

# WAVE PREDICTION IN THE SANTA BARBARA CHANNEL

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## ABSTRACT

Wave conditions in the Santa Barbara Channel impact fishing, commercial shipping, and recreation. In addition, nearshore waves drive sediment processes such as beach erosion and harbor entrance shoaling. Accurate historical wave information is needed for engineering design, environmental impact assessment and hazard mitigation. Wave fields in the channel are complex owing to the sheltering effects of Point Conception and the Channel Islands, the reflection of wave energy from the steep coastal cliffs of Santa Cruz Island, and the irregularity of the local continental shelf bathymetry. Wave model predictions and field observations from the Coastal Data Information Program are used to illustrate these phenomena. Ongoing and planned wave modeling in the channel is described.

**Keywords:** Santa Barbara Channel, physical oceanography, waves.

## INTRODUCTION

The complicated wind and wave conditions in the Santa Barbara Channel region are well known to mariners. The energy and direction of short period seas generated by local winds, and of long period swell radiated from distant storms, can vary greatly throughout the channel on any given day. Local seas often mirror the highly variable wind fields resulting from the mountainous coastal and island topography, and swells are dramatically affected by the sheltering of Point Conception and the Channel Islands. In addition, the complex shallow water bathymetry within the channel results in large wave height variations along the shoreline.

Wave conditions along the California coast have been monitored for the last two decades by the Coastal Data Information Program (CDIP) at Scripps Institution of Oceanography with the sponsorship of the California Department of Boating and Waterways and the U.S. Army Corps of Engineers (Seymour et al. 1993). In recent years, the program has used numerical wave models in conjunction with field measurements to predict regional wave conditions. As part of this effort, CDIP provides experimental real-time predictions of swell heights (no local seas) in the Santa Barbara Channel via the World Wide Web.

The present CDIP wave model is described and examples of the estimated swell height variability in the

channel are presented. A recent field study designed to validate the wave model is discussed. The model underpredicted swell energy in the lee of Point Conception during northwest swell events, and the measurements confirm that the model underprediction is primarily the result of (unmodeled) wave energy reflection back into the channel from the coastal cliffs of Santa Cruz Island. Future plans to incorporate both island wave reflection and local wind wave generation into the model are described.

## SWELL HEIGHT PREDICTION IN THE SANTA BARBARA CHANNEL

Computer models, supplemented with measurements from buoys and pressure sensors, are widely used to hindcast and forecast waves. Real-time model predictions (nowcasts) of swell wave heights (wave periods of 8 to 25 seconds) in the channel are disseminated hourly over the World Wide Web at [cdip.ucsd.edu](http://cdip.ucsd.edu) by CDIP (Figure 1).

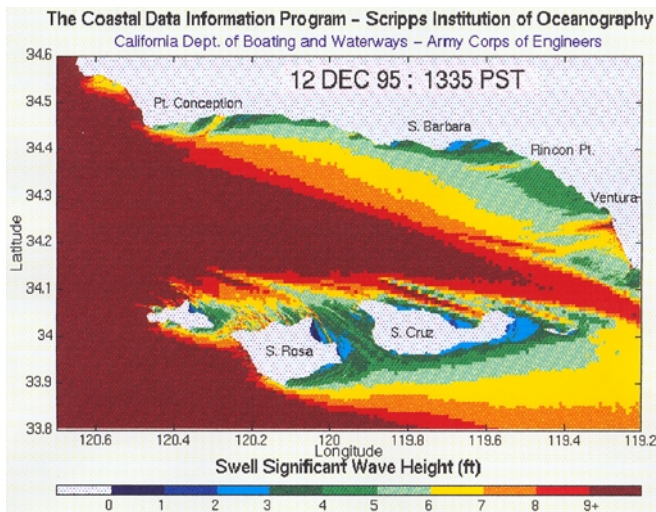
The predictions are based on a numerical refraction-diffraction model that simulates the propagation of waves from the deep ocean into shallow water depths of approximately 10 m (Kirby 1986; O'Reilly and Guza 1993; O'Reilly 1993). As an individual wave crest propagates into shallow water its speed decreases and its height increases (shoaling). However, at the same time, variations in the water depth along a crest lead to variations in speed and bending of the crest (refraction). Refraction results in the convergence or divergence of the wave energy associated with the crest, producing changes in wave height as well as wave direction. When the convergence or divergence of wave energy becomes very strong, producing large changes in wave energy over short distances, additional wave crests of significant size evolve to move wave energy away from or into these areas and reduce the spatial variation of energy (diffraction). Wave shoaling, refraction, and diffraction can all be important in the Santa Barbara Channel and are included in the numerical model. The model does not include the generation of seas by local winds, so the predictions are presently restricted to swell arriving from more distant sources.

