NOAA Technical Memorandum NOS CS 17

# VDATUM FOR THE COASTAL WATERS OF SOUTHERN CALIFORNIA: TIDAL DATUMS AND SEA SURFACE TOPOGRAPHY

Silver Spring, Maryland
December 2009

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

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**National Ocean Service**
**National Oceanic and Atmospheric Administration**
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# VDATUM FOR THE COASTAL WATERS OF SOUTHERN CALIFORNIA: TIDAL DATUMS AND SEA SURFACE TOPOGRAPHY

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December 2009

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## ABSTRACT

An application of VDatum, a vertical datum transformation software tool, is developed for the southern California coastal area and adjacent waters. VDatum allows users to convert vertical elevation/depth data between various tidal, orthometric, and ellipsoid-based 3D reference systems.

The tidal datums fields for this VDatum application were derived from tidal simulations using the finite element model ADCIRC. An unstructured triangular grid consisting of 181,420 nodes and 349,351 cells was created for this region. The model was forced with nine tidal constituents ($K_1$, $P_1$, $O_1$, $Q_1$, $M_2$, $S_2$, $N_2$, and $K_2$) and run for 40 days. Model-simulated water level time series were utilized to derive various tidal datum fields, including mean lower low water (MLLW), mean low water (MLW), mean high water (MHW), and mean higher high water (MHHW). Model results were validated through comparison with observations from 35 water level stations maintained by the NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). Discrepancies between model results and observational datums were attributed to model errors and interpolated over the whole model domain using TCARI (Tidal Constituent And Residual Interpolation), a spatial interpolation tool based on solution of Laplace's equation. These spatially varying error fields were added to the original model results to  to derive corrected tidal datum fields on the unstructured grid. These final tidal datum fields were interpolated onto regularly structured marine grid to be used by the VDatum software.

The Topography of Sea Surface (TSS), defined as the elevation of NAVD88 relative to local mean sea level (LMSL), was developed based on interpolation of bench mark data maintained by CO-OPS and the National Geodetic Survey (NGS). The NAVD88-to-LMSL values were derived either by fitting tidal model results to tidal bench marks leveled in NAVD88 or by calculating orthometric-to-tidal datum relationships at NOAA tidal gauges. Results by both methodologies were coupled to create the final TSS grids using spatial interpolation.

**Key Words:** tides, tidal datums, southern California, ADCIRC, mean sea level, bathymetry, coastline, spatial interpolation, marine grid, North American Vertical Datum of 1988.

## 1. INTRODUCTION

NOAA's NOS is developing a software tool called VDatum to transform elevation data among approximately 30 vertical datums (Milbert, 2002; Parker, 2002; Myers et al. 2005). Once VDatum has been established for a region, data sets referenced to different vertical datums can be integrated through transformations to a common vertical datum (Parker et al., 2003). VDatum allows all bathymetric and topographic data to be integrated in this manner through its inherent geoidal, ellipsoidal, and tidal relationships.

To be applicable over coastal waters, VDatum requires spatially-varying fields of the tidal datums and the Topography of Sea Surface (TSS). The former includes datums such as MHHW, MHW, MLW, MLLW, Mean Tidal Level (MTL), and Diurnal Tidal Level (DTL) defined relative to Mean Sea Level (MSL). The latter refers to the elevation of the North American Vertical Datum of 1988 (NAVD88) relative to MSL.

This report describes the development of VDatum for an area encompassing the southern California coastal waters between the U.S.-Mexico border in the south and Morro Bay, CA in the north. Figure 1 displays a map of the area. In the figure, the black line represents the MHW coastline and the green line denotes the 25-nm offshore demarcation. Tidal datums for VDatum are generally developed for water areas between the coastline and the 25-nm offshore limit.

Creation of VDatum begins with simulating tides using a hydrodynamic model. Water level time series at each model node were recorded and used to compute tidal datums. The tidal datums were then verified through comparisons with observational data, and error corrections were made based on model-data differences. Regularly structured VDatum marine grids were created and populated with the corrected tidal datums. Finally, for the same marine grids, the NAVD88-to-LMSL field was derived by either fitting tidal model results to tidal bench marks leveled in NAVD88 or calculating orthometric-to-tidal datum relationships at NOAA water level stations.

This technical report is organized as follows: After an introduction in Section 1, Section 2 discusses data input needed for the tidal simulation and verification of the model results. Such data inputs include the digital coastline, bathymetry, and tidal datums derived from observational data. Section 3 details the tidal datum simulation procedures, including a description of the tidal hydrodynamic model, its setup, result validation, and error corrections. Section 4 discusses creation of the regularly structured marine grid required for the VDatum software tool and its population with error-corrected model datums. In Section 5, the creation of TSS is described. Finally, a summary is given in Section 6.

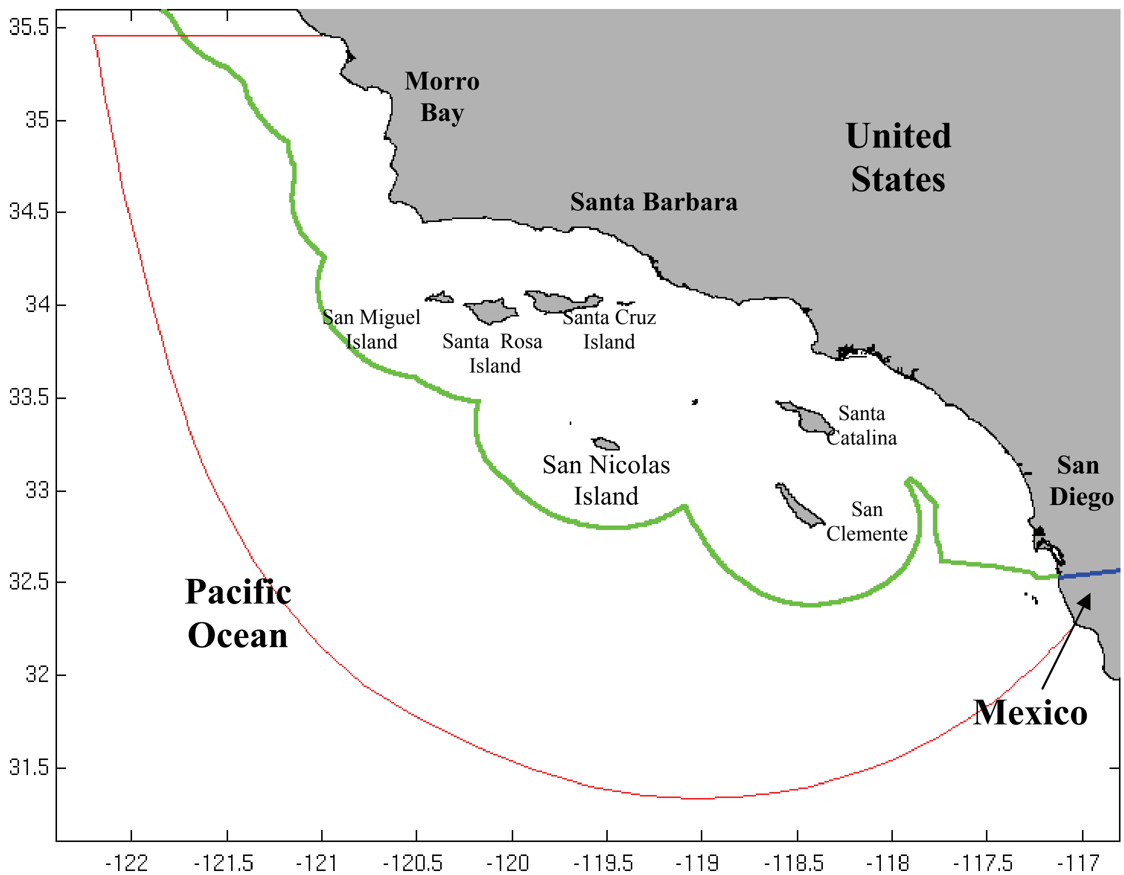



Figure 1. Map of the southern California coast and adjacent water areas. The grey areas represent land/islands and the surrounding black lines illustrate the MHW shoreline. The green line marks locations 25-nautical miles offshore. The blue line south of San Diego denotes the U.S. and Mexico border. The red line illustrates the open ocean boundary of the hydrodynamic model.

## 2. COASTLINE, BATHYMETRIC, AND WATER LEVEL DATA

VDatum requires an accurate representation of the spatial distribution of tidal datum fields (Milbert and Hess, 2001). To achieve this, VDatum applications are developed using a combination of observational data, hydrodynamic models, and spatial interpolation techniques (Myers, 2001; Spargo and Woolard, 2005). For this VDatum application in Southern California, a tide model was first set up to compute spatially varying tidal datums. The modeled tidal datums were next compared with those derived from CO-OPS observational data. Finally, spatial interpolation techniques were used to create a correction field to be applied to the model results to derive a corrected field of tidal datums that are consistent with the observations.
For the tidal simulations, coastline data are required for delineating land-water boundaries so as to define hydrodynamic model domains. In addition, bathymetric data are needed to provide the model grid bathymetry. Numerical model results may not exactly match CO-OPS observations, and therefore observational data are needed to verify and correct the model results.

### 2.1. Digital Coastline

For VDatum, the mean high water shoreline is used as the coastline to delineate the land-water boundaries (Parker, 2002). The shoreline data used in the present study were mainly based on the Extracted Vector Shoreline (EVS) dataset available from the NOS Office of Coast Survey (OCS). However, compared to NOAA nautical chart MHW shorelines, this dataset had errors in certain nearshore marshland areas. The erroneous MHW depictions were corrected using computer-aided techniques, so as to reach a close match with those illustrated on NOAA's Raster Navigational Charts (RNC). This was implemented via a commercial software package called Surface-Water Modeling System (SMS). Using SMS, geo-referenced NRC and the EVS data were contrasted visually. Wherever the two did not match, the EVS was judged to be incorrect and replaced by the corresponding chart coastline. In Figure 1, the black line illustrates the final corrected coastline.

### 2.2. Bathymetric Data

Bathymetric data used in this study were from three sources: (1) NOS soundings, (2) the NOAA Electronic Navigational Charts (ENCs) bathymetry, (3) manually digitized RNCs bathymetry, and (4) Coastal Relief model bathymetry. The soundings were from the NOS/OCS hydrographic database maintained at the National Geophysical Data Center (NGDC). The latter two were based on the NOAA ENCs and RNCs, respectively. Figure 2 displays spatial coverage of the soundings. Figure 3 and 4 respectively mark the locations of the ENC and RNC data points employed in the present study. Figure 5 shows the locations of the CRM bathymetry. Note that only those near the Mexico territory are used, due to the unavailability of any other data sets.

The NOS sounding data include surveys between 1930 and 2000. Table A.1 in Appendix A gives details on their horizontal and vertical accuracy standards. They were referenced to either MLW or MLLW, depending on the years of data collection. The ENC and RNC bathymetry were treated as being relative to MLW. It is noted that bathymetry data referenced to different tidal datums were adjusted to a common reference level before being merged for creating the model grid bathymetry. Details on the adjustment procedures are given in Section 3.3.

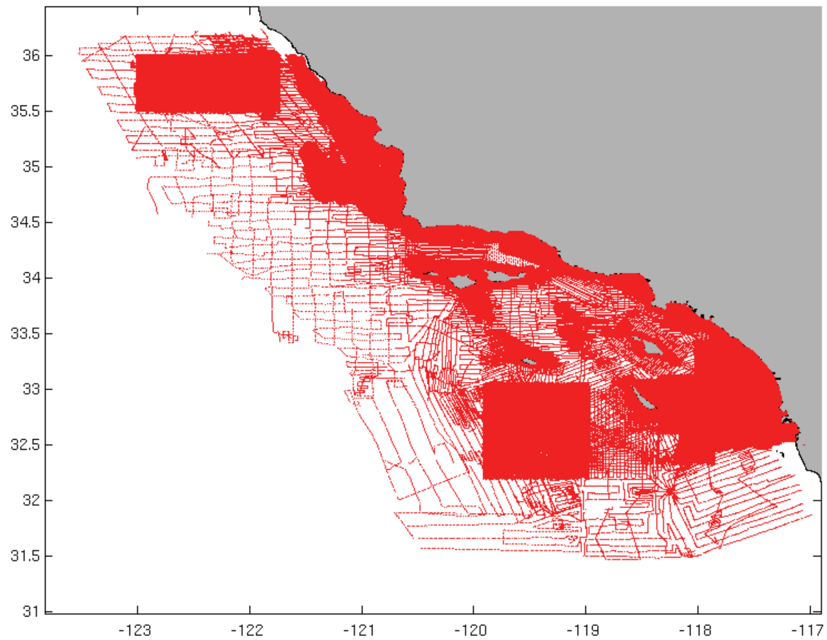



Figure 2. Spatial coverage  of sounding data

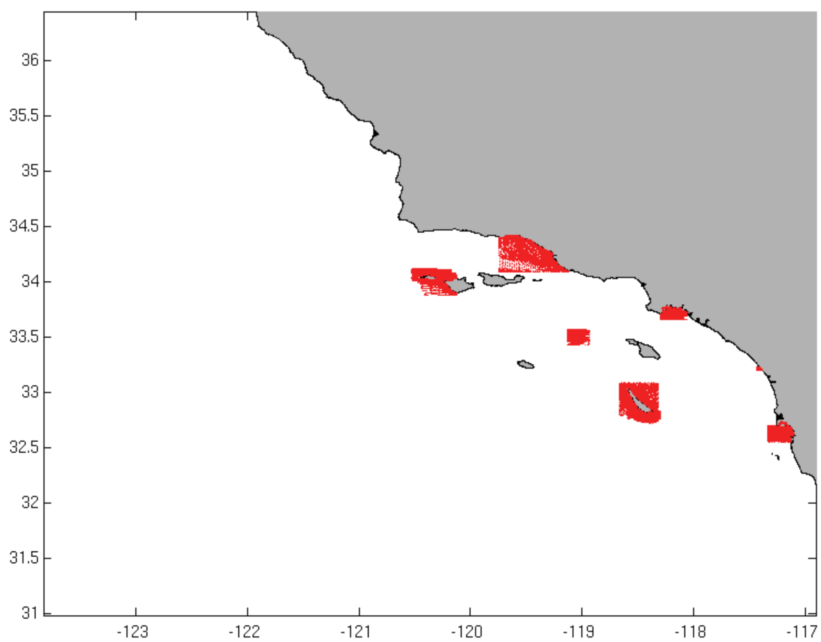



Figure 3. ENC bathymetry data used in the present study

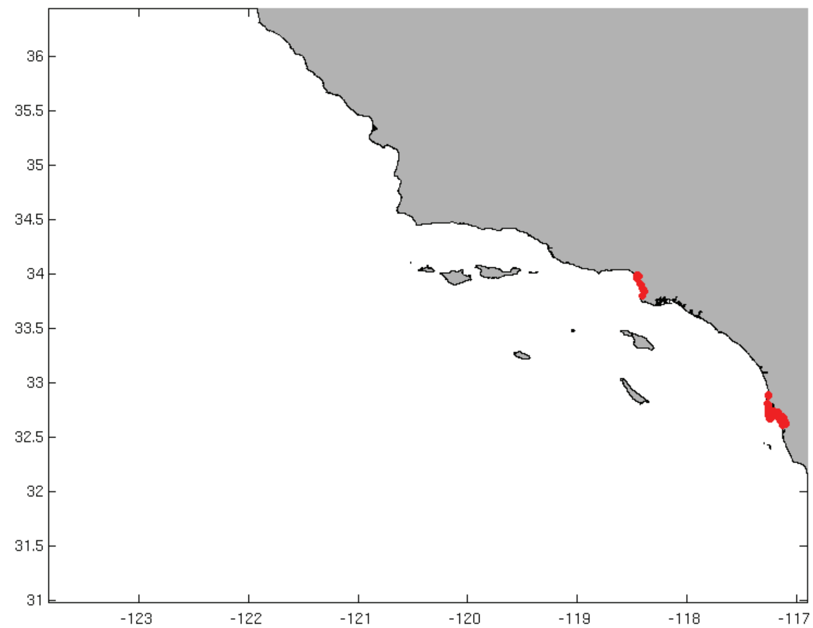



Figure 4. Digitized RNC bathymetry (It's mostly just in San Diego, but there are a couple of points along the coast where the data helped fill in some gaps)

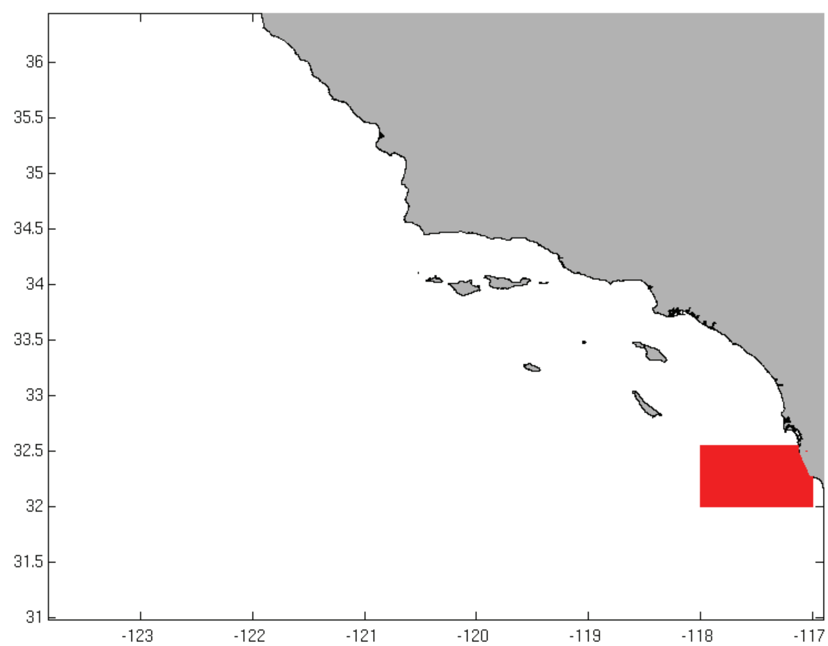



Figure 5. Coastal Relief Model for Mexico's coastal waters.

The NOS soundings possess a higher spatial distribution density than the ENC data. In some areas, the two are commonly available. However, neither of them provides complete coverage for the whole study area. Hence, they were blended for improved regional coverage. It is noted that even the merged data set left certain nearshore regions uncovered. NOAA nautical chart bathymetry was then manually digitized to compensate for this missing coverage. Since both the ENC and manually digitized bathymetries were grounded in nautical chart data, they were merged to form one data set and hereafter referred to as the ENC bathymetry without differentiation.

## 2.3. Tidal Datum Data

Tidal datum elevations from CO-OPS water level stations were used to verify and correct model results (Hess and Spargo, 2005). Many stations are located within either embayments or near obstructions not represented in the present model grid (Section 3.2), or at upper-reaches of riverine areas where datums exhibit strong seasonal variability. Observations at these stations were deemed to be unsuitable for validating model results and discarded. The observational data correspond to either the present National Tidal Datum Epoch (NTDE 1983-2001) or the older one (NTDE 1960-1979), and there were also some historical observations for which the epoch was not documented. It is noted that at some stations, datums are available for both the present epoch and others. In this case, only those with the most recent epoch are used. This resulted in 38 stations actually used for model validations. Tables B.1 and B.2 in Appendix B list the station and tidal datum information.

