MAPPING OF OCEAN SURFACE CURRENTS AND VERTICAL SHEAR BY HIGH FREQUENCY RADAR

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LONG-TERM GOAL

The long term goals of this project are to apply the ground wave HF radar technique to the measurement of ocean and fresh water surface currents, near surface vertical current shears, winds and waves. By mapping these quantities with a spatial resolution of 1 to 3 km or better and a temporal resolution of 1 hour or better over areas of thousands of square km we anticipate wide-spread applications in marine science, military operations and commerce.

SCIENTIFIC OBJECTIVES

Out scientific objectives can be summarized as follows:

1. Production of accurate maps of ocean surface currents as several depths in the top two meters of the ocean and of the surface wind field. Such maps would have spatial resolution of 1-3 km or better, a maximum range of 100 km or better and a temporal sampling rate of once per hour or better; and
2. Application of the HF radar observations above to the study of coastal ocean phenomena, such as the following:
    a) The land-sea breeze circulation and its impact on coastal ocean circulation;
    b) Response of the coastal ocean surface to fronts and other littoral circulation structures; and
    c) Impact of El Nino events on coastal ocean currents, winds and waves.

These studies are taking place at Monterey Bay CA and the mouth of Chesapeake Bay, VA.

APPROACH

A new high-frequency (4-25 MHz) phased-array radar, funded by ONR and designed and constructed jointly by the University of Michigan, Stanford University and ERIM International was installed at Santa Cruz, California in July, 1996. After initial equipment checkout and antenna calibration using a transponder (carried on a small boat), regular data collection started in October, 1996. The radar operates on four frequencies in the HF band using vertical transmit antennas and an array of eight wideband-loop-receive antennas. Both single and biphase coded pulses are used with a 20 μs chip length. Range resolution is about 3 km, and the 48 m phased-array aperture gives an angular resolution at the highest frequency of about 15°. Vertical current shear is estimated by using multiple radar frequencies which are scattered, thorough Bragg resonance, by ocean waves of different lengths that in turn are sensitive to currents at various depths (Ha, 1979; Fernandez, et al., 1996). For observations thus far the radar operated on four frequencies: 4.8, 6.8, 13.4 and 21.8 MHz,

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allowing estimation of the vertical current shear at 'effective' depths of 1.4, 1.0, 0.5 and 0.3 m respectively. The calculation of these effective depths assumes a logarithmic current profile. Unattended, remote operation is a key feature of the radar design. Nearly all radar functions can be controlled remotely using a modem or internet connection. Further description of the radar's design features and operation is given by Teague, et al., 1997.

RESULTS

Observations by this multifrequency HF radar are used to investigate the impact of wind stress, tidal flows and other factors on near-surface currents in the top few meters of the ocean. This work follows on previous investigations of surface current circulation in Monterey Bay using single frequency HF radars, e.g., Paduan and Rosenfeld, 1996. The observational geometry is shown in Figure 1.

Strong land-sea breeze circulation often dominates the surface wind field over Monterey Bay, especially during the summer. Typically sunlight warms the land surface in the Salinas Valley (east of Monterey Bay) beginning at sunrise. This action in turn causes cool air over Monterey Bay to flow from the sea toward the land. By noon a circulation is established with air flowing from sea to land near the surface and from land to sea at about a kilometer altitude. This process often produces westerly surface winds of 8 to 12 m/s by about 4 pm local time. After sunset the air over the ocean cools rapidly and the process reverses due to the relatively warm sea surface at night, but is weaker. For analysis we picked March 7-17, 1997 when the land-sea breeze circulation was strong. Wind speed fluctuations were observed at the M1 buoy deployed by the Monterey Bay Aquarium Research Institute (MBARI) and shown in Figure 1. We would have preferred a longer time series, but the strong land-sea breeze cycle was interrupted on March 18th.

We assembled a ten day time series of hourly surface current estimates at each of the four radar operating frequencies. Each point in the time series was an average over 5 range bins and three 15° angle bins centered on the M1 buoy location shown in Figure 1. This average covers a region about 10 km in radius centered on M1. An example of the time series of the average current in the neighborhood of the M1 buoy is given in Figure 2. The values displayed are the mean of the 12 resolution cells in the neighborhood of the M1 buoy. For each resolution cell the current was estimated from the first-order-Bragg line with the highest signal to noise. There were four possible choices amongst advancing and receding waves and two different radar pulse types. Typically the signal to noise ratio was 10 dB or more.

