NOAA Technical Memorandum NESDIS NGDC-3

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

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1. Introduction

In July 2006, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a bathymetric/topographic digital elevation model (DEM) of Port San Luis, California (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL), NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second (~10 meter) elevation grid was generated from numerous, diverse digital datasets in the region (grid boundary and sources shown in Fig. 2). The DEM will be used as input for the Method of Splitting Tsunami (MOST) model (http://www.pmel.noaa.gov/pubs/PDF/tito1927/tito1927.pdf) developed by PMEL to simulate tsunami generation, propagation and inundation. This report provides a summary of the data sources and methodology used in developing the Port San Luis DEM.

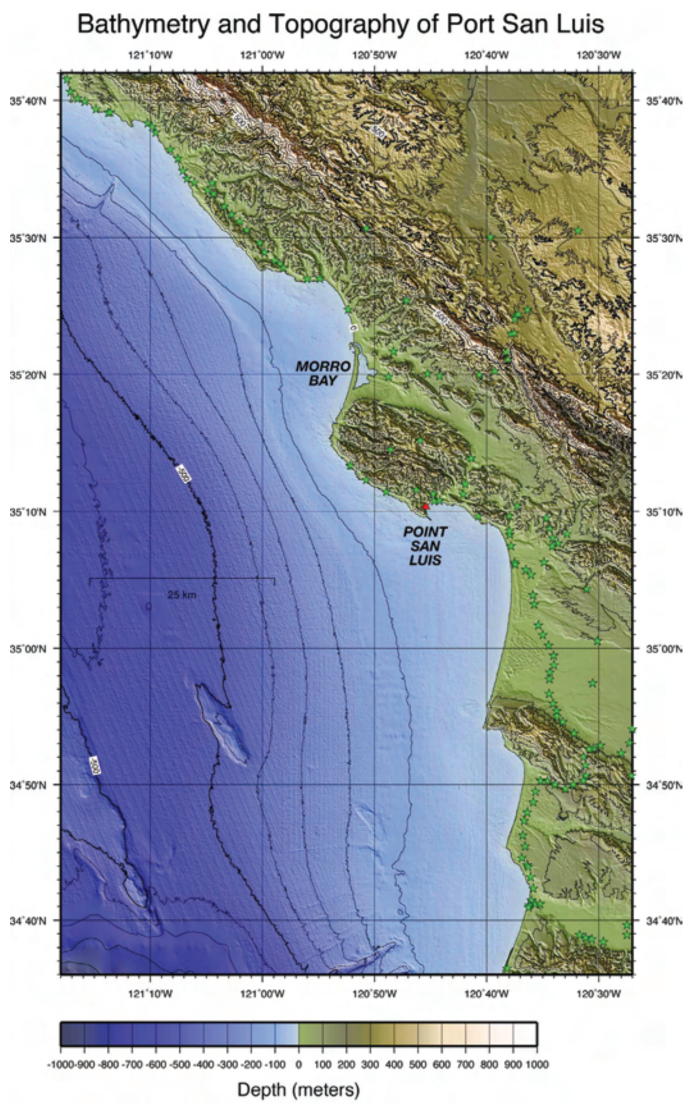

Figure 1. *Shaded-relief image, derived from the DEM, of the Port San Luis, California area. Red triangle locates tidal bench mark listed in Table 9; green stars locate USGS bench marks listed in Table 10. Contour interval (referenced to MHW): 100 meters.*

2. Study Area

The study area covers the coastal region of Port San Luis, California, approximately equal distances to Los Angeles and San Francisco. Located in San Luis Obispo County with coastal communities of Avila Beach, Pismo Beach, and Morro Bay, the area has populations of 797, 8,551 and 10,350 respectively. Avila Beach's population is recovering after oil spill and soil contamination problems that occurred in 1992. Pismo Beach is famous for having one of the longest and widest beaches in California, as well as its large clams. San Luis Obispo Creek empties into the bay just northeast of Avila Beach. The Morro Bay 76-square mile watershed is an important biological and economic resource. Two creeks, Los Osos and Chorro, drain the watershed into the bay.

In contrast to the sandy beaches, rocky headlands composed of igneous rocks--granites and basalts—resist wave erosion and provide locally endangered Peregrine falcons with nesting sites. The volcanic formations along the coast include Morro Rock in San Luis Obispo County and outcroppings of basaltic lava. Morro Rock, located at the entrance to Morro Bay, is one of a chain of nine extinct volcanic necks that stretch approximately 12 miles from Morro Bay to San Luis Obispo. The chain is actually known by two names: The Seven Sisters, or the Nine Morros/Sisters, depending on how many of the peaks are counted. It is theorized that the 22–28 million year old chain originally erupted along an old fault line, south of where they are now located with their remnants (the extinct necks) moving along the San Andreas fault to their present day locations. Morro Rock itself is the youngest of the chain (excluding Davidson Seamount, submerged 2.5 miles offshore of Morro Rock), is also the most eastern of the chain, located along the California coast. Morro Rock was mined on and off until 1963 and provided material for the breakwater of Morro Bay and Port San Luis Harbor. South of Morro Bay, pillow basalts can be seen in beach cliffs near the Port San Luis commercial fishing pier. Visit http://nagt.org/files/nagt/field/fieldtrips/undfieldtrip.pdf and http://ceres.ca.gov/ceres/calweb/coastal/geography.html for more information.

3. Methodology

The Port San Luis DEM was developed to meet PMEL required specifications (Table 1), based on input requirements for the MOST inundation model. The best available data were obtained by NGDC and used to produce the DEM. Data processing, grid assembly, and quality assessment are described in the following subsections.

Table 1: PMEL specifications for the Port San Luis, California DEM.

Grid Area	Port San Luis, California
Coverage Area	120.45 º to 121.3º W; 34.6º to 35.7º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System (WGS84)
Vertical Datum	Mean High Water
Vertical Units	Meters
Grid Spacing	1/3 arc-seconds
Grid Format	ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic data (Fig. 2) were obtained from numerous federal and state government agencies, and universities, including: the NOAA National Ocean Service (NOS), Office of Coast Survey (OCS), and Coastal Services Center (CSC); the U.S. Army Corps of Engineers (USACE); the U.S. Geological Survey (USGS); and the University of California, San Diego (UCSD). Safe Software's (http://www.safe.com/) FME data translation tool package was used to convert datasets into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed to assess data quality and manually edit datasets. Vertical datum transformations to Mean High Water (MHW) were largely achieved using VDatum model software (http://chartmaker.ncd.noaa.gov/csdl/vdatum.htm) developed jointly by OCS and NOAA's National Geodetic Survey.

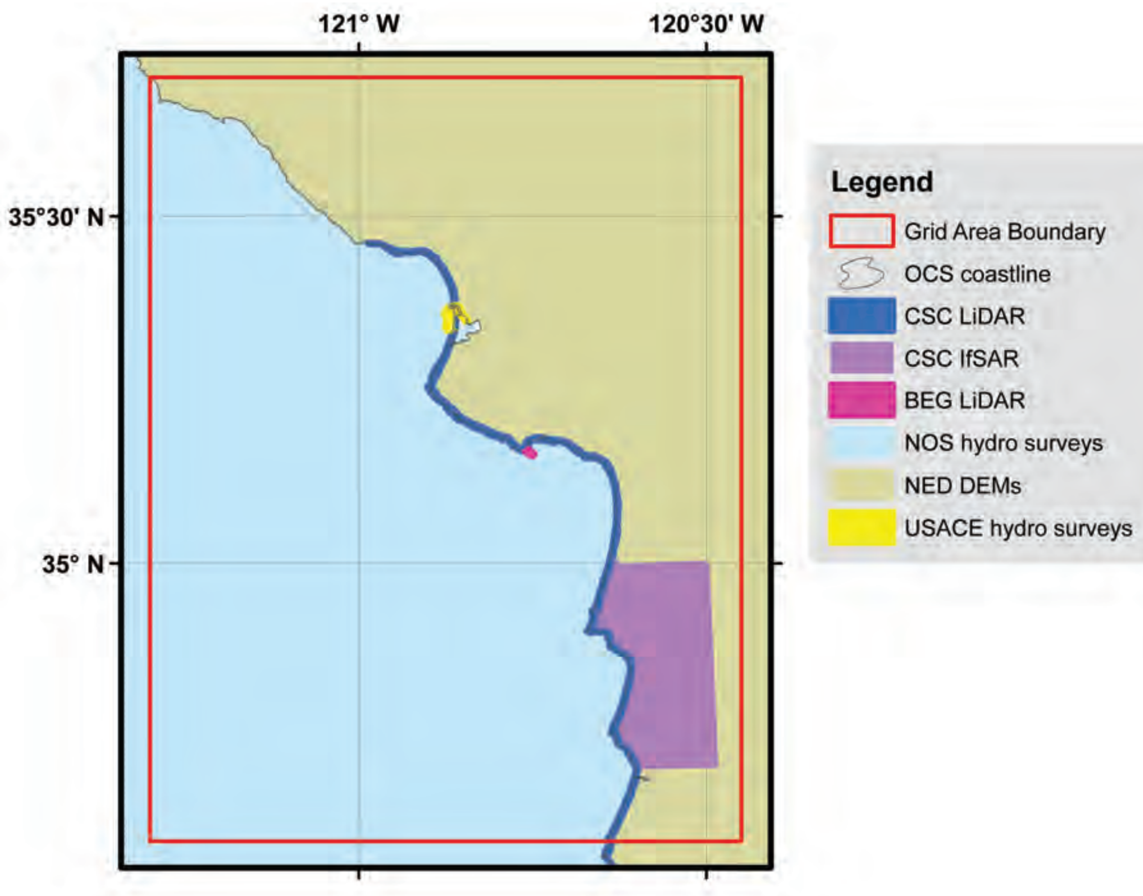

Figure 2. *Coverage of data sources used to compile the Port San Luis, California DEM.*

3.1.1 Shoreline

Coastline datasets of the Port San Luis region were obtained from NOAA's Office of Coast Survey (Table 2).