## 3. TIDAL DATUM SIMULATION

### 3.1. Hydrodynamic Model

The ADvanced CIRCulation (ADCIRC) model (Luettich et al., 1992; Westerink and Luettich, 1993; Luettich and Westerink, 2003) was employed to simulate water level time histories and derive tidal harmonic constant fields. The ADCIRC model is an unstructured grid, hydrodynamic circulation model. It solves the shallow water equations and has been used for modeling tides in various ocean, coastal and estuarine environments (Luettich et al., 1999; Mukai et al., 2002; Myers 2005). The ADCIRC model provides a variety of options for users to specify various aspects of tidal dynamics and execution modes. For instance, the model may be used in either 2- or 3-dimensonal modes, serial or parallel execution dependent on machine infrastructures, linear or quadratic bottom friction formulations with constant or variable friction coefficients, etc. More details on the model setup including the model grid generation, bathymetry specification, and parameter selections are addressed in following sections.

### 3.2. Model Grid

The model domain encompasses the southern portion of the California coastal waters between Morro Bay in the north and the U.S.-Mexico border in the south (Figure 4). The domain extends from the coastline toward an area beyond the shelf break. A high-resolution, unstructured, triangular grid of 181,420 nodes and 349,351 cells was created to represent the area up to the MHW shoreline. The grid spacing ranges from around 20 m nearshore to 44 km in the offshore regions. In general, finer grids were created for nearshore areas compared to those in deep waters, so as to accurately resolve fine coastline features and the bathymetric-dependent variability of tidal wavelengths. Figures 5(a) and (b) show close-up views of the grid in the areas (a) surrounding Santa Barbara and adjacent islands, and (b) along the coast between San Diego and Santa Monica. The grid resolves various coastal embayments and inlets.

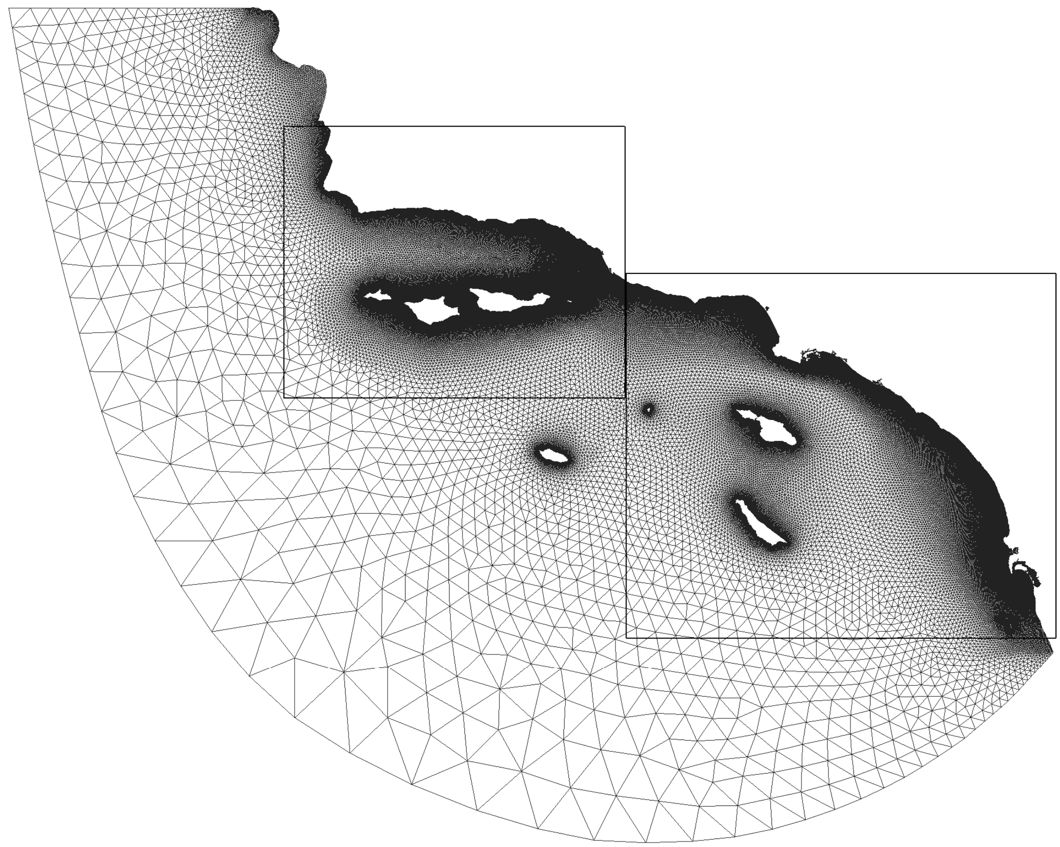


Figure 6. Finite element grid for the entire model domain. Red line represents the model open ocean boundary.

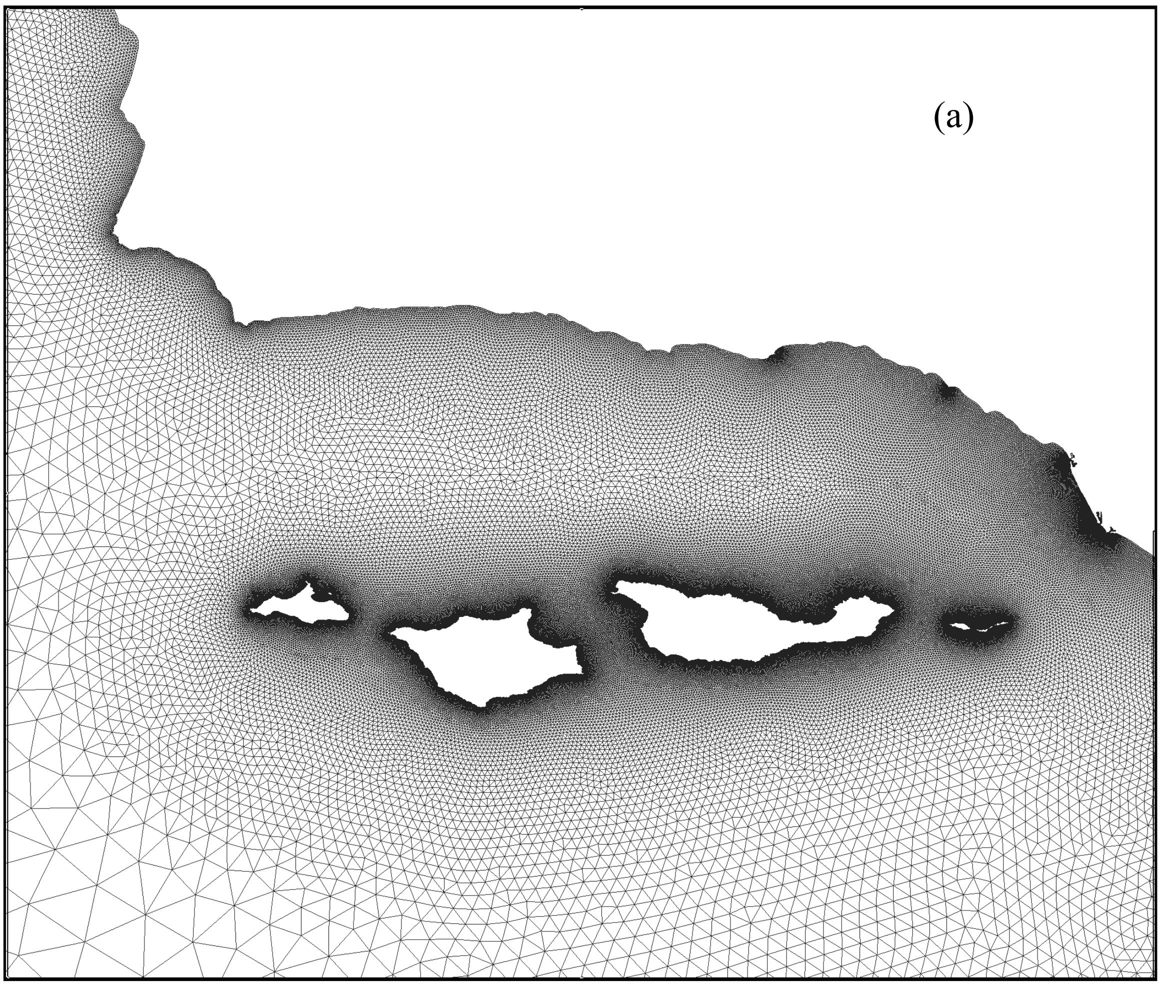



Figure 7. Close-up view of the hydrodynamic model grid for areas (a) surrounding Santa Barbara and adjacent islands, and (b) between San Diego and Santa Monica.

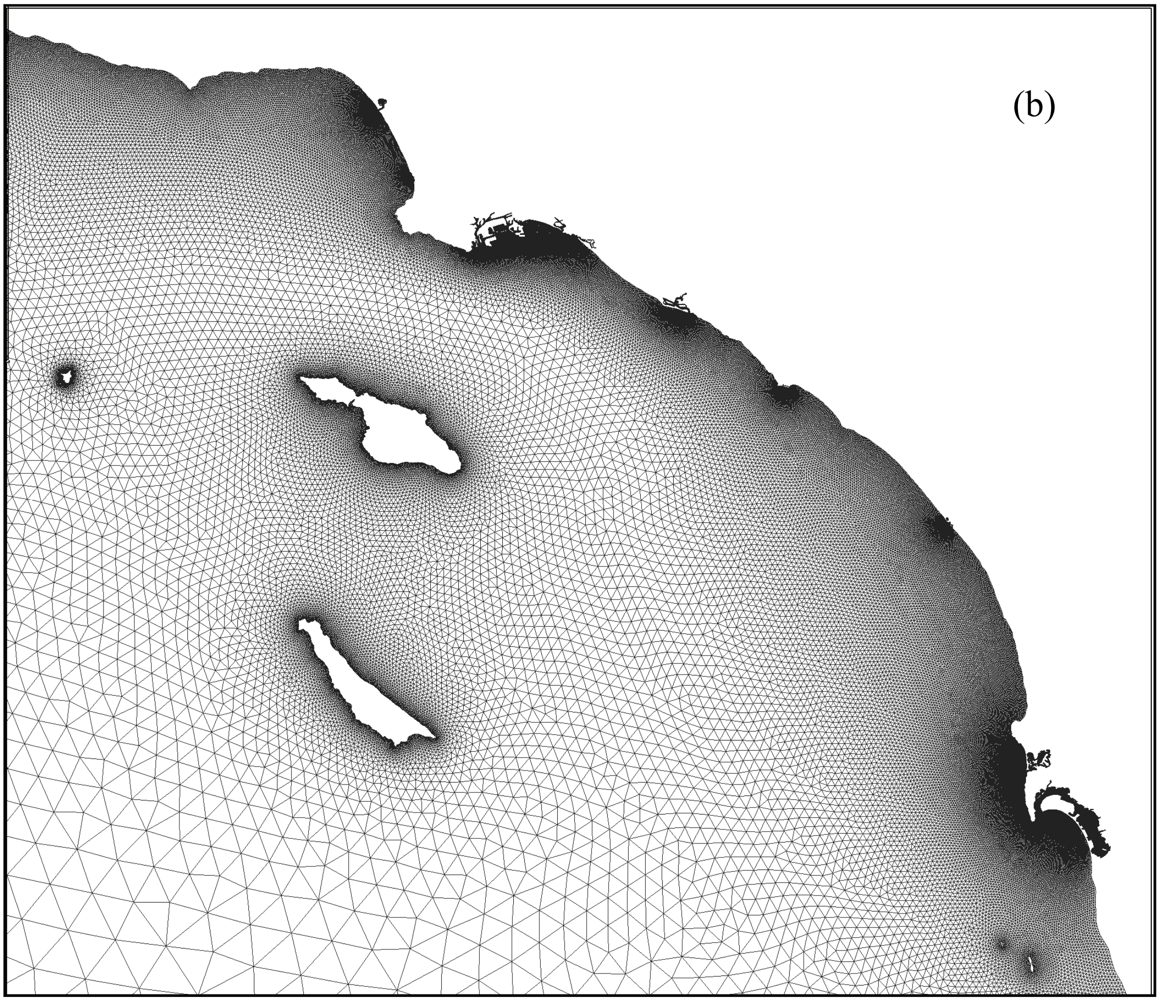



Figure 7. (Continued)

### 3.3. Bathymetry on Model Grid

The model grid was populated separately with the four bathymetric datasets (Section 2.2) using a cluster averaging approach (Yang et al., 2004) to form four bathymetry grids, corresponding to (1) ENC data, (2) NOS sounding data, (3) digitized RNC data, and (4) CRM data, respectively. Owing to the limited spatial coverage of each data set, each of the four grids left numerous unpopulated nodes. Meanwhile, the nodes with valid bathymetry vary from grid to grid.

The four grids were then merged for an improved coverage. First, the ENC grid was treated as a baseline grid. Next, the NOS grid was used to assign values to the baseline grid nodes with null bathymetry. Digitized RNC grid was then added to the remaining null-value nodes. Finally, the CRM grid was employed. After the merging, there were still 15,720 unpopulated nodes (about 8.5% of the domain). They were then filled in by interpolating or extrapolating from surrounding nodes with valid bathymetry depths.

The merged grid was referenced to MLLW. The hydrodynamic model requires bathymetry referenced to a model zero (MZ), which represents a constant geopotential surface. Prior to any initial model rerun, the difference between MZ and MLLW is unknown. For the initial guess, the bathymetry was adjusted to MSL, which was considered to be equal to MZ for the first run, by adding 0.84 meters to every node. This number was the average difference between MLLW and MSL at 38 stations in the region.

The model was run in an iterative fashion, such that the model results were used to adjust the original grid with bathymetry data referenced to MLLW to a new depths referenced to MZ. After 3 model runs, the results were "converged" in the sense that the results did not change from run to run. Figure 8 displays bathymetry used for the final model run.

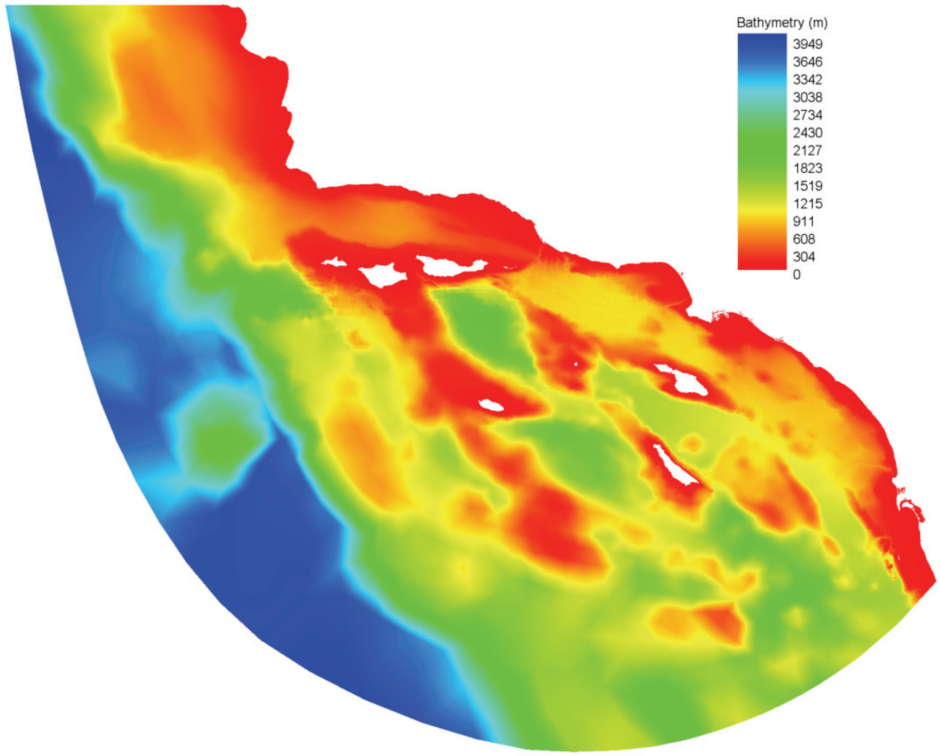



Figure 8. Model grid bathymetry relative to MZ. Color bar is in meters.

### 3.4. Model Parameters Setup

In the present study, model parameters were set up to solve the shallow water equations in Two-Dimensional Depth-Integrated (2DDI) mode with finite amplitude and convection terms. Lateral viscosity was set as a constant, 5.0 m $s^{-2}$, throughout the model domain. A quadratic friction scheme with a constant coefficient of $C_f$=0.0025 was specified to calculate bottom friction.

The eight most significant astronomical tidal constituents ($M_2$, $S_2$, $N_2$, $K_2$, $K_1$, $P_1$, and $O_1$) in the area were chosen as tidal forcings on the model's open boundary. Corresponding harmonic constants were interpolated based on a tidal database covering the eastern north Pacific ocean (ENPAC2003) (Spargo, 2003). A time step of 4.0s was used to ensure the model's numerical stability. The simulation covered a period of over 40 days. First, the model was ramped up for 5 days with a hyperbolic tangent function. Between days 5.5-40, time series of the modeled water levels were save at 6 minute intervals at each node in the grid.

The parallel version of ADCIRC model was adopted and the model run was conducted on 128-processors of the JET computer at Earth Research System Laboratory.

### 3.5. Tidal Datum Computation and Results

Water level time series from the final ADCIRC simulation were recorded at 6-minute intervals at each grid node. They were passed into the FORTRAN program lv5.f to calculate the following tidal datum fields: MSL, MHHW, MHW, MLW, and MLLW. The computed datums were referenced to MZ. The latter four were then adjusted to be referenced to the modeled MSL field. Henceforth, references to each of the tidal datums shall imply this adjusted value relative to MSL. Note that MTL is defined as the algebraic average of MHW and MLW, and DTL is the algebraic average of MHHW and MLLW. The two fields were not computed until error-corrected MHHW, MHW, MLW, and MLLW fields were obtained (Section 4.2).

Figures 9(a)-(d) display the model derived tidal datum fields for MHHW, MHW, MLW, and MLLW, respectively relative to MSL. The four fields exhibit a similar spatial pattern. Magnitudes of tidal datums are amplified as tides approach shorelines. For instance, MHHW starts from about 0.75 m along the shelf break and reaches up to about 0.8-0.9 m near the Southern California coasts. In general, tidal datum magnitudes in the southern portion of the domain appear greater than those in the northern portion. The MHHW reaches around 0.87 m near the Santa Monica coast as compared to a much smaller value of about 0.75 m at Morro Bay.

