NOAA Technical Memorandum NOS CS 6

MODELING OF TIDAL DATUM FIELDS IN SUPPORT OF VDATUM FOR THE NORTH AND CENTRAL COASTS OF CALIFORNIA

Silver Spring, Maryland
September 2006

noaa National Oceanic and Atmospheric Administration

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

Office of Coast Survey
National Ocean Service
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ABSTRACT

In a project funded by NOAA's National Marine Sanctuary Program, a VDatum application is developed for the northern and central coastal regions of California. The region of interest encompasses the Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries. VDatum will enable bathymetric data in these sanctuaries to be seamlessly transformed between tidal, orthometric and ellipsoidal vertical datums. In this report, we highlight the creation of the tidal datum fields used as input to the VDatum software. A numerical model of tides in the Eastern North Pacific Ocean, the domain of which includes coastal California and its major bays and estuaries, is used to compute spatially varying fields of the tidal datums. The model results are used in combination with spatial interpolation techniques to provide a final set of tidal datum fields that match exactly at locations where observations are available. These are then combined with geoid and ellipsoidal models developed by NOAA's National Geodetic Survey to complete the suite of transformations available in the VDatum software.

1. INTRODUCTION

In a project supported by NOS' National Marine Sanctuary Program, spatially varying tidal datums are computed offshore of central California and inside San Francisco Bay. The region of interest extends from Point Sal (34° 54.18' N) in the south to Point Arena (38° 57.5' N) in the north and is bounded in the west by a line running from (122°1.54' W, 34°54.18' N) to (125°00' W, 38°57.5' N). The region, shown in Figure 1.1, also includes Tomales Bay, Bodega Bay and San Francisco Bay up to the San Joaquin-Sacramento River delta. The tidal datums computed for this project include mean higher high water (MHHW), mean high water (MHW), mean lower low water (MLLW), mean low water (MLW), mean tide level (MTL) and diurnal tide level (DTL). Two numerical models are used to determine the spatial variations in these datums throughout the region of interest. The results, when combined with spatial variations of orthometric and ellipsoidal vertical datums provided by the National Geodetic Survey, will be incorporated into VDatum (Milbert and Hess, 2001), a software tool for transformation of height data.

The numerical models used in this study include a tidal inversion model for the Eastern North Pacific Ocean (Myers and Baptista, 2001), and a tide interpolation model based on solution of Laplace's equation (Hess, 2001a). Along the coast and in offshore regions, the tidal inversion model is used. Differences between this model and tide gauge data are made using a linear correction for each datum as a function of latitude. The tidal inversion model is also used in San Francisco Bay, though corrections cannot be made as a simple linear function. Instead, the tide interpolation model is used to simulate the differences between the tidal inversion model and the data. In those regions of San Francisco Bay that the inversion model does not cover, the tide interpolation model is used to compute the datums directly. The tidal inversion model does not extend into Tomales Bay, and datums there are likewise computed directly with the tide interpolation model.

Section 2 describes how the vertical datums were calculated for the coastal and offshore regions. Sections 3 and 4 describe the procedures used to determine the datums inside San Francisco Bay and Tomales Bay, respectively. Section 5 summarizes how the final VDatum grid is generated using the results from these three approaches.