Table 2. Shoreline data sources used in gridding.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS Electronic Navigational Charts	2001 to 2006	coastline	Digitized from 1:216,116 scale chart	WGS84	Inferred MHW	http://chartmaker.ncd.noaa.gov/
OCS MHW vector shoreline of Estero and Morro Bays	2003	MHW coastline	Digitized from 1:40,000 and 1:80,000 scale charts	NAD83	MHW	http://chartmaker.ncd.noaa.gov/

1) **NGA global shoreline**

The National Geospatial-Intelligence Agency's (NGA; http://www.nga.mil/) 'Prototype Global Shoreline Data' digital shoreline was used for evaluating the topographic LiDAR data (see Section 3.1.3). The NGA Global Shoreline Data is an unclassified vector dataset generated by Earth Satellite Corporation (http://www.earthsat.com/) of Rockville, Maryland for NGA, under contract to Boeing in 2004. The shoreline is an approximation to the High Water Line and constructed from consistently orthorectified Landsat TM satellite imagery (GeoCover Ortho), acquired between 1998-2002 for NASA under the Global Land Mapping Program (GLMP). NDVI and SWIR models were used to define the landward extent of inundation (i.e., MHW). Independently verified positional accuracy for the source product (GeoCover Ortho) is consistently better than 50 meter root mean square (RMS) error.

The NGA coastline does not match the topographic data along the open ocean–land boundary, due partly to its lower resolution, but topographic features also have a consistent southward shift of about 30 meters (see Fig. 3). The dataset also includes many false islands along the California coast, some of which are the ends of piers. This dataset was not used in the gridding process.

2) **OCS electronic navigational chart**

One electronic navigational chart (ENC), #18700 (Point Conception to Point Sur, scale 1:216,116), was available for the Port San Luis region (#), which was downloaded from NOAA's Office of Coast Survey (OSC) website (http://chartmaker.ncd.noaa.gov/). The chart data includes a coastline data file (inferred MHW, though not clearly specified), which was compared with the other coastline datasets, coastal topographic LiDAR data, and *Google Earth* satellite imagery.

The ENC coastline corresponds fairly well with the higher-resolution coastal topographic LiDAR data. However, the coastline dataset does not include some offshore islands and includes some other false ones (see Fig. 3), which necessitated some manual editing of the data.

3) **OCS mean high water vector shoreline**

OCS has also developed a MHW vector shoreline for the U.S., which was digitized from NOS navigational charts (http://chartmaker.ncd.noaa.gov/): in the Port San Luis gridding region the data is from Nautical Charts #18700, #18703 (Estero Bay, 1:80,000) and #18703 inset (Morro Bay, 1:40,000). Digital chart data are in NAD83 horizontal datum.

This shoreline dataset is also consistent with the coastal topographic LiDAR data, and the ENC coastline, though the Estero Bay and Morro Bay coastlines have significantly higher detail. These two OCS MHW coastlines were also used in the grid compilation, though each required editing to delete data along map edges and to remove piers (e.g, Fig. 3).

The ENC coastline and the OCS MHW coastlines of Estero Bay and Morro Bay were used in the gridding process. Each dataset was first subsampled to 10-meter spacing and converted to point data. Estero Bay coastline data were then excised where they overlapped the higher-resolution Morro Bay coastline; ENC coastline data were also excised where they overlapped the higher-resolution Estero Bay and Morro Bay coastlines. The edited coastlines were also combined, and used as a coastal buffer (30-meter spacing) for the NOS pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached "zero" at the coast.

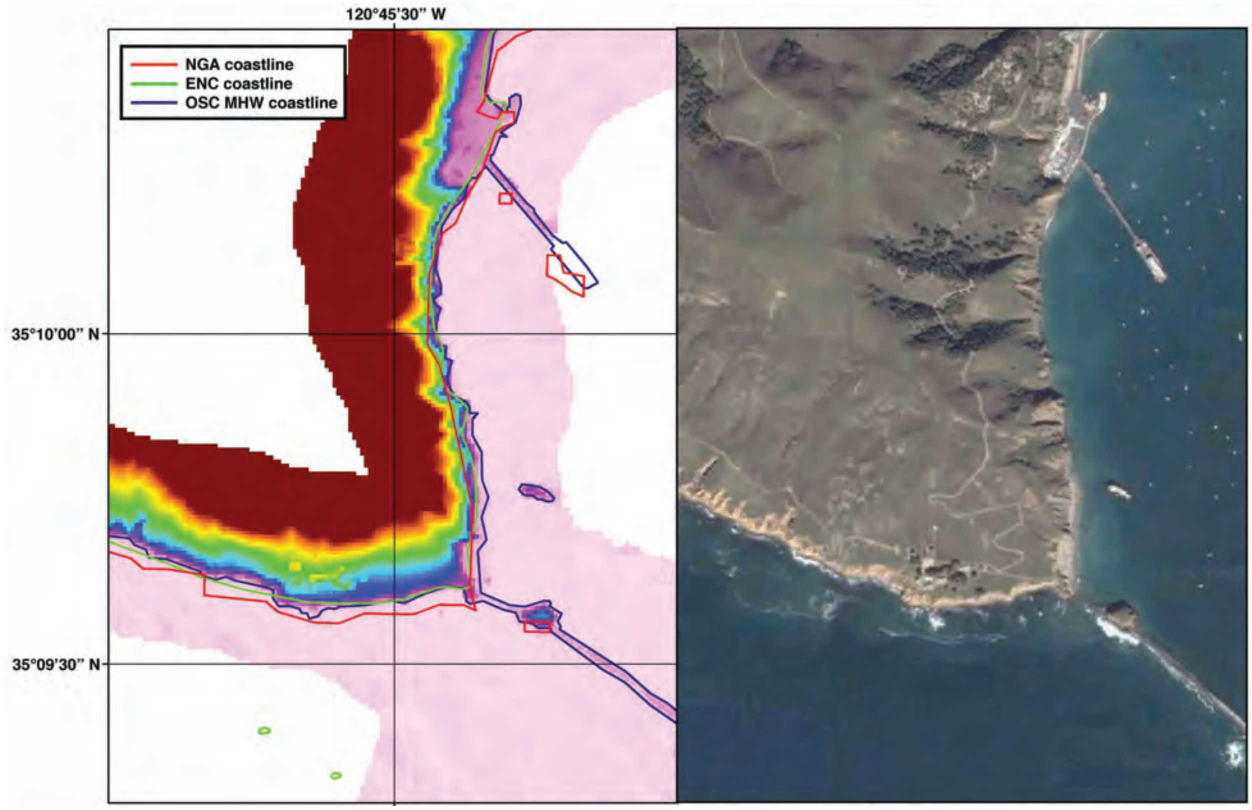

Figure 3. *Digital coastlines in the area of Point San Luis. Left panel compares the NGA (red), ENC (green) and OCS MHW coastlines (Estero Bay, dark blue) with coastal topographic LiDAR data. Right panel is Google Earth view of same area, which is consistent with the LiDAR data. The NGA coastline exhibits a distinct southward shift, while the ENC and OCS coastlines are more consistent with the LiDAR data; the higher-resolution OCS MHW coastline best conforms to the LiDAR topography. Some NGA offshore "islands" are actually structures on a pier; OCS "islands" in southeast corner of left panel do not exist. Whaler Island, on the breakwater in the southeast corner, is represented in the NGA coastline (though shifted southward), but not in the ENC dataset. Whaler Island and its breakwater are represented in the OCS MHW coastline, though the pier to the north is also, inappropriately, represented.*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Port San Luis DEM include 36 NOS hydrographic surveys, and multiple hydrographic surveys of Morro Bay conducted by USACE (Table 3).

Table 3. Bathymetric data sources used in gridding.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1933 to 1994	Hydrographic survey soundings	Ranges from 10 meters to 1 kilometer (varies with scale of survey, depth, traffic and probability of obstructions)	NAD27, NAD83	MLLW, MLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE, Los Angeles District	2001 to 2006	Hydrographic surveys of Morro Bay	1 to 5 meters	NAD83 California State Plane, Zone V (meters)	MLLW	http://www.spl.usace.army.mil/cms/index.php

1) **NOS hydrographic survey data**

A total of 36 NOS hydrographic surveys conducted between 1933 and 1994 were included in the Port San Luis DEM compilation (Fig. 4). The survey data were originally vertically referenced to either Mean Lower Low Water (MLLW) or Mean Low Water (MLW), and horizontally referenced to either NAD27 or NAD83 (Table 4). Data point spacing for the surveys ranged from about 10 meters in shallow water to 1 kilometer in deep water. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in NAD83 and MLLW or MLW datums. The data were then converted to WGS84 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 degrees (~5%) larger than the final gridding area to support data interpolation along grid edges.

After converting all NOS survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and compared to current NED topographic data, the combined OCS coastline, and *Google Earth* satellite imagery. Several NOS chart features—specifically, rocks protruding near to or above the sea surface—did not have digital representation and were thus digitized by NGDC for inclusion in the Port San Luis DEM (see Table 5). For much of the Port San Luis region, the NOS survey data come within only about 500 meters of the coast, leaving an unsurveyed gap in this critical area.

