PFRP Pelagic Fisheries Research Program

Volume 2, Number 3 July 1997

Oceanography and Fishery Management

The ocean environment affects fisheries for tunas and billfish in many ways. The productivity of the ocean mediates spawning of adults and the survival of larvae. Currents and vertical and horizontal gradients in temperature influence the effectiveness of fishing gear and the location of fishing grounds. Tunas and billfish are creatures of the upper ocean—their habitat extends from the interface between the warm surface water and the cold deep water to the sea surface. This is the part of the ocean most amenable to study by modern oceanographic methods.

This issue of the PFRP newsletter describes some of the oceanographic projects supported by the PFRP. The results show unique features in the ocean around the Hawaiian Islands, why this area may be so productive, and how it is possible that there may be "resident" populations of tuna. In the future, these results will be coupled to the physiological and behavioral studies to attempt to fully understand the dynamics of the populations of these fish in the north Pacific.

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Current and Eddy Statistics for the Hawai‘i EEZ

The PFRP Central Pacific Drifter Array project is resulting in a fivefold increase in the number of current measurements available in the lee of the Hawaiian Islands and over its northwest ridge, thus enabling scientists to map and better understand the oceanic flow in Hawai‘i's exclusive economic zone (from 3 to 200 nautical miles offshore). The project consists of drifting buoys—each with a 35-cm diameter surface float containing batteries and an ARGOS satellite transmitter, a 12-m tether, and a drogue of 92-cm diameter and 6.4 m length—that collect locations and water temperature daily.

Fifty-six buoys were deployed in September 1994, October 1994, August 1995, and throughout 1996 in successive clusters south of the island of Maui and west of the Kona (western) coast of the island of Hawai‘i. Another 25 buoys were deployed twice monthly in the channel between the islands of Maui and Hawai‘i from late 1995 through October 1996. The average life expectancy of the buoys is one year.

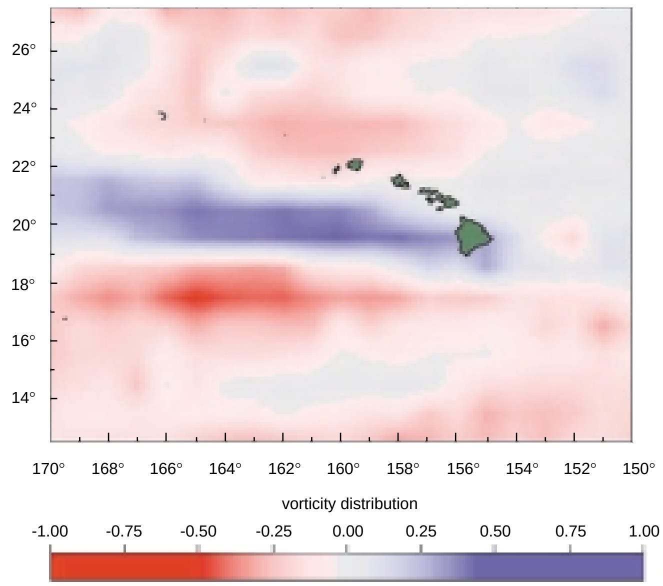

Figure 1. Drifter-derived vorticity

Figures 1 and 2 show eddy rotation (vorticity) and tracks of all buoys that drifted through Hawai‘i's Exclusive Economic Zone, both from the PFRP project and from the historical database of drifters released previously by other

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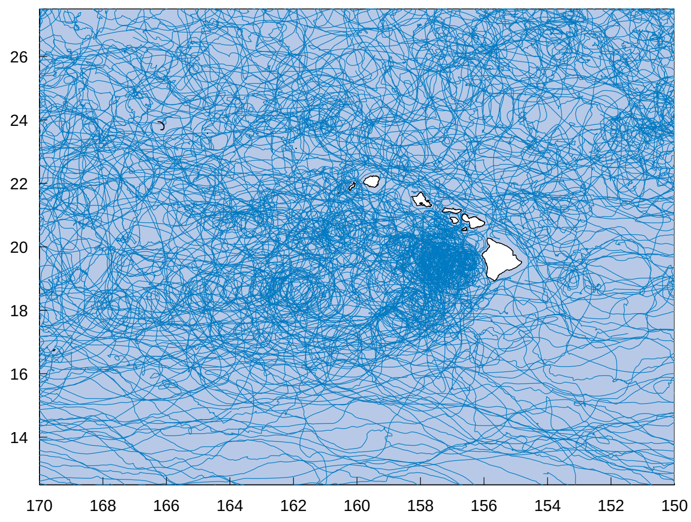

