Coastal Hazards Task of the USGS Multi-Hazards Demonstration Project in Southern California

The Framework of a Coastal Hazards Model—A Tool for Predicting the Impact of Severe Storms

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Introduction

The U.S. Geological Survey (USGS) Multi-Hazards Demonstration Project in Southern California (Jones and others, 2007) is a five-year project (FY2007-FY2011) integrating multiple USGS research activities with the needs of external partners, such as emergency managers and land-use planners, to produce products and information that can be used to create more disaster-resilient communities. The hazards being evaluated include earthquakes, landslides, floods, tsunamis, wildfires, and coastal hazards.

For the Coastal Hazards Task of the Multi-Hazards Demonstration Project in Southern California, the USGS is leading the development of a modeling system for forecasting the impact of winter storms threatening the entire Southern California shoreline from Pt. Conception to the Mexican border (fig. 1). The modeling system, run in real-time or with prescribed scenarios, will incorporate atmospheric information (that is, wind and pressure fields) with a suite of state-of-the-art physical process models (that is, tide, surge, and wave) to enable detailed prediction of currents, wave height, wave runup, and total water levels. Additional research-grade predictions of coastal flooding, inundation, erosion, and cliff failure will also be performed. Initial model testing, performance evaluation, and product development will be focused on a severe winter-storm scenario developed in collaboration with the Winter Storm Working Group of the USGS Multi-Hazards Demonstration Project in Southern California. Additional offline model runs and products will include coastal-hazard hindcasts of selected historical winter storms, as well as additional severe winter-storm simulations based on statistical analyses of historical wave and water-level data. The coastal-hazards model design will also be appropriate for simulating the impact of storms under various sea level rise and climate-change scenarios. The operational capabilities of this modeling system are designed to provide emergency planners with the critical information they need to respond quickly and efficiently and to increase public safety and mitigate damage associated with powerful coastal storms. For instance, high resolution local models will predict detailed wave heights, breaking patterns, and current strengths for use in warning systems for harbor-mouth navigation and densely populated coastal regions where beach safety is threatened. The offline applications are intended to equip coastal managers with the information needed to manage and allocate their resources effectively to protect sections of coast that may be most vulnerable to future severe storms.

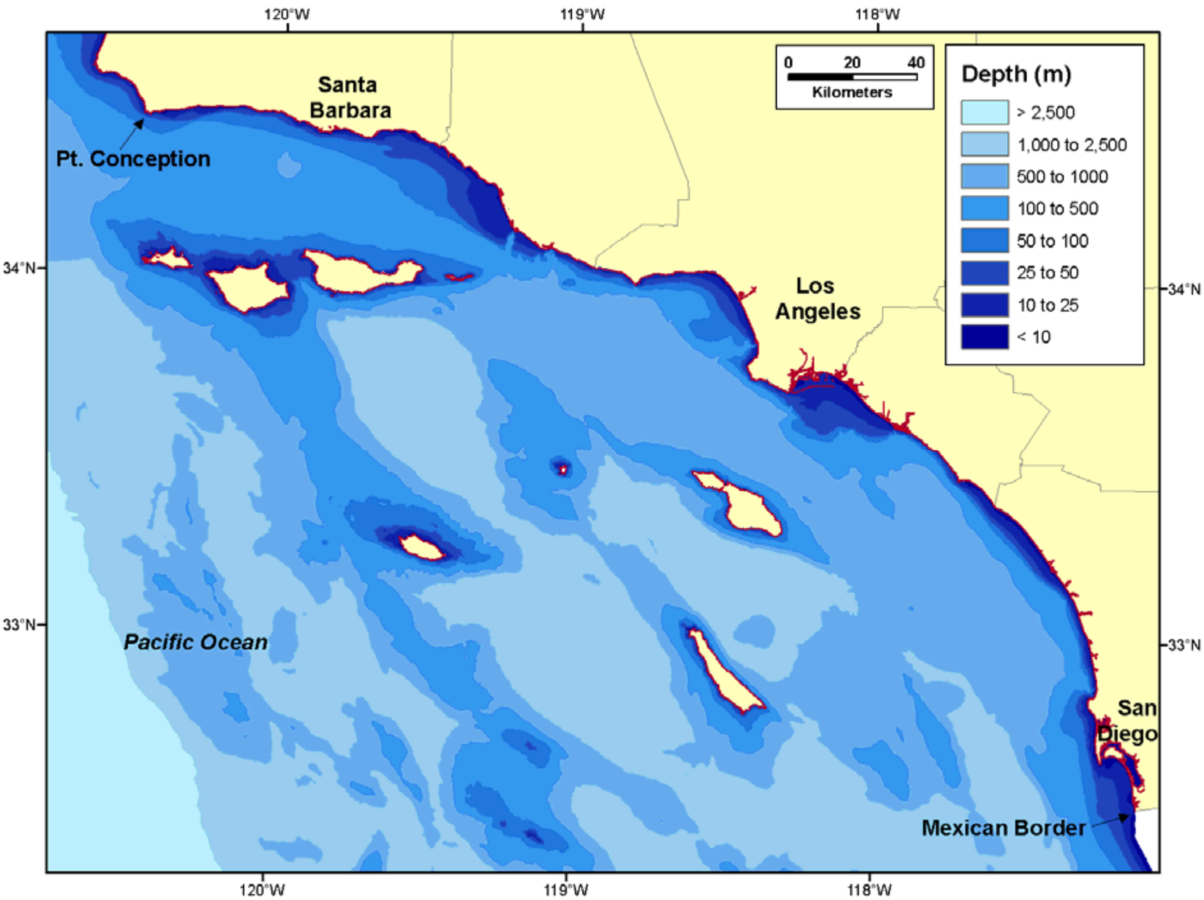

Figure 1. Coastline and bathymetry in the project area, which extends from Pt. Conception, California, to the Mexican Border.

Objectives

- Develop a state-of-the-art model for predicting hazards caused by severe storms along the Southern California coast.
- Develop Web products that are easily accessible and meet the needs of emergency planners and coastal managers.
- Integrate model products into the framework of the USGS Multi-Hazards Demonstration Project in Southern California.

Project Area

The project area extends 470 km from Pt. Conception, California, south to the Mexican border (fig. 1). The region includes microtidal basins, but has no significant inlets or narrow straits that would focus tidal currents in the nearshore. The coastline is highly variable in terms of its orientation (west to south facing), morphology (rocky to wide, flat beaches), structures (seawalls, jetties, groins, breakwaters, etcetera), exposure (open to significant island sheltering) and backbeach development (for example, rural coast to urban beach front). The continental shelf is narrow, so storm surge during even the largest winter storms approaches only 30 cm (D. Cayan, personal commun. 2009), and extreme coastal flooding is usually caused by waves.

Deep-water swell is primarily from the west and northwest, but long period southern swell can be important during the summer months and during El Niño years (O'Reilly, 1993). Wave energy is highly seasonal and episodic, with winter storms capable of significantly eroding local beaches (Shepard, 1950). To address nearshore wave variability adequately, Southern California wave modeling requires a high spatial resolution bathymetry grid in water depths less than 300 m, and high resolution directional wave spectra at the model-domain boundaries (O'Reilly and Guza, 1993; O'Reilly and others, 1993).

Model Framework

An overview of the model framework is given in figure 2. The model framework can be divided into two primary components: regional models and local models. The regional models are driven by boundary conditions derived from a global wave model (WaveWatch III), regional seas and swell data for Southern California provided by the Coastal Data Information Program (CDIP) and the National Data Buoy Center (NDBC) wave buoy network, a global tide model by TOPEX/Poseidon satellite altimetry, atmospheric pressure and wind forecasts by the National Weather Service (NWS), and bathymetric data sets by the National Ocean Service (NOS). The required inputs are swell, seas, wind, atmospheric pressure, tidal constituents, and bathymetry. The local models are driven primarily by output from the regional models.

