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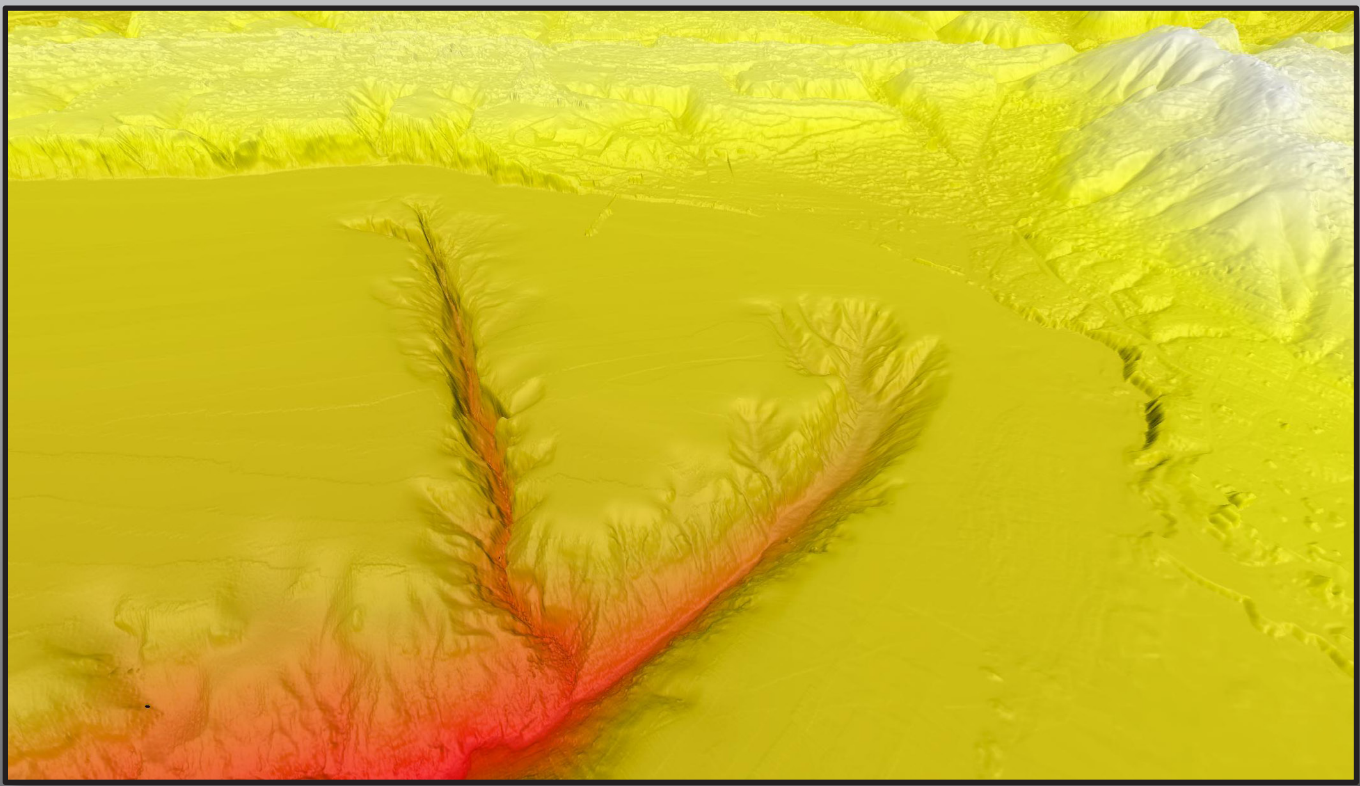
A Seamless, High-Resolution, Coastal Digital Elevation Model (DEM) for Southern California



Data Series 487

U.S. Department of the Interior
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COVER
Oblique 3-D image of La Jolla Submarine Canyon and the La Jolla coastline in central San Diego County, California.

A Seamless, High-Resolution, Coastal Digital Elevation Model (DEM) for Southern California

By Patrick L. Barnard and Daniel Hoover

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A Seamless, High-Resolution, Coastal Digital Elevation Model (DEM) for Southern California

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Introduction

A seamless, 3-meter digital elevation model (DEM) was constructed for the entire Southern California coastal zone, extending 473 km from Point Conception to the Mexican border. The goal was to integrate the most recent, high-resolution datasets available (for example, Light Detection and Ranging (Lidar) topography, multibeam and single beam sonar bathymetry, and Interferometric Synthetic Aperture Radar (IfSAR) topography) into a continuous surface from at least the 20-m isobath to the 20-m elevation contour.

This dataset was produced to provide critical boundary conditions (bathymetry and topography) for a modeling effort designed to predict the impacts of severe winter storms on the Southern California coast (Barnard and others, 2009). The hazards model, run in real-time or with prescribed scenarios, incorporates atmospheric information (wind and pressure fields) with a suite of state-of-the-art physical process models (tide, surge, and wave) to enable detailed prediction of water levels, run-up, wave heights, and currents. Research-grade predictions of coastal flooding, inundation, erosion, and cliff failure are also included. The DEM was constructed to define the general shape of nearshore, beach and cliff surfaces as accurately as possible, with less emphasis on the detailed variations in elevation inland of the coast and on bathymetry inside harbors. As a result this DEM should not be used for navigation purposes.