Figure 2. Drifter tracks

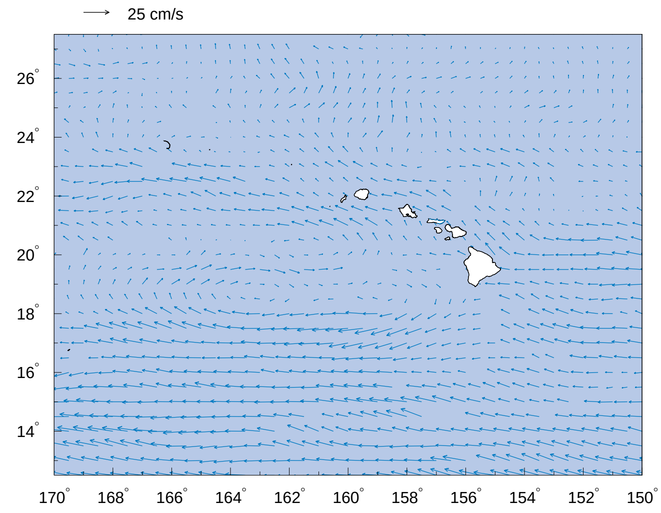

Figure 3. Drifter-derived mean currents

projects through November 1995. The tracks reveal an intense eddy field west and northwest of the Hawaiian Islands. Strong cyclonic eddies (which rotate counterclockwise in the northern hemisphere) observed in the lee, north of 19°30' N, are of particular interest to those in the fisheries, as they correspond to areas where the thermocline (a large temperature jump that separates the upper, wind-influenced ocean from the less energetic, abyssal ocean) rises upward, bringing nutrients to the near surface and affecting biological processes. On the other hand, strong anticyclonic eddies, corresponding to deepened thermoclines, occur south of 19°30' N, at the northern boundary of the North Equatorial Current.

A calculation of the tracks' average velocity (rate of time in a given direction) reveals that the mean currents for the area include a pair of elliptical counter-rotating gyres westward of the islands—the cyclonic one to the north of 19° N and the anticyclonic one to the south (Figure 3). The major axes of the gyres extend approximately from 157° W to 168° W. A strong, narrow eastward countercurrent exists along 19° N. These large gyres are interpreted to be the average expression of individual cyclonic and anticyclonic eddies spun up in the lee of the islands, which eventually drift westward and decay.

A calculation of the tracks' average curvature, which is related to eddy vorticity or rotation, shows that individual cyclonic eddies dominate north of the countercurrent, while anticyclonic eddies dominate south. As a result, the mean thermocline depth is reduced in the north and increased in the south.

Other findings by the project scientists—Pierre Flament, Claude Lumpkin and June Firing of the University of Hawaiʻi's Department of Oceanography—include mapping of the area's velocity variance (which reveals more than a tenfold increase in eddy kinetic energy in the lee of the islands) and a statistical analysis of the diffusion of the eddies.

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For a copy of PFRP technical reports, contact

PFRP Administrative Assistant Dodie Lau
tel (808) 956-7895 FAX (808) 956-4104
E-MAIL dlau@soest.hawaii.edu

or contact

The Joint Institute for Marine and Atmospheric Research
University of Hawaiʻi at Mānoa
1000 Pope Road, MSB 612
Honolulu, HI 96822
TEL (808) 956-8083 FAX (808) 956-4104.

Tracking Fish by Mapping Ocean Features

In five years, Hawai‘i's longline fishery has grown into a $50-million-a-year operation, primarily for swordfish to the north and for bigeye and yellowfin tuna around the Hawaiian Islands.