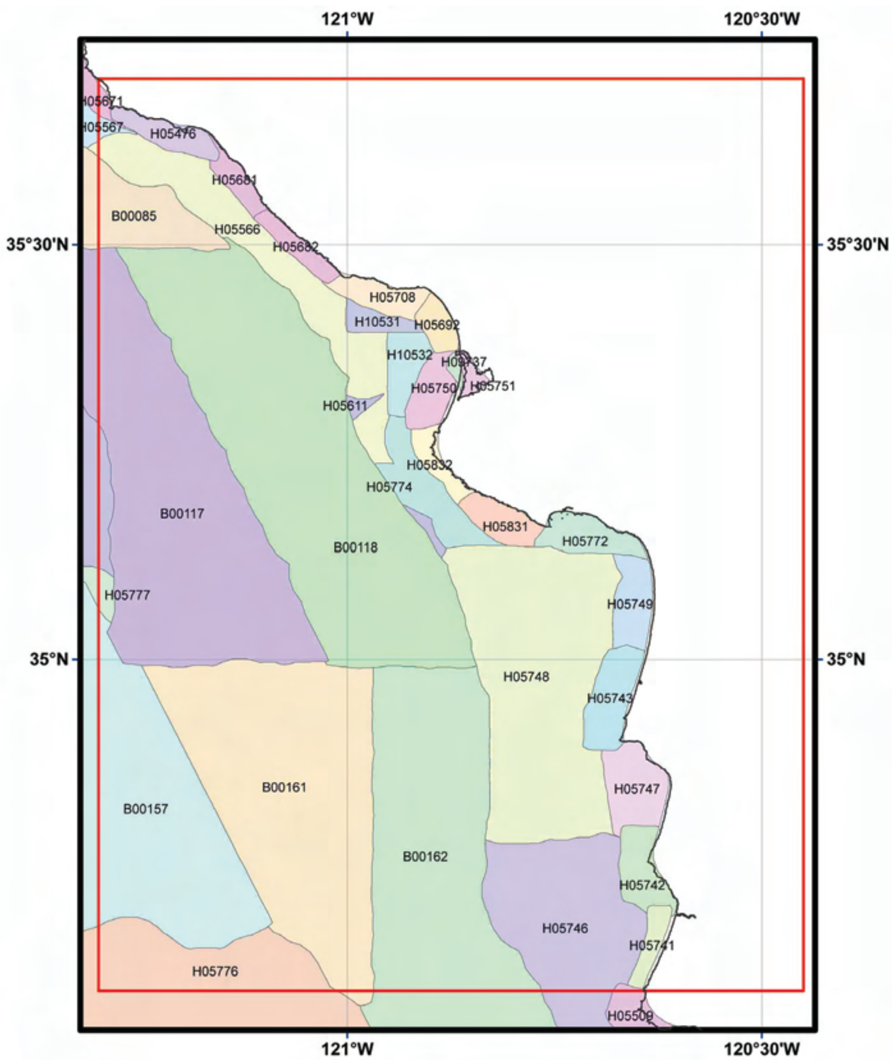

Figure 4. *Digital NOS hydrographic survey coverage in the Port San Luis region. Red line denotes DEM boundary; OCS coastline in black.*

Table 4. Digital NOS hydrographic surveys included in the Port San Luis, California DEM.

Survey ID	*Year*	*Survey Scale*	*Original Horizontal Datum*	*Original Vertical Datum*
B00085	1986	50,000	NAD83	MLLW
B00117	1987	50,000	NAD83	MLLW
B00118	1987	50,000	NAD83	MLLW
B00157	1988	50,000	NAD83	MLLW
B00161	1988	50,000	NAD83	MLLW
B00162	1988	50,000	NAD83	MLLW
H05476	1933	10,000	NAD27	MLLW
H05508	1933	10,000	NAD27	MLLW
H05509	1934	10,000	NAD27	MLLW
H05566	1933	40,000	NAD27	MLLW
H05567	1934	40,000	NAD27	MLLW
H05611	1933	80,000	NAD27	MLLW
H05642	1934	10,000	NAD27	MLLW
H05671	1934	10,000	NAD27	MLLW
H05681	1934	10,000	NAD27	MLLW
H05682	1935	10,000	NAD27	MLLW
H05692	1935	10,000	NAD27	MLW
H05708	1935	10,000	NAD27	MLLW
H05741	1934	10,000	NAD27	MLLW
H05742	1934	10,000	NAD27	MLLW
H05743	1934	10,000	NAD27	MLLW
H05746	1934	40,000	NAD27	MLLW
H05747	1934	10,000	NAD27	MLLW
H05748	1934	40,000	NAD27	MLLW
H05749	1934	10,000	NAD27	MLLW
H05750	1934	10,000	NAD27	MLLW
H05751	1935	5,000	NAD27	MLLW
H05772	1934	10,000	NAD27	MLLW
H05774	1934	40,000	NAD27	MLLW
H05776	1934	120,000	NAD27	MLLW
H05777	1933	120,000	NAD27	MLLW
H05831	1934	10,000	NAD27	MLLW
H05832	1934	10,000	NAD27	MLLW
H09737	1978	5,000	NAD27	MLLW
H10531	1994	10,000	NAD83	MLLW
H10532	1994	10,000	NAD83	MLLW

Table 5. Topographic features digitized from NOS sounding sheets.

Feature Name	*NOS Survey ID*	*Longitude*	*Latitude*	*Elevation (m above MHW)*
Von Helm Rock	H05681	-121.112376	35.538589	-5.9939
Cambria Rock	H05681	-121.1358	35.858064	3.04799
Pico Rock	H05681	-121.137725	35.596774	3.65759
White Rock	H05682	-121.088406	35.532919	6.09599
Avila Rock	H05772	-120.724605	35.170122	2.13359
Bird Rock	H05772	-120.684285	35.148444	2.13359
White Rock	H05772	-120.709765	35.163297	4.87679
Lone Black Rock	H05831	-120.771652	35.159767	0.60959
Pecho Rock	H05831	-120.816773	35.17954	12.19199
Lion Rock	H05832	-120.872554	35.217402	41.4
Whale Rock	H05692	-120.89	35.43	4.87679

2) USACE hydrographic data in Morro Bay

The U.S. Army Corps of Engineers (USACE) has conducted multiple high-resolution (~1 meter) hydrographic surveys of Morro Bay in connection with dredging of that bay (Fig. 5). These surveys, in the form of xyz data files, were provided to NGDC by Art Shak, USACE, and represent surveys conducted between 2001 and 2006, before and after dredging operations. The survey data are in NAD83 California State Plane, Zone V (meters) and MLLW (meters). According to USACE tidal estimates within Morro Bay, the difference between MLLW and MHW is 5.4 ft (1.646 m). NGDC utilized the most recent USACE hydrographic surveys of the bay, and offshore disposal site, that provided the most extensive spatial coverage for use in the gridding process.

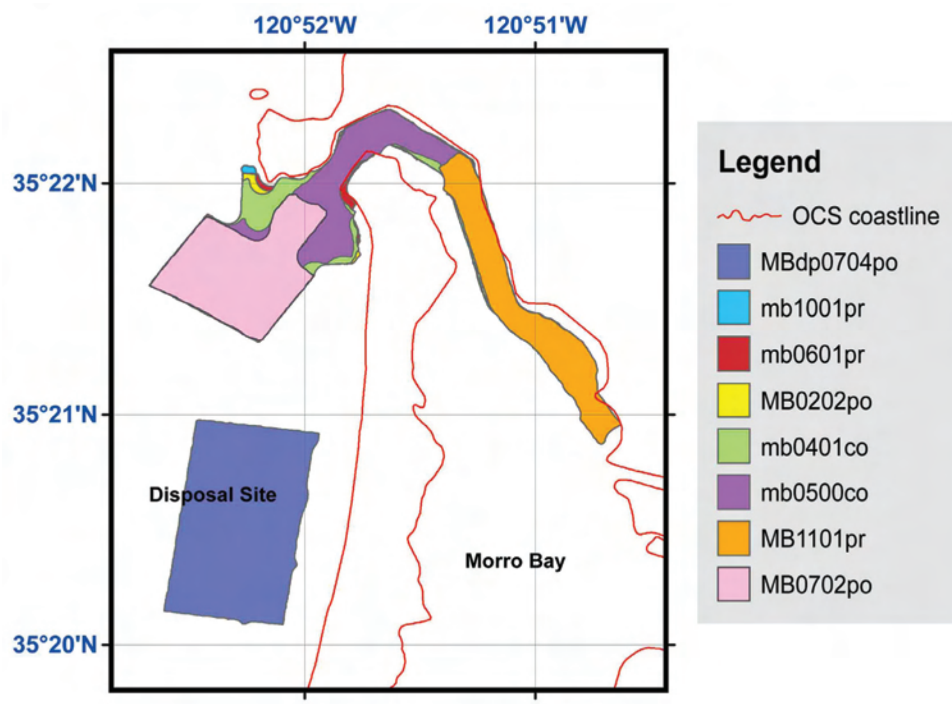

Figure 5. *Spatial coverage of USACE hydrographic surveys in Morro Bay that were utilized in DEM development.*

3.1.3 Topography

Topographic data were obtained from several sources: USGS National Elevation Dataset (NED) 1/3 arc-second (10 meter) gridded topography; NOAA Coastal Services Center (CSC) coastal LiDAR and IfSAR surveys; and ultra-high resolution (0.5 meter) Bureau of Economic Geology (BEG) LiDAR DEM of Point San Luis, San Luis Obispo Bay (Table 6).

Table 6. Topographic data sources used in gridding.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS NED	2006	Topographic DEM	1/3 arc-second grid	NAD83 geographic	NAVD88 (meters)	http://ned.usgs.gov/
BEG	2004	Topographic LiDAR	0.5 meter grid	NAD 83, UTM Zone 10, meters	NAVD88 (meters)	
NOAA CSC	2002 to 2003	Topographic IfSAR	3 meter grid	NAD 83, UTM Zone 11, meters	NAVD88 (meters)	http://www.csc.noaa.gov/lidar
NOAA CSC	1998	Topographic LiDAR	10 meter grid	NAD 83 geographic, meters	NAVD88 (meters)	http://www.csc.noaa.gov/lidar

1) **USGS NED topography**

The U.S. Geological Survey's (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1 arc-second coverage of the continental U.S. (Fig. 6)[1]. 1/3 arc-second DEMs are available for much of California and were downloaded by NGDC for use in the Port San Luis DEM. Data are in NAD83 geographic coordinates and NAVD88 vertical datum (meters). The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quad maps and aerial photos based on surveys conducted in the 1970s and 1980s.

