OCS Study
MMS 2001-055

Wave Prediction in the Santa Barbara Channel

Final Technical Summary

Final Study Report

MMS
U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

Wave Prediction in the Santa Barbara Channel

Final Technical Summary

Final Technical Report

Authors

Robert Guza
William O'Reilly
Principal Investigators

Prepared under MMS Cooperative
Agreement No. 14-35-0001-30758
by
Coastal Marine Institute
Marine Science Institute
University of California
Santa Barbara, CA 93106

U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

Camarillo
January 2001

Disclaimer

This report has been reviewed by the Pacific Outer Continental Shelf Region, Minerals Management Service, U.S. Department of the Interior and approved for publication. The opinions, findings, conclusions, or recommendations in this report are those of the authors, and do not necessarily reflect the views and policies of the Minerals Management Service. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use. This report has not been edited for conformity with Minerals Management Service editorial standards.

Availability of Report

Extra copies of the report may be obtained from:

U.S. Dept. of the Interior
Minerals Management Service
Pacific OCS Region
770 Paseo Camarillo
Camarillo, CA 93010
phone: 805-389-7621

A PDF file of this report is available at:
http://www.coastalresearchcenter.ucsb.edu/CMI/

Suggested Citation

The suggested citation for this report is:

R. Guza and W. O'Reilly. Wave Prediction in the Santa Barbara Channel. MMS OCS Study 2001-055. Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, California. MMS Cooperative Agreement Number 14-35-0001-30758. 8 pages.

Table of Contents

FINAL TECHNICAL SUMMARY

STUDY TITLE: Wave Prediction in the Santa Barbara Channel

REPORT TITLE: Wave Prediction in the Santa Barbara Channel

CONTRACT NUMBER: 14-35-0001-30758

SPONSORING OCS REGION: Pacific

APPLICABLE PLANNING AREA: Southern California

FISCAL YEAR(S) OF PROJECT FUNDING: FY97, FY98

COMPLETION DATE OF THE REPORT: January 2001

COST(S): FY 97 - $38,975, FY 98 - $49,166, FY 1999, 2000 **–** no cost

CUMULATIVE PROJECT COST: $88,141

PRINCIPAL INVESTIGATORS: Robert Guza, William O'Reilly

AFFILIATION: University of California, San Diego

ADDRESS: Center for Coastal Studies 0209, UCSD, La Jolla, CA 92093-0209

BACKGROUND:

Knowledge of past, present and future wave conditions in the Santa Barbara Channel is needed for numerous government, commercial and recreational activities in this heavily utilized coastal zone. Accurate historical wave estimates are important for coastal and ocean engineering design, planning, and environmental impact assessment. Real time wave "nowcasts" and forecasts are needed for efficient and safe marine operations, disaster preparedness, and beach safety.

Wave prediction in the Santa Barbara Channel is extremely complicated owing to the coastline orientation, the complex bathymetry, and the spatially variable wind field. The Channel Islands block remotely generated waves approaching the Channel from the south, and Point Conception blocks waves arriving from the northwest. Deep ocean waves that do propagate into the Channel are severely refracted and diffracted by the irregular shallow water bathymetry, producing the large spatial variations in swell wave height and direction typically observed throughout the region. Wave measurements in the Channel have shown that wave refraction-diffraction models underpredict wave heights at the east end of the Channel during WNW swell events, and that the source of this underprediction is the (unmodeled) reflection of wave energy from the rugged northern (i.e. facing the Channel) coastlines of the Channel Islands.

OBJECTIVES:

The primary objective is to investigate the reflection of ocean surface waves from the Channel Islands, and to use the results to improve existing swell predictions throughout the

Channel. A secondary objective is to lay the groundwork for future inclusion of locally generated wind seas, and their reflection from the Islands, in Santa Barbara Channel wave forecasts.

DESCRIPTION:

Waves propagating into the Santa Barbara Channel from the W-WNW impinge on the northern coasts of San Miguel, Santa Rosa, Santa Cruz, and Anacapa Islands, and a significant amount of the incident wave energy reflects from these rugged coasts back into Channel. This adds a significant southerly component to the waves along the Santa Barbara County coastline, in the lee of Pt. Conception, during these wave events.

A detailed analysis was performed on three sets of directional buoy measurements made in 50m water depth, ~2*km* offshore of the north coasts of Santa Rosa and Santa Cruz Island, to quantify the frequency and directional characteristics of the reflected wave field as a function of the incident wave conditions. In addition, directional wave measurements in the center of the Channel and along the Santa Barbara County coastline were analyzed to quantify the reflected waves in the far-field of the Islands.

Results of this analysis were used to model the Islands as a diffuse source of reflected wave energy with the amount of energy reflected from the islands being determined by the height, direction, and frequency of the incident waves reaching each island.