The regional models consist of:

- CDIP Spectral Refraction Wave Model—the primary swell model, and
- Delft3D FLOW/WAVE Model—the primary water-level model.

The regional models are designed to provide outputs of the key physical parameters at each of the 4,729 MOnitoring and Prediction (MOP) points established for the Scripps CDIP Program in the study area (fig. 3). The nearshore MOPs are located along the 10-m depth contour and are paired with the closest corresponding backbeach MOP, with spacing every 100 m alongshore for the entire study area. The MOPs are the critical interface where the regional models provide output and scale down with the local models. Output parameters from the CDIP spectral refraction wave model (standard wave parameters) and Delft3D FLOW/WAVE model (water level) provide offshore boundary forcings that drive the local models.

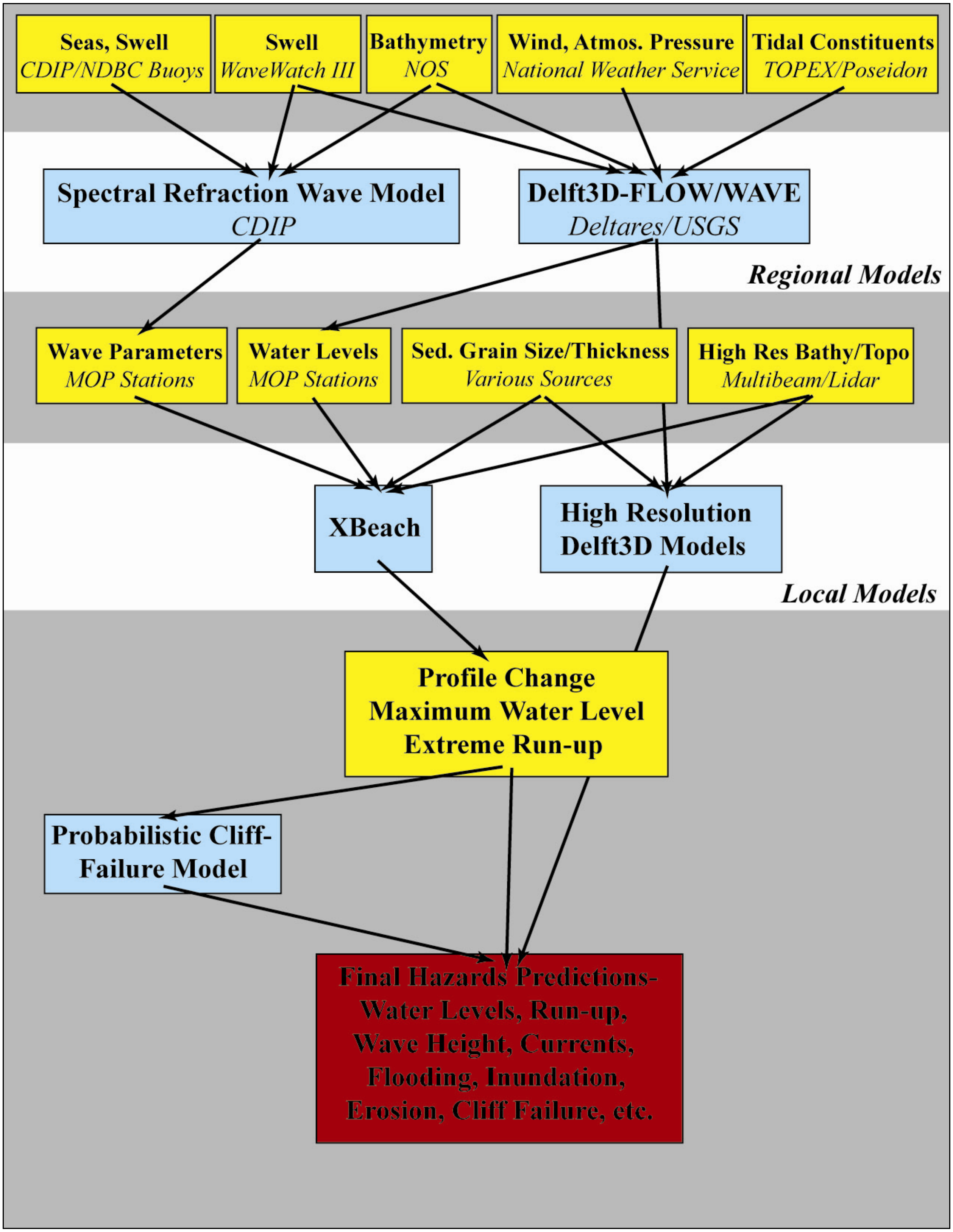

Figure 2. Coastal-hazards model framework.

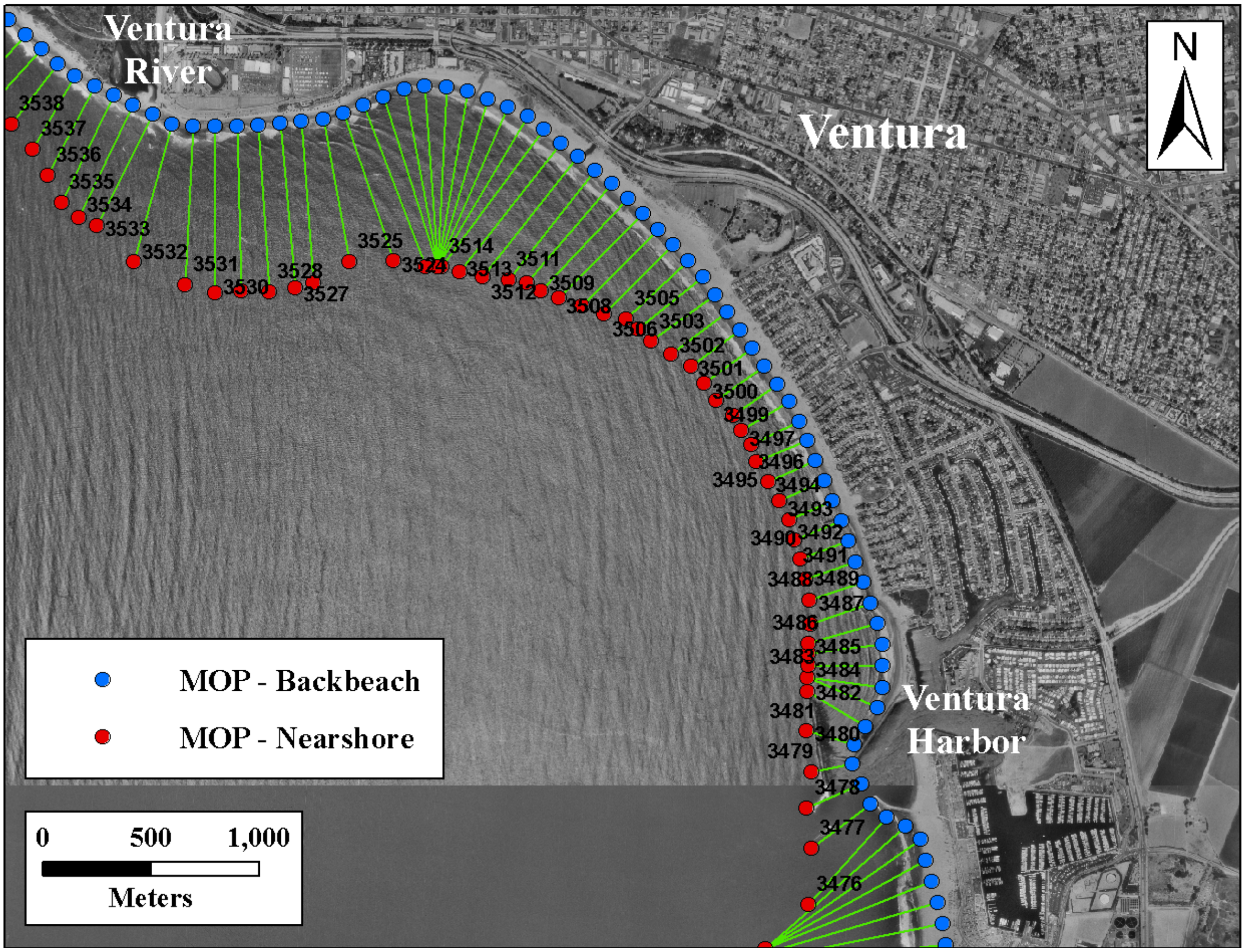

Figure 3. Example of MOnitoring and Prediction (MOP) points adjacent to the City of Ventura, California.

