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Data Descriptor

A Dataset of Two-Dimensional XBeach Model Set-Up Files for Northern California

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Abstract: Here, we describe a dataset of two-dimensional (2D) XBeach model files that were developed for the Coastal Storm Modeling System (CoSMoS) in northern California as an update to an earlier CoSMoS implementation that relied on one-dimensional (1D) modeling methods. We provide details on the data and their application, such that they might be useful to end-users for other coastal studies. Modeling methods and outputs are presented for Humboldt Bay, California, in which we compare output from a nested 1D modeling approach to 2D model results, demonstrating that the 2D method, while more computationally expensive, results in a more cohesive and directly mappable flood hazard result.

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Dataset License: CC0

Keywords: coastal model; coastal flood; coastal hazard model; numerical model; climate change; sea-level rise

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1. Summary (Required)

The data described here are model files developed for the Coastal Storm Modeling System (CoSMoS) [1–4] in northern California [5]. CoSMoS is comprised of a global scale wave model and a suite of regional ('tier I'), sub-regional ('tier II'), and local scale ('tier III') models that simulate coastal hazards in response to projections of 21st century sea level rise, storms, tides, river discharge, and waves. At the regional and sub-regional levels, a coupled wave–hydrodynamic model is used (SWAN and Delft3D) [4]. While the SWAN model is considered robust and well vetted, it does not include the physics of infragravity wave energy, which is critical to understanding wave setup and runup along coasts subjected to long-period swell, such as in California, where infragravity waves are one of the primary drivers of coastal water levels during storms. Previous implementations of CoSMoS in California [6,7] used 1-dimensional (1D) XBeach models at the local level to capture impacts from infragravity waves [4]. However, combining these 1D XBeach model outputs with the regional 2-dimensional (2D) Delft3D hydrodynamic outputs for final flood hazard outputs occasionally result in interpolation artifacts, especially in complicated coastal landscapes (e.g., barrier spits, inlets, harbors). Using spatially coherent 2D XBeach model outputs results in more cohesive and directly mappable flood outputs across larger coastal sections and complex topography. Importantly, the 2D XBeach models included in this dataset better capture infragravity wave impacts [8] and dynamic wave, water level, and current interactions along coasts with complex topobathymetry such as crenulations, steep elevation changes around cliffs, and offshore rocks [9–11]. However, while 2D XBeach is widely used to understand processes and impacts in complex coastal environments, ready-to-use model datasets, with all relevant simulation parameters as used in associated studies to aid other research and coastal efforts, are extremely limited [11,12].

In the northern California CoSMoS study area, there is a preponderance of cliff-fronted coastline and cliff-backed beaches, complex bathymetry, numerous larger fluvial contributions, and large bays fronted by barrier spits; thus, the use of 2D XBeach models presents obvious benefits.

This dataset can be used by researchers, technical coastal practitioners, and students, to inform coastal studies on SLR, storm-driven water levels, coastal change, and associated hazards. It includes all the required setup files to run the 2D XBeach models, such as the XBeach boundary condition files for forcing from water levels, waves, and fluvial discharge for this northern California region. Additionally, the dataset includes grid elevations depicting the evolved topobathymetric elevations considering the effects of shoreline change and cliff retreat due to SLR [4,13].

2. Data Description

The data are provided in various formats and packaged as "ready to run" 2D XBeach models for individual storm events over one tidal cycle; more information on running 2D XBeach and the formats of required model files is available from Roelvink et al. [14–16] and Deltares [17] (https://xbeach.readthedocs.io, accessed on 1 February 2024). The setup files and boundary conditions included in this dataset represent a 100-year storm event that was used in the northern California CoSMoS implementation; this same storm scenario was similarly used in preceding tier II simulations and is represented in corresponding model data [5]. For a detailed explanation of how storm scenarios are identified and set up in CoSMoS, refer to O'Neill et al. [4] and Erikson et al. [18], and see Barnard et al. [5] for implementation details in northern California. Model files were created and run with the XBeach Halloween release (v1.24). The provided data cover more than 175 km of coastline in the northern California study area (Humboldt County), split into 11 overlapping domains (Figure 1). Domains are identified by sequential numbers, starting with 'grid22' at the southern end of Humboldt County and increasing northwards (Figure 1). For each domain, there is a folder (with the same name as the domain ID) that contains all the model files for that domain. Model files are explained below, but greater detail on units, usage, and modification of the files are available in the XBeach manual online [17]. Grid bathymetries depict evolved coastal elevations for scenarios of SLR greater than 0 cm, which are based on projected shoreline changes [19–21] and cliff retreat [22,23]. These are contained within the 'bed_with_SLR' directory, named for each SLR amount in centimeters; see Section 3.2. Section File Names and Descriptions provides a description of each model file associated with a 2D XBeach domain. Bed and water elevations are referenced to NAVD88, unless otherwise stated.