DEM Construction Methods

Forty-five individual DEMs were constructed (fig. 1; table 1) using more than 40 bathymetric and topographic data sets. The data sets used are detailed in a downloadable spreadsheet at the

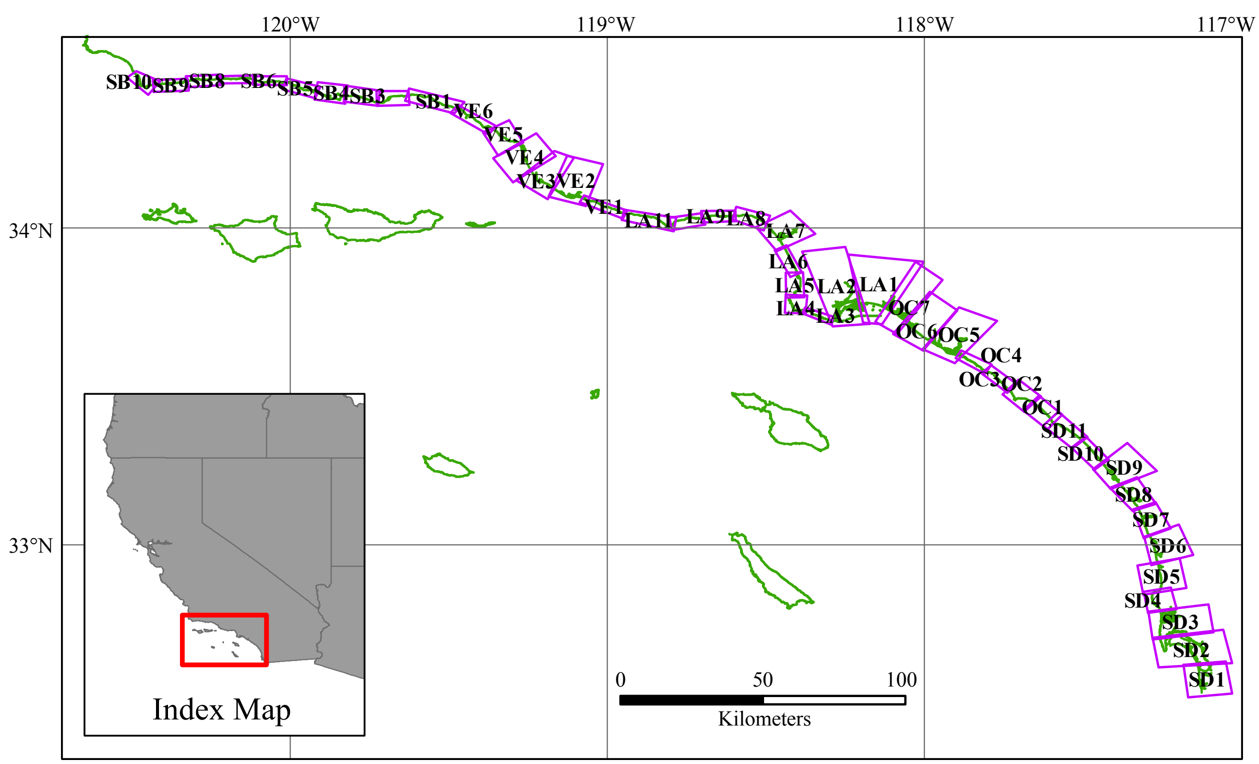

Figure 1. Southern California location map and identifiers (IDs) for the 45 individual Digital Elevation Models (DEMs).

Table 1. Individual DEM names and locations, listed from south to north. (IDs for each DEM are used in the metadata tables and shapefiles).

DEM ID	Geographic Name	County
sd1	Imperial Beach	San Diego
sd2	San Diego Harbor	San Diego
sd3	Mission Bay	San Diego
sd4	La Jolla	San Diego
sd5	Torrey Pines	San Diego
sd6	Del Mar/Solana/Cardiff	San Diego
sd7	Encinitas	San Diego
sd8	Carlsbad	San Diego
sd9	Oceanside	San Diego
sd10	Camp Pendleton	San Diego
sd11	San Onofre	San Diego
oc1	San Clemente	Orange
oc2	Dana Point	Orange
oc3	Laguna Beach South	Orange
oc4	Laguna Beach North	Orange
oc5	Newport Beach	Orange
oc6	Huntington Beach	Orange
oc7	Seal Beach	Orange
la1	Port of Long Beach	Los Angeles
la2	Port of Los Angeles	Los Angeles
la3	San Pedro	Los Angeles
la4	Palos Verdes	Los Angeles
la5	Redondo Beach	Los Angeles
la6	Manhattan Beach	Los Angeles
la7	Marina Del Rey	Los Angeles
la8	Pacific Palisades	Los Angeles
la9	Malibu	Los Angeles
la10	Dume East	Los Angeles
la11	Dume West	Los Angeles
ve1	Mugu East	Ventura
ve2	Mugu West	Ventura
ve3	Channel Islands Harbor	Ventura
ve4	Santa Clara River	Ventura
ve5	Ventura	Ventura
ve6	Rincon	Ventura
sb1	Carpinteria	Santa Barbara
sb2	Santa Barbara East (Harbor)	Santa Barbara
sb3	Santa Barbara West	Santa Barbara
sb4	UC Santa Barbara	Santa Barbara
sb5	Dos Pueblos	Santa Barbara
sb6	Tajiguas	Santa Barbara
sb7	Gaviota East	Santa Barbara
sb8	Gaviota West	Santa Barbara
sb9	Sacate	Santa Barbara
sb10	Point Conception	Santa Barbara