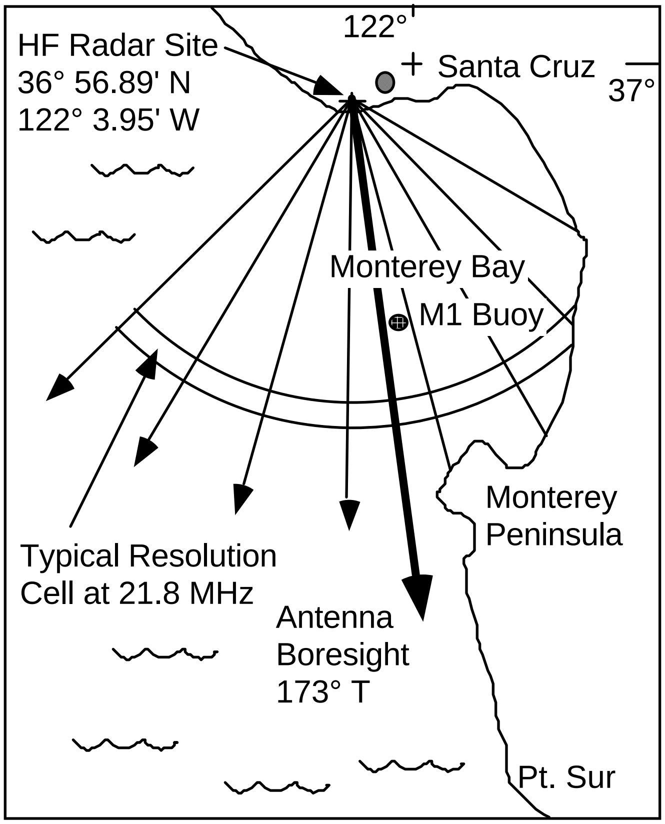

Figure 1. Observational Geometry for the Multi-Frequency HF Radar Located at the Long Marine Lab. of the University of California at Santa Cruz.

Figure 2 illustrates very well the advantages of using multiple radar frequencies stretching down to the lower part of the 3 to 30 MHz HF band. At the higher frequency of 13.4 MHz the effective depth of the measurement is about 0.5 m. At this depth the near-surface current (dashed line) responds strongly to the surface stress of the land-sea breeze. Thus, we see a very strong diurnal component with a bias toward receding current which is in the direction of the sea breeze when it peaks in the afternoon hours. Considering the observational geometry of Figure 1 the cause of the bias toward receding current is clearly due to the fact that near the M1 buoy location the radar is looking near the downwind direction. At the deeper depth of about 1.4 m corresponding to the 4.8 MHz observations we find that there is still a response to the diurnal forcing of the land-sea breeze circulation, but it is weaker. Further, there are other factors influencing the current at the deeper depth. Figure 2 also shows the vertical shear in the surface current in this situation. During the afternoon hours when the surface wind is strongest the difference in radial current speed reaches 0.1 m/s. Taking the difference in depth of measurement to be about (1.4 - 0.5) = 1 m we find a maximum shear of about 0.1 s^{-1}. The story that emerges from these observations is that at depths of 0.5 m and less the near-surface current is strongly controlled by the surface wind stress when the wind speed is above about 5 m/s. At deeper depths other factors, such as tide or upwelling driven currents, begin to make themselves felt as the wind stress influence decreases.