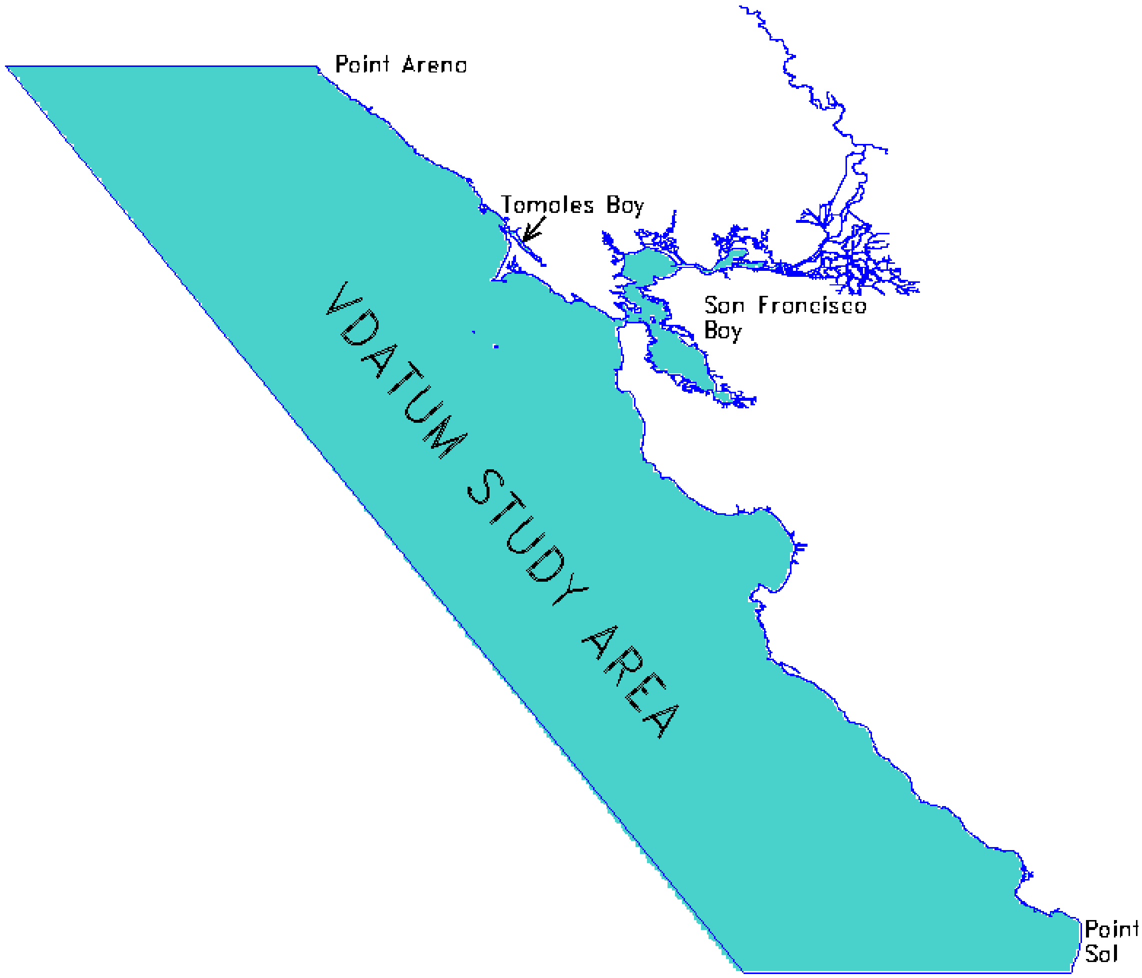

Figure 1.1. North/Central California region of interest for calculation of tidal datums.

2. OFFSHORE TIDAL DATUMS

Outside of San Francisco Bay and Tomales Bay, tidal datums are computed using the tidal inversion model results. The unstructured grid used in the model is shown in Figure 2.1. Boundary conditions for the grid were obtained using inversion techniques with the finite element model ADCIRC (Luettich et al., 1991). Using an initial set of boundary conditions from the TPX0.3 global tide model (Egbert et al., 1994), tide gauges within the grid were used to calibrate the inversion to the final set of boundary conditions. One of the primary strengths of the regional model over global tide models was that it provided enhanced representations of the tides along the continental shelf and coastal regions.

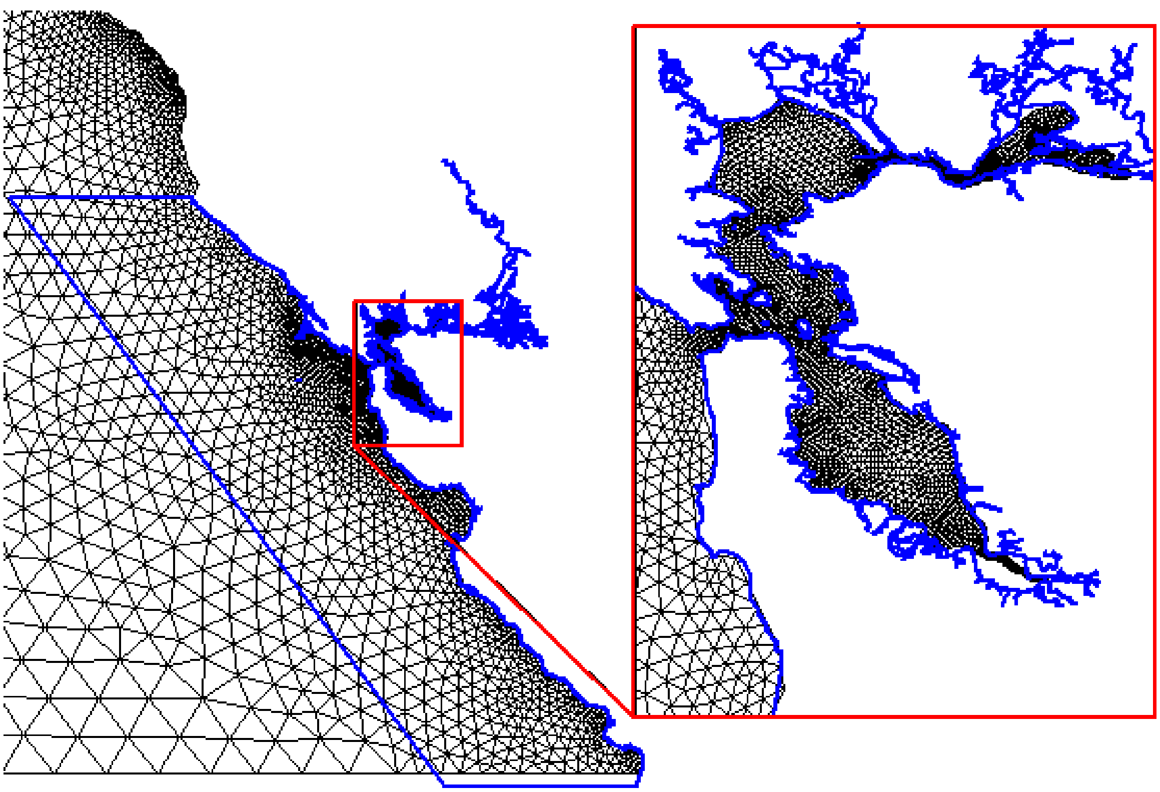

Figure 2.1. The unstructured grid used in the tidal inversion model (Myers and Baptista, 2001).

Equilibrium tidal amplitudes and phases from the regional tide model are available for the O_1, K_1, Q_1, P_1, K_2, N_2, M_2, S_2, M_4, MS_4, M_6, $2SM_2$, MN_4, and μ_2 tidal constituents. For each of the nodes in the grid, the amplitudes and phases are extracted and used to construct time series for a selected time period. For the purpose of this study, time series were generated for all of 1992 at 6-minute intervals using appropriate nodal factors and equilibrium arguments. The year 1992 was selected because the nodal factor for the strongest tidal constituent, M_2, was approximately 1.0, its average value during the 19-year tidal epoch.

Once time series are generated at each of the nodes in the grid, they are analyzed using a program developed within CSDL to calculate tidal datums (Hess, 2001b). The program selects the high and low water marks over 25-hour time periods using a cubic interpolation method. These highs and lows from the time series are then used to determine each of the datums. These computed datums are displayed in Figures 2.2-2.7. There are 26 coastal tide gauges in this region (excluding San Francisco Bay) available for contrasting the regional tide model results with observations. However, many of these gauges are located within small embayments or near obstructions not represented in the model grid. Therefore, the nine tide gauges in Figure 2.8 were determined to be the best suitable (i.e. least obstructed) locations for comparison with the model results.