The model is initialized with wave measurements from either an array of sensors attached to Chevron's Harvest Platform, or a wave buoy near the platform, located approximately 10 km west of Point Conception in 200 m water depth.

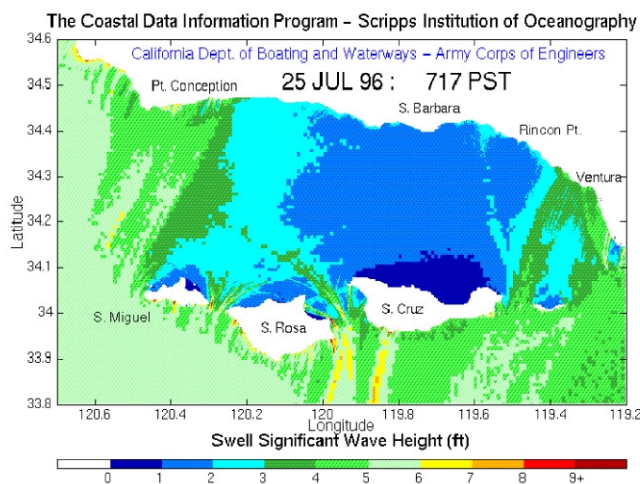
The measurements are transmitted by telephone lines to the CDIP central facility at Scripps where they are processed to estimate the deep water wave spectrum (the distribution of wave energy as a function of the wave period and direction). This wave spectrum is in turn used to initialize the refraction-diffraction model that predicts the wave field within the entire Southern California Bight. (Other offshore buoys are used to initialize model predictions for regions in central and northern California.) Examples of nowcasts in the Santa Barbara Channel for incident west and south swells with 17 second periods are shown in Figures 1 and 2, respectively. The location of areas that are sheltered by the Channel Islands depends critically on the swell direction.

### West (Winter) Swell

For the west swell event, relatively large swell heights are predicted to occur just east of Point Conception along



**Figure 1.** CDIP swell model prediction for the Santa Barbara Channel during a large west swell event in December 1995.



**Figure 2.** CDIP swell model prediction for the Santa Barbara Channel during a large south swell event in July 1996.

the south-facing coastline (e.g., Figure 1 where bands of yellow indicate larger waves than in the adjacent green regions). A submarine escarpment (steep slope) running along a SW-NE fault line across the continental shelf focuses westerly swell energy between Hollister Ranch and Drake's Point, as is well known to the local surfing community. Rincon Point also has significantly higher wave heights than the surrounding coastline during west swell events.

Wave heights are also significantly amplified along portions of the Channel Islands bordering the south side of the channel. Most of the "focusing zones" begin to develop in relatively deep water. That is, relatively large scale bathymetric features, like an escarpment or the curvature of the continental shelf bathymetry, produce these zones of higher waves along the coast. Small scale coastal features that are often associated with bigger waves, such as a popular surfing reef or headland, often fall within one of the larger focusing zones and are a final, very localized enhancement of this larger scale wave amplification.

Another area of high swell height is located at the east end of the Santa Barbara Channel just south of Ventura (Figure 1). In this case, wave focusing is caused by the massive subaerial fan of sediment deposited on the shelf by the Ventura and Santa Clara rivers. This large scale bathymetric feature extends nearly 40 km offshore and concentrates much of the wave energy propagating eastward down the channel onto a narrow stretch of coastline near the Santa Clara River mouth. When the deep water swell comes from a slightly WSW direction (e.g., the swell of an arriving winter storm) this focusing zone shifts northward directly into the Ventura area and is likely the underlying cause of the occasional storm damage to the Ventura Pier.