File Names and Descriptions

Each domain directory (for example, 'grid22') contains model files for that domain, as follows:

- bed.dep: bed/ground elevation (m) at grid nodes derived from recent topobathymetric digital elevation models [24]. Elevations below 0 m are negative (−), and elevations above 0 m are positive (+).
- bed_with_SLR: folder containing bed elevations (m) that incorporate coastal change due to SLR.
- bed_slrNNN.dep: bed/ground elevation (m) at grid nodes (as described for bed.dep) for a given SLR scenario; these bed elevations incorporate coastal changes due to shoreline change and cliff retreat [4,13] (Section 3.2). There are six SLR scenarios (50, 100, 150, 200, 300, and 500 cm) indicated by NNN (for example, bed_slr050.dep corresponds to the 50-cm SLR scenario). These files are within the bed_with_SLR folder.

- disch_loc_file.txt: in applicable domains only, the grid positions of fluvial discharge point sources. Columns 1 and 2 are x and y location (UTM 10), respectively. Columns 3 and 4 are also x and y location and are the same as columns 1 and 2 because the discharge is a point source (as opposed to a line). Multiple lines indicate multiple discharge sources in the domain, with each subsequent line corresponding to the same numbered line in rivers_info.txt and column in disch_timeseries_file.txt.;
- disch_timeseries_file.txt: in applicable domains only, time series of discharge at the source positions in dish_loc_file.txt. The first column is time in seconds, and each following column (one for each discharge source), is discharge (m^3 s^{-1}). The discharge time series are the same as described and included in [5].
- jonswapNN.txt: boundary wave conditions at locations annotated in loclist.txt; NN represents numerical identification of the location, which starts at 1 at the southern offshore end of the domain and increases northward across the domain. Columns are significant wave height (m), peak wave period (s), peak wave direction (degrees), peak wave enhancement factor, directional spreading coefficient, highest frequency used (s^{-1}), and step size frequency (s^{-1}) at each time step. Boundary conditions are derived from tier II simulations [5].
- loclist.txt: locations of the spatially and time-varying forcing within the domain. Columns 1 and 2 show x and y location (UTM 10), respectively; column 3 is the name of the corresponding jonswapNN.txt file. The x/y locations are the furthest offshore points of the cross-shore transects used in the model system architecture [5].
- nebed.sed: depth of mobile sediment (m) at each grid node (same size as the .grd files). Areas landward of back-beach boundaries and cliffs have mobile sediment depths set to 0.
- params.txt: text file outlining all model parameters including start and end time; see Section 3.1 for a description of parameters used. All model runs are referenced to a representative spring tide (starting 6 November 2010) [4].
- rivers_info.txt: where applicable, name of the discharge source(s) in the domain. The names are informal abbreviations of river/stream names and match those used in the tier II simulation parameters [5]. Multiple lines indicate multiple discharge sources.
- tide.txt: water level boundary conditions for both corners of the offshore boundary. Columns are time (s) and water elevation (m). All water level elevations are vertically referenced to NAVD88 (m) and are derived from tier II simulations [5].
- waterlevel_gridNN.ini: initial water level (m) at start of model simulation for each grid node (same size as the .grd files). NN corresponds to the numbered domain (for example, waterlevel_grid22.ini corresponds to domain 22). All water level elevations are vertically referenced to NAVD88 (m) and grid nodes with no water level values are set to −999. The use of this initial water level reduces model spin-up time.
- x.grd: x locations of model grid nodes (UTM 10).
- y.grd: y locations of model grid nodes (UTM 10).

