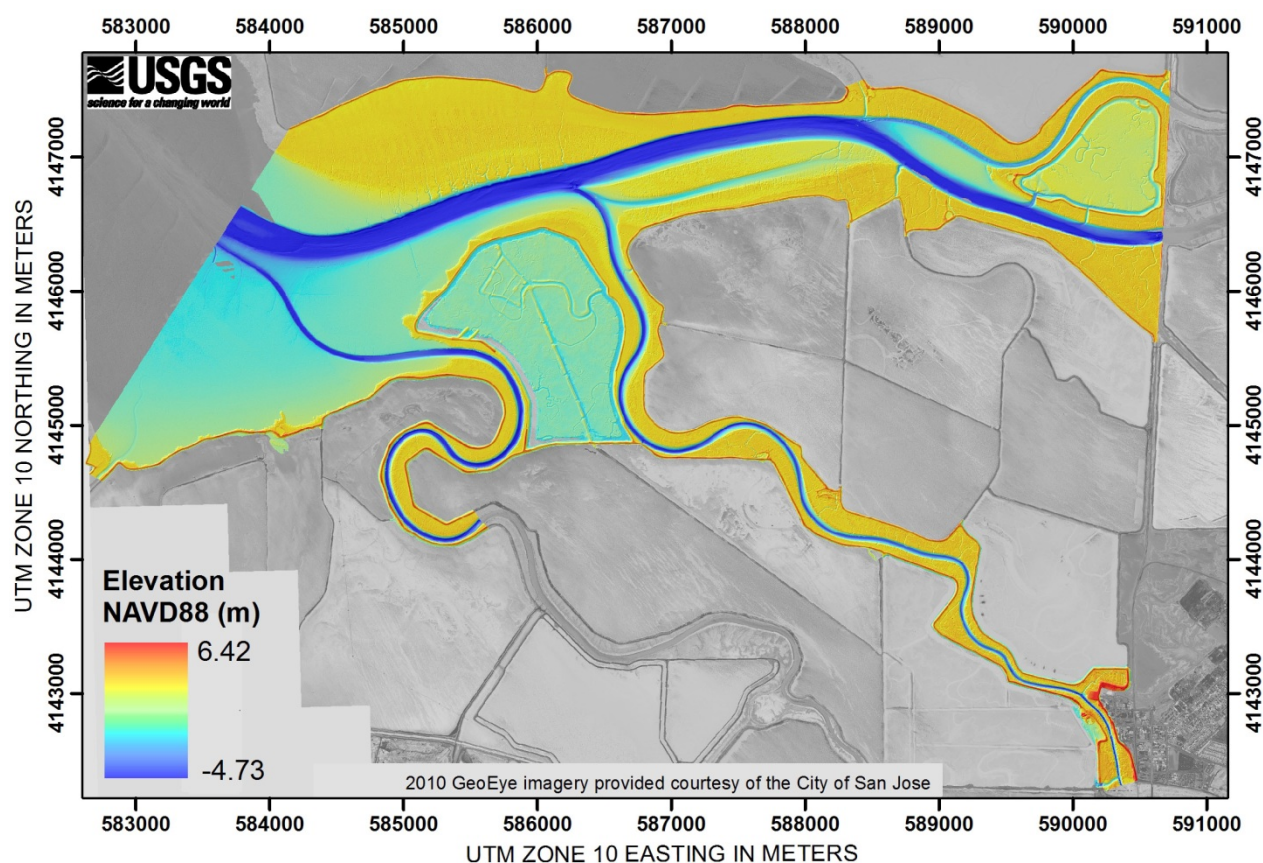![USGS - science for a changing world]

2010 Bathymetry and Digital Elevation Model of Coyote Creek and Alviso Slough, South San Francisco Bay, California

By Amy C. Foxgrover, David P. Finlayson, and Bruce E. Jaffe

U.S. Department of the Interior
U.S. Geological Survey

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Cover: Seamless bathymetric/topographic DEM of Coyote Creek and Alviso Slough, south San Francisco Bay, California; from figure 8

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Abstract

In 2010 the U.S. Geological Survey (USGS), Coastal and Marine Geology Program completed three cruises to map the bathymetry of the main channel and shallow intertidal mudflats in the southernmost part of south San Francisco Bay. The three surveys were merged to generate comprehensive maps of Coyote Creek (from Calaveras Point east to the railroad bridge) and Alviso Slough (from the bay to the town of Alviso) to establish baseline bathymetry prior to the breaching of levees adjacent to Alviso Slough as part of the South Bay Salt Pond Restoration Project (*http://www.southbayrestoration.org*).

The bathymetry surveys were done using the state-of-the-art research vessel R/V *Parke Snavely* outfitted with an interferometric sidescan sonar for swath mapping in extremely shallow water. We provide high-resolution bathymetry collected by the USGS and have merged the bathymetry with aerial lidar data that were collected for the USGS during the same time period to create a seamless, high-resolution digital elevation model (DEM) of the study area. The bathymetry datasets are provided at 1 m resolution and the bathymetric/topographic DEM at 2 m resolution. The data are formatted as both X, Y, Z text files and ESRI Arc ASCII files that are accompanied by FGDC compliant metadata.

Introduction

Data Collection

Three separate surveys were done in the southernmost reaches of south San Francisco Bay in 2010 to collect high-resolution bathymetry and coregistered acoustic backscatter of the main channels and adjacent intertidal flats. The first survey (USGS Field Activity ID: S-2-10-SF) was from January 13-15, 2010, the second survey (USGS Field Activity ID: S-18-10-SF) was from September 11-13, 2010, and the third survey (USGS Field Activity ID: S-24-10-SF) was on December 3, 2010. The combined bathymetric surveys consist of 220 survey lines covering an area of approximately 3.1 km^2 in water depths ranging from about 1.0 to 5.0 m NAVD88. The surveys extend east from Calaveras Point along Coyote Creek to the railroad bridge, along Alviso Slough to the town of Alviso (slightly more than 7 km), and along the 3.7 km of Guadalupe Slough closest to the bay (fig. 1).
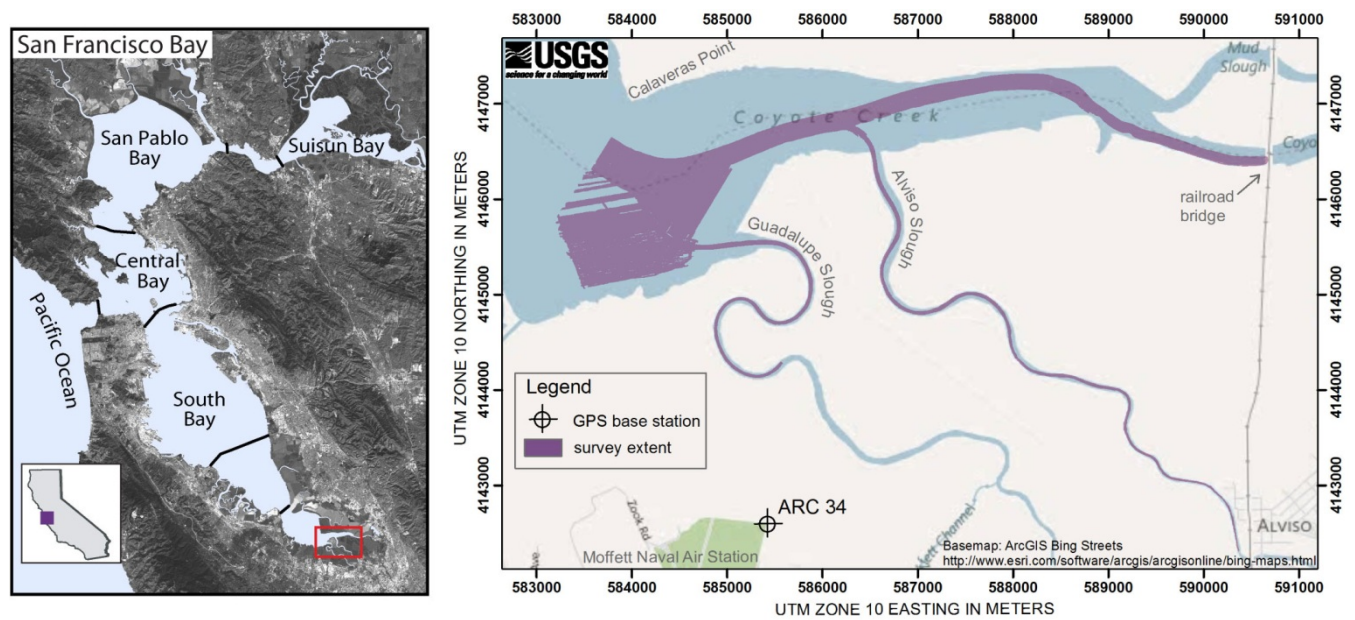
Figure 1.   Map of study area and location of GPS base station, south San Francisco Bay, California.

