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## **Coastal Environmental Quality Initiative**

### **Title**

Links between coastal circulation and pollutant dispersal in the Santa Barbara Channel

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# **FINAL REPORT**

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**Links between coastal circulation and pollutant  
dispersal in the Santa Barbara Channel**

(Proposal reference number: 01T CEQI 08 1091)

**&**

**CEQI Graduate Student Fellowship for  
Edwin Beckenbach**

(Proposal reference number: 01T CEQI 08 1077)

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**Project Period: 5/23/2001 – 6/30/2004 (with 1-year no-  
cost extension on 01T CEQI 08 1091)**

**Principal Investigator: Libe Washburn**

**Institute for Computational Earth System Science  
(ICESS)**

**University of California, Santa Barbara**

## **Final Report**

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## **1. Introduction**

### **1.2 Background**

The Southern California Bight (SCB), the curving section of coastline stretching from Point Conception to Cabo Colonet in Baja California, is home to almost 24 million Californians. Each year large quantities of pollutants are discharged into the waters of the SCB from urban and agricultural sources (National Research Council, 1993). Water pollutants have been directly linked with negative human health impacts in Southern California coastal waters (e.g. Wang, 1997). At the northern end of the SCB, the Santa Barbara Channel is the site of important recreational, aesthetic, mineral, sport and commercial fisheries resources. Because of the generally poleward coastal flow in the SCB, pollutants generated to the south are carried northward through the Channel and pose threats to regional resources. Surprisingly, circulation in the SCB is poorly understood compared with other California coastal regions such the shelf north of San Francisco.

As part of this Coastal Environmental Quality Initiative (CEQI) project, a current measuring high frequency (HF) radar system was purchased to augment an array of existing radars along the mainland coast of the Santa Barbara Channel. The radars use radio waves to produce hourly maps of the regional ocean circulation for use in studies of marine ecology, coastal oceanography, and water quality. Further discussion on the principles of operation of current-measuring radars is given by Barrick and Lipa (1998), Sterwart and Joy (1974), Teague et al. (1998), Gurgel, (1994), and Paduan and Rosenfeld (1996). Emery et al. (2004) evaluated the performance of the UCSB HF radar by comparison with current meters mounted on moorings in coastal waters.

A principal application of the radar systems of the UCSB array is to examine the evolving coastal circulation Santa Barbara Channel with the goal of understanding the dispersion and transport of larvae of various organisms and pollutants into regional ocean waters. Knowledge of the spatial and temporal evolution of surface currents is critical to understanding how buoyant pollutants such as stormwater runoff and oil disperse into the coastal ocean. The

flow in the Channel also affects the transport and retention of marine organisms in the region and thus has important ecological consequences.

These radars are now an essential tool for coastal oceanography and acquisition of a new radar in this CEQI project has helped UCSB gain prominence in their application to marine ecological and marine pollution issues. The Santa Barbara Channel radar array is also part of a new, larger cooperative effort of researchers at UCSB, UCLA, UCI, the Scripps Institution of Oceanography, UCSC, and Cal. Poly San Luis Obispo to establish an ocean observing network in the Southern California Bight known as the Southern California Coastal Ocean Observing System (SCCOOS). SCCOOS activities will compliment the research efforts of many agencies charged with monitoring water quality and marine resources throughout the Southern California Bight. It will also benefit local agencies such as the Central Coast Ambient Monitoring Program (CCAMP) and Santa Barbara County's Ocean Monitoring Program. In addition, data from the radar array is used extensively many oceanographic studies including two major marine ecological projects at UCSB:

(1) Santa Barbara Coastal Long Term Ecological Research (SBC-LTER) project. An important goal of the SBC-LTER is to investigate the importance of land and ocean processes in structuring giant kelp forest ecosystems.

(2) Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO). Among the goals of PISCO are to: a) determine the processes underlying the dynamics of the coastal ecosystems along the U.S. West Coast; b) establish the scientific basis design, monitoring & evaluation of marine reserves; and c) integrate this knowledge into the public and policy arenas.

The HF radar purchased with CEQI funding has been used to acquire an extensive data set in the Santa Barbara Channel which is widely used by investigators at UCSB and elsewhere. An archive of data and an extensive discussion of the UCSB HF radar array are available to the public via the internet at <http://www.icess.ucsb.edu/iog>.

