NOAA Technical Memorandum NESDIS NGDC-21

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1. Introduction

In March 2008, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed an integrated bathymetric–topographic digital elevation model (DEM) of Port Orford, Oregon (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 Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 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 Port Orford DEM.

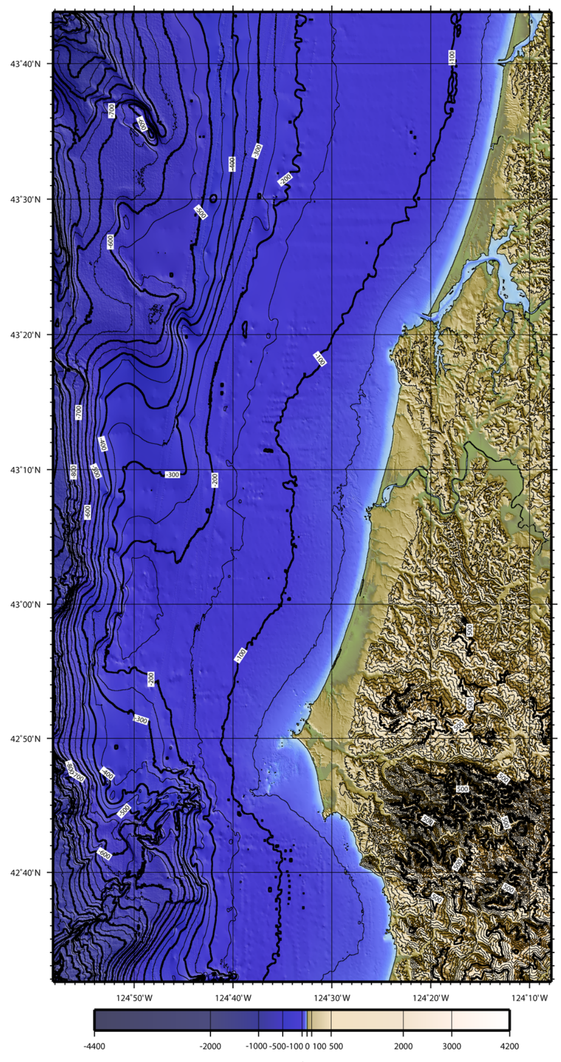


***Figure 1.** Shaded-relief image of the Port Orford, Oregon DEM. Contour interval is 50 meters in water and 100 meters on land. Image is in Mercator projection.*

1. The Port Orford 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 Port Orford, Oregon (42°44.6′ N, 124°29.8′ W) 1/3 arc-second of latitude is equivalent to 10.3 meters; 1/3 arc-second of longitude equals 7.6 meters.

2. Study Area

The Port Orford DEM covers the coastal region surrounding the town of Port Orford, Oregon from the Umpqua River in the north to the town of Ophir in the south and includes the communities of Port Orford, Langlois, Bandon, Charleston, Coos Bay, North Bend, and Winchester Bay (Fig. 2). Encompassing a portion of the Oregon Dunes National Recreation Area and the Oregon Islands National Wildlife Refuge, the DEM includes many offshore rocks, small islands, reefs, and shoreline cliffs. The region is home to many species of coastal bird and animal life which provide recreation and educational opportunities. The town of Port Orford is located south of Cape Blanco, the westernmost point of the Oregon coast, and has a population of approximately 1,100.

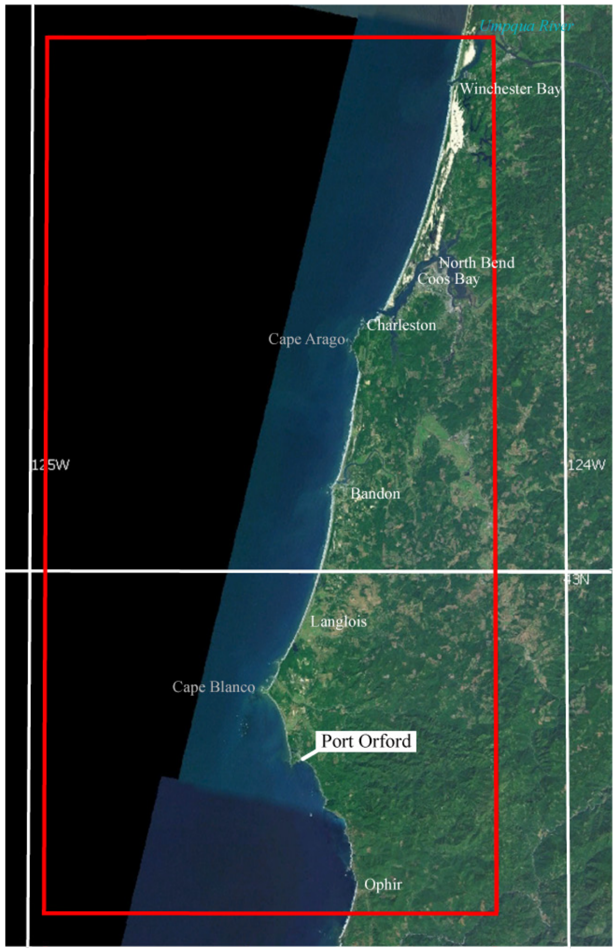


Figure 2. *Google Earth satellite image of the Oregon coast. Port Orford DEM boundary shown in red. Image is in Mercator projection.*

3. Methodology

The Port Orford, Oregon DEM was constructed to meet PMEL specifications (Table 1), based on input requirements for the development of Reference Inundation Models (RIMs) and Standby Inundation Models (SIMs) (V. Titov, pers. comm.) in support of NOAA's Tsunami Warning Centers use of SIFT to provide real-time tsunami forecasts in an operational environment. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North America Datum 1983 (NAD 83) and Mean High Water (MHW), for modeling of maximum flooding, respectively[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1: PMEL specifications for the Port Orford, Oregon DEM.

Grid Area	Port Orford, Oregon
Coverage Area	124.13º to 124.97º W; 42.53º to 43.73º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	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 DEM. Most GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the wave's passage across ocean basins. This DEM is identified as having a WGS 84 geographic horizontal datum even though the underlying elevation data were typically transformed to NAD 83 geographic. At the scale of the DEM, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 3) were obtained from several U.S. federal, state and local agencies including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) and Coastal Services Center (CSC); the U.S. Geological Survey (USGS); the U.S. Army Corps of Engineers (USACE); and the Oregon Department of Fish and Wildlife/Marine Resource Program (ORDFW). Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert them into ESRI (http://www.esri.com/) ArcGIS shape files[3]. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using FME, based upon data from the NOAA Port Orford tide station. Applied Imagery's Quick Terrain Modeler software (http://www.appliedimagery.com/) was used to evaluate processing and gridding techniques.

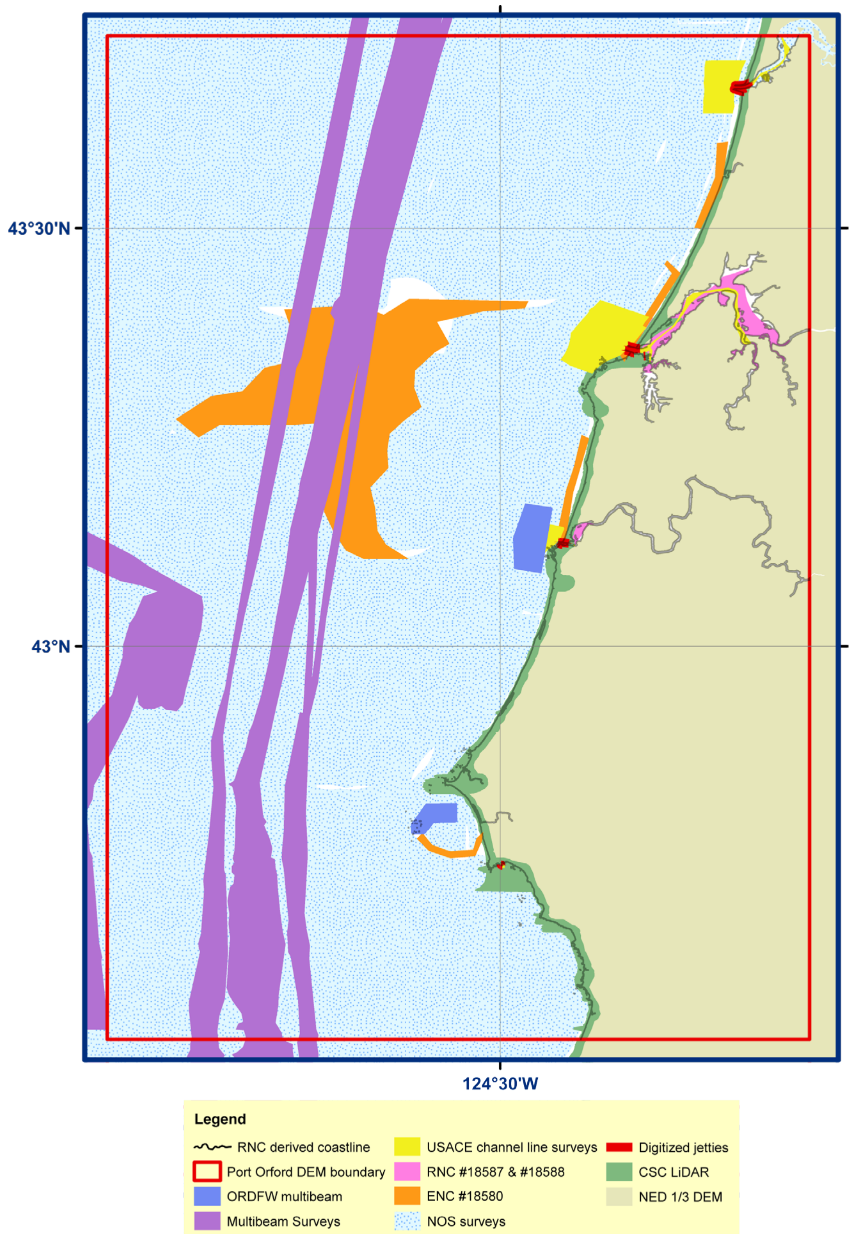


Figure 3. *Source and coverage of datasets used to compile the Port Orford DEM.*

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

3.1.1 Shoreline

Coastline datasets of the Port Orford region were obtained from NOAA's Office of Coast Survey as Electronic Navigational Charts (ENCs) and Raster Nautical Charts (RNCs); and the Oregon Resources Management Task Force (ORMTF). Of these datasets, only the RNCs were used to derive a coastline for the Port Orford DEM (Table 2; Fig. 4). Both the ORMTF coastline and the extracted ENC coastline were shifted in different directions up to 100 meters from topographic datasets and were not used in the Port Orford DEM. The resolution of the ENC coastline was also too coarse for use in the DEM.

Table 2: Shoreline dataset used in the Port Orford DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS RNC derived coastline	2007	derived from raster data	1:20,000 to 1:191,730	WGS 84 geographic (meters)	Mean High Water	http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm

1) OCS Raster Nautical Charts

Six raster nautical charts (RNCs) were available for the Port Orford area (Table 3) and downloaded from NOAA's Office of Coast Survey website (http://nauticalcharts.noaa.gov/mcd/enc/index.htm). The RNCs are provided online as georeferenced raster images and cover the entire coastline within the DEM boundaries. RNC #18600 was not used, as smaller scale raster images were available covering the same area.