SIGNIFICANT CONCLUSIONS:

The amount of wave energy reflected from all the Channel Islands is frequency dependent, with the lowest frequencies (longer wave periods) having larger reflection coefficients (The reflection coefficient is defined as the ratio of wave energy reflected by the island, to the wave energy incident to the island). Wave reflection coefficients for shorelines with rocky shallows (*e.g.* Santa Rosa Island) are also strongly energy dependent, with much smaller wave reflection coefficients during larger wave events when more wave breaking and dissipation occurs at the coast. In contrast, wave reflection coefficients from cliff-lined coast (*e.g.* Santa Cruz and Anacapa Islands) only decrease slightly with larger incident waves. In both high and low wave energy conditions, reflection from the Channel Islands can contribute significantly to the wave energy at the east end of the Channel and along the Santa Barbara County coastline

STUDY RESULTS:

In general, the relative amount of reflected wave energy depends greatly on the wave frequency, with observed reflection coefficients at low frequencies ($f < 0.07 Hz$) two or more times larger than at higher frequencies. The highest reflection coefficients (0.10-0.70, depending on the wave frequency) were observed at the western end of the north side of Santa Cruz Island, where long, sheer coastal cliffs extend directly into 10-20*m* water depth. Slightly lower reflection coefficients were observed at the north-east end of Santa Cruz Island, where the cliffs are more irregular, and off Santa Rosa Island, where the coast is better characterized as rocky shallows than as cliffs.

While the overall amount of observed reflection was similar for these three different types of rugged coasts, the estimated reflection coefficients at Santa Rosa were strongly energy dependent. Low energy waves were much more "reflective" (coefficients = 0.20-0.50) than higher energy waves (coefficients = 0.05-0.20), presumably owing to a more active dissipation region in the rocky shallows with higher waves. A similar, but somewhat weaker dependence was observed at the East Santa Cruz Island site, and only a slight energy dependence is observed at the West Santa Cruz site with its wall-like coastal cliffs.

These observations suggest the following wave reflection scenarios: When low energy swell propagates into the channel from the WNW, all the islands reflect a significant amount of this swell energy back into the Channel. The lower frequency, longer period swell ($T > 14$ *s*.) experience the highest amount of reflection (30%+). However, when larger swell is present in the Channel, active dissipation zones develop along most of the island coastlines, reducing the *relative* size of their reflected wave fields (i.e. low reflection coefficient) compared to low wave height events. The western half of the north coast of Santa Cruz, and perhaps the north side of Anacapa Island, continue to be highly reflective under energetic conditions.

STUDY PRODUCTS:

Study products include a web page on the Coastal Data Information Program web server that is dedicated to providing real-time wave and wind information for the Santa Barbara Channel: http://cdip.ucsd.edu/mms. This wave and wind prediction effort continues to receive support from the State of California and the products on the Channel web page will continue to expand over the next year, including the implementation of a wind-wave prediction model for local seas. Additional products include a paper in the proceedings of the 5th California Islands Symposium and a paper in preparation describing the wave measurements and island wave reflection model.

FINAL STUDY REPORT

WAVE PREDICTION IN THE SANTA BARBARA CHANNEL

W. C. O'Reilly, R. T. Guza and R. J. Seymour

Center for Coastal Studies, Scripps Institution of Oceanography, La Jolla, CA 92093-0209
(858) 534-4333, FAX (858) 534-0300
E-mail: woreilly@ucsd.edu, rguza@ucsd.edu, rseymour@ucsd.edu

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 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

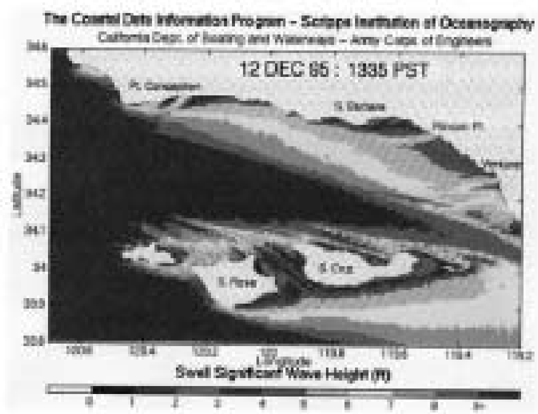

Figure 1. CDIP swell model prediction for the Santa Barbara Channel during a large west swell event in December 1995.

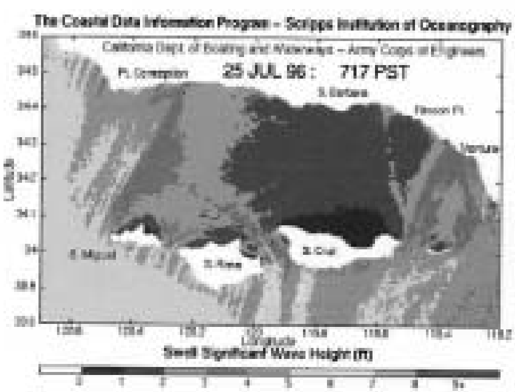

Figure 2. CDIP swell model prediction for the Santa Barbara Channel during a large south swell event in July 1996.