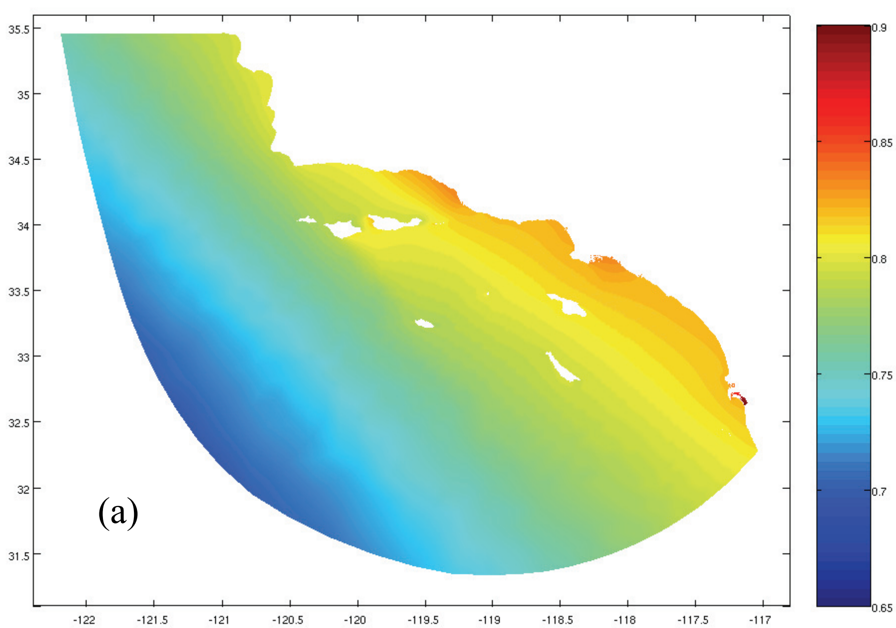
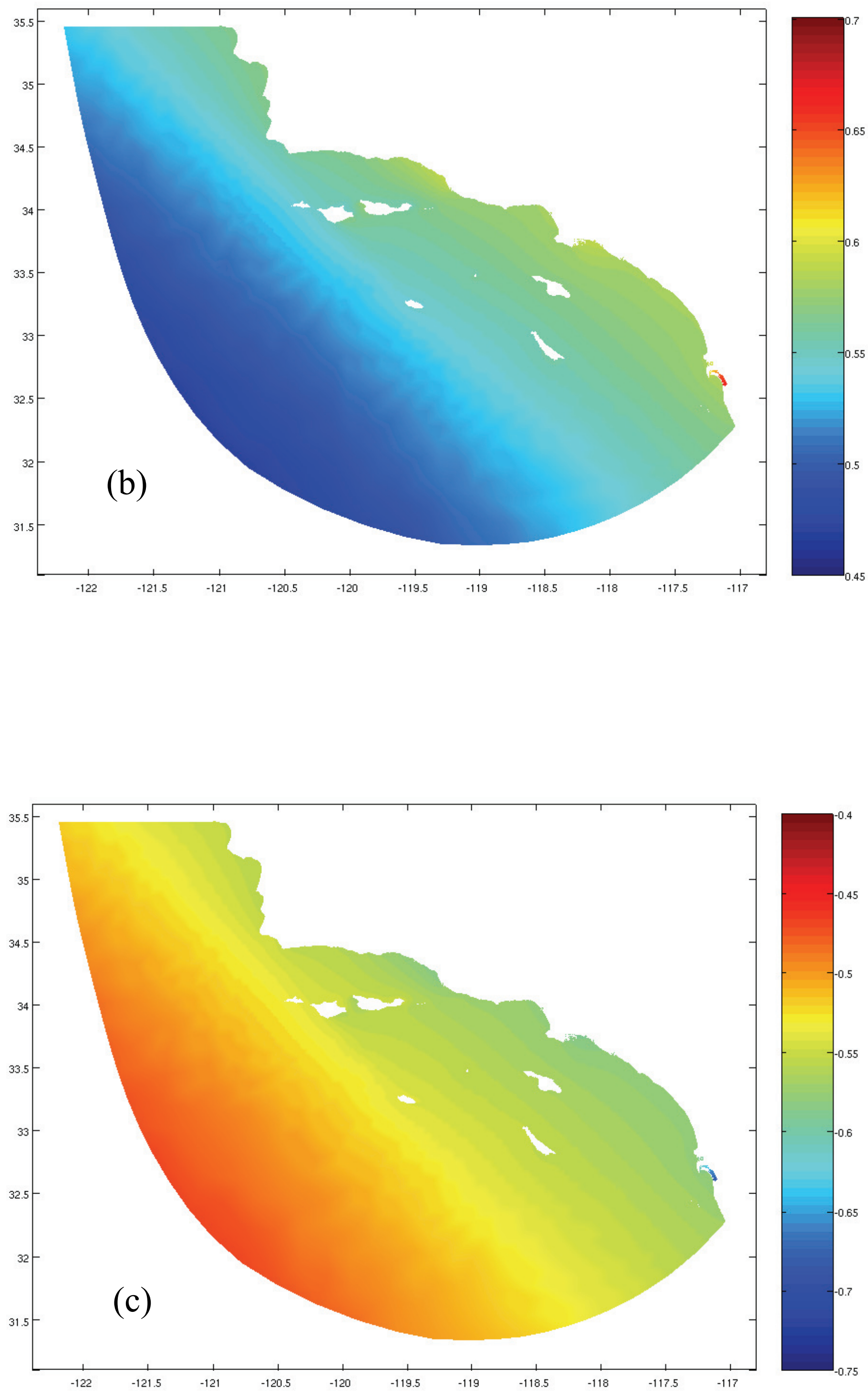



Figure 9. Model derived tidal datum fields, (a) MHHW, b) MHW, (c) MLW, and (d) MLLW. The Color Bars are in meters.

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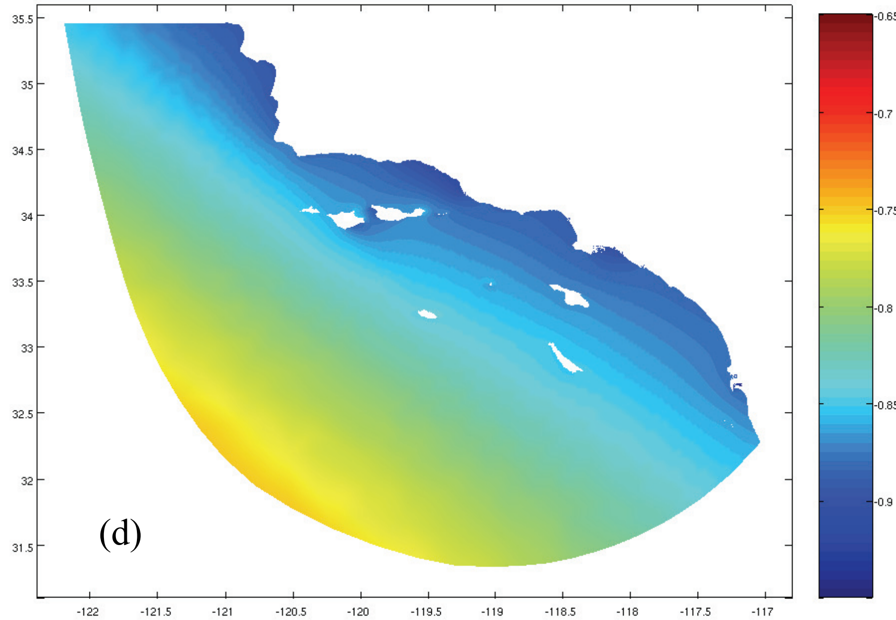



Figure 9. (Continued)

### 3.6. Verifications and Error Corrections

### 3.6.1. Comparisons with Observations

To verify model results, simulated tidal datums were compared with those from 38 NOS water level stations (Appendix B). Figures 10(a)-(d) display model-data contrasts for MHHW, MHW, MLW, and MLLW, respectively. In general, these exhibit good model-data agreement. Over the 38 stations, magnitudes of the model-data differences are averaged to be 2.8 cm, 1.3 cm, 1.9 cm, and 4.7 cm for MHHW, MHW, MLW, and MLLW, respectively. The model-data correlation coefficients demonstrate a constant 0.99 for all four tidal datums.

For each individual station, averaged magnitudes (|Avg|) of model-data differences over the four datums are examined. Figure 11 illustrates |Avg|'s scaled in color-coded symbols. The mean and standard deviation of |Avg| over all the 38 stations are 2.65 cm and 1.13 cm, respectively.

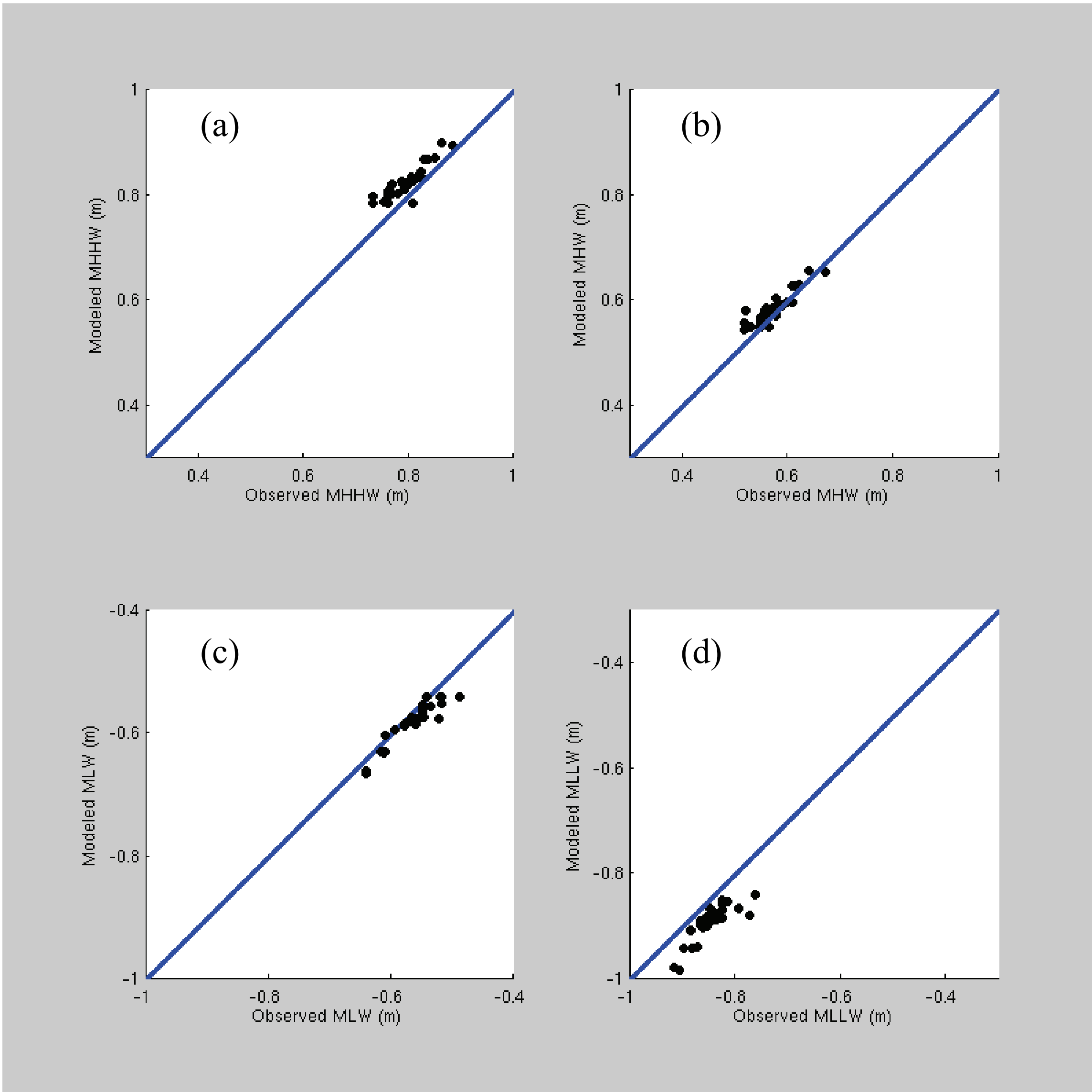



Figure 10. Comparisons of the modeled (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW datums against observations using 38 tide stains.

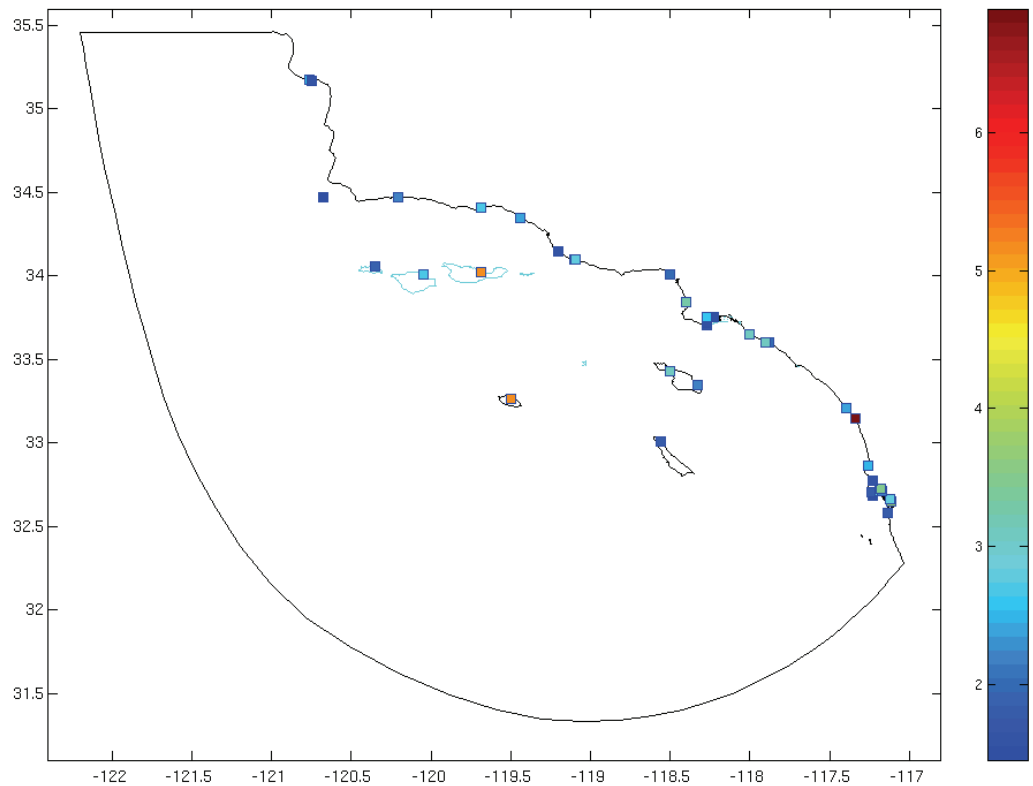



Figure 11. Color-coded model-data differences at each observational station

### 3.6.2. Match with Tidal Datums in Adjacent areas

The present model domain overlaps with the previously developed North and Central California VDatum areas (Myers and Hess, 2005). Figure 12 illustrates the coverage of the two domains. In the figure, the yellow line delineates the North and Central California domain, while the red line delineates the present model domain. The green line denotes the 25-nm offshore limit.

In reality, tidal datum fields should be matched seamlessly across the boundaries. However, this is not necessarily engendered when the two tidal datum fields were developed separately through slightly differing approaches and model setups. Therefore, it is worthwhile to examine discrepancies and work out ways to reach seamless matches if needed.

In Figure 12, blue circles along transect AA’ correspond to grid nodes of the present hydrodynamic model, which are chosen to denote boundaries between the two model domains. Tidal datums from resources across the boundaries are compared over these locations. Four datums (MHHW, MHW, MLW, and MLLW) from within the Central and

Southern CA regions are separately interpolated onto the comparison locations. Figure 13 shows the results along transect AA'. Table 1 tabulates the average tidal differences between the two models. In general, the differences are greater than 1 cm, which suggests the necessity of adjustments to reach seamless matching between the present results and those developed previously. Procedures for the adjustment are described in the next section.

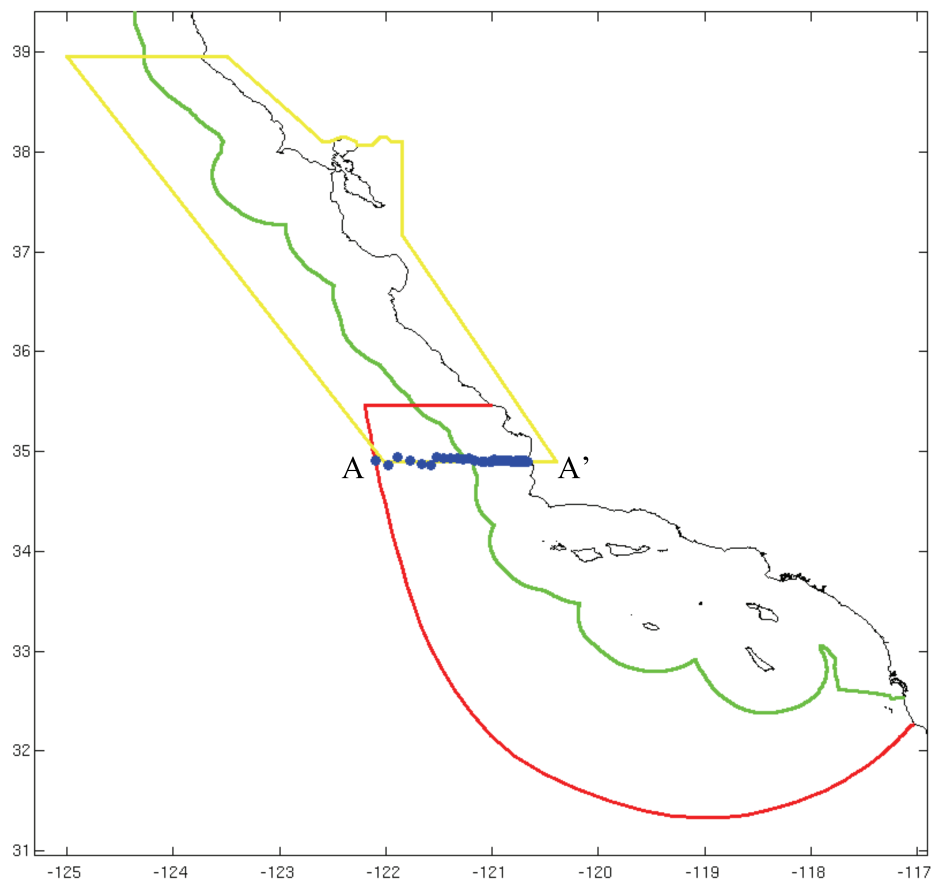



Figure 12. Map of the Southern California model domain (red line) and bounding polygons of the Central California VDatum region. Blue dots (transect AA') represent the southern CA model grid nodes adjacent to the southern border of the central CA VDatum region. The green line delineates 25-nm offshore locations.

Table 1. The average differences of MHHW, MHW, MLW, and MLLW across boundaries of different VDatum regimes.

| Boundaries | MHHW (cm) | MHW (cm) | MLW (cm) | *MLLW (cm)* |
|---|---|---|---|---|
| *AA'* | *1.5* | *2.2* | *2.3* | *0.9* |

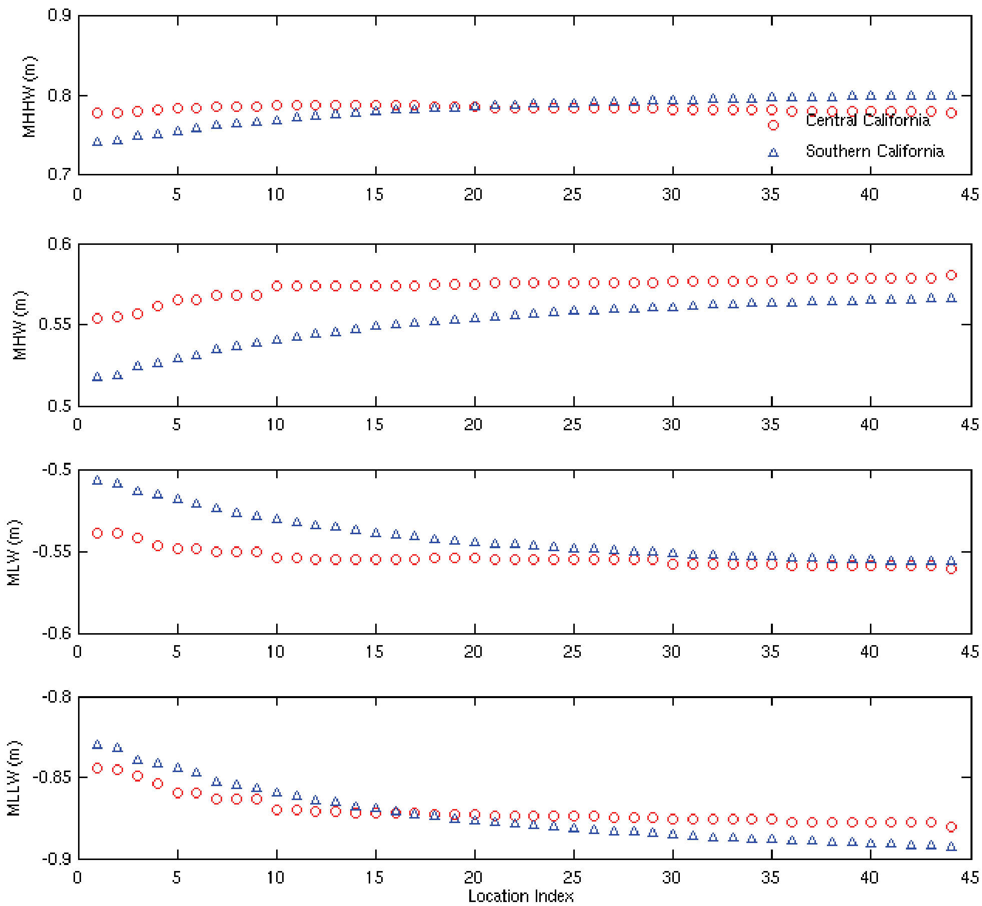



Figure 13. Comparisons of tidal datums at discrete locations (blue symbols along transect AA' in Figure 12), (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW. The abscissa, Location Index, is counted from A to A' (Figure 12.