All of the surveys were done aboard the R/V *Parke Snavely* outfitted with a 234.5 kHz SEA (Systems Engineering & Assessment, Ltd.) SWATHplus-M phase-differencing sidescan sonar (figs. 2 and 3). Real-time kinematic (RTK) global positioning system (GPS) data were passed through a CodaOctopus F180 inertial measurement unit (IMU) to the sonar hardware and data collection software. Sonar heads, GPS antennae, and the IMU were surveyed in place to a common reference frame with a Geodimeter 640 Total Station. The R/V *Parke Snavely* was outfitted with three networked workstations and a navigation computer for use by the captain and survey crew for data collection and initial processing. See table 1 for the sonar system specifications.

Figure 2.   U.S. Geological Survey, Coastal and Marine Geology R/V *Parke Snavely*. Photo courtesy of Thomas E. Reiss.

sonar head

Figure 3.   Fore and aft views of the SWATHplus sonar pole mount on the U.S. Geological Survey Coastal and Marine Geology R/V *Parke Snavely*.

Table 1. SWATHplus-M Sonar Specifications (Systems Engineering and Assessment, Ltd., 2004).

Sonar frequency	234.5 kHz
Maximum water depth	120 m
Maximum swath width	300 m (typically 7 to 12 times water depth)
Resolution across track (best case)	5 cm
Transmit pulse length	34 to 500 ms
Ping repetition rate	
150 m swath width	10 pings per second
300 m swath width	5 pings per second
Vertical accuracy (range dependent)	
57 m	0.1 m
114 m	0.2 m
171 m	0.3 m

Geodetic Control

Geodetic control for the survey was established using a shore based GPS base station broadcasting RTK corrections to the survey vessel by UHF radio link. The base station was at Moffett Naval Air Station, on a pre-existing benchmark identified as ARC 34 (fig. 1; table 2). The National Geodetic Survey (NGS) lists this monument as PID DG6881 (see appendix A for NGS datasheet).

Table 2. Global positioning system base-station benchmark.

Reference frame	NAD83 (NSRS2007)
Latitude	N 37° 25' 34.57880"
Longitude	W 122° 02' 05.53373"
Orthometric height	1.28 m (NAVD88 height modernization project elevation)
Epoch date	2007.00

The R/V *Parke Snavely* was equipped with a CodaOctopus F180 attitude and positioning system for the duration of the survey. The F180 runs F190 firmware, and receives RTK positioning corrections directly. The RTK GPS data (2 cm error ellipse) are combined with the inertial motion measurements directly within the F190 hardware so that high-precision position and attitude corrections are fed in real time to the sonar acquisition equipment. The NAD83 (NSRS2007) Epoch 2007.00 3-dimensional reference frame was used for horizontal positioning, with elevations referenced to NAVD88. All data are projected in UTM coordinate space in meters, zone 10 north.

Sound Velocity Measurements

Sound velocity measurements were collected continuously with an Applied Micro Systems Micro SV (accurate to ± 0.03 m/s) deployed on the transducer frame for real-time sound velocity adjustments at the transducer/water interface. Additionally, sound velocity profile measurements of the water column were collected at the beginning and ending of each survey day. Sound-velocity profile

measurements were collected using an Applied Micro Systems SvPlus 3472 which provides time-of-flight sound-velocity measurements using invar rods with a sound-velocity accuracy of ± 0.06 m/s, pressure measured by a semiconductor bridge strain gauge to an accuracy to 0.15 percent (full scale), and temperature measured by thermistor to an accuracy of 0.05 degrees Celsius (Applied Microsystems, Ltd., 2005).

Processing Procedures

The general processing workflow for converting raw bathymetric soundings to a DEM is shown in figure 4. Critical aspects of the processing procedure are discussed in more detail below.
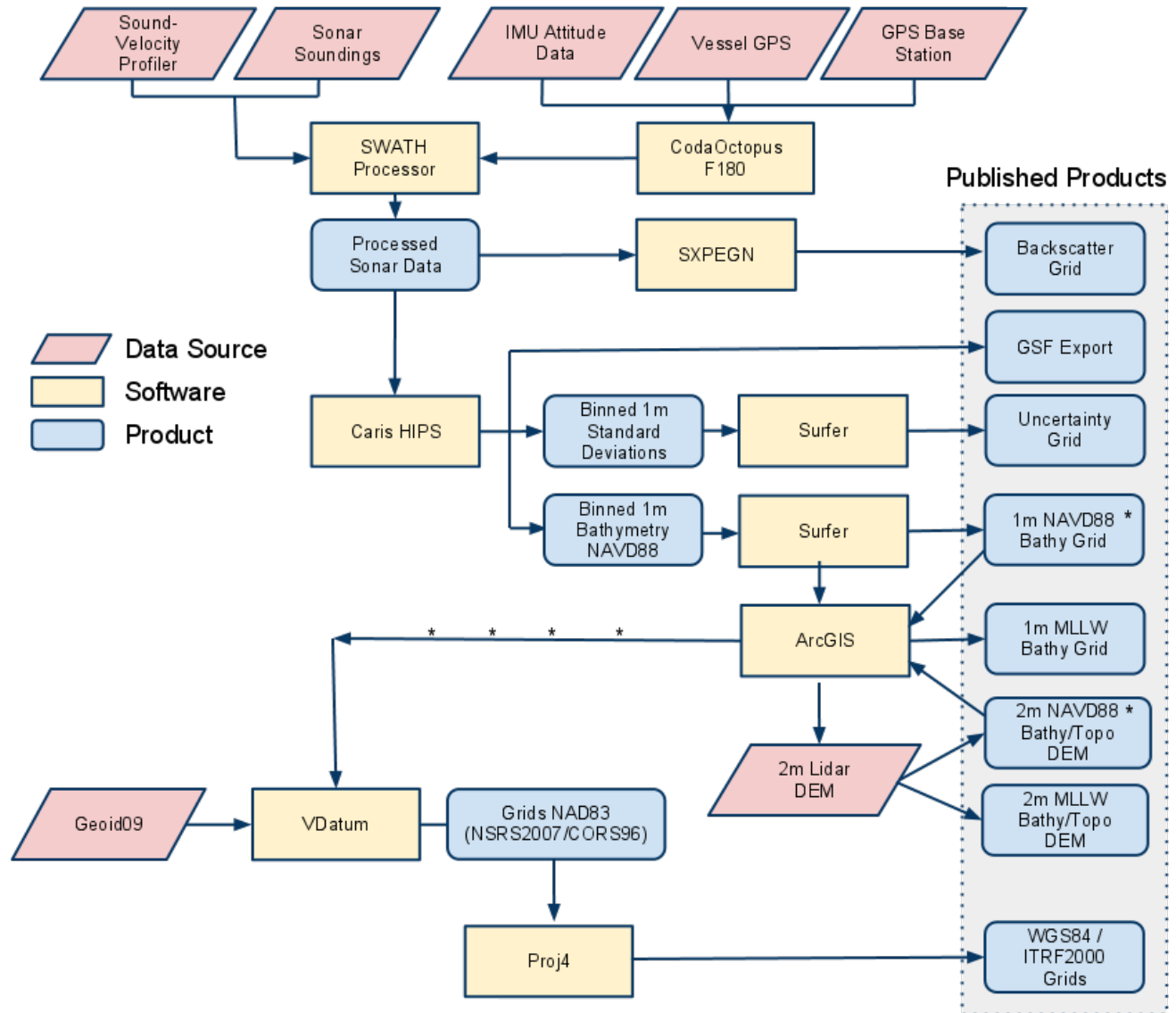
Figure 4.   Processing workflow diagram for converting soundings to a digital elevation model.