Regional Models

Spectral Refraction Wave Model

The CDIP Spectral Refraction Wave model uses measurements from a network of wave buoys and co-located point forecast spectra from the National Oceanic and Atmospheric Administration (NOAA) WaveWatch III global wave model (Tolman, 1997, 1999; NOAA, 2006) for its boundary conditions. The Spectral Refraction Model has been developed, calibrated, and extensively validated in Southern California since the early 1970s (O'Reilly and Guza, 1990, 1993, 1998; O'Reilly, 1993; O'Reilly and others, 1993). The CDIP program operates its coastal-wave MOP system on a 24/7 basis (Scripps Institution of Oceanography, 2009). CDIP will provide wave-parameter outputs at the aforementioned MOP sites to establish the wave boundary conditions for the local models. Regional bathymetry for the CDIP model is obtained primarily from the NOS hydrographic-survey archive

(National Ocean Service, 2009) but it is augmented with more recent, higher resolution bathymetry when available.

Delft 3D FLOW/WAVE Model

A framework of coupled model grids was built in the Delft3D FLOW and WAVE modules (Lesser and others, 2004; Delft Hydraulics, 2007) with sufficient resolution to predict stationary water levels at the MOPs (fig. 4). This framework allows (1) the flexible coupling of large-scale regional models and high-resolution models at key coastal locations, and (2) the exchange of input and output data with other models used in this project (for example, XBeach). The larger scale (regional) models will be forced with tidal constituents at the open boundary using the Oregon State University TOPEX/Poseidon tide data (Egbert and others, 1994) and swell through a link to the WaveWatch III wave model. The primary atmospheric-forcing parameters, surface winds and atmospheric pressure, will be obtained from the NWS real-time forecasts for Southern California (National Weather Service, 2009). Bathymetry is obtained from the same sources as in the Spectral Refraction Model. Water-level output and wave data from this regional-model coupling will also be used to drive a series of high-resolution Delft3D models at key coastal sites, such as harbor-mouth entrances, piers, and vulnerable beaches.

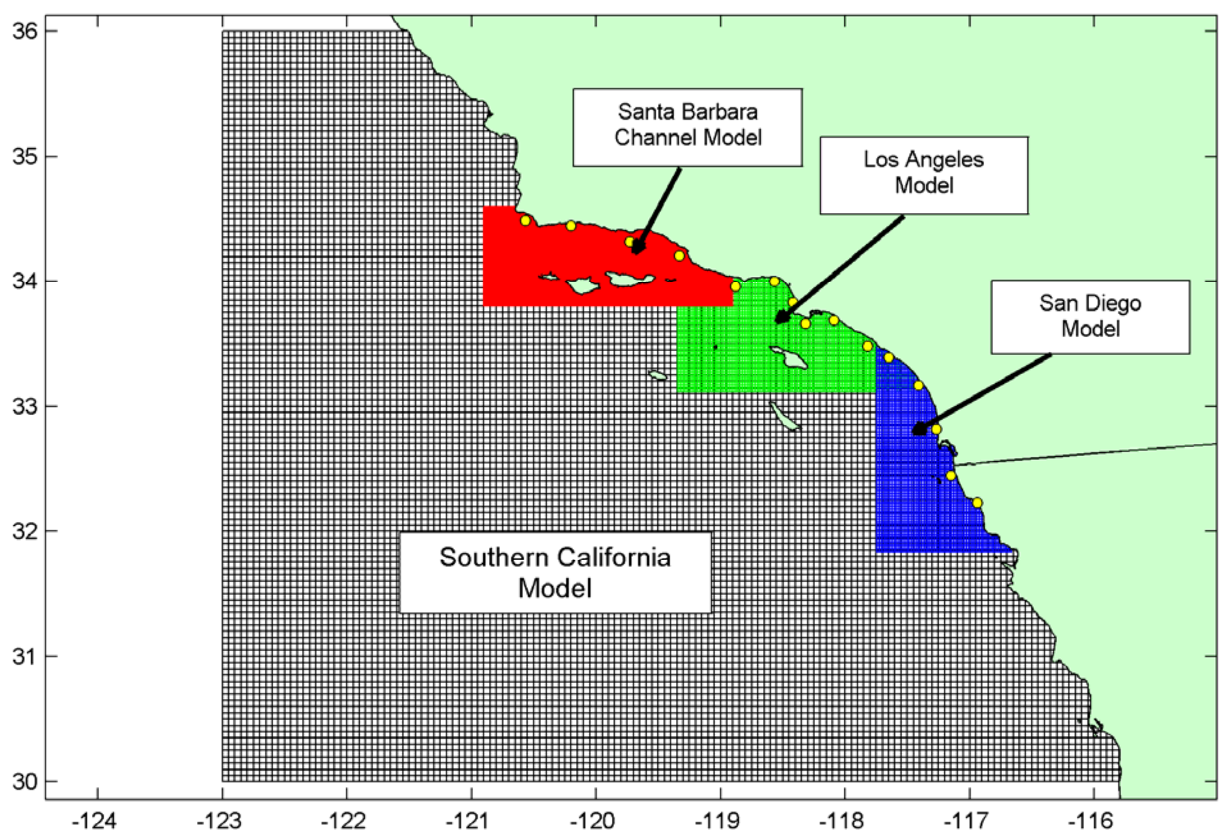

Figure 4. Regional Delft3D model grid with nested higher resolution grids.

Local Models

Wave parameters from the CDIP Spectral Refraction Model and water levels from the Delft3D FLOW/WAVE model assigned to each MOP station will drive the following local, high-resolution models where coastal hazards will be determined.

- XBeach Cross Shore Profile Model
- Delft3D High Resolution 2D/3D Morphological Models

These models will make local predictions of water levels, run-up, wave heights, and currents. The primary model interface would be MATLAB-based, with parameters input into a script as a matrix and output as another matrix, with graphical results then produced in MATLAB, ArcGIS, Google Earth, and/or other software packages for offline or online presentation.

At a given time step, such as in the middle of a major winter storm, the following parameters will be available for model input at the MOP sites and along MOP profiles.

Parameter	Source
significant wave height (Hs)	CDIP
peak wave period (Tp)	CDIP
incident wave angle/peak direction (θ)	CDIP
stationary water level (Zo)	Delft3D
nearshore slope	DEM
foreshore slope	DEM
beach slope	DEM
berm-crest elevation	DEM
dune-toe elevation	DEM
dune-crest elevation	DEM
cliff-toe elevation	DEM
cliff-top elevation	DEM
extreme back-beach elevation	DEM
elevation of infrastructure	DEM
obliqueness of wave approach	CDIP+DEM

Given these model inputs, the local models can be used to estimate numerous parameters, including

- breaking wave height and location,
- maximum water level,
- extreme run-up height ($R_{2\%}$), and
- flow velocities.