The datum values at the tide gauges are computed by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) and provided on their web pages as benchmark sheets. Differences between the data and the model are shown in Figure 2.9 for the nine selected tide gauges. Also shown is a linear fit of these differences as a function of latitude. These linear fits to the differences can subsequently be added to the model results as a correction. Differences between the corrected results and the data, shown as the open circles in Figure 2.9, show that errors are now limited to less than 5 cm and are generally between 0 and 3 cm.

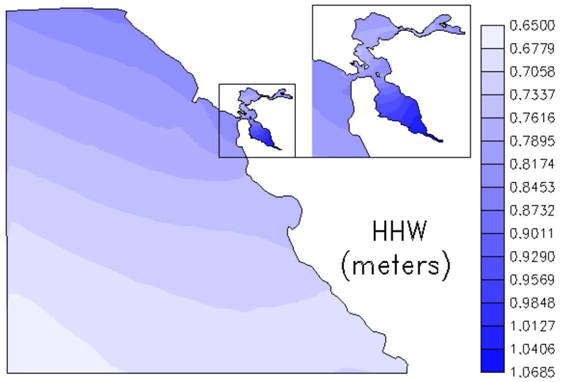

Figure 2.2. **M**HHW from the tidal inversion model.

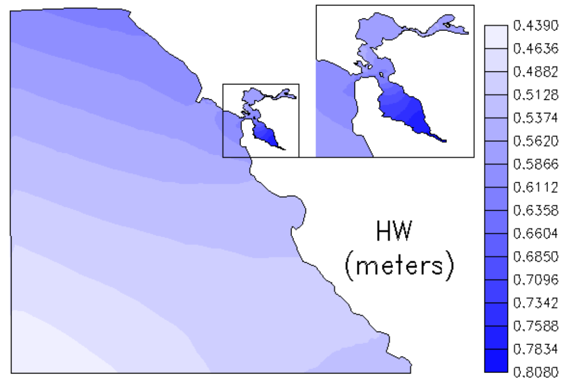

Figure 2.3. **M**HW from the tidal inversion model.

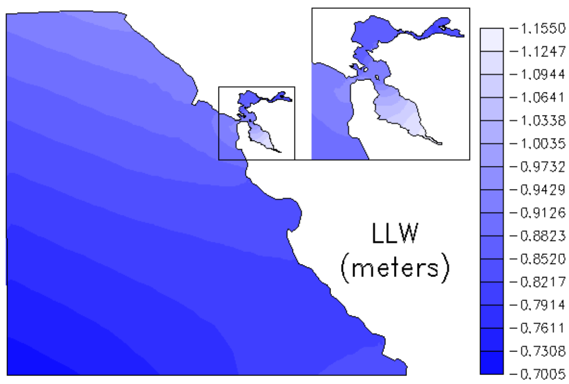

Figure 2.4. **M**LLW from the tidal inversion model.

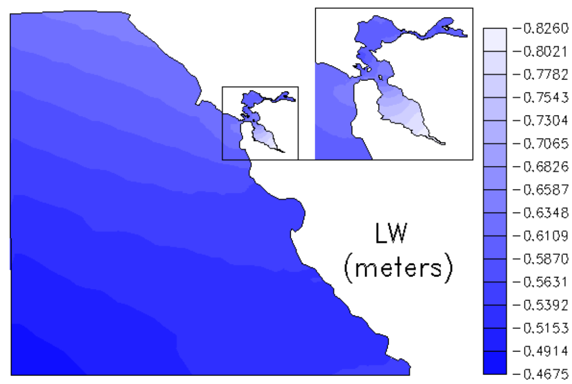

Figure 2.5. **M**LW from the tidal inversion model.

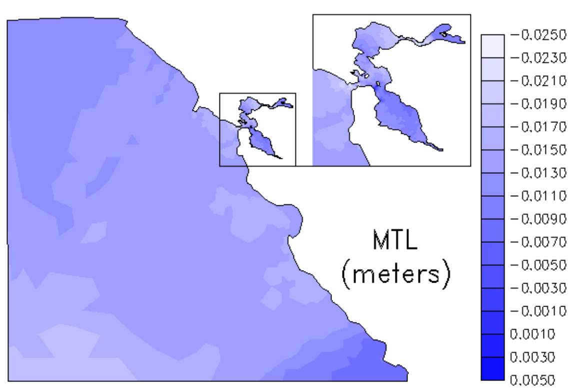

Figure 2.6. MTL from the tidal inversion model.

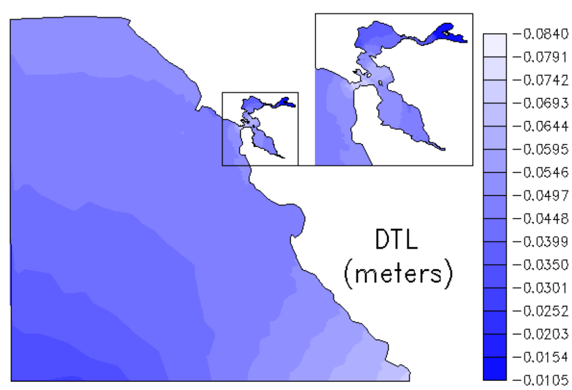

Figure 2.7. DTL from the tidal inversion model.