## **1.2. CEQI Fellowship for Edwin Beckenbach**

Dr. Edwin Beckenbach received a one-year CEQI Fellowship (\$25K) to complete his doctoral dissertation. This final report also serves as the final report for his fellowship since his work was an integral part of this project; the title for his fellowship was the same as this project. Dr. Beckenbach received his PhD at the Spring, 2004 Commencement Ceremony at UCSB. His dissertation title is: Surface Circulation in the Santa Barbara Channel: "An Application of High Frequency Radar for Descriptive Physical Oceanography in the Coastal Zone". Dr. Beckenbach is current a post doc at the Scripps Institution of Oceanography in La Jolla, CA.

## **2. Research Activities**

### **2.1 Acquisition and installation of the new HF radar**

The HF radar system acquired with CEQI funding accounted for most of the project's budget. The system was purchased in 2001 and was subsequently installed at the Mandalay Generating Station in Oxnard, CA. This added an important site in the eastern Santa Barbara Channel to the UCSB HF radar array. After installation, a number of operational procedures were performed on the new radar system including measurement of antenna patterns and evaluation of the ambient noise levels arising from communication broadcasts and ionospheric

propagation; and measurement of antenna patterns. These procedures were necessary to ensure proper measurements of the regional surface current field.

## **2.2 Observational programs using the UCSB HF radar array**

An important goal of this CEQI project was the installation of the new radar system to extend coverage of the UCSB radar array in the Santa Barbara Channel. The extended HF radar array has supported several basic and applied research programs in the Channel. Some of these are described below.

### **2.2a Surface circulation in the western Santa Barbara Channel.**

Graduate student Edwin Beckenbach worked with data from the radar array to study various processes which force the surface circulation in the western Santa Barbara Channel. Dr. Beckenbach was supported for one year on a CEQI fellowship; this helped him complete his Ph.D. dissertation entitled “Surface Circulation in the Santa Barbara Channel: An Application of High Frequency Radar for Descriptive Physical Oceanography in the Coastal Zone” in 2004. The radars revealed fascinating patterns of currents in the Channel which are driven by a combination of local forcing due to winds and remote forcing due to propagation of coastal trapped waves moving northward through the Southern California Bight. Dr. Beckenbach took advantage of the fact that the radars are able to resolve the two-dimensional flow structure of current fields in the Channel. This enabled him to investigate the detailed evolution of flow structures on spatial scales of a few kilometers up to scales of order 50 km. By combining the HF radar current observations with moored observations obtained by researchers at SIO, he was able to link flow processes in the Channel with the larger regional circulation in the Southern California Bight.

### **2.2b Applications of HF radar for coastal water quality studies**

Colleagues from the Jet Propulsion Laboratory in Pasadena, CA and I used a combination of HF radar-derived current observations and satellite remote sensing imagery to investigate important pollution hazards in the Southern California Bight. These hazards include: (1) stormwater runoff plumes which carry various pathogens; (2) municipal wastewater plumes which surface during winter; and (3) natural marine hydrocarbon seeps which discharge large volumes of oil into coastal waters. In addition to pollution monitoring, data from the UCSB HF radar array has been used to validate surface current measurements obtained from NASA-JPL’s airborne synthetic aperture radar (SAR) over the Santa Barbara Channel. This so-called air-SAR may become an important tool for investigating stormwater runoff plumes in Southern California coastal waters. Much remains to be done in the application of HF radar to coastal water quality studies, but these efforts show how the combination of satellite and coastal remote sensing measurements can monitor important pollution sources.

### **2.2c Small-scale eddies as near-shore transport mechanisms.**

Corinne Bassin (a masters student in the Marine Science Program at UCSB) and I discovered that small eddies often exist near shore along the coast of the Santa Barbara Channel. The discovery was made possible by the long term, high resolution observations supplied by the UCSB HF radar array. We hypothesize that the eddies are important transport mechanisms for moving water-borne materials such as nutrients and larvae to near shore habitats.