### 3.6.3. Corrections

Tidal datum corrections were developed to eliminate model-data differences at observational stations (Section 3.6.1) as well as to eliminate datum discrepancies across boundaries of different VDatum domains (Section 3.6.2). This was achieved using the TCARI (Tidal Constituent And Residual Interpolation) spatial interpolation tool (Hess, 2000; Hess, 2002). TCARI spatially interpolates the error fields defined at a number of individual control stations onto the whole domain by solving Laplace's equation. The technique was implemented for both structured or unstructured model grids, and a version of the latter was employed in this study.

To run TCARI, both the observational stations and locations along the domain boundary are treated equally as control stations. For each tidal datum, both model-data differences (at 38 tidal stations) and across-boundary discrepancies (at 38 boundary locations) were computed and merged into one dataset for input to TCARI.

After applying TCARI, error fields for MHHW, MHW, MLW, and MLLW were derived which matched the tidal datum differences at the 38 control stations. Figures 14(a)-(d) illustrate the four interpolated error fields, respectively. The initial model results (Section 3.5) were then corrected by subtracting the error fields over the entire model grid. Figures 15(a)-(d) display the four corrected datum fields relative to MSL.

Note that the other two tidal datum fields, the MTL and DTL shown in Figures 15 (e) and (f), were produced in a different way. They were derived from the four corrected datums by taking the averages between MHW and MLW and between MHHW and MLLW, respectively.

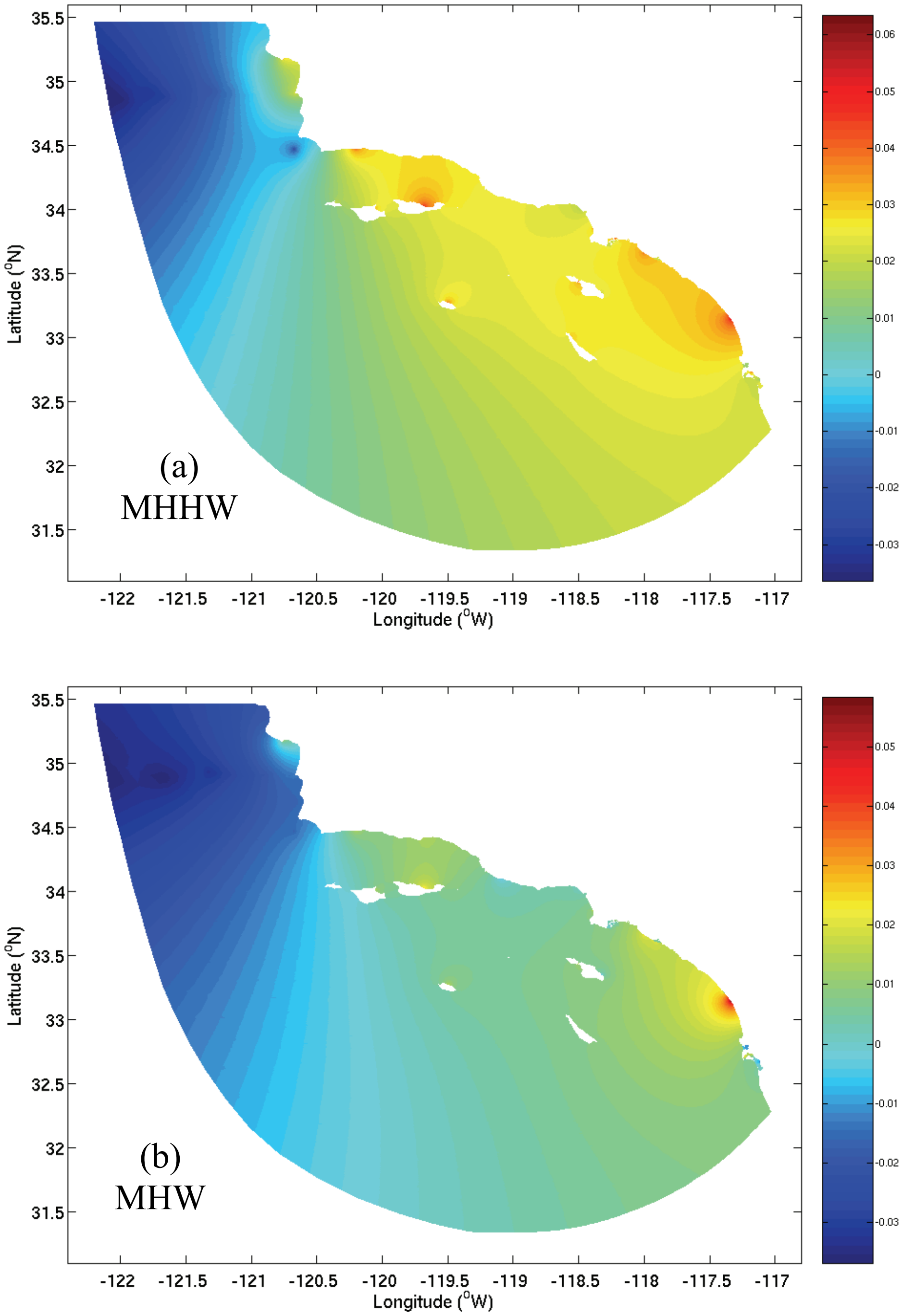
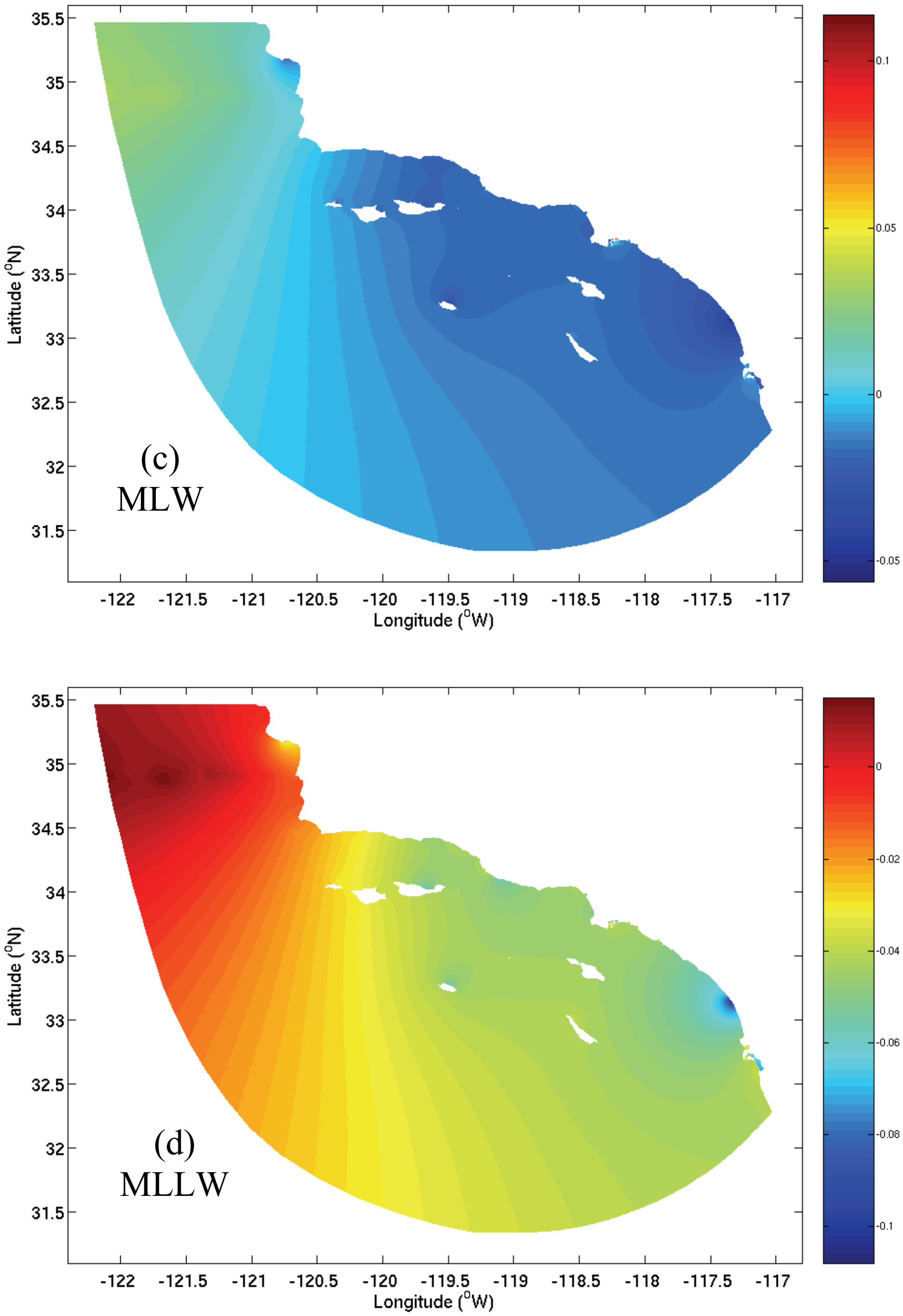



Figure 14. TCARI interpolated tidal datum error fields on the unstructured grid, (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW. Color bars are in the unit of meters.

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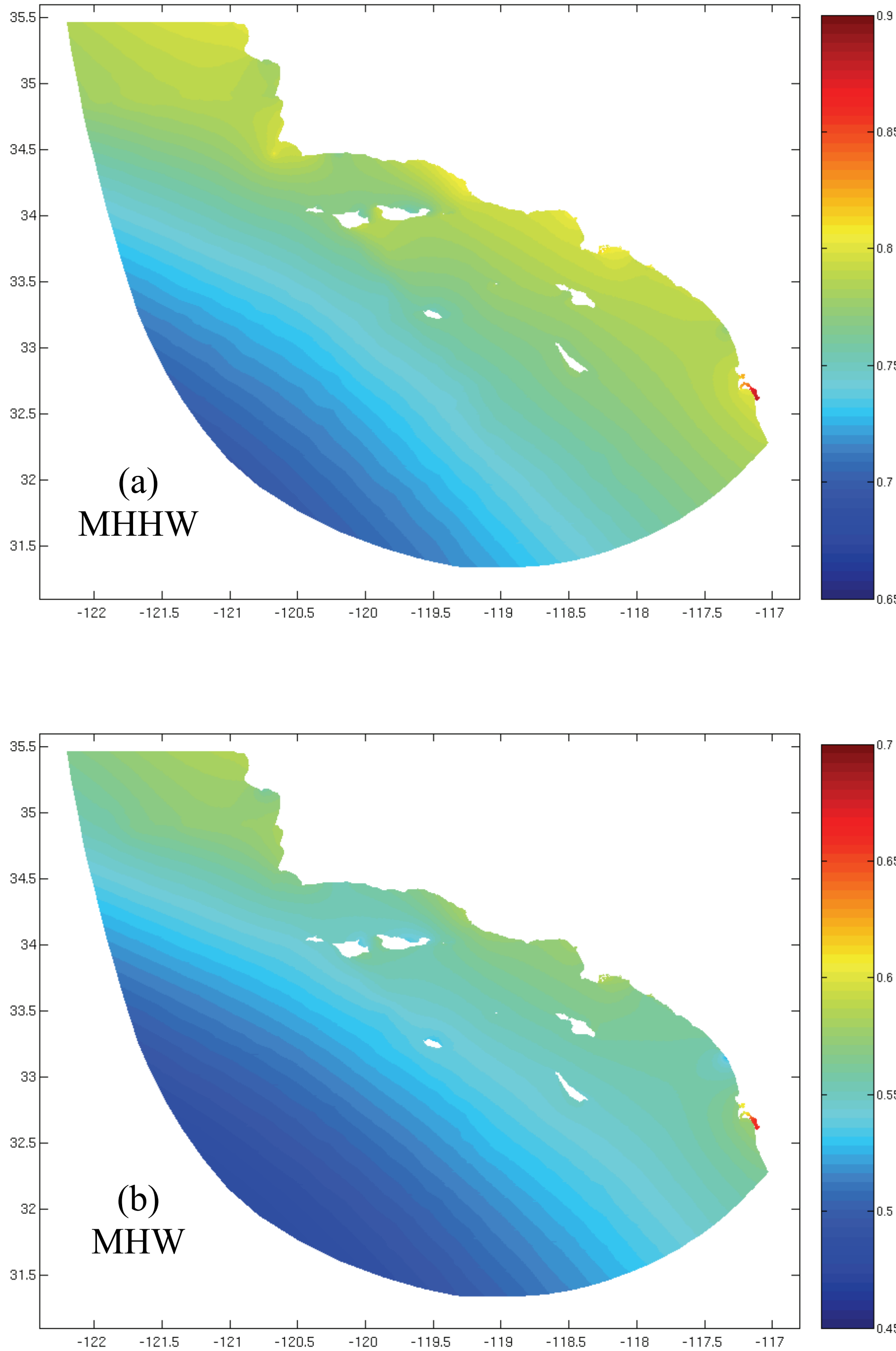
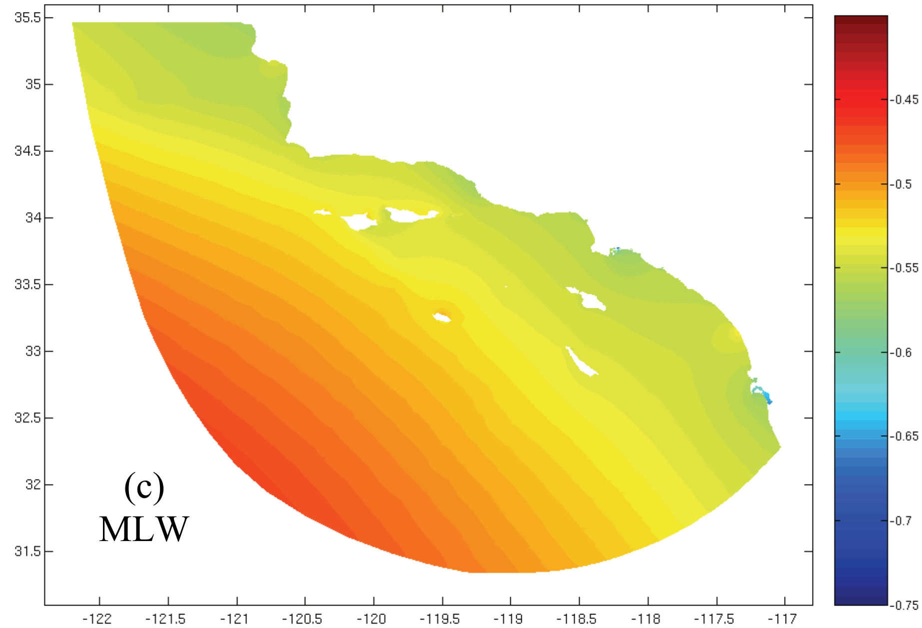



Figure 15. Corrected tidal datum fields on the unstructured grid, (a) MHHW, (b) MHW, (c) MLW, (d) MLLW, (e) MTL, and (f) DTL. Color bars are in meters.



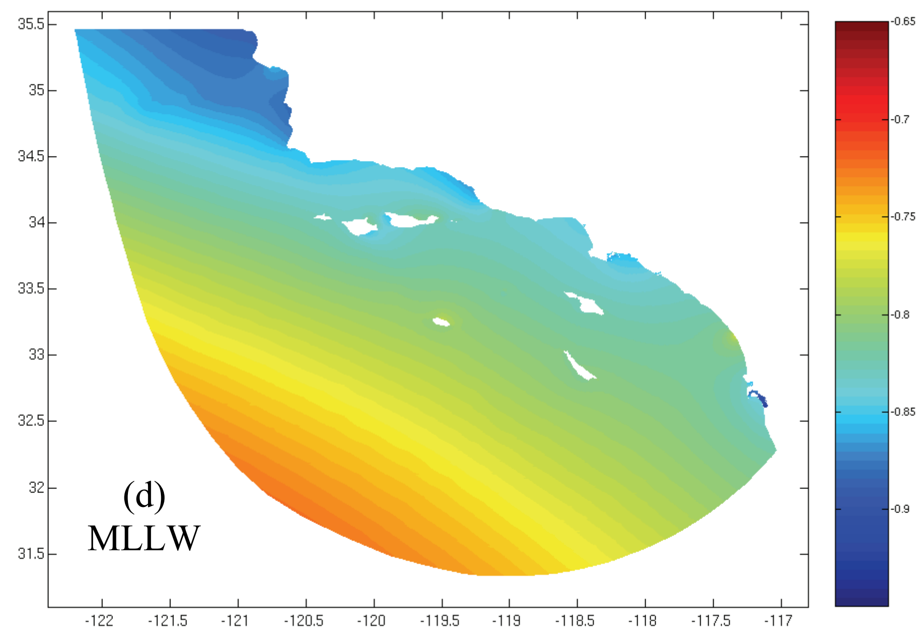




Figure 15. (Continued)

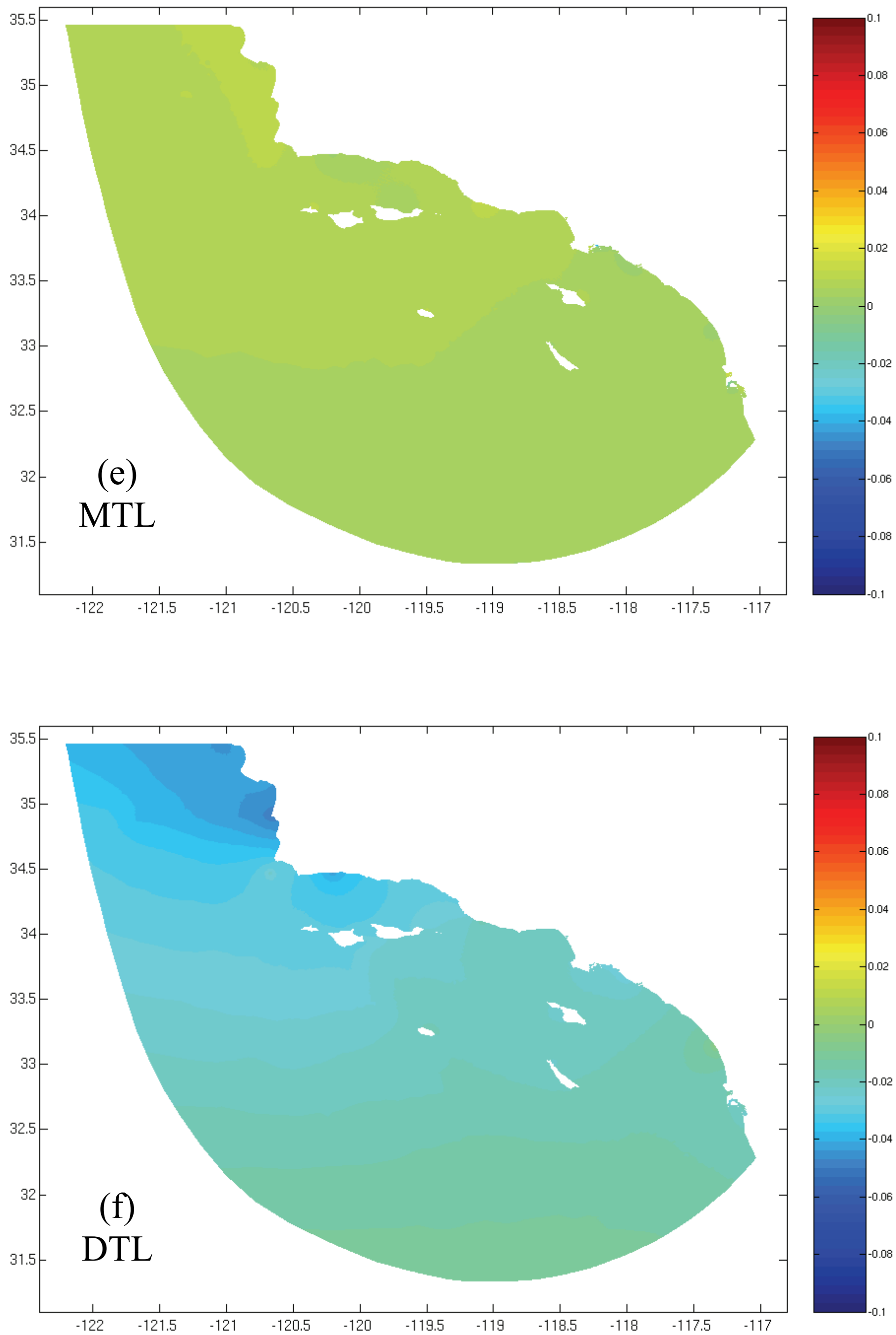



Figure 15. (Continued)

# 4. CREATION AND POPULATION OF THE MARINE GRID

## 4.1. Creation of VDatum Marine Grid

Tidal datums in the VDatum software are defined on a regularly structured grid, referred to as the marine grid (Hess and White, 2004). Hence, it is necessary to convert the tidal datum fields from the unstructured model grid onto the equally-spaced VDatum marine grid.