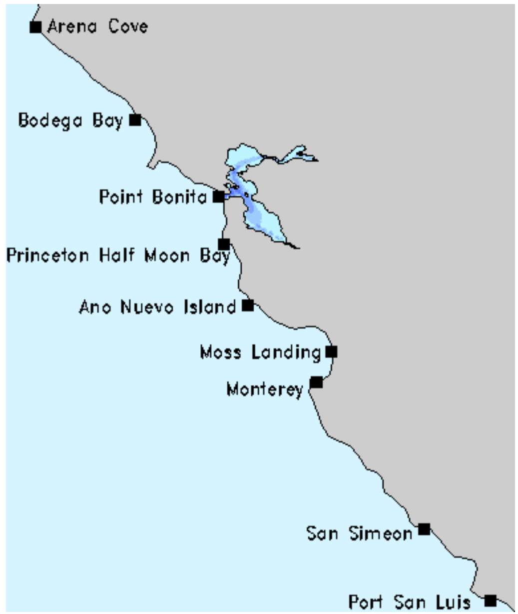

Figure 2.8. Tide gauges used for analysis of offshore datums.

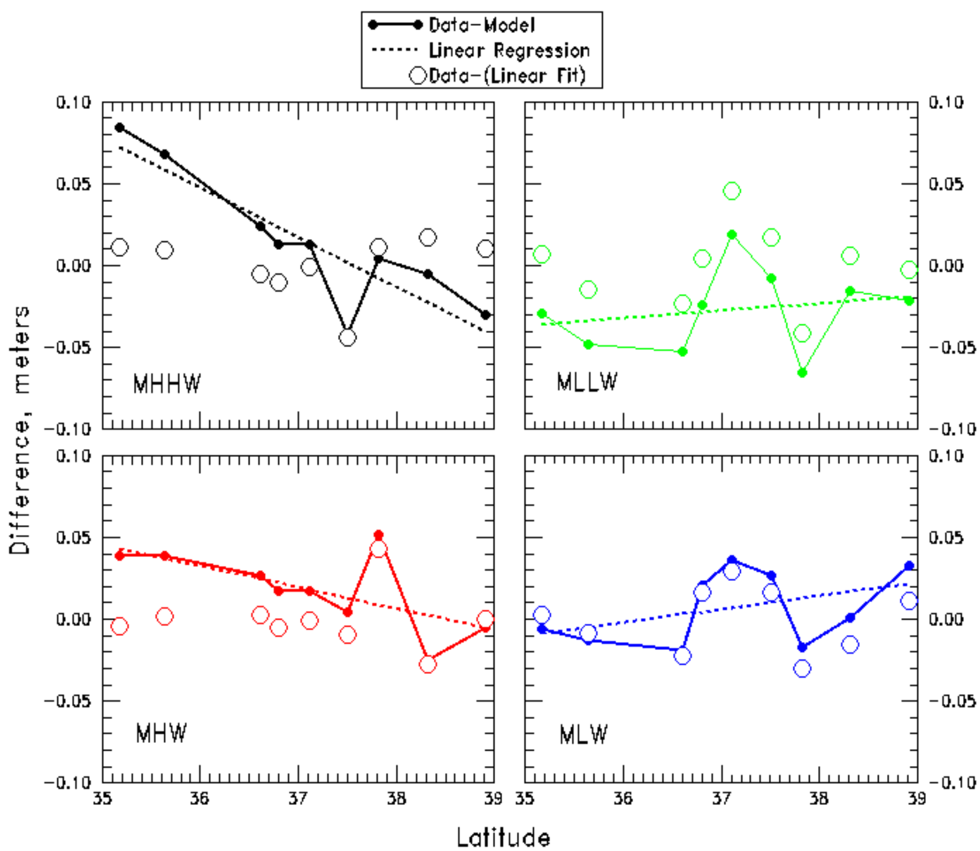

Figure 2.9. Datum comparisons between the tidal inversion model and the data for offshore region.

3. TIDAL DATUMS INSIDE SAN FRANCISCO BAY

The tidal inversion model results inside San Francisco Bay indicate that the magnitudes of the tides are underrepresented when contrasted with data. As an example, differences between the data and model are shown for MHHW in Figure 3.1. The values in the data are generally larger in magnitude than those of the model. This is most likely associated with a need for more grid refinement in San Francisco Bay in order for the model to more accurately depict both the bathymetry and tides.

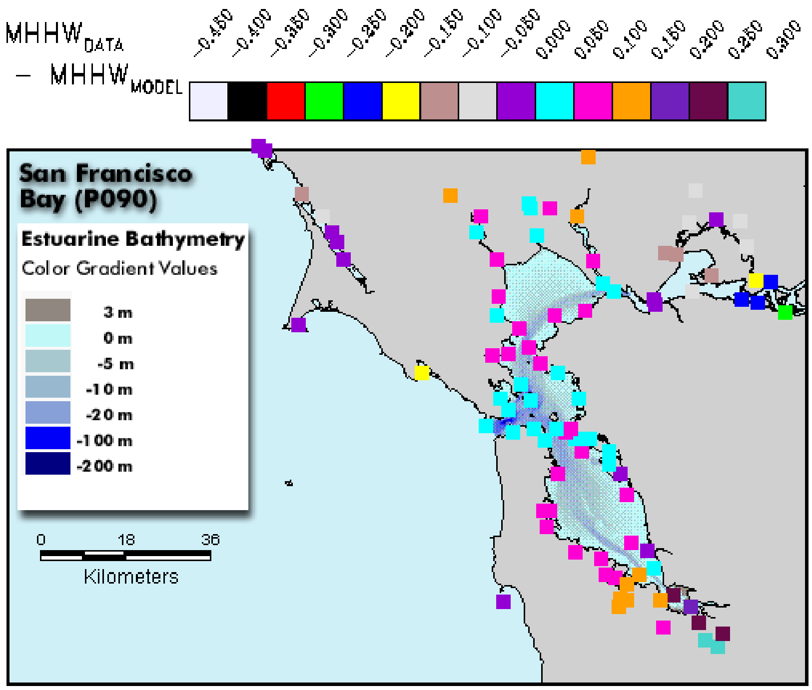

Figure 3.1. MHHW differences between data and model.