### **2.2d An interdisciplinary study to link oceanographic factors with settlement of rockfishes on oil production platforms.**

In some years, juvenile rockfishes recruit to some oil and gas production platforms in the Santa Barbara Channel region in astounding numbers, and the survivorship and growth of fishes residing around these structures are traceable over time as demonstrated in previous research (e.g. Love et al. 2001, 2003). Given the role of platforms as nursery habitats, it is important to assess the fate of juvenile rockfishes that settle on platforms and natural reefs, and to understand what processes affect the temporal and spatial variability of recruitment. This study, the first of its kind, has the objectives of 1) directly linking ocean current patterns to the timing of delivery of juvenile rockfishes settling on offshore platforms; and 2) estimating the proportion of these juvenile fishes that, if the platforms did not exist, would have been transported to natural reef habitat. This interdisciplinary biological and oceanographic study was conducted at two platforms, Gail and Gilda, in the eastern Santa Barbara Channel from May through August 2004. A private home owner in Summerland, CA allowed us to install one of our HF radar systems on his property for the four month experimental period. This period corresponds with the season of much of the rockfish recruitment in this area. These two platforms are in a dynamic area where ocean currents vary over time scales of hours to several days and where fronts and eddies have been observed in sea surface temperature imagery (Harms and Winant, 1998). Fish settlement was quantified every 3-4 days using SCUBA while oceanographic conditions were observed using a of oceanographic tools including acoustic Doppler current profilers (ADCP's) for measuring current profiles, temperature-salinity (T-S) recorders for measuring water properties, and HF radar for surface current mapping. This investigation of the process of juvenile fish recruitment on platforms will increase our understanding of how oil/gas production platforms contribute to the fish populations and fisheries in the Santa Barbara Channel. An extensive data set was collected in this experiment and is now being analyzed by Ms. Mary M. Nishimoto as part of her dissertation research. The HF radar purchased with CEQI funds was essential for the success of this project.

### **3. Accomplishments and Principal Findings**

The radar obtained as part of this CEQI project has contributed to the success of the UCSB HF radar array. Some of the most important accomplishments and research findings so far are summarized below.

#### **3.1. Discovery of topographic Rossby modes in the Santa Barbara Channel.**

A three-year record of HF radar observations of surface currents in the western Santa Barbara Channel (SBC) revealed sequences of alternating clockwise and counter-clockwise vortices propagating westward with a period of about two weeks. The sequences last up to a few months and occurred intermittently throughout the year. The surface velocity distribution these rotary flow structures showed a high degree of asymmetry such that the if the current patterns of a typical clockwise vortex were reversed, the new pattern would almost exactly match a counter-clockwise vortex. This asymmetry suggested that the eddy-like patterns resulted from a type of wave phenomenon. The vortices propagated westward at about ~5 kilometer per day. We concluded that the vortices resulted from the interaction of large scale propagating coastal trapped waves with the bowl-shaped bathymetry of the Santa Barbara Basin. The result is a type of resonant wave that is periodically excited in the Channel. These waves, called topographic Rossby modes, had been predicted based on theoretical arguments, but observations have been scarce in the oceanographic literature. When our results were submitted for publication, both reviewers commented that this was the best observational evidence for these waves to date. Our

paper describing are results in: Beckenbach, E.H., and L. Washburn 2004, "Low frequency waves in the Santa Barbara Channel observed by high frequency radar", *J. Geophys. Res.*, 109, doi:10.1029/2003JC00199.

### **3.2. High frequency radar and satellite remote sensing detect pollution hazards in Southern California coastal waters.**

Stormwater runoff plumes, municipal wastewater plumes, and natural hydrocarbon seeps are important pollution hazards for the heavily populated Southern California Bight (SCB). Due to their small size, dynamic and episodic nature, these hazards are difficult to sample adequately using in situ oceanographic methods. Complex coastal circulation and persistent cloud cover can further complicate detection and monitoring of these hazards. We used imagery from space-borne synthetic aperture radar (SAR), complemented by field measurements such as current-measuring radars, to examine these hazards in the SCB. The pollution hazards are detectable in SAR imagery because they deposit surfactants on the sea surface, smoothing capillary and small gravity waves to produce areas of reduced backscatter compared with the surrounding ocean. We suggest that high-resolution SAR, which obtains useful data regardless of darkness or cloud cover, could be an important observational tool for assessment and monitoring of coastal marine pollution hazards in the SCB and other urbanized coastal regions. In particular, we used the UCSB radar array in combination with SAR to observe the transport of oil from natural hydrocarbon seeps in the Santa Barbara Channel to nearby beach areas. Results of this work are summarized in DiGiacomo, P.M., L. Washburn, B. Holt, and B.H. Jones, 2004, "Coastal pollution hazards in Southern California observed by SAR imagery: Stormwater plumes, wastewater plumes, and natural hydrocarbon seeps", *Marine Pollution Bulletin*, 49, 1013-1024.