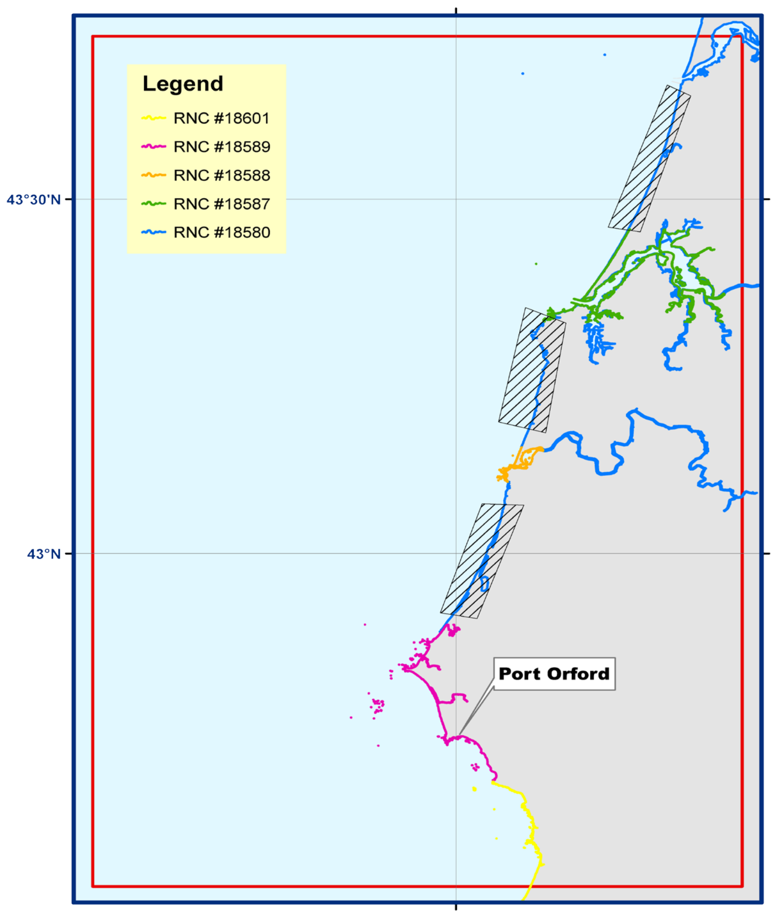


Figure 4. *RNC datasets used in developing a 'derived coastline' for the Port Orford DEM. Gray hachured regions show where manual adjustments to the coastline were made.*

Table 3: Raster nautical charts available in the Port Orford, Oregon region.

Chart	*Title*	*Edition*	*Edition Date*	*Scale*
18580	Cape Blanco to Yaquina Head	22	2005	1:191,730
18587	Coos Bay	70	2005	1:20,000
18588	Coquille River Entrance	37	2003	1:20,000
18589	Port Orford to Cape Blanco	16	2007	1:40,000
18600	Trinidad Head to Cape Blanco	14	2002	1:196,948
18601	Cape Sebastian to Humbug Mountain	14	2007	1:40,000

The coastlines shown on the RNC georeferenced raster images were extracted using the *ArcGIS* ‘Spatial Analyst’ tool, based on pixel values. The resulting data were resampled and converted to ESRI shape polygons. These lines were subsequently cleaned and edited to match the RNCs and be consistent with topographic datasets. These areas are shown in Figure 4 as hachured polygons. Some manmade features, such as bridges and piers, were removed to prevent their inclusion in the DEM. Jetties at Port Orford, Coquille River, Coos Bay, and Umpqua River were checked for accuracy against aerial photos, Google Earth images, and CSC LiDAR topography and adjusted to ensure representation in the DEM (See Sec. 3.1.3).

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Port Orford DEM include 34 NOS hydrographic surveys, 22 hydrographic channel line surveys from USACE, 7 multibeam sonar swath files downloaded from the NGDC multibeam sonar database, two multibeam sonar surveys from the Oregon Department of Fish and Wildlife/Marine Resources Program (ORDFW), extracted ENC sounding data, and digitized RNC soundings (Table 4; Fig. 5).

Table 4: Bathymetric datasets used in compiling the Port Orford DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1889 to 1991	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 27 or NAD 83 geographic	Mean Lower Low Water	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2006 to 2007	Hydrographic channel line surveys	various, from 3 to 40 meter point spacing	NAD 83 Oregon State Plane South (feet)	Mean Lower Low Water	https://www.nwp.usace.army.mil/op/nwh/xyzcoastal.asp
NGDC	1998 to 2003	Multibeam sonar swath files	raw MB files gridded to 1 arc-second	WGS 84 geographic	assumed Mean Sea Level	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
ORDFW/Marine Resources Program	1999 and 2000	Multibeam sonar surveys	1 to 2 meter grid	NAD 83 UTM Zone10 meters	Mean Lower Low Water	
OCS RNCs	2003 to 2005	digitized soundings from RNCs	1:20,000	WGS 84 geographic	Mean Lower Low Water	http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm
OCS ENC	2005	extracted soundings from ENC	1: 191,730	WGS 84 geographic	Mean Lower Low Water	http://www.nauticalcharts.noaa.gov/mcd/enc/index.htm

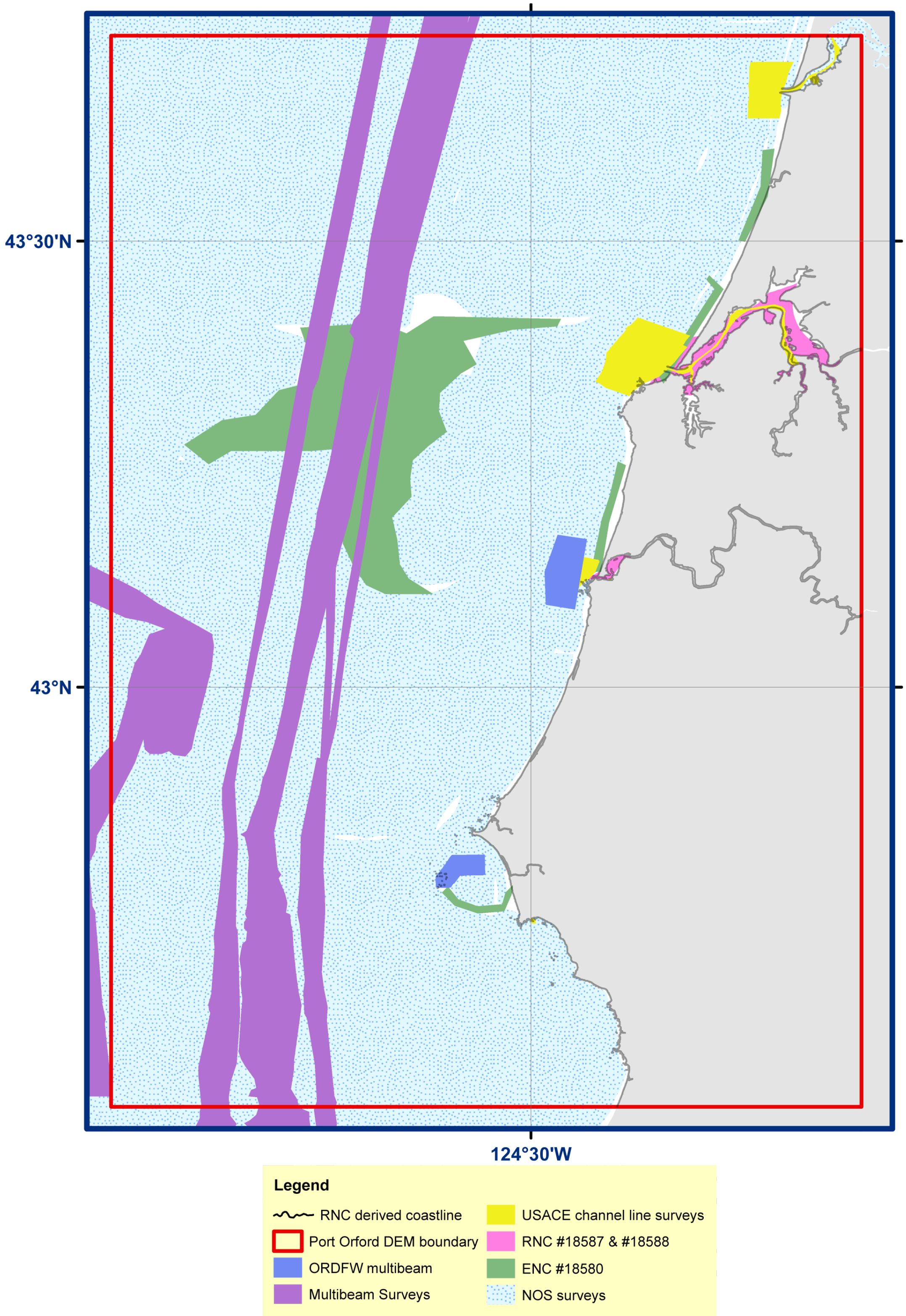


Figure 5. *Spatial coverage of bathymetric datasets used to compile the Port Orford DEM.*

1) NOS hydrographic survey data

A total of 34 NOS hydrographic surveys conducted between 1889 and 1991 were available for use in developing the Port Orford DEM. The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to either NAD 27 or NAD 83 datums (Table 5; Fig. 6).

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) referenced to NAD 83. The data were then converted to NAD 83 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 Port Orford DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW using a constant based on the Port Orford tide station (see Section 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 the topographic and other bathymetric datasets, the derived coastline, and NOS raster nautical charts (RNCs). The surveys were clipped to remove soundings that overlap the more recent multibeam surveys and where soundings from older surveys have been superseded by more recent NOS surveys.

Table 5: Digital NOS hydrographic surveys used in compiling the Port Orford DEM.