Finally, a significant amount of west swell energy propagates through the deep water passage between Anacapa Island and the mainland at the east end of the channel. This wave energy reaches a small section of coastline at the south end of Santa Monica Bay around Redondo Beach. This phenomenon has been linked to time periods when surprisingly large waves were observed in the Redondo Beach area relative to the rest of the Santa Monica Bay coastline.

### South (Summer) Swell

Swell conditions in the Santa Barbara Channel are quite different during the summer when south swell dominates the southern California wave climate. Most of the channel and the south-facing coastline are sheltered by the Channel Islands (Figure 2). The extent to which the west end of the channel is sheltered by San Miguel Island depends on the direction of the arriving swell. South swell arriving from storms near New Zealand (a common source region) reach the west end of the channel (Figure 2) whereas swell arriving from a slightly more easterly source (storms closer to South America) are almost completely blocked from the west end of the channel (not shown).

Wave conditions at the east end of the channel are similarly sensitive to the swell direction.

South swell propagates past Anacapa Island and typically reaches the coast near Ventura and Rincon Point (Figure 2). Swell from a direction slightly east of south (e.g., a true compass heading of  $160^\circ$ ) reaches Santa Barbara, but these events are rare.

### WAVE REFLECTION FROM THE CHANNEL ISLANDS

The swell model was tested using observations in the channel during the winter of 1994-1995. Three Datawell Directional Waverider buoys were deployed in 50 m water depth near Santa Rosa and Santa Cruz Islands, and a fourth buoy was installed near the mainland east of Santa Barbara (Figure 3, sites labeled as "Scripps Buoys (1995)"). The entire east end of the channel is heavily sheltered by Point Conception from the WNW swell that dominated during the experiment period. The Santa Barbara Buoy was deep in the theoretical Point Conception wave "shadow" (Figure 4, upper panel). The model underpredicted the swell energy (overpredicted the sheltering effects) at this location (Figure 4, lower panel). The directions of the measured waves, estimated from the directional buoy data, consistently showed that the primary cause of the model underprediction is the presence of reflected wave energy coming from Santa Cruz Island (Figure 5, right panel, and shown schematically in Figure 4, top panel) that is not included in the model. This hypothesis is further supported by the buoy measurements

close to Santa Cruz Island (Figure 5, left panel) showing waves coming from two directions; one direction corresponds to waves incident from the deep ocean and the other to waves reflected from the island. Similar results (not shown) were obtained by the buoy at the northeast corner of the island. The north side of Santa Cruz Island appears to be a particularly good wave reflector owing to the large extent of sheer coastal cliffs that drop straight into water depths of 10 m or more. Interestingly, the measurements from Santa Rosa Island (not shown) show little reflected wave energy. The Santa Rosa coastline has low cliffs, but these typically have rocky shallows at their base, and the continental shelf along the island is much broader and shallower than the Santa Cruz Island shelf.

### FUTURE MODEL IMPROVEMENTS

Through grants from the Minerals Management Service and the Office of Naval Research, efforts are underway to improve the CDIP Santa Barbara Channel wave predictions by incorporating wave reflection from Santa Cruz Island and wave generation by local winds.

The consistent CDIP model underprediction of wave energy in the lee of Point Conception during northwest swell events (Figure 4, lower panel) suggests that a simplified treatment of the reflected wave field may be possible for practical applications. Historical wave measurements from the channel (Figure 3) are presently being analyzed to