The NED data include "zero" values over the open ocean (Fig. 6), which had to be clipped from the dataset before gridding. Some anomalous values still remained over the open ocean, which were visually inspected and compared with NOAA nautical charts, the OCS coastline, and *Google Earth* satellite imagery. Some of these data points represented wharfs in San Luis Obispo Bay, which were deleted. Most of the data values less than 1.0 meters above NAVD88 (0.365 meters below MHW) that lie along the coastline were also inconsistent with other datasets and were deleted; the beach face for most of the coastline in the Port San Luis gridding region was also covered by higher-resolution topographic coastal LiDAR surveys performed by CSC (see below).

1. 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 Alaska. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NAVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

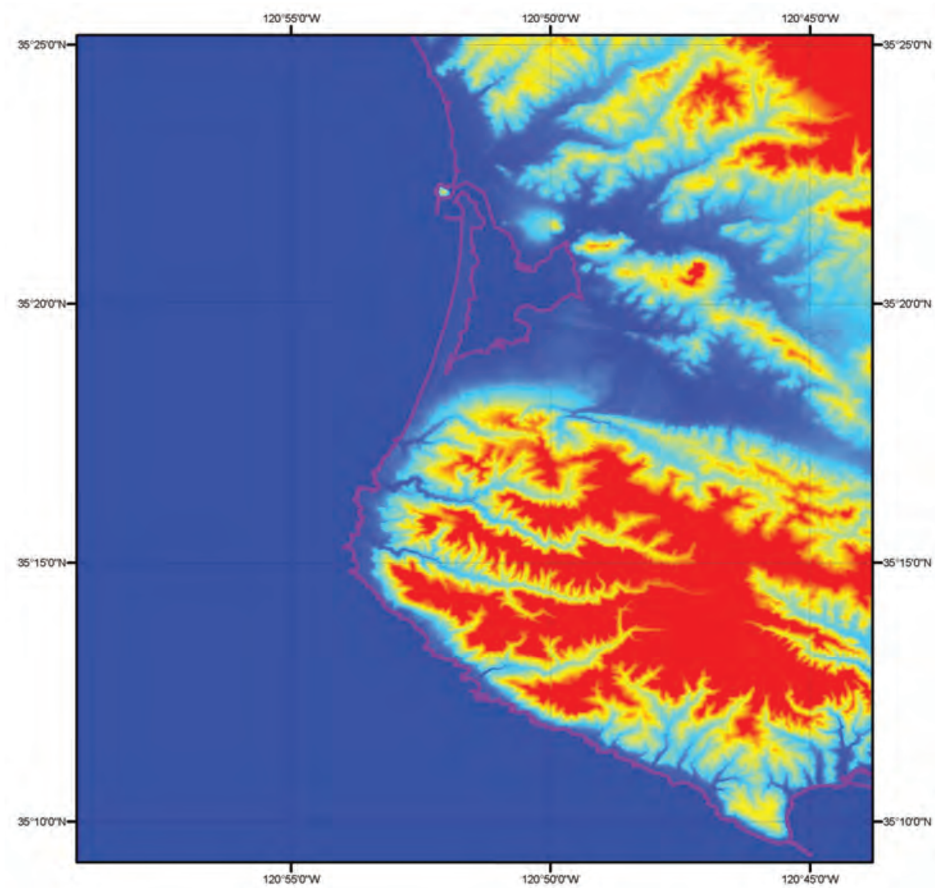

Figure 6. *Color image of Morro Bay derived from a USGS NED 1/3 arc-second DEM illustrating "zero" values (blue) over the open ocean and inland waterbodies that had to be deleted; OCS coastline in magenta.*

2) NOAA CSC topographic coastal LiDAR data

Laser beach mapping of parts of the U.S. West Coast were conducted by the NOAA Coastal Services Center (CSC), in partnership with the NASA Wallops Flight Facility, the U. S. Geological Survey (USGS) Center for Coastal and Regional Marine Geology, and the NOAA Aircraft Operations Center. Data were collected in 1998 with a LiDAR instrument that uses a pulsed laser ranging system mounted onboard an aircraft to measure ground elevation and coastal topography[2]. Coastal LiDAR data in the Port San Luis region were downloaded from the CSC website (http://www.csc.noaa.gov/lidar/) in NAD83 geographic coordinates (meters) and NAVD88 (meters). The LiDAR elevation points are horizontally accurate to +/- 0.8 meters at an aircraft altitude of 700 meters; raw elevation measurements are vertically accurate to within 15 cm. No processing was done by CSC to remove returns from water or vegetation. Thus data values offshore primarily represent wave features on the ocean surface, not true topography.

Examination of the nearshore data by NGDC indicated that a cutoff of 0.75 meters above NAVD88 datum (0.615 meters below MHW) would effectively eliminate most of the open-ocean surface returns while retaining much of the beach-face morphology. Visual inspection of each ESRI shape file after clipping revealed many remaining offshore data points that were evaluated in conjunction with NOAA nautical charts and *Google Earth* satellite imagery. Many of these were sea-surface returns, which were clipped, while others were of exposed rocks and islands that were retained. Others were of wharfs along the San Luis Obislo Bay coastline, which were deleted. There were also several patches of anomalous returns, greater than 100 meters above MHW in some cases, that did not correspond to offshore topographic features (e.g., Fig. 7); their origin is unclear but may be the result of laser reflections from low-lying clouds during the LiDAR surveys. These data points were also excised prior to gridding.

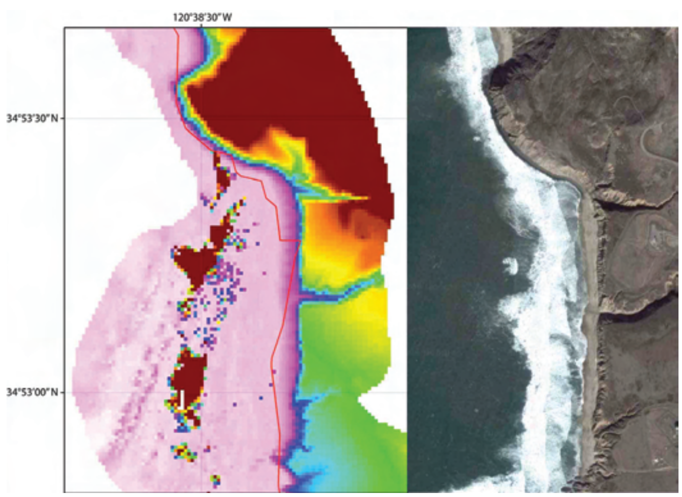

Figure 7. *Example of anomalous CSC beach LiDAR data values. Left panel: red values (highs) on mesa to north range from 50 to 110 meters above MHW; offshore reds are in the 50 to 140 meter range; NGA coastline in red. Google Earth satellite image on right panel shows no land offshore.*

2. The laser emits laser beams at high frequency and is directed downward at the Earth's surface through a port opening in the bottom of the aircraft's fuselage. The laser system records the time difference between emission of the laser beam and the reception of the reflected laser signal in the aircraft. The aircraft travels over the beach at approximately 60 meters per second while surveying from the low water line to the landward base of the sand dunes. This data set was collected with a LiDAR (Light Detection And Ranging) instrument designed and developed by the Observational Sciences Branch (OSB) of NASA at the Wallops Flight Facility in Virginia. The instrument, originally designed for mapping ice sheets in Greenland, is called the Airborne Topographic Mapper or ATM. The ATM II (the latest version), operates with a Spectra Physics laser transmitter, which provides a 7 nanoseconds long, 250 microjoules pulse at a frequency-doubled wavelength of 523 nanometers in the blue-green spectral region. The laser transmitter can function at pulse rates from 2 to 10 kHz. The laser system, with a separate cooling unit, weighs approximately 45 kg and requires approximately 15 amperes of power at 115 volts. The transmitted laser pulse is reflected to the surface of the earth with the aid of a small folding mirror mounted on the back of a secondary mirror of a rotating scan mirror assembly mounted directly in front of the telescope. The scan mirror, which is rotated at 20 Hz, is comprised of a section of round aluminum stock, machined to a specific off-nadir angle. A scan mirror with the off-nadir angle of 15 degrees was utilized, producing an elliptical scan pattern with a swath width equal to 50 percent of the approximately 700-meter aircraft altitude. The reflected laser pulse is transmitted to a photo-multiplier assembly that consists of a lens, a narrow bandpass filter, and a single photomultiplier tube. [Extracted from metadata]

3) NOAA CSC topographic IfSAR data

The NOAA Coastal Services Center (CSC) collaborated with the Southern California Water Research Project to conduct IfSAR (Interferometric Synthetic Aperture Radar) surveys in coastal areas of Southern California[3]. This project was designed to collect, process and disseminate topographic elevation data to provide coastal managers and partners with the decision support tools to more effectively manage and preserve America's coastal zone. IfSAR data within the Port San Luis region were extracted from the CSC website (http://www.csc.noaa.gov/lidar/) as a 3-meter cell-size DEM, created in ESRI ArcGIS (Fig. 8). The grid was in NAD83, UTM zone 11 (meters) and NAVD88 (meters), and was resampled to a 10-meter cell-size grid for use in gridding. Data were complied to meet 4.3-meter horizontal accuracy at 95% confidence level; data are vertically accurate to within 2.20 meters. An edge-effect along the north side of the CSC DEM necessitated deletion of 2 rows of data on that edge of the resampled 10-m DEM.

