# HF Radar Observations of Oceanic and Atmospheric Dynamics


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## LONG-TERM GOAL

The long term goal of this research is to develop multifrequency, high-frequency (HF) radar techniques and instrumentation for measuring surface currents, waves and winds in coastal regions and large lakes for scientific, civil and military applications. The goals include deployment of HF radar systems in coastal regions for air-sea interaction and coastal oceanography as well as technology development.

## OBJECTIVES

The objectives of this project begin with the completion and deployment of two multifrequency HF radar instruments (called MCR for Multifrequency Coastal Radar) to Monterey Bay, California. Next the radars were to be transported to sites near the mouth of Chesapeake Bay to participate in the Chesapeake Bay Outflow Plume Experiment (COPE-3) experiment. Finally the data collected at these sites was to be reduced, analyzed and interpreted to improved radar performance and to make current, current shear and wind measurements of the coastal ocean.

## APPROACH

This project requires an expert team of engineers and oceanographers from many institutions, including Peter Hansen and Jason Daida (University of Michigan), Calvin Teague (Stanford University), Robert Onstott (ERIM International), Dan Fernandez (Califonia State University, Monterey Bay), Jeff Paduan (Naval Postgraduate School) and Kenneth Laws and Steve Petersen (University of California at Santa Cruz). The team designed the radar under previous ONR funding and deployed the initial unit to Monterey Bay. A second radar unit was constructed and deployed to Monterey Bay in the spring of 1997. These radars currently operate under FCC license at 4.8, 6.8, 13.5 and 21.8 MHz. These two units were then deployed to sites near Virginia Beach, Virginia to participate in the COPE-3 experiment in the Autumn of 1997. These units were operated on four frequencies to gather information on currents at depths of from 0.3 to 1.5 m below the surface. The two units are situated so as to have overlapping coverage and thus produce current vectors from the radial currents measured at each site. Regarding azimuthal resolution, data from all sites was processed with both beam forming and direction finding (MUSIC) methods to assess the effectiveness of these two techniques. In addition a simulation effort was begun to investigate the accuracy of these techniques, particularly the relative effectiveness of the beam forming and direction finding (MUSIC) methods for obtaining azimuthal resolution. To study

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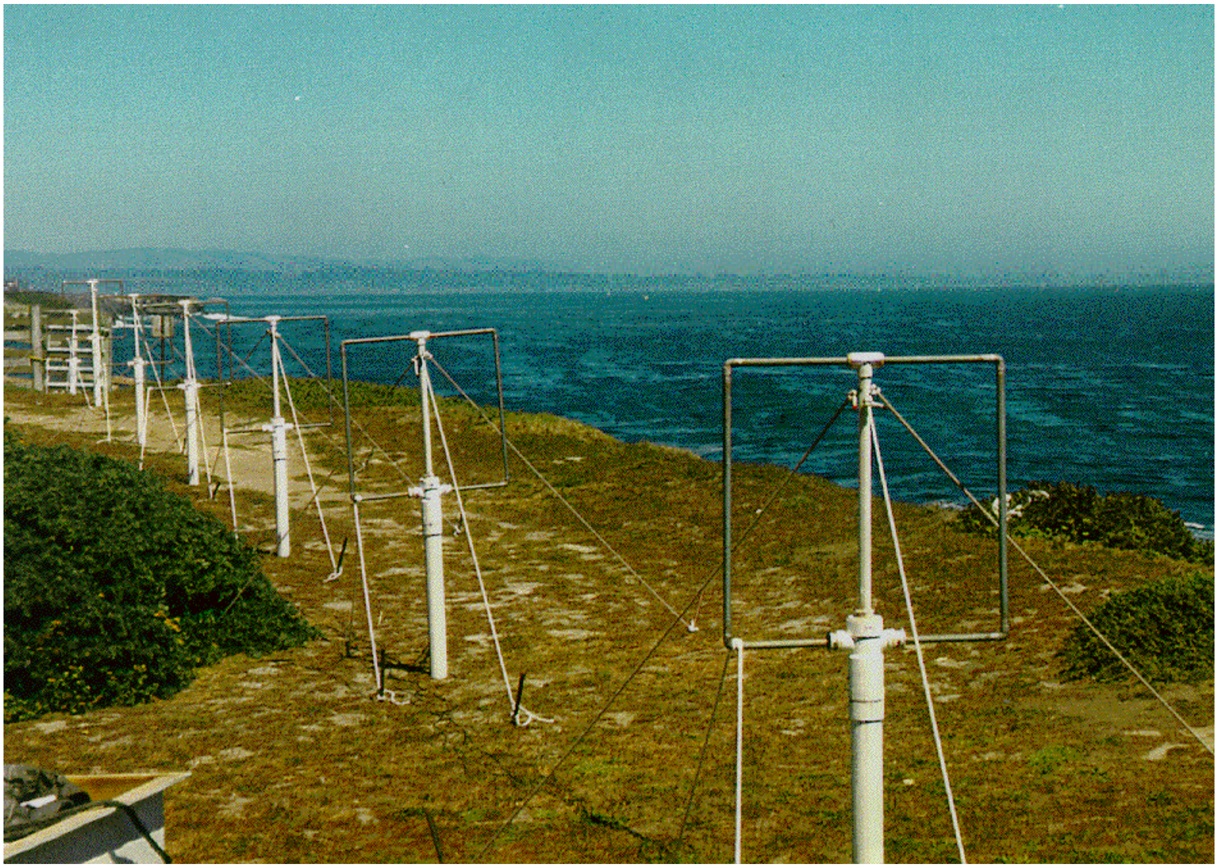