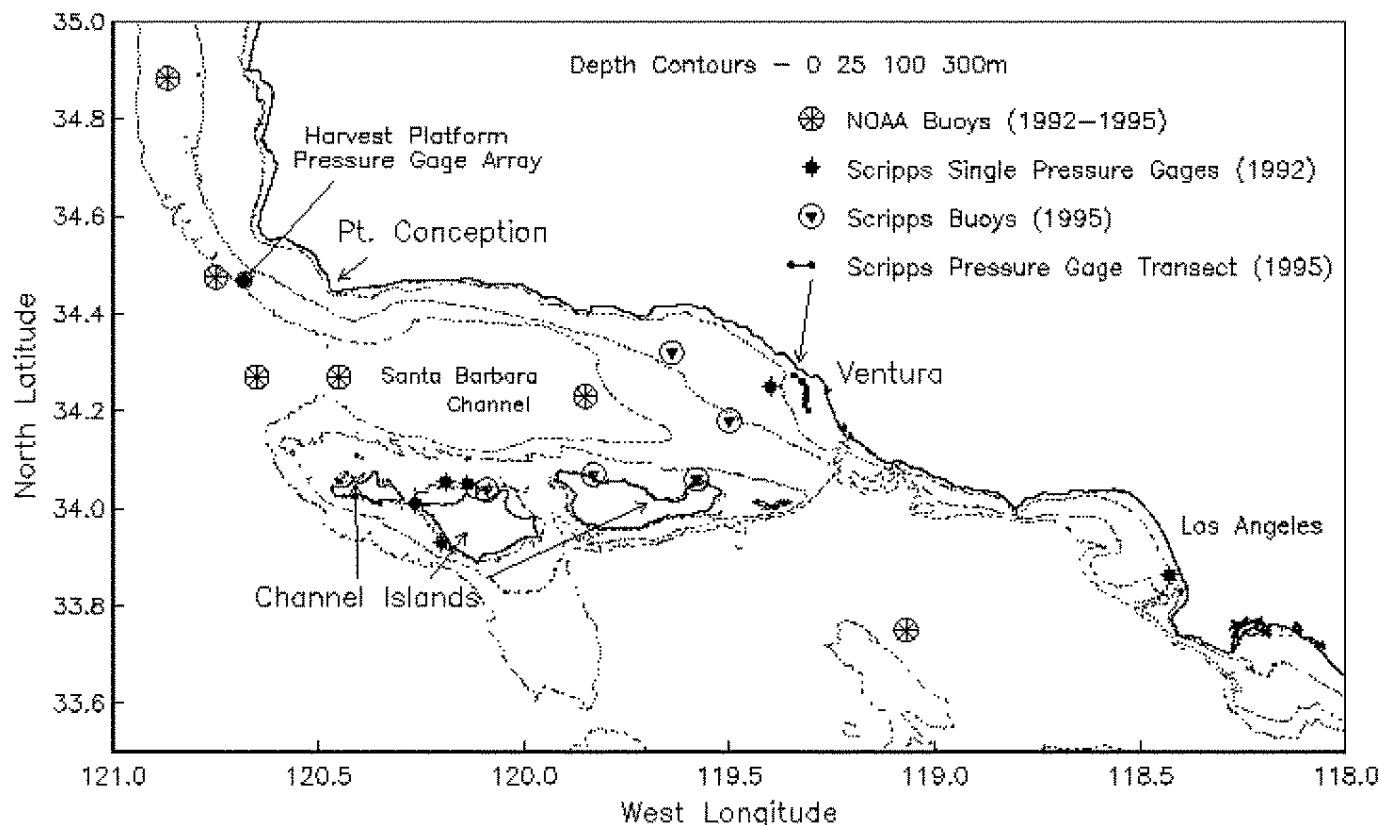
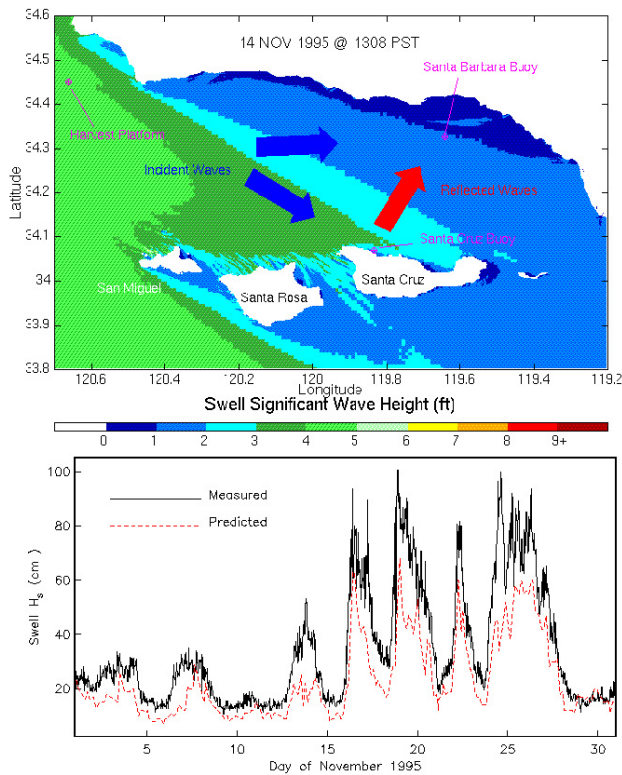


Figure 3. Historical wave data locations from 1992 to 1995 that will be used to improve swell model predictions and study local seas. NOAA buoys collected both wind and wave (mostly directional) data. Scripps directional buoy and pressure gage deployments typically spanned several winter months.