Survey ID	*Year*	*Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H01946	1889	20,000	MLW	NAD 27
H04217	1922	40,000	MLLW	NAD 27
H04218	1922	120,000	MLLW	NAD 27
H04452	1924	40,000	MLLW	NAD 27
H04479	1924	40,000	MLLW	NAD13
H04487	1925	20,000	MLLW	NAD 27
H04505	1925	40,000	MLLW	NAD 27
H04531	1925	120,000	MLLW	NAD 27
H04503A	1925/26	120,000	MLLW	NAD 27
H04812	1928	10,000	MLLW	NAD 27
H04813	1928	20,000	MLLW	NAD 27
H04814	1928	10,000	MLLW	NAD 27
H04815	1928	40,000	MLLW	NAD 27
H04817	1928	20,000	MLLW	NAD 27
H04819	1928	20,000	MLLW	NAD 27
H04883	1928	40,000	MLLW	NAD 27
H04885	1928	20,000	MLLW	NAD 27
H04886	1928	20,000	MLLW	NAD 27
H04887	1928	10,000	MLLW	NAD 27
H04889	1928	120,000	MLLW	NAD 27
H04890	1928	40,000	MLLW	NAD 27
H04891	1928	20,000	MLLW	NAD 27
H04896A	1928	80,000	MLLW	NAD 27
H09238	1971	10,000	MLLW	NAD 27
H09239	1971	10,000	MLLW	NAD 27
H09240	1971	2,500	MLLW	NAD 27
B00232	1990	50,000	MLLW	NAD 83
B00236	1990	50,000	MLLW	NAD 83
B00237	1990	50,000	MLLW	NAD 83

B00240	1990	50,000	MLLW	NAD 83
B00246	1990	50,000	MLLW	NAD 83
B00247	1990	50,000	MLLW	NAD 83
B00283	1991	50,000	MLLW	NAD 83
B00287	1991	50,000	MLLW	NAD 83

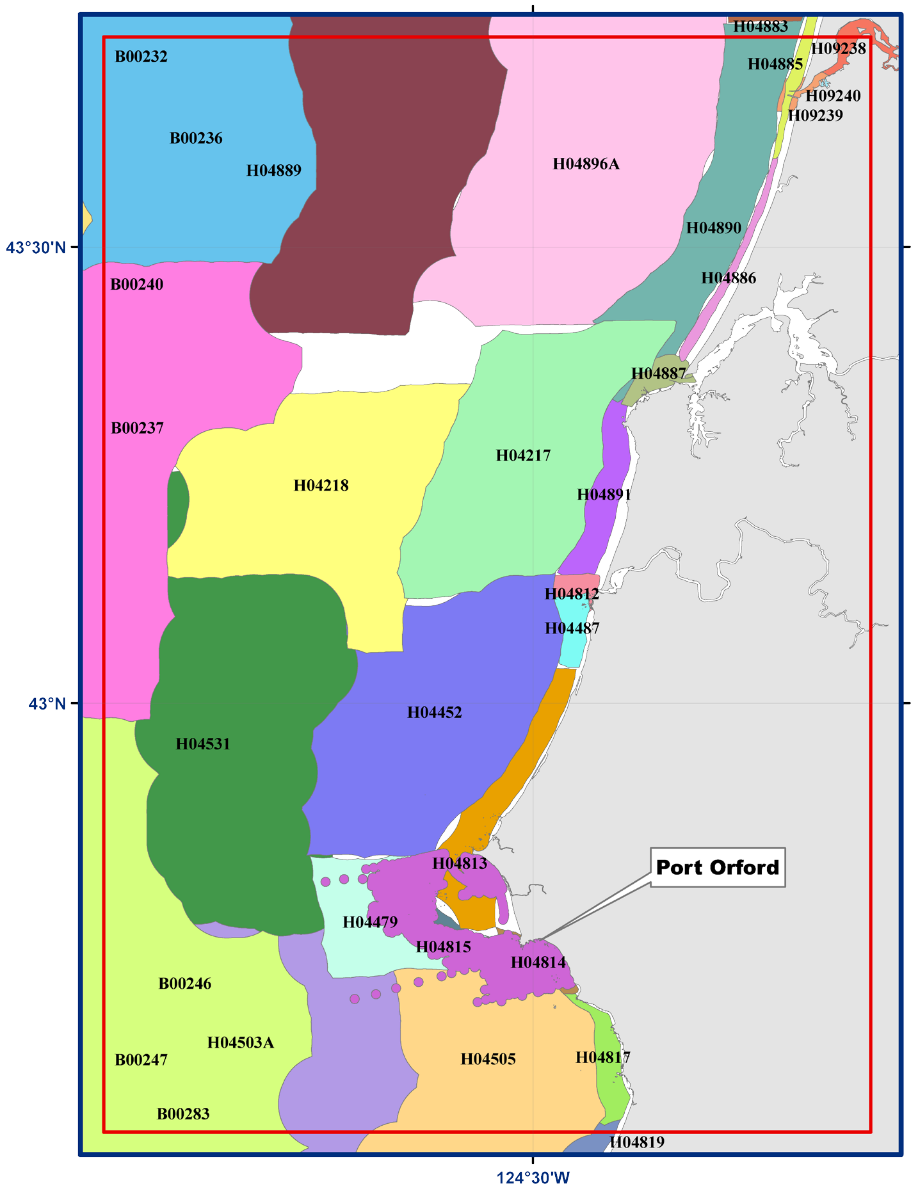


Figure 6. Digital NOS hydrographic survey coverage in the Port Orford region. Some older surveys were not used as they have been superseded by more recent surveys. DEM boundary in red.

2) USACE hydrographic channel line surveys

Twenty-two hydrographic channel line surveys were downloaded in xyz format from the USACE Portland District website (https://www.nwp.usace.army.mil/op/nwh/xyzcoastal.asp). The data were transformed to NAD 83 and MHW and changed to shape files using FME and quality checked in ArcMap against other bathymetric datasets.

Table 6: USACE hydrographic surveys used in compiling the Port Orford DEM.

Survey ID	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Resolution*
Port Orford	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space from 5 to 30 meters with point spacing from 3 to 10 meters
Coos Bay Approaches	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~300 meters with point spacing of ~35 meters
Coos Bay Empire	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos Bay Ranges	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos Charleston	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space from 10 to 15 meters with point spacing of ~8 meters
Coos Entrance Ranges	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space from 15 to 50 meters with point spacing from 13 to 18 meters
Coos Ferndale Marshfield	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos Jarvis	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos North Bend	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos North Bend Ranges	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~22 meters with point spacing of ~12 meters
Coos site E	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~50 meters with point spacing of ~25 meters
Coos site F	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~150 meters with point spacing of ~25 meters
Coos site H	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~60 meters with point spacing of ~22 meters
Coquille Approaches	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~155 meters with point spacing of ~40 meters
Coquille Bandon boat basin	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Point spacing < 10 meters
Coquille ODMDS	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~60 meters with point spacing of ~25 meters
Umpqua River Approaches	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~300 meters with point spacing of ~25 meters
Umpqua River Entrance	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~15 meters with point spacing of ~10 meters
Section 103 Site	2006	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~55 meters with point spacing of ~20 meters
Salmon Harbor Reach	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~15 meters with point spacing of ~12 meters
Winchester Bay	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space from 8 to 15 meters with point spacing of ~10 meters
Barretts Range	2007	MLLW	NAD 83 Oregon State Plane South (feet)	Line space of ~15 meters with point spacing of ~12 meters

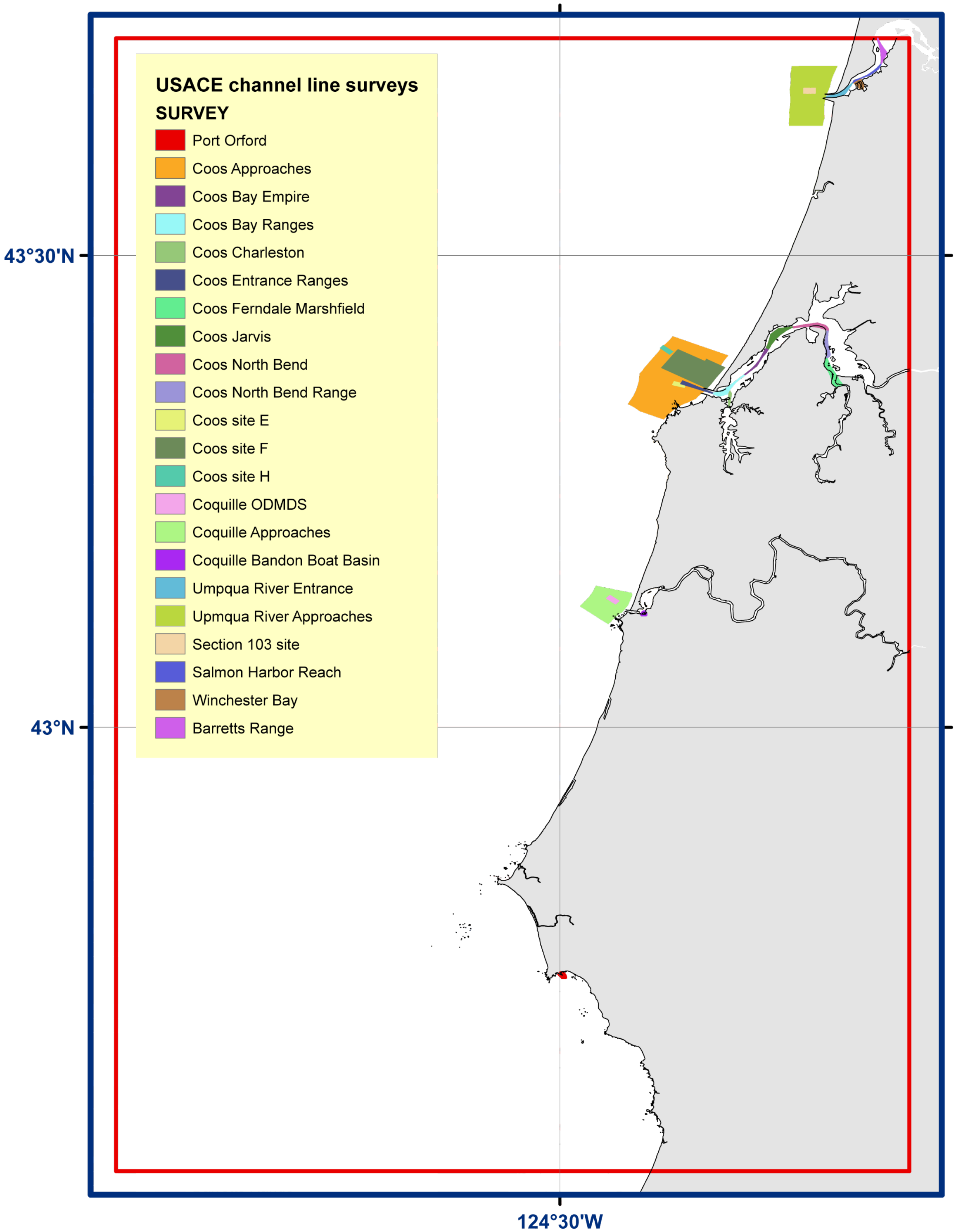


Figure 7. *Spatial coverage of USACE hydrographic channel line surveys for the Port Orford DEM.*

3) Multibeam swath sonar files

Nine multibeam swath sonar surveys were available from the NGDC multibeam database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) for use in the Port Orford DEM (Fig. 8, Table 7). This database is comprised of the original swath sonar files of surveys conducted mostly by the U.S. academic fleet. The downloaded data were gridded to 1 arc-second resolution using MB-System. Two 1994 Ewing surveys by Columbia University, Lamont-Doherty Earth Observatory (LDEO) were not used in building the DEM as analysis of the gridded data showed numerous, anomalous spikes and artifacts.

Most of the multibeam swath surveys offshore southern Oregon were transits rather than dedicated sea-floor surveys. All have a horizontal datum of WGS 84 geographic and undefined vertical datum, and were assumed to be referenced to mean sea level (MSL).

Table 7: Multibeam swath sonar files used in compiling the Port Orford DEM.

