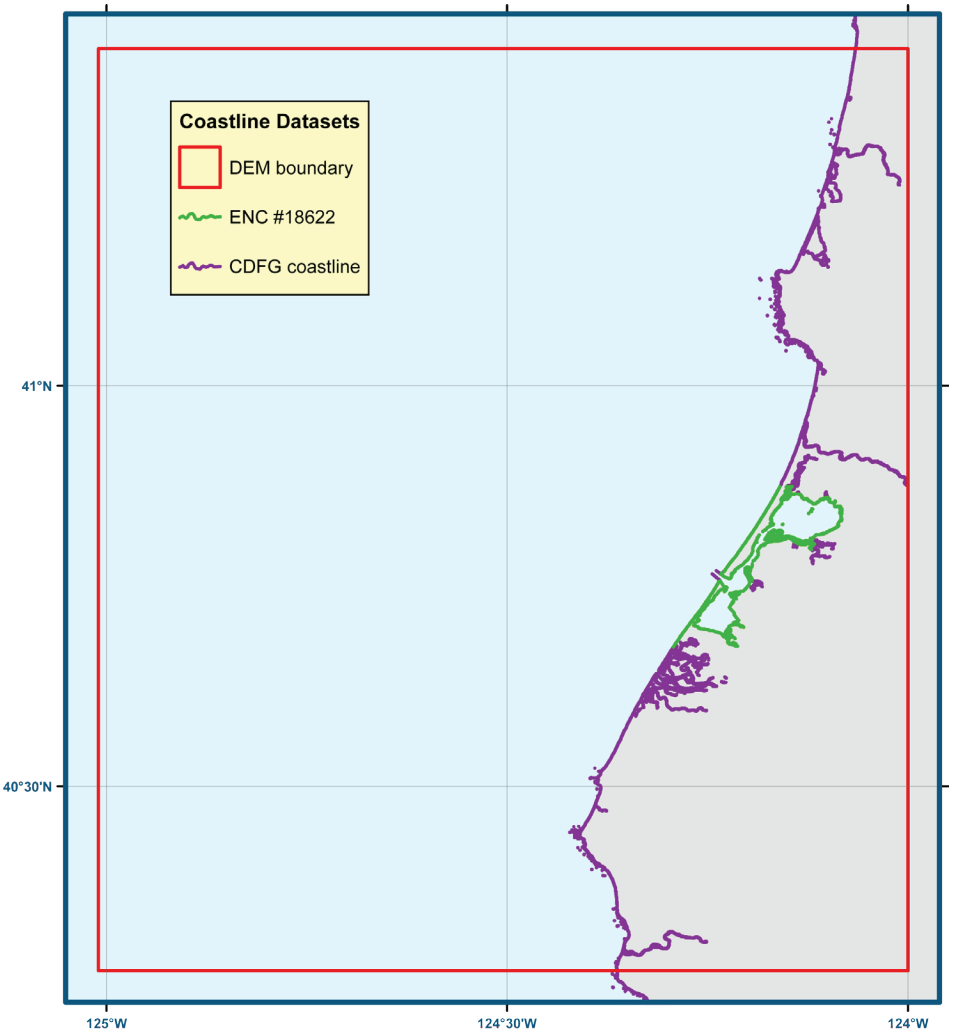


Figure 5. *Digital coastline datasets used in developing a combined coastline of the Eureka region.*

4. The Office of Coast Survey (OCS) produces NOAA Electronic Navigational Charts (NOAA ENC®) to support the marine transportation infrastructure and coastal management. NOAA ENC®s are in the International Hydrographic Office (IHO) S-57 international exchange format, comply with the IHO ENC Product Specification and are provided with incremental updates, which supply Notice to Mariners corrections and other critical changes. NOAA ENC®s are available for free download on the OCS web site. [Extracted from NOAA OCS web site: http://nauticalcharts.noaa.gov/mcd/enc/]

1) Office of Coast Survey extracted Electronic Navigational Chart coastline

Three ENCs were available for the Eureka area (Table 3) and downloaded from NOAA's OCS web site. The ENCs are in S-57 format and include coastline data referenced to MHW. The coastline shapefiles were extracted from ENCs #18600, 18620, and 18622 using *ArcCatalog* and compared to large-scale RNCs and ESRI's *World 2D* imagery. Only the large scale ENC #18622 coastline was used. The extracted coastline was merged with the CDFG coastline using *ArcCatalog* and used to create a "combined coastline" of the Eureka region.

Table 3: NOAA nautical charts available in the Eureka region.

Chart	*Title*	*Format*	*Edition*	*Issue Date*	*Scale*
18600	Trinidad Head to Cape Blanco	ENC and RNC	9	2009	1:196,948
18605	Trinidad Harbor	RNC	12	2009	1:15,000
18620	Point Arena to Trinidad Head	ENC and RNC	23	2009	1:200,000
18622	Humboldt Bay	ENC and RNC	54	2009	1:25,000
18623	Cape Mendocino and Vicinity	RNC	11	2009	1:40,000

2) California Department of Fish and Game vector shoreline

The CDFG coastline was originally developed by the California State Land Commission from digitized USGS 7.5' quads to define the mean high tide line and was subsequently rebuilt to reduce tolerances by the CDFG in 1996.

The "combined coastline" was modified to include large offshore rocks and small islets shown on the larger-scale RNCs and clipped to 0.05 degrees larger than the DEM boundary. Piers and docks within Humboldt Bay were deleted from the coastline. The coastline was further modified based on *World 2D* imagery to reflect the most current coastal morphology, particularly at the mouth of the Eel River (Fig. 6) and the Mad River. An xyz file of the "combined coastline" with points every 10 meters was generated using NGDC's *GEODAS* software for use in creating a bathymetric surface (see Sec. 3.3.2).

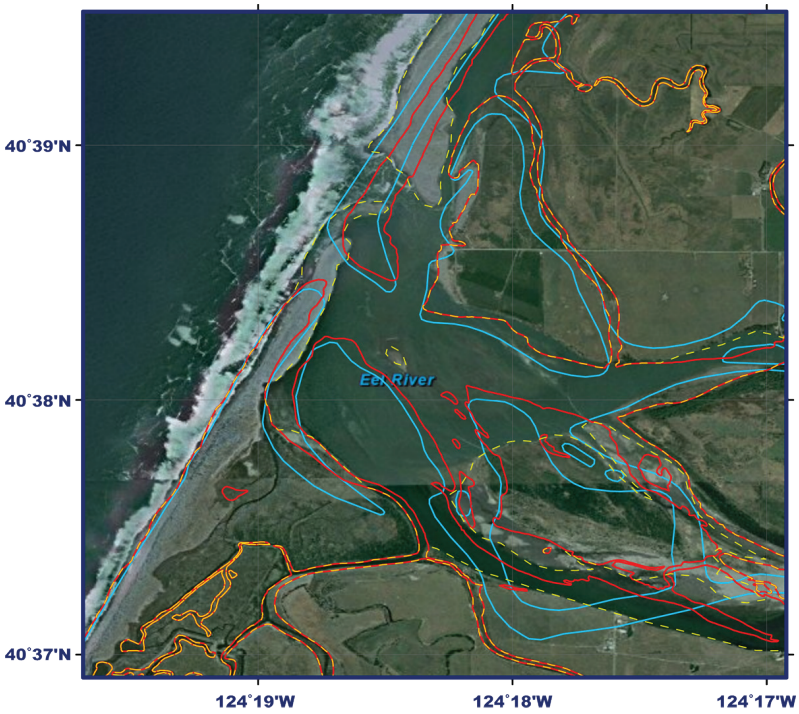


Figure 6. *Comparison of ESRI World 2D imagery of the mouth of the Eel River with available coastline datasets. ENC #18620 coastline in blue, CDFG coastline in red, and edited combined coastline used in building the Eureka DEMs shown as yellow dashed line.*

3.1.2 Bathymetry

Bathymetric datasets available for use in the compilation of the Eureka DEM include 24 NOS hydrographic surveys; multibeam surveys downloaded from the NGDC multibeam database; a recent multibeam swath sonar survey from CCOM-JHC; hydrographic surveys from USACE; multibeam surveys from CSUMB; and soundings extracted from an ENC (Table 4; Fig. 7).

Table 4: Bathymetric datasets used in compiling the Eureka NAVD 88 DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NGDC	1921 to 2008	NOS hydrographic survey soundings	Ranges from less than 10 meters to 600 meters (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 83 geographic	MLLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC	1984 to 2006	Multibeam swath sonar	Gridded to 1 arc-second	WGS 84 geographic	Assumed mean sea level	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
CCOM-JHC	2009	Multibeam swath sonar	40 meter grid	WGS 84 geographic	Inferred mean sea level	http://www.ccom-jhc.unh.edu
USACE	2009	Hydrographic survey		NAD 83 California State Plane I (feet)	MLLW	http://www.spn.usace.army.mil/hydrosurvey_2
CSUMB	2005	Multibeam swath sonar	1 meter grid	WGS 84 UTM 10 North	NAVD 88	http://seafloor.csumb.edu
OCS	1992 to 2008	ENC extracted soundings		WGS 84 geographic	MLLW	http://www.nauticalcharts.noaa.gov/staff/chartspubs.html

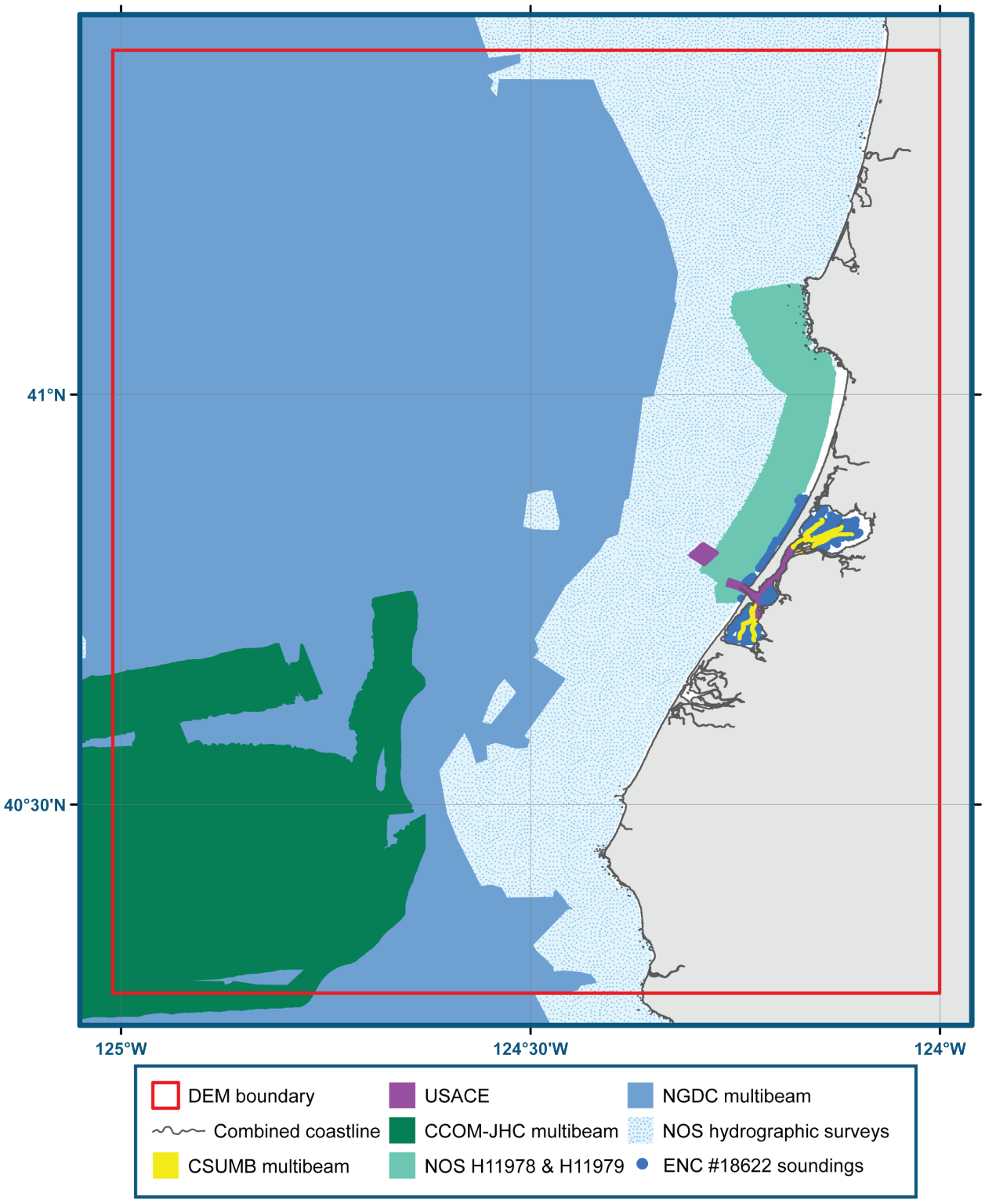


Figure 7. *Spatial coverage of the bathymetric datasets used in compiling the Eureka NAVD 88 DEM.*

1) NOS hydrographic survey data

A total of 24 NOS hydrographic surveys conducted between 1921 and 2008 were available for use in developing the Eureka DEM. Surveys were extracted from NGDC's online NOS hydrographic database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) except for surveys H11978 and H11979. The downloaded hydrographic survey data[5] were vertically referenced to mean lower low water (MLLW) and horizontally referenced to NAD 83 geographic. H11919 was horizontally referenced to NAD 83 UTM Zone 10N. H11978 and H11979 were provided to NGDC by Brooke McMahon at the NOS Pacific Hydrographic Branch (PHB) in xyz format and referenced to NAD 83 UTM Zone 10N and MLLW. Twenty-three of the 24 surveys were used in building the Eureka DEM, as H06163 has been superseded (Table 5; Fig. 8).

Data point spacing for the NOS surveys varied by scale. In general, small scale surveys had greater point spacing than large scale surveys. The data were converted to shapefiles 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 (~5%) larger than the Eureka DEM area to support data interpolation along grid edges.

After converting all NOS survey data to NAVD 88 using the *VDatum* transformation tool (see Sec. 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to other bathymetric datasets, the combined coastline, and NOS Raster Nautical Charts (RNCs). Older surveys were clipped to remove soundings that have been superseded by more recent NOS surveys, USACE surveys, and multibeam data.