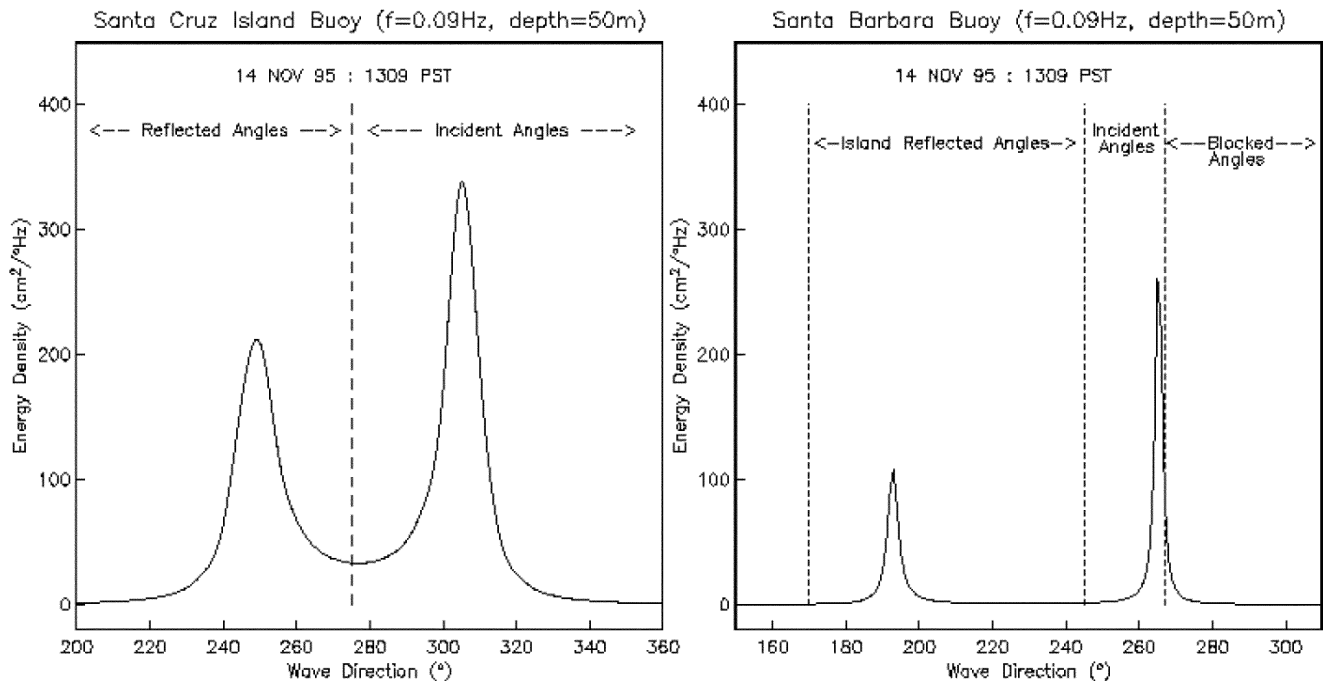


**Figure 4. UPPER PANEL:** Swell model prediction overlaid with schematic illustration of incident swell propagating into the channel (blue arrows) and reflecting from Santa Cruz Island (red arrow). **LOWER PANEL:** Underprediction of swell wave heights at the Santa Barbara Buoy (upper right of upper panel) owing to the unmodeled reflected wave energy.

determine if the reflection from Santa Cruz Island is directionally specular (e.g., waves reflect off the cliffs much like a billiard ball reflects off the side of a pool table) or directionally broad (e.g., a narrow directional beam of incident wave energy is scattered into many directions by the irregular facets of the cliff face).