end of this report, but primarily consist of topographic Lidar, multibeam bathymetry, and Interferometric Synthetic Aperture Radar (IfSAR) topography. Additional data sources that were included, but have relatively small spatial extents, include local beach and nearshore topographic elevation data obtained using all-terrain vehicle (ATV) and walking surveys, near-shore bathymetric data from personal watercraft (PWC) and bathymetric Lidar (that is, CHARTS and SHOALS) surveys; and regional, 10- to 90-m resolution, DEMs constructed by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center and the National Geophysical Data Center (NGDC). Most of the individual DEMs cover approximately 10 km of alongshore distance, with the cross-shore extent highly variable due to variations in the off- and onshore positions of the 20-m isobath and the 20-m elevation contour, respectively. The ~10 km alongshore extent was chosen to keep file sizes and processing times reasonable during DEM construction. Each DEM overlaps with the adjoining DEMs by at least 250 m. The final DEM resolution of 3 m was selected because it was the coarsest resolution of the primary data sets used in the project, and the coarser 10- to 90-m resolution secondary datasets used to fill small gaps could reasonably be "pushed" to 3 m in these noncritical areas.

DEM Construction Overview

ArcGIS was the primary software used for DEM construction. For each individual DEM, the native data sets were mosaiced into a single grid to preserve the original surfaces as closely as possible. Prior to mosaicing, data sets were gridded and/or resampled to 3-m resolution (if necessary), and their spatial extents were modified according to the following guidelines.

- Data sets of comparable quality (for example, overlapping multibeam data), or where relative data quality could not be determined (for example, older multibeam and recent but lower resolution personal-watercraft data), were not clipped. In these instances the overlapping regions were blended together using the "Blend" algorithm in the "Mosaic to New Raster" tool in Arc Toolbox.
- In overlapping regions where the quality of one data set was clearly inferior to the other (for example, IfSAR overlapping with Lidar), the spatial extent of the inferior data set was clipped so there was minimal overlap, typically about ~10-30 m, with the superior data set. The overlapping regions then were smoothed together using

the Blend algorithm. This range of overlap was found to be the most efficient for ensuring a smooth transition between data sets while minimizing the use of lower quality data.

DEM Construction Procedures

1. Divide study area into ~10 km alongshore segments
   - Define DEM coverage area/polygon that extends ~10 km alongshore from -20 m isobath to 20-m topographic contour, or to 750 m from back beach, whichever is longer
   - Ensure that adjacent DEM coverage areas overlap by ~ 250 m
   - Cut off DEMs at county boundaries with ~500 m overlap
2. Acquire most recent or highest resolution data sets in DEM coverage areas (fig. 2)
   - Lidar
   - Multibeam bathymetry
   - Local high-resolution beach topography (usually ATV-acquired) and nearshore bathymetry (usually PWC-acquired)
   - IfSAR
3. Fill gaps with older/lower resolution data sets (fig. 2)
   - Lidar (for example, NOAA Digital Coast, 1997-98)
   - NOAA lower-resolution multibeam (for example, Los Angeles Harbor entrance)
   - Regional, lower resolution DEMs (for example, NOAA Santa Barbara Channel 10-m DEM)
4. Convert all data sets into identical horizontal coordinate system, vertical datum, and grid resolution
   - Horizontal coordinate system: UTM NAD 83 Zone 11 North
   - Vertical Datum: NAVD88
     - If different [usually mean lower-low