Cruise ID	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
AT07L14	2002	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AVON08MV	1999	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
AVON09MV	1999	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
CNTL04RR	2003	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
LWAD99MV	1999	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
Tecfluc	1998	assumed Mean Sea Level	WGS 84 geographic	Monterey Bay Aquarium Research Institute (MBARI)
Tran2sou	1998	assumed Mean Sea Level	WGS 84 geographic	Monterey Bay Aquarium Research Institute (MBARI)

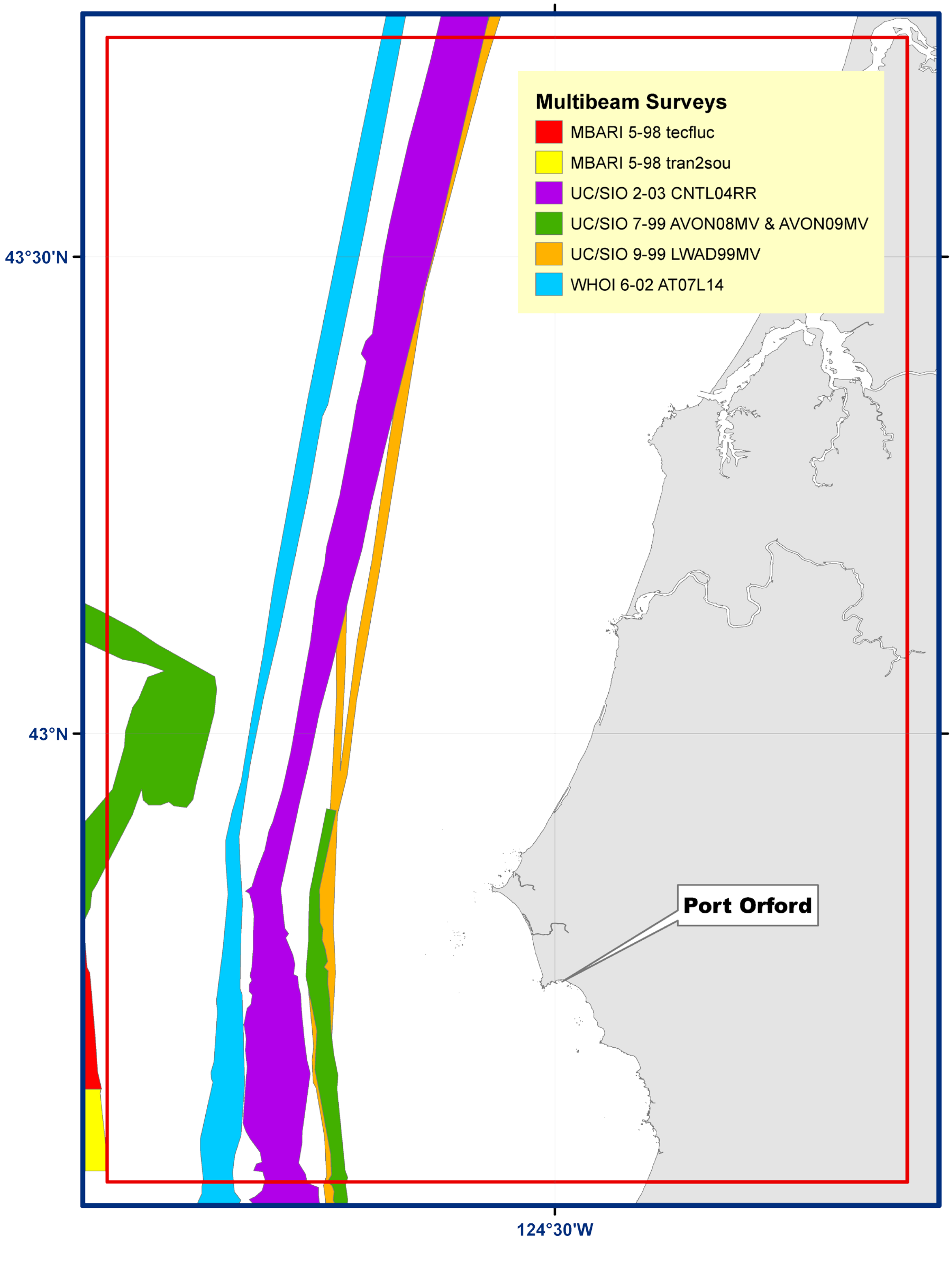


Figure 8. *Spatial coverage of multibeam swath sonar files from NGDC multibeam database used in the Port Orford region.*

After assessing individual survey quality, the gridded data were transformed to MHW in xyz format using FME, displayed in QT Modeler and edited using GEODAS Hydroplot and QT Modeler. Figure 9 shows a band of anomalous data spikes in survey Tran2sou, which were removed before use in the DEM. Difficulties with multibeam data collection included center beam noise errors (Fig. 10) and swath end rolling, "smiles and frowns" (Fig. 11). Surveys were manually edited down the center beam and at the edges where these errors were most pronounced, before creating a gridded bathymetric surface. Figure 11 shows the difference between a pre-edited and post-edited bathymetric surface.

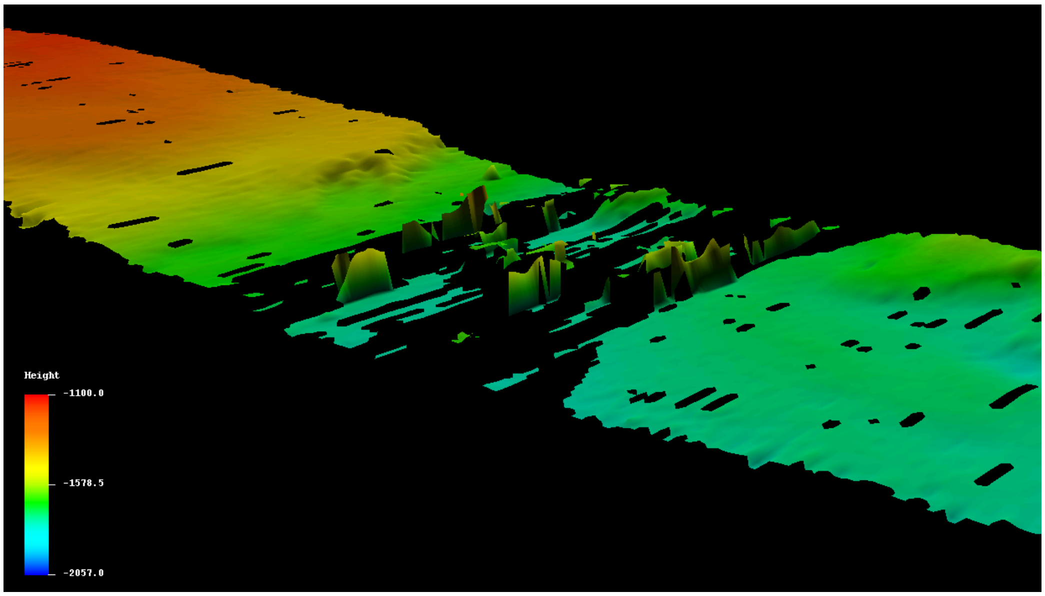


Figure 9. *QT Modeler image of anomalous data spikes in the multibeam sonar survey Tran2sou. These spikes were removed by clipping out this section of trackline.*

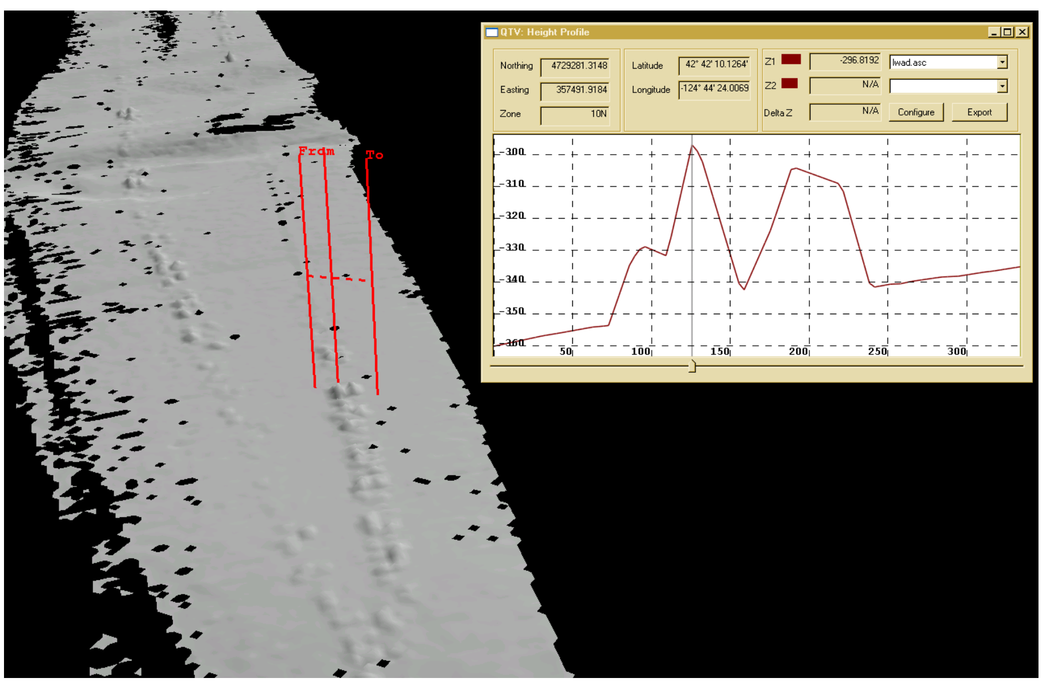


Figure 10. *QT Modeler image of multibeam survey LWAD99MV showing center beam noise errors of up to 50 meters. The survey was manually edited in strips or by individual points to remove the most significant errors.*