To better understand the environmental causes of changes in fish catch rates, a group of researchers in a PFRP project led by Jeffrey Polovina of the National Marine Fisheries Service, Honolulu Laboratory, and Gary Mitchum, University of Southern Florida, is mapping the ocean's eddies, currents and other features. Using data from the TOPEX/POSEIDON satellite altimeter, an instrument that measures the ocean's height with an accuracy of an inch, the scientists are able to compute the ocean's surface currents and thus update the map every 10 days.

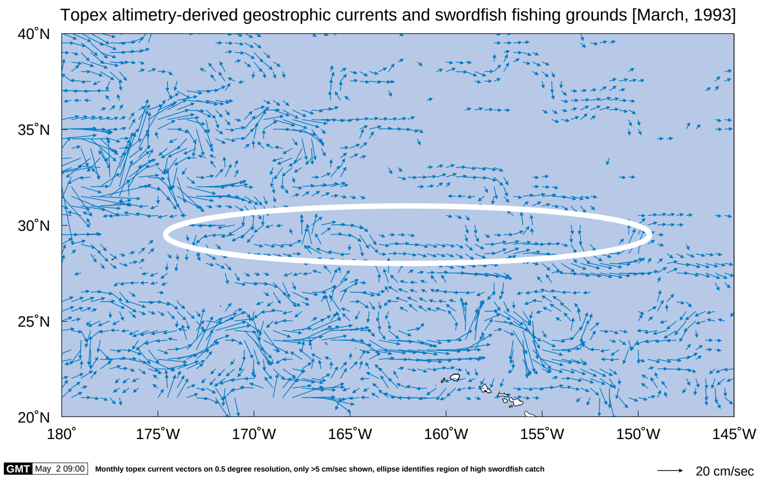

Figure 1. Subtropical front and swordfish grounds (March 1993)
Monthly TOPEX current vectors on 0.5° resolution (only >5 cm/sec shown). Ellipse identifies region of high swordfish catch.

A subtropical front is a particularly rich area for swordfish. Research cruises on the NOAA vessel *Townsend Cromwell*, led by Mike Seki, have shown that the front represents the boundary between cold, dense, productive subarctic water on the north and warm, less productive subtropical water on the south. Driven by the current flow and meandering of the front, the dense, productive subarctic water converges and sinks beneath the less dense subtropical water. This region of downwelling supports high density of zooplankton, which can maintain its vertical position and forage on the sinking phytoplankton. Small fishes congregate to forage on the zooplankton, which in turn are fed upon by squids, and they serve as forage for swordfish.

The close relationship between the subtropical front and the swordfish grounds can be seen from March 1993 altimetry data (Figure 1). This subtropical front is an eastward meander centered at 30°N; the main portion of the Hawai‘i longline fleet fishing ground for swordfish is outlined with an ellipse located around the front.

A higher resolution image from March 1994 (Figure 2) shows high catch rates oriented along the frontal meander. More than 90 percent of the swordfish catch during the first six months of the year came from a fishing ground oriented along the front.

Research cruises and altimetry data over the past few years have shown that this subtropical front weakened in 1994 and shifted about 200 km south in 1997; these changes help explain observed interannual variation in catch and catch rates.

Another area where the altimetry data show interesting features is around the main Hawaiian Islands in the vicinity of the longline tuna fishery grounds. Strong eddies and cur-

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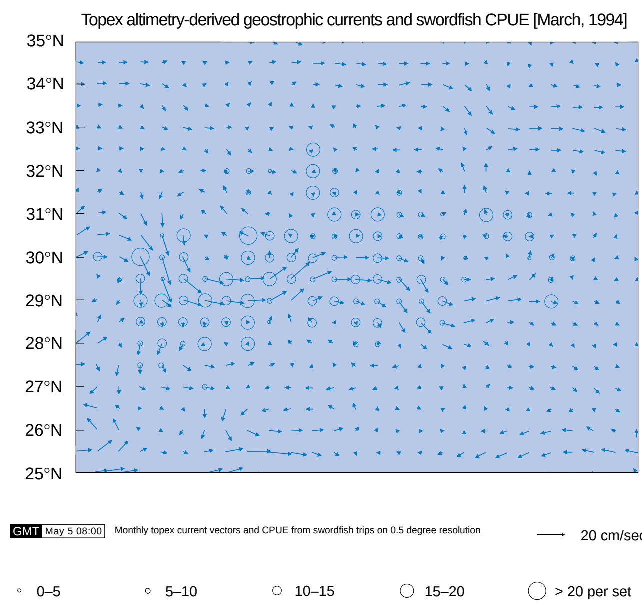

Figure 2. Subtropical front and swordfish grounds (March 1994)
Monthly TOPEX current vectors and catch-per-unit effort (CPUE) from swordfish trips on 0.5° resolution.

