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Development of a Seamless Multisource Topographic/Bathymetric Elevation Model of Tampa Bay

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Abstract

Many applications of geospatial data in coastal environments require knowledge of the near-shore topography and bathymetry. However, because existing topographic and bathymetric data have been collected independently for different purposes, it has been difficult to use them together at the land/water interface owing to differences in format, projection, resolution, accuracy, and datums. As a first step toward solving the problems of integrating diverse coastal datasets, the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) are collaborating on a joint demonstration project to merge their data for the Tampa Bay region of Florida. The best available topographic and bathymetric data were extracted from the USGS National Elevation Dataset and the NOAA hydrographic survey database, respectively. Before being merged, the topographic and bathymetric datasets were processed with standard geographic information system tools to place them in a common horizontal reference frame. Also, a key part of the preprocessing was transformation to a common vertical reference through the use of VDatum, a new tool created by NOAA's National Geodetic Survey for vertical datum conversions. The final merged product is a seamless topographic/bathymetric model covering the Tampa Bay region at a grid spacing of 1 arc-second. Topographic LIDAR data were processed and merged with the bathymetry to demonstrate the incorporation of recent third party data sources for several test areas. A primary application of a merged topographic/bathymetric elevation model is for user-defined shoreline delineation, in which the user decides on the tidal condition (for example, low or high water) to be superimposed on the elevation data to determine the spatial position of the water line. Such a use of merged topographic/bathymetric data could lead to the development of a shoreline zone, which could reduce redundant mapping efforts by Federal, State, and local agencies by allowing them to customize their portrayals of the shoreline using a standard baseline elevation dataset.

Introduction

It is widely recognized that coastal environments, where the ocean meets the land, contain some of the most dynamic ecosystems. These ecosystems at the land/water interface experience significant change owing to both natural and human-induced factors. Currently, over one-half of the U.S. population lives within the coastal zone, and this number continues to increase each year (Culliton, 1998). Because of the growing population and increasing commercial and residential development in coastal areas, the impacts and costs of natural hazards continue to climb each year. Many of the physical processes at the land/water interface are controlled by the shape and configuration of the adjacent land (topography) and underwater surface (bathymetry). In low-relief coastal areas, the topographic and bathymetric gradients can be very gentle, and the associated landforms are susceptible to significant changes, from both erosion and accretion. Studies of such a dynamic environment require high-resolution, up-to-date measurements of near-shore topography and bathymetry. In a recent survey of coastal resource managers (NOAA Coastal Services Center, 1999), the following datasets were identified as being "very useful" or "moderately useful" by at least two-thirds of the respondents: near-shore bathymetry, estuarine and bay bathymetry, and coastal topography. These datasets were also listed in the top 10 (out of 29) data needs identified by the coastal managers. Unfortunately, the required data do not exist for many locations along the coast. Even where they do exist, it can be very difficult to integrate the topographic and bathymetric data because of different projections, datums, and data formats. In most cases, the topographic and bathymetric data were collected and processed independently by different agencies for specific purposes, so seamless integration across the land/water interface was not a requirement. As studies in the coastal environment increasingly take a more holistic approach to understanding the physical processes at work, they require seamless integration of recent, high-resolution topographic and bathymetric data.

Because topographic data produced by the U.S. Geological Survey (USGS) and bathymetry data produced by the National Oceanic and Atmospheric Administration (NOAA) were collected at different times and to different specifications, especially the vertical datum, it is difficult for geospatial data users in the coastal resource management community to use USGS and NOAA data together for shoreline applications. State and local agencies also collect extensive spatial datasets in coastal areas, and these data are often difficult to integrate effectively with Federal data because of the inconsistent geospatial framework. With over 95,000 miles of U.S. coastline, the significant challenge of maintaining up-to-date mapping requires that all data sources (Federal, State, and local) be used together to meet the information requirements for scientists, engineers, and resource managers working in coastal environments.

As a first step toward solving the problems of integrating diverse coastal datasets, the USGS's Cooperative Topographic Mapping Program and NOAA's National Ocean Service are collaborating on a joint demonstration project to merge their data for the Tampa Bay region of Florida. The goal of the project is to develop tools and techniques to facilitate the integration of the best available USGS topographic data and NOAA hydrographic survey data. The project start included a users workshop in December 1999 at which local coastal managers in the Tampa Bay region identified the difficulty in using USGS and NOAA data together. They expressed the view that data *consistency* was more important than data *accuracy* for many of their applications (in which many different demographic and environmental data types must be georeferenced). They also cited the resolution, accuracy, and age of both the topographic and the bathymetric data as areas where significant improvements were needed.

Data Sources and Processing

The primary data sources merged for Tampa Bay are the currently best available USGS topography and NOAA bathymetry datasets. Another aspect of the Tampa Bay project is to demonstrate the integration of third party data into the geospatial framework, and this has been accomplished by processing high-resolution topographic LIDAR data for several test areas in the Tampa Bay region. The key requirement for creating a seamless, merged product is that each of the input datasets must be in a common geospatial framework, consisting of a coordinate system, horizontal datum, and vertical datum. The geographic coordinate system (decimal degrees of latitude and longitude) referenced to the North American Datum of 1983 (NAD 83) was used for horizontal coordinates, and decimal feet were used for vertical coordinates (referenced vertically to the NAD 83 ellipsoid). Details on the characteristics and processing approach for each of the input data sources are given below.