***Fig. 1. Receiving array of eight loop antennas. The array run east to west and so looks south into Monterey Bay. The site is kindly provided by the Long Marine Laboratory of the University of California at Santa Cruz (Steve Davenport, director).***

air-sea interaction we compared HF radar current measurements with environmental observations, primarily surface current and current shear with wind. To obtain

information regarding HF techniques, data from three independent radar systems were collected during the COPE-3 experiment and HF measurements of surface currents were compared with acoustic doppler current profiler (ADCP) data in collaboration with Dr. Zak Hallock of NRL, Stennis.

## WORK COMPLETED

1. Construction of two multifrequency, HF radars was completed with deployment to Monterey Bay by the spring of 1997. In Fig. 1 we show the receive antenna array at a site near Santa Cruz CA. The second radar is situated at the Moss Landing Marine Laboratory of the California State University (Fig. 2, right). These radars provide coverage of Monterey Bay and surrounding waters.

2. Two of these MCR's were transported to the Atlantic Coast just south of the mouth of Chesapeake Bay with logistic help from the Chesapeake Center for Physical Oceanography (Denny Kirwan,

director). The MCR’s joined two CODAR units from the Naval Postgraduate School (Jeff Paduan) and California State University, Monterey Bay (Dan Fernandez) and two OSCR units from the University of Miami (Hans Graber) to observe the waters just south of the mouth of Chesapeake Bay. MCR’s were deployed courtesy of Ft. Storey at Cape Henry and the Navy Fleet Combat Tranining Center, Atlantic at Dam Neck. These units were operated during Oct. and Nov. of 1997.

3. The two MCR’s were maintainanced and returned to Monterey Bay where they have been operated to the present time.

4. The data from these deployments has been reduced and analyzed for selected periods at Monterey Bay and for the entire COPE-3 deployment. The resulting vector current fields and in situ sensors have been used to investigate air-sea interaction phenomena, in particular the vertical current shear due to wind stress.

5. Simulations of HF radar operation were developed to evalutate performance of different antenna configuations and processing techniques (beam forming and MUSIC) under differing environmental conditions.

**RESULTS**

1. Development of a suite of algorithms to reduce the radar echo data to radial and then to vector current maps. This development includes the use of both beam forming and direction finding (MUSIC) techniques to obtain azimuth resolution. It is clear that the MUSIC algorithm allows good azimuth resolution (< 10°) to be obtained at the lower MCR frequencies which beam formation processing does not because the antenna array is less than a wavelength long at the lowest MCR frequency. An example current vector map from Monterey Bay is show in Fig. 2 below.