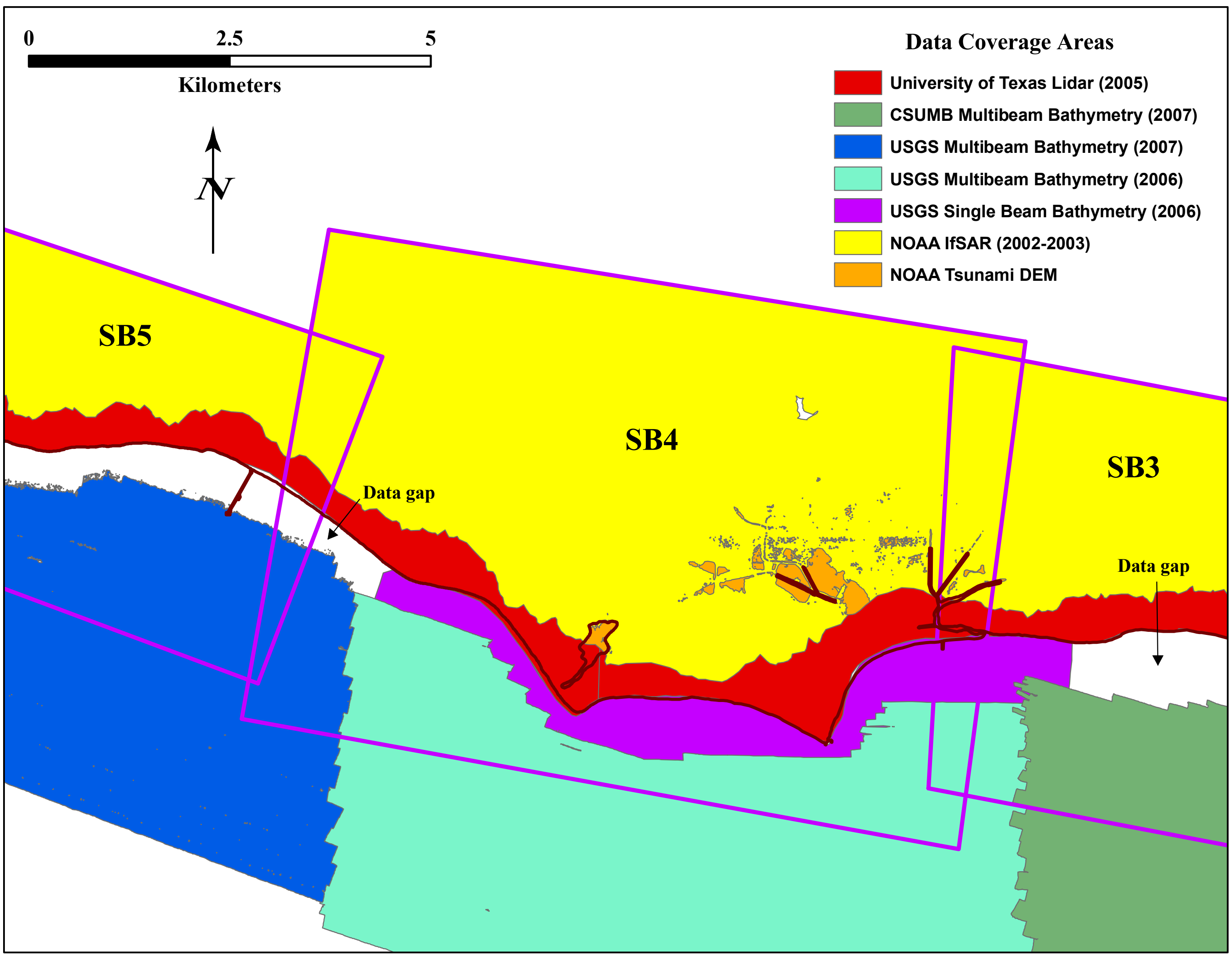

Figure 2. Areal extent of data sources used for DEM SB4 (University of California Santa Barbara). CSUMB, California State University Monterey Bay.

water(MLLW)], convert using local NOAA tide station information [http://tidesandcurrents.noaa.gov/ (last accessed December 2, 2009)] based on survey metadata

- Grid resolution: 3 m
  - If already gridded at higher (<3-m), or lower resolution (up to 10-m resolution), resample to 3 m using bilinear interpolation
  - If already gridded at resolution of ≥10-m, export as xyz, reimport as xyz, create TIN (triangular irregular network), create 3-m grid from TIN using linear interpolation of the TIN triangles, and clip to survey extent
  - Ungridded:
    - Lidar (topography), 3-m grid using natural-neighbor interpolation to preserve abrupt elevation changes (for example, beaches backed by cliffs)
    - Multibeam, 3-m grid using inverse distance weighting using "Average Gridder" in Fledermaus (ideal for data sets having more than 10 million points)
    - Lower resolution surveys (for example, PWC-collected bathymetry): create TIN from points then convert to 3-m grid using linear interpolation of the TIN triangles

5. Clip data sets to DEM/coverage needs, if necessary
   - Useful for data management and processing efficiency
   - Necessary for very large data sets, such as county-wide IfSAR, or very large Lidar data sets (for example, Los Angeles County)
   - Clip ocean and waves from topographic Lidar and IfSAR
     - Clip water level by determining sea level at time of survey then using "Extract by Attributes" tool in Arc Toolbox
     - Clip wave crests manually using mask

6. Manage overlapping data sets
   - Data sets allowed to overlap extensively only if they are of comparable quality, otherwise allow only minimal (~10–30 m) overlap to ensure smooth DEM transitions
   - Clip IfSAR data (lower quality) to minimal overlap with topographic Lidar (better quality)
   - Clip low-resolution data sets "pushed" to 3-m resolution, such as Personal Watercraft data and regional DEMs, to minimal overlap with adjacent high-resolution data sets (usually multibeam and topographic Lidar)
   - Extensive overlap between adjacent Lidar and multibeam data sets is rare but allowed as quality is comparable