In order to correct the model results in San Francisco Bay, the tide interpolation model TCARI (Hess, 2001a) was used to spatially interpolate the differences between the model and the data. These corrections could then be added to the model results to provide a more accurate representation of each datum. The gauges shown in Figure 3.2 are those that were not located in small tributaries/embayments, were not obstructed, and were inside or within one nautical mile of the tidal inversion grid.

As will be discussed in Section 5, final calculations of the datums are provided on a VDatum grid of regularly spaced points. Within San Francisco Bay, the VDatum values are interpolated from the corrected model results. However, there may be some VDatum points that lie outside of the regional tide model grid but are still in the water area. For these areas, TCARI was also run to simulate the datums from available data (instead of simulating the differences between model and data).

The corrected MHHW from the tidal inversion model is shown in Figure 3.3, where the correction was made using the TCARI interpolation of the data-model differences. The TCARI interpolation of the MHHW data is displayed in Figure 3.4.

Figure 3.2. Tide gauges used in the spatial interpolation of the datums.

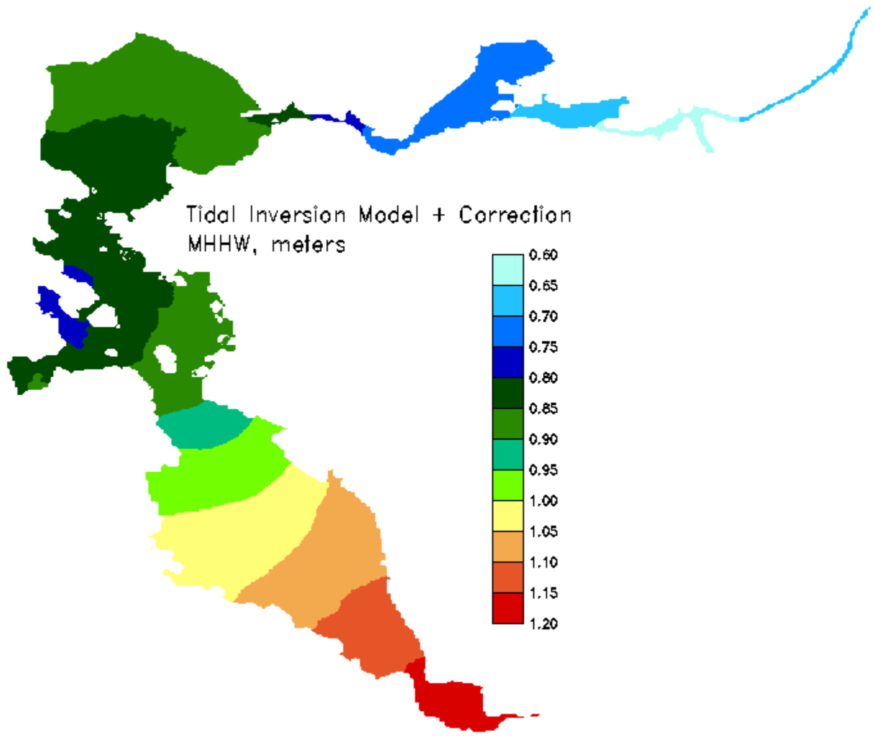

Figure 3.3. MHHW from the tidal inversion model, corrected using the TCARI interpolation of MHHW differences between the data and the tidal inversion model.

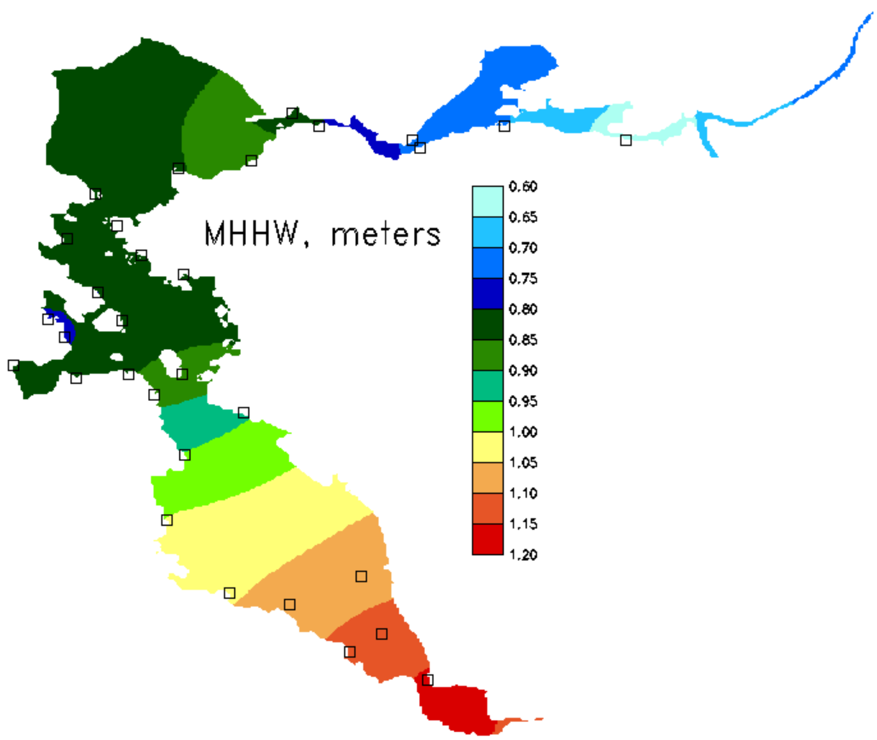

Figure 3.4. TCARI results for MHHW.