Additional parameters that can be estimated but only as research products with a high level of uncertainty include

- berm overtopping,
- coastal flooding/inundation,
- profile change,

- cliff failure,
- littoral transport (divergence and convergence), and
- infrastructure impact.

Digital elevation models (DEMs) will be constructed from the latest available Lidar (Light detection and ranging) and swath bathymetry mapping surveys (table 1) to generate a continuous grid from the 20-m depth contour through the shoreline and to 500 m beyond the backbeach, a distance where, in most cases, the coastal-hazards risks have significantly dissipated. DEMs will be built with a 3 m grid resolution using standard gridding techniques (for example, nearest neighbor, inverse distance weighting). The horizontal coordinate system will be the Universal Transverse Mercator system (UTM), Zone 11, north. The North American Vertical Datum of 1988 (NAVD88) will be used as the vertical reference point for all depths and elevations. Data gaps will be filled in with other available data, such as personal watercraft-collected single-beam bathymetry (for example, Barnard and others, 2007, 2009), NOS bathymetry, and NOAA IfSAR (Interferometric Synthetic Aperture Radar). Finally, cross-shore profiles will be extracted from the DEM along the MOP transects for direct input into XBeach, as well as for determination of morphological parameters for other local model inputs, such as slope, and for determining the elevation of important morphological features, such as dune and cliff toes. DEMs and profiles will be updated as data become available. Where new profile data are not available following several seasons of storms, typical winter/summer profiles may be used. Despite using the most recent, high-resolution data sets available, beach morphology changes daily and responds significantly seasonally and to individual storms. The storm response of beaches is highly dependent on the antecedent topography. Further, sediment-composition data and sediment-thickness data are available only for portions of the project area (for example, Mustain and others, 2007). Therefore, predictions that rely on highly accurate pre-storm beach shape (for example, erosion), elevations (for example, berm overtopping, flooding/inundation), and local sediment transport (for example, littoral transport) are highly speculative and, therefore, should be considered as qualitative/research products with high levels of uncertainty.

Table 1. Examples of high resolution data sets available for DEM construction in Southern California. [The agency listed controls the data. USGS, U.S. Geological Survey; CSUMB, California State University, Monterey Bay]

County	Survey	Agency	Horizontal resolution, in meters	Date
Santa Barbara/Ventura	Lidar	USGS	1	2005
Santa Barbara/Ventura	Multibeam	USGS/CSUMB	1-2	2005-8
Los Angeles	Lidar	Los Angeles County	1-2	2005
Orange	Lidar	Scripps	1	2008
San Diego	Lidar	Scripps	1	2007

XBeach Cross-Shore Profile Model

Instantaneous profile change, extreme run-up, and maximum water level will be determined using the XBeach profile model (Roelvink and others, 2008). Computation time for each of the 4,729 XBeach cross-shore models is on the order of minutes allowing for near real-time prediction of profile changes only if a multinode computer cluster is available. If a multinode computer cluster is not available, selected profiles can be run for real-time applications. Calibration coefficients will be determined for MOP locations in defined littoral cells and subsets thereof using available data and data collected during the proposed 2009-10 field work.

Delft3D High-Resolution 2D Morphological Models

High-resolution Delft3D models will be coupled to the regional Delft3D models using a nesting procedure. These models will be constructed in areas where detailed information of coastal conditions is critical to identify areas where safe navigation, public safety, and high-value infrastructure are likely to be compromised during a storm. A preliminary list of these sites is presented in figure 5 and table 2. These high-resolution models will predict wave height, breaking patterns, water levels, and current strength to support warning systems for harbor-mouth navigation and densely populated coastal regions where beach safety is threatened. Sediment transport (for example, channel shoaling and migration) may also be predicted, but this product is associated with a high level of uncertainty.

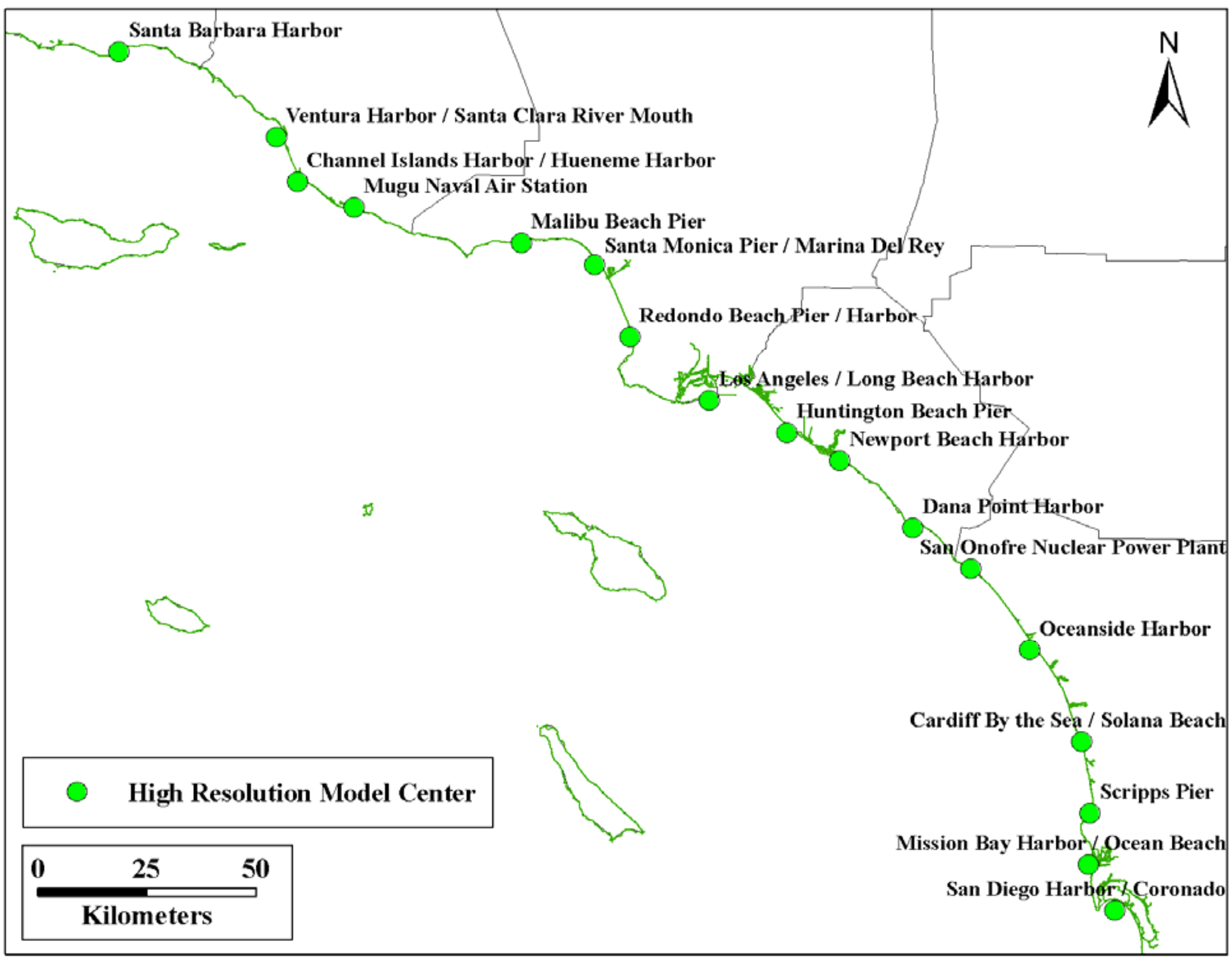

Figure 5. Map of the proposed high resolution Delft3D model locations in Southern California.