Tracking Fish (continued from page 3)

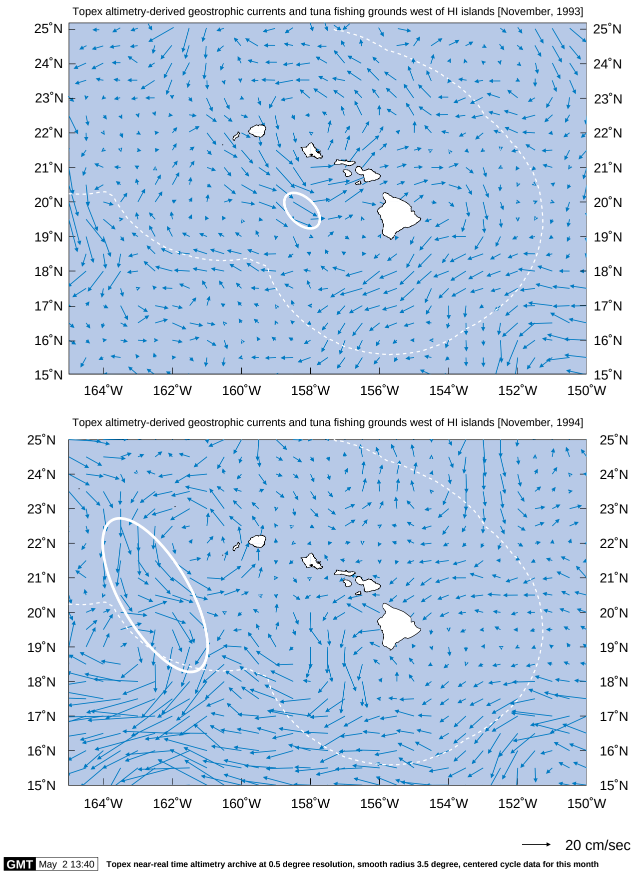

Figure 3. TOPEX/POSEIDON estimated currents around the Hawaiian Islands in November 1993 and 1994 with the white ellipses indicating tuna fishing grounds on the west side of the islands. In 1993 the fishing grounds were associated with a current close to the islands while in 1994 the fishery exploited a feature of strong current further to the west, which was absent in 1993.

rents seen around the islands may be important in enhancing and concentrating forage for tunas. For example, in Figure 3, currents around the Hawaiian Islands, estimated from altimetry data, are shown for November 1993 and 1994 along with tuna longline fishing grounds indicated as white ellipses. The location of the fishery appears to shift with the currents. In 1993 the fishing grounds were associated with an eddy close to the islands while in 1994 strong currents developed further west and the fishery shifted further offshore.

The scientists have also used the satellite data in a computer simulation program to show where lobster larvae would travel a year after leaving Maro Reef and Necker Island. Those from Necker never made it to the northerly reef, but the ones from Maro went to Necker, and larvae from both places reached O‘ahu. Such information is valuable for fisheries managers because it indicates where lobsters can sustain heavy fishing and where they can't.

The ocean maps generated by the scientists may also become increasingly useful for fishermen, Polovina says. The maps, updated every 10 days, may someday appear on a Web page and thus be accessible to the growing number of fishermen who have computers on board their vessels.

For more information, contact PFRP for “Use of Satellite Altimetry to Describe Ocean Features Important to Pelagic Fishes and Fisheries” by Jeffrey Polovina, Gary Mitchum, Don Kobayashi, Mike Seki and Cheryl Kihlstrom.

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Modeling the Ocean Circulation Around the Main Hawaiian Islands

The physical ocean environment can affect pelagic fisheries in many ways. The movement of water, as well as its temperature and oxygen concentration, determines the overall patterns of movement of fish and other organisms. It also affects the retention of eggs and larvae and the creation of productive zones.