4. TIDAL DATUMS INSIDE TOMALES BAY

Since the regional tide model does not extend into Tomales Bay, TCARI is used to spatially interpolate the datums inside the bay based on available benchmark data. Tidal datums are calculated at the five tide gauges displayed in Figure 4.1. TCARI uses the data at these five locations and spatially interpolates them to a user-defined set of points dispersed throughout the bay, accounting for shoreline location.

The results from the interpolation for MHHW, MHW, MLLW, and MLW are shown in Figures 4.2-4.5, respectively. The tidal range increases with distance into the bay, as seen by the increase in magitudes for each of the datums. The TCARI results are computed on a set of regularly spaced points (0.06 nautical miles spacing) that are subsequently triangulated into a mesh grid.

Figure 4.1. Tomales Bay tide gauges.

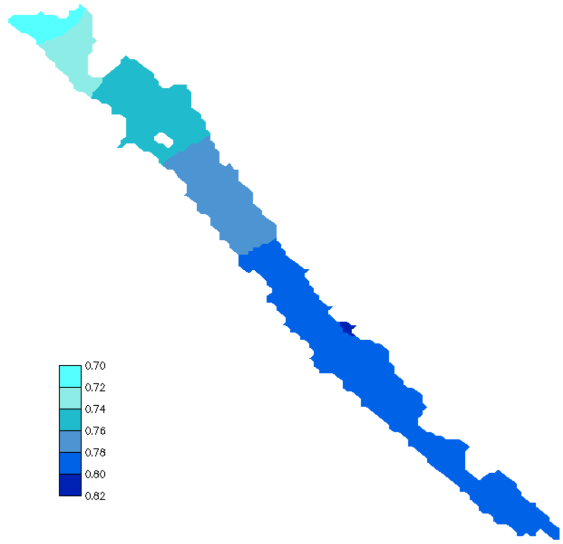

Figure 4.2. Interpolated MHHW in Tomales Bay.

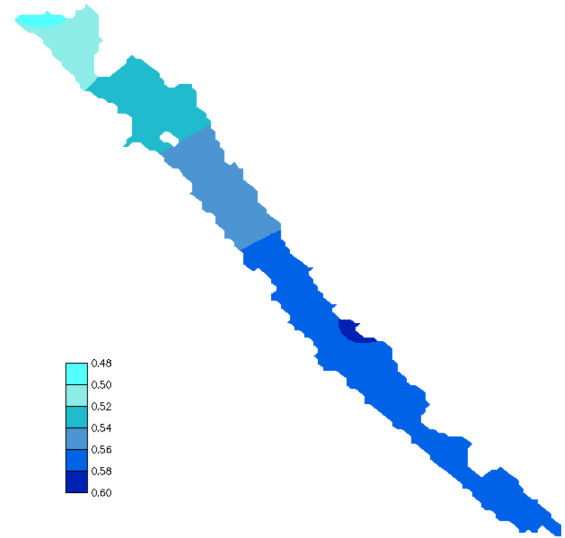

Figure 4.3. Interpolated MHW in Tomales Bay.

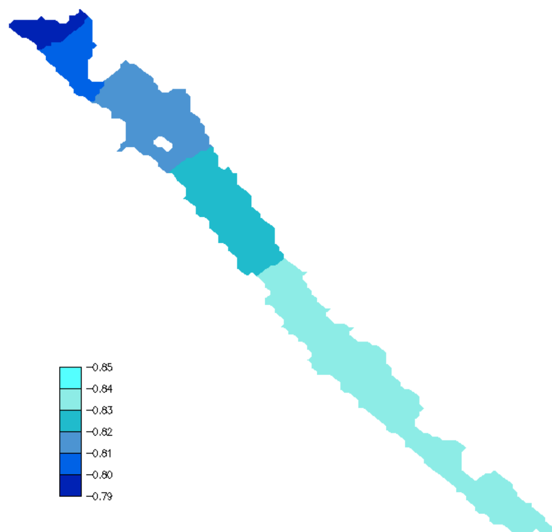

Figure 4.4. Interpolated MLLW in Tomales Bay.

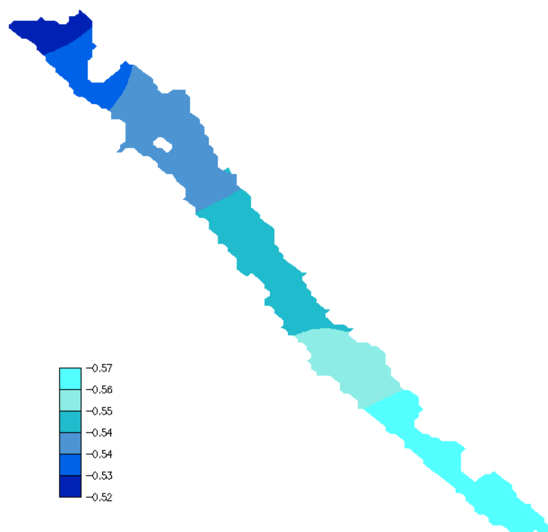

Figure 4.5. Interpolated MLW in Tomales Bay.

5. TIDAL MARINE GRID

The final set of computed tidal datums are provided on a grid of regularly spaced points (0.01 degree spacing). All points that lie outside of the region of interest (Figure 1.1) are given a value of –88.8888. The general algorithm followed for determining the datum values on the VDatum grid is shown in Figure 5.1:

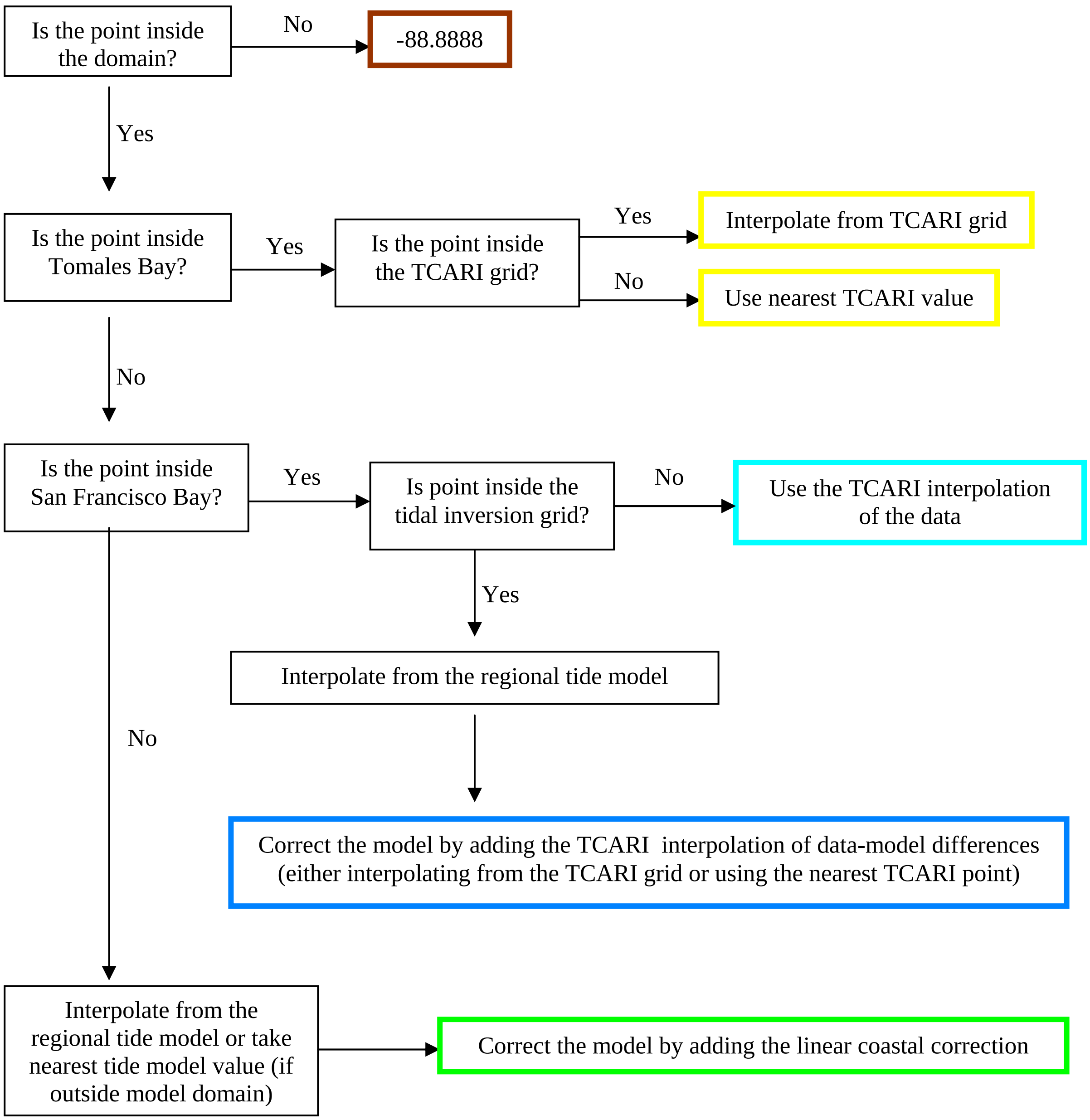

Figure 5.1. Algorithm used in generating the final datums for the VDatum grid.

The final values in Figure 5.1 are color coded in their boxes. Figure 5.2 shows the VDatum points using the same color codes, i.e. which approaches were used in different parts of the region of interest. An enlargement of the VDatum grid near San Francisco

Bay is shown in Figure 5.3. A bounding polygon was created to delineate those areas where VDatum transformations are applicable for this region, as shown in Figure 5.4.

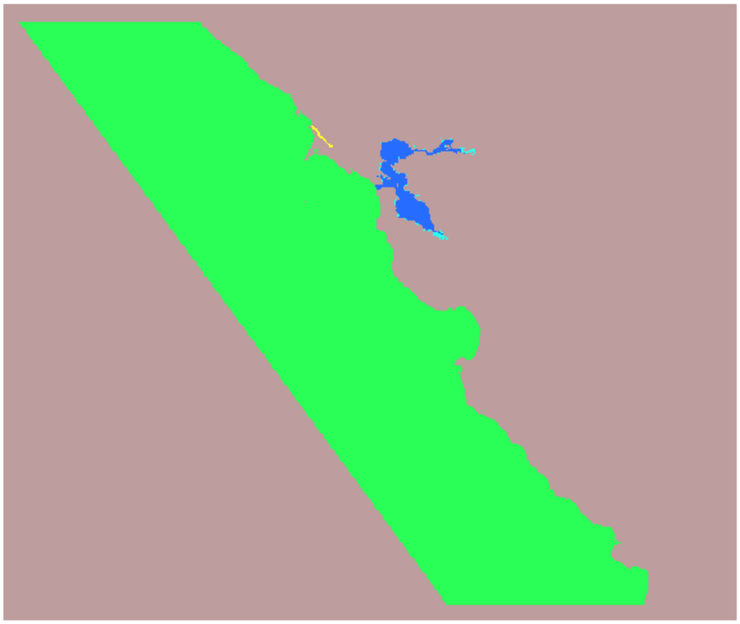

Figure 5.2. VDatum grid. Brown represents points outside the region of interest, green are offshore and coastal points, light blue are points outside the tidal inversion grid but inside the coastline, dark blue are inside the tidal inversion grid and corrected with TCARI interpolation of data-model differences, and yellow points are inside Tomales Bay.