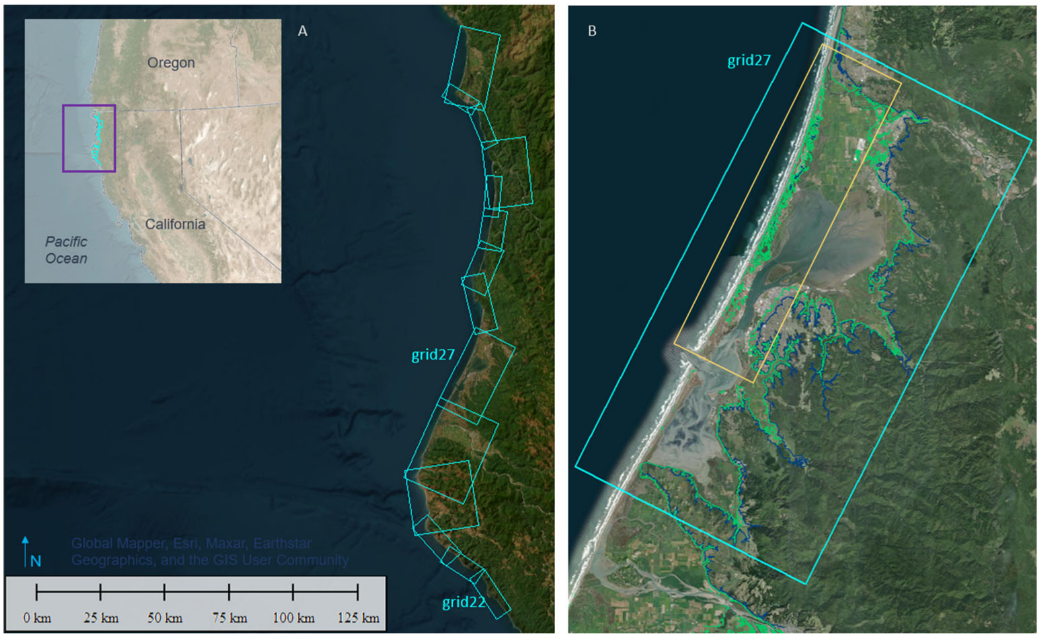

Figure 1. (**A**) Map of the northern California study area. Blue boxes show footprints of the XBeach domains across the study area in northern California. (**B**) Map of Humboldt Bay and grid27 placement (light blue) and area used for comparisons in Section 3.4 (yellow). The 10-m and 20-m contours are shown in green and dark blue, respectively.

3. Methods

3.1. 2D XBeach Domain Setup

XBeach is an open-source model to investigate storm impacts from wave propagation, nearshore processes, and morphological changes, including beach erosion, overwash, and flooding of sandy coasts [15,16]. For the northern California area, our 2D XBeach grids are setup as shore-normal domains along 16–34 km sections of coast. The rectilinear grids extend offshore such that they cover at least the 15 m isobath and all cross-shore transect locations, and they extend onshore to extend inland past the landward 10 m topographic contour (Figure 1) and locations of fluvial contributions. The grid cross-shore resolution varies from 20 m to 5 m, with the highest resolution located nearshore and on the coast; the coarsest resolutions are located offshore on and in high terrain. Alongshore grid resolution is ~20 m. A median grain diameter of 0.2 mm (default model value) and sediment thickness of 2 m was used for all beach and nearshore areas oceanward of back beach boundaries [4]. A uniform bed friction coefficient of 55 (default value) is used with the Chezy formulation. Areas landward of back beach boundaries are set to be immobile (no mobile sediment), disabling erosion in these areas during the storm. The locations and amounts of discharge are the same as those used in the Delft3D hydrodynamic models that provide boundary conditions to these XBeach models [4,5]. Time- and space-varying boundary conditions are applied to the offshore boundary, where water levels, significant wave heights, peak wave period, peak wave direction, and directional spreading values from tier II Delft3D models provide the forcing. These forcing values were extracted at the most off-shore locations of the cross-shore transects [5] and were written out as JONSWAP and tide files. To reduce the influence of boundary artifacts, lateral boundaries were set up as an intermediate between Neumann and wall-boundary assumptions [17] (keyword no_advec). The models were run in surf-beat mode where wave groups were resolved but not individual waves. The outputs for bed level, water surface elevation, water depth, H_{rms} wave height, and current speed at grid cell centers were written out in 2D netCDF files every 3 h (tint = 10,800) and were written out every second at numerous alongshore point locations (the number of which is dictated by domain size and location).

3.2. Grid Node Elevations

Topobathymetric elevations for depths at grid nodes are from the U.S. Geological Survey (USGS) Coastal National Elevation Database (CoNED) application Digital Elevation Models (DEMs) [24]. Grid depths are assigned at each node as a spatial average of all DEM data within a 0.7 grid-cell radius. Modified grid depths which reflect coastline changes [20,21] and cliff erosion [22,23] with SLR follow the methods outlined in [4] (Section 2.2.2.5 in that reference) and in [13]. The modified grid depths are assigned using the same spatial average as above. All elevations are in meters (m) and are vertically referenced to NAVD88.