Real-Time Sonar Sounding Processing

GPS data and measurements of vessel motion are combined in the F180 hardware to produce a high-precision vessel attitude packet. This packet is transmitted to the Swath Processor acquisition software in real-time and combined with instantaneous sound velocity measurements at the transducer head before each ping. Up to 20 pings per second are transmitted with each ping consisting of 2,048 samples per side (port and starboard). The returned samples are projected to the seafloor using a ray-tracing algorithm working with the previously measured sound velocity profiles in SEA Swath Processor (version 3.05.18.04). A series of statistical filters are applied to the raw samples that isolate the seafloor returns from other uninteresting targets in the water column. Finally, the processed data are stored line-by-line in both raw (.sxr) and processed (.sxp) trackline files. For these surveys, processed files were filtered across-track with a mean filter at 0.2 m resolution.

Backscatter Image Production

The relative differences in bay-floor backscatter strength (that is, the amplitude of the acoustic signal that is reflected back to the sonar head) can be a valuable tool for identifying changes in texture or composition of bay floor sediments. The raw 16-bit backscatter that is recorded simultaneously with the bathymetry by the SWATHplus was georefrenced and gain-normalized by the program SXPEGN (build 151) by David Finlayson (USGS) to enhance the backscatter of the SWATHplus system. The program normalizes for time-varying signal loss and beam directivity differences. The resulting normalized amplitude values are rescaled to 16-bit and gridded in Surfer (v 10.3.705) as shown in figure 5.
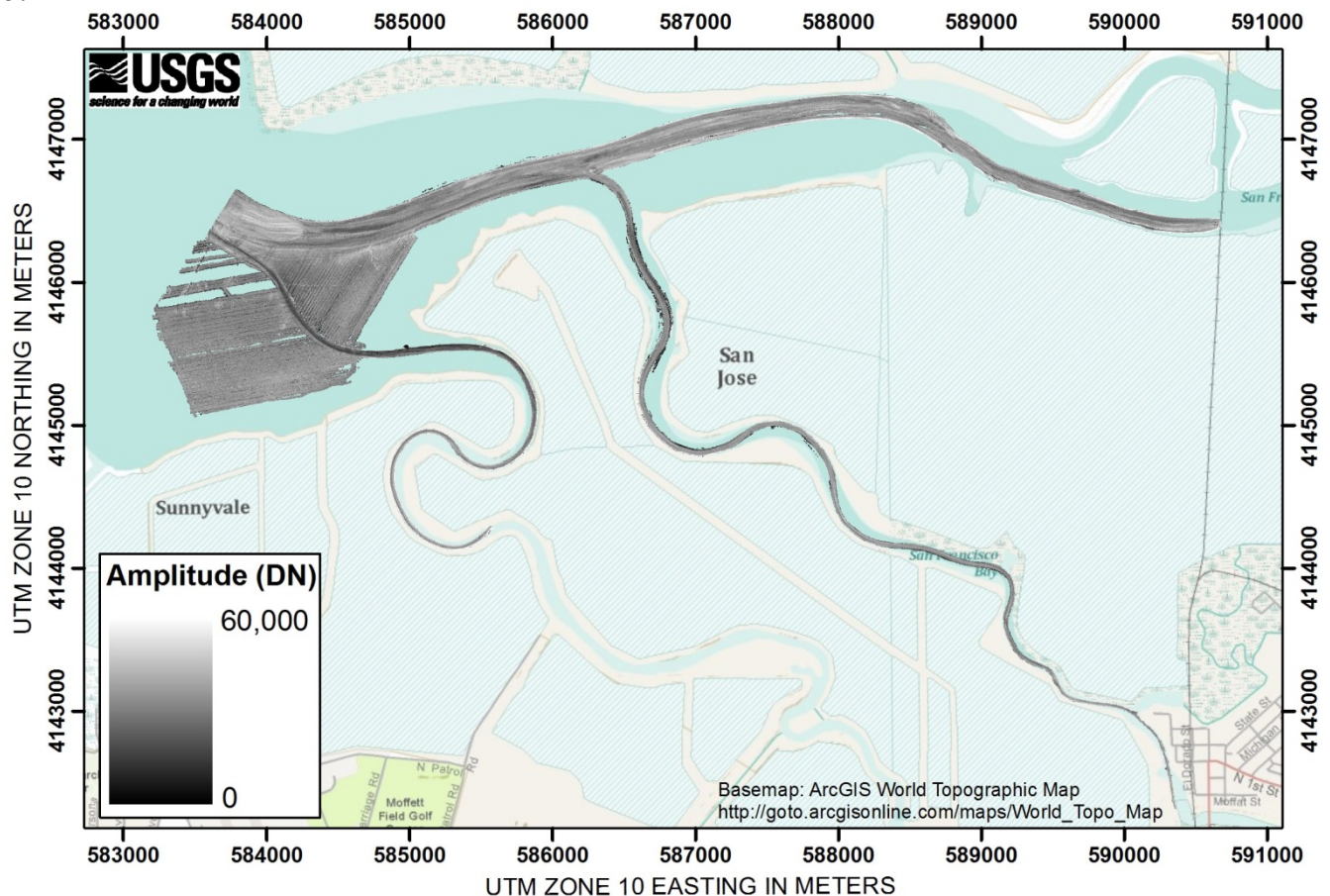

Figure 5.   Map of backscatter amplitude (raw 16-bit digital number, DN), south San Francisco Bay, California.

Swath Cleaning and Filtering

Prior to creating the bathymetry grids, the processed .sxp files were imported to CARIS HIPS and SIPS (version 7.1) for additional cleaning and filtering. Swath filters were applied to clean the data based upon characteristics such as depth, across track angle, and across track distance. A CARIS Swath Angle BASE (Bathymetric with Associated Statistical Error) surface was created at 1 m resolution and the subset editor was used to eliminate any remaining outliers or artifacts manually. The average depth within each 1 × 1 m cell was exported as an ASCII text file along with calculations of the binned (of all soundings within the 1 × 1 m cell spacing), standard deviation, and sounding density. These ASCII files were used for statistical analyses and imported into Surfer (version 10.3.705) for gridding.

Digital Elevation Model Production

Bathymetric Grids

The 1 m resolution ASCII data were imported to Surfer (version 10.3.705) for statistical analysis and DEM generation. The binned ASCII data were interpolated in Surfer using a linear kriging algorithm with a 1-sigma nugget of 0.05 m (the mean standard deviation of all 1 × 1 m cells in the dataset) and a 2 × 2 m search radius. This process filled small gaps in the surface and provided some minor smoothing through the statistical noise inherent to interferometric bathymetry. The 1 m resolution bathymetry grid was exported to ESRI ArcMap software for display purposes (fig. 6) and converted from NAVD88 to the tidal datum of mean lower low water (MLLW) using the conversions generated by NOAA and provided in Foxgrover and others (2007).
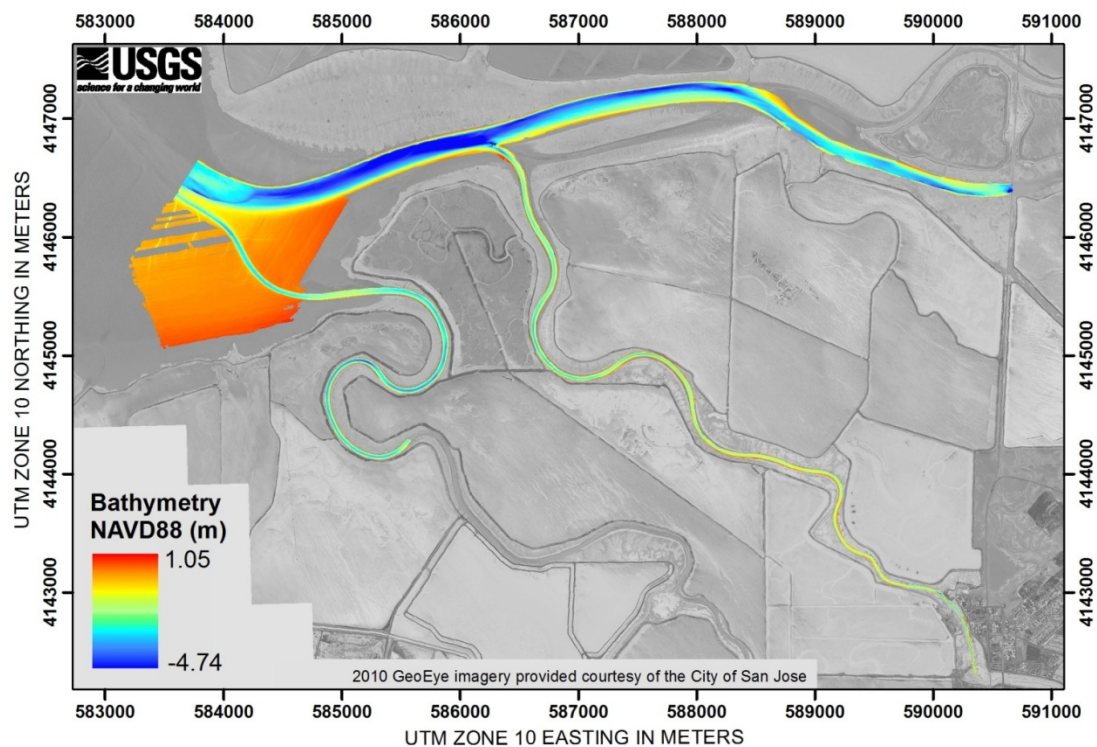