USGS Topography Data

The best available topographic data for the Tampa Bay region (Figure 1) were extracted from the USGS National Elevation Dataset (NED). The NED (Gesch and others, 2002) is an implementation of the National Spatial Data Infrastructure (NSDI) concept of framework data. Framework data are defined as those spatial datasets that are fundamental to many applications (Federal Geographic Data Committee, 1995). In this case, land elevation is a basic layer of information upon which other data layers can be overlaid. The NED is a seamless raster elevation dataset that provides national U.S. coverage at a grid spacing of 1 arc-second (approximately 30 meters). It is derived from USGS map-based digital elevation models (DEM) that have a resolution of either 10 meters or 30 meters. NED production includes the following processing steps performed on the individual source 7.5-minute DEM files: datum and coordinate unit conversion (horizontal and vertical), projection transformation and resampling, filtering (for removal of production artifacts), mosaicking, edge matching, and metadata generation. The resulting 50-gigabyte dataset includes an elevation value posted every 1 arc-second on a latitude/longitude grid (referenced to the NAD 83 horizontal datum). Elevations are expressed in decimal meters referenced to the North American Vertical Datum of 1988 (NAVD 88).

Because the native horizontal coordinate system and datum of the NED are the same as those chosen for the merged dataset to be produced in the demonstration project, no transformation was required to place the topographic data into the common horizontal geospatial reference frame. After elevation units were converted from decimal meters to decimal feet, the NED elevations were transformed to the common ellipsoid vertical reference frame using industry standard tools and datasets (VERTCON and GEOID99) from the National Geodetic Survey (NGS) (Zilkoski, 2001; Smith and Roman, 2001).

NOAA Bathymetry Data

The best available bathymetric data for the Tampa Bay region were extracted from NOAA's hydrographic survey database. The hydrographic surveys are accessed through the Geophysical Data System (GEODAS) at NOAA's National Geophysical Data Center. For the Tampa Bay region, data were available from 47 hydrographic surveys conducted from 1950 to 1996 (Figure 2).

Approximately 800,000 soundings were extracted from GEODAS and loaded into the ArcView[*] geographic information system (GIS) for processing. Because the hydrographic surveys overlap