Nodes in the marine grid were specified as either water points or land points. The water nodes are to be populated with valid tidal datum values and the land nodes are assigned with null values. To create and populate the marine grid, a high-resolution coastline and a bounding polygon were used (Figure 16). Only nodes within the bounding polygons or within up to one half of a cell size outside the coastline are delineated as water nodes; those outside of the bounding polygons or those more than one half of a cell size away from the coastline are marked as land nodes.

Marine grid points are equally spaced within each region. For a point at the *i*-th row and *j*-th column relative to the point $(longitude_0, latitude_0)$ at the region's southwest corner, its location *(longitude_i, latitude_j)* is defined as,

$$\text{Longitude\_i} = \text{longitude}_0 + (i-1)\times \text{del\_lon}, \quad i=1, \ldots, \text{N\_lon},$$
$$\text{Latitude\_j} = \text{latitude}_0 + (j-1) \times \text{del\_lat}, \quad j=1, \ldots, \text{N\_lat},$$

where *del_lon*, and *del_lat* denote separation between neighboring points along the meridional and zonal directions, respectively; *N_lon* and *N_lat* represent, respectively, the longitude and latitude dimensions of the raster data set. It is noted that the *del_lon* and *del_lat* are prescribed parameters representing the expected grid resolutions, while *N_lon* and *N_lat* are derived parameters according to

$$\text{N\_lon} = 1 + (\text{longitude}_1 - \text{longitude}_0)/\text{del\_lon}$$
$$\text{N\_lat} = 1 + (\text{latitude}_1 - \text{latitude}_0)/\text{del\_lat}$$

where $(longitude_1, latitude_1)$ are the coordinate at the raster region's northeast corner. Table 2 lists the marine grid parameters used in the present study.

Table 2. Marine grid parameters

| Marine Grids | $\text{Longitude}_0$ (degree) | $\text{Latitude}_0$ (degree) | del_lon (degree) | del_lat (degree) | N_lon | *N_lat* |
|---|---|---|---|---|---|---|
| *Southern California* | *-122.03* | *32.25* | *0.001* | *0.001* | *5101* | *2891* |

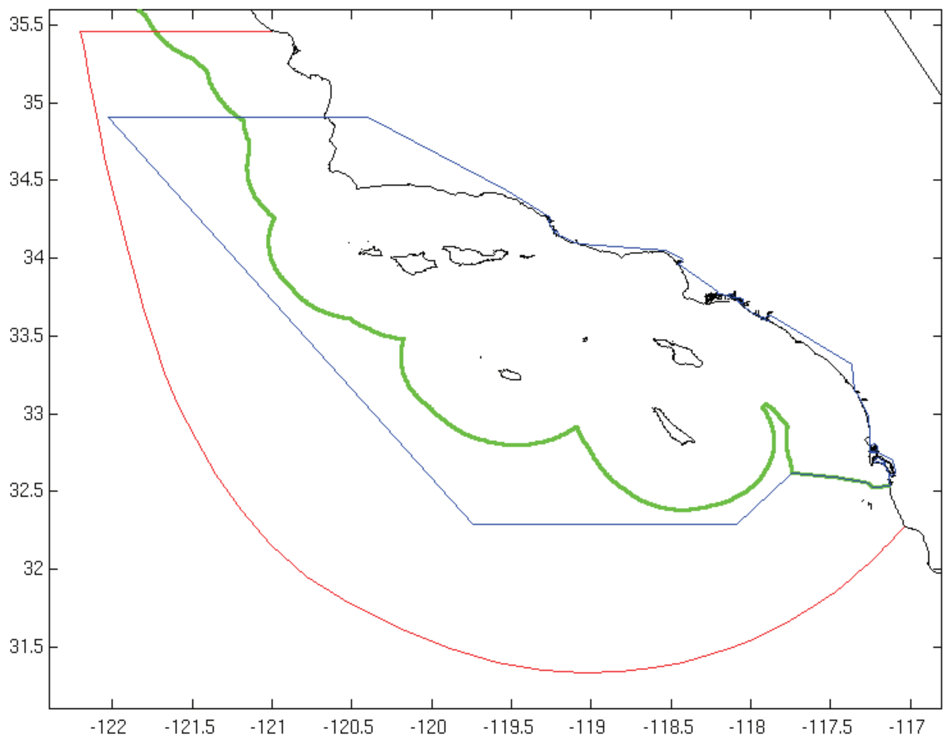



Figure 16. The marine grid bounding polygon (blue line). The green line marks locations 25-nautical miles offshore. The red line illustrates the open boundary of the hydrodynamic model.

## 4.2. Population of VDatum Grid with Tidal Datums

Tidal datums on the VDatum marine grid were populated by interpolating TCARI-corrected tidal datums (Section 3.6) according to the algorithm of Hess and White (2004). Datums at each VDatum marine grid point were computed by averaging or linearly interpolating values within a user-specified searching radius or the closest user-specified number of points. In the present case, the interpolation was made using a FORTRAN program, vpop10.f. It populates marine points differently depending on whether the point is inside/outside of the ADCIRC model grid elements. If the point was inside an element, datums were calculated using an interpolation of the 3 nodes of the element; if the point is outside any elements, datums were computed using the inverse distance weighting of the closest two node values. Figures C.1 (a) – (f) display the populated tidal datums (MHHW, MHW, MLW, MLLW, MTL, DTL) defined on the marine grid (Section 4.1).

Two types of verifications were conducted for the tidal datums populated on the marine grids: comparison with observations from the 38 CO-OPS tidal stations and examining the match across its boundaries with the central California VDatum application (Myers, 2005). For each of the four datums (MHHW, MHW, MLW, and MLLW), both the average model-data error and the rms error are less than 1 mm.

Datum fields across the boundaries of different VDatum regimes demonstrate good consistency as well. For each of MHHW, MHW, MLW, and MLLW, the average difference across the border between the Central California and the present VDatum regime is less than 1 mm.

## 5. GENERATION OF TSS

The TSS is defined as the elevation of NAVD 88 relative to local MSL. It is created by combining observed datums at NGS bench marks and CO-OPS water level stations with the tidal model results. Figure 17 illustrates the station locations used in this application (see details of the station information at Table D.1 of Appendix D). To create the TSS over the VDatum domain, the TSS values at the observation stations were first derived. These values were then interpolated over the whole domain. Afterwards, a quality control procedure was followed and appropriate changes were made to meet certain criteria. For the Southern California vicinity, the NAVD 88 heights are realized utilizing either GEOID99 or GEOID03, and therefore two sets of NAVD88 data were created. It is noted that the generation of both data sets shared the same algorithms and procedures.

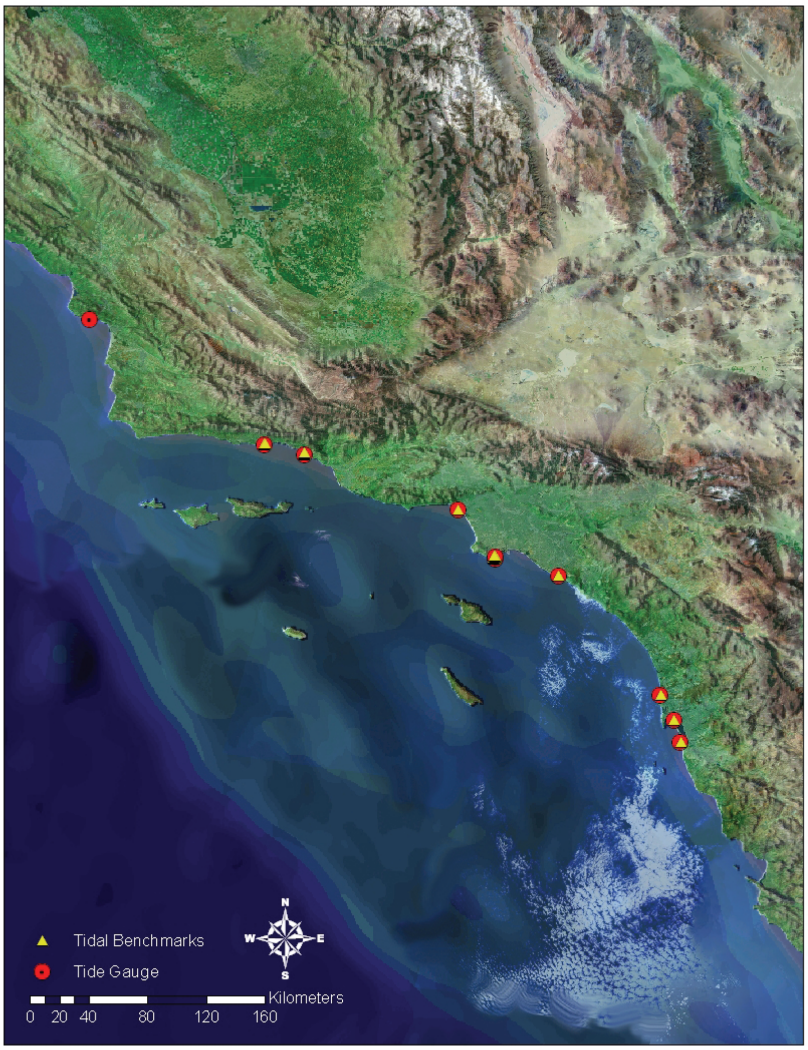



Figure 17. Location of tidal bench marks and tide stations used to compute the Southern California VDatum TSS grids.

## 5.1. Derivation of TSS

Two methodologies were used to compute the TSS at the observational stations: an indirect method using data from the NGS database (see Appendix E) and a direct method using data from the CO-OPS database (see Appendix F). To derive the TSS at the NGS stations using the indirect method, residuals ($R_{datum}$) at every NGS bench mark location are computed as:

$$R_{datum} = TBM_{navd88} - TBM_{datum} + VD_{datum}$$

where $TBM_{navd88}$ and $TBM_{datum}$ are the observed (NAVD88–MLLW) and (Datum-MLLW) differences, respectively, and $VD_{datum}$ denotes modeled (Datum–MSL) differences. The residual, $R_{datum}$, represents an estimation of the (NAVD88-MSL) difference.

There are four sets of $R_{datum}$, corresponding to MHHW, MHW, MLW, and MLLW. Each represents an independent estimation of the quantity MSL–NAVD88 associated with a tidal datum. Tables E.1 and 2 list $R_{datum}$'s at stations located within the VDatum bounding polygon (Figure 16). At each station, the four $R_{datum}$'s are then averaged to produce a mean residual ($\overline{R}_{datum}$). $\overline{R}_{datum}$ represents an overall estimation of MSL–NAVD88 and is used for further development of the TSS grid.

The TSS values at CO-OPS stations were simply derived by calculating orthometric-to-tidal datum relationships. Table D show the station location inventories and observations of elevation information.

Next, the $\overline{R}_{datum}$ values are merged with TSS values from CO-OPS stations to form a data set for creating a TSS mesh using the gridding software, Surfer©. A grid covering the entire area of bench marks and water level stations with a spatial resolution similar to that of the VDatum marine grid was created. Breaklines were inserted to represent the influence of land. The Surfer© software's minimum curvature algorithm was employed to create a primary TSS field ($TSS_{grid}$) that honors the data as closely as possible. It is noted that the $TSS_{grid}$ represents an estimation of the quantity MSL- NAVD88 and still requires further quality control and correction procedures (Section 5.2). Figures 18 shows the final TSS fields for the VDatum region (Table 2). In the figures, a positive value specifies that the NAVD 88 reference value is further from the center of the Earth than the local mean sea level surface. Figures 18 and 19 display the TSS fields based on NAVD88 realized through GEOID99 and GEOID03, respectively. Data derived from both the indirect and direct methodology are initially relative to NAVD88 realized through GEOID03. This data derived for both methods is transformed back through GEOID03 to an ellipsoidal reference and then transformed back utilizing GEOID99. Therefore, we now have two datasets for both methods, one relative to GEOID03 and the other relative to GEOID99.

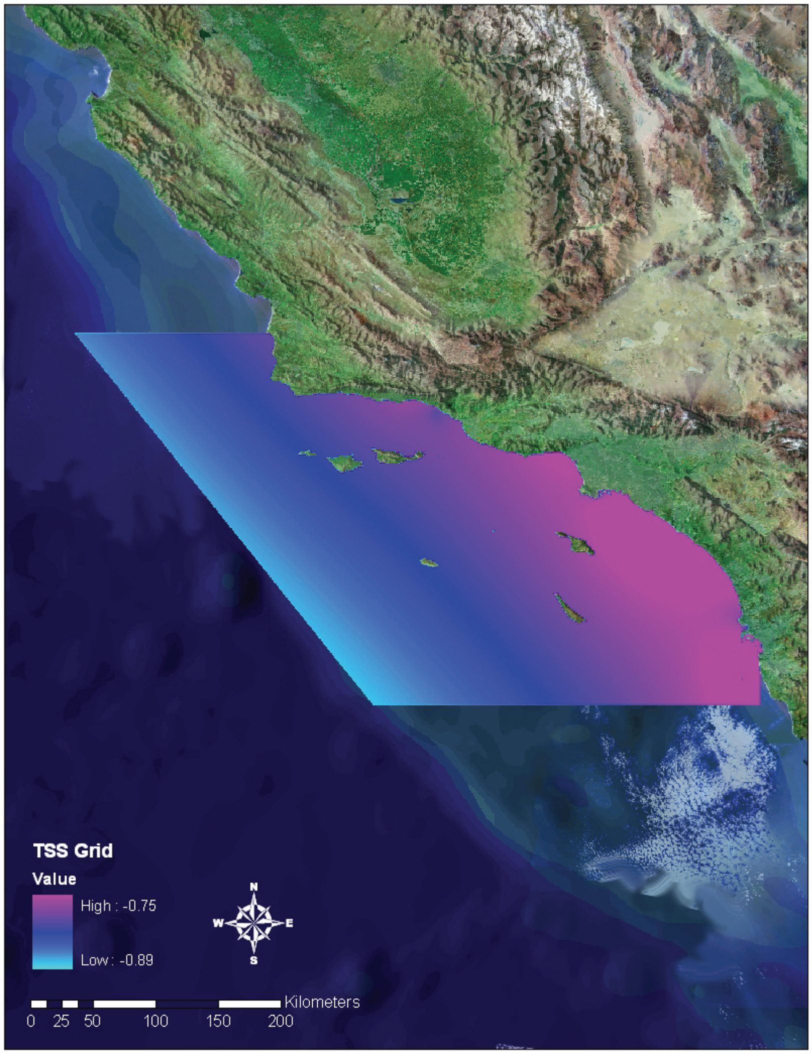



Figure 18. The Southern California TSS field based on NAVD88 realized through GEOID99.

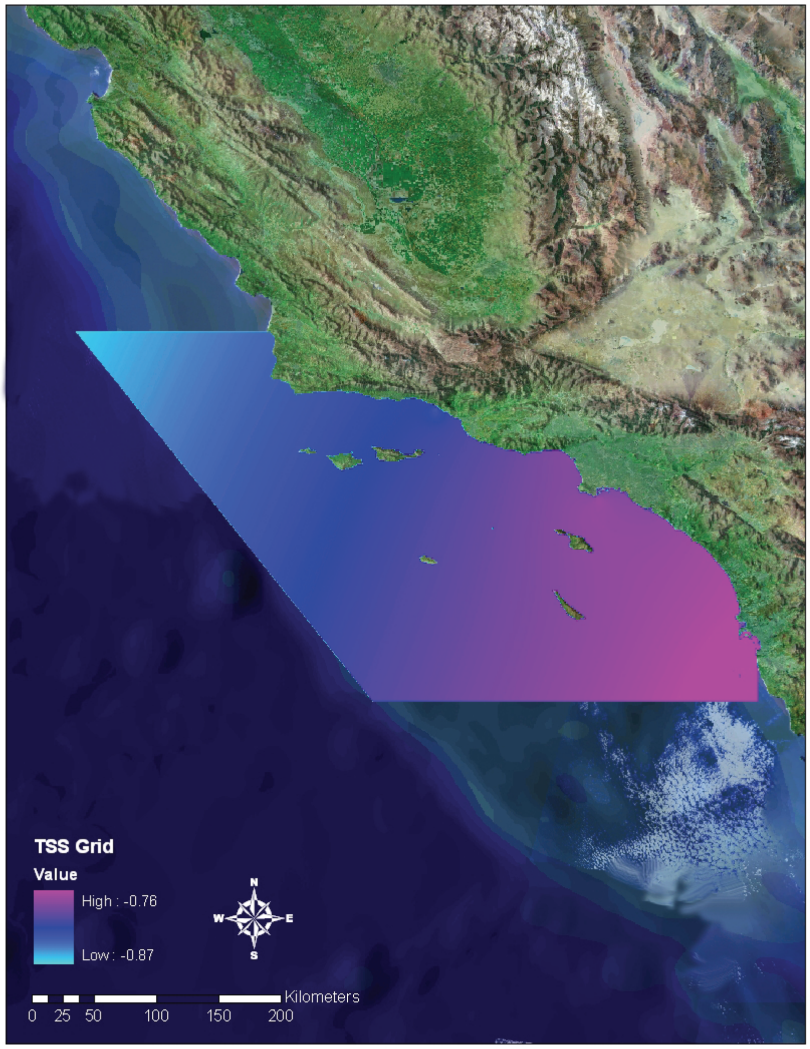



Figure 19. The Southern California TSS field based on NAVD88 realized through GEOID03.