Figure 6.　1 m resolution bathymetry grid generated by merging surveys S-2-10-SF, S-18-10-SF and S-24-10-SF. Elevation in meters relative to NAVD88.

Lidar Data

In 2010 the USGS, with funding provided by the American Recovery and Reinvestment Act (ARRA), contracted the acquisition of aerial topographic lidar in the San Francisco Estuary that included our study area. Data for the USGS San Francisco Coastal Lidar project were collected by Terrapoint USA, and Dewberry served as the prime contractor for the project and was responsible for all final data post-processing and classification necessary to develop project deliverables. The USGS aerial lidar was collected between June 11and November 7, 2010, using a Piper Navajo twin engine aircraft equipped with a 100 kHz Optech ALTM 3100EA lidar system. Acquisition was designed to support a nominal point spacing of 1 m and was collected at low tide to optimize coverage of the intertidal flats. Lidar data was processed by Dewberry to achieve a bare earth ground surface and provided as 2 m resolution hydro-flattened DEMs. When Dewberry compared the lidar to survey-grade GPS points in generally flat, nonvegetated areas, the vertical accuracy of 95 percent of the positions had errors less than or equal to 18 cm (equivalent to a 9 cm RMSE if evenly distributed). The lidar is projected in UTM coordinate space, zone 10 north. The vertical datum is NAVD88 and the horizontal datum NAD83(NSRS2007). Within our study area NAD83(NSRS2007) closely approximates the horizontal datum of the bathymetric data, NAD83(CORS96), and is within the accuracy of the data. For our purposes, the two versions of NAD83 are considered equivalent. For additional information on USGS's ARRA San Francisco Coastal Lidar project or to download the data directly, visit *http://lidar.cr.usgs.gov/.*

Bathymetric / Topographic DEM

Prior to merging the bathymetry data with the topographic lidar data, a comparison was made between elevations of the two independent datasets where they overlap in the intertidal flats. There is approximately 1.5 km^2 of overlap between lidar and bathymetry data within the study area (fig. 7). For all areas of overlap, the lidar is a maximum of 3.3 m higher than or 1.2 m lower than the bathymetry in the region of overlap. The average difference is 0.05 m (SD=0.30). Upon close examination, it became apparent that large differences between the two surfaces (greater than 1 m) occurred along very narrow strips of channel margins or at two specific sites: (1) along Coyote Creek (fig. 7B), and (2) along Alviso Slough south of UTM northing 4144000 (fig. 7C). At these two locations the lidar elevations are more than 1 m higher than the bathymetry elevations and are an artifact of the lidar reflecting off the water surface, not the bay floor. These areas were removed from the lidar DEM and excluded from further analyses. When the difference analyses were restricted to the intertidal flat areas adjacent to the confluence of Guadalupe Slough and Coyote Creek (fig. 7A) the statistics greatly improved. In the intertidal flats the lidar is a maximum of 1.2 m higher than or 0.8 m lower than the bathymetry. The mean offset on the tidal flats is 0 m (SD=0.07), which suggests that there is not a consistent offset or bias between the two and serves as an independent check on the quality of the two datasets.
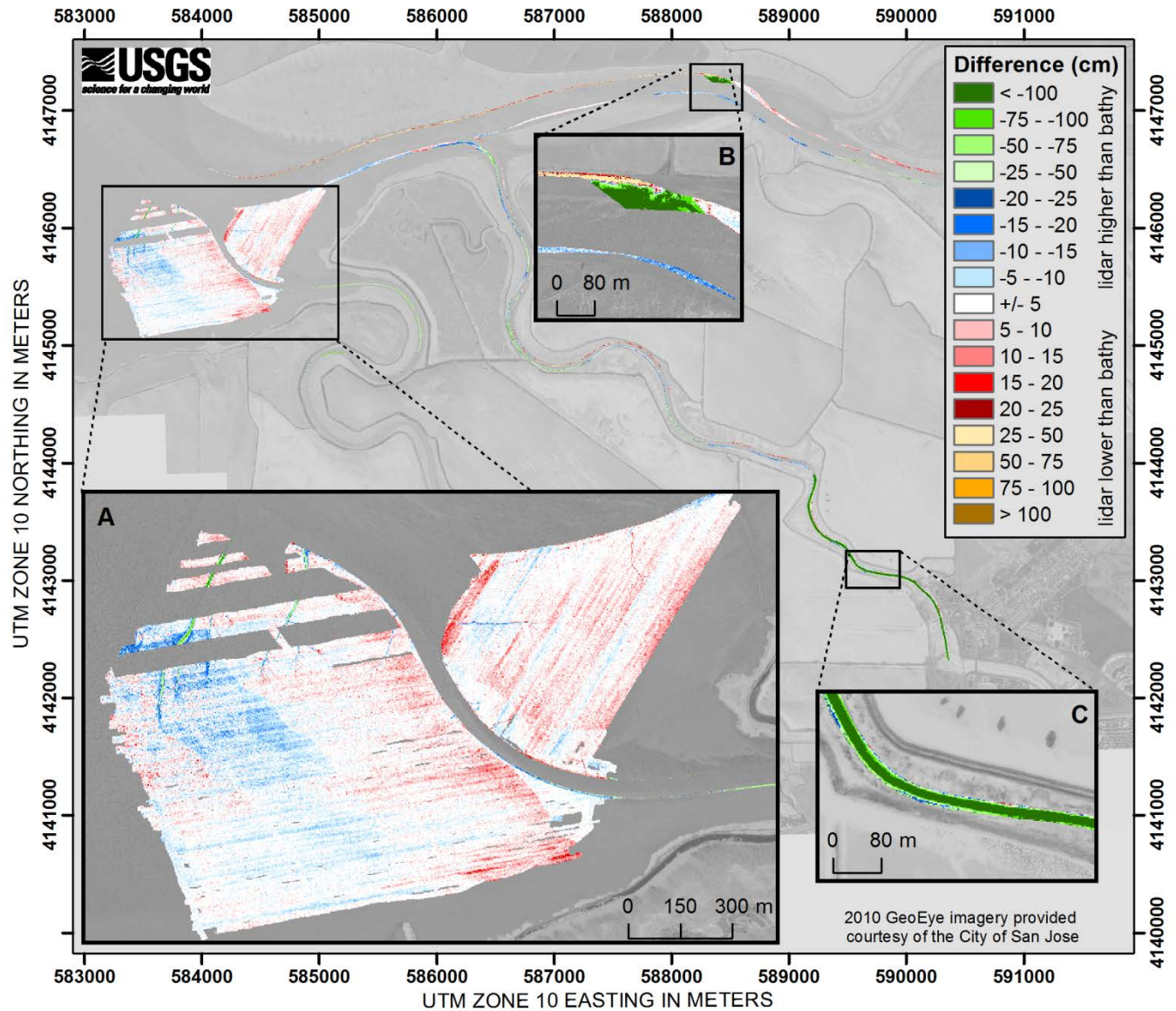
Figure 7.   Difference between tidal flat elevations calculated from aerial lidar data versus bathymetry data, south San Francisco Bay, California.