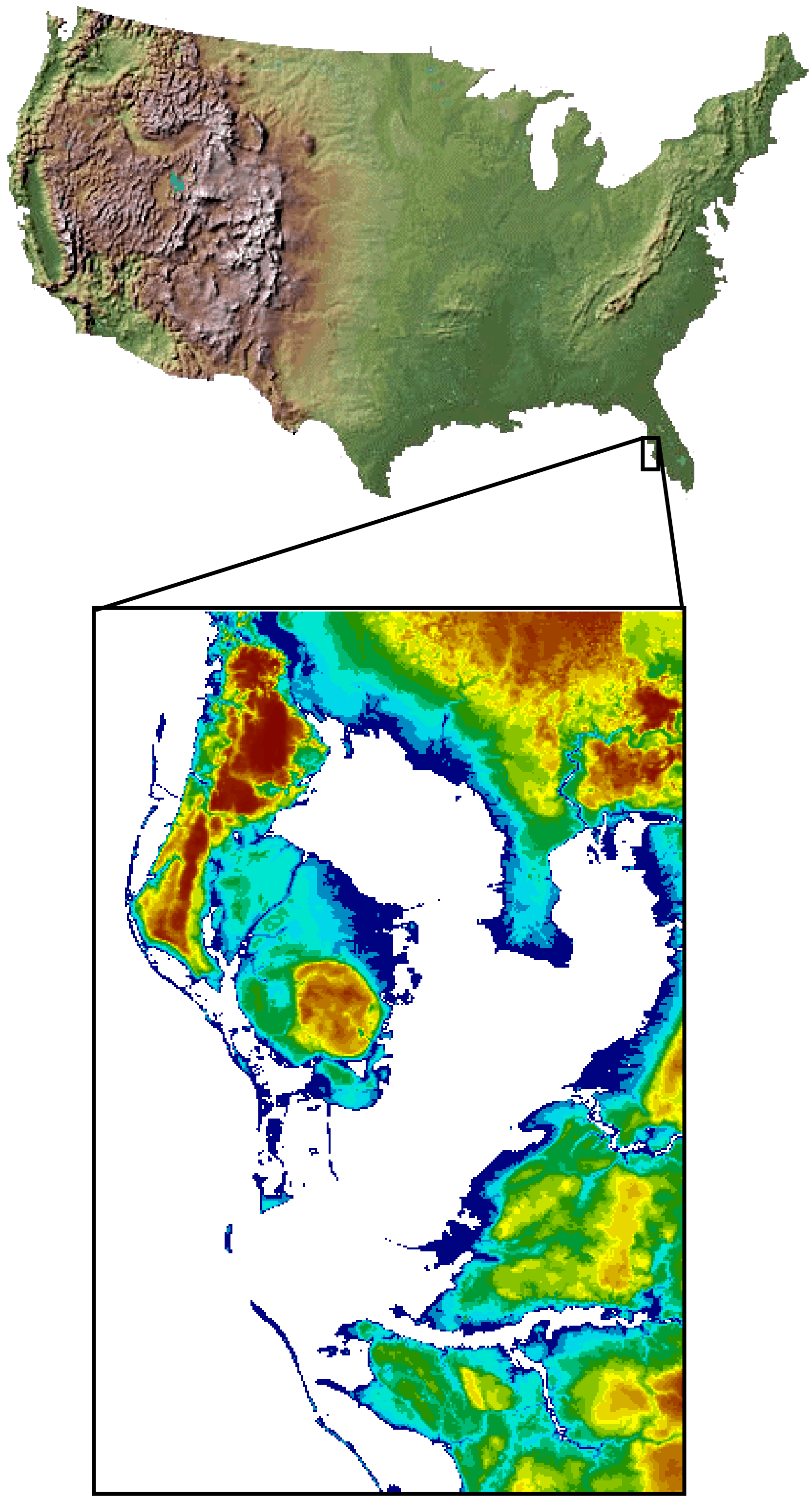

Figure 1. USGS topography data extracted from the NED for the Tampa Bay region.

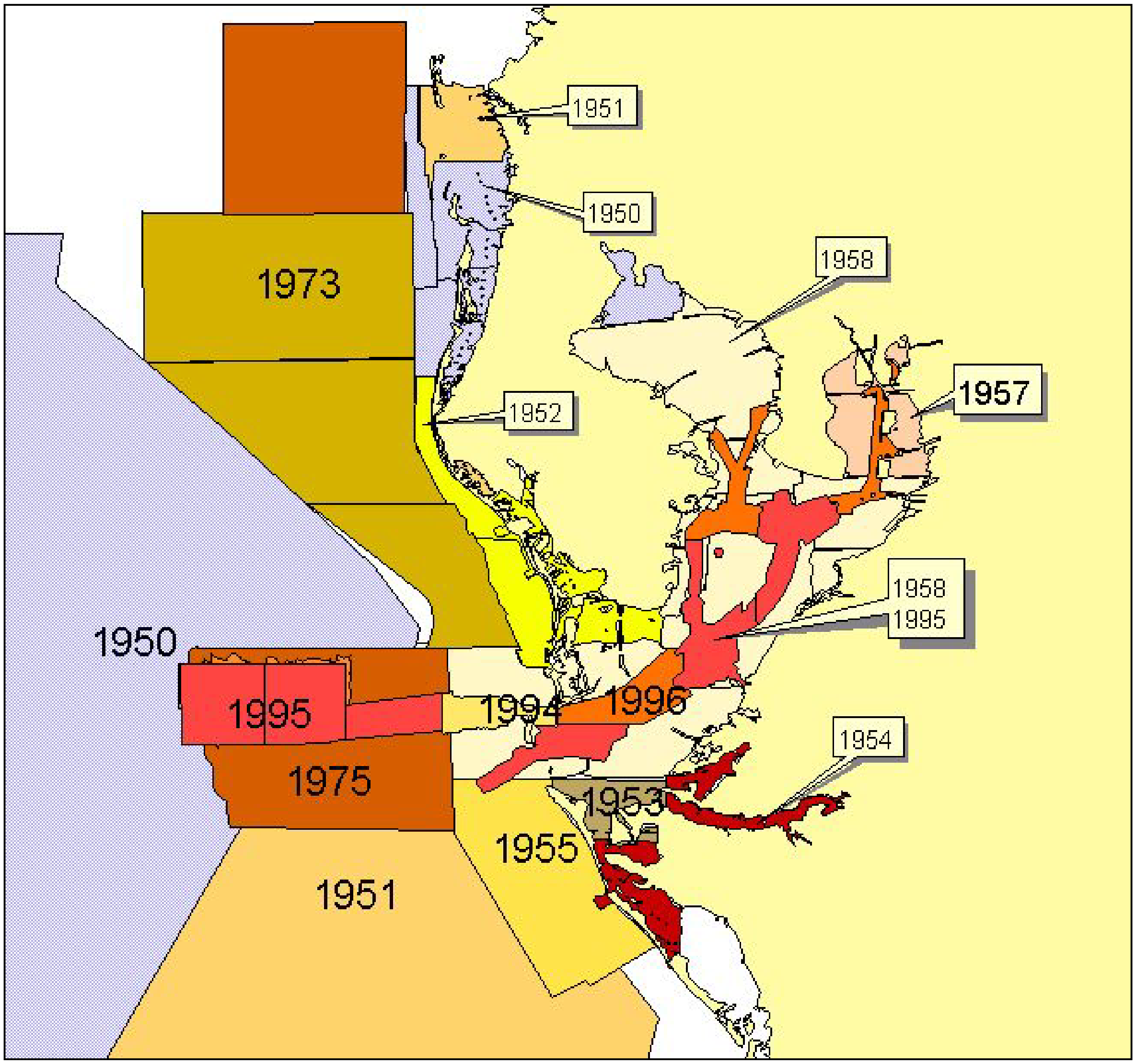

Figure 2. NOAA hydrographic surveys for Tampa Bay.