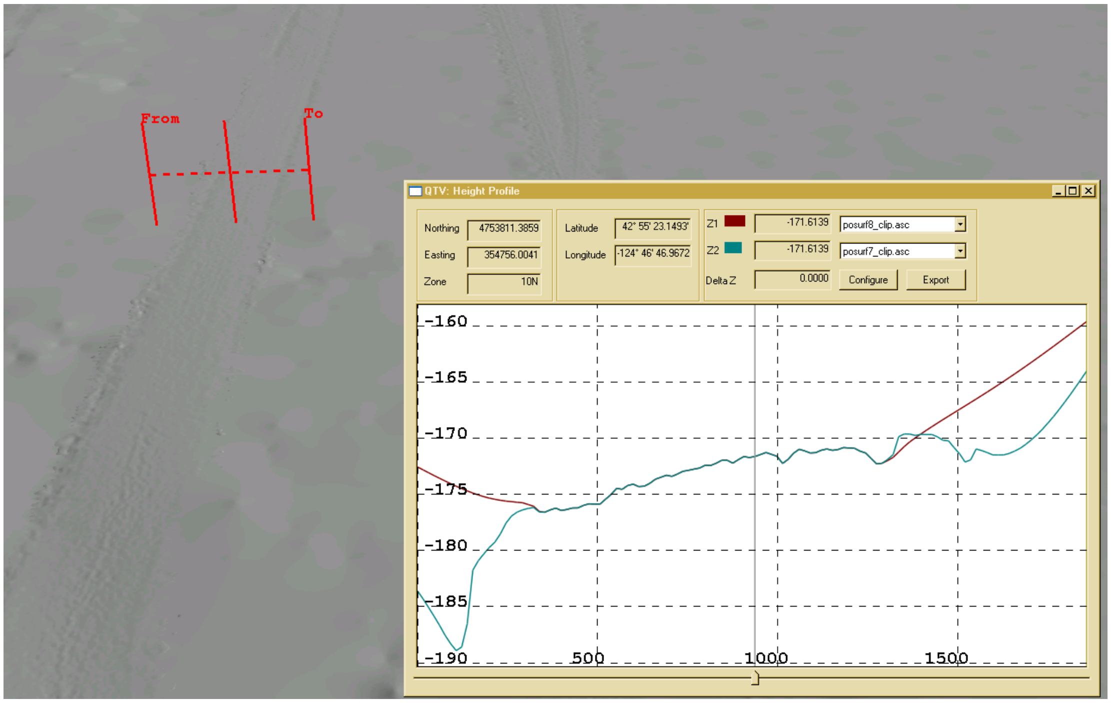
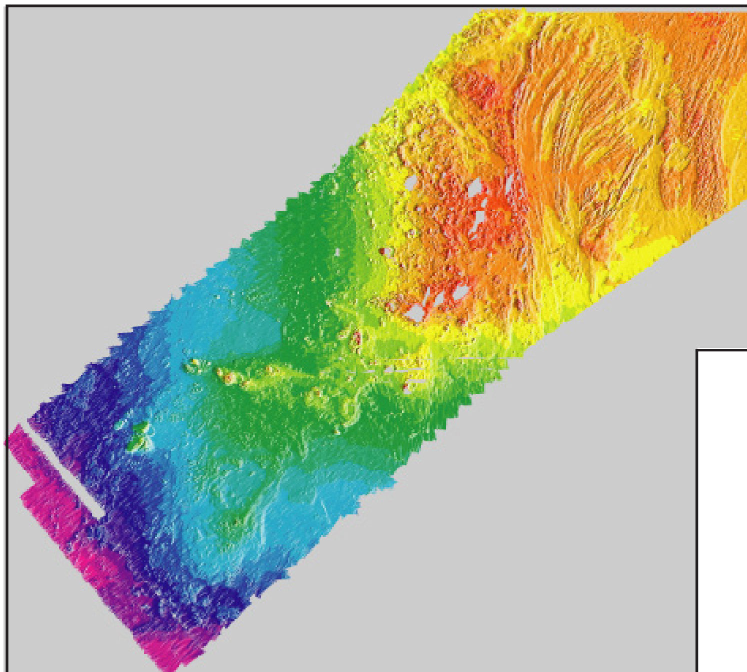


Figure 11. *QT Modeler image of cross section comparing gridded bathymetric surfaces of pre-edited data (shown in blue on the graph) and the post edited data (shown in red on the graph).*

4) Oregon Department of Fish and Wildlife/Marine Resources Program Multibeam survey

The Oregon Department of Fish and Wildlife/Marine Resources Program provided two high-resolution multibeam surveys for Orford Reef south of Cape Blanca (top image in Fig. 12) and for Bandon Reef, the near shore area at the entrance to the Coquille River (lower right image in Fig. 12). Information on these surveys is detailed in habitat reports (Fox et. al, 1999 and 2000) and was downloaded from the ORDFW website (http://www.dfw.state.or.us/MRP/publications/). The surveys were transformed to MHW and NAD 83 using FME and processed using the GMT 'blockmedian' tool, for use in creating a bathymetric surface. The full-resolution data files were used in the final gridding process.



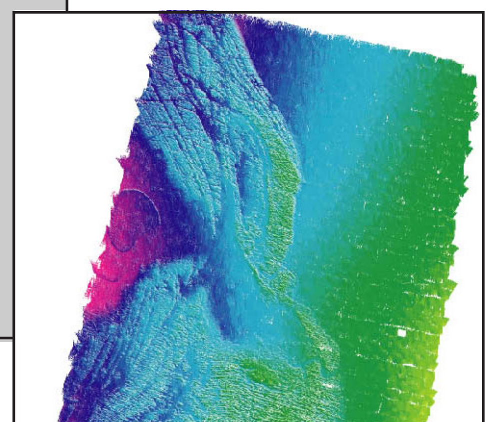


Figure 12. *Images of gridded multibeam surveys provided by the Oregon Dept. of Fish and Wildlife/MarineReseources Program. Orford Reef in gray box above and Bandon Reef in box to right.*

5) Office of Coast Survey chart soundings

The OCS electronic navigational chart (ENC) sounding data were extracted from chart #18580 and converted to MHW in a region without digital NOS soundings. Soundings were clipped to the multibeam sonar surveys, the USACE hydrographic surveys, and the more recent NOS hydrographic surveys. Additional soundings digitized from RNCs #18587 and #18588 were added near Coos Bay and Coquille River to ensure negative elevations in the bathymetric surface where no other digital sounding data were available.

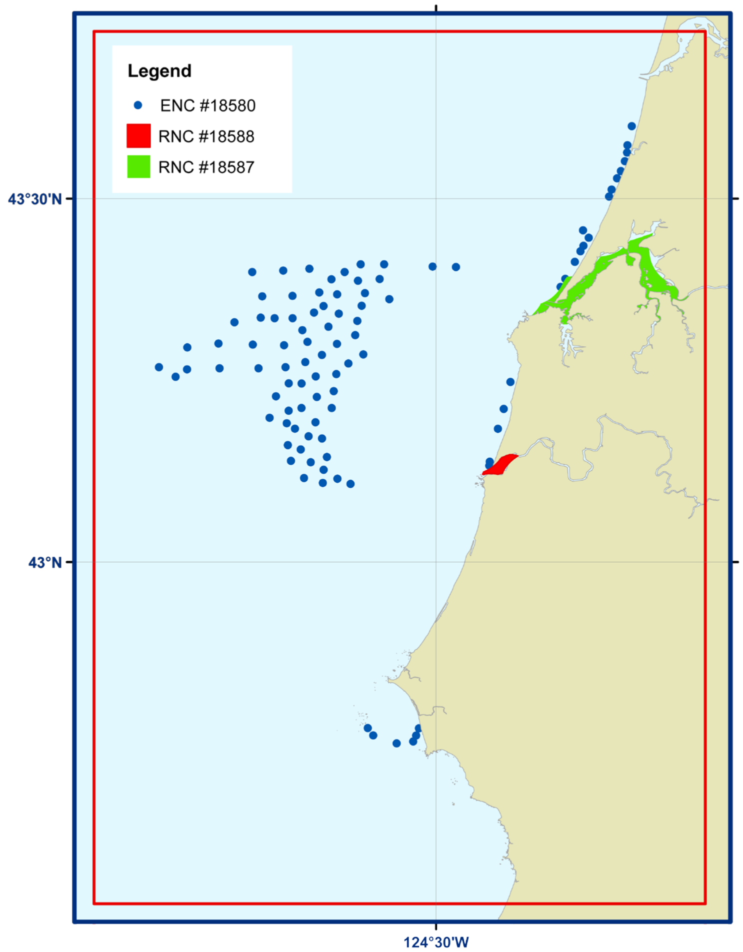


Figure 13. *Spatial coverage of the OCS chart sounding data used to compile the Port Orford DEM.*

Inconsistencies were identified while merging the bathymetric datasets due to the range in ages of the NOS hydrographic surveys and differences in resolution. In areas where more recent data were available, the older NOS surveys were either edited or removed.

3.1.3 Topography

Three topographic datasets in the Port Orford region were obtained and used to build the Port Orford DEM (Table 8; Fig. 14). The USGS NED 1/3 arc-second data provided full coverage for the DEM area and the 2002 CSC LiDAR dataset covered the entire coastline. NGDC created an additional topographic dataset representing four coastal features not fully resolved in the NED or CSC dataset. NGDC evaluated but did not use the Shuttle Radar Topography Mission (SRTM) Elevation 1 arc-second DEM available from USGS, as the higher-resolution 1/3 arc-second NED DEMs provided complete coverage.

Table 8: Topographic datasets used in compiling the Port Orford DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS	1999-2006	NED DEM	1/3 arc-second	NAD 83 geographic	NAVD88 (meters)	http://ned.usgs.gov/
CSC	2002	LiDAR	~2 meters	NAD 83 geographic	NAVD88 (meters)	http://maps.csc.noaa.gov/TCM/
NGDC		digitized elevation points	~10 meters	WGS 84 geographic	MHW (meters)	

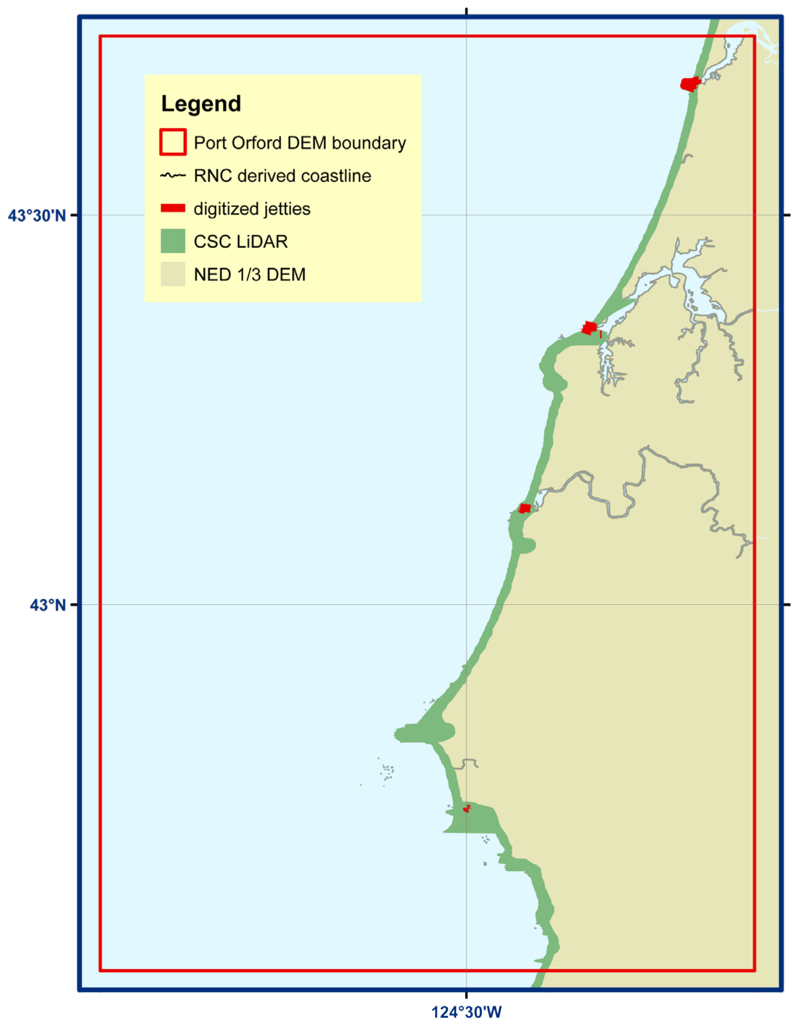


Figure 14. *Spatial coverage of topographic datasets used in the Port Orford DEM.*

1) **USGS NED topographic 1/3 arc-second DEMs**

The U.S. Geological Survey (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1/3 arc-second coverage of the Port Orford region[4]. Data are in NAD 83 geographic coordinates and NAVD88 vertical datum (meters), and are available for download as raster DEMs. 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; it has been revised using data collected in 1999 and 2000. The NED DEM included "zero" elevation values over the open ocean, which were removed from the dataset by clipping to the combined coastline. The clipping process also removed artifacts shown in Figure 15.