Table 5: Digital NOS hydrographic surveys available in the Eureka region.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum†*
H04186	1921	40,000	MLLW	Undetermined
H04216	1921	40,000	MLLW	Undetermined
H04848	1928	20,000	MLLW	NAD 13 geographic
H04852	1928-1929	40,000	MLLW	NAD 13 geographic
H04874	1928	120,000	MLLW	NAD 13 geographic
H04966	1929	20,000	MLLW	NAD 13 geographic
H04967	1929	20,000	MLLW	NAD 13 geographic
H04997	1929	10,000	MLLW	NAD 13 geographic
H06163*	1936	10,000	MLLW	NAD 27 geographic
H06164	1936	10,000	MLLW	NAD 27 geographic
H06222	1937	10,000	MLLW	NAD 27 geographic
H06221	1938	40,000	MLLW	NAD 27 geographic
H06320	1938	10,000	MLLW	NAD 27 geographic
H06406	1937	20,000	MLLW	NAD 27 geographic
H06407	1938	10,000	MLLW	NAD 27 geographic
H06415	1940	40,000	MLLW	NAD 27 geographic
H06416	1938	10,000	MLLW	NAD 27 geographic
H06420	1938	10,000	MLLW	NAD 27 geographic
H06422	1938	120,000	MLLW	NAD 27 geographic
H06606	1940	40,000	MLLW	NAD 27 geographic
H06621	1940	10,000	MLLW	NAD 27 geographic
H11919	2008	10,000	MLLW	NAD 83 UTM zone 10N
H11978	2008	2 meter	MLLW	NAD 83 UTM zone 10N
H11979	2008	2 meter	MLLW	NAD 83 UTM zone 10N

* superceded survey not used in building the Eureka NAVD 88 DEM
† digitized datum recorded as NAD 83 geographic or unknown

5. *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 NOS hydrographic survey data from NAD 27 geographic to NAD 83 geographic. NADCON is the U.S. Federal Standard for NAD 27 geographic to NAD 83 geographic datum transformations.

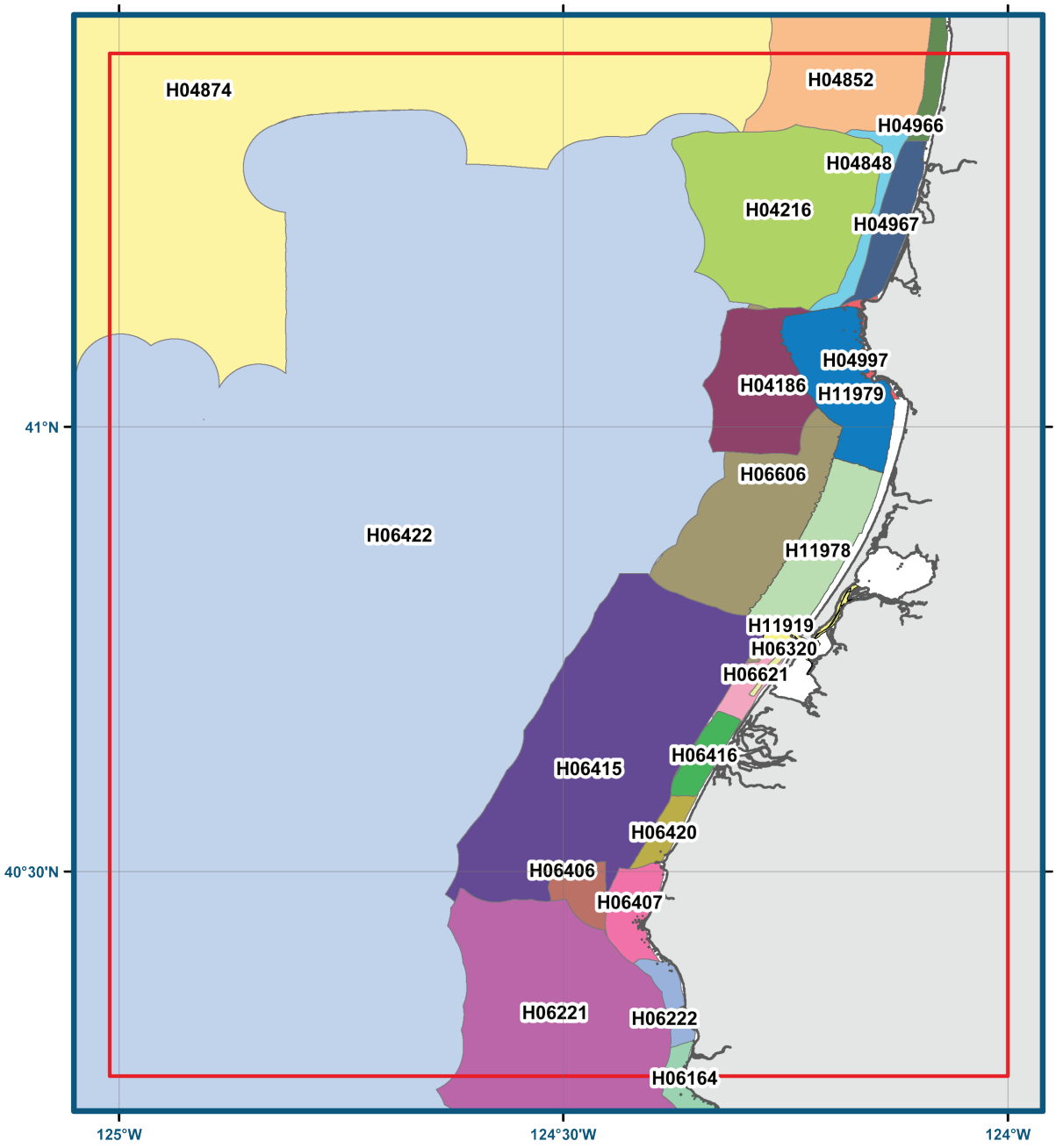


Figure 8. *Digital NOS hydrographic survey coverage in the Eureka region. Some older surveys were not used as they have been superseded by more recent surveys. DEM boundary in red.*

2) NGDC multibeam swath sonar surveys

Thirty-seven multibeam swath sonar surveys were downloaded from the NGDC multibeam bathymetry database (Fig. 9; Table 6). The downloaded data are referenced to WGS 84 geographic horizontal datum and are assumed to be in essentially mean sea level (MSL) vertical datum. The data were gridded using *MB-System*[6] at 1 arc-second and viewed in *QT Modeler* for quality analysis. Editing was done using *QT Modeler* and *ArcMap* to eliminate errors where survey data overlapped. The grid was then converted to xyz format and the elevations were transformed from MSL to NAVD 88 using *VDatum* for use in the final gridding process.

Table 6: NGDC multibeam swath sonar survey available in the Eureka region.

Survey ID	*Date*	*Institution*	*Ship*
AT07L14	2002	Woods Hole Oceanographic Institution (WHOI)	Atlantis
AT11L33	2005	WHOI	Atlantis
AT15L07	2006	WHOI	Atlantis
AT15L11	2006	WHOI	Atlantis
AVON08MV	1999	University of California, Scripps Institution of Oceanography (SIO)	Melville
AVON09MV	1999	SIO	Melville
AVON10MV	1999	SIO	Melville
AVON11MV	1999	SIO	Melville
AVON12MV	1999	SIO	Melville
B00001	1984	NOAA	Surveyor
B00004	1984	NOAA	Davidson
B00005	1984	NOAA	Surveyor
B00032	1985	NOAA	Surveyor
B00033	1985	NOAA	Surveyor
B00127	1988	NOAA	Davidson
B00132	1988	NOAA	Davidson
CNTL04RR	2003	SIO	Roger Revelle
DI-95-03	1995	NOAA	Discoverer
DRFT01RR	2001	SIO	Roger Revelle
Eel-riv	1998	Monterey Bay Aquarium Research Institute (MBARI)	Ocean Alert
EW0209	2002	Lamont-Doherty Earth Observatory (LDEO)	Maurice Ewing
EW9407	1994	LDEO	Maurice Ewing

6. *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 (LDEO) and is now a collaborative effort between the Monterey Bay Aquarium Research Institute (MBARI) and LDEO. 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.]

Survey ID	*Date*	*Institution*	*Ship*
EW9408	1994	LDEO	Maurice Ewing
EW9414	1994	LDEO	Maurice Ewing
EW9504	1995	LDEO	Maurice Ewing
EW9505	1995	LDEO	Maurice Ewing
EW9905	1999	LDEO	Maurice Ewing
HLY03TA	2003	LDEO	USCGC Healy
LWAD99MV	1999	SIO	Melville
Mfz	1998	MBARI	Ocean Alert
NECR01RR	2000	SIO	Roger Revelle
Pioneer	1998	MBARI	Ocean Alert
RB9702	1997	NOAA	Ronald Brown
REM-01MV	1993	SIO	Melville
SO108	1996	University of Kiel, Germany, GEOMAR Forshungszentrum (GEOMAR)	Sonne
SU-95-02	1995	NOAA	Surveyor
Tran2sou	1998	MBARI	Ocean Alert

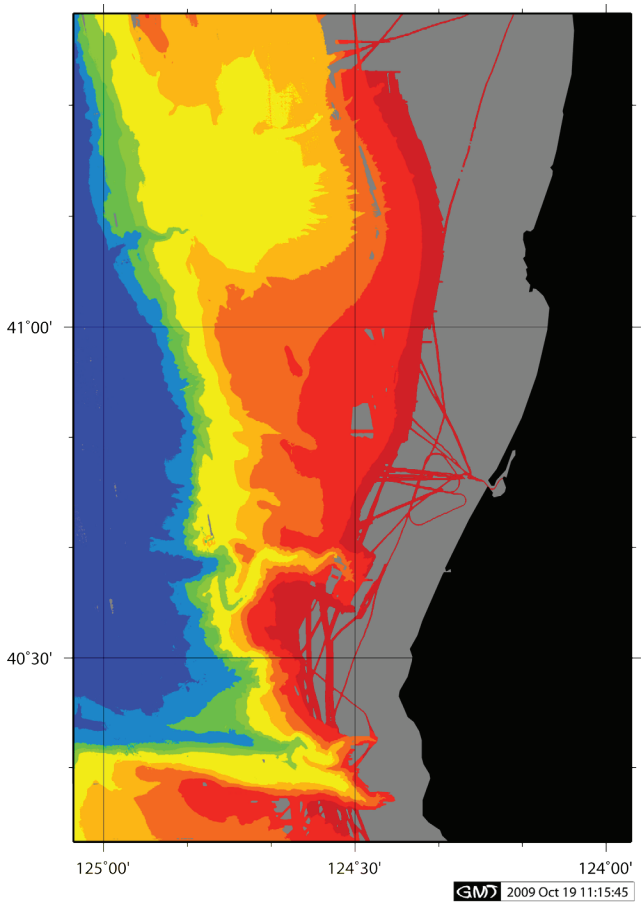


Figure 9. *Spatial coverage of swath sonar NGDC multibeam surveys available in the Eureka region. Reds indicate shallow depths and blues, deeper depths.*

3) University of New Hampshire, CCOM-JHC multibeam swath sonar survey

A 2009 multibeam swath sonar survey of the eastern portion of the Mendocino Ridge was downloaded from the CCOM-JHC web site. Only the far eastern portion of the survey, shown in Figure 10, was located within the Eureka DEM boundary. The survey data were downloaded as a 40 meter grid and converted to xyz format and transformed from inferred MSL to NAVD 88 using *VDatum*. The resulting xyz data file was visually quality checked in *QT Modeler* and used in the final gridding process.

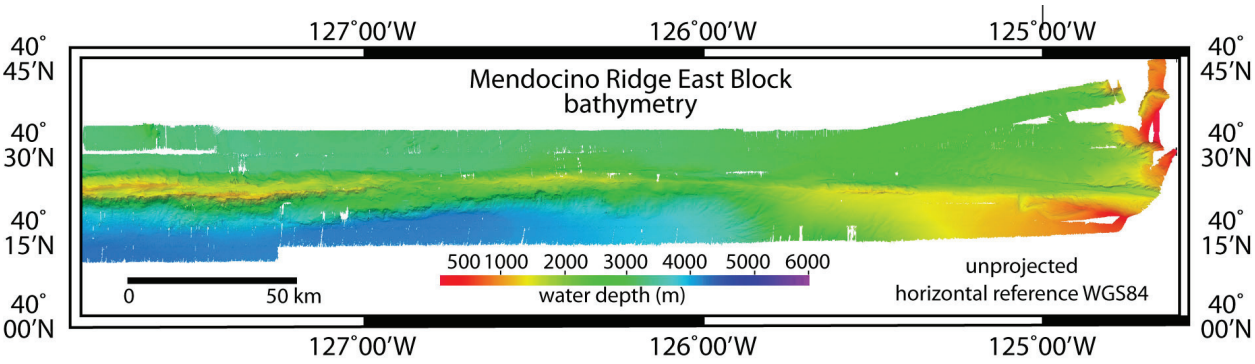


Figure 10. *Mendocino Ridge bathymetry. Image taken from UNH CCOM-JHC web site.*

4) U.S. Army Corps of Engineers Hydrographic surveys

Four channel line surveys and one offshore survey in xyz format were downloaded from the USACE San Francisco region web site (Fig. 11). These surveys, referenced to NAD 83 California State Plane I (feet) and MLLW were transformed to NAVD 88 using *VDatum* and transformed to NAD 83 geographic in shapefile format using *FME*. No current survey file was online for Eureka Channel so a 2005 survey available from CSUMB was used and processed similarly.

Table 7: USACE bathymetric surveys used in compiling the Eureka NAVD 88 DEM.