in many areas, the soundings were subjected to a spatial-temporal filtering process to select the most recent bathymetric data for all areas in the Tampa Bay region. Spatial survey polygons, or indexes, were created for each of the 47 hydrographic surveys. The survey polygons were sorted by date, merged with other survey polygons for the same year, and clipped on the basis of the survey date. The resulting dataset was tested for topological consistency, and polygon slivers from overlapping surveys were removed. As a result of this process, 15 new master spatial-temporal polygons were produced. Each new polygon represents the spatial location of the most current NOAA soundings in Tampa Bay. Approximately 99% of the project area is covered by digital sounding data at variable data densities. The soundings identified as the most recent from the polygon processing were merged into a single file and sorted on the basis of the vertical datum. For Tampa Bay, approximately half of the soundings were collected in reference to a mean low water (MLW) vertical datum, and the other half were collected for surveys using a mean lower low water (MLLW) vertical datum.

A vertical datum transformation was required to place the soundings into the required common vertical reference frame for merging with the topographic data. The transformation was accomplished with VDatum, a tool developed by the NGS specifically for the conversion of elevation data from one datum to another datum (Milbert and Hess, 2001). VDatum converts elevation data among 26 different vertical datums that may be categorized into three general classes: orthometric datums, tidal datums, and three-dimensional datums. Orthometric datums, such as NAVD 88, are based on a form of mean sea level (MSL). Tidal datums, including MLW, MLLW, and mean high water (MHW) often used on nautical charts, are tidally derived surfaces of low or high water. Three-dimensional datums are Earth-centered datums realized through the use of space-based geodetic methods, including the Global Positioning System. For conversions involving one of the tidal datums, VDatum uses the geographic distribution of tidal surfaces calculated either from a fully calibrated numerical hydrodynamic model of Tampa Bay or from spatial interpolation (Hess, 2001). The inputs to the hydrodynamic model include coastal water levels (measured at tide gages), inflow from seven rivers into the bay, winds, air temperature, and water salinity and temperature. The outputs from the model incorporated into VDatum include a set of grids representing the vertical differences among MLLW, MSL, and the other tidal datums for geographic locations throughout Tampa Bay. For the selected set of NOAA soundings, VDatum was used to transform the depth values from their tidal datum reference to values referenced to the three-dimensional datum of the NAD 83 ellipsoid.

Topography/Bathymetry Merge Processing

Before the merged topographic/bathymetric elevation model was generated, the digital soundings (point data) were processed as described below to create a bathymetric grid at the same resolution as the extracted NED topographic data. The NED "shoreline" (interface of zero/nonzero elevations) was used to make the final selection of bathymetry and topography points for merging. All land elevations within 600 meters of the shoreline were converted from raster format to XYZ point data. All bathymetry points coinciding with areas of zero elevation in the NED were selected. Because of the age of some of the hydrographic surveys, some of the soundings were located on areas that had been filled and are now represented as land in the DEM. These points were withheld from further processing.

The selected topography points within the shoreline buffer zone and the bathymetry points were gridded to produce a raster surface model with 1-arc-second grid spacing to match the resolution of the NED. The points were processed in the ArcInfo GIS package with TOPOGRID, an implementation of the ANUDEM thin plate spline interpolation algorithm that is optimized for the generation of topographic surfaces (Hutchinson, 1989). The bathymetry points could have been gridded independently of the topographic data, but the shoreline zone land elevations were included in the interpolation to ensure a better match of the bathymetric and topographic surfaces in the subsequent mosaicking step. To avoid the introduction of any interpolation edge effects into the merged elevation model, the output grid from the interpolation was clipped to include land elevations within 300 meters of the shoreline (half of the original 600-meter buffer). The final processing step involved mosaicking the bathymetry grid and the NED elevation grid. The values in the 300-meter overlap area were blended using a GIS function that performs weighted averaging on a cell-by-cell basis according to the cell's proximity to the edges of the overlap area. The resulting final merged product is a seamless topographic/bathymetric model covering the Tampa Bay region at a grid spacing of 1 arc-second (Figure 3).

Topographic LIDAR

Topographic data derived from an airborne LIDAR survey conducted by the University of Florida (Carter, Shrestha, and Leatherman, 2000) were processed for several test areas to demonstrate the usefulness of incorporating recent, high-resolution, high-accuracy data. The LIDAR survey covered the Pinellas County part of the Tampa Bay region. LIDAR XYZ point data representing "bare earth" elevations were gridded to produce a DEM with a $1/9^{th}$-arc-second posting (approximately 3 meters). A merge of this high-resolution DEM and gridded bathymetry was done using the same methodology as described earlier for the 1-arc-second product (summarized in Figure 4). The results of the high-resolution topographic/bathymetric merge are seen in Figure 5.