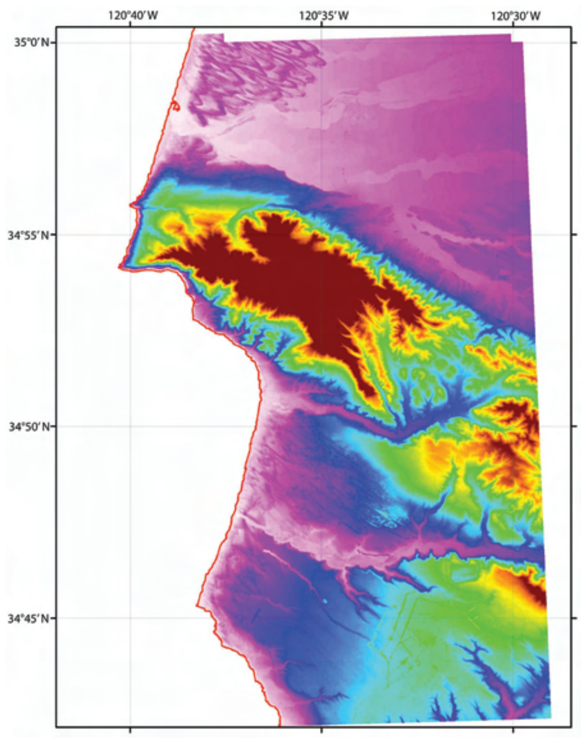

Figure 8. *Color-relief image of the CSC IfSAR topographic DEM in Port San Luis region. OCS coastline in red.*

3. The 'GeoSAR Mapping of Southern California' project was flown using EarthData's modified Gulfstream-II jet aircraft. The IfSAR data was captured using a dual-frequency, dual-polarimetric, interferometric airborne radar mapping system (GeoSAR) that generates digital elevation models (DEMs) and orthorectified radar reflectance maps near the tops of trees as well as beneath foliage. Data was captured simultaneously in both X-band (first surface, near the tops of trees) and P-band (beneath the foliage). X-band antenna are mounted under the wings close to the fuselage and have a 160 MHz bandwidth at a center frequency of 9.7 GHz. P-band antennas are mounted on the wingtips and have a center frequency of 350 MHz. Each X-band and P-band antenna provides two looks at each point on the ground for a total of four looks on each side. Flight lines are overlapped to provide coverage of the space directly beneath the aircraft. As a result, some points on the ground are covered eight times. Left-right look angles on each side of the aircraft combined with mosaicking process mitigates radar shadow and layover. X-band data has been processed for the entire project area and P-band has been processed for an area of approximately 300 square kilometers within the Phase I project area. Due to flight clearance requirements all data was normally collected between the hours of 10 PM and 7 AM. Ground control and GPS base station locations were established to provide the necessary control to meet the accuracy requirements of the project. Radar reflective corner reflectors were deployed across the project area to be used in the mosaicking stage to ensue that the data met the accuracy requirements. A total of fourteen reflectors were deployed across the total project area with six reflectors deployed within the Phase I project area. A total of ten additional ground control points were established using GPS for vertical and horizontal coordinate values. These points were used during the quality control process to evaluate the accuracy of the final mosaicked data. Ground control references UTM Zone 11, NAD83, GRS80. [Extracted from metadata]

4) BEG topographic LiDAR of San Luis Obispo Bay breakwater

The Bureau of Economic Geology, University of Texas at Austin (BEG), in partnership with the United States Army Corps of Engineers, collected topographic LiDAR data[4] in 2004 over a breakwater at the mouth of the San Luis Obispo Bay/Point San Luis (Figs. 9 and 10). BEG compared the LiDAR data to the 1998 NOAA coastal LiDAR data set (see above) for evaluation and processing; the data were not processed to bare earth. A DEM of the BEG LiDAR data—0.5 meter cell-size, created in GMT (nearest neighbor)—was supplied to NGDC by Randy Bucciarelli, U.C., San Diego. This grid, in NAD83 UTM Zone 10 (meters) and NAVD88 (meters) was resampled to 10-meter cell-size by NGDC for use in gridding. Points less than 1 meter above NAVD88 (0.365 meters below MHW) were clipped from the grid so as to exclude sea-surface reflections.

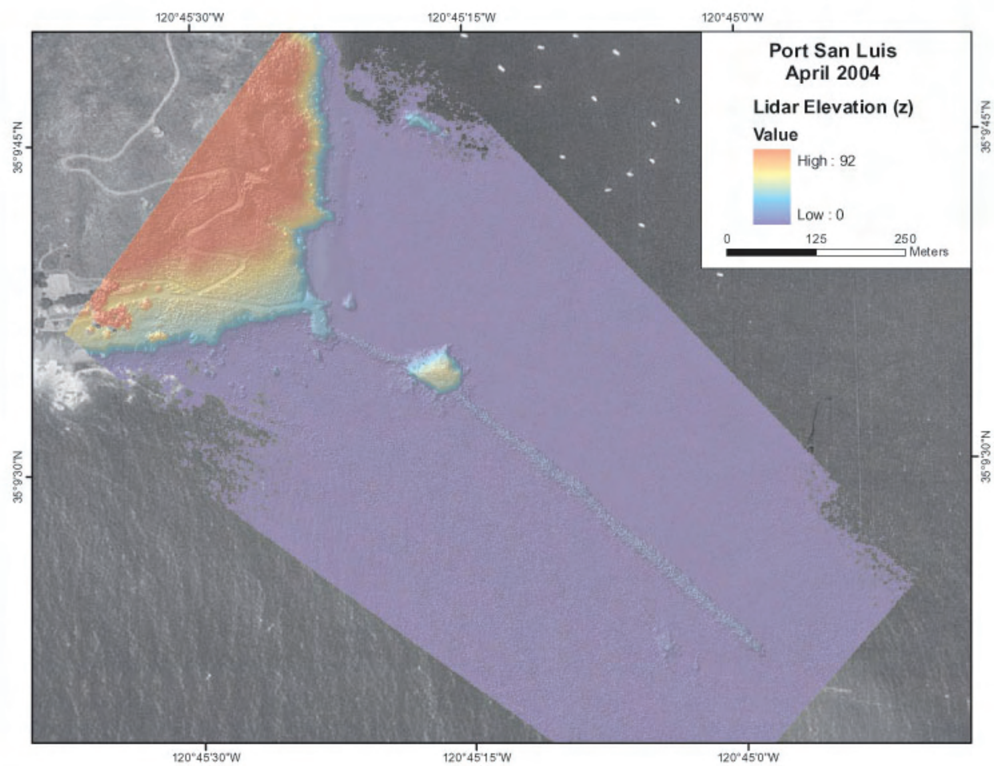

Figure 9. *Map view of BEG grid of Point San Luis LiDAR survey. [Image courtesy of Randy Bucciarelli, UCSD]*

4. The data set was created by combining data collected using an Optech Inc. Airborne Laser Terrain Mapper (ALTM) 1225 in combination with geodetic quality Global Positioning System (GPS) airborne and ground-based receivers. The Bureau of Economic Geology, the University of Texas at Austin owns and operates an ALTM 1225 system (serial number 99d118). The system was installed in a twin engine Partenavia P-68 Observer (tail number N6602L) owned and operated by Aspen Helicopter, Inc. The lidar data set described by this document was collected on 4 April 2004 (Julian Day 09504) between 2100 and 2143 UTC on 09504 (see Lineage, Source_Information, Source_Contribution for pass information). Conditions on 4 April were clear skies over breakwater, low clouds surrounding study area, and few wispy clouds overland adjacent to the breakwater. 99d118 instrument settings for this flight were; laser pulse rate: 25 kHz, scanner rate: 26 Hz, scan angle: +/-15-20 deg, beam divergence: narrow, altitude: 580-780m AGL, and ground speed: 95-111 kts. Two GPS base stations (both at the San Luis Obispo County-McChesney Field Airport, see Lineage, Source_Information, Source_Contribution for coordinates) were operating during the survey. The ALTM 1225 has the following specifications: operating altitude = 410-2,000 m AGL; laser pulse rate = 25 kHz; laser scan angle = variable from 0 to +/-20deg from nadir; scanning frequency = variable, 28 Hz at the 20 deg scan angle; and beam divergence = 0.2 milliradian (half angle, 1/e). The ALTM 1225 does not digitize and record the waveform of the laser reflection, but records the range and backscatter intensity of the first and last laser reflection using a constant-fraction discriminator and two Timing Interval Meters (TIM). ALTM elevation points are computed using three sets of data: laser ranges and their associated scan angles, platform position and orientation information, and calibration data and mounting parameters (Wehr and Lohr, 1999). Global Positioning System (GPS) receivers in the aircraft and on the ground provide platform positioning. The GPS receivers record pseudo-range and phase information for post-processing. Platform orientation information comes from an Inertial Measurement Unit (IMU) containing three orthogonal accelerometers and gyroscopes. An aided-Inertial Navigation System (INS) solution for the aircraftâ€™s attitude is estimated from the IMU output and the GPS information. Wehr, A. and U. Lohr, 1999, Airborne laser scanning - an introduction and overview, ISPRS Journal of Photogrammetry and Remote Sensing, vol. 54, no.2-3, pp.68-82. [Extracted from metadata]

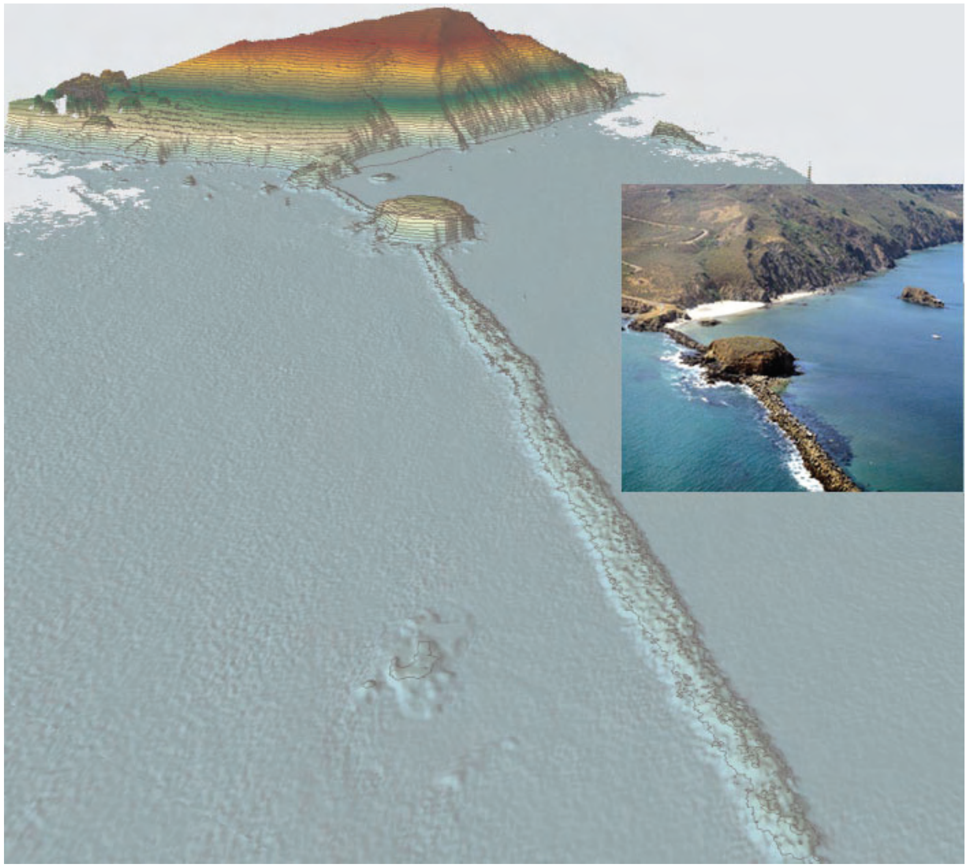

Figure 10. *Perspective view of BEG grid of the breakwater off of Point San Luis, with Whaler Island in foreground (inset is corresponding aerial photograph). [Image courtesy of Randy Bucciarelli, UCSD]*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation of the Port San Luis DEM were originally referenced to a number of vertical datums including: Mean Low Water (MLW), Mean Lower Low Water (MLLW), and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW to provide the worst case scenario for inundation modeling.