Survey name	*Date*	*Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*
Bar Entrance	2009	Channel line survey spacing ~40 meters apart with ~5 meter point spacing	NAD 83 California State Plane I (feet)	MLLW
Eureka Channel	2005	Channel line survey spacing ~30 meters apart with ~3 meter point spacing	WGS 84 UTM Zone 10	NAVD 88
Fields Landing	2009	Channel line survey spacing ~30 meters apart with ~5 meter point spacing	NAD 83 California State Plane I (feet)	MLLW
Hoods	2009	Offshore survey spacing ~90 meters apart with ~10 meter point spacing	NAD 83 California State Plane I (feet)	MLLW
North Bay	2009	Channel line survey spacing ~30 meters apart with ~5 meter point spacing	NAD 83 California State Plane I (feet)	MLLW
Samoa	2009	Channel line survey spacing ~30 meters apart with ~5 meter point spacing	NAD 83 California State Plane I (feet)	MLLW

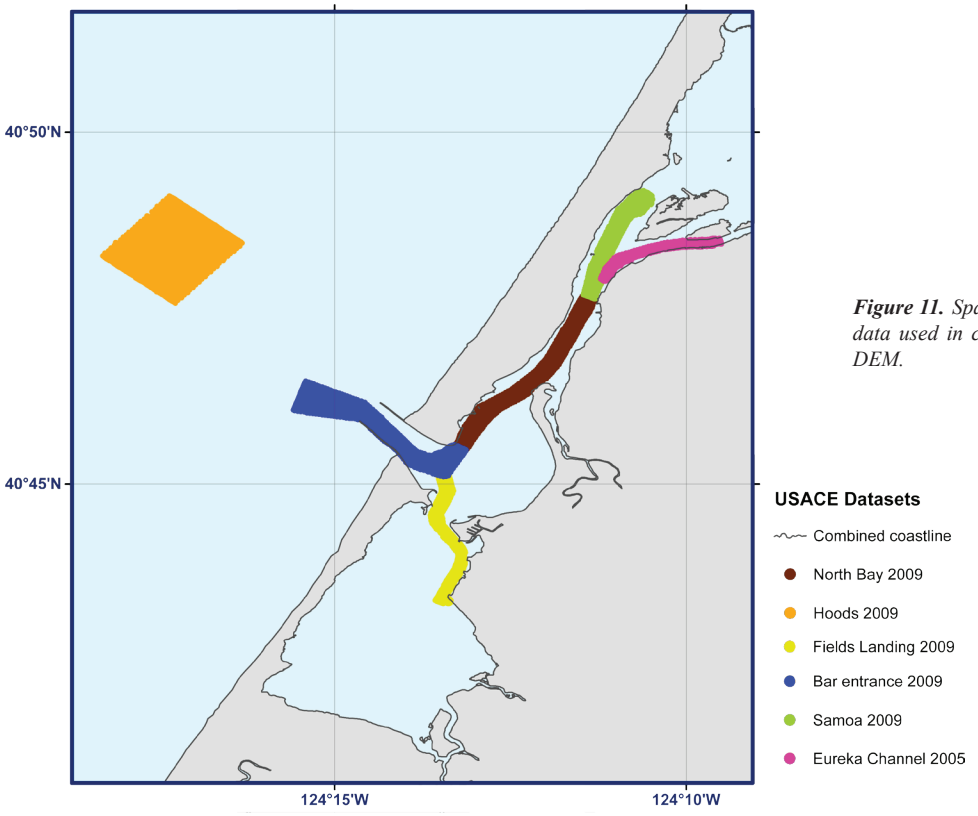


Figure 11. *Spatial coverage of USACE survey data used in compiling the Eureka NAVD 88 DEM.*

5) California State University at Monterey Bay multibeam swath sonar surveys

As part of a benthic mapping and bottom characterization of Humboldt Bay through the Center for Integrative Coastal Observation, Research, and Education (CICORE) partnership, CSUMB conducted multibeam and single beam sonar surveys in 2005. Data used in this study were acquired, processed, archived, and distributed by CSUMB. Two xyz files, one of the north bay and one of the south bay as shown in Figure 12, of 1 meter gridded bathymetric data were downloaded from CSUMB, horizontally referenced to WGS 84 UTM Zone 10 North and vertically referenced to NAVD 88. Horizontal transformations were done using *FME*. Figure 13 shows perspective views of the two surveys with deposition waves visible in both areas.

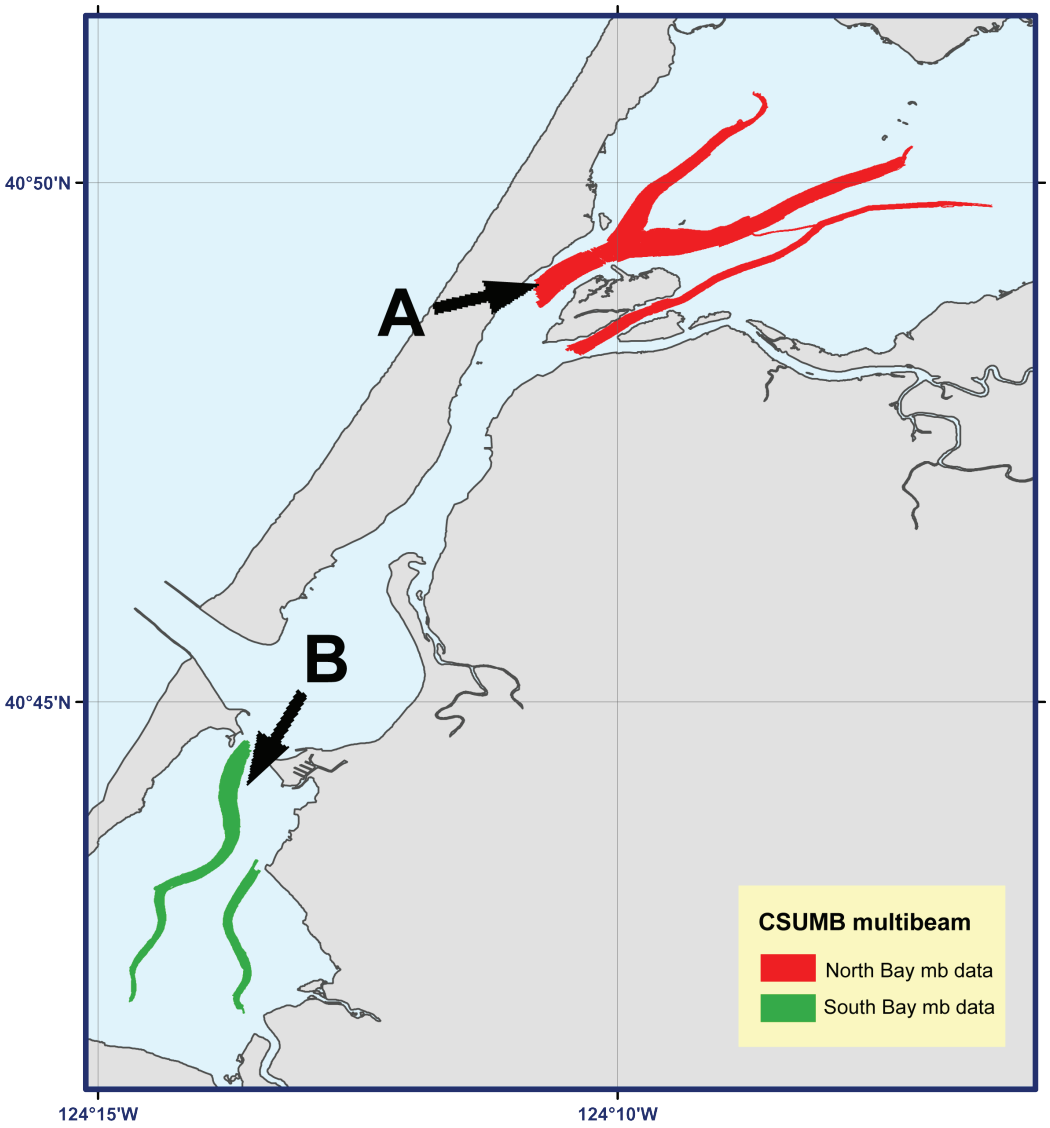


Figure 12. *Spatial coverage of CSUMB bathymetric survey data used in compiling the Eureka NAVD 88 DEM. Arrows reference Figure 13.*

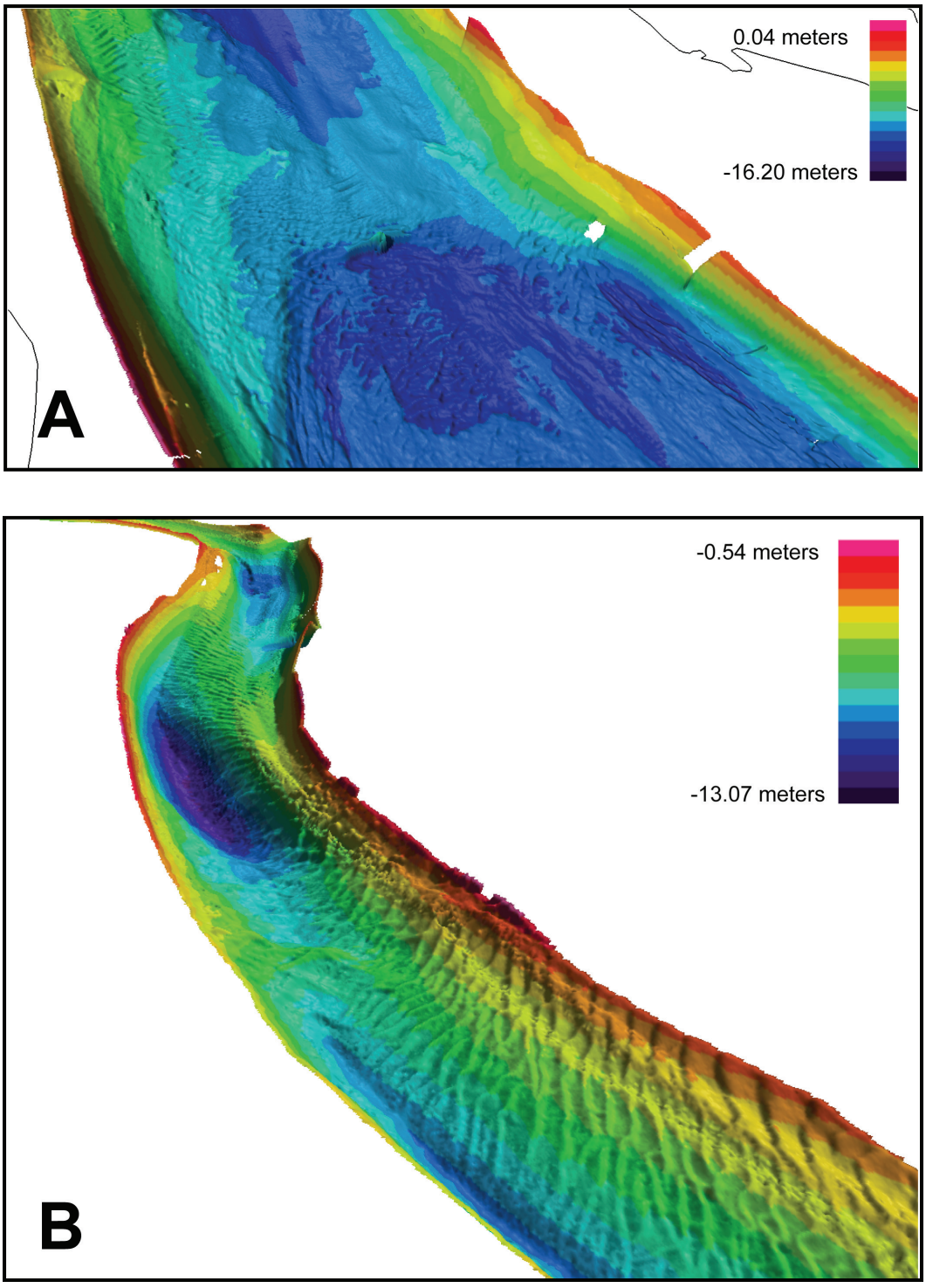


Figure 13. *Perspective views of CSUMB bathymetric survey data. A) View looking north up channel. B) View looking south from entrance channel.*

6) Electronic Navigation Chart soundings

Soundings from ENC#18622 were used to supplement the other bathymetric data within the bay, up the smaller river channels in the bay, and just along the shoreline north of the jetty entrance (Fig. 14, Table 3). The extracted soundings were transformed from MLLW to NAVD 88 using *VDatum*.

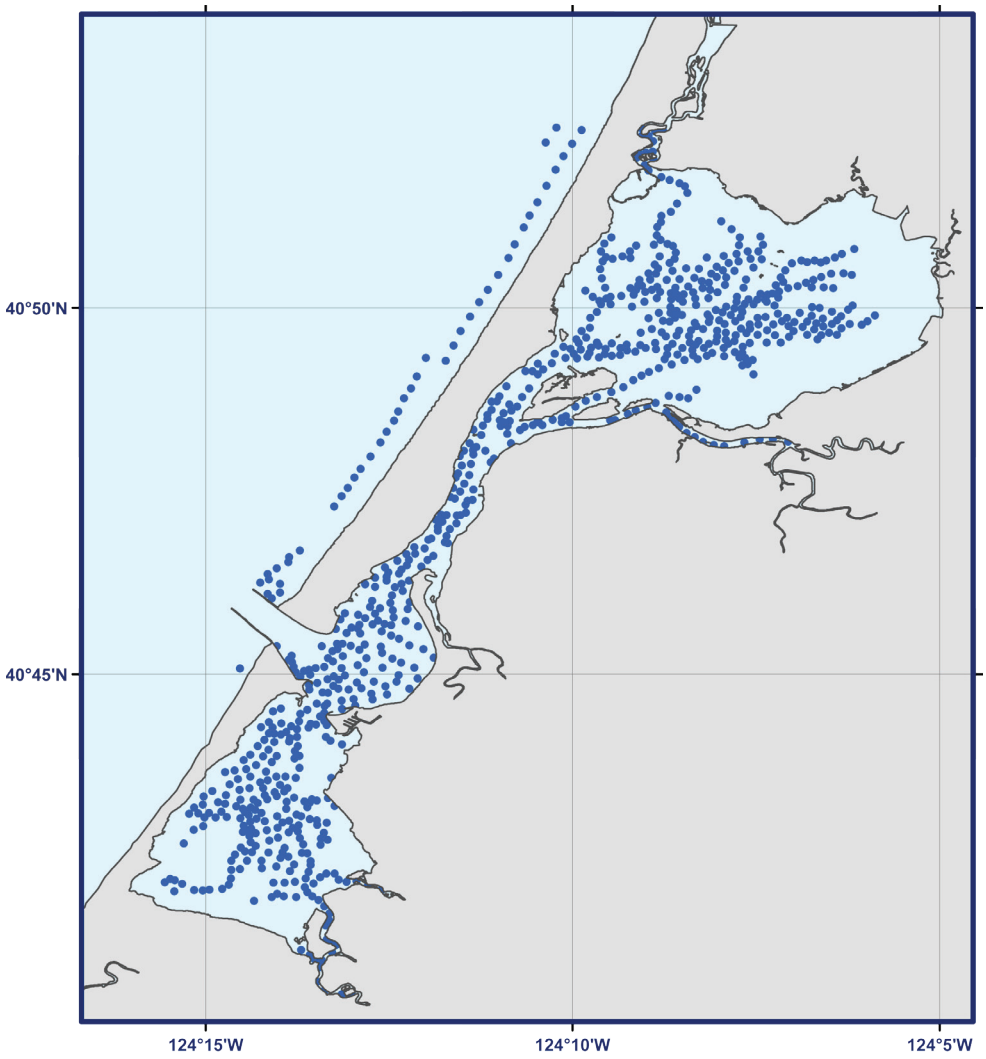


Figure 14. *Location of extracted soundings from the 1:25,000 scale ENC #18622.*

3.1.3 Topography

Five topographic datasets in the Eureka region, obtained from the California Regional Water Quality Control Board, North Coast Region (CRWQCB); CSC; CSUMB; GEON; and USGS, were used to build the Eureka NAVD 88 DEM (Table 8; Fig. 15). In addition, NGDC digitized elevation points along the length of the Humboldt Bay jetties as they were not resolved completely in the other topographic datasets. Data provided to NGDC from the City of Arcata was reviewed but not used in building the NAVD 88 DEM as higher resolution data overlapped the data coverage area.