Around the Hawaiian Islands, many observational studies have been conducted to determine the ocean's circulation. The Hawaiian Islands are part of the Hawaiian Ridge

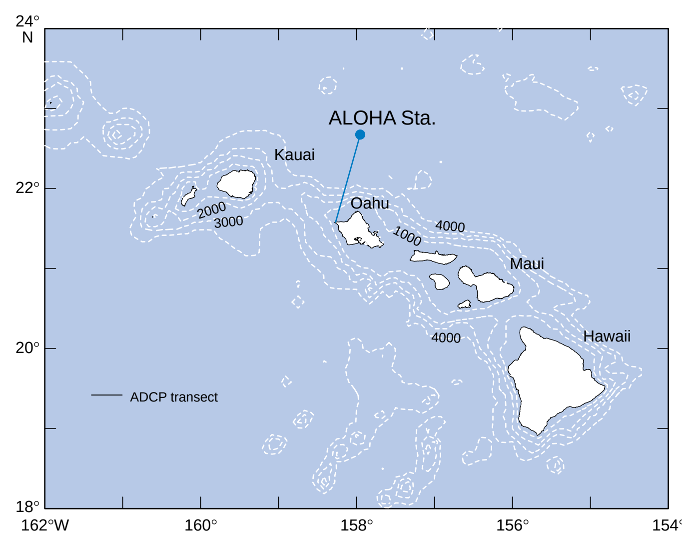

Figure 1. Bottom topography in the vicinity of the Hawaiian Islands. The contour interval for the bathymetry is 1000 m. The solid line north of O‘ahu denotes the ADCP transect of the HOT cruises.

(Figure 1), which extends for more than 2000 km from the island of Hawai'i (20°N, 156°E) to the Midway Island (30°N, 180°). Although a nearly continuous barrier below 2000 m, the Hawaiian Ridge is extremely porous above the 500-m depth, and it is only around the main Hawaiian Islands, including the islands of Hawai'i, Maui, Moloka'i, Lana'i, O'ahu, and Kaua'i, that the ridge extends near and above the sea surface (Figure 2).

Historical studies show that the main thermocline (a large, vertical temperature jump that separates the upper, wind-influenced ocean from the less energetic, abyssal ocean) around the Hawaiian Ridge is typically 300–400 m deep. However, observational studies alone do not fully explain the dynamics of the ocean near the islands nor do they provide fisheries managers and fishermen with the tools needed to predict fish movements.

To clarify the physical processes dominating the ocean circulation near the Hawaiian Islands, two studies using numerical modeling, co-sponsored by the Pelagic Fisheries Research Program, have been completed by teams led by Bo Qiu of the University of Hawai'i's Department of Oceanography.

The Mean NHRC

The first study, published in the March 1997 issue of the *Journal of Physical Oceanography*, establishes the existence and formation mechanism of the North Hawaiian Ridge Current (NHRC), a northwestward flowing current that has been predicted and observed since the 1980s.

The first objective of the study was to clarify the horizontal pattern of the mean NHRC through analysis of the data collected from surface drifters deployed in the tropical and subtropical Pacific Ocean as part of the Pelagic Fisheries Research Program and the World Ocean Circulation Experiment's Surface Velocity Program. These drifters consisted of a fiberglass surface float containing a satellite (ARGOS) transmitter, a subsurface float, and drogue of diameter 1 m and length 7 m, centered at 15 m depth.

Analysis of surface drifter data from within the vicinity of the Hawaiian Islands between 1986 and 1996 (Figure 3) shows that the North Equatorial Current (NEC) south of the Hawaiian Islands is strongly influenced by the Hawaiian Islands, resulting in southwestward propagating anticyclonic eddies. In the lee of the islands, two elongated gyres appear, separated by a countercurrent at 19°N extending from 170° to 158°W, named the Hawaiian Lee Counter Current (HLCC).