3.3. Setup for Running Models in High-Performance Computing (HPC) Resources

These models were set up to run on the USGS Advance Computing Resource [25]. XBeach was run in parallel mode, which allowed the model domain to be subdivided in sub-models, where each sub-model was computed on a separate core. These sub-models were devised such that the alongshore and cross-shore extents of the domains each contained an equal number of sub-models. This setup increased the computational speed of the model run. Each domain used a variable number of cores to allow each simulation to finish within a wall clock time of 2 days. For comparison, this is more than twice as long as the run time for 1D XBeach models run on desktop computers covering the entire domain. While XBeach could only use central processing units (CPUs) on this computational resource, using graphics processing units (GPUs) may offer more efficiency and shorter run times [26].

3.4. Comparison to Previous 1D XBeach Methods

Comparisons and validations for the 2D XBeach model are presented for the Humboldt Bay region (Figure 1). Humboldt Bay is a good example of the complexity in spatial scales and processes associated with the northern California region; it includes a complex estuarine system, multiple fluvial inputs, and a highly energetic barrier spit coast, with increasingly strong tidal influence toward the inlet mouth. The bay is covered by a single domain (grid27) and is validated using the same storm event used in the tier II Delft3D hydrodynamic simulations (January 2010) [5]. Water levels at the North Spit tide gage in Humboldt Bay [27] show the XBeach model has an RMSE of 14 cm.

Previous implementations of CoSMoS in southern and central California did not directly use XBeach runup to generate cohesive flood extents [4]. Rather, water levels from 1D XBeach models were frequency-filtered to durations of longer than 1 min to capture dynamic wave setup and the increases in water levels from breaking waves at the shore. At all cross-shore transects, these frequency-filtered values were then merged with maximum water levels from 2D Delft3D outputs to produce final flood surfaces, which were subsequently depth-differenced with the high-resolution DEM for final flood extents and depths.

Validations of wave-driven runup and setup for previous 1D methods were completed in locations south of this study area [4,28]. While a validation of coastal water levels for 2D XBeach in northern California was conducted at the North Spit tide gage, sufficient runup/setup data in the study region were not available for a direct validation of wave-driven coastal water levels; hence, the 2D XBeach model setup was compared to the validated 1D XBeach model setup. To compare the previous method with the one presented herein, both 1D XBeach models and a 2D XBeach model (grid27) were run for a 100-year storm event used in northern California CoSMoS. Runup locations (landward extent) and elevations along the cross-shore transects for the coastal section north of the harbor mouth are shown in Figure 2.