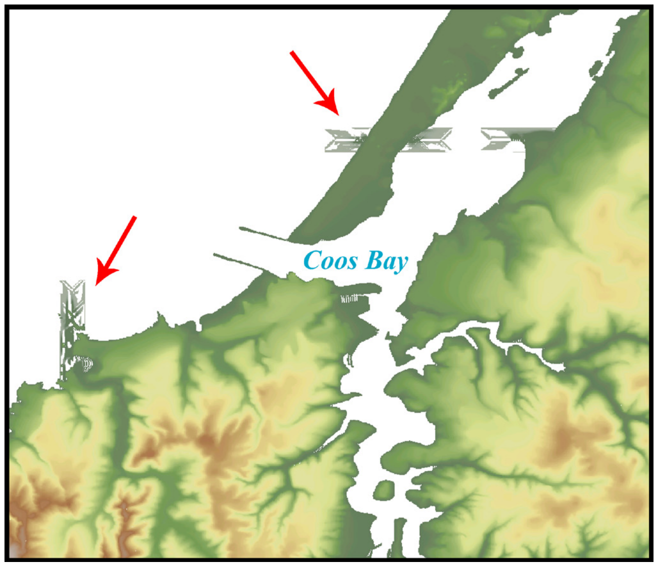


Figure 15. *NED topographic data at Coos Bay. Red arrows point to artifacts present in the raw dataset.*

4. 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, except for AK, which is NAD 27. 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]

2) CSC LiDAR topography

The 2002 NASA/USGS Airborne LiDAR Assessment of Coastal Erosion (ALACE) Project topographic LiDAR dataset was downloaded from the CSC website (http://maps.csc.noaa.gov/TCM/) and transformed to NAD 83 and MHW using FME.

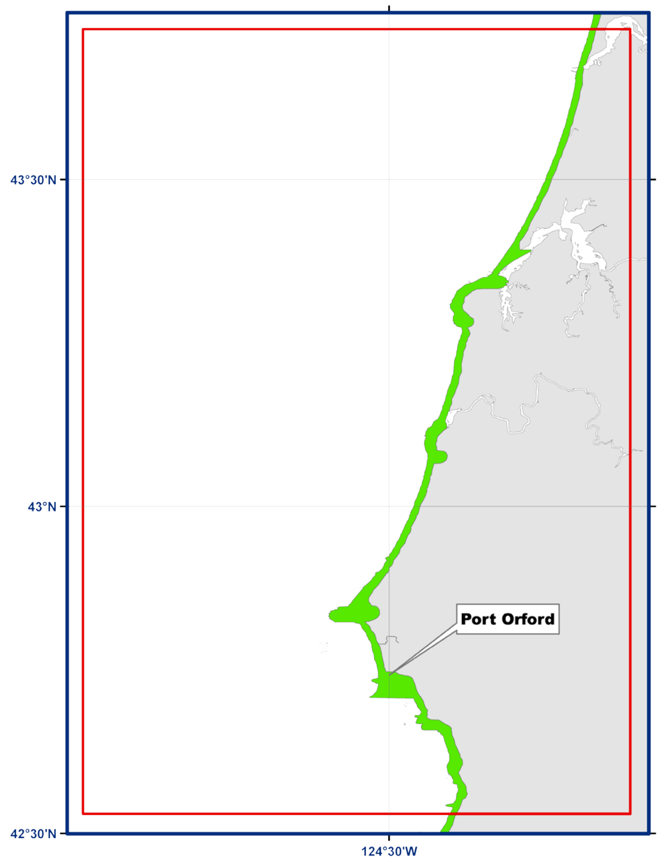


Figure 16. *Spatial coverage of the CSC topographic LiDAR within the Port Orford DEM boundary.*

As this dataset was not processed to bare earth and contained elevation values over open water, NGDC processed the data to simulate bare earth. First, elevations below 0.85 meters were filtered out, removing the majority of water-surface returns. Next, the data were gridded using MB-System to create a 1/3 arc-second grid that aligned the USGS NED topographic DEM. ArcGIS 3D Analyst was used to remove points where the difference between the NED and the LiDAR data were greater than 7 meters. Areas where data were removed by this technique roughly correspond to false color satellite images representing vegetation (Fig. 17; Table 9). This technique also created a smoother seam between the two datasets.

Table 9: Summary of True Color and Short-Wavelength InfraRed (SWIR) satellite imagery representing surface features (https://zulu.ssc.nasa.gov/mrsid/tutorial/Landsat%20Tutorial-V1.html).

Surface Feature	*True Color*	*SWIR (GeoCover2000)*
	Red: Band 3	Red: Band 7
	Green: Band 2	Green: Band 4
	Blue: Band 1	Blue: Band 2
Trees and Bushes	olive green	shades of green
Crops	medium to light green	shades of green
Wetland Vegetation	dark green to black	shades of green
Water	shades of blue and green	black to dark blue
Urban Areas	white to light blue	lavender
Bare Soil	white to light blue	magenta, lavender, or pale pink

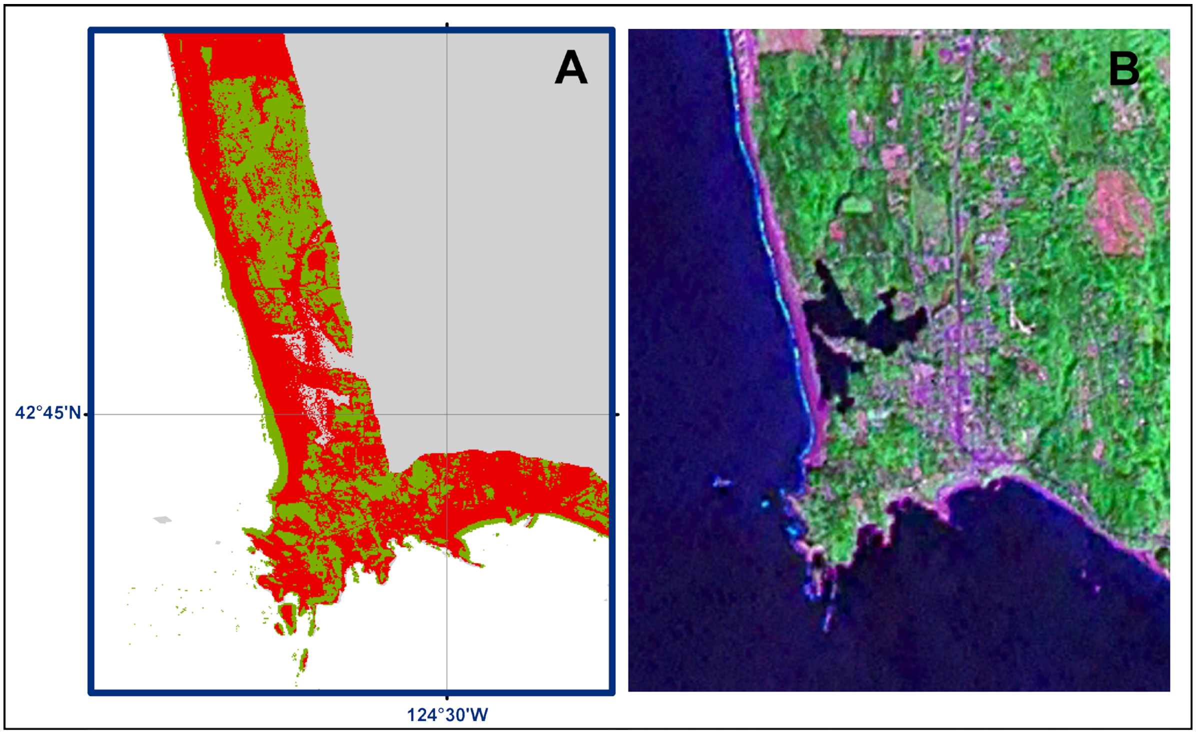


***Figure 17**. Comparison of CSC LiDAR data coverage before and after NGDC processing and NASA Geocover2000 short-wavelength infrared image of the Cape Blanca and Port Orford region. A) CSC LiDAR coverage. Green is coverage before processing, red is post processing coverage. B) Pink/magenta areas in satellite image have less vegetation than green colored areas.*

3) NGDC digitized elevation points

As neither the NED DEMs nor the CSC LiDAR data fully represent the jetties at Port Orford, Coquille River, Coos Bay, and Umpqua River, NGDC created digital representations of the features in ArcMap. Elevations assigned to the jetties are based on NGS monument elevations where available or CSC LiDAR values (point spacing ~10 meters).

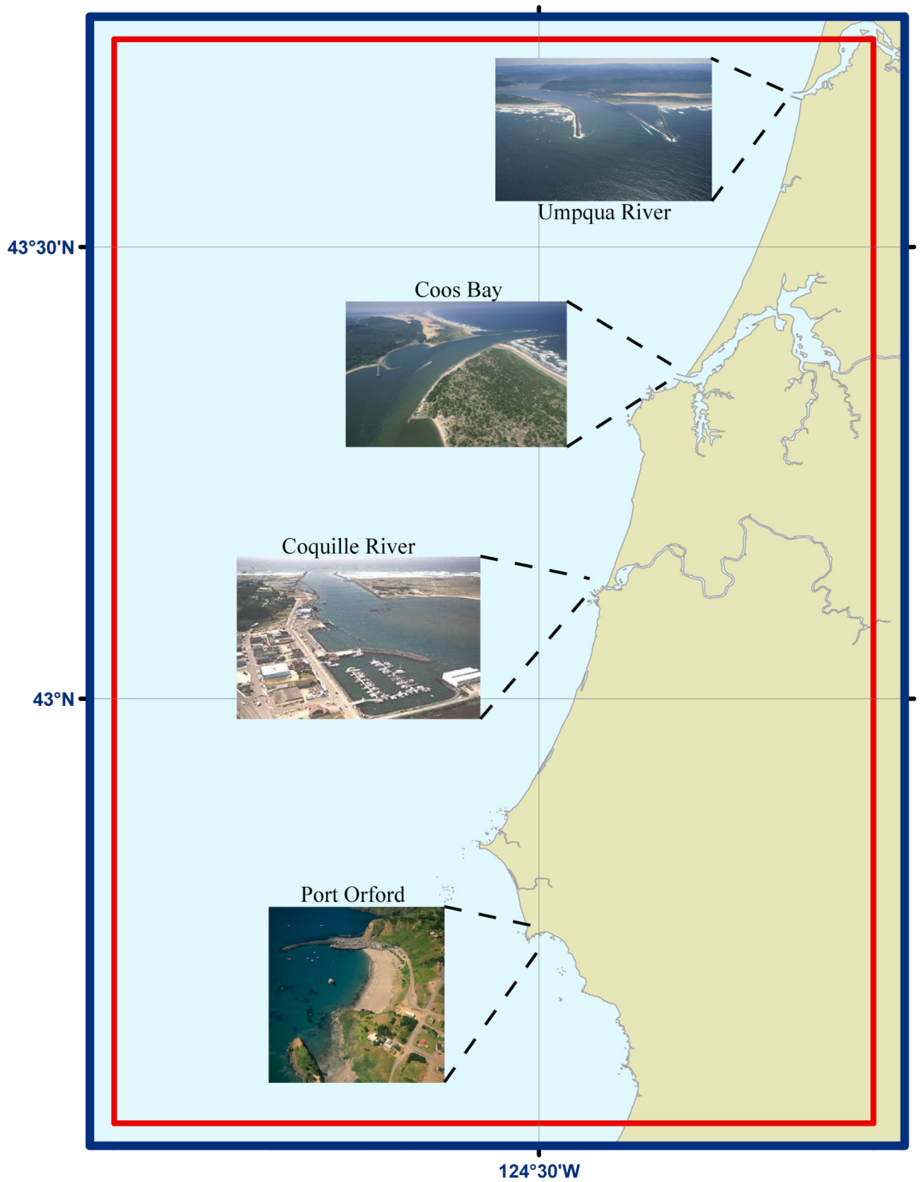


Figure 18. *Location and aerial photos of four NGDC digitized jetties. Photos from USACE photo database (https://eportal.usace.army.mil/sites/DVL/default.aspx)*

After processing, the topographic data were viewed in ArcMap to make sure that the transitions along dataset edges were smooth. The data were then converted to xyz format using FME for the final gridding process.