East of the Hawaiian Islands, the impinging NEC flows due westward. This impinging flow divides east of the island of Hawai'i, with a branch of the current—the NHRC—continuing northwestward along the island ridge. The width of the NHRC is approximately 100 km. The ridge appears to

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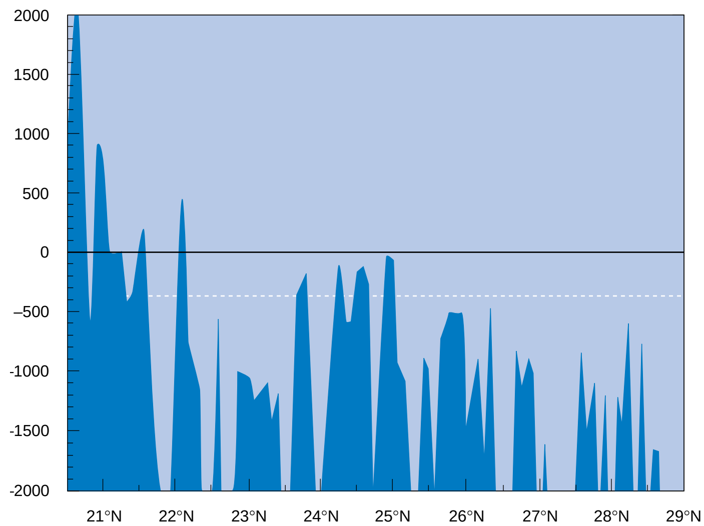

Figure 2. Height profile (in meters) of the Hawaiian Ridge as a function of latitude from 20.5° to 29.0° N. Here the height is defined as the highest point along the ridge. The dashed line at 300–400 m indicates the typical thermocline depth in this region.

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Editor John Sibert
Writers Sylvia Spalding and John Sibert
Layout May Izumi
Printing Service Printers, Honolulu, HI 96819

For more information

Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai'i at Mānoa
1000 Pope Road, MSB 612
Honolulu, HI 96822

TEL (808) 956-4109 FAX (808) 956-4104

E-MAIL jsibert@soest.hawaii.edu
WWW http://www.soest.hawaii.edu/PFRP

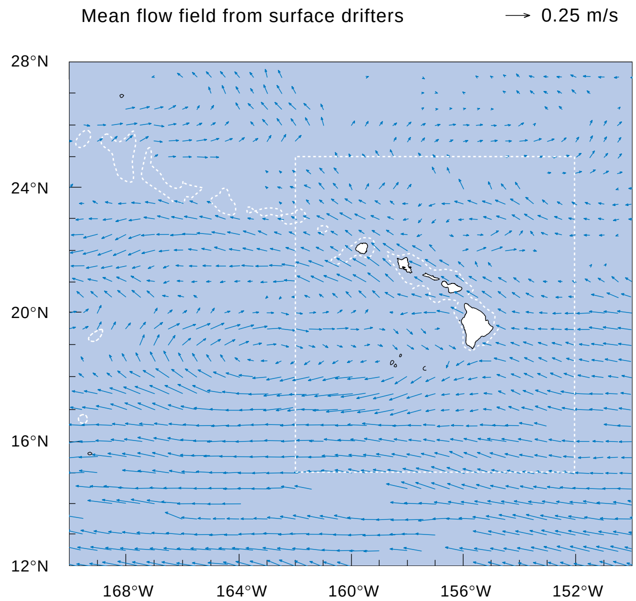

Figure 3. Mean flow pattern derived from available surface drifter data. Current vectors are estimated on a 0.5° x 0.5° grid; no estimation is made (in blank areas) where the mean flow is either undersampled or not significantly different from zero at the 90% confidence level. The dashed box denotes the area where detailed comparison with model results are made. Dashed contours denote the 2000-m isobaths.

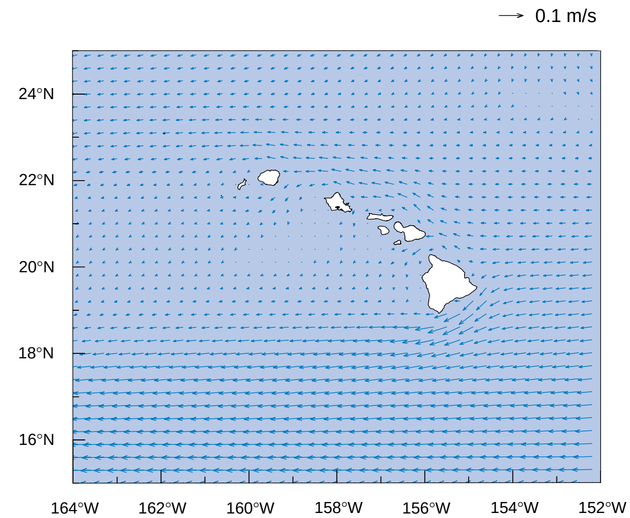

Figure 4. Annually averaged surface layer flows around the Hawaiian Islands. The model ocean in this case is forced by the monthly, climatological winds.

veer westward northwest of the island of Kaua'i, passing over the submerged Hawaiian Ridge.