7. Fill in data gaps between high-resolution data sets
   - If no high-resolution data are available between the 10-m isobath and coastal Lidar, in protected harbors/embayments, or in other areas where interpolation from surrounding data sets will create a surface unlikely to reflect actual bathymetry/topography accurately, fill in gaps with regional DEMs or other low-resolution data sets. Otherwise, interpolate across gaps.
     - Filling in using regional DEMs/other low-resolution data:
       - Clip best available regional DEM to gap area, allowing only minimal overlap (~10-30 m) with adjacent high-resolution data sets
       - Export clipped grid as xyz, reimport as points, create TIN, create 3-m grid from TIN, clip to gap extent
     - Interpolation:
       - Create preliminary DEM using Mosaic tool (fig. 3) with the following settings:
       - Coordinate System: UTM Zone 11 North
Pixel Type: 32_Bit_Float
Cell Size: 3
Mosaic Method: Blend
Mosaic Color Map: Last
       - Create mask of data gap(s) to fill with preliminary DEM surface, ensuring minimal overlap with surrounding data
       - Clip preliminary DEM with mask, export clipped grid as xyz, reimport as points (fig. 4), create TIN, create 3-m grid from TIN, clip to gap extent

8. Compile final DEMs
   - Load all data sets for DEM
   - Verify all significant data gaps filled (few missing cells OK) in DEM coverage area
   - Build DEM using "Mosaic to New Raster" tool in ArcGIS with same setting as noted above in Step 7
   - Clip DEM to DEM coverage area (fig. 5)
   - Create contours and plot cross-shore profiles to verify data quality and consistency

DEM Accuracy and Limitations

Original data were preserved as much as possible by minimizing exporting, regridding, smoothing and/or resampling during the DEM construction process. However, the vertical accuracy of the resulting DEM is only as good as the accuracy of the native data, which varies considerably. Vertical accuracy reported by the data-source agencies ranges from about ±8 cm for most of the Lidar data to about ±1 m for IfSAR data. The final DEMs have been reviewed and corrections have been applied for obvious anomalies, but we have not thoroughly analyzed the native data sets to determine whether the reported horizontal and vertical uncertainties are correct. We also assume that grids provided to us were constructed using appropriate techniques and in the proper resolution from cleaned point data, which often were not available to us. Users should contact the original data sources for inquiries about all metadata and related issues, such as data