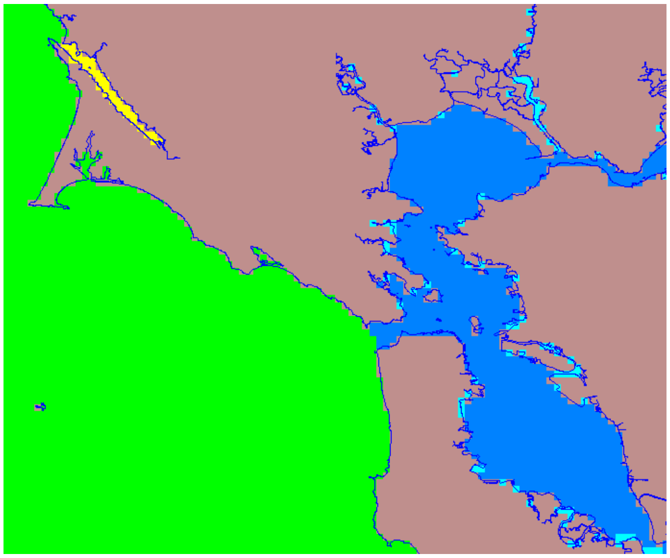

Figure 5.3. Enlargement of VDatum grid near San Francisco Bay.

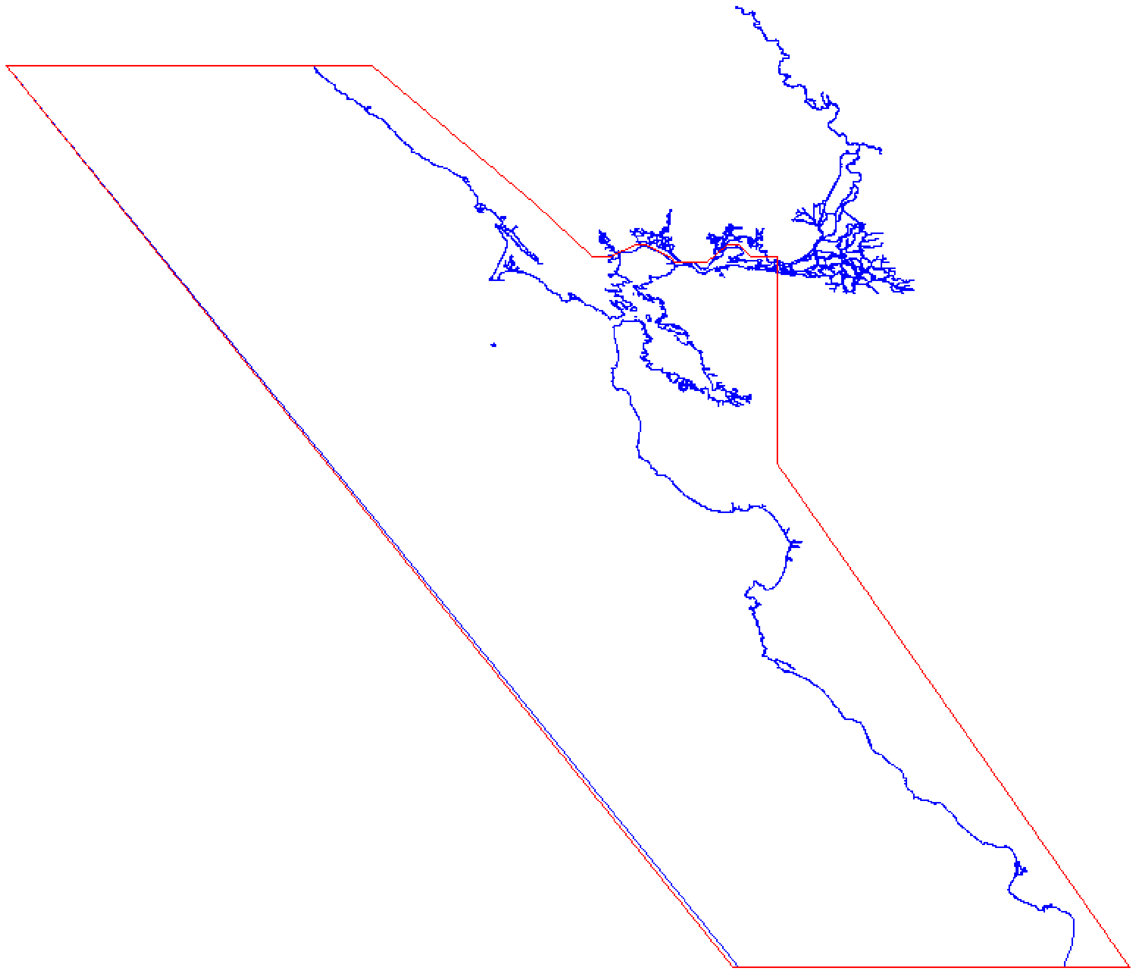

Figure 5.4. Bounding polygon (shown in red), inside of which VDatum transformations are available.

6. TOPOGRAPHY OF THE SEA SURFACE

To reference the collective group of tidal datums to the orthometric class of datums, the topography of the sea surface (TSS) was used to relate MSL to the North American Vertical Datum of 1988 (NAVD88). Observed MSL-NAVD88 differences were spatially interpolated by NOS' National Geodetic Survey using a linear Kriging technique on a grid of regularly structured points at 0.01 degree spacing. The TSS and tidal datum results were then input to the VDatum software for this region, along with transformations relating NAVD88 with the National Geodetic Vertical Datum of 1929 (NGVD29), NAVD88 with the North American Datum of 1983 (NAD83), and NAD83 with other ellipsoidal vertical reference systems.

ACKNOWLEDGMENTS

This work was made possible through support from the National Marine Sanctuary Program on a project coordinated by Christine Taylor. Development of this VDatum application for North/Central California fits into the vision that Dr. Bruce Parker had for building a national VDatum tool. Dr. Dennis Milbert and Jason Woolard of the National Geodetic Survey incorporated the tidal datums into the VDatum software which links them to the geoid and ellipsoidal models.

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