1) **Bathymetric data**

Most of the NOS survey data were transformed to MHW using VDatum (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) model software developed jointly by NOAA's Office of Coast Survey and National Geodetic Survey. For the Port San Luis gridding area, the VDatum Transformation Tool consists of a Java based program applicable to the North/Central California region (Fig. 11).

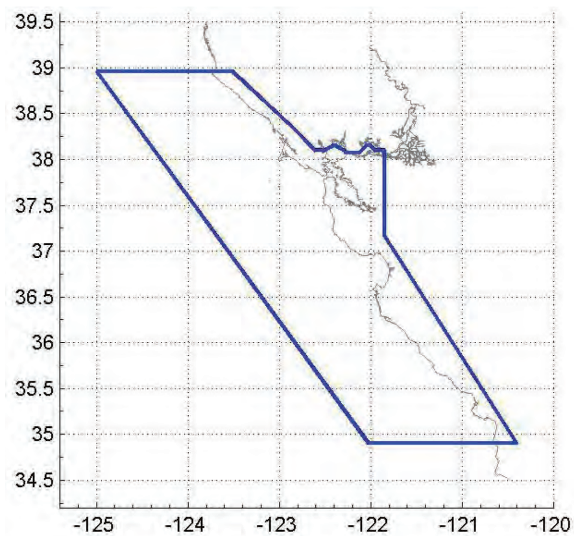

Figure 11. *VDatum coverage for coastal California.*

NOS surveys were grouped by reference to original vertical datum (see Table 2) and input to VDatum using the batch mode utility (Fig. 12).

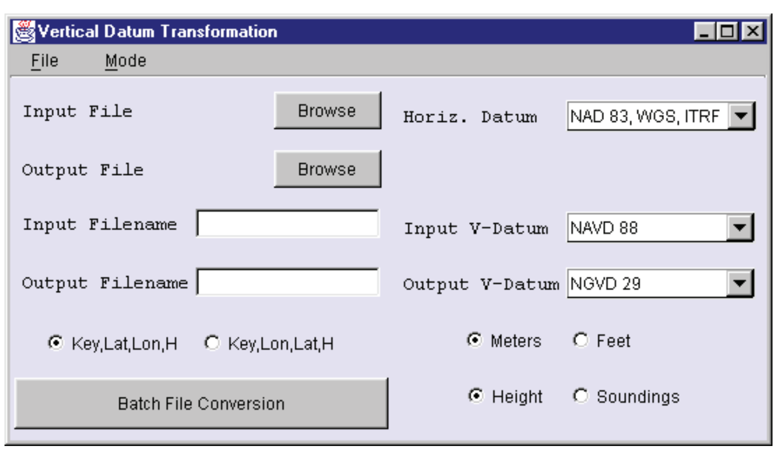

Figure 12. *VDatum model software Java input window.*

NOS survey data outside the California VDatum region (Fig. 13) were converted from MLLW to MHW using a constant offset of -1.4462 meters – the average offset on the south edge of the VDatum region. USACE hydrographic survey data within Morro Bay were converted from MLLW to MHW using a constant of -1.646 meters, determined by USACE tidal measurements in the bay.

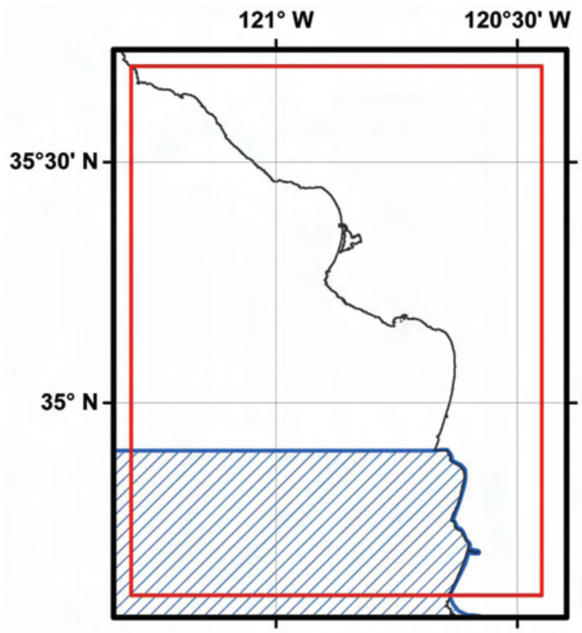

Figure 13. *Bathymetric area outside VDatum region. NOS survey data within the blue-hachured region were converted from MLLW to MHW using a constant offset of -1.4462 meters; OCS coastline in black, grid boundary in red.*

2) Topographic data

Topographic LiDAR and IfSAR data, and the NED DEMs were converted from NAVD88 to MHW using FME software by adding a constant value of -1.365 meters (see Table 7), determined at the Port San Luis tide station (http://tidesandcurrents.noaa.gov/).

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

Vertical datum	*Difference to MHW*
NGVD29	-0.472
MSL	-0.573
MLW	-1.109
NAVD88	-1.365
MLLW	-1.426

* Datum relationships determined by tidal station at Port San Luis, California.

3.2.2 Horizontal datum transformations

Datasets used to compile the Port San Luis DEM were originally referenced to NAD83, WGS84, UTM Zone 10, UTM Zone 11, or California State Plane Zone V horizontal datums; the relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of WGS84 using FME software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

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

- Data values over the open ocean in the NED DEMs and coastal topographic LiDAR surveys by CSC and BEG. Each dataset required automated clipping of the erroneous values and visual inspection and comparison of remaining offshore values with NOAA nautical charts and *Google Earth* satellite imagery to determine their reliability.
- Significant offshore high values (in the tens of meters, up to 140 meters) within the CSC coastal LiDAR data were determined to be data artifacts (cloud returns?) and were excised.
- Numerous offshore rocks and shoals on NOS survey charts had to be digitized by NGDC for inclusion of those features in the Port San Luis DEM.
- Data gap of roughly 500 meters between NOS hydrographic soundings and the coast.
- Inconsistency between topographic values of the NED DEMs with the CSC LiDAR and IfSAR data. Because of this, then NED data were given lower preference in the gridding hierarchy (see Section 3.3.3).

3.3.2 Smoothing of sparse NOS data

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second (10 meter) grid: in deep water, the NOS survey data had point spacings up to 4 kilometers apart. There is also an approximately 500 meter gap between the shallowest NOS soundings and the coastline. In order to reduce the effect of artifacts in the form of lines of “pimples” in the grid due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing (30 meter) ‘pre-surface’ or grid was generated using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The NOS point data were first combined into a single file, along with points extracted every 30 meters from the combined OCS coastline—to provide a “zero” buffer along the entire coastline—and points from the CSC coastal topographic LiDAR, which defines the near-shore beach-face morphology for much, though not all, of the Port San Luis region (see Fig. 2). These point data were then smoothed using the GMT tool ‘blockmean’ onto a 1 arc-second grid 0.05 degrees (~5%) larger than the Port San Luis gridding region. The GMT tool ‘surface’ then applied a tight spline tension to interpolate cells without data values; ‘surface’ does not support a data hierarchy (see Section 3.3.3). The GMT grid created by ‘surface’ was converted into an Arc ASCII grid file using the MB-System tool ‘mbm_grd2arc’. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid by the OCS coastline polygon (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy, converted to a shape file, and then exported as an xyz file for use in the final gridding process (e.g., Fig. 14).

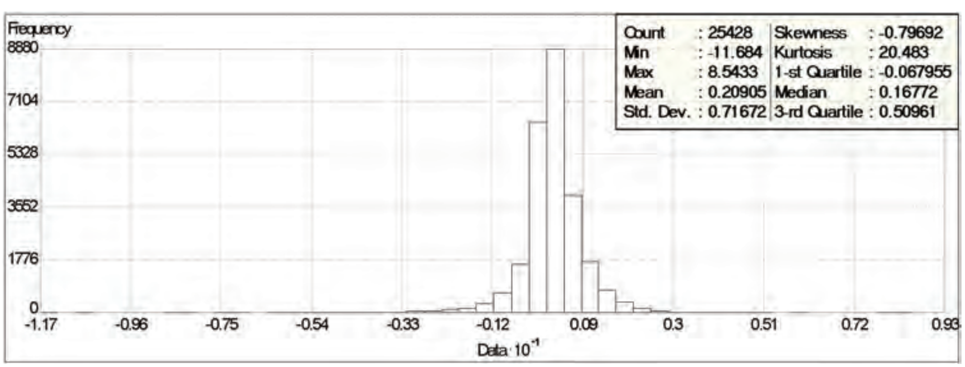

Figure 14. *Histogram of the difference between NOS soundings for survey H10532 (relatively dense 1994 multibeam sonar survey) and the NOS pre-surface grid. The greatest differences derive from the averaging of multiple, closely-spaced soundings in shallow areas with highly variable relief.*

3.3.3 Gridding the data with MB-System

All processed xyz files were gridded using MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/). MB-System is an NSF-funded share-ware 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 create the Port San Luis DEM—a modeled surface draping the point data—of weighted sounding and topographic point data, using a tight spline tension to interpolate cells without data values. The data hierarchy used in the 'mbgrid' gridding algorithm as relative gridding weights is listed in Table 6. Greatest weight was given to the topographic LiDAR and IfSAR data, and high-resolution USACE hydrographic surveys of Morro Bay. Least weight was given to the pre-surfaced NOS grid. Gridding was performed in quadrants, each with a 5% data overlap buffer. Resulting Arc ASCII grids were seamlessly merged in ArcCatalog to create the final DEM.