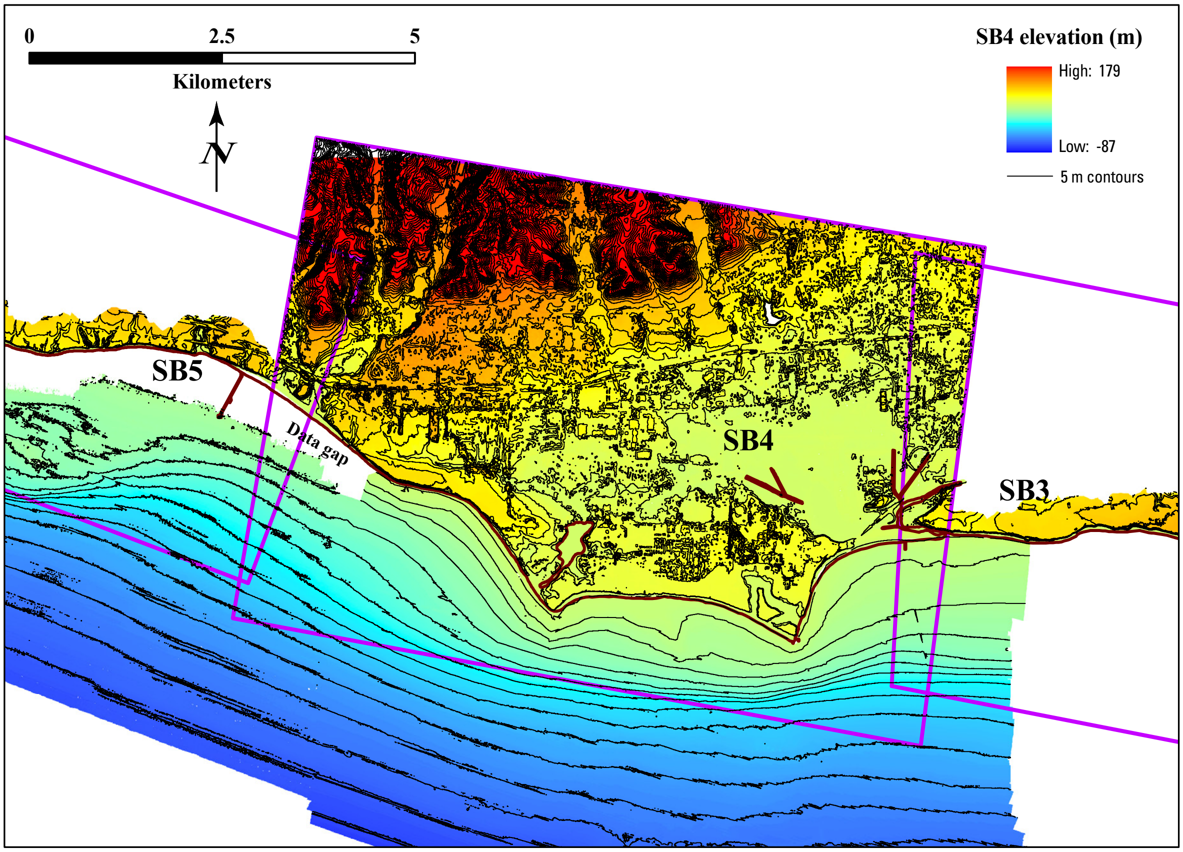

Figure 3. Preliminary DEM for SB4 prior to interpolation of data gaps and clipping to DEM area.

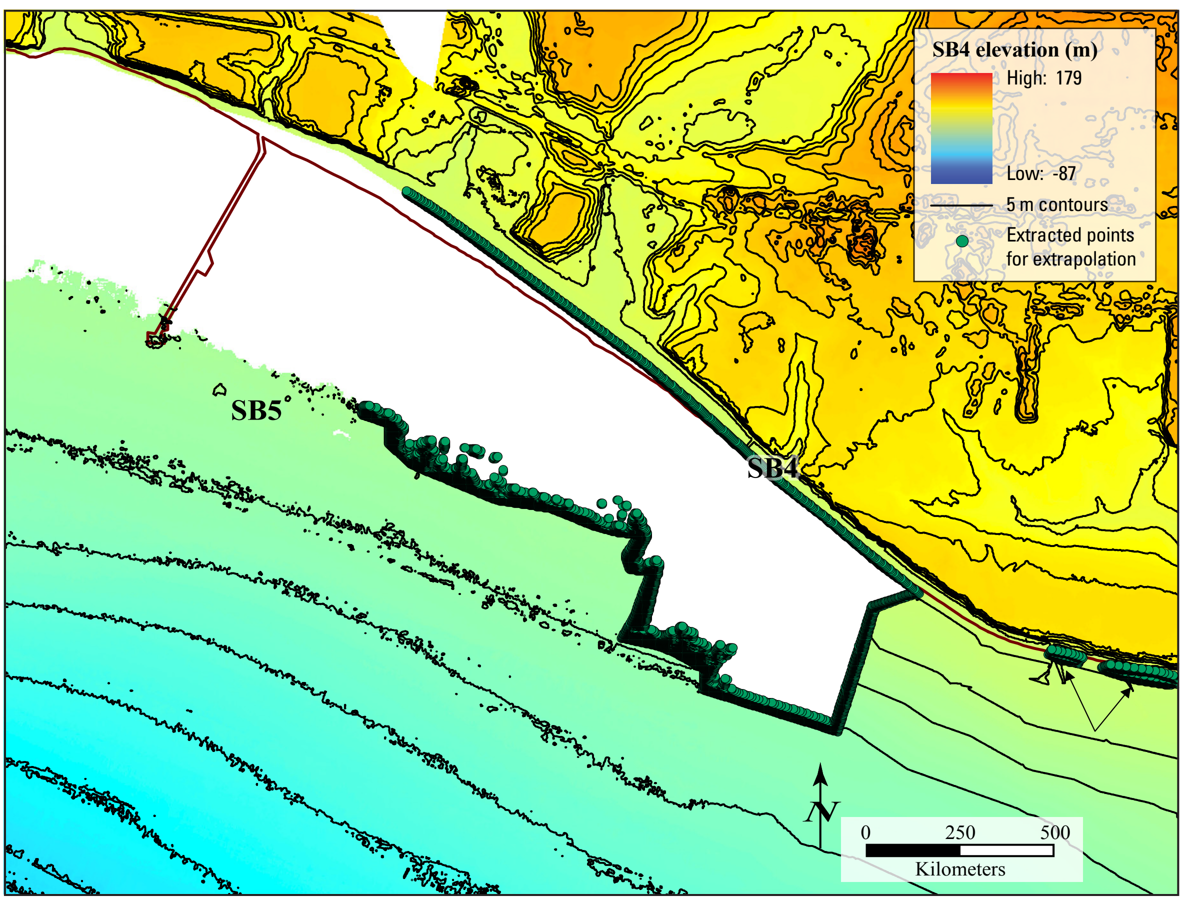

Figure 4. West end of SB4 showing preliminary DEM and points extracted for use in interpolating elevations in data gaps.