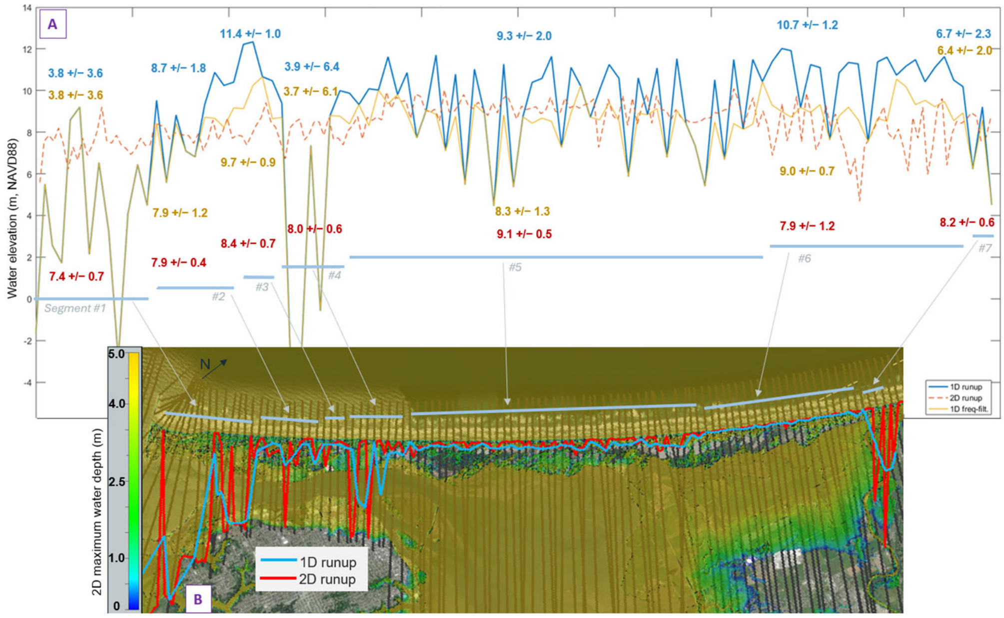

Figure 2. (**A**) Elevations of water level from one-dimensional (1D) and two-dimensional (2D) XBeach models along a section of coast north of the harbor mouth (Figure 1B): 1D runup (blue), frequency-filtered 1D runup (used in prior methodology for flood-extent generation; yellow), and 2D runup (red). Elevations are calculated and shown at cross-shore transects. Different coastal segments (with varying dune system elevations and similar runup behavior) are denoted by light blue-gray lines; each segment's average runup elevations +/− standard deviations are shown for both 1D (runup as blue; frequency-filtered runup as yellow) and 2D (red) models. (**B**) Top-down view of 1D (blue) and 2D (red) runup location along cross-shore transects (dark gray) for the same coastal region as A. Coastal segments are denoted by light gray lines, corresponding to A. Maximum water depth derived from the 2D XBeach model run for the simulated 100-year storm event (maximum flood depth calculated over the entire simulation of one tidal cycle) is also shown.

The two-dimensional runup elevations were generally lower than 1D XBeach runup values (Figure 2A); this is expected as wave energy was not confined along the cross-shore dimension in 2D model runs. However, 2D runup was more consistent with the 1D frequency-filtered water levels previously used for mapping flood extent. The alongshore section of this area was further subdivided into different alongshore coastal segments, which were delineated based on their dune system characteristics and the runup variance (Figure 2 and Table 1). In areas with higher dune systems (segments 2, 3, 5, and 6), segment-averaged 2D runup elevations were within 1.3 m of the 1D frequency-filtered levels, compared to 1D runup that was up to 3.0 m larger, and 2D runup elevations were also more uniform alongshore, showing much more consistent behavior transect to transect. In sections of coast with lower dune systems (segments 1, 4, and 7), 2D runup showed slightly reduced overtopping potential (fewer points of overtopping) compared to 1D runup. However, in cases of overtopping, the 2D runup is not directly comparable to the 1D runup or 1D frequency-filtered water elevations. This is because 1D runup outputs in overtopping situations reflect the bare DEM elevation as the lens of water proceeds landward, whereas 2D runup reflects the most landward wetted cell including consideration of continuous water bodies (e.g., the bay). The 2D models yield continuous mapped flood surfaces that can be depth-differenced with the DEM to produce fine-scale flood depths and extents, without introducing numeric artifacts from merging modeled water elevations across transects with inconsistent runup behavior.

Table 1. Mean and maximum (and standard deviation) elevation (m) of foredune ridge characteristics within each coastal segment shown in Figure 2. The number of dune ridge parts used in the statistics is listed as N.

Statistic	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7
Mean (std) (m)	7.82 (0.93)	8.68 (1.21)	8.67 (0.34)	8.11 (0.82)	8.92 (0.79)	10.53 (0.95)	7.98 (1.37)
Maximum (std) (m)	8.24 (1.04)	9.60 (1.67)	9.23 (0.60)	8.98 (1.00)	10.01 (1.07)	11.65 (1.11)	8.79 (1.44)
N	85	21	26	34	199	307	102

For locations where there was no overtopping into the bay, the 2D runup locations roughly match the 1D output (Figure 2B). The 2D runup is generally more oceanward and shows less landward extent than the 1D runup output, consistent with comparisons of runup elevation.

Given the similarity in 2D runup to 1D frequency-filtered water levels, we find that the maximum water levels (identified at each grid point) from the 2D XBeach are preferable for generating flood hazards within CoSMoS. While the 2D models are more computationally expensive, the outputs yield more continuous and directly mappable hazards, without the processing time and potential numerical artifacts from merging 1D model output.

4. Conclusions and User Access

This dataset of 2D XBeach model input files can help scientists and coastal professionals better understand coastal flood hazards from climate-change-driven storms and SLR, and explore how these hazards change with different forcing scenarios. By providing this full dataset, users can leverage these models to build their own experiments and inform site-specific projects.

See online documentation [17] for information on downloading and using the latest versions of XBeach.

The model files explained in this document and associated metadata are available in [5] (https://doi.org/10.5066/P9048D1S). Open-source code and detailed information for XBeach can be found at [17] (https://xbeach.readthedocs.io, accessed on 1 February 2024).

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Abbreviations

U.S.	United States
USGS	United States Geological Survey
UTM 10	Universal Transverse Mercator Zone 10
1D	1-dimensional
2D	2-dimensional
CoNED	Coastal National Elevation Database
CoSMoS	Coastal Storm Modeling System
H_s	Significant wave height
H_{rms}	Root mean square wave height
JONSWAP	Joint North Sea Wave Project wave spectra
m	meter
NAVD88	North American Vertical Datum of 1988
RMSE	Root Mean Squared Error
SLR	Sea-level rise

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