## 5.2. Quality Control

Quality control is necessary for obtaining a final TSS field. This is facilitated through examining the differences ($\Delta_{R\text{-}TSS}$) between $R_{datum}$ and $TSS_{grid}$ observational stations:

$$\Delta_{R\text{-}TSS} = -(R_{datum} - TSS_{grid})$$

The $\Delta_{R\text{-}TSS}$ approximately represents the difference between the observed tidal datum and the datum as computed by the gridded fields. The mean $\Delta_{R\text{-}TSS}$ at each bench mark should be less than 0.01 m. If it is not, the input data and grids are checked, appropriate changes are made, and the values are recomputed until the criterion is met. This results in a final TSS field. Finally, a land mask is applied to denote the presence of land.

A final quality control was conducted by evaluating mean $\Delta_{R\text{-}TSS}$ over four tidal datums (MHHW, MHW, MLW, and MLLW) at each bench mark station. Note that $\Delta_{R\text{-}TSS}$ represents the difference between the observed and modeled tidal datums. The results gave mean ($\Delta_{R\text{-}TSS}$) values that are less than the criteria value of 0.01 m. Tables F.1and F.2 of Appendix F tabulate the differences for TSS realized through GEOID99 and GEOID03, respectively. Tables G.1 and G.2 show the average mean $\Delta_{R\text{-}TSS}$ values and the corresponding standard deviations for each station. Both values were less than $5\times10^{-3}$ m, thus indicating good model-data agreement. It should be noted that there is a lack of observational data offshore on the channel islands. Therefore consideration should be taken when utilizing these transformation results.

## 6. SUMMARY

In support of development of the national vertical datum transformation software tool, VDatum, tidal datum and TSS fields for the southern California coastal and adjacent water areas were developed in this study. Tidal datum fields were created by simulating tidal level time histories using the ADCIRC hydrodynamic model. The model domain was represented with an unstructured, triangular-element grid of 181,420 nodes and 349,351 elements. ADCIRC simulations were forced with harmonic constants of 8 tidal constituents ($M_2$, $S_2$, $N_2$, $K_2$, $K_1$, $P_1$, $O_1$, and $Q_1$) along the model's open ocean boundary. At each grid node, a water level time series spanning 5 days was used to compute four tidal datums, MHHW, MHW, MLW, and MLLW.

Modeled results were verified by contrasting with observations at 38 CO-OPS water level stations. The average model-data discrepancy of the four datums was 3.8 cm, with a rms difference of 1.6 cm. The errors were interpolated over the whole model grid using the TCARI interpolation program. The resulting error fields were incorporated into the initial model results to derive error-corrected tidal datum fields.

A regular VDatum marine grid was created to be used as input for the VDatum software tool. Tidal datums defined on the unstructured grid were interpolated onto the regular marine grid to form the final datums as input to VDatum.

The TSS fields were created for the marine grid as well. They were derived using two methodologies: by fitting tidal model results to tidal bench marks leveled in NAVD88 and by calculating orthometric-to-tidal datum relationships at NOAA water level gauges. Results from the two methods were coupled to create the final TSS grids and were incorporated into the VDatum tool.

## ACKNOWLEDGMENTS

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## APPENDIX A. HORIZONTAL AND VERTICAL ACCURACY STANDARDS FOR NOAA BATHYMETRY SURVEY

**Table A.1.** The required horizontal and vertical accuracy standards for NOAA surveys. Accuracy requirements before 1957 were prescribed for survey projects.

| Survey Year* | Horizontal Accuracy | Vertical Accuracy | Standard |
|---|---|---|---|
| 1998 – present | Order 1<br>1 – 100 m depth:<br>5.0 m + 5% of depth<br><br>Order 2<br>100 – 200 m depth:<br>20 m + 5% of depth<br><br>Order 3<br>100 – 200 m depth:<br>150 m + 5% of depth | Order 1<br>1 – 100 m depth:<br>0.5 – 1.4 m<br><br>Order 2<br>100 – 200 m depth:<br>2.5 – 4.7 m<br><br>Order 3<br>> 100 m depth:<br>same as Order 2 | IHO S-44 [1]<br>and NOAA [2] |
| 1988 – 1998 | 95% probability that the true position lies within a circle of radius 1.5 mm, at the scale of the survey | 0 – 30 m depth: 0.3 m<br>> 30 m depth: 1% of depth | IHO S-44 [1]<br>and NOAA [2] |
| 1982 – 1988 | probable error shall seldom exceed twice the plottable error (1.0 mm) at the scale of the survey | 0 – 20 m depth: 0.3 m<br>20 – 100 m depth: 1.0 m<br>> 100 m depth: 1% of depth | IHO S-44 [1]<br>and NOAA [2] |
| 1957 – 1982 | maximum error of plotted positions shall seldom exceed 1.5 mm at the scale of the survey | 0 – 20 m depth: 0.3 m<br>20 – 100 m depth: 1.0 m<br>> 100 m depth: 1% of depth | IHC [3]<br>NOAA [2]<br>and<br>IHO S-44 [1] |
| before 1957 | undetermined | undetermined | undocumente<br>d |

* end of field collection

[1] International Hydrographic Organization (IHO) Standards for Hydrographic Surveys, Special Publication 44, (First Edition, 1968; Second Edition, 1982; Third Edition, 1987; Fourth Edition, 1998).

[2] U.S. Department of Commerce Coast and Geodetic Survey Hydrographic Manual (1931, 1942, 1960, 1976)
NOAA NOS Office of Coast Survey Specifications and Deliverables, 1999 – 2006.
NOAA was established in 1970.

[3] International Hydrographic Conference, 1957.

## APPENDIX B. WATER LEVEL STATION DATA

**Table B.1. Tidal and orthometric datums (meters) relative to mean sea level for NOS water level stations in the Southern CA area. The 'N/A's in the table denote missing values.**

| No. | Station ID # | Latitude (°N) | Longitude (°W) | MHHW (m) | MHW (m) | MLW (m) | MLLW (m) | NAVD88 (m) | Epoch Year |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 9410032 | -118.557 | 33.005 | 0.762 | 0.549 | -0.549 | -0.823 | N/A | N/A |
| 2 | 9410068 | -119.497 | 33.2667 | 0.732 | 0.518 | -0.488 | -0.762 | N/A | N/A |
| 3 | 9410079 | -118.325 | 33.345 | 0.792 | 0.579 | -0.549 | -0.823 | N/A | N/A |
| 4 | 9410092 | -118.503 | 33.4317 | 0.762 | 0.549 | -0.549 | -0.823 | N/A | N/A |
| 5 | 9410120 | -117.135 | 32.5783 | 0.798 | 0.575 | -0.565 | -0.839 | 0.074 | 1983-2001 |
| 6 | 9410136 | -117.113 | 32.6483 | 0.863 | 0.64 | -0.64 | -0.905 | N/A | 1960-1978 |
| 7 | 9410152 | -117.118 | 32.665 | 0.884 | 0.671 | -0.64 | -0.914 | N/A | N/A |
| 8 | 9410155 | -117.233 | 32.6867 | 0.817 | 0.598 | -0.594 | -0.856 | N/A | 1960-1978 |
| 9 | 9410166 | -117.235 | 32.7033 | 0.823 | 0.579 | -0.61 | -0.884 | N/A | N/A |
| 10 | 9410169 | -117.187 | 32.7117 | 0.838 | 0.616 | -0.616 | -0.881 | N/A | 1960-1978 |
| 11 | 9410170 | -117.173 | 32.7133 | 0.849 | 0.623 | -0.611 | -0.896 | 0.132 | 1983-2001 |
| 12 | 9410175 | -117.182 | 32.725 | 0.829 | 0.609 | -0.61 | -0.872 | N/A | 1960-1978 |
| 13 | 9410191 | -117.233 | 32.775 | 0.823 | 0.61 | -0.579 | -0.853 | N/A | N/A |
| 14 | 9410230 | -117.258 | 32.8667 | 0.791 | 0.569 | -0.557 | -0.833 | 0.058 | 1983-2001 |
| 15 | 9410384 | -117.337 | 33.1433 | 0.768 | 0.521 | -0.521 | -0.771 | N/A | 1960-1978 |
| 16 | 9410396 | -117.395 | 33.21 | 0.798 | 0.573 | -0.558 | -0.832 | N/A | 1983-2001 |
| 17 | 9410580 | -117.883 | 33.6033 | 0.804 | 0.579 | -0.566 | -0.845 | 0.055 | 1983-2001 |
| 18 | 9410583 | -117.9 | 33.6 | 0.79 | 0.558 | -0.555 | -0.835 | N/A | 1960-1978 |
| 19 | 9410614 | -118.005 | 33.6533 | 0.787 | 0.561 | -0.56 | -0.847 | N/A | 1960-1978 |
| 20 | 9410650 | -118.273 | 33.7067 | 0.811 | 0.586 | -0.574 | -0.86 | 0.075 | 1983-2001 |
| 21 | 9410660 | -118.272 | 33.72 | 0.813 | 0.588 | -0.574 | -0.861 | 0.062 | 1983-2001 |
| 22 | 9410680 | -118.227 | 33.7517 | 0.815 | 0.59 | -0.579 | -0.866 | N/A | N/A |
| 23 | 9410683 | -118.268 | 33.7533 | 0.805 | 0.586 | -0.56 | -0.853 | N/A | N/A |
| 24 | 9410738 | -118.398 | 33.8467 | 0.789 | 0.564 | -0.546 | -0.833 | N/A | 1983-2001 |
| 25 | 9410840 | -118.5 | 34.0083 | 0.804 | 0.579 | -0.566 | -0.849 | 0.057 | 1983-2001 |
| 26 | 9410842 | -118.498 | 34.0067 | 0.808 | 0.579 | -0.557 | -0.844 | N/A | 1960-1978 |
| 27 | 9410962 | -120.047 | 34.0083 | 0.753 | 0.532 | -0.519 | -0.814 | N/A | 1983-2001 |
| 28 | 9410971 | -119.683 | 34.02 | 0.732 | 0.519 | -0.518 | -0.792 | N/A | N/A |
| 29 | 9410988 | -120.355 | 34.0567 | 0.762 | 0.549 | -0.518 | -0.823 | N/A | N/A |
| 30 | 9411013 | -119.098 | 34.1017 | 0.792 | 0.579 | -0.549 | -0.823 | N/A | N/A |
| 31 | 9411015 | -119.095 | 34.0983 | 0.792 | 0.579 | -0.549 | -0.823 | N/A | N/A |
| 32 | 9411065 | -119.203 | 34.1483 | 0.801 | 0.567 | -0.567 | -0.866 | N/A | 1960-1978 |
| 33 | 9411270 | -119.443 | 34.3483 | 0.803 | 0.573 | -0.56 | -0.861 | 0.03 | 1983-2001 |
| 34 | 9411340 | -119.685 | 34.4083 | 0.793 | 0.563 | -0.55 | -0.85 | 0.029 | 1983-2001 |
| 35 | 9411405 | -120.205 | 34.4683 | 0.762 | 0.549 | -0.548 | -0.853 | N/A | N/A |
| 36 | 9411406 | -120.673 | 34.4683 | 0.807 | 0.565 | -0.542 | -0.847 | N/A | 1983-2001 |
| 37 | 9412110 | -120.76 | 35.1767 | 0.77 | 0.555 | -0.536 | -0.853 | 0.024 | 1983-2001 |
| 38 | 9412113 | -120.752 | 35.17 | 0.78 | 0.563 | -0.546 | -0.863 | N/A | 1960-1978 |

**Table B.2. NOS Water Level Station Names**

| No. | Station ID # | Station Name |
|---|---|---|
| 1 | 9410032 | WILSON COVE SAN CLEMENTE IS CA |
| 2 | 9410068 | SAN NICOLAS ISLAND CA |
| 3 | 9410079 | AVALON SANTA CATALINA ISLAND CA |
| 4 | 9410092 | CATALINA HAR SANTA CATALINA IS CA |
| 5 | 9410120 | IMPERIAL BEACH  PACIFIC OCEAN |
| 6 | 9410136 | SWEETWATER CHANNEL CA |
| 7 | 9410152 | NATIONAL CITY SAN DIEGO BAY CA |
| 8 | 9410155 | BALLAST POINT CA |
| 9 | 9410166 | U S QUARANTINE STATION S D BAY CA |
| 10 | 9410169 | NORTH ISLAND NAVY WHARF CA |
| 11 | 9410170 | SAN DIEGO  SAN DIEGO BAY |
| 12 | 9410175 | US COAST GUARD AIR STATION CA |
| 13 | 9410191 | MISSION BAY CA |
| 14 | 9410230 | LA JOLLA  PACIFIC OCEAN |
| 15 | 9410384 | AGUA HEDIONDA LAGOON CA |
| 16 | 9410396 | OCEANSIDE HARBOR |
| 17 | 9410580 | NEWPORT BEACH  NEWPORT BAY ENTRANCE |
| 18 | 9410583 | BALBOA CA |
| 19 | 9410614 | HUNTINGTON BCH PIER CA |
| 20 | 9410650 | CABRILLO BEACH |
| 21 | 9410660 | LOS ANGELES  OUTER HARBOR |
| 22 | 9410680 | LONG BEACH  TERMINAL ISLAND |
| 23 | 9410683 | LONG BEACH TURNING BASIN CA |
| 24 | 9410738 | KING HARBOR  SANTA MONICA BAY |
| 25 | 9410840 | SANTA MONICA  PACIFIC OCEAN |
| 26 | 9410842 | SANTA MONICA WLTS CA |
| 27 | 9410962 | BECHERS BAY  SANTA ROSA ISLAND |
| 28 | 9410971 | PRISONERS HARBOR SANTA CRUZ IS CA |
| 29 | 9410988 | CUYLER HARBOR SAN MIGUEL IS CA |
| 30 | 9411013 | MUGU LAGOON BRIDGE CA |
| 31 | 9411015 | MUGU LAGOON ENTRANCE CA |
| 32 | 9411065 | PORT HUENEME CA |
| 33 | 9411270 | RINCON ISLAND  PACIFIC OCEAN |
| 34 | 9411340 | SANTA BARBARA  PACIFIC OCEAN |
| 35 | 9411405 | GAVIOTA CA |
| 36 | 9411406 | OIL PLATFORM HARVEST (TOPEX PROJECT) |
| 37 | 9412110 | PORT SAN LUIS  PACIFIC OCEAN |
| 38 | 9412113 | PORT SAN LUIS WLTS CA |

## APPENDIX C. CORRECTED TIDAL DATUMS ON MARINE GRID

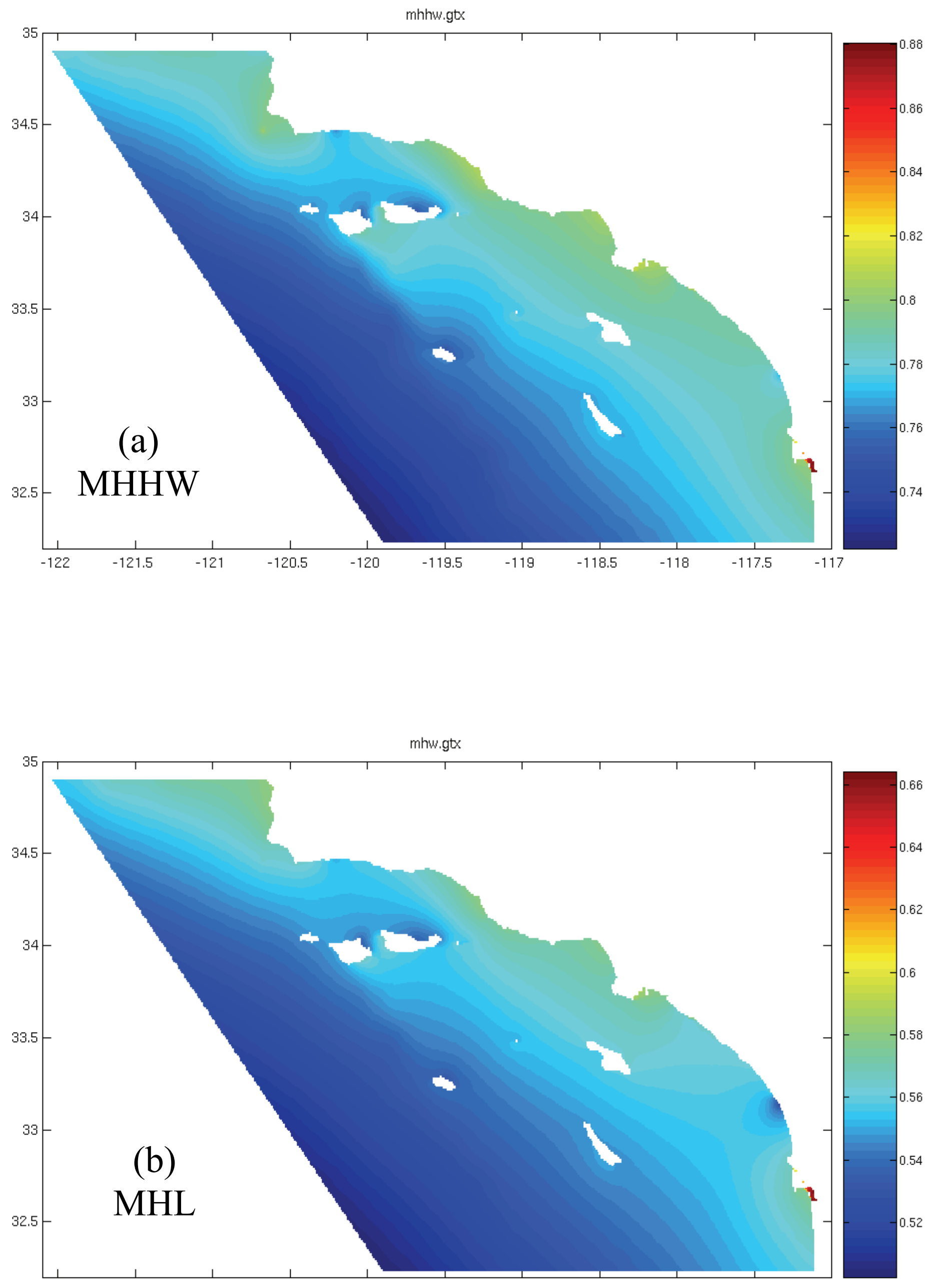
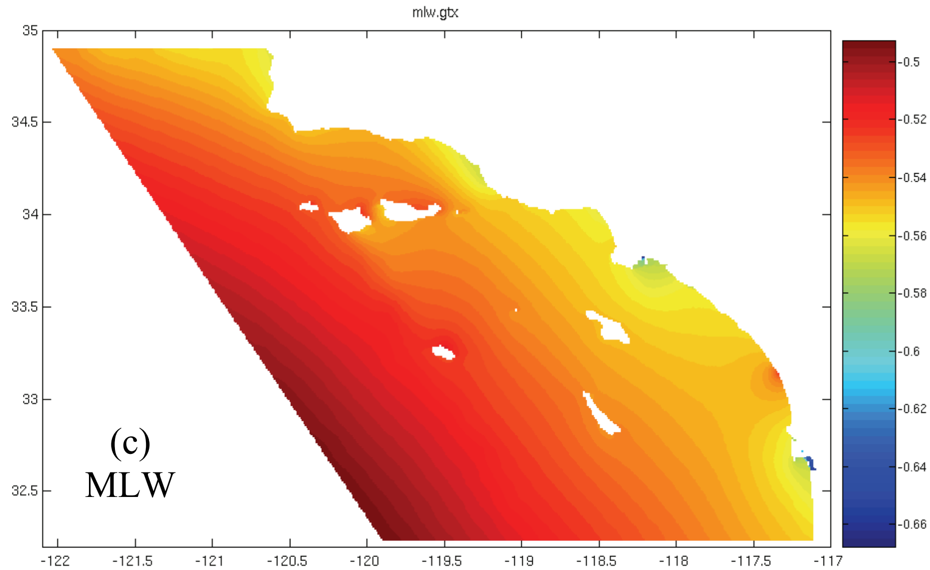



**Figure C.1.** Tidal datums on marine grid, (a) MHHW, (b) MHW, (c) MLW, (d) MLLW, (e) MTL, and (f) DTL. Color bars are in the unit of meters.