### **3.3 Small-scale eddies transport nutrients to kelp forests in shallow water environments.**

Small eddies were discovered along the mainland coast of the Santa Barbara Channel based on observations from the UCSB HF radar array and near-shore moorings. The eddies are 4-15 kilometers in diameter and typically last about 2 days, although some last up to 6 days. Most of the eddies rotate clockwise, but a few rotate counter-clockwise. The rates of rotation are very large, comparable to the earth's rotation rate. The clockwise rotation probably arises because the eddies form in a westward flowing current with a coastal boundary to the right of the flow direction. Subjective examination of a 4-year time series of radar observations near Coal Oil Point, California shows that eddies are present 11% of the time and occur throughout the year. No seasonal trend in eddy frequency was found. Swirl velocities of the eddies are sufficiently strong to reverse the normally westward flow near the coast. Moored observations near shore of a sequence of two eddies in December 2001 show a strong increase in nutrient concentration near shore when the eddies are present. Decreases in temperature of 1-3 °C and increases in salinity accompanied the higher nutrient concentrations. Underwater current observations showed that the velocity field of the eddies extends throughout the shallow water column. We speculate that these eddies are an important transport mechanism for nutrients and biogenic particles to inner shelf ecosystems of the Southern California Bight. Results of this study are summarized in a paper soon to be submitted for publication: Bassin, C.J., L. Washburn, M. Brzezinski, and E. McPhee-Shaw, 2004, "Sub-mesoscale coastal eddies observed by high

frequency radar: A new mechanism for delivering nutrients to kelp reefs in the Southern California Bight” (manuscript available).

### **3.4 New projects leveraged from this CEQI funding**

The following projects directly benefited from the leverage provided by the purchase of the new HF radar from CEQI funds:

1. “Lagrangian modeling of drifter trajectories based on high frequency radar”, National Science Foundation, Principal Investigator: C.J. Ohlmann, Co-Investigators: L. Washburn and A. Mariano, \$459K.
2. UCSB component of the Southern California Coastal Ocean Observing System, Principal Investigator: L. Washburn \$1.2 M for operations; \$750K for equipment.
3. “Assessing the fate of juvenile rockfishes at offshore platforms and natural reefs in the Santa Barbara Channel”, Principal Investigator: M. Love, \$175K.

### **4. Participants**

The following students and staff at UCSB participated in this project:

Bassin, Corinne	Graduate Student
Beckenbach, Edwin	Graduate Student
Nishimoto, Mary	Graduate Student
Salazar, David	Staff Research Associate
Washburn, Libe	Principal Investigator
Emery, Brian	Computer Network Technologist
Pearson, Justin	Undergraduate student
Ow, Leah	Undergraduate student
Visin, Kyle	Undergraduate student

### **5. Publications**

The following publications based on the UCSB radar array:

- Bassin, C.J., L. Washburn, M. Brzezinski, and E. McPhee-Shaw, 2004, “Sub-mesoscale coastal eddies observed by high frequency radar: A new mechanism for delivering nutrients to kelp reefs in the Southern California Bight”, to be submitted to Geophysical Research Letters (manuscript available).
- Beckenbach, E.H., and L. Washburn 2004, “Low frequency waves in the Santa Barbara Channel observed by high frequency radar”, J. Geophys. Res., 109, doi:10.1029/2003JC00199.
- DiGiacomo, P.M., L. Washburn, B. Holt, and B.H. Jones, 2004, “Coastal pollution hazards in Southern California observed by SAR imagery: Stormwater plumes, wastewater plumes, and natural hydrocarbon seeps”, Marine Pollution Bulletin, 49, 1013-1024.



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