Table 2. Preliminary list of high resolution Delft3D model locations in Southern California. [B, Beach Safety; I, Infrastructure; N, Navigation]

Site	County	Issue
Cardiff By the Sea/Solana Beach	San Diego	B
Coronado/San Diego Harbor	San Diego	B,I,N
Mission Bay Harbor/Ocean Beach	San Diego	B,I,N
Oceanside Harbor	San Diego	B,I,N
San Onofre Nuclear Power Plant	San Diego	I
Scripps Pier	San Diego	B,I
Dana Point Harbor	Orange	N
Huntington Beach Pier	Orange	B,I
Newport Beach Harbor	Orange	B,I,N
Long Beach/Los Angeles Harbor	Los Angeles	I,N
Malibu Beach Pier	Los Angeles	B,I
Marina Del Rey/Santa Monica Beach Pier	Los Angeles	B,I,N
Redondo Beach Pier/Harbor	Los Angeles	B,I,N
Hueneme/Channel Islands Harbor	Ventura	B,I,N
Santa Clara River/Ventura Harbor	Ventura	B,I,N
Santa Barbara Harbor	Santa Barbara	I,N

Empirical Run-up Models

For validation purposes, and as a quick comparison with the run-up estimates from XBeach, the run-up height will also be estimated along each MOP profile using empirical run-up formulations to define the limit of landward inundation, extent of potential beach-width change, and frequency of exposure of dunes and cliffs to wave run-up. Although several formulations will be tested, the ones presented by Ruggiero and others (2001) and Stockdon and others (2006) are expected to be the most advantageous as they have both been tested against west coast data. The Ruggiero and others (2001) formulation ($C\sqrt{\beta H_o L}$), similar to Hunt's (1959) relationship, relies on four parameters: deep-water wave height (H_o) and wavelength (L), which can both be back-calculated from the spectral wave model, surf-zone slope (β), which will be available from the DEM dataset and is expected to be somewhat constant over seasons, and an empirical coefficient (C) that is dependent on several variables, such as breaker type, sediment grain size (friction and percolation), and foreshore slope. These dependencies and run-up predictions will be tested against available data and data collected in the field during the winter 2009-10 field campaign.

Longshore Transport Model

As an additional research application, we will use the quasi process-based Coastal Engineering Research Center's (CERC) equation (U.S. Army Corps of Engineers, 1984) to compute longshore sediment transport along the Southern California coast. This formulation has been applied to shoreline-change prediction in other studies, with moderate success along sandy, open-ocean coasts. By evaluating the effectiveness of the CERC equation along the sediment-starved coast of the project area, we expect to demonstrate the need for a hydrodynamics-based sediment-transport model, as illustrated by List and others (2008). The CERC equation will be used to identify erosion hot spots during storms due to longshore transport gradients. The coast is "naturally protected" by the presence of a beach, which depends on the sediment mass balance within a littoral control volume and the nearshore wave field that drives longshore sediment transport. A recent study investigated changes in the Southern California deep-water wave climate during the past 50 years (Adams and others, 2008) and documented a relationship among the Pacific Decadal Oscillation, El Niño Southern Oscillation (ENSO), and deep-water wave height, period, and direction. Changes in deep-water wave conditions will affect nearshore wave conditions and, hence, drive a response in spatial distribution of beach sediment. Using modeled nearshore wave conditions at the MOP sites, we will use the CERC equation to calculate longshore sediment-transport potential at each MOP location for the imposed wave climate during the assigned time step. Where the first spatial derivative of the longshore sediment-transport potential (also known as the divergence of drift) is negative, an erosional hot spot emerges; conversely, positive divergence results in sediment accumulation and coastal accretion during that time step. However, it is important to note that this calculation is based on potential longshore transport; actual longshore transport is limited by sediment availability, which can only be known from geophysical surveys of the subbottom and reliable estimates of sediment supply from fluvial sources and sea-cliff retreat, data that is only available in a few areas. Erosional hot spots identified with the longshore transport model can be used to guide the cliff-erosion and failure models by identifying specific sites where sea cliffs are less frequently protected by a sandy beach and, hence, are more frequently vulnerable to direct wave attack.

Probabilistic Cliff-Failure Model

Cliff failure is episodic and difficult to predict using real-time response models similar to those proposed elsewhere in this document due to the high temporal and spatial variability of coastal cliff retreat. However, if a particular area can be well constrained in terms of its geometry, material strength, and predominant failure mode, a process model can be applied to give reasonable estimates of expected cliff response (Collins and Sitar, 2008). In San Diego, for example, data sets currently exist that will provide a starting point for this type of work. Unfortunately, the effort required to perform this type of a study along the entire Southern California area precludes the extended application of a process-based method. For areas with large spatial extent, such as those being investigated here, the best approach to estimating regional cliff response to storm hazards will be to develop probabilistic models that are based on a likelihood of failure function and to use process-based models as a tool for model verification.

The likelihood of failure model will incorporate estimated total water levels associated with various storm scenarios, cliff geometry and lithology parameters. In addition, historical data on regional cliff-failure patterns (Hapke and Reid, 2007; Hapke and others, in press) will be used to identify erosion hotspots for more focused analyses. We will use a Bayesian statistical-based probabilistic cliff-failure model to develop predictions for wave-induced coastal cliff failure along the Southern California coastline. Although precipitation also leads to cliff failures, at this time it will be assumed that all cliff forcing from model inputs is solely wave driven. Run-up elevations determined from the XBeach Cross-shore Model, Lidar-based cliff-toe elevation and slope data, GIS datasets of regional geology, and cliff sediment strength parameters estimated from existing data (for example, California Geological Survey Seismic Hazard Mapping Act reports and California Coastal Commission permit reports) will drive the model using an iterative process to integrate accumulating information. Cliff-sediment strength will guide the model to those sections of the coastline most susceptible to wave-action induced cliff failure. Given the model inputs, the current state of knowledge regarding cliff-retreat hazards will be assessed, with new data subsequently gathered to address remaining questions. Finally, the site-specific, process-based modeling will be used to guide and verify probabilistic model output.

Products

Inundation and other hazard-assessment maps will be designed to meet emergency planner (for example, Los Angeles County Fire Department) and coastal management (for example, National Park Service, California Coastal Commission) agency needs. The results will be presented in a Google Map interface displaying predictions at each MOP site of parameters such as wave height, maximum water level, and maximum run-up. In addition, 2-D maps of inundation and harbor-mouth conditions (for example, breaking waves and current strength), as determined from the high-resolution Delft3D models, will be presented in an interactive format. Threshold values for parameters such as predicted breaking wave height and maximum run-up will be assessed to determine a rating for coastal hazards along each of the profile locations. Operational modeling may include an e-mail or phone-alert system for emergency planners to get the information out quickly. Coastal vulnerability based on the offline model simulations of severe winter storms can be used by the coastal-management agencies to assist in long-term planning and regional sediment management. Extensive product development is not planned to begin until fall 2009, after the critical needs of end users are identified.

Field Testing

The USGS is planning rapid storm-response surveys for October 2009 to March 2010 in Santa Barbara and Ventura Counties along predefined transects where semiannual monitoring has been conducted since October 2005 (Barnard and others, 2009). This will entail pre- and post-storm topographic and nearshore bathymetric surveys using personal watercraft to test profile evolution predicted by XBeach. A series of buried beach pressure sensors are planned for installation prior to the winter-storm season for analyzing run-up conditions.

The USGS will use continuous video imaging at the Goleta Pier, City of Carpinteria Beach, and Ventura Pier in the Santa Barbara area, and at Scripps Pier and Tijuana Estuary in the San Diego area, to monitor shoreline response, run-up conditions, and/or wave height during the winter-storm season for calibration and validation of the hazards-model package.