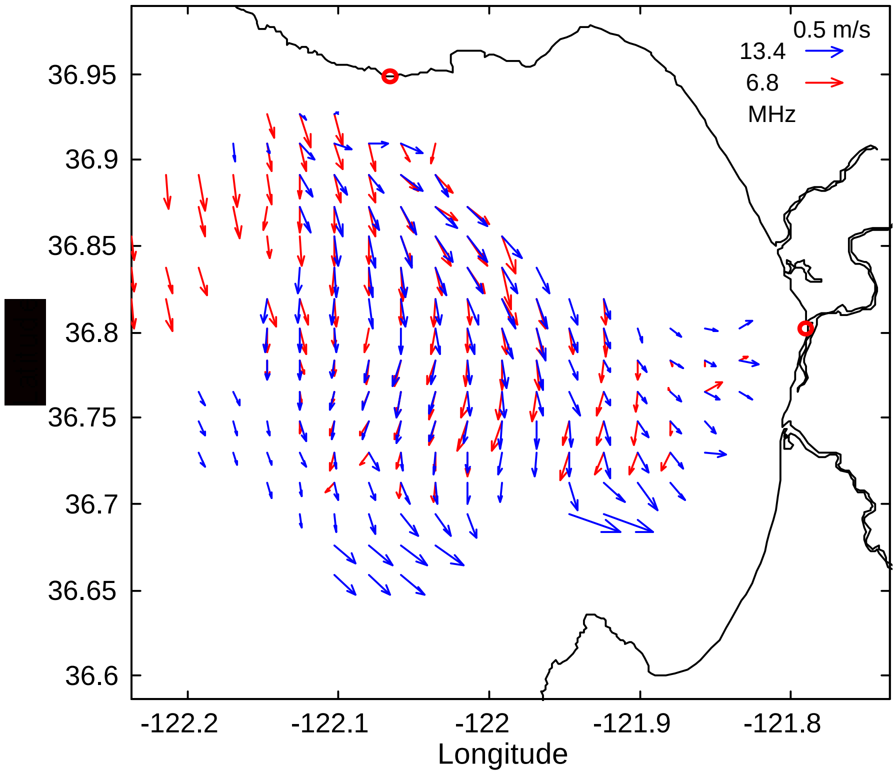


***Fig. 2. Vector current map observed over Monterey Bay, California from 1600 to 1630 local time on July 3, 1997. The 13.5 MHz results (50 cm depth) are shown in blue and the 6.8 MHz (1 m depth) results are shown in red. The two multifrequency HF radars are located at Long Marine Laboratory of the University of California at Santa Cruz (top center) and at the Moss Landing Marine Laboratory of the California State University System (right center).***

2. Using the MCR data from Monterey Bay (Fig. 2) we investigated the vertical current shear set up by the land-sea breeze circulation so common over Monterey Bay. This set of environmental conditions allows the shear due to the wind to be clearly identified since the land-sea breeze has a strong diurnal period. Fig. 3 shows a time series of the nearly north-south, radial current component observed at the Santa Cruz site (top of Fig. 2) at two effective depths (0.5 and 1.4 m below the surface) and the M1 buoy, wind speed near the center of the Monterey Bay mouth. (The M1 buoy data were kindly provided by Francisco Chavez at the Monterey Bay Acquarium Research Institute.) The currents are averaged over a 10 x 10 km area surrounding M1. Note how the currents tend to the south (negative currents) as the synopitc scale wind is out of the northwest with the land-sea breeze adding to this prevailing wind. Shear values reach more than 0.1 1/s when the wind speed peaks. This is the first such observation of wind driven, vertical shear near the ocean surface known to the investigators.

3. The data set collected during COPE-3 is the most comprehensive comparison of different HF radar systems to this time. In additon to the three radar systems there were several ADCP moorings in the radar footprint. Preliminary comparisons between radar systems and with meteorological and ADCP data have revealed several points. First, all three HF radar systems (MCR, CODAR and OSCR) measure currents that track each other very well in general. There are some cases when the measurements are somewhat at variance and we are investigating the causes of such disagreements. Second, the different radars and the ADCP moorings measure currents at different depths. For example, the CODAR and OSCR measure currents very near the surface (a few 10’s of cm depth) while the MCR

measures currents from these depths down to about 1.4 m. The ADCP's top bin is about 2 m from the surface depending on the tidal height at the mooring. In comparing these measurements at different depths we find that at times they all track very well, but at other times there is strong shear in the top few meters of the ocean. In comparing these events with wind and tidal data we tentatively conclusion that the strongest shears occur when the wind and tidal flow are opposed.