Results, Conclusions, and Future Directions

The seamless topographic/bathymetric elevation model for the Tampa Bay region demonstrates the successful integration of disparate USGS and NOAA data sources that previously have been difficult for GIS users to integrate. The key to effectively combining USGS topographic data and NOAA bathymetric data for applications in the dynamic coastal zone is the availability of tools developed by the NGS for transformation to a common vertical reference frame. Standard GIS processing and analysis tools were used for the other steps of the data merging, including data reformatting and subsetting, transformation to a common horizontal reference frame, surface interpolation, and mosaicking. Further details on the Tampa Bay demonstration project, including background information, data visualizations, and links to tools and datasets developed in the project, are available on the project Web site at http://chartmaker.ncd.noaa.gov/bathytopo/.

Because the source bathymetric and topographic data vary in density and accuracy, users need to be made aware of the spatially varying quality of the merged model. In some areas, the spacing of the soundings would support gridding at a much higher resolution than 1 arc-second, but in other areas the values of the 1-arc-second grid were interpolated only on the basis of distant points. Likewise, the vertical accuracy of the model varies spatially, owing mainly to the wide

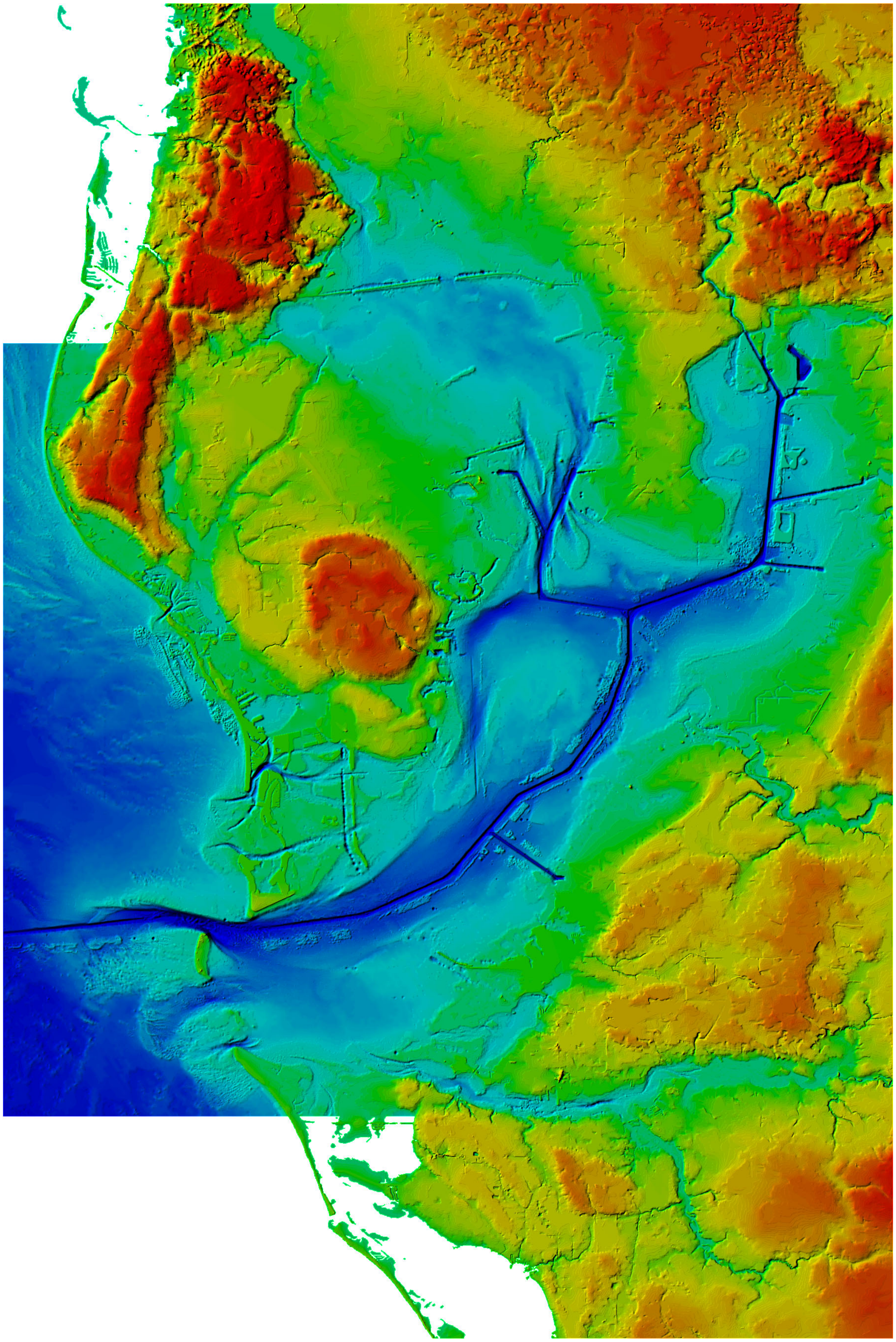

Figure 3. 1-arc-second seamless topographic/bathymetric elevation model of Tampa Bay.