Table 8: Topographic datasets used in compiling the Eureka NAVD 88 DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
CRWQCB	2005	Bare earth DEM	<2 meter grid	NAD 83 UTM zone 10	NAVD 88	http://www.waterboards.ca.gov/northcoast
CSC Lidar	2002	FLT	~2 meter grid	NAD 83 geographic	NAVD 88	http://www.csc.noaa.gov
CSUMB EarthData	2002	Bare earth DEM	5 meter grid	WGS 84 UTM zone 10 north	NAVD 88	http://seafloor.csumb.edu
GEON Lidar	2007	DEM	1 meter	WGS 84 UTM zone 10 north	Ellipsoid ITRF 2000	http://www.opentopography.org
USGS NED	1999	Topographic DEM	1/3 arc-second	NAD 83 geographic	NAVD 88	http://seamless.usgs.gov
NGDC		Digitized points	10 meters	WGS 84 geographic	NAVD 88	

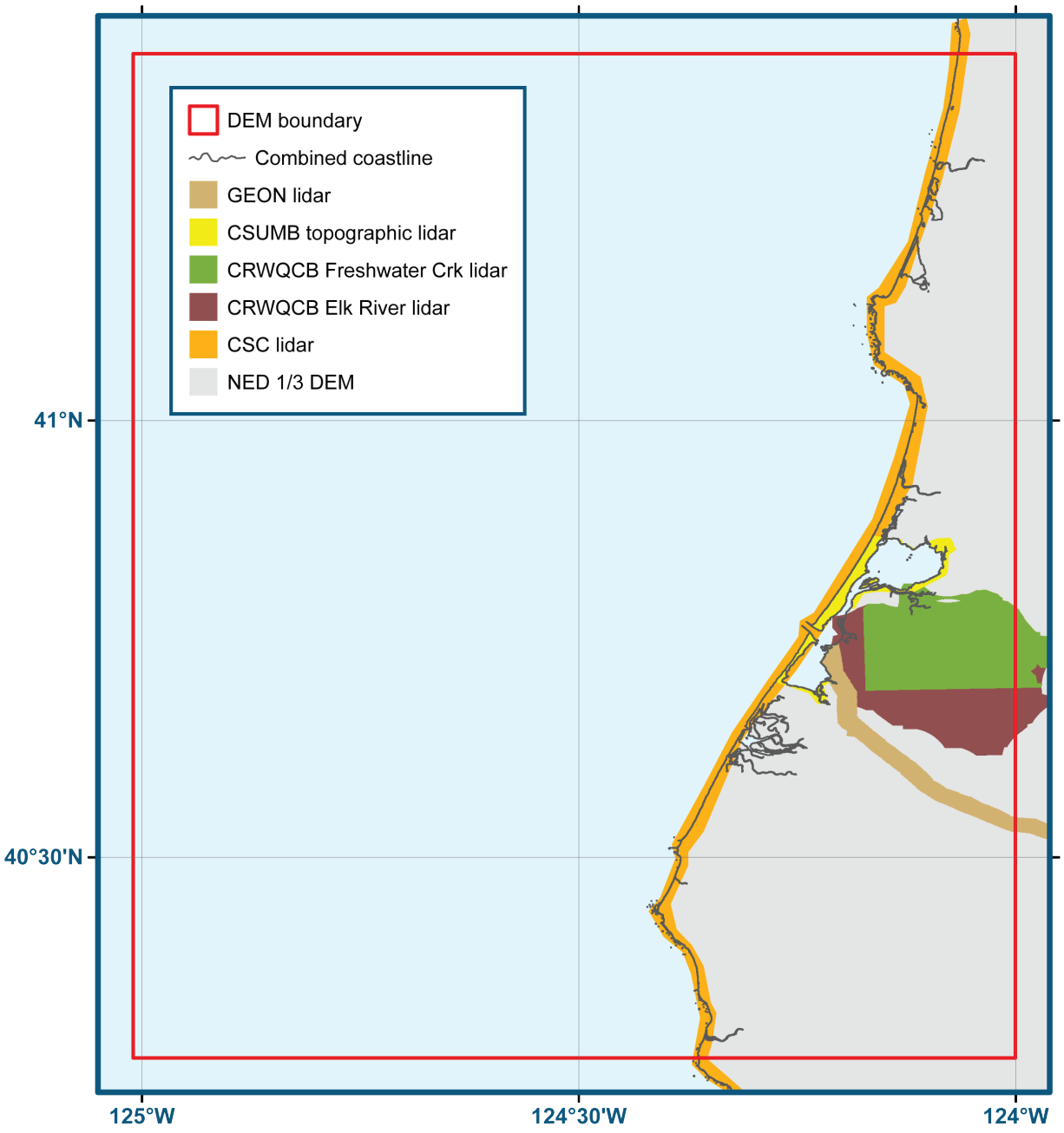


Figure 15. *Spatial coverage of the topographic datasets used in compiling the Eureka NAVD 88 DEM.*

1) California Regional Water Quality Control Board DEMs

CRWQCB provided NGDC with two bare-earth DEMs referenced to a vertical datum of NAVD 88 geographic of the Elk River and Freshwater Creek hydrology units (Fig. 16). The DEMs had been processed as 1 meter lidar postings then gridded to <2 meter cell size. NGDC converted the data from a gridded ASCII format to raster with 5 meter cell size using *ArcGIS*. The rasters were then transformed from NAD 83 UTM Zone 10 to NAD 83 geographic and converted to shapefiles using *FME*. Data from the water surface were removed by clipping to the coastline using *ArcGIS*. The resulting data files were converted to xyz format for the final gridding process.

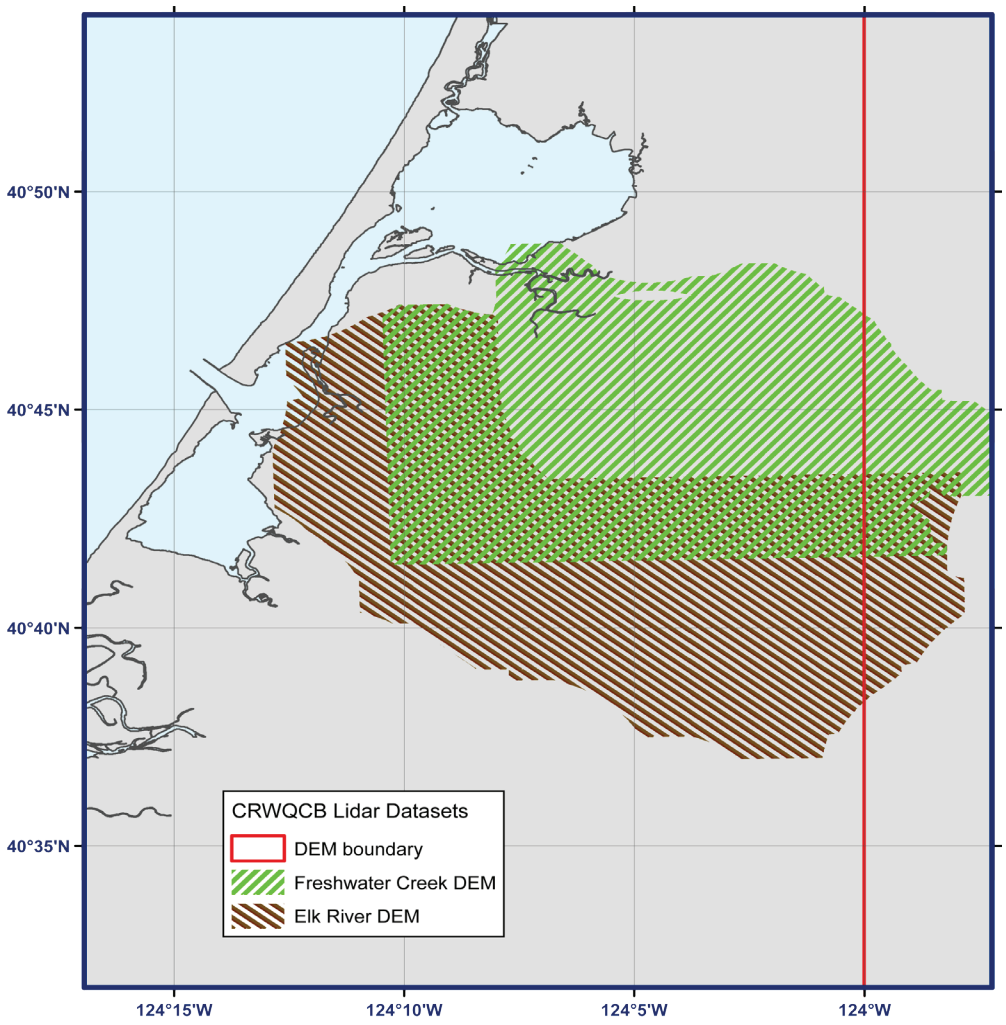


Figure 16. *Spatial coverage of the CRWQCB DEMs. Freshwater Creek DEM in green and Elk River DEM in brown.*

2) Coastal Services Center 2002 NASA/USGS Airborne Lidar Assessment of Coastal Erosion lidar

Airborne Lidar Assessment of Coastal Erosion (ALACE)[7] non bare-earth coastal lidar data horizontally referenced to NAD 83 geographic and vertically referenced to NAVD 88 were downloaded from the CSC web site in FLT format and converted to rasters using *ArcGIS*. The rasters were then converted to xyz format using *FME*. The data had significant water returns, which were manually removed from the dataset in *QT Modeler*. Anomolous spikes and returns were also removed where possible, however, along the northern coast thicker vegetation rendered manual editing impossible so these returns remain (Figs. 17 and 18).

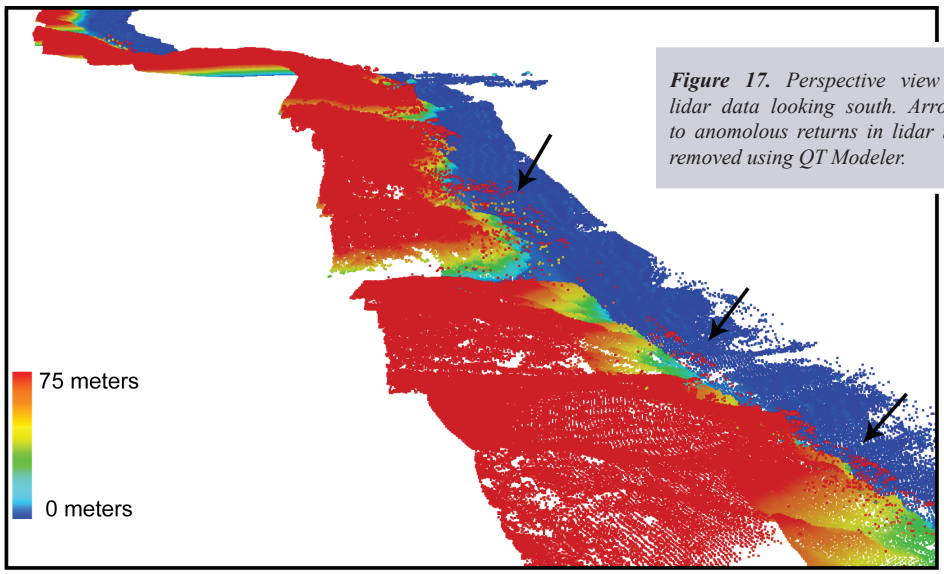


Figure 17. *Perspective view of CSC lidar data looking south. Arrows point to anomolous returns in lidar that were removed using QT Modeler.*

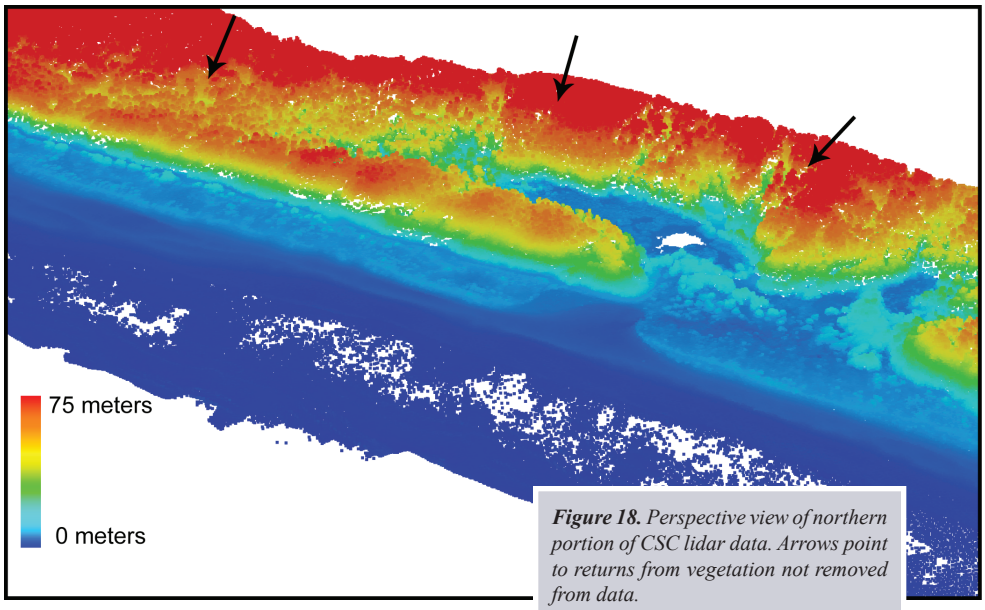


Figure 18. *Perspective view of northern portion of CSC lidar data. Arrows point to returns from vegetation not removed from data.*

7. The Airborne Lidar Assessment of Coastal Erosion (ALACE) project was a partnership between NOAA, NASA, and U.S. Geological Survery (USGS). It has been collecting baseline coastal topographic data for the conterminous U.S. since 1996. The ALACE collections are typically targeted at a narrow strip of sandy beach and are usually a kilometer or less in width. Many areas have both baseline data and post-storm data. In general, this data has not been checked with ground control, but has undergone internal consistency checks.The acquisition of baseline coastal topographic data primarily occurs during the fall, prior to winter erosion and when the beach is generally at its widest due to sand accumulation over the summer months. All flights are timed to occur within a few hours of low tide, when the beach is most exposed. [Extracted from the CSC Digital Coast web site.]