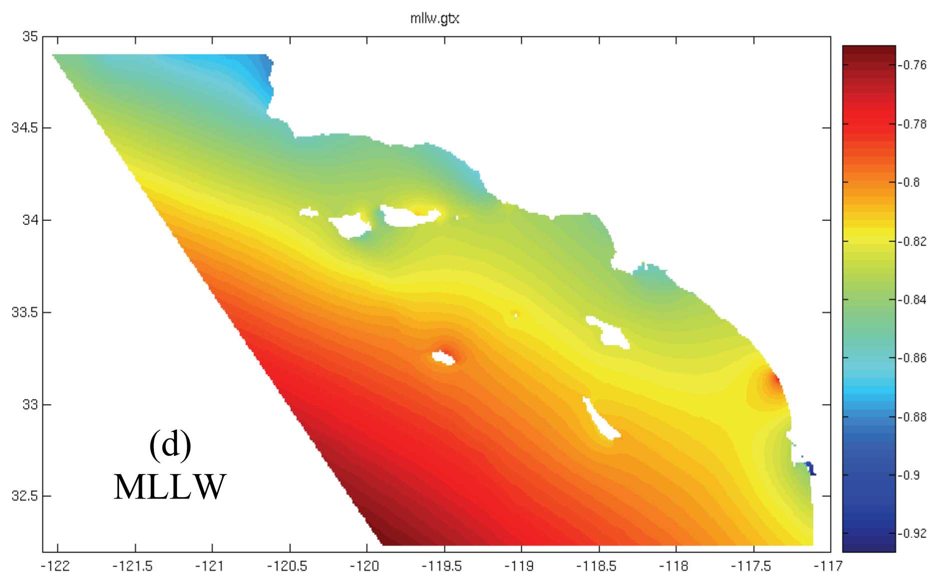




**Figure C.1. (Continued)**

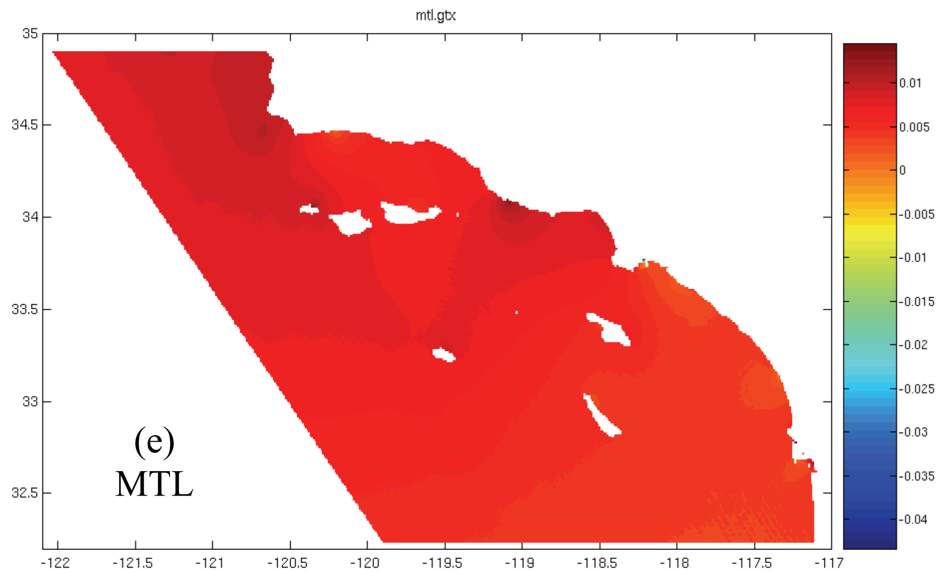



**Figure C.1. (Continued)**

## APPENDIX D. Tidal gauge and bench marks data used to create the TSS

**Table D.1. Location and elevation information for NOAA water level gauges used to create the TSS grid. Tidal datums are relative to MLLW. MSL data are from CO-OPS and NAVD88 heights were calculated by NGS.**

| Station ID | Latitude (deg) | Longitude (deg) | MSL (m) | NAVD88 [GEOID03] (m) | NAVD88 [GEOID99] (m) | TSS [GEOID03] (m) | TSS [GEOID99] (m) |
|---|---|---|---|---|---|---|---|
| 9410120 | 32.57833 | -117.13500 | 1.695 | 0.930 | 0.946 | -0.765 | -0.749 |
| 9410170 | 32.71333 | -117.17333 | 2.052 | 1.287 | 1.271 | -0.765 | -0.781 |
| 9410230 | 32.86667 | -117.25833 | 2.163 | 1.389 | 1.353 | -0.774 | -0.811 |
| 9410580 | 33.60333 | -117.88333 | 1.861 | 1.071 | 1.103 | -0.790 | -0.758 |
| 9410650 | 33.70667 | -118.27333 | 11.029 | 10.244 | 10.233 | -0.785 | -0.796 |
| 9410660 | 33.72000 | -118.27167 | 2.028 | 1.229 | 1.213 | -0.799 | -0.815 |
| 9410840 | 34.00833 | -118.50000 | 1.594 | 0.802 | 0.802 | -0.792 | -0.792 |
| 9411270 | 34.34833 | -119.44333 | 2.178 | 1.347 | 1.346 | -0.831 | -0.832 |
| 9411340 | 34.40833 | -119.68500 | 1.824 | 1.003 | 1.017 | -0.821 | -0.807 |
| 9412110 | 35.17667 | -120.76000 | 2.149 | 1.320 | 1.287 | -0.829 | -0.863 |

## APPENDIX E. DERIVED NAVD 88-TO-LMSL VALUES

**Table E.1. QC Deltas from the Southern California TSS Grid, based on NAVD88 heights realized through GEOID 99.**

| Bench-mark | Latitude | Longitude | From MLLW (m) | From MLW (m) | From MHW (m) | From MHHW (m) | Average (m) | Std. Dev. (m) |
|---|---|---|---|---|---|---|---|---|
| DC1339 | 32.57888 | -117.13138 | -0.747 | -0.747 | -0.747 | -0.747 | -0.747 | 0.000 |
| DC1340 | 32.57972 | -117.13111 | -0.748 | -0.748 | -0.748 | -0.748 | -0.748 | 0.000 |
| DC0888 | 32.71388 | -117.17333 | -0.777 | -0.781 | -0.781 | -0.777 | -0.779 | 0.002 |
| DC1322 | 32.71555 | -117.17250 | -0.771 | -0.784 | -0.789 | -0.788 | -0.783 | 0.008 |
| DC1313 | 32.86527 | -117.25333 | -0.808 | -0.808 | -0.814 | -0.813 | -0.811 | 0.003 |
| DC1312 | 32.86583 | -117.25305 | -0.811 | -0.811 | -0.817 | -0.816 | -0.814 | 0.003 |
| DC0986 | 32.86611 | -117.25277 | -0.811 | -0.811 | -0.817 | -0.816 | -0.814 | 0.003 |
| DC1308 | 32.86611 | -117.25305 | -0.808 | -0.808 | -0.814 | -0.813 | -0.811 | 0.003 |
| DC0990 | 32.86638 | -117.25305 | -0.808 | -0.808 | -0.814 | -0.813 | -0.811 | 0.003 |
| DC1310 | 32.86638 | -117.25250 | -0.805 | -0.805 | -0.811 | -0.810 | -0.808 | 0.003 |
| DX1969 | 33.60250 | -117.88388 | -0.758 | -0.759 | -0.758 | -0.759 | -0.758 | 0.001 |
| DX3663 | 33.60250 | -117.88333 | -0.758 | -0.759 | -0.758 | -0.759 | -0.758 | 0.001 |
| DX1968 | 33.60277 | -117.88333 | -0.758 | -0.759 | -0.758 | -0.759 | -0.758 | 0.001 |
| DX3420 | 33.60305 | -117.88222 | -0.755 | -0.756 | -0.755 | -0.756 | -0.755 | 0.001 |
| DX1967 | 33.60333 | -117.88277 | -0.758 | -0.759 | -0.758 | -0.759 | -0.758 | 0.001 |
| DX1970 | 33.60361 | -117.88416 | -0.759 | -0.760 | -0.758 | -0.759 | -0.759 | 0.001 |
| DY2509 | 33.70722 | -118.27388 | -0.798 | -0.799 | -0.797 | -0.797 | -0.798 | 0.001 |
| DY2508 | 33.70777 | -118.27500 | -0.792 | -0.793 | -0.791 | -0.791 | -0.792 | 0.001 |
| DY2507 | 33.70805 | -118.27638 | -0.789 | -0.790 | -0.788 | -0.788 | -0.789 | 0.001 |
| DY2506 | 33.70861 | -118.27722 | -0.797 | -0.799 | -0.799 | -0.799 | -0.798 | 0.001 |
| DY2505 | 33.70916 | -118.27944 | -0.787 | -0.789 | -0.797 | -0.796 | -0.792 | 0.005 |
| DY1100 | 33.70944 | -118.28277 | -0.783 | -0.787 | -0.799 | -0.798 | -0.792 | 0.008 |
| DY1099 | 33.71000 | -118.28333 | -0.801 | -0.803 | -0.801 | -0.801 | -0.801 | 0.001 |
| DY1083 | 33.71972 | -118.27166 | -0.812 | -0.813 | -0.813 | -0.813 | -0.813 | 0.000 |
| DY2515 | 33.72000 | -118.27138 | -0.813 | -0.813 | -0.813 | -0.813 | -0.813 | 0.000 |
| DY1080 | 33.72055 | -118.27138 | -0.816 | -0.816 | -0.816 | -0.816 | -0.816 | 0.000 |
| DY2514 | 33.72250 | -118.27250 | -0.816 | -0.816 | -0.817 | -0.817 | -0.816 | 0.000 |
| DY2513 | 33.72472 | -118.27333 | -0.816 | -0.816 | -0.817 | -0.818 | -0.817 | 0.001 |
| DY1085 | 33.72527 | -118.27611 | -0.813 | -0.814 | -0.815 | -0.815 | -0.814 | 0.001 |
| DY9300 | 33.72666 | -118.27138 | -0.819 | -0.819 | -0.820 | -0.821 | -0.820 | 0.001 |
| DY2512 | 33.72694 | -118.27361 | -0.813 | -0.813 | -0.814 | -0.815 | -0.814 | 0.001 |
| EW1586 | 34.01027 | -118.49555 | -0.787 | -0.784 | -0.793 | -0.787 | -0.788 | 0.004 |
| EW6485 | 34.34750 | -119.44361 | -0.834 | -0.836 | -0.834 | -0.835 | -0.835 | 0.001 |
| EW6484 | 34.34777 | -119.44388 | -0.834 | -0.836 | -0.834 | -0.835 | -0.835 | 0.001 |
| EW6804 | 34.35555 | -119.44083 | -0.822 | -0.824 | -0.821 | -0.823 | -0.823 | 0.001 |
| EW6807 | 34.35555 | -119.44000 | -0.795 | -0.797 | -0.794 | -0.796 | -0.796 | 0.001 |
| EW6481 | 34.35583 | -119.44138 | -0.819 | -0.821 | -0.818 | -0.820 | -0.820 | 0.001 |
| EW6480 | 34.35611 | -119.44138 | -0.801 | -0.803 | -0.800 | -0.802 | -0.802 | 0.001 |
| EW6488 | 34.35666 | -119.43861 | -0.825 | -0.827 | -0.824 | -0.826 | -0.825 | 0.001 |
| EW6801 | 34.35666 | -119.44083 | -0.810 | -0.812 | -0.809 | -0.811 | -0.810 | 0.001 |
| EW7026 | 34.41000 | -119.69055 | -0.809 | -0.807 | -0.809 | -0.808 | -0.808 | 0.001 |
| EW3742 | 34.41250 | -119.68750 | -0.809 | -0.807 | -0.808 | -0.808 | -0.808 | 0.001 |
| EW6796 | 34.41388 | -119.68583 | -0.811 | -0.810 | -0.811 | -0.810 | -0.811 | 0.000 |
| EW3748 | 34.41472 | -119.68472 | -0.808 | -0.807 | -0.807 | -0.807 | -0.807 | 0.001 |

**Table E.2. QC Deltas from the Southern California TSS Grid, based on NAVD88 heights realized through GEOID 03.**

| PID | Latitude (deg) | Longitude (deg) | MHHW Deltas (m) | MHW Deltas (m) | MLW Deltas (m) | MLLW Deltas (m) | Avg. (m) | Std. Dev. (m) |
|---|---|---|---|---|---|---|---|---|
| DC1339 | 32.57888 | -117.13138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC1340 | 32.57972 | -117.13111 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC0888 | 32.71388 | -117.17333 | 0.003 | -0.001 | -0.002 | 0.002 | 0.000 | 0.002 |
| DC1322 | 32.71555 | -117.17250 | 0.010 | -0.003 | -0.008 | -0.007 | -0.002 | 0.008 |
| DC1313 | 32.86527 | -117.25333 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1312 | 32.86583 | -117.25305 | 0.001 | 0.001 | -0.005 | -0.004 | -0.002 | 0.003 |
| DC0986 | 32.86611 | -117.25277 | 0.001 | 0.000 | -0.005 | -0.005 | -0.002 | 0.003 |
| DC1308 | 32.86611 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC0990 | 32.86638 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1310 | 32.86638 | -117.25250 | 0.007 | 0.006 | 0.001 | 0.001 | 0.004 | 0.003 |
| DX1969 | 33.60250 | -117.88388 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3663 | 33.60250 | -117.88333 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| DX1968 | 33.60277 | -117.88333 | 0.001 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3420 | 33.60305 | -117.88222 | 0.003 | 0.002 | 0.004 | 0.003 | 0.003 | 0.001 |
| DX1967 | 33.60333 | -117.88277 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX1970 | 33.60361 | -117.88416 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DY2509 | 33.70722 | -118.27388 | -0.001 | -0.002 | 0.000 | 0.000 | -0.001 | 0.001 |
| DY2508 | 33.70777 | -118.27500 | 0.000 | -0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| DY2507 | 33.70805 | -118.27638 | 0.002 | 0.000 | 0.002 | 0.002 | 0.002 | 0.001 |
| DY2506 | 33.70861 | -118.27722 | -0.001 | -0.003 | -0.003 | -0.003 | -0.003 | 0.001 |
| DY2505 | 33.70916 | -118.27944 | 0.006 | 0.003 | -0.004 | -0.004 | 0.000 | 0.005 |
| DY1100 | 33.70944 | -118.28277 | 0.012 | 0.009 | -0.003 | -0.003 | 0.004 | 0.008 |
| DY1099 | 33.71000 | -118.28333 | 0.000 | -0.001 | 0.000 | 0.001 | 0.000 | 0.001 |
| DY1083 | 33.71972 | -118.27166 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY2515 | 33.72000 | -118.27138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY1080 | 33.72055 | -118.27138 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 | 0.000 |
| DY2514 | 33.72250 | -118.27250 | 0.000 | 0.000 | 0.000 | -0.001 | 0.000 | 0.000 |
| DY2513 | 33.72472 | -118.27333 | 0.000 | 0.000 | -0.001 | -0.001 | 0.000 | 0.001 |
| DY1085 | 33.72527 | -118.27611 | 0.001 | 0.000 | -0.001 | -0.001 | 0.000 | 0.001 |
| DY9300 | 33.72666 | -118.27138 | 0.000 | 0.000 | -0.001 | -0.002 | -0.001 | 0.001 |
| DY2512 | 33.72694 | -118.27361 | 0.001 | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 |
| EW1586 | 34.01027 | -118.49555 | 0.001 | 0.004 | -0.005 | 0.001 | 0.000 | 0.004 |
| EW6485 | 34.34750 | -119.44361 | 0.000 | -0.002 | 0.000 | -0.002 | -0.001 | 0.001 |
| EW6484 | 34.34777 | -119.44388 | 0.000 | -0.001 | 0.001 | -0.001 | 0.000 | 0.001 |
| EW6804 | 34.35555 | -119.44083 | -0.011 | -0.013 | -0.010 | -0.012 | -0.012 | 0.001 |
| EW6807 | 34.35555 | -119.44000 | 0.004 | 0.002 | 0.005 | 0.003 | 0.004 | 0.001 |
| EW6481 | 34.35583 | -119.44138 | -0.004 | -0.006 | -0.003 | -0.005 | -0.005 | 0.001 |
| EW6480 | 34.35611 | -119.44138 | 0.014 | 0.012 | 0.015 | 0.013 | 0.013 | 0.001 |
| EW6488 | 34.35666 | -119.43861 | -0.003 | -0.005 | -0.002 | -0.004 | -0.004 | 0.001 |
| EW6801 | 34.35666 | -119.44083 | 0.001 | -0.001 | 0.002 | 0.000 | 0.000 | 0.001 |
| EW7026 | 34.41000 | -119.69055 | 0.000 | 0.001 | -0.001 | 0.000 | 0.000 | 0.001 |
| EW3742 | 34.41250 | -119.68750 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| EW6796 | 34.41388 | -119.68583 | -0.001 | 0.000 | -0.001 | 0.000 | -0.001 | 0.000 |
| EW3748 | 34.41472 | -119.68472 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 |

## APPENDIX F. QA/QC Deltas at Stations for TSS Grids

### Table F.1. QC Deltas from the Southern California TSS Grid, based on NAVD88 heights realized through GEOID99.

| PID | Latitude (deg) | Longitude (deg) | MHHW Deltas (m) | MHW Deltas (m) | MLW Deltas (m) | MLLW Deltas (m) | Avg. (m) | Std. Dev. (m) |
|---|---|---|---|---|---|---|---|---|
| DC1339 | 32.57888 | -117.13138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC1340 | 32.57972 | -117.13111 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC0888 | 32.71388 | -117.17333 | 0.003 | -0.002 | -0.002 | 0.002 | 0.000 | 0.002 |
| DC1322 | 32.71555 | -117.17250 | 0.010 | -0.003 | -0.008 | -0.007 | -0.002 | 0.008 |
| DC1313 | 32.86527 | -117.25333 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1312 | 32.86583 | -117.25305 | 0.001 | 0.001 | -0.005 | -0.004 | -0.002 | 0.003 |
| DC0986 | 32.86611 | -117.25277 | 0.001 | 0.000 | -0.005 | -0.005 | -0.002 | 0.003 |
| DC1308 | 32.86611 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC0990 | 32.86638 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1310 | 32.86638 | -117.25250 | 0.007 | 0.006 | 0.001 | 0.001 | 0.004 | 0.003 |
| DX1969 | 33.60250 | -117.88388 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3663 | 33.60250 | -117.88333 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| DX1968 | 33.60277 | -117.88333 | 0.001 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3420 | 33.60305 | -117.88222 | 0.003 | 0.002 | 0.004 | 0.003 | 0.003 | 0.001 |
| DX1967 | 33.60333 | -117.88277 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX1970 | 33.60361 | -117.88416 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DY2509 | 33.70722 | -118.27388 | -0.001 | -0.002 | 0.000 | 0.000 | -0.001 | 0.001 |
| DY2508 | 33.70777 | -118.27500 | 0.000 | -0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| DY2507 | 33.70805 | -118.27638 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.001 |
| DY2506 | 33.70861 | -118.27722 | -0.002 | -0.003 | -0.003 | -0.003 | -0.003 | 0.001 |
| DY2505 | 33.70916 | -118.27944 | 0.006 | 0.003 | -0.004 | -0.004 | 0.001 | 0.005 |
| DY1100 | 33.70944 | -118.28277 | 0.013 | 0.009 | -0.003 | -0.003 | 0.004 | 0.008 |
| DY1099 | 33.71000 | -118.28333 | 0.000 | -0.001 | 0.000 | 0.001 | 0.000 | 0.001 |
| DY1083 | 33.71972 | -118.27166 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY2515 | 33.72000 | -118.27138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY1080 | 33.72055 | -118.27138 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 | 0.000 |
| DY2514 | 33.72250 | -118.27250 | 0.000 | 0.000 | 0.000 | -0.001 | 0.000 | 0.000 |
| DY2513 | 33.72472 | -118.27333 | 0.000 | 0.000 | -0.001 | -0.001 | -0.001 | 0.001 |
| DY1085 | 33.72527 | -118.27611 | 0.001 | 0.000 | -0.001 | -0.001 | 0.000 | 0.001 |
| DY9300 | 33.72666 | -118.27138 | 0.000 | 0.000 | -0.001 | -0.002 | -0.001 | 0.001 |
| DY2512 | 33.72694 | -118.27361 | 0.001 | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 |
| EW1586 | 34.01027 | -118.49555 | 0.001 | 0.004 | -0.005 | 0.001 | 0.000 | 0.004 |
| EW6485 | 34.34750 | -119.44361 | 0.000 | -0.002 | 0.000 | -0.002 | -0.001 | 0.001 |
| EW6484 | 34.34777 | -119.44388 | 0.000 | -0.001 | 0.001 | -0.001 | 0.000 | 0.001 |
| EW6804 | 34.35555 | -119.44083 | -0.011 | -0.013 | -0.010 | -0.012 | -0.012 | 0.001 |
| EW6807 | 34.35555 | -119.44000 | 0.004 | 0.002 | 0.005 | 0.003 | 0.003 | 0.001 |
| EW6481 | 34.35583 | -119.44138 | -0.004 | -0.006 | -0.003 | -0.005 | -0.005 | 0.001 |
| EW6480 | 34.35611 | -119.44138 | 0.014 | 0.012 | 0.015 | 0.013 | 0.013 | 0.001 |
| EW6488 | 34.35666 | -119.43861 | -0.004 | -0.005 | -0.003 | -0.005 | -0.004 | 0.001 |
| EW6801 | 34.35666 | -119.44083 | 0.001 | -0.001 | 0.002 | 0.000 | 0.000 | 0.001 |
| EW7026 | 34.41000 | -119.69055 | 0.000 | 0.001 | -0.001 | 0.000 | 0.000 | 0.001 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EW3742 | 34.41250 | -119.68750 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| EW6796 | 34.41388 | -119.68583 | -0.001 | 0.000 | -0.001 | 0.000 | 0.000 | 0.000 |
| EW3748 | 34.41472 | -119.68472 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 |