3.2 Establishing Common Datums

3.2.1 *Vertical datum transformations*

Datasets used in the compilation and evaluation of the Port Orford DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), and Mean Sea Level (MSL). All datasets were transformed to MHW to provide the maximum flooding for inundation modeling. Units were converted from feet to meters as appropriate.

1) **Bathymetric data**

   The NOS hydrographic surveys, the multibeam sonar surveys, the navigation chart soundings, and the USACE channel line surveys were transformed from MLLW and MSL to MHW, using constants based on the Port Orford tide station (Table 10).

2) **Topographic data**

   The USGS NED 1/3 arc-second DEMs and the CSC topographic LiDAR data were originally referenced to NAVD88. Conversion to MHW, using FME software, was accomplished by adding a constant offset of -1.853 meters (Table 10) as measured at the Port Orford tide station.

Table 10. Relationship between Mean High Water and other vertical datums at the Port Orford tide station #9431647.

Vertical datum	*Difference to MHW*
MSL	-0.805
NAVD88	-1.853
MLW	-1.589
MLLW	-2.004

3.2.2 *Horizontal datum transformations*

Datasets used to compile the Port Orford DEM were originally referenced to WGS 84 geographic, NAD 83 geographic, NAD 27 geographic, or NAD 83 Oregon State Plane South datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of NAD 83 geographic 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 ArcMap for consistency between datasets. 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:

- Suspect topographic elevations located on open-ocean in both NED and CSC datasets.
- Inconsistencies between the NED and CSC topographic data.
- Data errors in multibeam swath sonar surveys, which were expressed as anomalous spikes. Manual editing of the multibeam sonar data were necessary to minimize these artifacts.
- Topographic CSC LiDAR dataset not processed to bare earth. The dataset required filtering of elevation values on land and removal of returns from the water surface.
- Digital, measured bathymetric values from NOS surveys date back over 100 years. More recent data, such as the USACE hydrographic surveys depths, differed from older NOS data by as much as 10 meters nearshore and up to 75 meters in deeper water compared to multibeam data. The older NOS survey data were excised where more recent bathymetric data exists.

3.3.2 *Smoothing of bathymetric data*

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second Port Orford DEM: in both deep water and in some areas close to shore, the NOS survey data have point spacing up to 1900 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’ bathymetric 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 clipped to remove overlap with the USACE soundings, the NGDC multibeam data, the ORDFW multibeam survey data, the ENC sounding data, and the digitized RNC sounding data and combined into a single file, along with points extracted from the combined coastline—to provide a buffer along the entire coastline. The coastline elevation value was set at -1.0 m to ensure a bathymetric surface below zero in areas where data are sparse or non-existent.

The point data were median-averaged using the GMT tool ‘blockmedian’ to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Port Orford 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 (e.g., Fig. 19) and exported as an xyz file for use in the final gridding process (see Table 11).

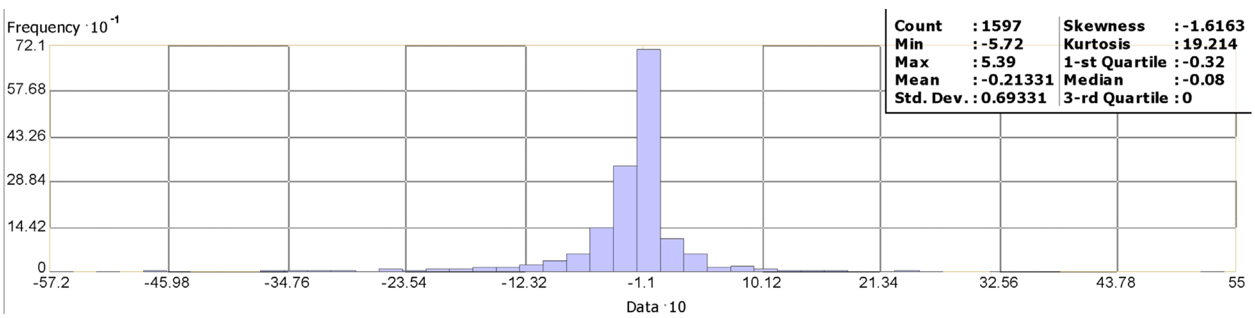


Figure 19. *Histogram of the differences between NOS hydrographic survey H04891 and the 1 arc-second pre-surfaced bathymetric grid.*

3.3.3 *Gridding the data with MB-System*

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the 1/3 arc-second Port Orford DEM. MB-System is an NSF-funded free software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. 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 CSC LiDAR data. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid. Gridding was performed in quadrants, with the resulting Arc ASCII grids seamlessly merged in ArcCatalog to create the final 1/3 arc-second Port Orford DEM.

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

Dataset	*Relative Gridding Weight*
CSC topographic coastal LiDAR	1,000,000
OR DFW Multibeam surveys	10,000
NGDC Multibeam surveys	1,000
USACE surveys	10,000
Digitized Nautical Charts	100
USGS NED topographic DEM	100
Digitized Jetties	10,000
NOS hydrographic surveys	10
Derived coastline	1
Pre-surfaced bathymetric grid	1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Port Orford DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of up to 10 meters: CSC topographic LiDAR data have an accuracy between 1 and 3 meters; NED topography is accurate to within about 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, potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys, and by manmade morphologic change (e.g., channel dredging and building of jetties).

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Port Orford DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy between 0.1 to 0.3 meters for CSC LiDAR data, and up to 7 meters for NED topography. Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth. 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 Port Orford DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 20). The DEM was transformed to UTM Zone 10 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 was accomplished using ESRI ArcScene (e.g., Fig. 21). 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 Port Orford DEM in its final version.

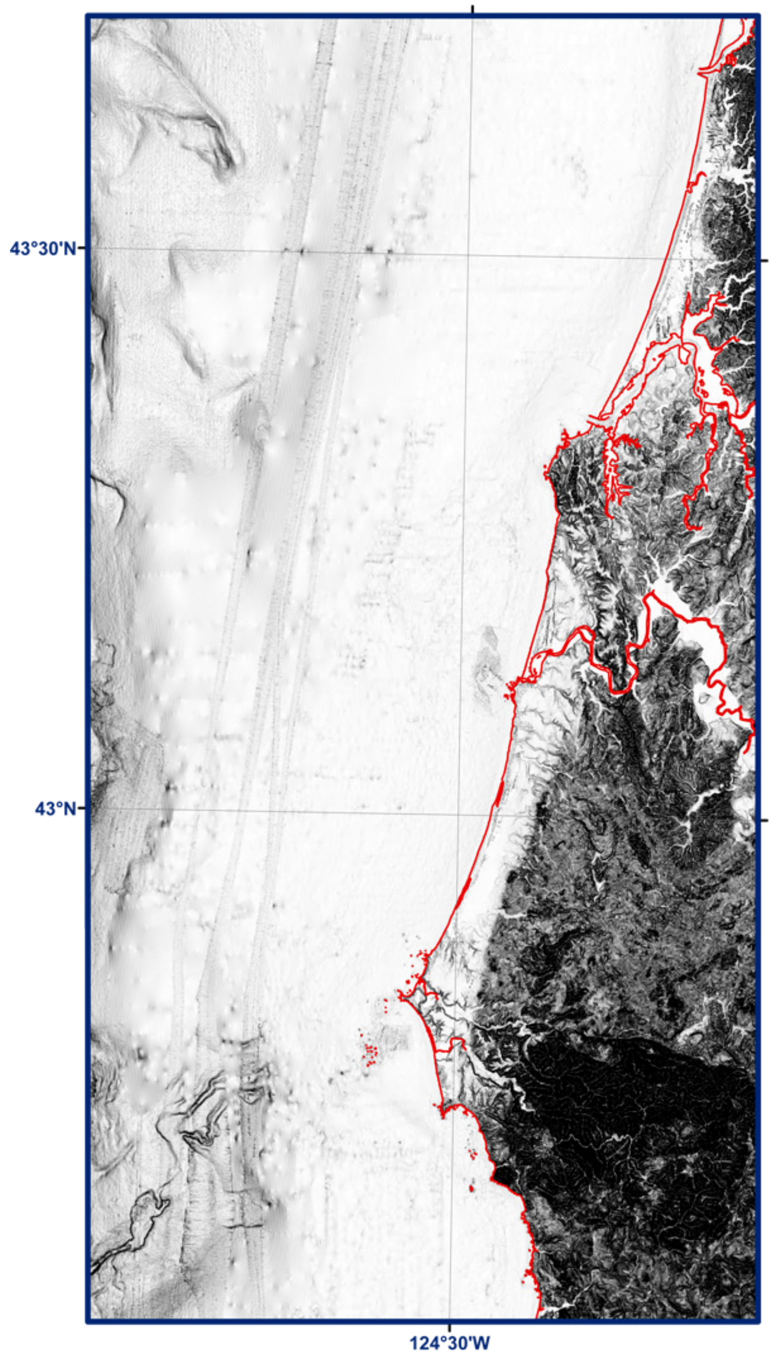


Figure 20. *Slope map of the Port Orford DEM. Flat-lying slopes are white; dark shading denotes steep slopes; derived coastline in red.*