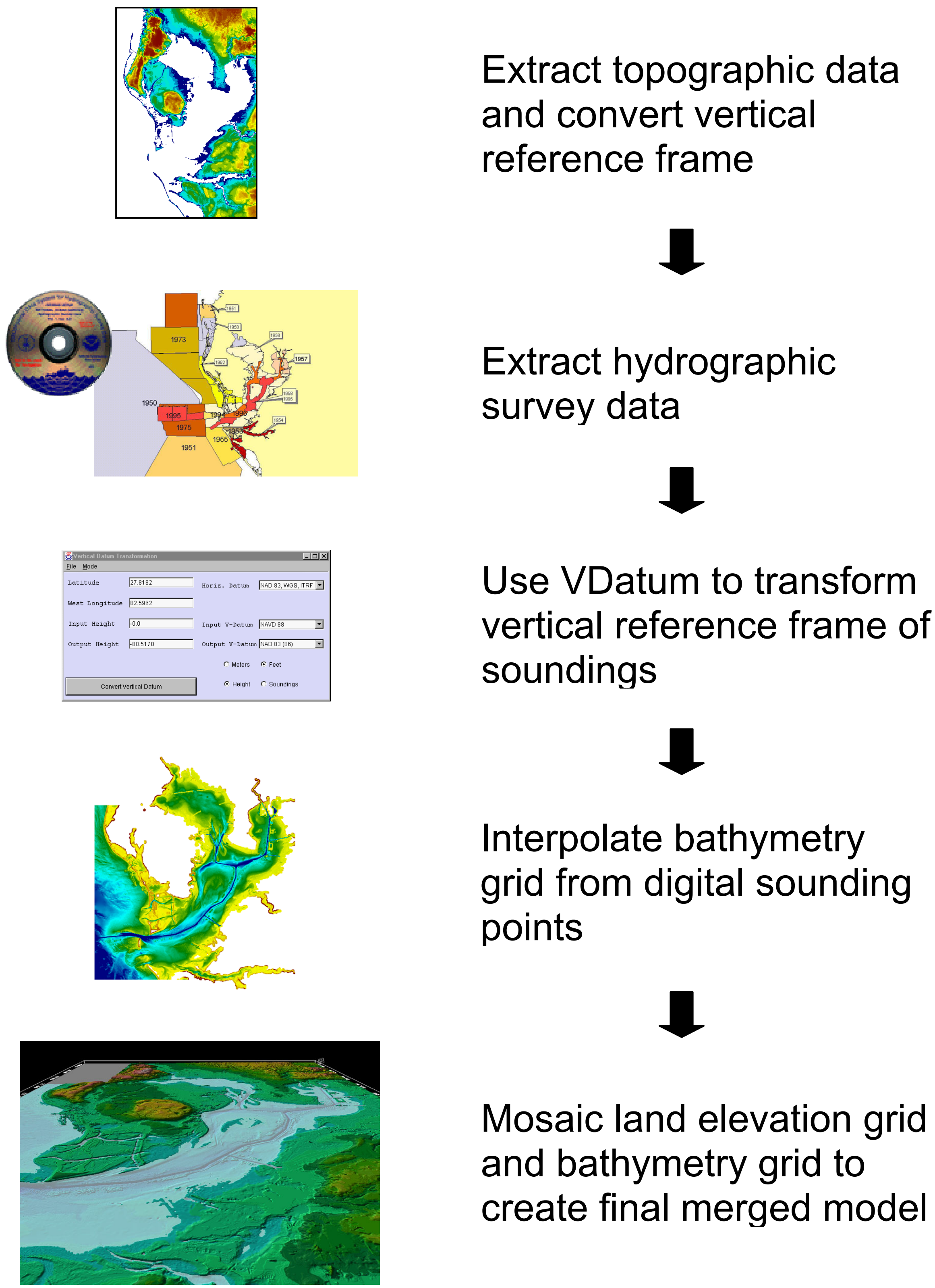

Figure 4. Processing stages for generation of merged topographic/bathymetric elevation model.