To understand the formation of the NHRC, a model that covers the tropical and subtropical oceans in the North Pacific was formulated. Figure 4 shows the detailed upper-layer circulation pattern from the model in the vicinity of the Hawaiian Islands. Similar to the observations shown in Figure 3, the mean inflow east of the Hawaiian Island is nearly due westward. This inflow divides east of the Big Island, joining the NEC as its southern branch and becoming the NHRC as its northern branch. The modeled NHRC eventually veers and continues westward north of the island of Kaua'i, a result also suggested by the surface drifter data. However, the overall strength of the circulation in the model is about 20–30% weaker than in Figure 3. This is likely because the surface drifter data represent the near-surface flows, whereas Figure 4 gives the averaged flow pattern in the upper thermocline, which has a depth of 250–300 m in this region.

The model, which is driven by climatological wind data that do not include regional winds effects, such as shear layers formed by trade winds around each islands' northern and southern boundaries, is less successful in simulating the circulation leeward of the island.

One important outcome of the modeling work is that the mean NHRC is due primarily to the mean force of the wind rather than to its seasonal variability. When an island exists in a steady ocean circulation, mass conservation requires that the north-south transport of water across individual east-west sections between the island (in this case, the Hawaiian Islands) and the ocean's eastern boundary (in this case, North America) must be constant. This constant transport is solely determined by the surface wind stress values along the contour that circulates the western flanks of the island and the eastern boundary, and along the latitudes of the island's northern and southern tips. It is worth noting that this theory has been previously shown to explain the mean ocean circulation around New Zealand in the South Pacific Ocean.

Time-Varying NHRC

While unraveling the formation mechanism of the mean NHRC was an important initial step, a better understanding of the circulation around the Hawaiian waters required a further investigation into the time-dependent characters of NHRC. Large fluctuations of the NHRC had been detected by repeated shipboard measurements using an Acoustic Doppler Current Profiler (ADCP), an instrument that uses acoustic beams sent downward and laterally to estimate a

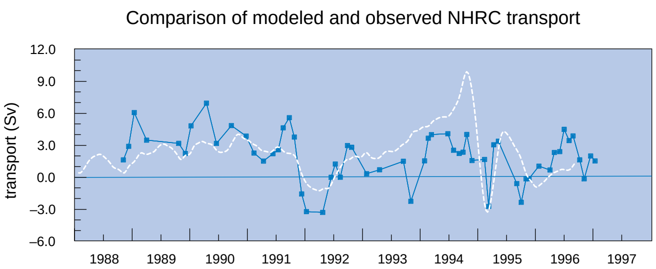

Figure 5. Comparison of modeled transport (dashed line) and observed transport from the repeat ADCP measurements (black squares). The cross-correlation coefficient between the two time series is 0.39.

current's flow speed. Repeated shipboard ADCP measurements from O'ahu to station ALOHA of the Hawai'i Ocean Time-series (HOT) program (see Figure 1 for locations) are now available for 58 cruises from 1988 to 1996. Noticeable features from the past eight-year surveys include a clear interannual transition of the NHRC from a relatively stable to a highly variable state around the end of 1991 and the absence of a clear annual signal. This latter observed feature of the NHRC is in sharp contrast to the trade winds over the eastern North Pacific, which have a prominent annual signal.

To complement the spatially limited ADCP measurements, observed monthly wind data for the Pacific Ocean compiled by Florida State University were added to the model used previously to understand the mean NHRC. With this added data, the model hindcast well many of the observed time-dependent signals of the NHRC (Figure 5). Both, for example, indicate that the NHRC is significantly weakened or reversed in direction between December 1991 and May 1992 and between February 1995 and April 1995. They also show that the NHRC transport is positive and relatively constant prior to October 1991 and becomes highly variable after June 1994.