In conjunction with these USGS efforts, CDIP has requested assistance from San Diego County coastal cities in identifying problem areas and documenting wave-flooding events. Local city engineering and planning departments have agreed to document the extent and severity of the flooding. This documentation will contribute to the validation of the inundation predictions and warning system.

A 7-year data set at Torrey Pines Beach in San Diego relates beach-profile changes to the incident wave field (Yates and others, 2009). The performance of the XBeach model will be compared with field data to determine the capability of the model to predict profile evolution and shoreline change on high-energy, west coast beaches, and to assess the level of uncertainty in predictions of beach morphologic changes within the coastal-hazards model.

Field verification of the probabilistic cliff-failure model will focus on one to three areas extending up to one to two kilometers in length. Both ground-based and aerial surveys will be conducted to identify areas of incipient failure and to monitor their response. These studies will form the inputs for future process-based modeling and for probabilistic model verification. Geologic and topographic cliff mapping, along with geotechnical testing, will be incorporated with both seasonal and historical observations of cliff failure to develop a process model that links the effects of storm input to cliff failure. The process model output (predictions of cliff failure given particular storm scenarios) will provide a direct verification of the probabilistic model output for these particular locations.

Model Applications

In addition to operational predictions, the modeling framework lends itself to a variety of offline applications, such as sea-level rise impacts and coastal vulnerability to rare, unusually powerful storms. Coastal Managers need information on sea-level rise, coastal vulnerability, and storm impacts for their short- and long-term planning needs. The following winter-storm scenarios will provide information critical for their resource planning.

Winter-Storm Scenario with Multi-Hazards Demonstration Project in Southern California

The USGS, in collaboration with the NWS, is designing a “massive but plausible” winter-storm scenario to serve as a preliminary test for the various tasks in the USGS Multi-Hazards Demonstration Project in Southern California. The storm is loosely modeled after the 1861-1862 winter flood, which is believed to have been a greater than 100-year recurrence-interval event, but one that is more likely to occur under future climate-change scenarios. A simulated hourly time-series of the key atmospheric components (for example, rainfall, surface wind speed and direction, and atmospheric pressure) will be provided for the western Pacific region. The event will be simulated using standard Atmospheric simulation Reanalysis tools and by stitching together two very large winter storms for which extensive historical data exists, probably storms from the winters of 1969 and 1986. Coastal-hazards model results from the winter-storm scenario will be provided to emergency planners, coastal managers, and structural engineers so that they can become familiar with, and plan appropriately for, the kinds of impacts the Southern California coast will experience during a storm of this magnitude. This exercise will also greatly aid in developing products that are appropriate for the end users, and identifying model components that need refinement.

Other Winter-Storm Scenarios

Coastal-hazard simulations of selected historical winter storms will also be performed using existing physical-forcing data, such as archived wind and wave parameter data and detailed hindcasts from the last decade. For instance, hourly MOP site wave-parameter hindcasts for Southern California date back to 2000. Additionally, 50-year wave hindcasts of the Western Pacific are available (Graham and Diaz, 2001) and may be utilized to simulate storms that predate 2000, such as the severe storms that occurred during the 1982-83 El Niño winter. These simulations will serve to validate the model where quantitative, or at least anecdotal, information exists on storm impacts in the project area, and will inform coastal managers of the stretches of coast that were most vulnerable to these events.

The Intergovernmental Panel on Climate Change (IPCC) conservatively projects up to 79 cm of global sea-level rise by 2100, barring more dramatic changes that my be induced by the collapse of the West Antarctic ice sheet and other influences (Intergovernmental Panel on Climate Change, 2007). Additionally, increasing storm intensity, frequency, and wave heights on the west coast (Allan and Komar, 2006) will subject many beaches to elevated coastal-hazards risks for the foreseeable future.

Current statistical trends suggest that coastal storms that include the damaging combination of large waves and higher water levels will be more frequent in the future, resulting in greater risk of coastal inundation (fig. 6). Therefore, additional simulations of storms based on current trends in sea level and

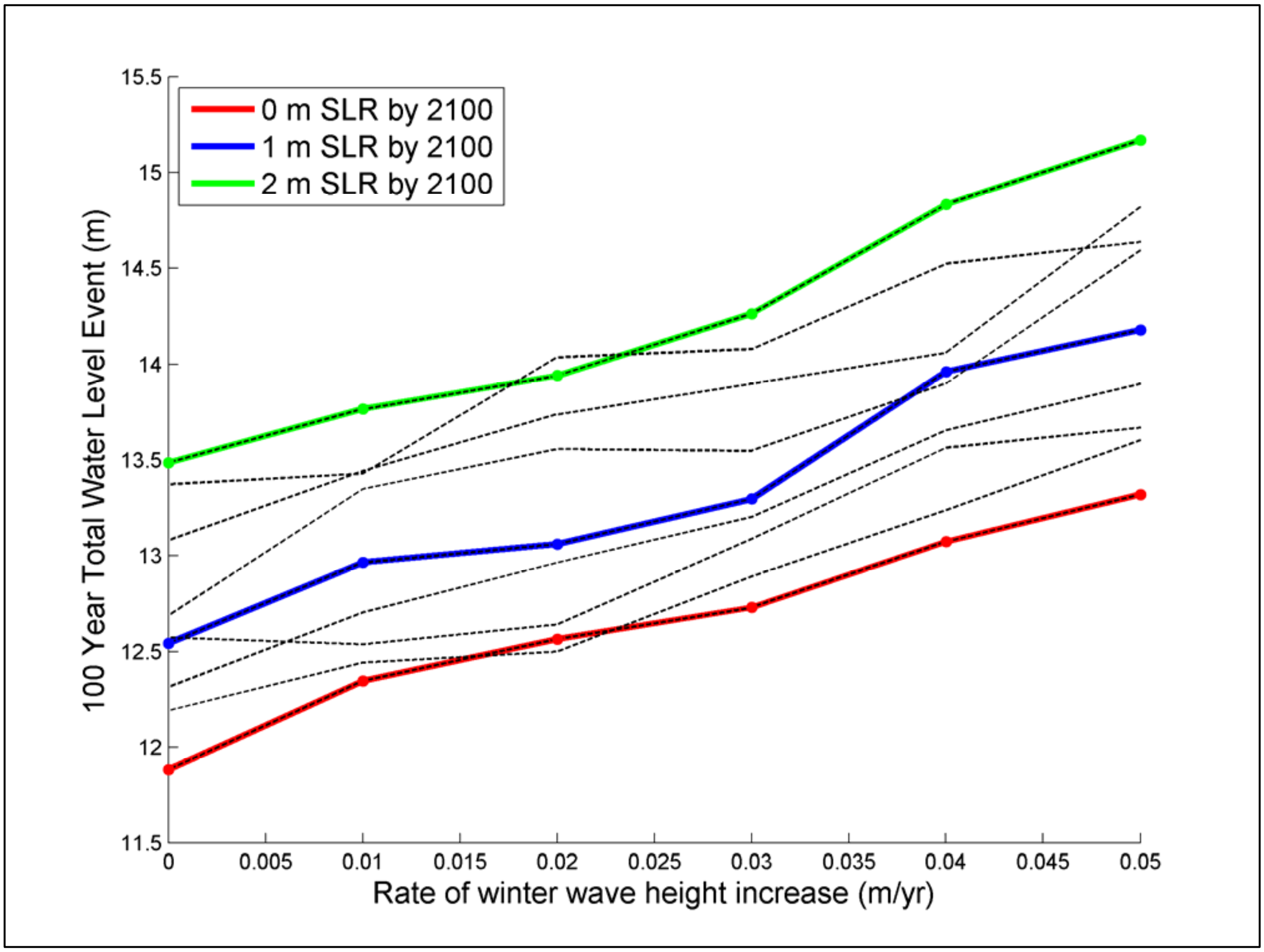

Figure 6. Example from Southwest Washington State of the relationship between winter wave height increases and 100-year water-level events under various sea-level rise (SLR) scenarios. Each 100-year Total Water Level (TWL) results from 500 year Monte Carlo simulations of both wave runup and storm surge including the dependency between extreme wave heights and extreme storm surge.