The present swell model does not include local wind effects. Although long period swell waves arriving from the deep ocean are largely unaffected by local winds, sea waves continue to grow downwind of the Point Conception measurement site used to initialize the operational model. Predictions of seas, based solely on wave propagation theory (no generation), are therefore valid only over a small area near the initialization location. There are many models that predict wave generation given the wind field near the sea surface. Deep water wind-wave generation models have been used for the last decade on global scales (e.g., the third-generation WAM model, The WAMDI Group 1988). These models have more recently been modified to include shallow-water effects, but the simplified wave propagation algorithms (e.g., no diffraction) limit their accuracy in regions with complex bathymetry like the Santa Barbara Channel.

The Office of Naval Research has recently started an advanced wave prediction program to improve the SWAN model (Shallow Water Numerical model) developed at Delft Hydraulics in the Netherlands (Holthuijsen et. al. 1993). This model includes wave generation and was designed specifically for shallow water applications. The Point Conception area has been chosen as a field testing site for the SWAN model improvements (Figure 6, upper left model region),

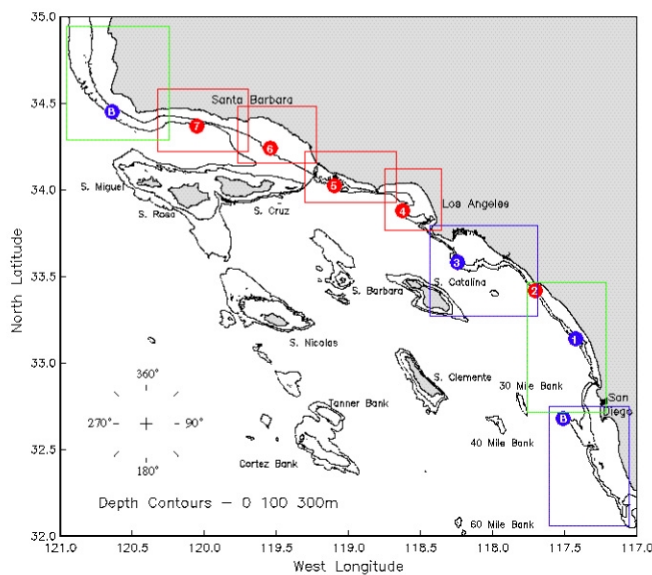


**Figure 5. Directional wave spectra** observed in the near field of Santa Cruz Island (left panel) and in the far field near Santa Barbara (right panel, see upper panel Figure 3 for locations). **Left Panel:** incident 11 second northwest swell refracts to 305° at the Santa Cruz buoy, reflects from the island and propagates at 245° towards the mainland. **Right Panel:** near the mainland, the incident northwest swell refracts to 265° and the swell reflected from Santa Cruz Island has refracted to 195°.



and it is anticipated that the test area will be expanded over time to include the entire Santa Barbara Channel. Of particular interest is the local generation of seas in the presence of pre-existing swell, which is a common occurrence in the channel.

Finally, CDIP plans to establish two long-term directional wave buoy stations in the channel in the next three to five years as part of a multi-year wave network expansion funded by the California Department of Boating and Waterways (Figure 6). Real-time data from these buoys will be used to validate future model improvements and enhance CDIP nowcasts through data assimilation methods. The designation of the Point Conception - Santa Barbara Channel as a "test bed" for U.S. wave model research will insure that government and commercial marine activity in this area will be the direct beneficiary of state-of-the-art wave nowcast and forecasts in the near future.



**Figure 6.** Locations of present (blue), planned for 1999 (green), and future (red) local CDIP buoy stations (circles) and model regions (boxes). This network is designed to provide combined sea and swell predictions for the Southern California coastline.

## ACKNOWLEDGMENTS

The Coastal Data Information Program (CDIP) is supported jointly by the California Department of Boating and Waterways wave data utilization program for furthering boating access and safety, and the U.S. Army Corps of Engineers Field Wave Gaging Program. Wave model validation data was collected by CDIP and the U.S. Naval Postgraduate School (NPS), and was supervised by David Castel and Julie Thomas (CDIP), and Paul Jessen (NPS). Ongoing wave model research in the Santa Barbara Channel is sponsored by the Minerals Management Service and the Office of Naval Research Waves BE program.

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