Prior to merging the surfaces, the bathymetry was resampled to 2 m resolution to match the lidar DEM by using a bilinear interpolation. The bathymetry was then merged with the topographic lidar by using the blend algorithm in the "Mosaic to New Raster" tool in Arc Toolbox. The resultant DEM is provided at 2 m resolution with elevations relative to NAVD88 (fig. 8). To provide intertidal elevations relative to the tidal datum of MLLW, the DEM was clipped to the approximate extent of the shoreline (modified from the San Francisco Estuary Institute EcoAtlas modern baylands shoreline, 1998) and converted to MLLW by using the NAVD88 to MLLW conversions calculated by NOAA and provided by Foxgrover and others (2007; fig. 9).

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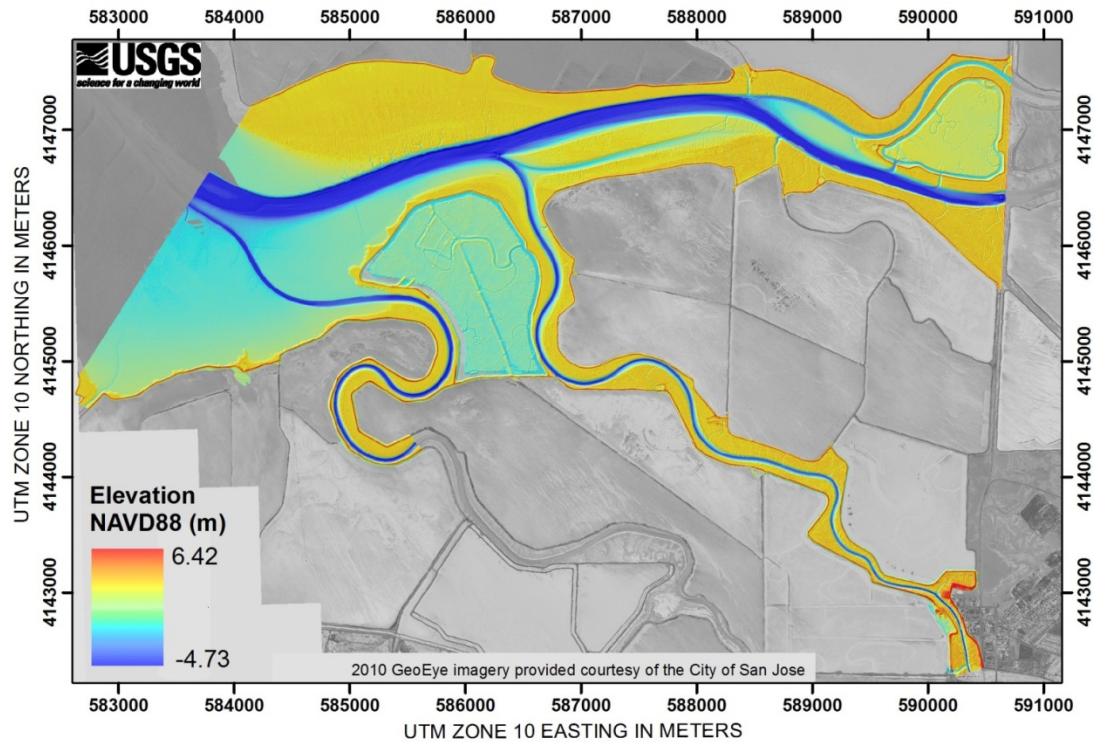
Figure 8. Seamless bathymetric/topographic DEM of the region surrounding Coyote Creek and Alviso Slough, south San Francisco Bay, California. Elevations relative to NAVD88.

Figure 9. Seamless bathymetric/topographic DEM of Coyote Creek and Alviso Slough clipped to the approximate extent of the shoreline, south San Francisco Bay, California. Elevations relative to MLLW.

Horizontal and Vertical Datum Conversions

To meet the varying needs of the end users of these data products the surfaces are provided relative to orthometric heights NAD83(CORS96)/NAVD88, the ellipsoid WGS84(G1150), and relative to the tidal datum of MLLW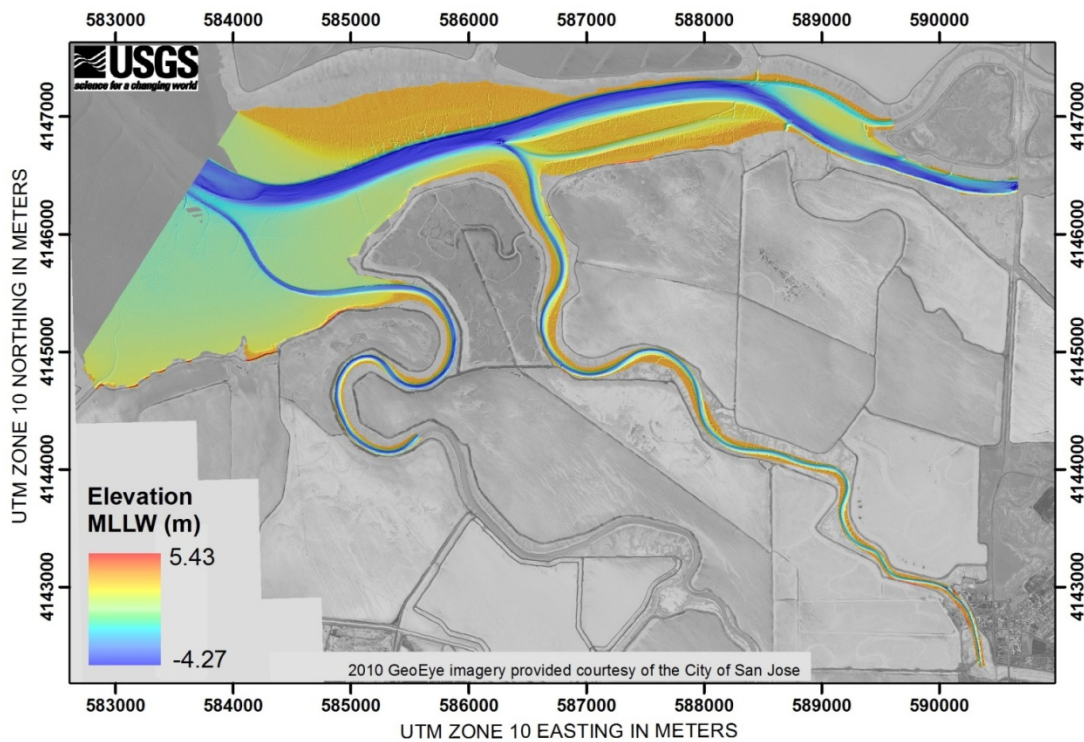. V-Datum (version 2.3.3) does a poor job of converting between geodetic and tidal datums in far south San Francisco Bay. Some investigations have revealed that benchmark information for the Dumbarton Bridge Station (station 9414509) was not used in development of the VDatum model. Due to the lack of model constraint in this region, VDatum consistently underestimates the offset between NAVD88 and MLLW for regions south of the Dumbarton Bridge. A comparison of conversions from NAVD88 to MLLW generated by VDatum to those provided by the CO-OPS division of NOAA for a 2005 bathymetric survey of south San Francisco Bay (Foxgrover and others, 2007) reveals a difference between the two of approximately 17 cm near Dumbarton Bridge, approximately 20 cm where Guadalupe Slough meets Coyote Creek, and greater than 30 cm near the island ponds. The conversion to MLLW used for this report is based upon the CO-OPS data provided by Foxgrover and others (2007), and we caution that using VDatum for converting between geodetic and tidal datums south of Dumbarton Bridge could introduce errors on the order of tens of centimeters.

To convert the data from orthometric heights NAD83(CORS96)/NAVD88 to ellipsoid heights on ITRF2000 (also known as WGS84 G1150), the Surfer grids were exported as ASCII tables. NOAA's VDatum Version 2.3.0 (*http://vdatum.noaa.gov*) was used to apply Geoid09 (National Geodetic Survey, 2009) and convert the orthometric height data into ellipsoid heights on the NAD83 (CORS96) ellipsoid. The data were next transformed from the NAD83(CORS96) ellipsoid to the ITRF2000 ellipsoid by using a 14-point Helmert transformation described by Soler and Snay (2004) using the command line tool CS2CS in the Proj4 library (*http://trac.osgeo.org/proj/*). The parameters were calculated for an Epoch date of 2007.0000 as shown in table 3. The conversion from NAD83 (CORS96) to ITRF2000 shifts the Easting coordinates of the survey by approximately -1.3 m, the Northing coordinate by approximately +0.40, and the z coordinate by about -0.54 m.