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

Dataset	*Relative Gridding Weight*
CSC topographic coastal LiDAR	100
CSC topographic IfSAR	100
BEG topographic LiDAR	100
USACE hydrographic surveys, Morro Bay	100
OCS coastlines	1
USGS NED topographic DEMs	1
NOS hydrographic surveys: soundings	1
NOS hydrographic surveys: gridded	0.01

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The digital elevation model has an estimated horizontal accuracy of no better than 10 meters for topographic features; the LiDAR data have an accuracy of 0.8 meters for individual postings, IfSAR data are horizontally accurate to within 4.3 meters. Bathymetric features are resolved only to within a few tens to a few hundred meters in deep water areas; shallow, near-coastal regions have an accuracy approaching the subaerial topographic features. Positional accuracy is limited by the sparseness of deep-water soundings, and potentially large positional accuracy of pre-satellite navigated (GPS) hydrographic surveys.

3.4.2 Vertical accuracy

The DEM has an estimated vertical accuracy of between 0.1 and 15 meters for topographic areas, and 0.15 meters to 5% of water depth for bathymetric areas, depending upon source dataset. Topographic values are derived from: USGS NED DEMs, which have an estimated vertical accuracy between 7 and 15 meters; CSC coastal LiDAR surveys, which have an estimated vertical accuracy of 0.15 to 0.20 meters; and CSC IfSAR data, which are accurate to 2.20 meters. Bathymetric values are derived from the wide range of input data single and multibeam sounding measurements from the early 20th centuries to recent: NOS standards are 0.3 m in 0–20 m of water, 1.0 m in 20–100 m of water, and 1% of the water depth in 100 m of water. Bathymetric values in the shallowest coastal areas, where CSC coastal LiDAR were collected, area accurate to 0.15 to 0.2 meters. 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 San Luis DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 15). 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 (e.g., Fig. 16) was accomplished using ESRI ArcScene. Analysis of preliminary grids revealed suspect data points, which were corrected before regridding the data.

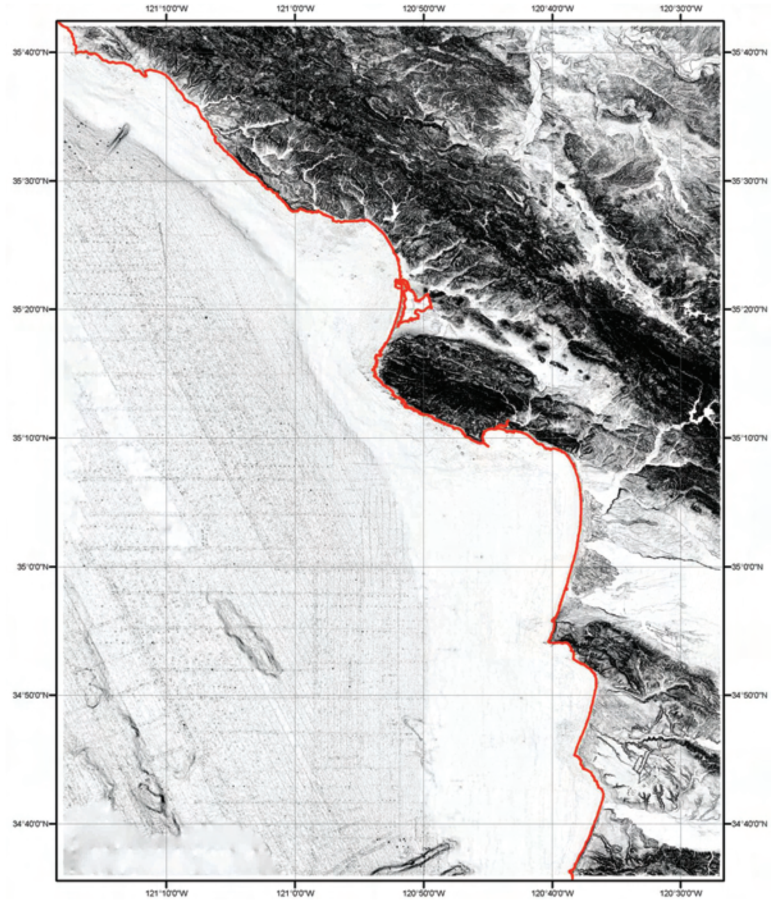

Figure 15. *Slope map of the 1/3 arc-second Port San Luis DEM. Flat-lying slopes are white; dark shading denotes steep slopes; OCS coastline in red.*

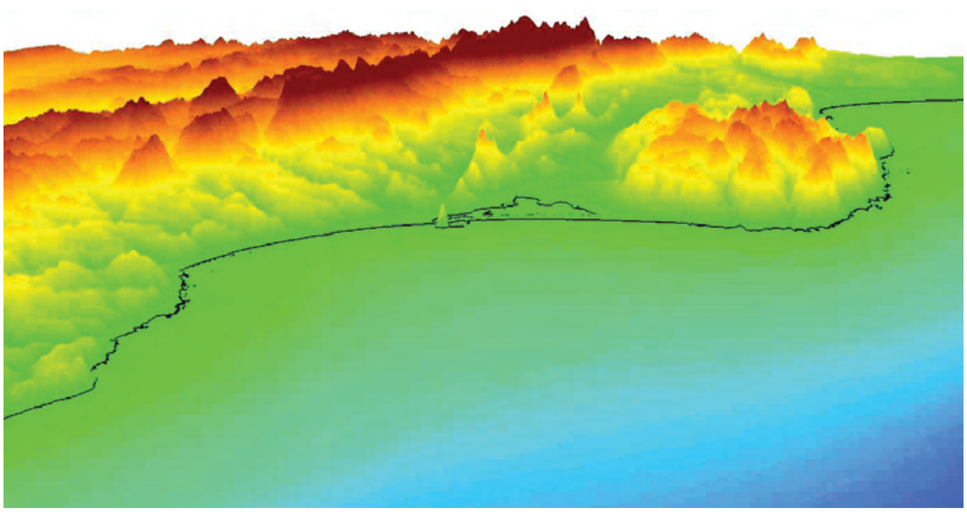

Figure 16. *Perspective view from the west of the Morro Bay region of the Port San Luis DEM. OCS coastline in black; vertical exaggeration–times 5.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Port San Luis 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 overlap over comparable-weight data files. A histogram of the comparison of one CSC coastal LiDAR file with the DEM is shown in Fig. 17.

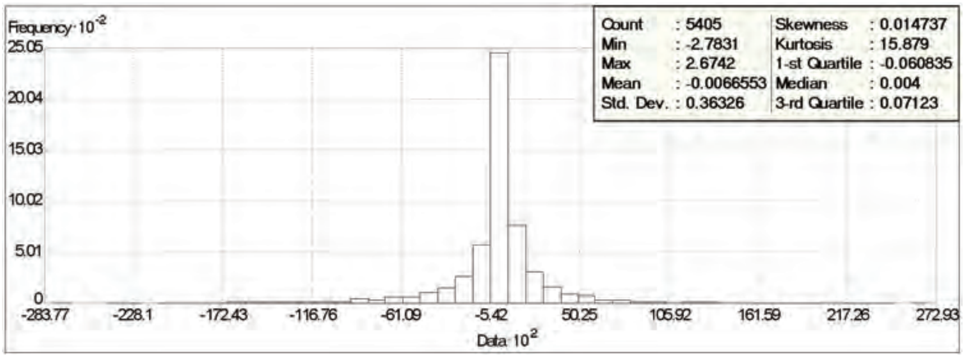

Figure 17. *Histogram of the difference between one CSC coastal LiDAR file and the Port San Luis DEM.*

3.4.5 Comparison with NOAA tidal bench marks

The National Geodetic Survey (NGS) data sheets for the tidal stations document benchmark elevation above MHW, in meters, allowing for direct comparison with DEM values at those locations. There is only one tidal bench mark lying within the Port San Luis study area, which was compared with the value taken at the same locale from the 1/3 arc-second (~10 meter) DEM (see Fig. 1 and Table 9 for station location). The bench mark has a geographic position recorded to within 1 arc-second, with an accuracy of +/-6 arc-seconds (http://tidesandcurrents.noaa.gov/). The bench mark is flush with the concrete walkway surrounding the Port San Luis Harbor building.

The origin of the large difference between the bench mark elevation and the DEM likely stems from the large uncertainty in the position of the bench mark (+/- 6 arc-seconds; ~180 m). The coastal topography drops steeply to the coastline in this area: the coastline is ~130 meters to the east; 130 meters to the west the elevation reaches 108 meters above MHW. The DEM properly reflects the closest CSC coastal LiDAR data value (18.2 m), just 3 meters from the recorded position of the tidal bench mark.

Table 9. Comparison of NOAA tidal benchmark elevation, in meters above MHW, with the Port San Luis DEM.