extreme wave heights are planned. We will take advantage of recent developments in extreme-values modeling to develop additional plausible severe winter-storm scenarios within a probabilistic framework. Our goal is to improve upon existing approaches, such as using worst-case benchmark events (for example, the largest measured wave height) as design parameters for assessing coastal flood and erosion hazards. For physical systems like those that govern coastal flood and erosion hazards, outcome severity involves two or more random variables (for example, wave heights, periods, and water levels), and the return period of outcomes (for example, flooding) is not equal to the forcing return period of a single variate (Hawkes and others, 2002). Unless wave height and still-water level are completely dependent or independent, multivariate extremes are difficult to predict directly from observational data, particularly in light of the relatively short wave- and water-level records that typically are available. Thus, our goal will be to produce design events that incorporate joint probability analysis based on distributions fitted to water levels and wave heights (and wave steepness), including the dependence between them. We then will apply a full simulation method using the Monte Carlo simulation technique and the fitted distributions. In this manner, hundreds to thousands of years of total water-level time series (or other structural functions, such as dune-erosion models) can be simulated and accurate design event return levels can be determined. This approach is readily modified to include the potential impacts of climate change and variability on coastal-flood and erosion hazards (Callaghan and others, 2008).

Additional Considerations

There are additional coastal hazards that should be considered during severe storms, including wind damage, terrestrial flooding, and water-quality issues. However, due to funding constraints, these items are not going to be considered under this project. Only Oceanside Harbor (San Diego County), Marina Del Rey (Los Angeles County), and the Santa Clara River mouth (Ventura County) could have potentially significant terrestrial flooding issues during a major storm, so the omission of this component would not be significant for most of the project area.

The influence of shoreline armoring and the undercutting of structures during coastal storms also deserve special consideration, however, the detail required to accurately identify these issues is beyond the scope of this project.

Model Transferability

The coastal-hazards model outlined here has been designed for efficient transferability and application to a variety of coastal settings where the magnitude and relative balance between waves, tidal currents, and surge may vary significantly during coastal storms. To test model transferability, a small pilot project is currently being planned for the mouth of San Francisco Bay in Northern California. This site was chosen because of the importance of understanding storm conditions at the entrance to a major harbor, and because the USGS has an extensive bathymetric and topographic data set for the area, including video-camera monitoring (Barnard and others, 2007), which will enable hindcast testing of the coastal-hazards model for a series of recent winter storms.

Collaboration and Peer-Review

The USGS has developed formal working relationships with the following institutions to collaborate in the development of this model:

- Deltares (Maarten van Ormondt, Edwin Elias),
- Oregon State University (Peter Ruggiero),
- Scripps Institution of Oceanography (Bill O'Reilly, Julie Thomas and Robert Guza), and
- University of Florida (Peter Adams).

The USGS is interacting with the following agencies to ensure that model products meet emergency planner and coastal management needs:

- Bay Area Conservation and Development Commission (Carolynn Box),
- Beach Erosion Authority for Clean Oceans and Nourishment (Jim Bailard),
- California Coastal Commission (Lesley Ewing),
- California Department of Boating and Waterways (Kim Sterrett),
- California Ocean Protection Council (Doug George),
- California Resources Agency (Brian Baird),
- California State Parks (Sydney Brown),
- Federal Emergency Management Agency (Kathleen Schaefer),
- Los Angeles County Fire Department, Urban Search and Rescue Task Force (Larry Collins),
- Los Angeles County Lifeguards (Angus Alexander),
- National Park Service (Rebecca Beavers),
- Southern California Coastal Ocean Observing System (Julie Thomas),
- U.S. Army Corps of Engineers, Los Angeles District (Heather Schlosser), and
- U.S. Army Corps of Engineers, San Francisco District (Peter Mull).

The following coastal scientists are being consulted for evaluation of model development and performance:

- Dan Hanes, USGS, Coastal and Marine Geology Program, Santa Cruz, CA,
- Jeff List, USGS, Coastal and Marine Geology Program, Woods Hole, MA,
- Nathaniel Plant, USGS, Coastal and Marine Geology Program, St. Petersburg, FL,
- Bruce Richmond, USGS, Coastal and Marine Geology Program, Santa Cruz, CA,
- Dano Roelvink, UNESCO-IHE Institute for Water Education, The Netherlands,
- Hilary Stockdon, USGS, Coastal and Marine Geology Program, St. Petersburg, FL,
- Dave Thompson, USGS, Coastal and Marine Geology Program, St. Petersburg, FL,
- Dirk-Jan Walstra, Deltares, The Netherlands, and
- John Warner, USGS, Coastal and Marine Geology Program, Woods Hole, MA.

Project Timeline

- Spring/Summer 2009—Set-up preliminary model and testing.
- Summer 2009—Winter-Storm Scenario.
- Fall/Winter 2009-10—Field testing, model improvements, and product development.
- Spring 2010—Additional storm scenarios.
- June 2010—Publish results of winter-storm scenario(s).
- June 2010+—Full model implementation (online?).
- September 2011—Project completion.

Summary

The USGS is developing a coastal-hazards model to determine the impact of severe winter storms, both in real-time and using prescribed scenarios. The model and forecasts in this project can be updated periodically to include new changes in sea level and other inputs (for example, wave climate, bathymetry, topography), and can be used as the basis for local hazard assessments and real-time warning systems in strategic partnership with numerous Federal, State, local, and academic partners. Once developed and validated in southern California, the modeling framework can readily be adapted and applied for other priority areas, such as coastal urban centers and threatened ecosystems, particularly on the west coast.

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References Cited

Adams, P., Inman, D.L., and Graham, N.E., 2008, Southern California deep-water wave climate—Characterization and application to coastal processes: Journal of Coastal Research, v. 24, no. 4, p. 1022-1035.

Allan, J.C., and Komar, P.D., 2006, Climate controls on US West Coast erosion processes: Journal of Coastal Research, v. 22, no. 3, p. 511-529.

Barnard, P.L., Eshleman, J.L., Erikson, L.H., and Hanes, D.M., 2007, Coastal processes study at Ocean Beach, San Francisco, CA—summary of data collection 2004-2006: U.S. Geological Survey Open-File Report 2007-1217, 165 p., [available online at http://pubs.usgs.gov/of/2007/1217/, last accessed April 26, 2009].

Barnard, P.L., Revell, D.L., Hoover, D. Warrick, J., Brocatus, J., Draut, A.E., Dartnell, P., Elias, E., Mustain, N., Hart, P.E., and Ryan, H.F., 2009, Coastal processes study of Santa Barbara and Ventura Counties, California. U.S. Geological Survey Open-File Report 2009-1029, 928 p., [available online at http://pubs.usgs.gov/of/2009/1029/, last accessed April 26, 2009].

Callaghan, D.P., Nielsen, P., Short, A., and Ranasinghe, R., 2008, Statistical simulation of wave climate and extreme beach erosion: Coastal Engineering, v. 55, p. 375-390.

Collins, B.D., and Sitar, N., 2008, Processes of coastal bluff erosion in weakly lithified sands, Pacifica, California, USA: Geomorphology, v. 97, nos. 3-4, p. 483-501, [doi:10.1016/j.geomorph.2007.09.004].