3) California State Seafloor Mapping Laboratory lidar

Bare-earth lidar data from 2002 were downloaded from the CSUMB web site. The data were vertically referenced to NAVD 88 and gridded to 5 meters by CSUMB. The raster data were converted to shapefiles using *FME*. The shapefiles were transformed from UTM Zone 10 coordinate system to NAD 83 geographic with *FME*. The shapefiles were clipped to the coastline to remove water returns (Fig. 19). Data used in this study were acquired, processed, archived, and distributed by CSUMB.

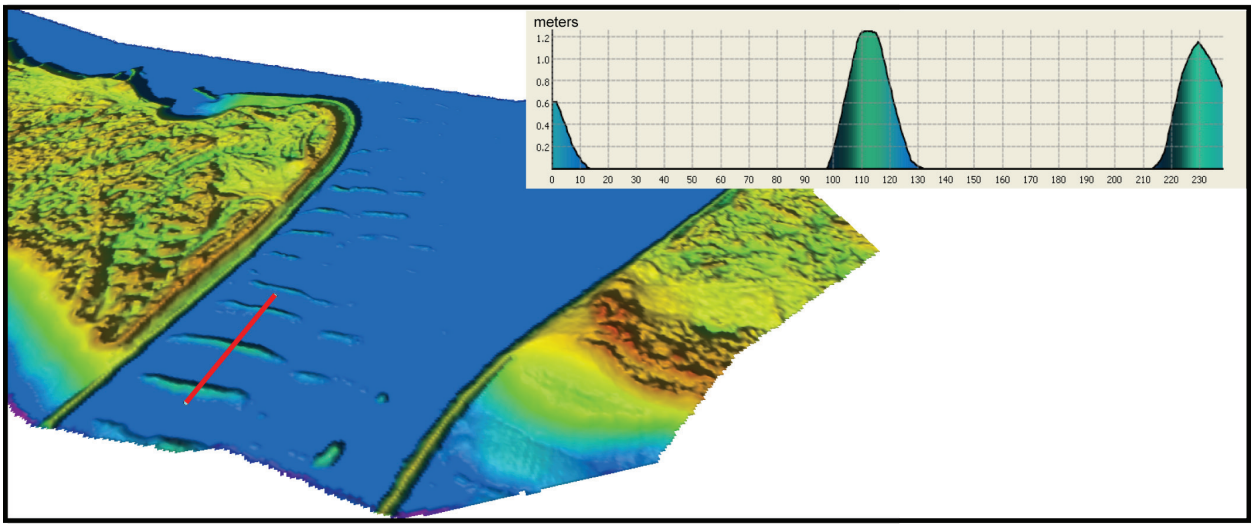


Figure 19. *Perspective view of CSUMB lidar data at Humboldt Bay entrance. Red line is profile in window. Water returns were remove from dataset by clipping data to the coastline.*

4) GEON lidar

The GeoEarthScope Northern California Lidar Project acquired high-resolution airborne laser swath mapping imagery along major active faults as part of the EarthScope Facility project funded by the National Science Foundation (NSF).

The bare-earth data were downloaded from the GEON Portal system, which delivers an xyz point cloud format data file. The data were transformed from UTM Zone 10 to NAD 83 geographic with *FME*. Elevations were referenced to the ellipsoid (ITRF 2000) and transformed to NAVD 88 using *VDatum*. Figure 20 is an example of the data along Humboldt Bay. Returns on the water and the pier, marked by an arrow, were removed using *QT Modeler*.

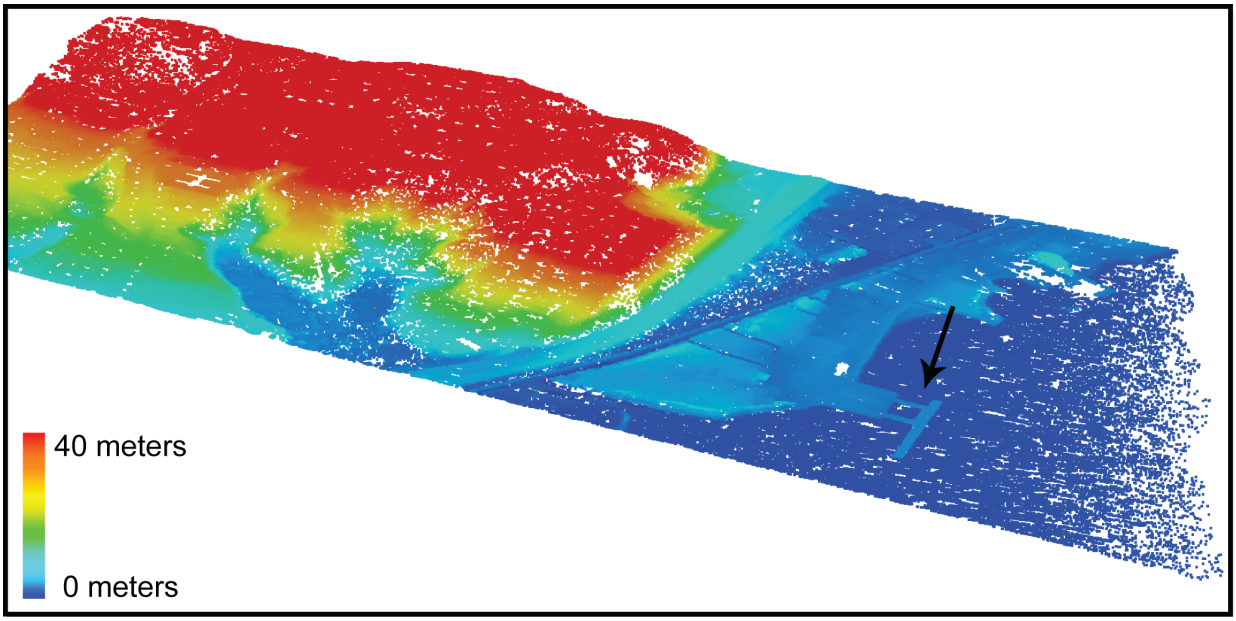


Figure 20. *Perspective view of the GEON topographic lidar returns from water surface (dark blue).*

5) U.S. Geological Survey NED Topographic DEM

USGS National Elevation Dataset (NED) provides complete 1/3 arc-second coverage of the Eureka region[8]. The dataset is available for download as raster DEMs in NAD 83 geographic horizontal datum and NAVD 88 vertical datum (meters). The 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.

The USGS NED 1/3 arc-second DEM data were downloaded from the USGS web site. *FME* was used to convert raster data to xyz format. The data were edited to remove anomolous elevation values over the water using *QT Modeler*. NED data were edited removing data within ~20 meters of overlapping lidar datasets creating a buffer to reduce the edge effects of merging different resolution datasets. A comparison of contour lines generated from the NED raster data (NAVD 88) to the USGS topographic quadrangles showed that the NED DEMs in the Eureka region are in a mixed vertical datum of NADV 88 inland and of MHW at the coast (see *Lim et al., 2009* for further details). To partially correct for this, elevations in this dataset that were below 2.0 meters were converted to 2.0 meters, roughly the difference between NAVD 88 and MHW in the Eureka region. This prevented some coastal areas from inappropriately "flooding" when generating the MHW DEM.

Figure 21 illustrates the morphological change at the mouth of the Eel River. Comparing Figure 21A, the NED DEM, to Figrue 21B, 2004 imagery, sediment distribution and water depth vary considerably. Similar changes in location of other river and creek mouths in the Eureka region are likely to occur over time due to tidal influences and flooding.

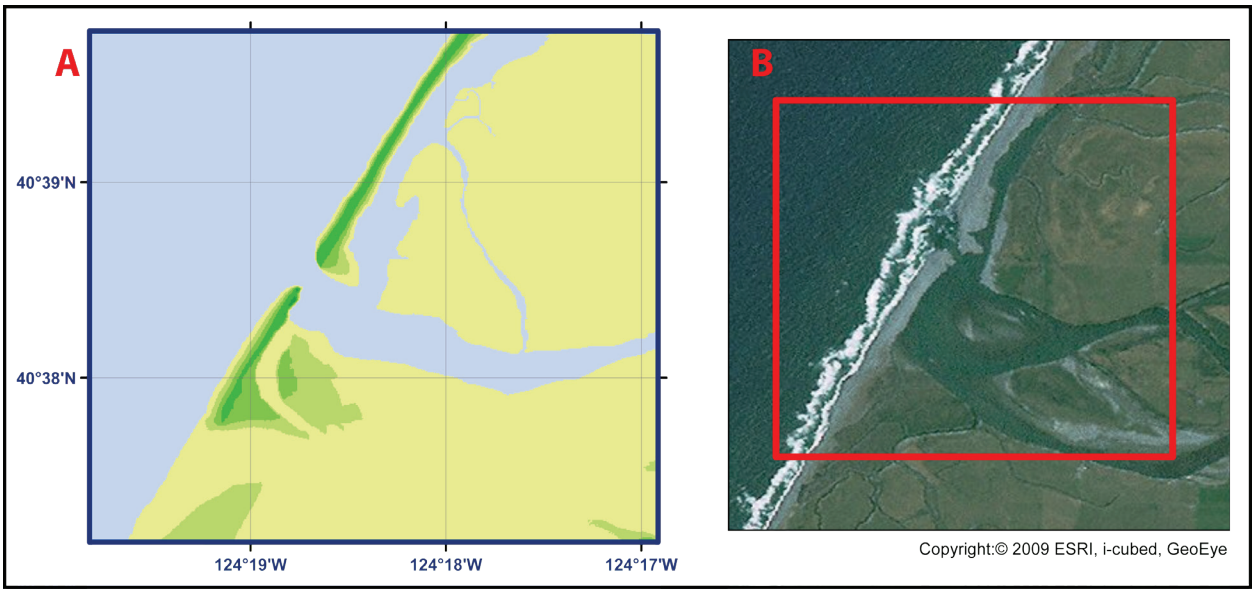


Figure 21. *Comparison of A) NED topographic DEM and B) satellite imagery illustrating considerable morphological change in the mouth of Eel River.*

8. 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 NAD 83 geographic, except for AK, which is NAD 27 geographic. The vertical datum is NAVD 88, 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 web site]

6) NGDC digitized elevation points

The jetties at the entrance to Humboldt Bay were not resolved completely in the topographic data. Therefore a point shapefile was created using elevations from a USACE publication on monitoring structures (*Bottin et al., 1997*). The jetties were inspected in 1997 by USACE and control points were surveyed using global positioning system control surveying and electronic land surveying techniques (Fig. 22). The positions and elevations of these points are listed in Table 9 and referenced to NAD 83 California State Plane Coordinate System and MLLW. Conversions to NAD 83 geographic and NAVD 88 were done using *FME* and *VDatum,* respectively. The resulting xyz files were used to generated an interpolated line of points with 10 meter spacing along the jetties using *GEODAS*.

North of Humboldt Bay along the coast are Big Lagoon and Stone Lagoon. There was no digital data representing the bed of the lagoons so NGDC digitized values based on elevations in a report describing stratification in Big Lagoon (*Crandell et al., 1973*).

Table 9: USACE control points for the Humboldt Bay jetties.

North Jetty			
ID	*Longitude*	*Latitude*	*MLLW elevation (meters)*
54+00	-124.233966	40.765219	5.648
68+00	-124.237523	40.767948	6.593
74+00	-124.239109	40.769069	9.629
South Jetty			
ID	*Longitude*	*Latitude*	*MLLW elevation (meters)*
62+00	-124.237183	40.759094	6.239
84+00	-124.242507	40.763567	7.184
90+05.21	-124.244036	40.764753	9.984

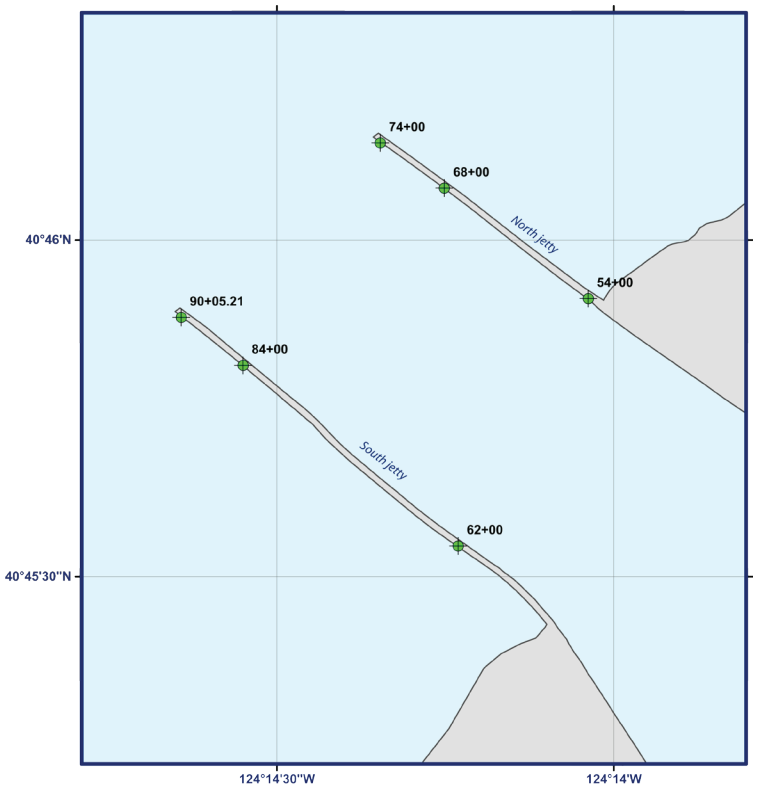


Figure 22. *Location and ID of USACE control points.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Eureka NAVD 88 DEM were originally referenced to a number of vertical datums including MLLW, MSL, and the ellipsoid (ITRF 2000). All datasets were transformed to NAVD 88 using the *VDatum* transformation tool. Spatial coverage of *VDatum* is shown in Figure 23.