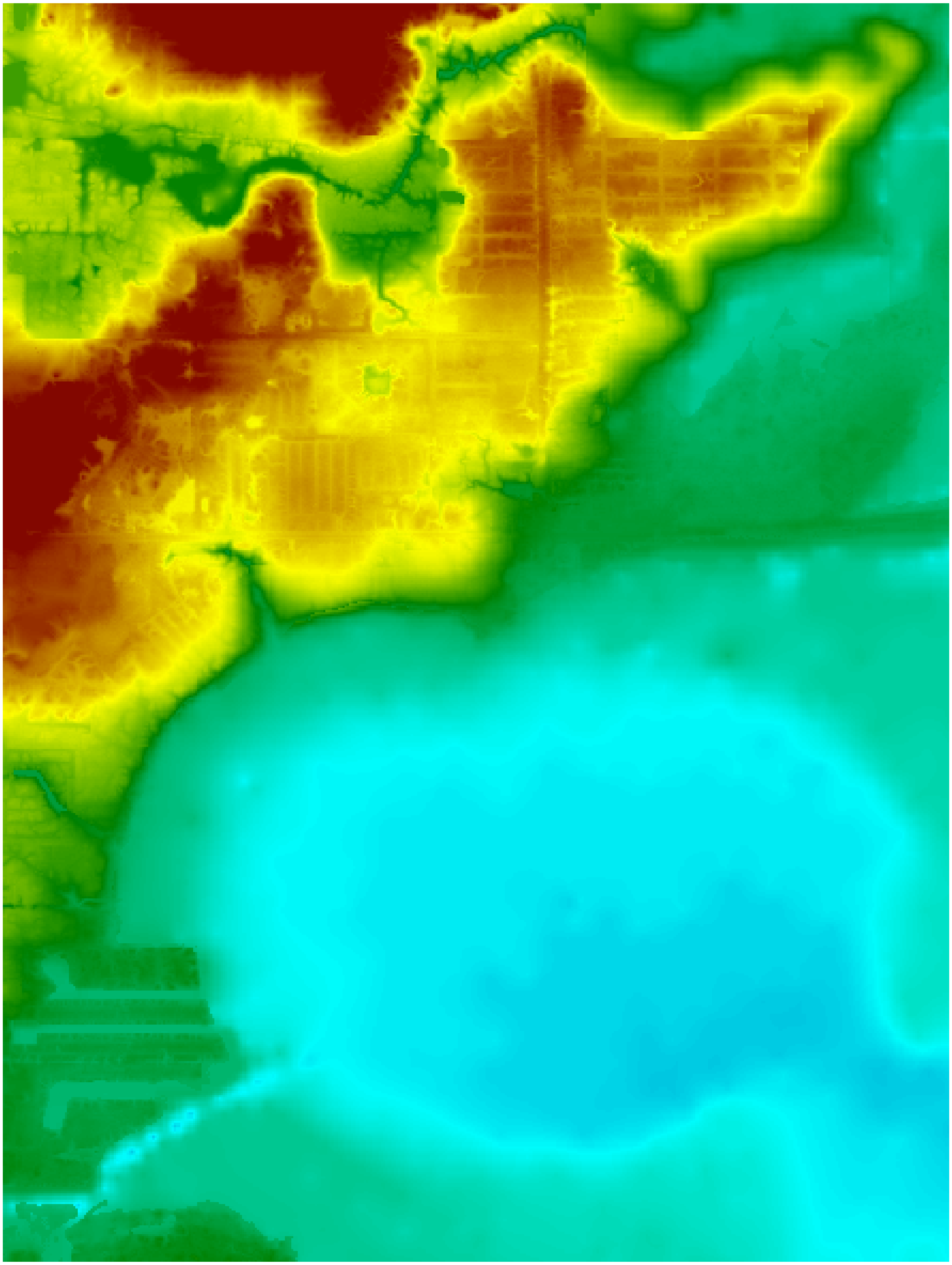

Figure 5. High-resolution merge of topographic LIDAR data and gridded bathymetry data.

variety of dates and data collection technologies used for source data acquisition. A merged raster model at a uniform grid cell spacing was produced because most users require such a product for their computer mapping systems. Current work involves generating spatial indices of data quality and accuracy that are coregistered with the model to help users better judge the applicability of the model for their application in a specific location. One index will be a representation of the density (point spacing) of the input sounding data. Another index will portray the estimated vertical accuracy of the bathymetric and topographic data. This index will be helpful for indicating to users the inherent accuracy of the source data and, thus, the derived merged model. Without such labeling, users may assume more accuracy than is actually present, especially because the data are presented in a seamless fashion where discontinuities among data sources have been intentionally minimized, and the vertical units are expressed to a precision of decimal feet.

The generation of a gridded bathymetric surface from NOAA digital sounding data points provides a useful data layer for GIS users working in coastal areas. The raster bathymetric data work well in integration with other raster data and visualization of the near-shore marine environment. For many users, it will be easier to work with a raster grid derived from the best available archived soundings, rather than the voluminous point data from multiple overlapping hydrographic surveys. The bathymetric grid generated for this project was produced from historical data collected at various times over 45 years. In order to assess the accuracy of the bathymetric grid derived from the diverse soundings, the grid was compared with recent (1999) high-accuracy bathymetric transect data collected by a NOAA hydrographic survey team at several locations in Tampa Bay. Figure 6 shows the transect locations and the statistics of the differences between the bathymetric grid and the reference transect data. An overall root mean square error of 1.4 feet was calculated for the bathymetric grid.

A primary application of a merged topographic/bathymetric dataset is for shoreline definition (Parker, 2001). USGS topographic products and NOAA nautical charts have different delineations of the shoreline because of different criteria used to define the land/water interface. In many cases, both sources are most likely out-of-date in areas where shorelines have changed because of natural and human influences. Up-to-date, high-resolution, high-accuracy topographic and bathymetric data that have been effectively merged to create a “shoreline zone” will allow users to define their own criteria for shoreline portrayal without having to choose among static representations from differing spatial data sources. A number of “shorelines” could be generated by moving the water level on the merged DEM to the desired tidal datum heights. This would be especially effective in areas of broad sloping beaches where low-water and high-water shorelines differ significantly. In such areas, use of a combined bathymetric/topographic LIDAR data source, such as the U.S. Army Corps of Engineers SHOALS system (Irish and Lillycrop, 1999), would provide the best quality data where the need is the greatest, at the land/water interface. High-resolution and high-accuracy data that cover both near-shore bathymetry and near-shore elevations would be ideal because it would serve as the reference dataset to which the inland topographic data and the offshore bathymetric data would be matched. The merging process could be the same as that used for the current model; surface interpolation across the overlap area by including points from all three data sources, followed by raster mosaicking with weighted average data blending to minimize discontinuities at data source transition zones.