The model also revealed that most of the NHRC variability is due to the surface wind forcing over the extratropical regions and that the influence of coastal waves originating in the equatorial Pacific is negligible. Focusing upon the oceanic layer above the main thermocline, the model showed the weak annual signal in the NHRC is due to the "absorption" of the wind forcing through the water column

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Upcoming Events

August 6-8

PACON 97 Symposium on Resource Development/Environment Issues and the Sustainable Development of Coastal Waters, Shatin, Hong Kong
PACON International (808) 956-6163, pacon@wiliki.eng.hawaii.edu

August 24-28

127th Annual Meeting of the American Fisheries Society, Monterey, California
American Fisheries Society (301) 897-8616, main@fisheries.org

September 1-14

The Summit of the Sea, St. John's, New Foundland, Canada
(709) 579-1997, david_finn@porthole.entnet.nf.ca

September 16-19

44th Eastern Pacific Ocean Conference, South Lake Tahoe, California
Naval Postgraduate School (408) 656-2712, paduan@nps.navy.mil

September 22-24

ICES International Symposium on Recruitment Dynamics of Exploited Marine Populations: Physical-Biological Interactions
John Hopkins University, Maryland
ICES Secretariat (Denmark) 45-33-154-225, ices.info@ices.dk

September 22-27

Pacific-Asian Marginal Seas (PAMS)–Japan & East-China Seas Study (JECSS) IX Workshop, Taipei, Taiwan
National Taiwan Ocean University 886-2-462-2610, lihw@sun4.oce.ntou.edu.tw

October 8-11

International Symposium on Fisheries Stock Assessment Models for the 21st Century: Combining Multiple Information Sources; 15th Lowell Wakefield Symposium, Anchorage, Alaska
Alaska Sea Grant College Program (907) 474-6701, fnbrb@aurora.alaska.edu

October 14-26

PICES 6th Annual Meeting, Pusan, Korea
PICES Secretariat (Canada) (604) 363-6366, pices@ios.bc.ca

October 17-18

PICES Climate Change & Carrying Capacity Workshop on the Development of Cooperative Research in Coastal Regions, Pusan, Korea
PICES Secretariat (Canada) (604) 363-6366, (604) 363-6827, pices@ios.bc.ca
Alaska Fisheries Science Centre (206) 526-4223, (206) 526-6723, hollowed@afsc.noaa.gov

October 25-27

INFOFISH-TUNA 97, Bangkok, Thailand
INFOFISH (Malaysia) 603-291-4466, infish@po.jaring.my

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during the 3.5 to 4 years that it takes for waves to reach Hawai‘i from the North American coast.

Future Studies

One of the eventual goals of these studies is to combine the results from the numerical models with observations from fisheries scientists to analyze the coupling between the physiological behavior of pelagic fish and the simulated physical flow fields. Large-scale, convergent, wind-driven currents in the Hawaiian Island region form fronts that can bring nutrients into the upper layers of ocean where sufficient light penetration permits growth of phytoplankton, thus affecting fish populations. Cyclonic upwellings in the southwest side of the Hawaiian ridge, resulting in shallowing of the thermocline from about 200 m to less than 50 m, can also transport nutrients up into the near-surface waters, thus affecting biological processes. The numerical model results could be a useful tool to analyze the dependency of fish movement on these various physical features.

For detailed information on the mean NHRC, see “Existence and Formation Mechanism of the Northern Hawaiian Ridge Current,” by Bo Qiu, Deborah A. Koh, Claude Lumpkin, and Pierre Flament, *Journal of Physical Oceanography*, 27 (3): 431-444.

For detailed information on the time-varying NHRC, contact Bo Qiu regarding “Time-Dependent Island Rule and Its Application to the Time-Varying North Hawaiian Ridge Current,” by Bo Qiu, Weifeng Miao and Eric Firing. He may be reached at the Department of Oceanography, University of Hawai‘i at Mānoa, 1000 Pope Road, Honolulu, HI 96822 or by e-mail at bo@lunarmax.soest.hawaii.edu.

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Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai‘i at Mānoa
1000 Pope Road, MSB 612
Honolulu, HI 96822