1) Bathymetric data

The NOS hydrographic surveys, multibeam sonar surveys, ENC soundings, and USACE surveys were transformed from MLLW and MSL to NAVD 88 using *VDatum*.

2) Topographic data

The majority of the topographic datasets were originally referenced to NAVD 88 requiring no vertical transformations. The GEON lidar dataset was referenced to the ellipsoid (ITRF 2000) and transformed to NAVD 88 using *VDatum*.

Table 10: Relationship between NAVD 88 and other vertical tidal datums at North Spit, Humboldt Bay.

Tidal datums at NORTH SPIT, HUMBOLDT BAY based on:
LENGTH OF SERIES: 19 Years
TIME PERIOD: January 1983 - December 2001
TIDAL EPOCH: 1983-2001
CONTROL TIDE STATION:

Elevations of tidal datums referred to mean lower low water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (01/26/1983)	= 2.963
MEAN HIGHER HIGH WATER (MHHW)	= 2.090
MEAN HIGH WATER (MHW)	= 1.874
MEAN TIDE LEVEL (MTL)	= 1.129
MEAN SEA LEVEL (MSL)	= 1.129
MEAN LOW WATER (MLW)	= 0.384
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	= 0.103
MEAN LOWER LOW WATER (MLLW)	= 0.000
LOWEST OBSERVED WATER LEVEL (01/19/1988)	= -0.883

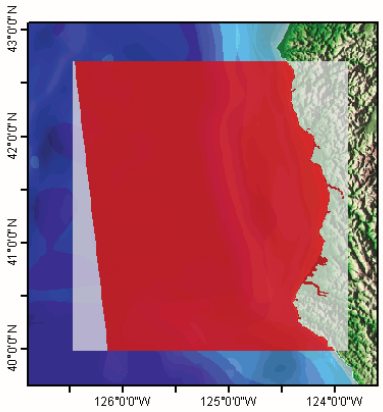


Figure 23. *Spatial coverage of the VDatum transformation tool in the Eureka region.*

3.2.2 Horizontal datum transformations

Datasets used to compile the Eureka NAVD 88 DEM were originally referenced to NAD 83 geographic, WGS 84 geographic, WGS 84 UTM Zone 10N, NAD 83 UTM Zone 10N, and NAD 83 California State Plane I (feet) horizontal datums. Transformations to NAD 83 geographic were done using *ArcGIS* or *FME*.

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* for consistency between datasets. 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:

- Inconsistant, overlapping high-resolution topographic datasets. Datasets were weighted based on quality and age in gridding process.
- Data values over the ocean in the NED DEMs, CSUMB lidar, GEON lidar, and CRWQCB lidar topographic datasets. These datasets required automated clipping to the combined coastline or were edited manually.
- Discrepancies in NED DEM vertical datum. NGDC assigned elevation value of 2.0 meters relative to NAVD 88 to cells below 203 meters.
- Digital, measured bathymetric values from NOS surveys date back over 70 years. More recent data, such as the multibeam surveys, differed from older NOS data by as much as 150 meters vertically. The older NOS survey data were excised where more recent bathymetric data exists.
- Water returns and returns from vegetation in CSC coastal lidar dataset. Anomalous returns were edited manually while returns from vegetation were edited where possible.
- Estuaries and river outlets have changed considerably in some areas, since coastal lidar data was collected. No recent data exists in these areas that corresponds to current morphology.

3.3.2 Smoothing of bathymetric data

The older NOS hydrographic survey data are generally sparse at the resolution of the Eureka DEMs 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 these low resolution datasets, and to provide effective interpolation into the coastal zone, a 1 arc-second-cell size "pre-surface" bathymetric grid was generated using *GMT*[9], an NSF-funded shareware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu).

The NOS hydrographic point data, in xyz format, were clipped to remove overlap with the newer NOS surveys, NGDC multibeam data, and CCOM-UNH multibeam data and then combined with CSUMB multibeam data, USACE data, ENC soundings, and points extracted from the combined coastline—to provide a buffer along the entire coastline. The coastline elevation value was set to zero meters to ensure a bathymetric surface near zero relative to NAVD 88 in areas where bathymetric data are sparse or non-existent.

The point data were then median-averaged using the *GMT* tool "blockmedian" to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Eureka 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 *GMT* grid created by "surface" was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy. Figure 24 shows a histogram of the pre-2008 NOS surveys compared to the 1 arc-second pre-surfaced bathymetric grid. Differences cluster around zero with only 129 out of 76047 points varying more than 5 meters from the bathymetric surface. These points are located in shallow, rocky areas and in the submarine canyons where several soundings are averaged to a single cell elevation value.

Some inconsistencies were identified while merging the bathymetric datasets due to the range in ages and resolutions of the NOS hydrographic 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.

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

For Humboldt Bay, a higher resolution 1/3 arc-second bathymetric surface was generated. Decreasing the cell size within the bay reduced gridding artifacts such as "humps" due to sparse data. NGDC also digitized points in the bay to minimize this effect. Along portions of the coastline in the bay, where topographic data slopes steeply into the bay, artificial dips in the surface were generated. The artificial dips were corrected by using higher tension in the final bathymetric surface. This corrected 1/3 arc-second surface for Humboldt Bay was converted to an xyz file and used along with the 1 arc-second surface xyz file in the final gridding process (see Sec. 3.3.3).

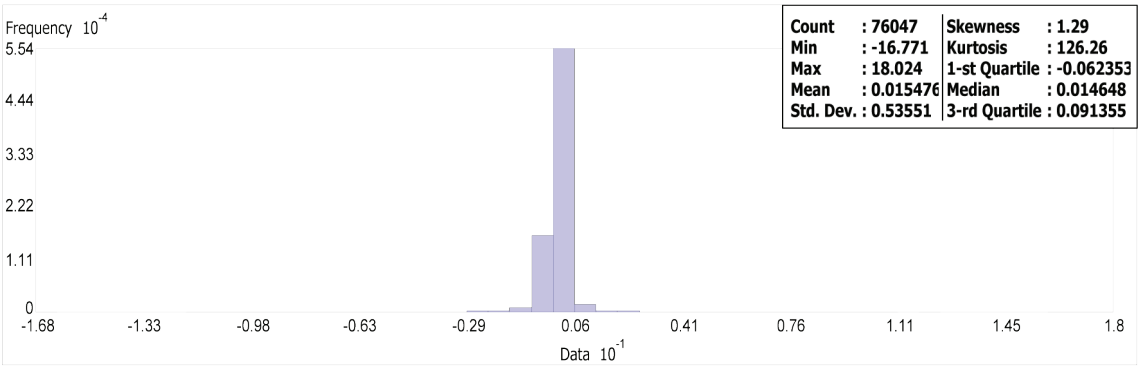


Figure 24. *Histogram of the differences between pre-2008 NOS hydrographic surveys and the 1 arc-second pre-surfaced bathymetric grid.*

3.3.3 Building the NAVD 88 DEM

MB-System was used to create the 1/3 arc-second Eureka NAVD 88 DEM. The *MB-System* tool "mbgrid" was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the "mbgrid" gridding algorithm, as relative gridding weights, is listed in Table 11. Greatest weight was given to the high resolution topographic lidar, the high resolution multibeam surveys, and the NGDC digitized features. Least weight was given to the pre-surfaced bathymetric grids, the NED DEM, and the CSC non bare-earth coastal lidar.

Table 11. Data hierarchy used to assign gridding weight in *MB-System*.

Dataset	*Relative Gridding Weight*
NOS surveys H11919, H11978, and H11979	100
USACE surveys	100
CSUMB multibeam	100
CRWQCB lidar	100
GEON lidar	100
ENC soundings	100
NGDC digitized features	100
CCOM-JHC multibeam survey	10
NOS hydrographic surveys	10
NGDC multibeam surveys	10
CSUMB lidar	10
Pre-surfaced bathymetric grids	1
USGS NED DEM	1
CSC coastal lidar	.01

3.3.4 Developing the MHW DEM

The MHW DEM was created by adding an "NAVD 88 to MHW" conversion grid to the NAVD 88 DEM.

1) Developing the conversion grid

Using extents slightly larger (~ 5 percent) than the DEM, an initial xyz file was created that contained the coordinates of the four bounding vertices and midpoint of the larger extents. The elevation value at each of the points was set to zero. The *GMT* tool "surface" applied a tension spline to interpolate cell values making a zero-value 3 arc-second grid. This zero-value grid was then converted to an intermediate xyz file using the *GMT* tool "grd2xyz".

Conversion values from NAVD 88 to MHW at each xyz point were generated using *VDatum*. Null values were removed and a converted xyz file was created by clipping the data to the combined coastline using *FME*. The converted xyz file was then interpolated with the *GMT* tool "surface" to create the 1/3 arc-second "NAVD 88 to MHW" conversion grid with the extents of the NAVD 88 DEM.

2) Assessing accuracy of conversion grid

The "NAVD 88 to MHW" conversion grid was assessed using the NOS survey data. For testing of this methodology, the NOS hydrographic survey data were transformed from MLLW to NAVD 88 using *VDatum*. Shapefiles of the resultant xyz files were created and null values removed using *FME*. The shapefiles were then merged to create a single shapefile of all NOS surveys with a vertical datum of NAVD 88. A second shapefile of NOS data was created with a vertical datum of MHW using the same method. Elevation differences between the MHW and NAVD 88 shapefiles were computed after performing a spatial join in *ArcGIS*.

To verify the conversion grid methodology, the difference shapefile created using *ArcGIS* was converted to xyz format using *FME*. The CrossCheck module in *Fledermaus* was used to evaluate the performance of the 1/3 arc-second conversion grid by comparing the "NAVD 88 to MHW" grid to the difference xyz file. The *Fledermaus* results indicated agreement to approximately +/- 0.0002 meters. The *Fledermaus* results were then converted to shapefile format using *FME* to visualize the comparison and to produce a histogram of the variations in *ArcGIS* (Fig. 20). The same methodology was used to check the "NAVD 88 to MHW" conversion grid against a USACE harbor survey with similar results (Fig. 21).

Errors in the vertical datum conversion method will reside for the most part in the "NAVD 88 to MHW" conversion grid, most topographic data are already in NAVD 88. Errors in the source datasets will require rebuilding just the NAVD 88 DEM.

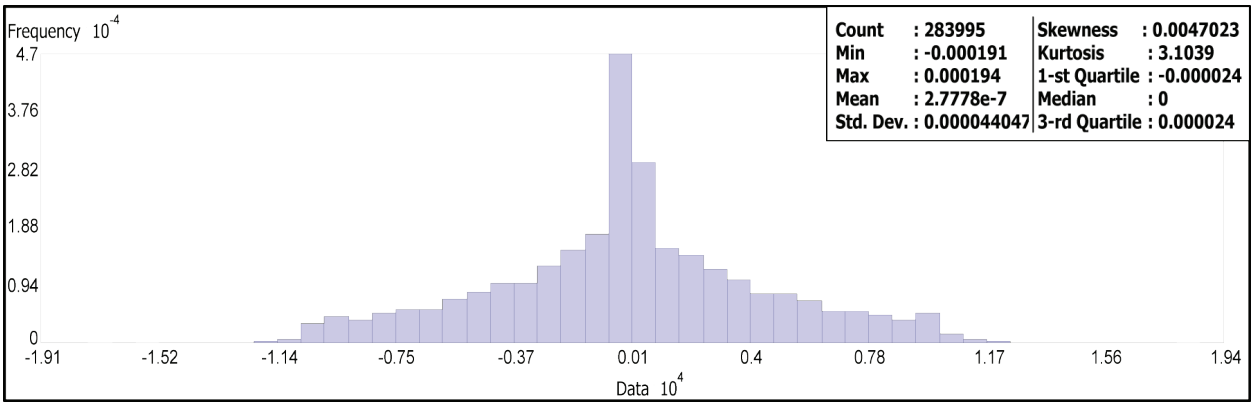


Figure 25. *Histogram of the differences between the conversion grid and xyz difference files using NOS hydrographic survey data.*

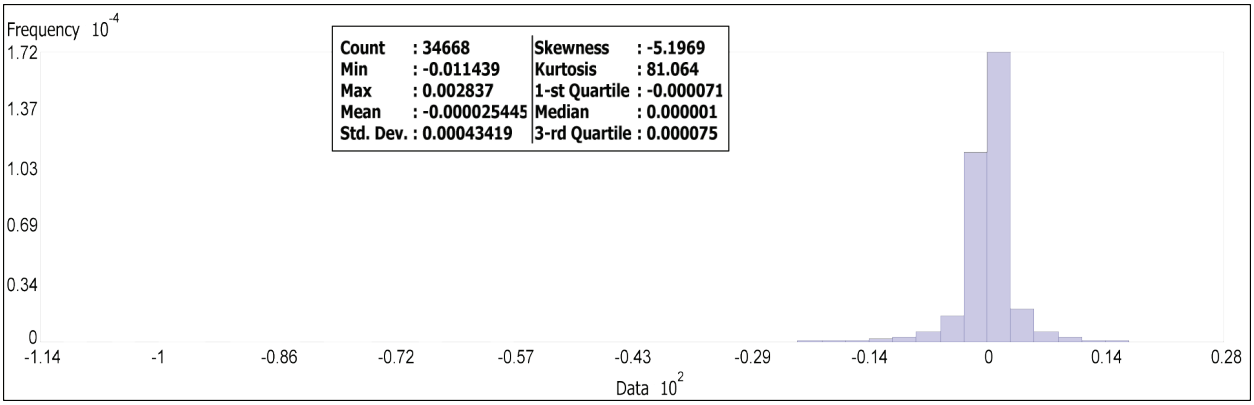


Figure 26. *Histogram of the differences between the conversion grid and xyz difference files using USACE hydrographic survey data.*

3) Creating the MHW DEM

Once the NAVD 88 DEM was complete and assessed for errors, the conversion grid was added using *ArcCatalog*. The resulting MHW DEM was reviewed and assessed using RNCs, USGS topographic maps, and ESRI *World 2D* imagery. Problems encountered were determined to reside in source datasets, which were corrected before building a new NAVD 88 DEM.