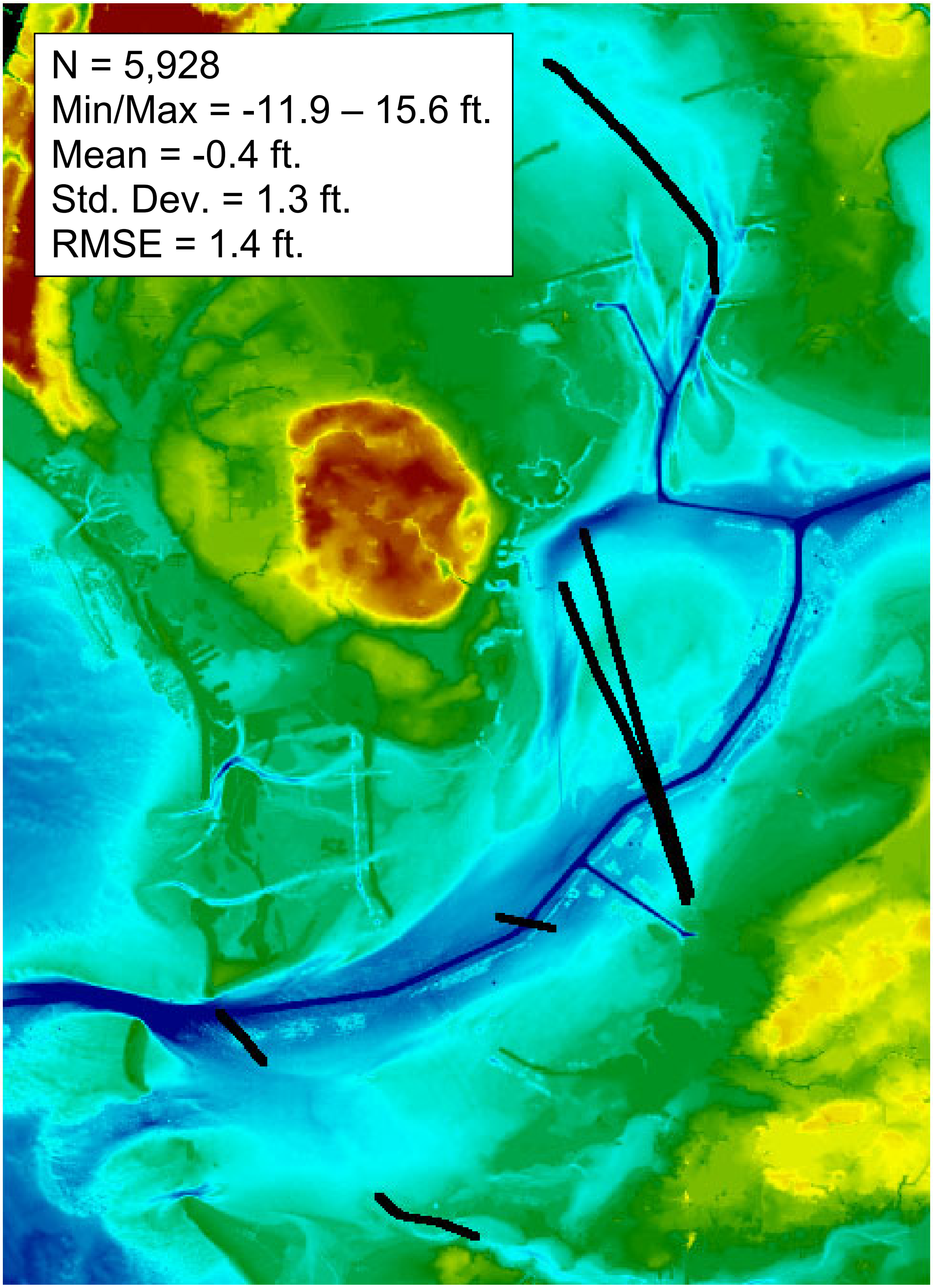

Figure 6. Reference transects (heavy black lines), and accuracy statistics for gridded bathymetry data.

The advantages of integrating USGS topographic data and NOAA hydrographic data to create a seamless elevation model for the coastal zone have been recognized by other groups using spatial data for coastal applications. Preliminary work has begun to produce integrated models for study areas along the New York/New Jersey coast and in the Gulf of Mexico along the coast in southeastern Louisiana. The Tampa Bay elevation model is currently being used as a key baseline geospatial dataset for the various geologic, biologic, and hydrologic studies that are part of the USGS integrated science initiative for Gulf of Mexico estuaries (http://gulfsci.usgs.gov/index.html).

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