Table 3. Parameters adopted for transformation between NAD83(CORS96) and ITRF2000

Parameter	Definition	Units	Value at t_0 = 1997.0	Value at t_F = 2007.0
T_x	x-shift	meters	0.9956	1.0026
T_y	y-shift	meters	-1.9013	-1.9083
T_z	z-shift	meters	-0.5215	-0.5165
ω_x	x-rotation[1]	arc seconds	-0.025915	-0.026585
ω_y	y-rotation[1]	arc seconds	-0.009426	-0.001856
ω_z	z-rotation[1]	arc seconds	-0.011599	-0.011089
s	scale	parts-per-million	-0.00062	-0.00118

[1]Note that the Proj4 program cs2cs reverses the sign of the rotation parameters from the Soler and Snay (2004) algorithm. Because the transformation here is from NAD83 to ITRF2000, the program is run in reverse-mode (-I).

Estimates of Bathymetric Uncertainty

There are multiple techniques for assessing the uncertainty of bathymetric surveys. For relatively flat portions of the seafloor, the standard deviation of sounding elevations within a small area is a good measure of the precision of the sonar instrumentation; this is not true in areas where the

seafloor is naturally variable or steep. In these areas, the standard deviation reflects the combination of natural variation of the surface in addition to sonar measurement uncertainty.

A plan-view map of spatial variability in standard deviations throughout the study area is shown in figure 10. The overall spatial pattern of standard deviation reveals low standard deviation in the low-relief intertidal flats and increases with increasing depth and slope (that is, in and along channel banks). The mean standard deviation of the soundings within each 1×1 m cell (containing 19 soundings on average) for the entire study area is 0.05 m, and 97 percent of the cells have a standard deviation less than 0.15 m (fig. 11). However, since a large portion of our study area is comprised of channels, the overall mean standard deviation alone does not provide an adequate approximation of survey precision.
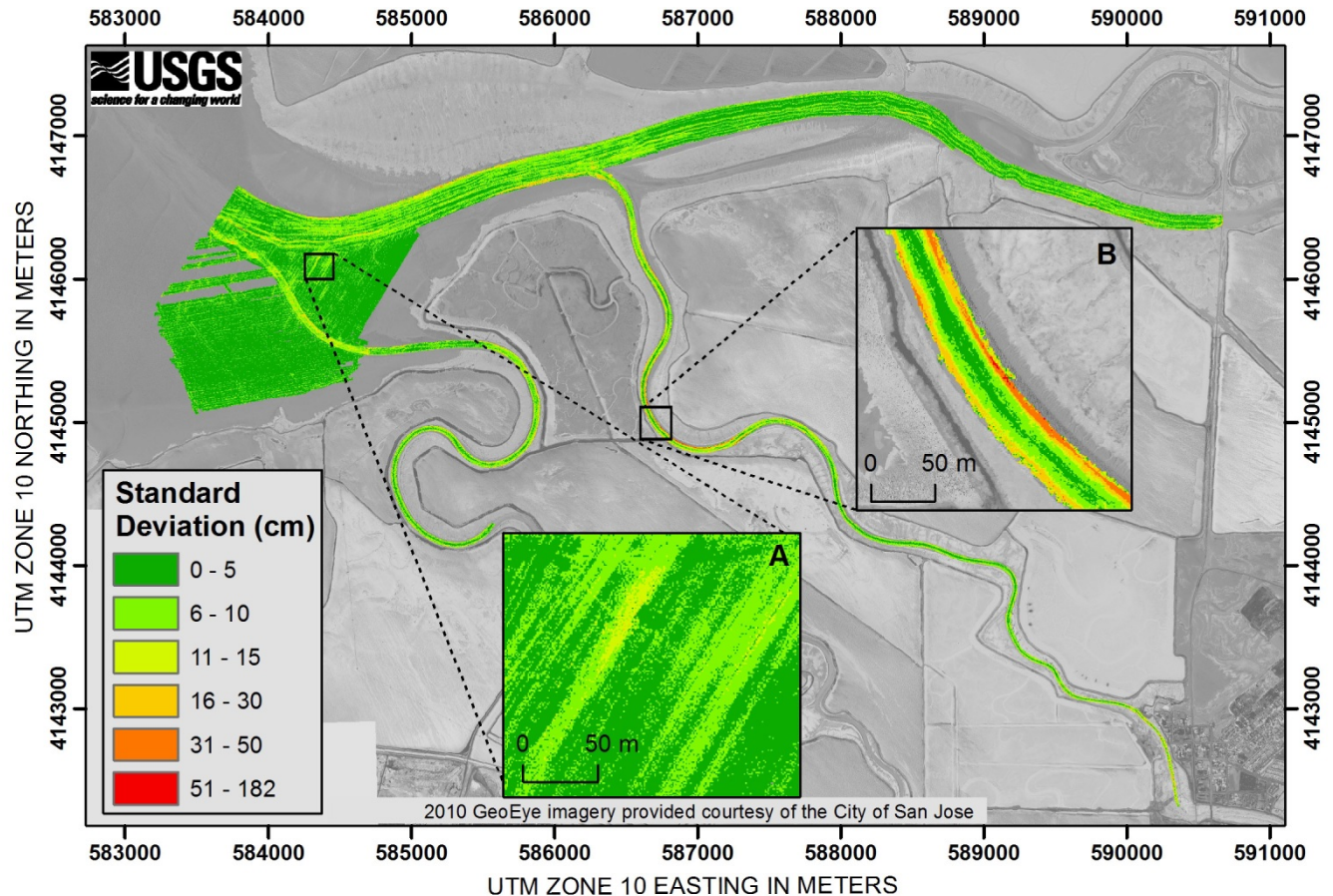

Figure 10. Plan-view map of bathymetric soundings standard deviation within each 1×1 m cell, south San Francisco Bay, California.
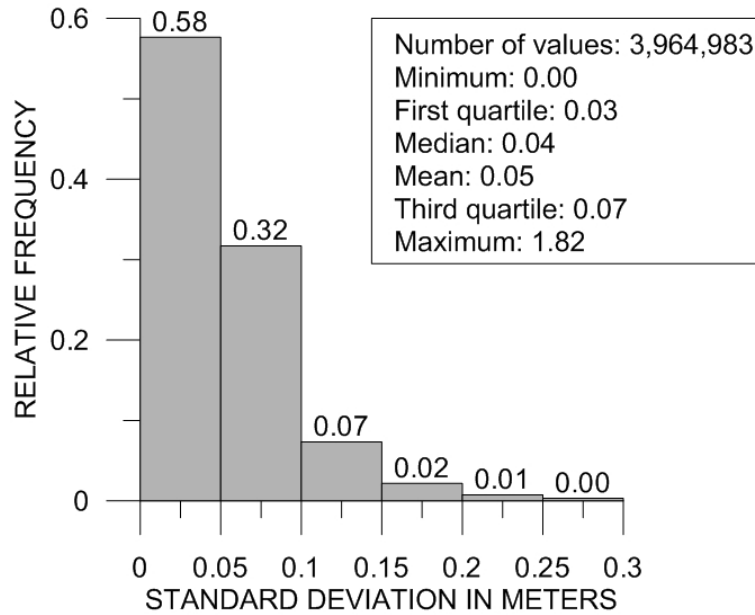
Figure 11. Histogram of sounding elevation standard deviations within each 1 × 1 m cell.

A second technique for assessing the precision of bathymetric data is to compare the elevation at a given location as calculated from independent tracklines that intersect. For this analysis two survey tracklines were collected during cruise S-18-10-SF that bisect the intertidal flats just west of the where Guadalupe Slough meets Coyote Creek. These intersecting tracklines (also known as tie lines) are oriented approximately northwest/southeast and nearly perpendicular to the primary trackline orientation for this region, resulting in approximately 100 intersections. For the purposes of error assessment, the tie lines were aggressively trimmed in CARIS to retain only the soundings greater than 1 m and less than 2 m from nadir (the soundings across each swath with the highest precision). The surface generated from these tie lines was differenced from the bathymetric surface generated from the northeast/southwest oriented primary survey tracklines to see how the two compared. The mean difference between the two surfaces was 1 cm and the standard deviation 3 cm, which suggests a vertical uncertainty of approximately ± 5 cm in the intertidal flats.