3.4 Quality Assessment of the DEMs

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Eureka DEMs is dependent upon DEM cell size and source datasets. Topographic features have an estimated horizontal accuracy of 10 meters: gridded CSC coastal lidar and CRWQCB lidar DEM data have an accuracy of approximately 2 meters, GEON lidar data have an accuracy of 1 meter, CSUMB lidar have an accuracy of 5 meters, and NED DEM data is accurate to approximately 10 meters. Bathymetric features are resolved only to within a few tens 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 Eureka DEMs is also dependent upon the source datasets contributing to DEM cell values. Topographic data have an estimated vertical accuracy between 0.5 meters for inland GEON lidar data and 7 meters for NED DEMs. 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 20th 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 Onsite assessment of the MHW DEM

Assessment of the MHW DEM showed low lying coastal areas surrounding the bay as below zero (MHW) elevation. These areas, described as marshes, sloughs, and wetlands, are accurately portrayed in the DEMs where high resolution lidar data was present. Levees prevent these areas from flooding at high tide, which was verified during a site visit (Fig. 27).



Figure 27. *Image showing the water level differences at Fields Landing levee. The higher bay side is on the right side of the image and the lower inland side is on the left. Person in image for scale is 1.88 meters tall.*

3.4.4 Slope map, 3-D perspective, and data contribution plot

ESRI *ArcCatalog* was used to generate a slope grid from the Eureka NAVD 88 DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 28). The DEM was transformed to UTM Zone 10 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 *Quick Terrain Modeler* and *Fledermaus* revealed suspect data points, which were corrected before recompiling the DEM. Figure 1 shows a color image of the 1/3 arc-second Eureka NAVD 88 DEM in its final version. Figure 29 shows a perspective rendering of the final NAVD 88 DEM. Figure 30 shows a data contribution plot of the Eureka DEMs.

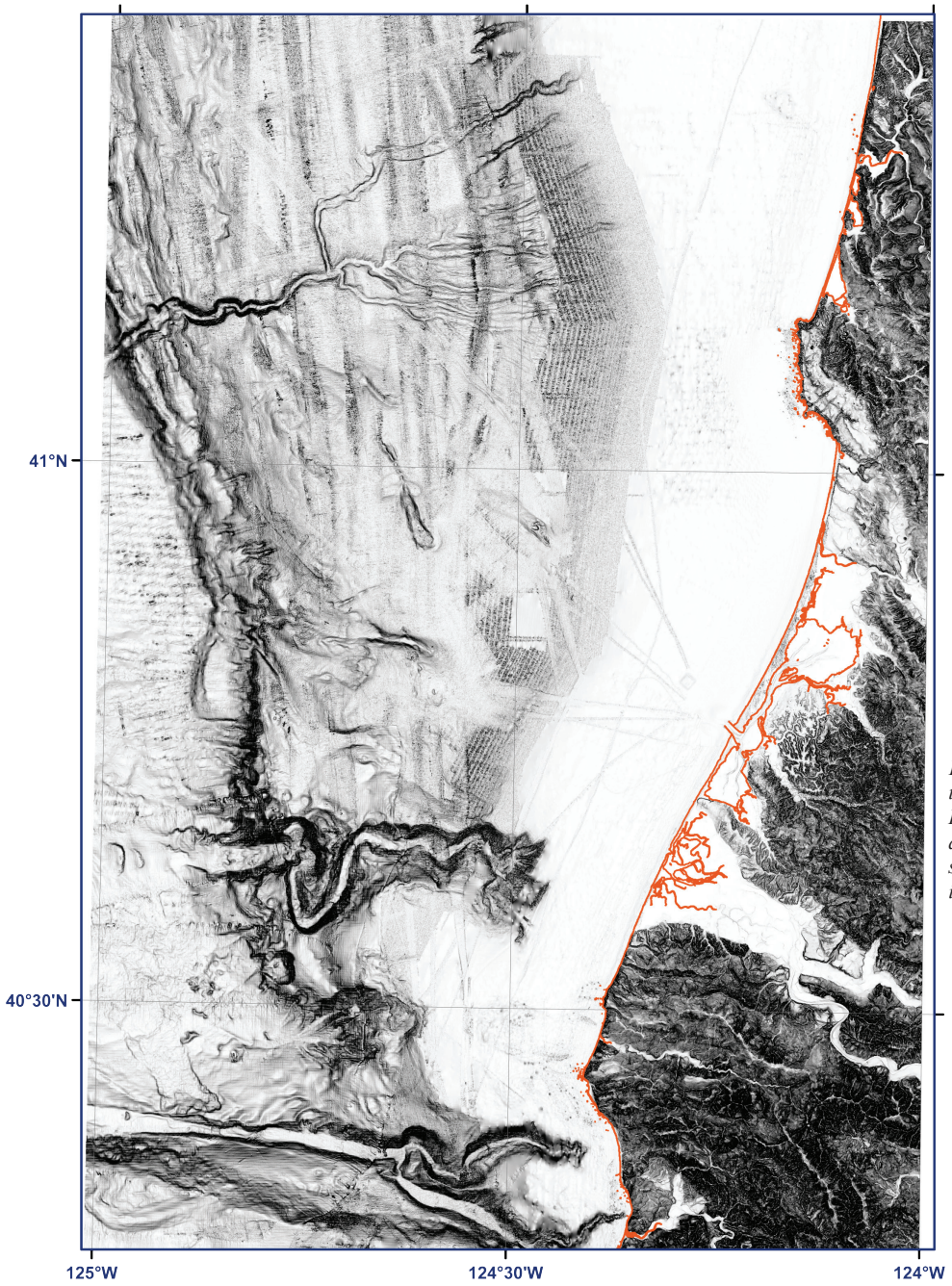


Figure 28. *Slope map of the Eureka NAVD 88 DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

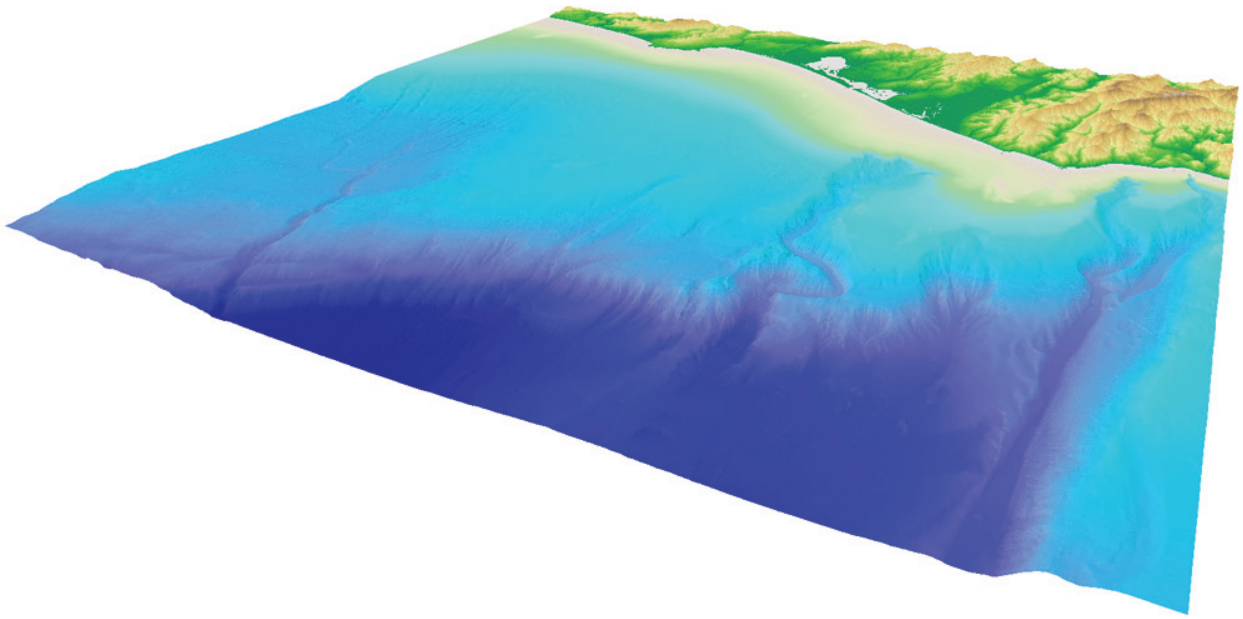


Figure 29. *Perspective view from the southwest of the Eureka NAVD 88 DEM. Vertical exaggeration 2 times.*

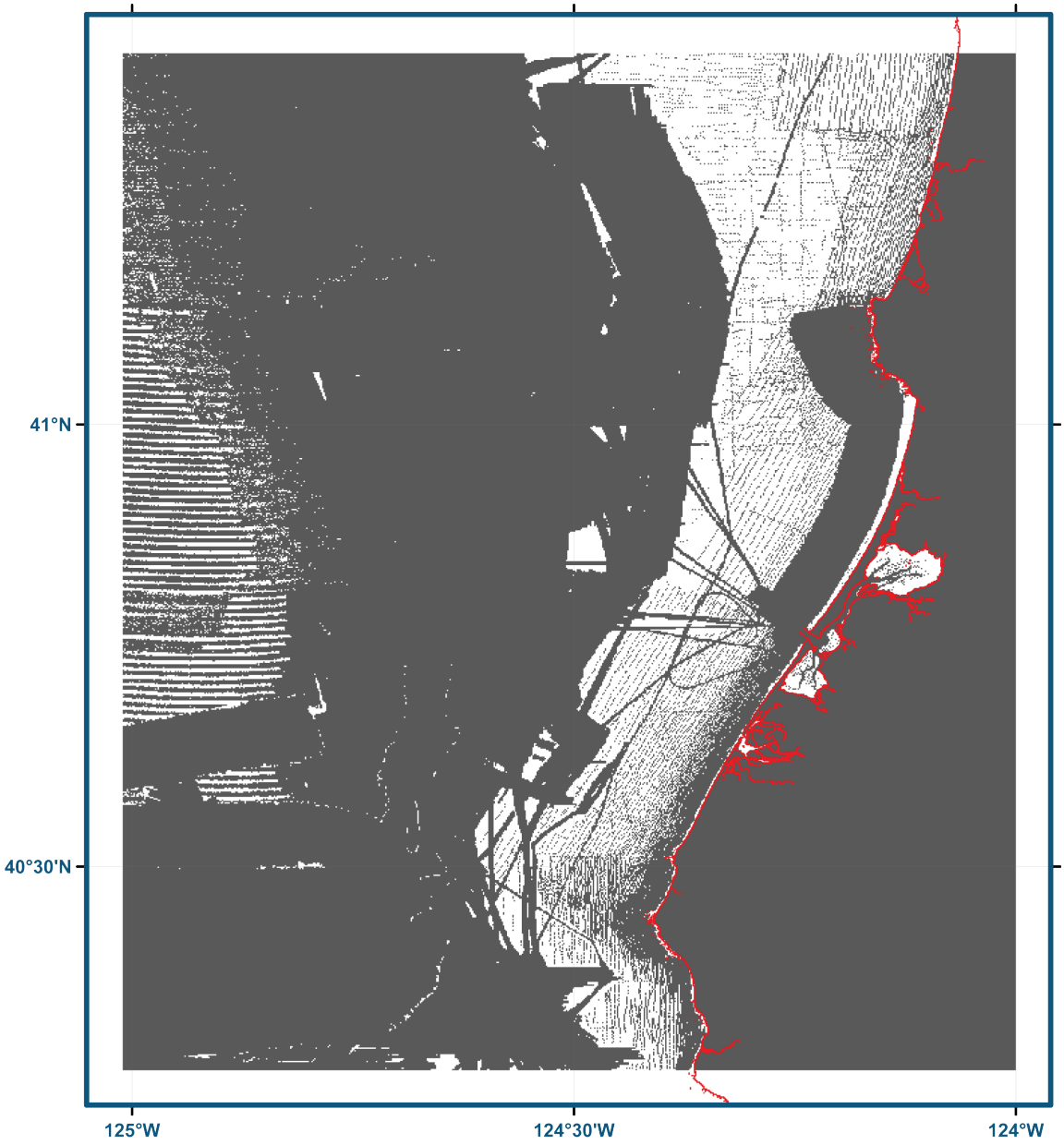


Figure 30. *Data contribution plot of the Eureka DEMs. Gray depicts DEM cells constrained by source data; white depicts cells with elevation values derived from interpolation; coastline in red.*

3.4.5 *Comparison with NGS geodetic monuments*

The elevations of 602 geodetic monuments were extracted from the NOAA's National Geodetic Survey (NGS) web site (http://www.ngs.noaa.gov) in shapefile format (see Fig. 31 for monument locations). Shapefile attributes give postions in NAD 83 geographic (typically sub-mm accuracy) and elevations in NAVD 88 (in meters). Elevations were compared to the Eureka NAVD 88 DEM (Fig. 32). Differences between the DEM and the monument elevations range from -50.428 to 31.978 meters, half of which are within ± 2 meters. Large differences in elevations occured where monuments are located on road cuts, on top of a pole, or have not been recovered. All but four of these monuments with large discrepencies in elevation were located where high-resolution lidar topographic data was not available.