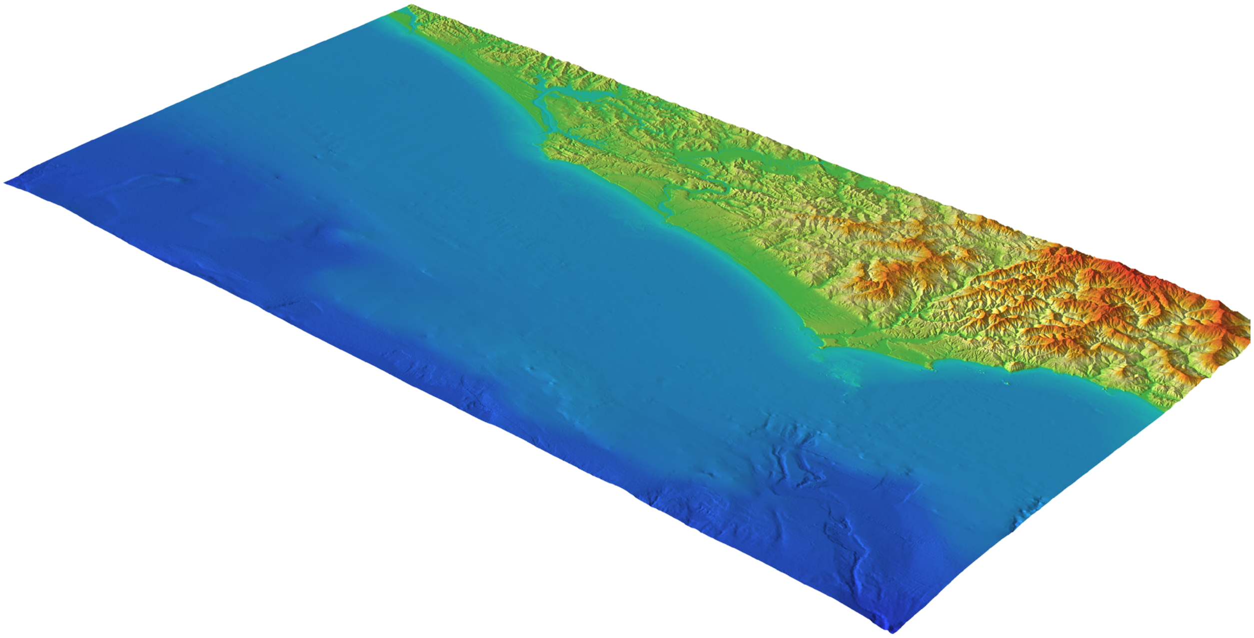


Figure 21. *Perspective view from the southwest of the Port Orford DEM. No vertical exaggeration.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Port Orford 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 differences between a USACE hydrographic survey file located at the approach to Coos Bay and the Port Orford DEM is shown in Figure 22. Differences range from -4.0 to 3.4, with 39 out of 3829 soundings exceeding 1.0-meter discrepancy from the DEM. These soundings were located where two USACE surveys overlapped and around the reef at Gregory Point.

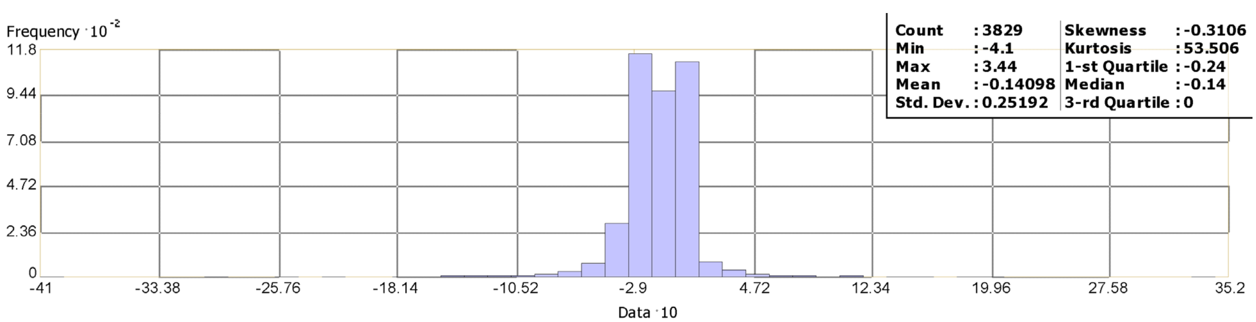


Figure 22. *Histogram of the differences between one USACE hydrographic survey and the Port Orford DEM.*

3.4.5 *Comparison with NGS geodetic monuments*

The elevations of 710 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 NAD 83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Monuments installed on lighthouses or buildings were not included in assessment of the DEM.

Elevations were shifted to MHW vertical datum (see Table 10) for comparison with the Port Orford DEM (see Fig. 24 for monument locations). Differences between the Port Orford DEM and the NGS geodetic monument elevations range from -304 to 60 meters, with the majority of them within ± 10 meters (Fig. 23). Negative values indicate that the DEM is less than the monument elevation. Monuments located in a lighthouse, on sand dunes, and at a rock quarry had the greatest negative values. The monuments with the greatest positive values were located in areas with steep terrain and have a horizontal accuracy of ± 6 arc-seconds (~180 meters).

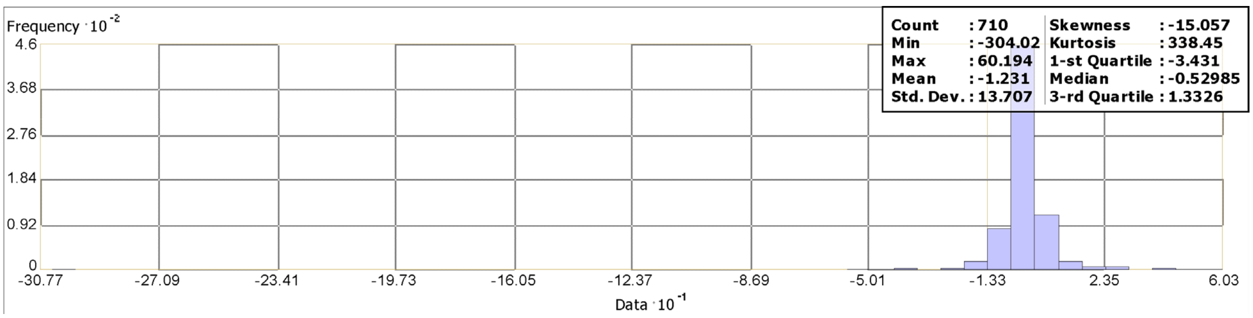


Figure 23. *Histogram of the differences between NGS geodetic monument elevations and the Port Orford DEM.*

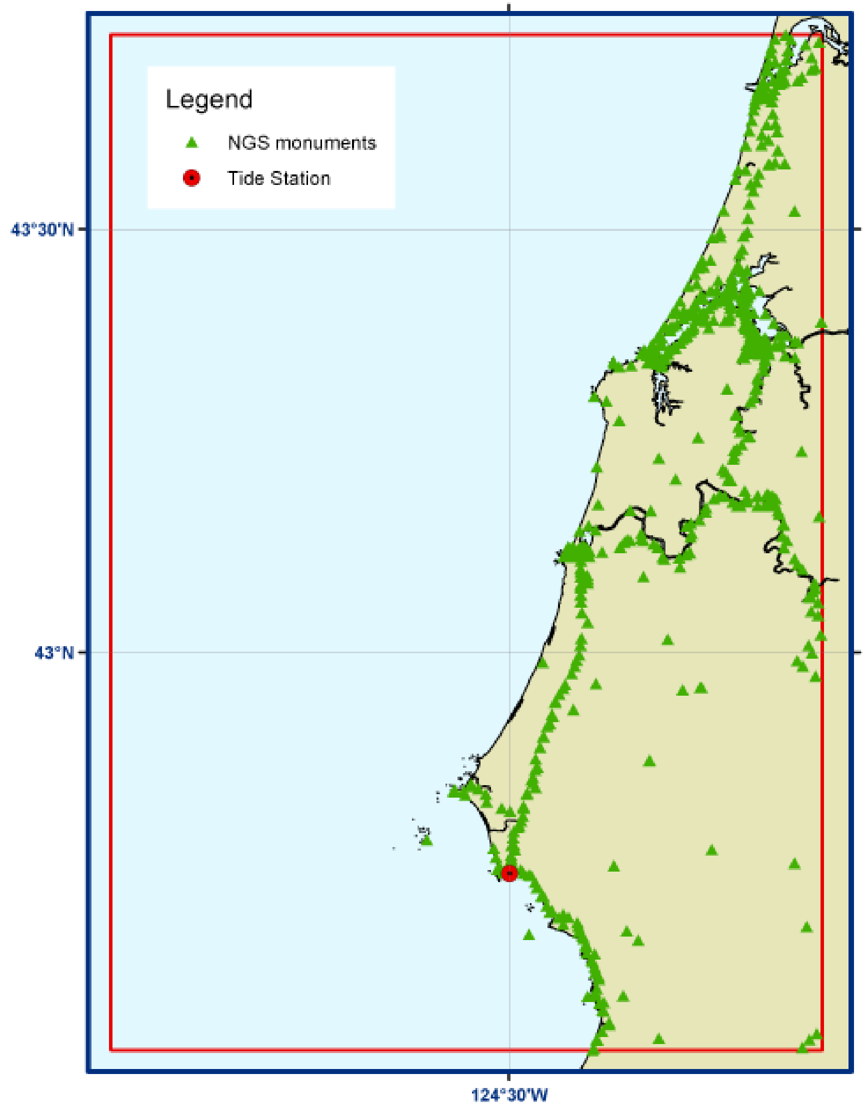


Figure 24. *Location of NGS geodetic monuments, shown as green triangles, and the NOAA Port Orford tide station, red circle. NGS monument elevations were used to evaluate the DEM.*

4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of the Port Orford, Oregon 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, state and local agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT, MB-System and Quick Terrain Modeler software.

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

- Conduct hydrographic surveys for near-shore areas, especially in bays and river inlets.
- Complete bathymetric–topographic LiDAR surveying of entire region, especially within coastal zones.
- Process CSC topographic LiDAR data to bare earth.
- Re-survey older, low-resolution NOS hydrographic surveys in deeper waters.

5. Acknowledgments

The creation of the Port Orford DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin and Vasily Titov (PMEL); Daniel Proudfit of U.S. Army Corp of Engineers, Portland District; and Arlene Merems and David Fox of Oregon Department of Fish and Wildlife/Marine Resources Program.

6. References

Nautical Chart #18580 (RNC and ENC), 22nd Edition, 2005. Cape Blanco to Yaquina Head. Scale 1: 191,730. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18587 (RNC), 70th Edition, 2005. Coos Bay. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18588 (RNC), 37th Edition, 2003. Coquille River Entrance. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18589 (RNC), 16th Edition, 2007. Port Orford to Cape Blanco. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18600 (RNC and ENC), 14th Edition, 2002. Trinidad Head to Cape Blanco. Scale 1:196,948. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18601 (RNC), 14th Edition, 2007.Cape Sebastian to Humbug Mountain. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Fox, D.S.; Amend, M.; Merems, A. 1999. 1999 Nearshore Rocky Reef Assessment, Final Report for 1999 Grant Contract No.99-072. Oregon Department of Fish and Wildlife/Marine Program.

Fox, D.S.; Amend, M.; Merems, A.; Appy, M. 2000. 2000 Nearshore rocky reef assessment. Newport, OR: Oregon Department of Fish and Wildlife. 32 pp.

7. Data Processing Software

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

FME 2007 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

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

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

Quick Terrain Modeler v. 6.0.1, LiDAR processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/