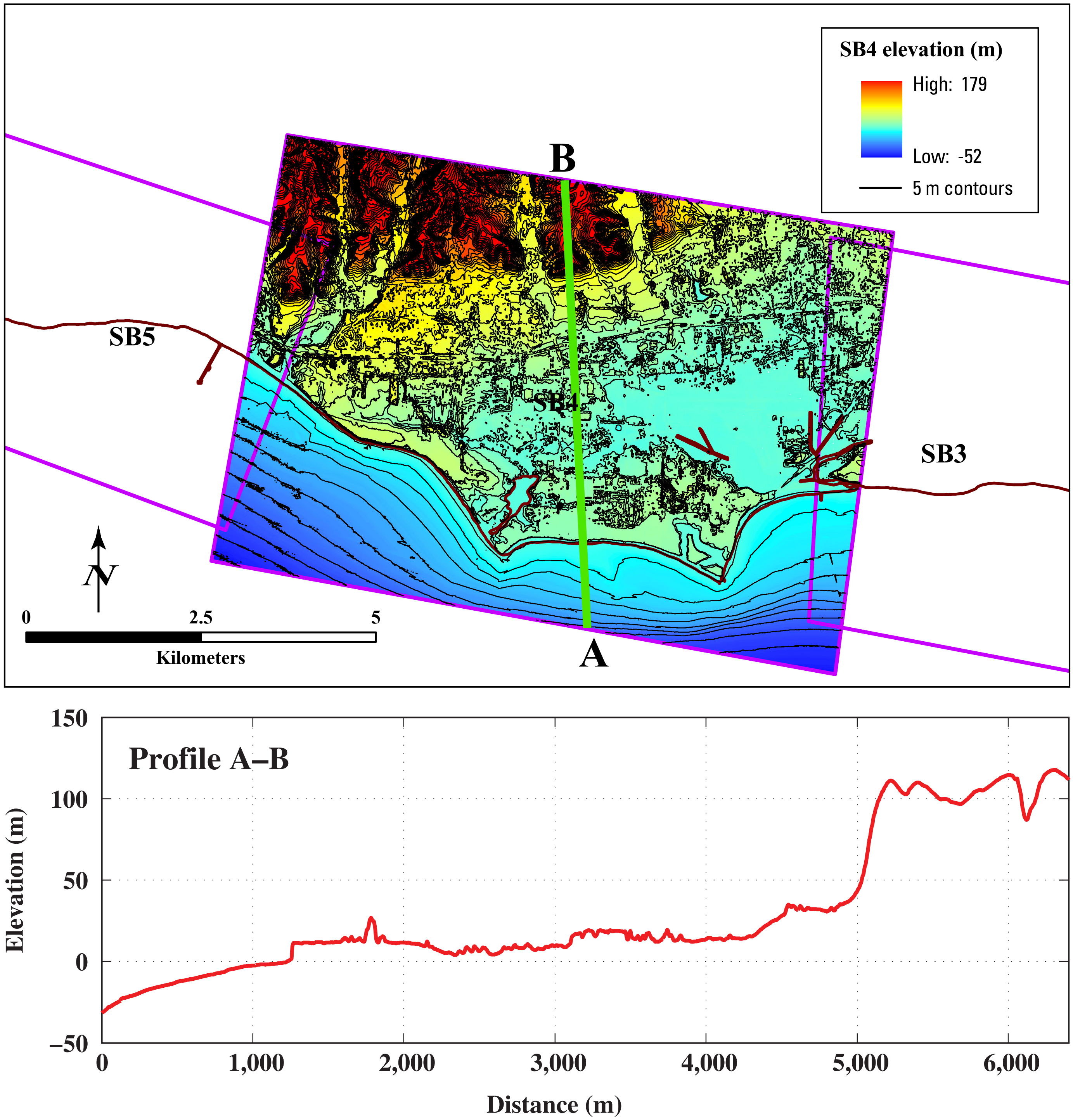

Figure 5. Final DEM for SB4 (top) and onshore to offshore elevation profile along section A-B (bottom).

accuracy or consistency. No guarantee is given for the quality of any of the data. Users must carefully consider the inherent limitations and potential issues associated with these data when using these grids.

The coastal zone is an extremely dynamic environment. Single storms can modify local beach and nearshore elevations by more than one meter and move elevation contours horizontally by tens of meters; and seasonal and interannual changes can significantly affect coastal bathymetry and topography. Because the data sets used for the DEM were obtained at different times (mostly from 2005 to 2008) and at different resolutions, we make no assurances regarding the local accuracy of the DEM surface. However, where possible, we used data collected in the fall to minimize the potential for winter storm effects.

Table 2. Geospatial statistics of the DEM's.