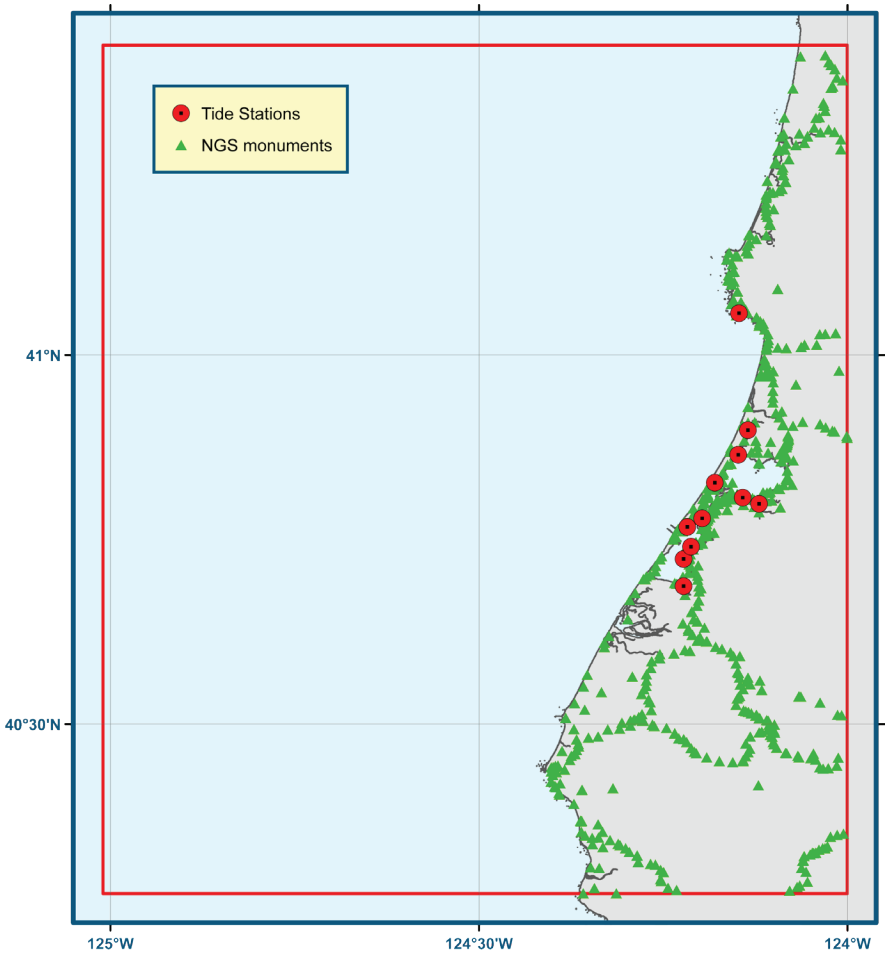


Figure 31. *Location of NGS monuments, shown as green triangles, and NOAA tide stations, shown as red circles.*

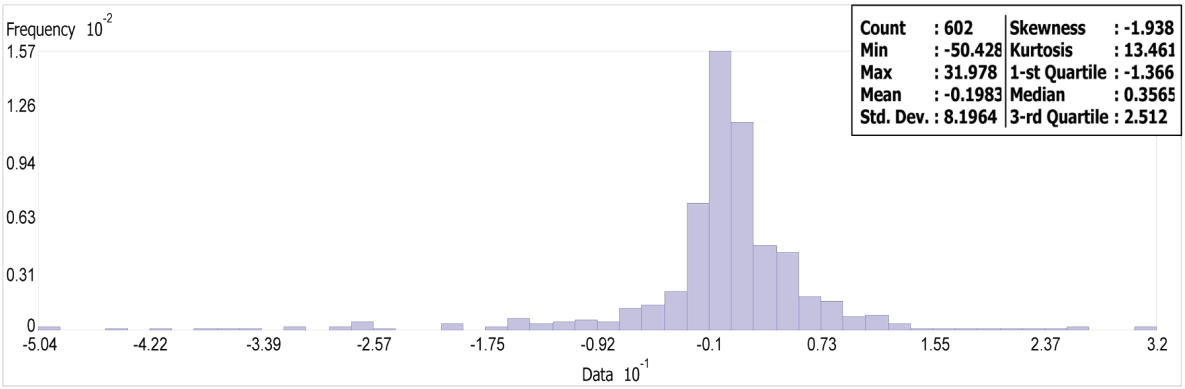


Figure 32. *Histogram of the differences between NGS geodetic monument elevations and the Eureka NAVD 88 DEM.*

3.4.6 NAVD 88 DEM comparison with source data files

To ensure grid accuracy, the Eureka NAVD 88 DEM was compared to source data files. Select bathymetric data and topographic data files were chosen for comparison to the Eureka NAVD 88 DEM using *Fledermaus*, *FME* and *ArcMap*. A histogram of the differences between all pre-2008 NOS hydrographic surveys and the Eureka NAVD 88 DEM is shown in Figure 33. Differences cluster around zero. The major differences in elevations in NOS surveys with the grid (-5.945 meters and +10.343 meters) are located at the heads of the Mattole and Mendocino canyons.

Comparison of the USACE hydrographic survey data and the Eureka NAVD 88 DEM are shown in Figure 34. Elevation differences range from -4.973 to 9.297 meters. Large differences occur where 2009 USACE data overlaps NOS survey H11919, which may occur due to changes in dredged depths or sediment deposition in channels.

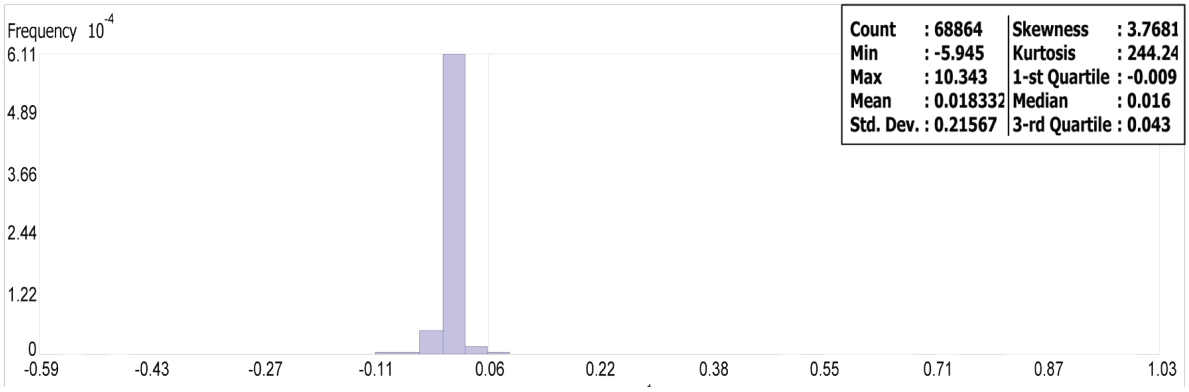


Figure 33. *Histogram of the differences between all pre-2008 NOS soundings and the Eureka NAVD 88 DEM.*

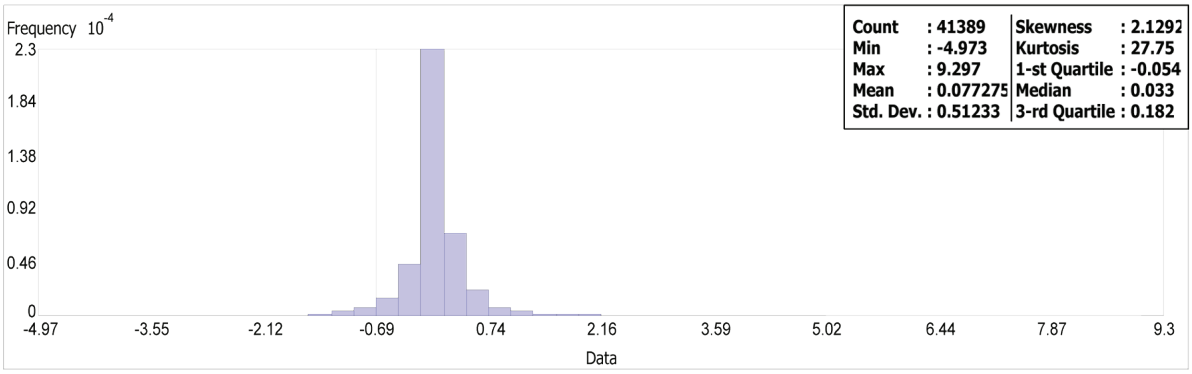


Figure 34. *Histogram of the differences between all the USACE survey elevations and the Eureka NAVD 88 DEM.*

A selection of CSUMB topographic lidar points located along the bay were compared to the Eureka NAVD 88 DEM (Fig. 35). The histogram shows the differences in elevations are between -3.043 and 6.012 meters and the majority are within ± 2 meters. The largest differences are located right at the coastline and on the jetty.

A portion of the NED NAVD 88 DEM located along Humboldt Bay was compared to the Eureka DEM (Fig. 36). The histogram shows the difference in elevations range from -65.803 to 52.395 meters. Generally, NED elevations were lower at high elevations and higher closer to coastline than the high-resolution lidar data.

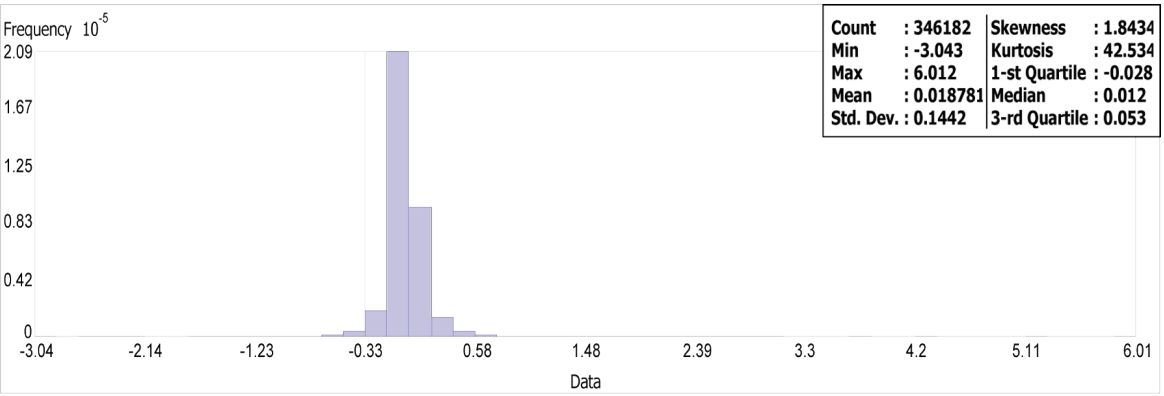


Figure 35. *Histogram of the differences between select CSUMB topographic lidar elevations and the Eureka NAVD 88 DEM.*

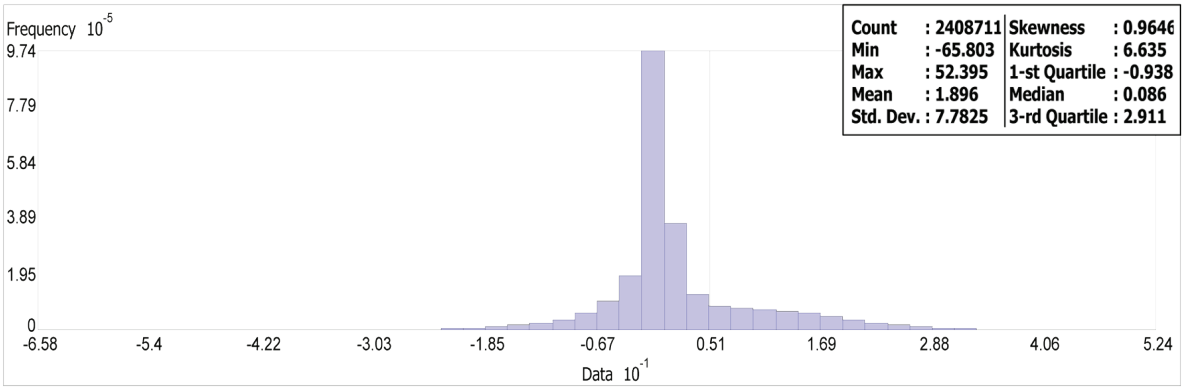


Figure 36. *Histogram of the differences between select NED DEM elevations and the Eureka NAVD 88 DEM.*

4. Summary and Conclusions

A bathymetric–topographic digital elevation model of the Eureka, California, region, with cell size of 1/3 arc-second, was developed for the Pacific Marine Environmental Laboratory (PMEL), NOAA Center for Tsunami Research. The best available digital data from U.S. federal, state, local, and academic agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI *ArcGIS*, ESRI *ArcGIS World Imagery 2-D*, *FME*, *Fledermaus*, *GMT*, *MB-System*, *Quick Terrain Modeler*, and *VDatum* software.

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

- Conduct hydrographic surveys in Humboldt Bay.
- Conduct bathymetric–topographic coastal lidar survey.
- Complete data processing on shallow water multibeam surveys for regions around Cape Mendocino and north of Trinidad Head.
- Process CSC lidar data to bare-earth.

5. Acknowledgments

The creation of the Eureka DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank: Jason Chaytor, Nazila Merati, Marie Eble, Chris Chamberlin and Vasily Titov (PMEL); Brian Kang, City of Arcata; George Fong, U.S. Army Corps of Engineers; Greg Crawford and Lori Dengler, Humboldt State University; Dave Scharff, NOAA; Dave Ryan and Jerry Van Dohlan, County of Humboldt; Brooke McMahon, PHB; Adona White and Matthew Beffleben, California Regional Water Quality Control Board, North Coast Region; and James V. Gardner, University of New Hampshire.

6. References

Bottin, Robert R., and William S. Appleton. Periodic Inspection of Humboldt Bay Jetties, Eureka, California. 1997. U.S. Army Corps of Engineers, Waterways Experiment Station Technical Report CHL-97-17. http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Publications!592

Crandell, George F., and B. Horecek. Stratification in Big Lagoon, California and its Effect on Copepod Populations. 1973. *Crustaceana*, Vol. 25, No. 3, p. 261-266. http://dx.doi.org/10.1163/156854073X00245

Lim, E., L.A. Taylor, B.W. Eakins, K.S. Carignan, R.R. Warnken, P.R. Medley. Digital Elevation Model of Portland, Maine: Procedures, Data Sources and Analysis. 2009. NOAA Technical Memoradum NESDIS NGDC-30. http://www.ngdc.noaa.gov/mgg/inundation/tsunami/data/portland_me/portland_me.pdf

Nautical Chart #18600 (ENC and RNC), 9th Edition, 2009. Trinidad Head to Cape Blanco. Scale 1:1,196,948. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18605 (RNC), 12th Edition, 2009. Trinidad Harbor. Scale 1:15,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18620 (ENC and RNC), 23rd Edition, 2009. Point Arena to Trinidad Head. Scale 1:200,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18622 (ENC and RNC), 54th Edition, 2009. Humboldt Bay. Scale 1:25,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18623 (RNC), 11th Edition, 2009. Cape Mendocino and Vicinity. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

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

Fledermaus v. 6.7.0 and 7.0.0 – developed and licensed by Interactive Visualization Systems (IVS 3D), Fredericton, New Brunswick, Canada, http://www.ivs3d.com.

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.

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.

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, Oregon/California - Cape Blanco and Punta Gorda, v. 01 – developed and maintained by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/welcome.html.