**Table F.2. QC Deltas from the Southern California TSS Grid, based on NAVD88 heights realized through GEOID 03.**

| PID | Latitude (deg) | Longitude (deg) | MHHW Deltas (m) | MHW Deltas (m) | MLW Deltas (m) | MLLW Deltas (m) | Avg. (m) | Std. Dev. (m) |
|---|---|---|---|---|---|---|---|---|
| DC1339 | 32.57888 | -117.13138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC1340 | 32.57972 | -117.13111 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DC0888 | 32.71388 | -117.17333 | 0.003 | -0.001 | -0.002 | 0.002 | 0.000 | 0.002 |
| DC1322 | 32.71555 | -117.17250 | 0.010 | -0.003 | -0.008 | -0.007 | -0.002 | 0.008 |
| DC1313 | 32.86527 | -117.25333 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1312 | 32.86583 | -117.25305 | 0.001 | 0.001 | -0.005 | -0.004 | -0.002 | 0.003 |
| DC0986 | 32.86611 | -117.25277 | 0.001 | 0.000 | -0.005 | -0.005 | -0.002 | 0.003 |
| DC1308 | 32.86611 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC0990 | 32.86638 | -117.25305 | 0.004 | 0.004 | -0.002 | -0.001 | 0.001 | 0.003 |
| DC1310 | 32.86638 | -117.25250 | 0.007 | 0.006 | 0.001 | 0.001 | 0.004 | 0.003 |
| DX1969 | 33.60250 | -117.88388 | 0.001 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3663 | 33.60250 | -117.88333 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| DX1968 | 33.60277 | -117.88333 | 0.001 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX3420 | 33.60305 | -117.88222 | 0.003 | 0.002 | 0.004 | 0.003 | 0.003 | 0.001 |
| DX1967 | 33.60333 | -117.88277 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DX1970 | 33.60361 | -117.88416 | 0.000 | -0.001 | 0.001 | 0.000 | 0.000 | 0.001 |
| DY2509 | 33.70722 | -118.27388 | -0.001 | -0.002 | 0.000 | 0.000 | -0.001 | 0.001 |
| DY2508 | 33.70777 | -118.27500 | 0.000 | -0.001 | 0.001 | 0.001 | 0.000 | 0.001 |
| DY2507 | 33.70805 | -118.27638 | 0.002 | 0.000 | 0.002 | 0.002 | 0.002 | 0.001 |
| DY2506 | 33.70861 | -118.27722 | -0.001 | -0.003 | -0.003 | -0.003 | -0.003 | 0.001 |
| DY2505 | 33.70916 | -118.27944 | 0.006 | 0.003 | -0.004 | -0.004 | 0.000 | 0.005 |
| DY1100 | 33.70944 | -118.28277 | 0.012 | 0.009 | -0.003 | -0.003 | 0.004 | 0.008 |
| DY1099 | 33.71000 | -118.28333 | 0.000 | -0.001 | 0.000 | 0.001 | 0.000 | 0.001 |
| DY1083 | 33.71972 | -118.27166 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY2515 | 33.72000 | -118.27138 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| DY1080 | 33.72055 | -118.27138 | -0.001 | -0.001 | -0.001 | -0.001 | -0.001 | 0.000 |
| DY2514 | 33.72250 | -118.27250 | 0.000 | 0.000 | 0.000 | -0.001 | 0.000 | 0.000 |
| DY2513 | 33.72472 | -118.27333 | 0.000 | 0.000 | -0.001 | -0.001 | 0.000 | 0.001 |
| DY1085 | 33.72527 | -118.27611 | 0.001 | 0.000 | -0.001 | -0.001 | 0.000 | 0.001 |
| DY9300 | 33.72666 | -118.27138 | 0.000 | 0.000 | -0.001 | -0.002 | -0.001 | 0.001 |
| DY2512 | 33.72694 | -118.27361 | 0.001 | 0.002 | 0.001 | 0.000 | 0.001 | 0.001 |
| EW1586 | 34.01027 | -118.49555 | 0.001 | 0.004 | -0.005 | 0.001 | 0.000 | 0.004 |
| EW6485 | 34.34750 | -119.44361 | 0.000 | -0.002 | 0.000 | -0.002 | -0.001 | 0.001 |
| EW6484 | 34.34777 | -119.44388 | 0.000 | -0.001 | 0.001 | -0.001 | 0.000 | 0.001 |
| EW6804 | 34.35555 | -119.44083 | -0.011 | -0.013 | -0.010 | -0.012 | -0.012 | 0.001 |
| EW6807 | 34.35555 | -119.44000 | 0.004 | 0.002 | 0.005 | 0.003 | 0.004 | 0.001 |
| EW6481 | 34.35583 | -119.44138 | -0.004 | -0.006 | -0.003 | -0.005 | -0.005 | 0.001 |
| EW6480 | 34.35611 | -119.44138 | 0.014 | 0.012 | 0.015 | 0.013 | 0.013 | 0.001 |
| EW6488 | 34.35666 | -119.43861 | -0.003 | -0.005 | -0.002 | -0.004 | -0.004 | 0.001 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EW6801 | 34.35666 | -119.44083 | 0.001 | -0.001 | 0.002 | 0.000 | 0.000 | 0.001 |
| EW7026 | 34.41000 | -119.69055 | 0.000 | 0.001 | -0.001 | 0.000 | 0.000 | 0.001 |
| EW3742 | 34.41250 | -119.68750 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| EW6796 | 34.41388 | -119.68583 | -0.001 | 0.000 | -0.001 | 0.000 | -0.001 | 0.000 |
| EW3748 | 34.41472 | -119.68472 | 0.000 | 0.001 | 0.000 | 0.001 | 0.000 | 0.001 |

## APPENDIX G. COMPARISONS of DERIVED TSS WITH OBSERVATIONS AT TIDAL GAUGE AND TIDAL BENCH MARKS

### Table G.1. Southern California TSS Comparison to Tide Gauges and Tidal Bench marks. NAVD88 realized through GEOID99.

| ID | Latitude (deg) | Longitude (deg) | NAVD 88 to MSL (m) | TSS Derived Value (m) | Delta (m) |
|---|---|---|---|---|---|
| 9410120 | 32.57833 | -117.13500 | -0.7490 | -0.7490 | 0.0000 |
| 9410170 | 32.71333 | -117.17333 | -0.7810 | -0.7801 | 0.0009 |
| 9410230 | 32.86667 | -117.25833 | -0.8110 | -0.8110 | 0.0000 |
| 9410580 | 33.60333 | -117.88333 | -0.7580 | -0.7584 | -0.0004 |
| 9410650 | 33.70667 | -118.27333 | -0.7960 | -0.7963 | -0.0003 |
| 9410660 | 33.72000 | -118.27167 | -0.8150 | -0.8134 | 0.0016 |
| 9410840 | 34.00833 | -118.50000 | -0.7920 | -0.7918 | 0.0002 |
| 9411270 | 34.34833 | -119.44333 | -0.8320 | -0.8321 | -0.0001 |
| 9411340 | 34.40833 | -119.68500 | -0.8070 | -0.8071 | -0.0001 |
| DC1339 | 32.57888 | -117.13138 | -0.7474 | -0.7478 | -0.0004 |
| DC1340 | 32.57972 | -117.13111 | -0.7476 | -0.7478 | -0.0002 |
| DC0888 | 32.71388 | -117.17333 | -0.7788 | -0.7791 | -0.0003 |
| DC1322 | 32.71555 | -117.17250 | -0.7830 | -0.7808 | 0.0022 |
| DC1313 | 32.86527 | -117.25333 | -0.8107 | -0.8119 | -0.0012 |
| DC1312 | 32.86583 | -117.25305 | -0.8137 | -0.8122 | 0.0015 |
| DC0986 | 32.86611 | -117.25277 | -0.8137 | -0.8114 | 0.0023 |
| DC1308 | 32.86611 | -117.25305 | -0.8107 | -0.8120 | -0.0013 |
| DC0990 | 32.86638 | -117.25305 | -0.8107 | -0.8118 | -0.0011 |
| DC1310 | 32.86638 | -117.25250 | -0.8077 | -0.8114 | -0.0037 |
| DX1969 | 33.60250 | -117.88388 | -0.7584 | -0.7586 | -0.0002 |
| DX3663 | 33.60250 | -117.88333 | -0.7583 | -0.7584 | -0.0001 |
| DX1968 | 33.60277 | -117.88333 | -0.7584 | -0.7584 | 0.0000 |
| DX3420 | 33.60305 | -117.88222 | -0.7553 | -0.7583 | -0.0030 |
| DX1967 | 33.60333 | -117.88277 | -0.7584 | -0.7583 | 0.0001 |
| DX1970 | 33.60361 | -117.88416 | -0.7587 | -0.7588 | -0.0001 |
| DY2509 | 33.70722 | -118.27388 | -0.7977 | -0.7971 | 0.0006 |
| DY2508 | 33.70777 | -118.27500 | -0.7917 | -0.7921 | -0.0004 |
| DY2507 | 33.70805 | -118.27638 | -0.7887 | -0.7903 | -0.0016 |
| DY2506 | 33.70861 | -118.27722 | -0.7984 | -0.7956 | 0.0028 |
| DY2505 | 33.70916 | -118.27944 | -0.7923 | -0.7927 | -0.0004 |
| DY1100 | 33.70944 | -118.28277 | -0.7920 | -0.7959 | -0.0039 |
| DY1099 | 33.71000 | -118.28333 | -0.8014 | -0.8012 | 0.0002 |
| DY1083 | 33.71972 | -118.27166 | -0.8126 | -0.8129 | -0.0003 |
| DY2515 | 33.72000 | -118.27138 | -0.8127 | -0.8131 | -0.0004 |
| DY1080 | 33.72055 | -118.27138 | -0.8158 | -0.8145 | 0.0013 |
| DY2514 | 33.72250 | -118.27250 | -0.8162 | -0.8162 | 0.0000 |
| DY2513 | 33.72472 | -118.27333 | -0.8167 | -0.8162 | 0.0005 |
| DY1085 | 33.72527 | -118.27611 | -0.8139 | -0.8137 | 0.0002 |
| DY9300 | 33.72666 | -118.27138 | -0.8199 | -0.8190 | 0.0009 |
| DY2512 | 33.72694 | -118.27361 | -0.8137 | -0.8146 | -0.0009 |

| | | | | | |
|---|---|---|---|---|---|
| EW1586 | 34.01027 | -118.49555 | -0.7877 | -0.7877 | 0.0000 |
| EW6485 | 34.34750 | -119.44361 | -0.8348 | -0.8339 | 0.0009 |
| EW6484 | 34.34777 | -119.44388 | -0.8347 | -0.8344 | 0.0003 |
| EW6804 | 34.35555 | -119.44083 | -0.8227 | -0.8112 | 0.0115 |
| EW6807 | 34.35555 | -119.44000 | -0.7957 | -0.7991 | -0.0034 |
| EW6481 | 34.35583 | -119.44138 | -0.8197 | -0.8151 | 0.0046 |
| EW6480 | 34.35611 | -119.44138 | -0.8016 | -0.8149 | -0.0133 |
| EW6488 | 34.35666 | -119.43861 | -0.8254 | -0.8214 | 0.0040 |
| EW6801 | 34.35666 | -119.44083 | -0.8104 | -0.8107 | -0.0003 |
| EW7026 | 34.41000 | -119.69055 | -0.8082 | -0.8081 | 0.0001 |
| EW3742 | 34.41250 | -119.68750 | -0.8078 | -0.8077 | 0.0001 |
| EW6796 | 34.41388 | -119.68583 | -0.8105 | -0.8101 | 0.0004 |
| EW3748 | 34.41472 | -119.68472 | -0.8074 | -0.8078 | -0.0004 |

**Table G.2. Southern California TSS Comparison to Tide Gauges and Tidal Bench marks. NAVD88 is realized through GEOID03.**

| ID | Latitude (deg) | Longitude (deg) | NAVD 88 to MSL (m) | TSS Derived Value (m) | Delta (m) |
|---|---|---|---|---|---|
| 9410120 | 32.57833 | -117.13500 | -0.765 | -0.765 | 0.0001 |
| 9410170 | 32.71333 | -117.17333 | -0.765 | -0.764 | 0.0009 |
| 9410230 | 32.86667 | -117.25833 | -0.774 | -0.774 | 0.0000 |
| 9410580 | 33.60333 | -117.88333 | -0.790 | -0.790 | -0.0002 |
| 9410650 | 33.70667 | -118.27333 | -0.785 | -0.785 | -0.0003 |
| 9410660 | 33.72000 | -118.27167 | -0.799 | -0.797 | 0.0016 |
| 9410840 | 34.00833 | -118.50000 | -0.792 | -0.792 | 0.0001 |
| 9411270 | 34.34833 | -119.44333 | -0.831 | -0.831 | -0.0003 |
| 9411340 | 34.40833 | -119.68500 | -0.821 | -0.821 | -0.0001 |
| DC1339 | 32.57888 | -117.13138 | -0.763 | -0.763 | -0.0004 |
| DC1340 | 32.57972 | -117.13111 | -0.763 | -0.763 | -0.0004 |
| DC0888 | 32.71388 | -117.17333 | -0.763 | -0.763 | -0.0003 |
| DC1322 | 32.71555 | -117.17250 | -0.767 | -0.764 | 0.0021 |
| DC1313 | 32.86527 | -117.25333 | -0.774 | -0.775 | -0.0011 |
| DC1312 | 32.86583 | -117.25305 | -0.777 | -0.776 | 0.0017 |
| DC0986 | 32.86611 | -117.25277 | -0.777 | -0.775 | 0.0023 |
| DC1308 | 32.86611 | -117.25305 | -0.774 | -0.776 | -0.0012 |
| DC0990 | 32.86638 | -117.25305 | -0.774 | -0.775 | -0.0010 |
| DC1310 | 32.86638 | -117.25250 | -0.771 | -0.775 | -0.0037 |
| DX1969 | 33.60250 | -117.88388 | -0.790 | -0.790 | -0.0001 |
| DX3663 | 33.60250 | -117.88333 | -0.790 | -0.790 | 0.0000 |
| DX1968 | 33.60277 | -117.88333 | -0.790 | -0.790 | -0.0001 |
| DX3420 | 33.60305 | -117.88222 | -0.787 | -0.790 | -0.0030 |
| DX1967 | 33.60333 | -117.88277 | -0.790 | -0.790 | 0.0000 |
| DX1970 | 33.60361 | -117.88416 | -0.790 | -0.790 | -0.0001 |
| DY2509 | 33.70722 | -118.27388 | -0.787 | -0.786 | 0.0006 |
| DY2508 | 33.70777 | -118.27500 | -0.781 | -0.781 | -0.0004 |
| DY2507 | 33.70805 | -118.27638 | -0.778 | -0.779 | -0.0015 |
| DY2506 | 33.70861 | -118.27722 | -0.787 | -0.784 | 0.0026 |

| | | | | | |
|---|---|---|---|---|---|
| DY2505 | 33.70916 | -118.27944 | -0.781 | -0.781 | -0.0003 |
| DY1100 | 33.70944 | -118.28277 | -0.781 | -0.784 | -0.0037 |
| DY1099 | 33.71000 | -118.28333 | -0.790 | -0.790 | 0.0001 |
| DY1083 | 33.71972 | -118.27166 | -0.797 | -0.797 | -0.0004 |
| DY2515 | 33.72000 | -118.27138 | -0.797 | -0.797 | -0.0005 |
| DY1080 | 33.72055 | -118.27138 | -0.800 | -0.798 | 0.0012 |
| DY2514 | 33.72250 | -118.27250 | -0.800 | -0.800 | 0.0001 |
| DY2513 | 33.72472 | -118.27333 | -0.800 | -0.799 | 0.0004 |
| DY1085 | 33.72527 | -118.27611 | -0.797 | -0.797 | 0.0003 |
| DY9300 | 33.72666 | -118.27138 | -0.802 | -0.802 | 0.0008 |
| DY2512 | 33.72694 | -118.27361 | -0.796 | -0.797 | -0.0009 |
| EW1586 | 34.01027 | -118.49555 | -0.788 | -0.788 | 0.0000 |
| EW6485 | 34.34750 | -119.44361 | -0.834 | -0.833 | 0.0009 |
| EW6484 | 34.34777 | -119.44388 | -0.834 | -0.834 | 0.0003 |
| EW6804 | 34.35555 | -119.44083 | -0.824 | -0.813 | 0.0115 |
| EW6807 | 34.35555 | -119.44000 | -0.797 | -0.800 | -0.0034 |
| EW6481 | 34.35583 | -119.44138 | -0.821 | -0.816 | 0.0048 |
| EW6480 | 34.35611 | -119.44138 | -0.803 | -0.816 | -0.0131 |
| EW6488 | 34.35666 | -119.43861 | -0.827 | -0.823 | 0.0038 |
| EW6801 | 34.35666 | -119.44083 | -0.812 | -0.812 | -0.0002 |
| EW7026 | 34.41000 | -119.69055 | -0.823 | -0.823 | 0.0001 |
| EW3742 | 34.41250 | -119.68750 | -0.823 | -0.823 | 0.0002 |
| EW6796 | 34.41388 | -119.68583 | -0.826 | -0.826 | 0.0005 |
| EW3748 | 34.41472 | -119.68472 | -0.823 | -0.823 | -0.0003 |