DEM ID	Surface Area (km2)	Minimum Elevation (m)	Maximum Elevation (m)	Mean Elevation (m)
sd2	238.8	-52.8	156.0	13.7
sd3	178.2	-43.6	154.6	35.3
sd4	64.2	-149.5	258.2	44.2
sd5	133.3	-486.1	155.8	-8.4
sd6	129.0	-37.6	138.0	45.0
sd7	80.9	-40.2	140.2	40.7
sd8	84.5	-84.0	127.3	20.5
sd9	151.7	-30.4	221.1	28.5
sd10	57.9	-30.0	225.4	2.1
sd11	75.4	-31.4	374.9	32.5
oc1	65.1	-46.0	271.5	21.0
oc2	63.0	-48.8	268.6	44.4
oc3	41.1	-66.5	287.2	62.5
oc4	34.3	-76.2	233.4	40.8
oc5	206.2	-221.6	89.6	7.1
oc6	184.7	-23.9	48.9	4.1
oc7	206.2	-39.0	48.0	5.0
la1	320.8	-28.3	109.2	11.4
la2	322.3	-34.8	138.9	14.6
la3	22.4	-39.5	287.6	42.0
la4	38.9	-393.6	398.8	102.7
la5	45.4	-292.6	345.9	-3.0
la6	39.3	-90.4	68.0	-4.5
la7	126.9	-28.5	145.7	21.1
la8	51.9	-26.6	536.1	45.0
la9	38.7	-34.5	485.4	72.1
la10	41.1	-51.1	311.5	11.9
la11	64.6	-194.5	357.7	11.0
ve1	39.6	-118.4	386.3	36.4
ve2	169.7	-303.9	475.9	17.0
ve3	134.3	-251.2	57.5	-0.3
ve4	153.0	-24.5	282.3	6.7
ve5	78.7	-26.5	380.0	39.8
ve6	47.5	-23.0	321.0	37.7
sb1	72.5	-33.0	222.0	13.1
sb2	47.2	-39.3	152.1	8.9
sb3	55.7	-44.4	191.2	23.5
sb4	55.9	-51.9	178.8	16.9
sb5	42.0	-59.4	179.1	11.8
sb6	29.9	-42.4	260.5	52.6
sb7	27.4	-51.8	235.3	14.9
sb8	38.0	-61.0	306.6	24.2
sb9	41.9	-51.1	198.6	1.1
sb10	37.4	-74.8	185.9	19.5
Mean (All-DEMs)	96.1	-89.0	234.4	24.4

DEM bathymetry in harbors should be used with extreme caution. Only rarely was high-resolution multibeam data available in harbors, and as these areas were not crucial for our project objectives we often used low-resolution, 10- to 90-m DEMs. These DEMs presumably were constructed from various NOAA National Ocean Service (NOS) survey datasets, but native datasets for these DEMs were not reviewed for this project. Therefore, harbors may have the least accurate bathymetries in the DEM. Piers commonly were included in Lidar data, and although piers usually act as semi permeable barriers to waves, tidal currents, and littoral transport, they appear as impermeable barriers in the DEM.

Table 2 lists some basic geospatial statistics of the final DEMs. Preliminary analysis of the overlapping DEM regions in Santa Barbara County indicates that individual grid cell elevation offsets along the coastal strip (approximately ±500 m cross-shore) are almost always < 10 cm, and mean elevation offsets for the entire overlapping region between all DEMs is ~2 cm. Most of the bias can be attributed to grid-cell misalignments (that is, areas where grid cells in adjacent DEMs are not aligned) in the upper elevations of the DEMS where steep slopes are common, far removed from the active coastal zone. This analysis suggests a high level of internal precision in DEM production, but the accuracy of the native data sets relative to user needs still must be carefully considered when using these DEMs.

The Digital Files

For all spatial data files the horizontal coordinate system is Universal Transverse Mercator (UTM), Zone 11 North, North American Datum of 1983 (NAD83). All elevations are relative to the North American Vertical Datum of 1988 (NAVD88).

Each of the 45 DEMs is posted as a 3-m resolution Arc ASCII grid (table 3). Arc ASCII grids can easily be converted to ARC raster grids using Arc Toolbox. A variety

Table 3. List of DEMs (zipped Arc ASCII grids) by county.

San Diego	Orange County	Los Angeles	Ventura	Santa Barbara
sd1.zip	oc1.zip	la1.zip	ve1.zip	sb1.zip
sd2.zip	oc2.zip	la2.zip	ve2.zip	sb2.zip
sd3.zip	oc3.zip	la3.zip	ve3.zip	sb3.zip
sd4.zip	oc4.zip	la4.zip	ve4.zip	sb4.zip
sd5.zip	oc5.zip	la5.zip	ve5.zip	sb5.zip
sd6.zip	oc6.zip	la6.zip	ve6.zip	sb6.zip
sd7.zip	oc7.zip	la7.zip		sb7.zip
sd8.zip		la8.zip		sb8.zip
sd9.zip		la9.zip		sb9.zip
sd10.zip		la10.zip		
sd11.zip		la11.zip		

of other GIS-related software packages also can handle this format, including Surfer, Global Mapper, Fledermaus, and Imagine.

There are two polygon shapefiles; DEMCoverageAreas.zip and DataCoverageAreas.zip (with layer file). The first shapefile shows the DEM coverage areas for all 45 DEMs (fig. 1). The second shapefile shows the coverage area for each of the native data sets, with fields displaying key metadata, such as the data source and resolution.

Finally, there is a Microsoft Excel spreadsheet (DEM_Metadata.xls) that lists all primary metadata for all the data sets used in this project, as well as the dataset components for each of the 45 individual DEMs, grouped by county.

Polygon Shapefiles

DEMCoverageAreas.zip

DataCoverageAreas.zip (with layer file)

Spreadsheet

DEM_Metadata.xls

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