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°) 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

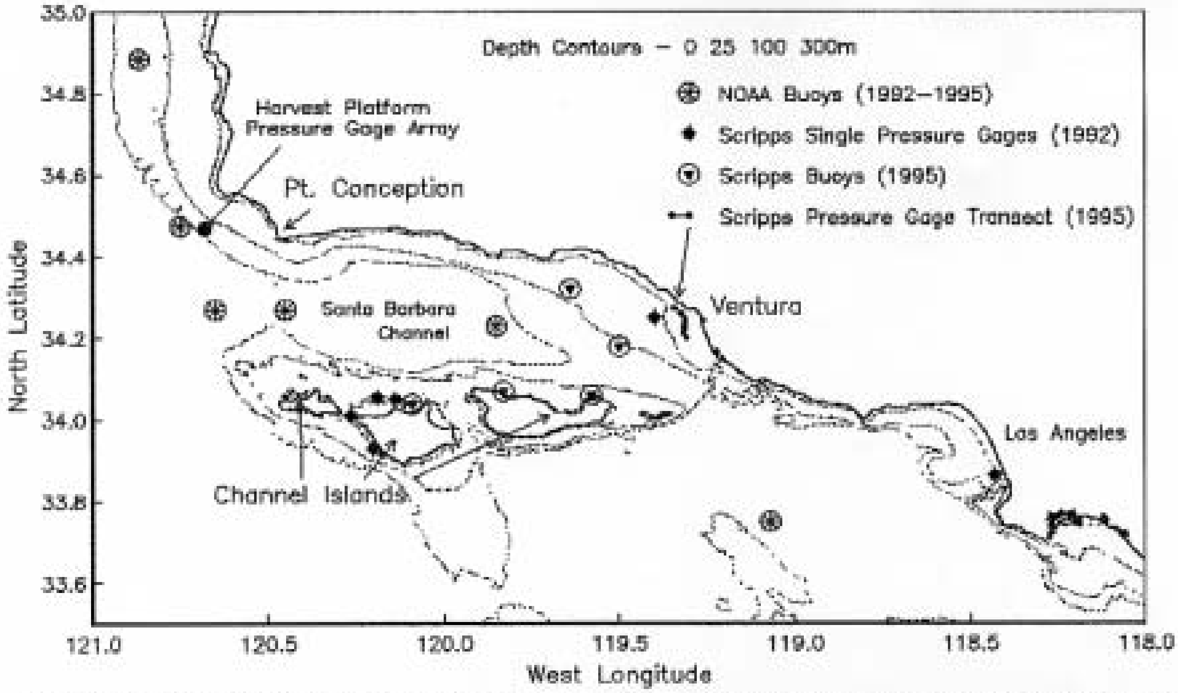

Figure 3. Historical wave data locations from 1992 to 1995 that will be used to improve swell model predictions and study local seas. NOAA buoys collected both wind and wave (mostly directional) data. Scripps directional buoy and pressure gage deployments typically spanned several winter months.

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.

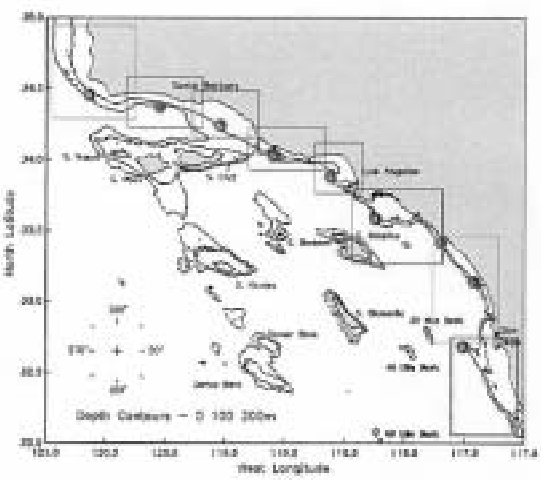

Figure 6. Locations of present (blue), planned for 1999 (green), and future (red) local CDIP buoy stations (circles) and model regions (boxes). This network is designed to provide combined sea and swell predictions for the Southern California coastline.

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.

LITERATURE CITED

Holthuijsen, L. H., N. Booij, and R. C. Ris. 1993. A spectral wave model for the coastal zone. Pages 630-641 *in* Proceedings of the 2nd International Symposium on Ocean Wave Measurement and Analysis, New Orleans, LA.

Kirby, J. T. 1986. Higher-order approximations in the parabolic equation method for water waves. Journal of Geophysical Research 91:933-952.

O'Reilly W. C. 1993. The southern California wave climate: effects of islands and bathymetry. Shore and Beach 61(3):14-19.

O'Reilly, W. C., and Guza, R. T. 1993. A comparison of two spectral wave models in the Southern California Bight. Coastal Engineering 19:263-282.

Seymour, R., D. McGehee, D. Castel, J. Thomas, and W. O'Reilly. 1993. New Technology in Coastal Wave Monitoring. Pages 105-123 *in* Proceedings of the 2nd International Symposium on Ocean Wave Measurement and Analysis, New Orleans, LA.

The WAMDI Group. 1988. The WAM model-A third generation ocean wave prediction model. Journal of Physical Oceanography 18:1775-1810.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.