**IMPACT/APPLICATION**

The development and application of these multifrequency radars has demontrated their usefulness in measureing surface currents and current shear in the top few meters of the ocean. No other technique can make such measeuements over a large area, at frequent times and at a reasonable cost. We are now working on extending the suite of measurements to winds and waves. Applications of these of these instruments lie in the marine science, civil and military sectors. Some example applications are air-sea interaction, coastal circulation, transport of marine life (e.g. barnacle larvae) in near surface waters, surveillance of ships in coastal waters, coastal engineering works amd movement of surface pollutants, such as oil and chemical spills, and special military operations in the littoral zone.

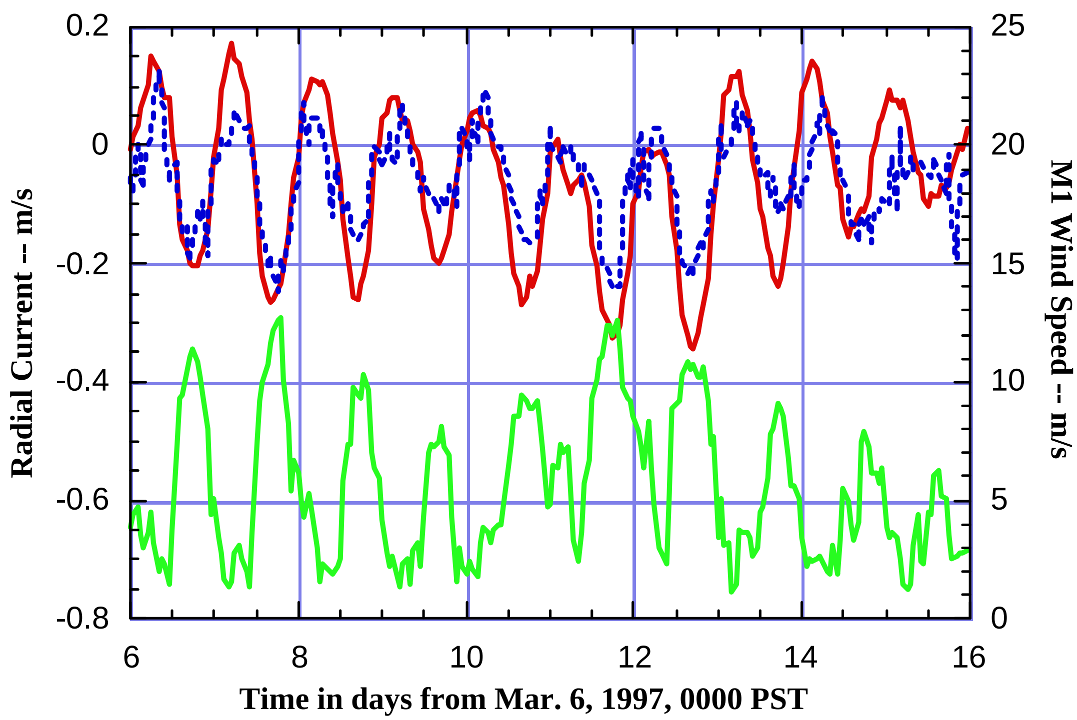


***Fig. 3. Time series of radial currents (upper curves -- left axis) and wind speed (lower curve -- right axis) at the mouth of Monterey Bay (near the M1 buoy). The radial direction is very near due south with currents approaching the radar being positive and receding currents negative. The solid red line is the current at a depth of 0.5 m and the dashed blue line is the current at a depth of 1.4 m. Note how the maxima in northwest wind speed correspond to the maxima in current receding from the radar.***

## TRANSITIONS

We are currently working under an STTR grant with Metratek Inc. of Fairfax VA (Ray Harris, President) to develop a commercial version of MCR for government, science and civil customers.

## RELATED PROJECTS

1. We are deploying MCR's on the shore of Lake Michigan to help define the circulation of the lake during episodic events driven by strong winds blowing down the lake from the north. These winds drive currents which resuspend sediments and thus pollutants, carrying them to other regions of the lake. This project, called EEGLE, is a cooperative program between NOAA and NSF.

2. We are also participating in the National Ocean Partnership Program element involving remote sensing and data assimilation over Monterey Bay (Jeff Paduan, Steve Ramp and Dan Fernandez, co-investigators)

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