Comparison with IHO Standards

An additional method for assessing the quality of a bathymetric survey is to compare it to standards established by the International Hydrographic Organization (IHO) which defines several survey orders based on a combination of coverage, depth, and accuracy (International Hydrographic Organization, 2008). The IHO defines maximum allowable total vertical uncertainty (TVU) by using a depth-dependent formula with two additional variables as defined below (from IHO Standards for Hydrographic Surveys 5th Edition):

$$\pm\sqrt{a^2 + (b \times d)^2} \tag{1}$$

where a represents the portion of the uncertainty that does not vary with depth, b is a coefficient which represents that portion of the uncertainty that varies with depth, and d equals depth.

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IHO standards require a 95 confidence level defined as 1.96 × standard deviation in sounding uncertainty. IHO survey orders use the values found in table 4 as minimums for their survey orders (note that descriptions are generalized and Order 1 and 1a are combined because they have the same values for minimum TVU). If we assume that the elevation uncertainty in bathymetric soundings is normally distributed, we can estimate the TVU in an elevation cell at the 95 percent level using:

$$TVU_{(x,y)} = 1.96 \times \sigma_{(x,y)} \tag{2}$$

where $\sigma_{(x,y)}$ is the standard deviation of all soundings in a cell located at coordinate (x, y). By comparing the calculated values from equation 2 against the standardized TVU thresholds represented by equation 1, we have an objective measure of the quality of the bathymetric surface.

Table 4.   Minimum IHO survey order requirements.

Survey order	Special	Combined 1 and 1a	2
Description	Areas where under-keel clearance is critical	Areas shallower than 100 meters	Areas generally deeper than 100 meters
Maximum allowable TVU 95 percent confidence level	a=0.25 m b=0.0075	a=0.5 m b=0.013	a=1.0 m b=0.023

Figure 12 shows a plot of the calculated TVU values (equation 2) for a representative subset of our bathymetric survey as a function of water depth. For reference, lines indicating the IHO thresholds for Special Order, First Order, and Second Order surveys derived from equation 1 are also displayed. Approximately 99 percent of the data satisfies the IHO standard for First Order surveys, the same standard that NOAA's National Ocean Service follows, which serves as a testament to the quality of the surveys as a whole.
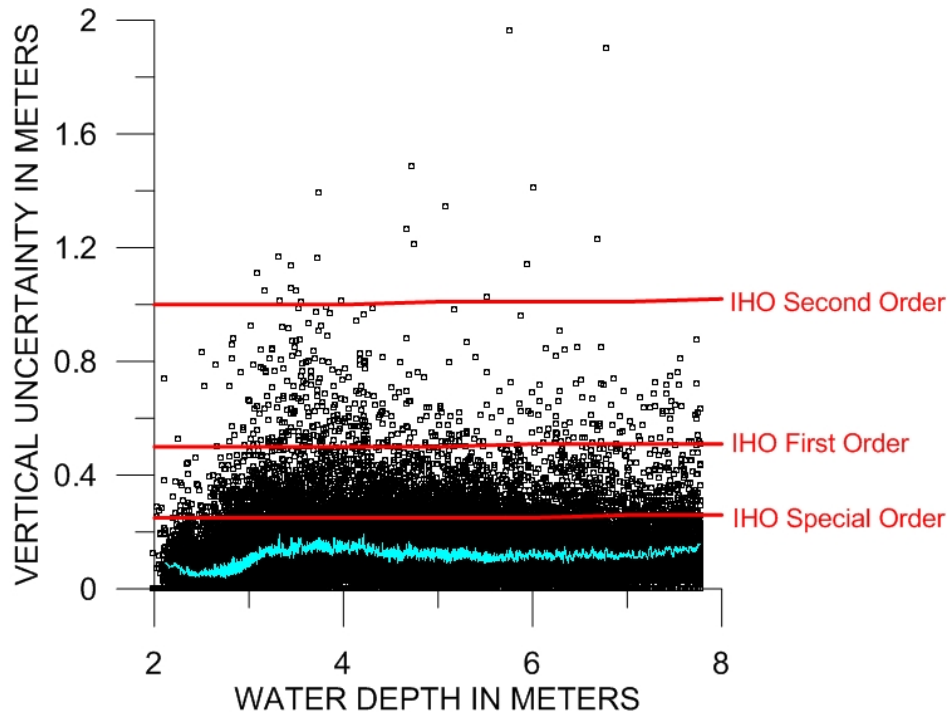
Figure 12.   Uncertainty in sounding elevation compared to International Hydrographic Organization standards as a function of water depth (approximated to mean high water). For improved clarity, only 1 percent of the data set (randomly selected) is shown out of nearly 4 million cells in the digital elevation model. The maximum vertical uncertainty allowed for each IHO Survey order is plotted as red lines along with the running average vertical uncertainty of the data set in cyan.

Data Tables

Bathymetry

Bathymetry data are provided as elevation in meters relative to both the ellipsoid WGS84(G1150) and as orthometric heights NAD83(CORS96)/NAVD88, as well as relative to the tidal datum of MLLW (table 5). All data are projected in UTM, zone 10 north, and all values (eastings, northings, and elevation) are in meters. Each zip file contains the data formatted as both ASCII X, Y, Z text files (*.xyz) and ESRI ASCII GRID files (*.asc; see appendix A), as well as FGDC compliant metadata in both text and .xml format.

Table 5.   Bathymetric data files provided.

File name	Horizontal resolution, in meters	Reference frame	Vertical datum
Alviso_bathy_1m_NAVD88.zip	1	NAD83(CORS96)	NAVD88
Alviso_bathy_1m_WGS84.zip	1	WGS84(G1150)	WGS84(G1150)
Alviso_bathy_1m_MLLW.zip	1	NAD83(CORS96)	MLLW

Bathymetric / Topographic DEM

Seamless bathymetric/topographic DEMs generated from merging the bathymetry (above) with aerial lidar are provided as elevations in meters relative to both the ellipsoid WGS84(G1150) and as orthometric heights NAD83(CORS96)/NAVD88 (table 6). The merged DEM was clipped to extent of the shoreline and converted from the geodetic vertical datum of NAVD88 to the tidal datum of MLLW based upon the conversions calculated by NOAA and provided in Foxgrover and others (2007). All data are projected in UTM, zone 10 north and all values (eastings, northings, and elevation) are in meters. Each zip file contains the data formatted as both ASCII X, Y, Z text files (*.xyz) and ESRI ASCII GRID files (*.asc; see Appendix A) as well as FGDC compliant metadata in both text and .xml format.

Table 6.   Bathymetric/topographic DEM files provided.

File name	Horizontal resolution, in meters	Reference frame	Vertical datum
Alviso_DEM_2m_NAVD88.zip	2	NAD83(CORS96)	NAVD88
Alviso_DEM_2m_WGS84.zip	2	WGS84(G1150)	WGS84(G1150)
Alviso_DEM_bay_2m_NAVD88.zip	2	NAD83(CORS96)	NAVD88
Alviso_DEM_bay_2m_WGS84.zip	2	WGS84(G1150)	WGS84(G1150)
Alviso_DEM_bay_2m_MLLW.zip	2	NAD83(CORS96)	MLLW

A Note on Coordinate Systems and Datums

WGS84 and NAD83 have been revised several times resulting in coordinate shifts of up to several meters in X, Y, and Z. The revision is indicated by the designator following the name (G1150 following WGS84, for example). Software that does not distinguish between the different versions of these datums likely does not support 3D datums properly. Users should pay particular attention to the accompanying metadata files to ensure that the data are properly georeferenced. In particular, note that most current GIS software (including ArcGIS 10) cannot properly transform high-resolution elevation data from one 3D datum to another (such as WGS84 G1150 to NAD83 CORS96) without introducing errors on the order of 1-2 m in X, Y, and Z. For this reason, data are provided in both WGS84(G1150), which is equivalent to ITRF2000, and NAD83(CORS96), which is equivalent to NSRS2007.