Station number	*Station name*	*Year*	*Longitude*	*Latitude*	*Bench mark*	*DEM*	*Difference*
9412110	PORT SAN LUIS	1992	120°45’25” W	35°10’20” N	3.425	18.064	14.639

3.4.6 Comparison with USGS bench marks

USGS benchmark elevations were extracted from online digital USGS topographic quadrangles (http://www.topozone.com), which give benchmark position and elevation in WGS84 and NGVD29 vertical datum (in feet). Elevations were converted to meters and shifted to MHW vertical datum (see Table 7) for comparison with the Port San Luis DEM (see Fig. 1 and Table 10 for station location). The USGS bench mark with the largest difference (18.1 m: 60.6 - 42.5 m) is at -120.5685° W, 35.1338° N and listed as 141 ft (42.5 m), though it lies next to the 200 ft (61 m) contour. The other USGS bench marks with large differences exhibit similar disconnects between their elevation and location relative to contour lines. The reason for this is unknown.

Table 10. Comparison of USGS topographic quadrangle benchmark elevations, in meters above MHW, with the Port San Luis DEM.

Longitude	*Latitude*	*Bench mark*	*DEM*	*Difference*
-120.56850	35.13380	42.5	60.6	18.1
-120.51400	34.87620	112.3	122.5	10.2
-120.60510	34.73230	48.0	57.9	9.9
-120.73660	35.33170	74.5	81.7	7.1
-120.77090	35.19300	233.6	240.0	6.3
-120.69840	35.19990	15.4	21.0	5.6
-120.67880	35.16040	29.4	34.7	5.3
-120.63500	35.35170	409.8	415.1	5.3
-121.02350	35.50890	52.9	57.7	4.9
-120.86950	35.22220	30.0	34.9	4.8
-120.81260	35.33060	3.8	8.2	4.4
-120.56670	34.97950	23.6	27.0	3.4
-120.58630	34.83790	69.3	72.6	3.3
-120.59470	34.68680	2.6	5.4	2.8
-120.63230	35.13830	6.8	9.6	2.8
-121.07250	35.55290	73.6	75.8	2.2
-120.54710	35.13920	60.8	62.9	2.1
-120.93340	35.44970	5.6	7.7	2.1
-120.63770	35.36070	383.6	385.6	2.0
-120.56510	34.83310	76.6	78.6	1.9
-120.60640	34.73470	48.9	50.7	1.8
-120.45130	34.84390	125.7	127.5	1.8
-120.51960	34.64520	18.1	19.9	1.8
-120.50200	35.00910	44.6	46.2	1.5
-120.97350	35.46790	19.3	20.8	1.5
-120.57600	34.83760	76.3	77.8	1.5
-120.54950	34.82770	76.6	78.0	1.3
-120.91480	35.44980	16.3	17.5	1.2
-121.15860	35.62730	8.7	9.8	1.1
-120.56260	34.92350	46.8	47.9	1.1
-120.59610	35.05360	27.9	28.9	1.1
-120.53680	34.89600	81.2	82.2	1.0
-120.59410	34.82470	55.6	56.6	1.0
-120.62400	35.40470	304.6	305.6	0.9
-120.63280	35.14270	7.2	8.1	0.9
-120.84560	35.51080	430.8	431.7	0.9
-120.80950	35.24170	216.9	217.6	0.8
-120.46650	34.87190	69.3	70.0	0.7
-120.62550	35.38380	318.0	318.7	0.7
-120.60350	34.68500	12.3	13.0	0.6
-120.52820	34.64890	13.9	14.4	0.6
-120.84580	35.20490	38.5	38.9	0.3
-121.04590	35.52790	37.6	38.0	0.3
-120.65470	35.33730	276.6	276.8	0.2
-120.62440	35.10170	2.3	2.5	0.2
-120.57290	35.14560	81.8	82.0	0.2
-120.58310	35.01620	15.4	15.5	0.1
-120.60570	35.41220	292.4	292.5	0.1
-120.51040	34.64320	19.3	19.4	0.1
-120.68980	35.23120	25.1	25.2	0.1
-120.49300	34.64010	22.4	22.4	0.0
-120.56730	34.99110	27.6	27.5	0.0
-120.61930	35.40650	295.5	295.4	0.0
-120.62500	35.10400	2.9	2.8	-0.1
-120.61420	34.74330	60.8	60.7	-0.1
-120.96840	35.46310	8.7	8.6	-0.1
-120.99670	35.48190	37.9	37.8	-0.1
-120.63050	35.12410	5.9	5.8	-0.1
-120.87270	35.41230	5.6	5.5	-0.1
-121.10140	35.56710	5.6	5.5	-0.1
-120.73660	35.17950	3.2	3.0	-0.2
-120.60950	34.75710	63.8	63.6	-0.2
-121.28520	35.67680	13.6	13.3	-0.3
-120.58990	35.02800	14.8	14.5	-0.3
-120.61270	34.77100	57.1	56.8	-0.3
-121.00390	35.49360	52.0	51.6	-0.3
-120.45780	34.64880	28.8	28.4	-0.4
-120.74610	35.18800	46.8	46.4	-0.4
-120.45010	34.90140	71.2	70.7	-0.5
-120.53780	34.83300	80.9	80.4	-0.5
-121.26400	35.66530	20.0	19.4	-0.6

-120.57340	34.96240	26.1	25.5	-0.6
-120.60460	34.68250	15.4	14.8	-0.6
-121.13730	35.60700	18.1	17.5	-0.7
-120.55340	34.90970	62.0	61.4	-0.7
-120.57730	35.15840	140.4	139.6	-0.7
-120.56810	34.93240	35.8	35.1	-0.7
-120.81590	35.19030	53.8	53.0	-0.8
-120.60130	34.71980	33.4	32.5	-0.8
-120.60610	34.79900	31.8	31.0	-0.8
-120.45780	34.66080	27.3	26.4	-0.8
-120.58120	35.10440	19.3	18.5	-0.9
-120.62990	35.38310	329.6	328.8	-0.9
-120.60070	35.08980	8.4	7.5	-0.9
-120.57490	35.00360	22.4	21.5	-0.9
-120.57360	34.94430	24.5	23.5	-1.0
-120.59710	34.70590	18.1	17.0	-1.1
-120.62140	35.17300	33.1	32.0	-1.1
-120.49740	34.88100	57.1	56.0	-1.1
-120.52270	34.86690	120.8	119.7	-1.1
-120.57300	34.97060	25.4	24.3	-1.1
-120.98170	35.47210	10.5	9.3	-1.2
-120.45410	34.88420	74.8	73.6	-1.2
-120.53060	35.50830	348.8	347.6	-1.2
-120.50880	34.95710	46.2	44.8	-1.4
-120.52290	34.83780	95.5	94.1	-1.4
-121.11830	35.58120	7.5	6.0	-1.4
-121.12590	35.59590	7.5	5.9	-1.6
-120.56170	34.91690	52.6	51.0	-1.6
-120.59750	34.81160	42.5	40.8	-1.7
-120.76530	35.25300	406.7	405.0	-1.7
-120.80530	35.36140	16.9	15.2	-1.7
-120.51890	34.84410	104.1	102.3	-1.8
-120.52000	34.85710	118.4	116.5	-1.9
-121.16400	35.63430	12.9	10.9	-2.1
-120.75440	35.33440	56.5	54.4	-2.1
-120.50770	34.87760	77.9	75.7	-2.1
-120.66120	35.50040	254.3	251.9	-2.4
-120.67760	35.33280	219.0	216.6	-2.4
-121.17070	35.63850	16.3	13.8	-2.5
-120.62470	35.40090	346.1	343.6	-2.5
-120.59780	35.06500	29.1	26.5	-2.6
-120.60030	34.69130	5.0	2.4	-2.6
-120.61090	34.78880	34.9	32.2	-2.7
-120.56900	35.12420	38.5	35.8	-2.8
-120.56900	35.12420	38.5	35.8	-2.8
-120.51800	35.07270	113.2	110.2	-3.0
-121.29060	35.69230	4.1	1.0	-3.1
-120.74460	35.17900	62.0	58.9	-3.1
-121.27510	35.66880	29.4	26.2	-3.2
-120.60840	35.09520	8.7	5.5	-3.2
-120.78580	35.42380	114.1	110.7	-3.4
-120.70170	35.18740	18.4	14.2	-4.2
-121.05670	35.53760	29.4	25.2	-4.2
-120.58730	34.68670	6.8	2.5	-4.3
-120.63270	35.16080	18.7	14.2	-4.5
-121.22900	35.65190	5.6	0.8	-4.8
-121.22630	35.65210	6.2	0.8	-5.4
-120.56070	35.12790	45.9	40.2	-5.6
-121.24740	35.65580	9.9	4.2	-5.7
-121.07460	35.56600	21.5	15.4	-6.0
-121.03380	35.51930	44.9	38.3	-6.6
-121.11210	35.57160	9.9	2.4	-7.5
-121.08150	35.55730	83.0	75.1	-8.0
-120.63590	34.60730	34.3	23.0	-11.3
			Average:	*-0.3*
			Standard Deviation:	*3.4*

4. Summary and Conclusions

A topographic/bathymetric digital elevation model with cell spacing of 1/3 arc-second (~10 meters) of the Port San Luis, California area was developed for the Pacific Marine Environmental Laboratory (PMEL), NOAA Center for Tsunami Inundation Mapping Efforts (TIME). The best available data from U.S. federal and state agencies, and academic institutions were obtained for grid compilation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, VDatum, GMT, and MB-System software.

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

- Conduct bathymetric LiDAR surveys of the nearshore areas within the Port San Luis region to accurately incorporate tsunami-influencing offshore rocks and shoals.

5. Acknowledgments

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6. References

Nautical Chart #18700, 18th Edition, 1995. Point Conception to Point Sur. Scale 1:216,116. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18703, 22nd Edition, 1993. Estero Bay, and Morro Bay inset. Scale 1:40,000, and 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18704, 12th Edition, 1990. San Luis Obispo Bay. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.1, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

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

GMT v. 4.1.1 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.0.9, 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/

VDatum Transformation Tool v. 1.0.6, developed jointly by NOAA's Office of Coast Survey and National Geodetic Survey, http://chartmaker.ncd.noaa.gov/csdl/vdatum.htm