Delft Hydraulics, 2007, User manual Delft3D- FLOW: WL/ Delft Hydraulics, 614 p.

Egbert, G., Bennett, A., and Foreman, M., 1994, TOPEX/Poseidon tides estimated using a global inverse model: Journal of Geophysical Research, v. 99, no. C12, p. 24,821-24,852.

Graham, N.E., and Diaz, H.F., 2001, Evidence for intensification of North Pacific winter cyclones since 1948: Bulletin of the American Meteorological Society, v. 82, no. 9, p. 1869-1893.

Hapke, C.J., and Reid, D., 2007, The national assessment of shoreline change, Part 4, Historical coastal cliff retreat along the California coast: U.S. Geological Survey Open-File Report 2007-1133, [available online at http://pubs.usgs.gov/of/2007/1133, last accessed April 26, 2009].

Hapke, C., Reid, D., and Richmond, B.M., *in press*, Rates and trends of coastal change in California and the regional behavior of the coastal system: Journal of Coastal Research.

Hawkes, P.J., Gouldby, B.P., Tawn, J.A., and Owen, M.W., 2002, The joint probability of waves and water levels in coastal engineering design: Journal of Hydraulic Research, v. 40, no. 3, p. 241-251.

Hunt, I.A., 1959, Design of seawalls and breakwaters: Journal of Waterways and Harbors Division, v. 85 (WW3), p. 123-152.

Intergovernmental Panel on Climate Change, 2007, IPCC Fourth Assessment Report: Climate Change 2007, 4 volumes.

Jones, L., Bernknopf, R., Cannon, S., Cox, D.A., Gaydos, L., Keeley, J., Kohler, M., Lee, H., Pont, D., Ross, S., Schwarzbach, S., Shulters, S., Ward, A.W., and Wein, A., 2007, Increasing resiliency to natural hazards—A strategic plan of the Multi-Hazards Demonstration Project in Southern California: U.S. Geological Survey Open-File Report 2007-1255, 19 p., [available online at http://pubs.usgs.gov/of/2007/1255/, last accessed April 26, 2009].

Lesser, G.R., Roelvink, J.A., van Kester, J.A., and Stelling, G.S., 2004, Development and validation of a three-dimensional morphological model: Coastal Engineering, v. 51, p. 883-915.

List, J.H., Hanes, D.M., Ruggiero, P., Benedet, L., Elias, E.P., and Erikson, L.H., 2008, Modeling coastal morphodynamics using local estimates of alongshore sediment transport—Limits and alternatives: EOS Transactions of the American Geophysical Union, v. 89, no. 53, Fall Meeting Supplement, Abstract OS34A-01.

Mustain, N., Griggs, G., and Barnard, P.L., 2007, A rapid compatibility analysis of potential offshore sand sources for beaches of the Santa Barbara littoral cell, *in* Kraus, N.C., Rosati, J.D. (eds.), Coastal sediments '07, Proceedings of the 6th International Symposium on Coastal Engineering and Science of Coastal Sediment Processes, American Society of Civil Engineers, New Orleans, v. 3, p. 2501-2514.

National Oceanic and Atmospheric Administration, 2006, WaveWatch III Model, Center of Operational Products and Services, [http://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.html, last accessed April 26, 2009].

National Ocean Service, 2009, NOS Hydrographic Survey Viewer, [http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm, last accessed April 26, 2009].

National Weather Service, 2009, National Weather Service Forecast Office – GIS Weather Data, [http://www.wrh.noaa.gov/gis/index.php, last accessed April 26, 2009].

O'Reilly, W., 1993, The southern California wave climate—effects of islands and bathymetry: Shore and Beach, v. 61, no. 3, p. 14-19.

O'Reilly, W.C., and Guza, R.T., 1990, A comparison of spectral refraction and refraction-diffraction wave propagation models: Journal of Waterway, Port, Coastal, and Ocean Engineering, v. 117, no. 3, p. 199-215.

O'Reilly, W.C., and Guza, R.T., 1993, A comparison of spectral wave models in the Southern California Bight, Coastal Engineering, v. 19, no. 3, p. 263-282.

O'Reilly, W.C., and Guza, R.T., 1998, Assimilating coastal wave observations into regional swell predictions, Part I—Inverse methods: Journal of Physical Oceanography, v. 28, no. 4, p. 679-691.

O'Reilly, W.C., Seymour, R.J., Guza, R.T., and Castel, D., 1993, Wave monitoring in the Southern California Bight: Ocean Wave Measurement and Analysis, Proceedings of 2nd International Symposium, p. 849-863.

Roelvink, D., Reniers, A., Van Dongeren, A., van Thiel de Vries, J., Lescinski, J., and McCall, R., 2008, Modeling hurricane impacts on beaches, dunes, and barrier islands, *in* Smith, J.M. (ed.), Coastal Engineering 2008, Proceedings of the 31st International Conference, Hamburg, Germany, August 31 to September 5, v. 5, 14 p.

Ruggiero, P., Holman, R.A., and Beach, R.A., 2004, Wave run-up on a high-energy dissipative beach: Journal Of Geophysical Research-Oceans, v. 109 (C6).

Scripps Institution of Oceanography, 2009, The Coastal Data Information Program: San Diego, Integrative Oceanography Division, Scripps Institution of Oceanography, [http://cdip.ucsd.edu, last accessed April 26, 2009].

Shepard, F.P., 1950, Beach cycles in Southern California: Memo 20, Beach Erosion Board. U.S. Army Corps of Engineers, Washington, D.C., 26 p.

Stockdon, H.F., Holman, R.A., Howd, P.A., and Sallenger, A.H., 2006, Empirical parameterization of setup, swash, and runup: Coastal Engineering, v. 53, no. 7, p. 573-588.

Tolman, H.L., 1997, User manual and system documentation of WAVEWATCH-III version 1.15: NOAA/NWS/NCEP/OMB Technical Note 151, 97 p.

Tolman, H.L., 1999, User manual and system documentation of WAVEWATCH-III version 1.18: NOAA/ NWS/NCEP/OMB Technical Note 166, 110 p.

U.S. Army Corps of Engineers, 1984, Shore protection manual: Coastal Engineering Research Center. U.S. Government Printing Office, Washington, D.C.

Yates, M.L., Guza, R.T., O'Reilly, W.C., and Seymour, R.J., 2009, Overview of seasonal sand level changes on Southern California beaches: Shore and Beach, v. 77, no. 1, p. 39-46.

Appendix

Important Websites

- Coastal Data Information Program: http://cdip.ucsd.edu (last accessed April 26, 2009)

- USGS Coastal Hazards Project: http://walrus.wr.usgs.gov/coastal_processes/socalhazards/ (last accessed April 26, 2009)

- XBeach: http://www.xbeach.org/ and http://www.unesco-ihe.org/About/Academic-departments/Water-Engineering/Hydraulic-Engineering-Coastal-Engineering-and-Port-Development/Research/Research-Projects/Modeling-hurricane-impacts-on-beaches-dunes-and-barrier-islands-XBeach (last accessed April 26, 2009)

- Delft3D Model: http://delftsoftware.wldelft.nl/index.php?option=com_content&task=view&id=109 (last accessed April 26, 2009)

List of Acronyms

BEACON—Beach Erosion Authority for Clean Oceans and Nourishment

CDIP—Coastal Data Information Program

CERC—Coastal Engineering Research Center

CSUMB—California State University, Monterey Bay

DEM—Digital Elevation Model

MOP—Monitoring and Prediction

NDBC—National Data Buoy Center

NOAA—National Oceanic and Atmospheric Administration

NOS—National Ocean Service

USGS—U.S. Geological Survey