Acknowledgments

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Appendix A

National Geodetic Survey Datasheet for Monument ARC 34 (PID DG6881) Used as geodetic control for the Alviso Survey

```
DATABASE = ,PROGRAM = datasheet, VERSION = 7.85


1 National Geodetic Survey, Retrieval Date = JUNE 8, 2010
DG6881 ***********************************************************************
DG6881 HT_MOD - This is a Height Modernization Survey Station.
DG6881 DESIGNATION - ARC 34
DG6881 PID - DG6881
DG6881 STATE/COUNTY- CA/SANTA CLARA
DG6881 USGS QUAD - MOUNTAIN VIEW (1997)
DG6881
DG6881 *CURRENT SURVEY CONTROL
DG6881 _____
DG6881* NAD 83(2007)- 37 25 34.57880(N) 122 02 05.53373(W) ADJUSTED
DG6881* NAVD 88 - 1.28 (meters) 4.2 (feet) GPS OBS
DG6881 _____
DG6881 EPOCH DATE - 2007.00
DG6881 X - -2,690,026.780 (meters) COMP
DG6881 Y - -4,299,118.359 (meters) COMP
DG6881 Z - 3,855,050.006 (meters) COMP
DG6881 LAPLACE CORR- 0.35 (seconds) DEFLEC09
DG6881 ELLIP HEIGHT- -31.308 (meters) (02/10/07) ADJUSTED
DG6881 GEOID HEIGHT- -32.62 (meters) GEOID09
DG6881
DG6881 ------- Accuracy Estimates (at 95 percent Confidence Level in cm) --------
DG6881 Type PID Designation North East Ellip
DG6881 ----------------------------------------------------------------
DG6881 NETWORK DG6881 ARC 34 0.39 0.35 1.02
DG6881 ----------------------------------------------------------------
DG6881
DG6881.The horizontal coordinates were established by GPS observations
DG6881.and adjusted by the National Geodetic Survey in February 2007.
DG6881
DG6881.The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).
DG6881.See National Readjustment for more information.
DG6881.The horizontal coordinates are valid at the epoch date displayed above.
DG6881.The epoch date for horizontal control is a decimal equivalence
DG6881.of Year/Month/Day.
DG6881
DG6881.The orthometric height was determined by GPS observations and a
DG6881.high-resolution geoid model using precise GPS observation and
DG6881.processing techniques.
DG6881
DG6881.The X, Y, and Z were computed from the position and the ellipsoidal ht.
DG6881
DG6881.The Laplace correction was computed from DEFLEC09 derived deflections.
DG6881
DG6881.The ellipsoidal height was determined by GPS observations
DG6881.and is referenced to NAD 83.
DG6881
DG6881.The geoid height was determined by GEOID09.
DG6881
DG6881; North East Units Scale Factor Converg.
```

```
DG6881;SPC CA 3   -   603,912.284  1,864,158.605 MT  0.99994515  -0 56 22.9
DG6881;SPC CA 3   - 1,981,335.55   6,115,993.69 sFT  0.99994515  -0 56 22.9
DG6881;UTM 10     - 4,142,598.916    585,392.741 MT  0.99968982  +0 35 11.7
DG6881
DG6881! - Elev Factor x Scale Factor = Combined Factor
DG6881!SPC CA 3   - 1.00000491 x 0.99994515 = 0.99995006
DG6881!UTM 10     - 1.00000491 x 0.99968982 = 0.99969473
DG6881
DG6881 SUPERSEDED SURVEY CONTROL
DG6881
DG6881 NAD 83(1998)- 37 25 34.57542(N) 122 02 05.53012(W) AD(2002.75) B
DG6881 ELLIP H (08/23/04) -31.247 (m) GP( ) 4 1
DG6881
DG6881.Superseded values are not recommended for survey control.
DG6881.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
DG6881.See file dsdata.txt to determine how the superseded data were derived.
DG6881
DG6881_U.S. NATIONAL GRID SPATIAL ADDRESS: 10SEG8539242598(NAD 83)
DG6881_MARKER: DD = SURVEY DISK
DG6881_SETTING: 7 = SET IN TOP OF CONCRETE MONUMENT
DG6881_STAMPING: ARC 34
DG6881_STABILITY: C = MAY HOLD, BUT OF TYPE COMMONLY SUBJECT TO
DG6881+STABILITY: SURFACE MOTION
DG6881_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
DG6881+SATELLITE: SATELLITE OBSERVATIONS - September , 2002
DG6881
DG6881 HISTORY    - Date    Condition    Report By
DG6881 HISTORY    - UNK     MONUMENTED   NASA
DG6881 HISTORY    - 200209  GOOD         JOHFRA
DG6881
DG6881 STATION DESCRIPTION
DG6881
DG6881'DESCRIBED BY JOHNSON-FRANK 2002 (RAF)
DG6881'THE STATION IS ON MOFFETT AIRFIELD, NEAR MOUNTAIN VIEW. FROM THE
DG6881'INTERSECTION OF HWY 101 AND ELLIS ST (SE OF HWY 85), EXIT NORTH TO
DG6881'THE ENTRANCE TO MOFFETT FIELD. AFTER GOING THROUGH THE GUARDPOST,
DG6881'CONTINUE AHEAD TO SIGNAL LIGHT. TURN RIGHT ON PERIMETER RD
DG6881'(LOCALLY-CALLED) AND DRIVE 0.7 MI PARALLELING HWY 101 UNTIL THE SHARP
DG6881'BEND TO THE LEFT. FOLLOW THE ROAD AND DRIVE 1.3 MI TO A SIDE ROAD
DG6881'RIGHT AND A GOLF COURSE. TURN RIGHT AND DRIVE 0.2 MI TO AN
DG6881'INTERSECTION, THEN LEFT FOR 0.5 MI TO THE STATION ON THE RIGHT JUST
DG6881'BEFORE THE ROAD MAKES A NINETY-DEGREE TURN TO THE LEFT AT THE VERY
DG6881'NORTHEAST CORNER OF THE MOFFETT FIELD FACILITY. THE MARK IS ABOUT 23
DG6881'M (75 FT) SOUTH OF A CHAIN LINK GATE.
DG6881'
DG6881'MARK IS AN 8.2 CM (3.25 IN) NATIONAL AERONAUTICS AND SPACE
DG6881'ADMINISTRATION DISK STAMPED 'ARC 34' WITH A PUNCH NEXT TO THE '34'.
DG6881'THE DISK IS SET IN AN IRREGULAR CONCRETE MASS FLUSH WITH THE SOIL,
DG6881'6.7 M (22 FT) EAST OF THE CENTER OF THE PAVED PERIMETER ROAD, 22.8 M
DG6881'(75 FT) SOUTH OF A CHAIN LINK FENCE GATE AT THE END OF THE ROAD, 4.3
DG6881'M (14 FT) SOUTH OF THE CONCRETE BASE FOR A SMALL SQUARE WHITE TANK.
DG6881'
DG6881'THIS STATION WAS OBSERVED AS PART OF THE SOUTH SAN FRANCISCO BAY
DG6881'HEIGHT MODERNIZATION PROJECT.

*** retrieval complete.
Elapsed Time = 00:00:00
```

Appendix B

Description of the ESRI ASCII Grid raster format:

To import ASCII Grids into common GIS packages:
ArcGIS: Use ArcTools's Import ASCII to GRID function
ArcView: Use the import ASCII Grid function (May need Spatial Analyst)
GRASS: Use the 'r.in.arc' function.

The ASCII file consists of header information containing a set of keywords, followed by cell values in row-major order. The file format is:

<NCOLS xxx>
<NROWS xxx>
<XLLCENTER xxx | XLLCORNER xxx>
<YLLCENTER xxx | YLLCORNER xxx>
<CELLSIZE xxx>
{NODATA_VALUE xxx}
row 1
row 2
.
.
.
row n

where xxx is a number, and the keyword nodata_value is optional and defaults to -9999. Row 1 of the data is at the top of the grid, row 2 is just under row 1 and so on. The nodata_value is the value in the ASCII file to be assigned to those cells whose true value is unknown. In the grid they will be assigned the keyword NODATA. Cell values are be delimited by spaces. No carriage returns are necessary at the end of each row in the grid (although they are included in this case). The number of columns in the header is used to determine when a new row begins. The number of cell values is equal to the number of rows times the number of columns.