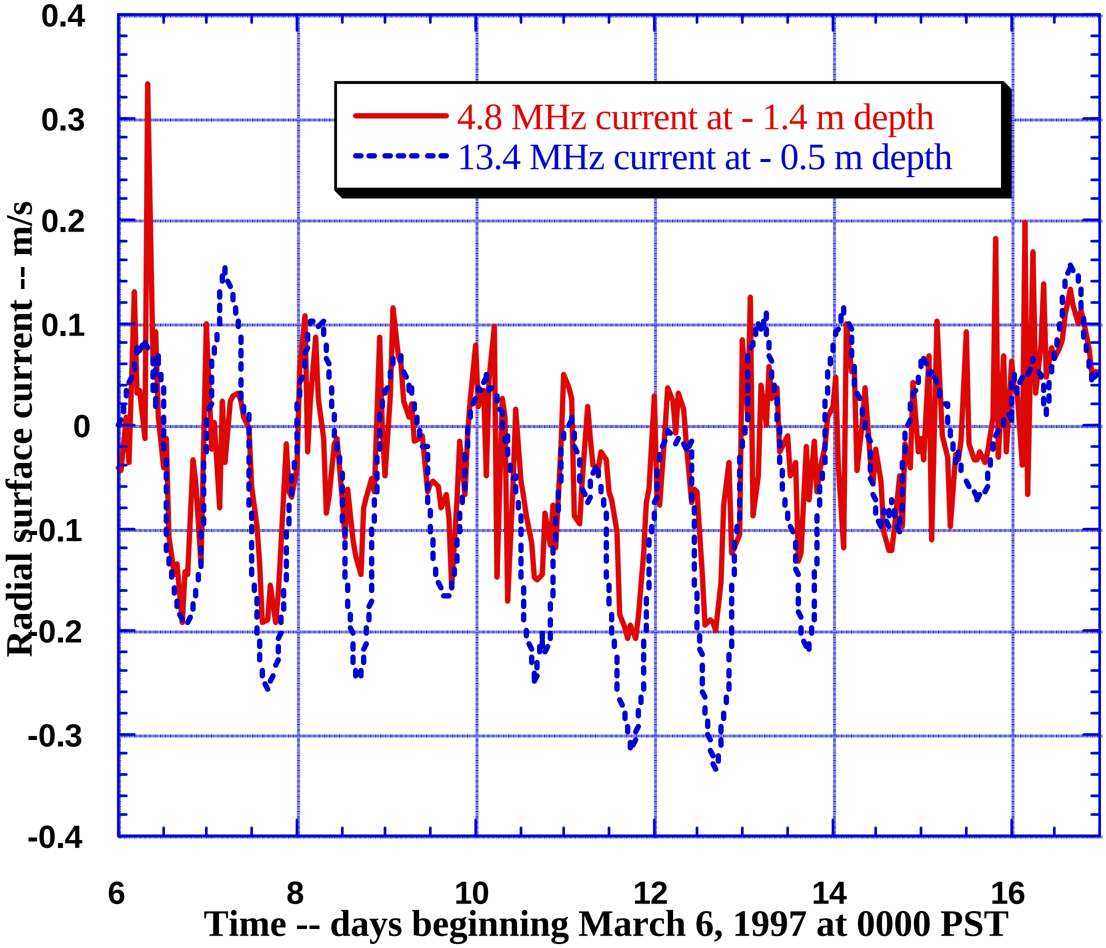

Figure 2. Time Series of Radial Currents Measured at Frequencies of 13.4 MHz (dashed line) and 4.8 MHz (solid line) Corresponding to Approximate Depths of 0.5 m and 1.4 m Below the Surface. Note how the current at the shallower depth is more responsive to the wind forcing of the land-sea breeze circulation that peaks in the mid-afternoon.

IMPACT/APPLICATION

Measurement of near-surface currents is very difficult by any technique aside from HF radar. HF radar can map currents accurately over ranges of up to 100 km from the coast or can be mounted on ships. The multifrequency technique allows measurement of vertical current shear as well. In the results above we notice how wind stress is the dominant forcing for surface currents down to depths of 1.5 m and more. Thus, in a situation like Monterey Bay estimation of surface currents by tidal and density driven effects alone would be quite incorrect -- the land-sea breeze is the dominant factor during the daytime and much of the night. Thus, if one needs to predict the movement of surface pollutant films (oil spills, etc.), surface objects (mines, etc.) or the drift of shallow draft boats or near surface swimmers it is clear that surface wind stress is an important factor. Further, HF radar is an ideal instrument for allowing the aforementioned predictions.

TRANSITIONS

We are currently participating with Metratek Inc. of Reston VA in a Small Business Technology Transfer Grant to design and build a commercial HF radar for sale to the military, commercial and scientific markets. Phase I of this STTR began in Sept., 1997 and construction of the prototype is anticipated during 1998.

RELATED PROJECTS

Related projects are the HF radar and other experiments during the Chesapeake Bay Outflow Plume Experiment (COPE-3) and the CODAR and other radar measurements made in Monterey Bay CA.

REFERENCES

Ha, E. C., 1979. “Remote sensing of ocean surface current and current shear by HF backscatter radar,” Ph.D. dissertation, Stanford Univ., Stanford, Calif.,Tech. Rep. D415-1.

Fernandez, D. M., J. F. Vesecky and C. C. Teague, 1996. “Measurements of upper ocean surface current shear with high-frequency radar,” *J. Geo. Res.*, vol. 101, 28615-28625.

Paduan, J. D. & L. K. Rosenfeld, 1996. “Remotely sensed surface currents in Monterey Bay from shore based HF radar (CODAR),” *J. Geophys. Res.*, vol. 101, 20,669-20,686.

Teague, C. C. et al., 1997. “Initial observations of ocean currents, current shears and wind direction using multi-freq. HF radar,” *IGARSS '97 Proc*., IEEE Press, Piscataway NJ.

Vesecky, J. F., C. C. Teague, R. G. Onstott, J. M. Daida, P. M. Hansen, D. M. Fernandez, N. Schnepf and K. Fischer, 1997. “Observations of near-surface ocean currents at varying depths using a new multifrequency HF radar,” CD-Rom, *IGARSS '97 Conf. Proc*., IEEE Press, Piscataway NJ.

Vesecky, J. F., F. L. Ludwig, C. C. Teague, W. Nuss, R. G. Onstott, P. Hansen, D. Fernandez, J. Daida and K. Fischer, 1998. “Estimating the surface wind field over the coastal oceans using high frequency radar and in situ observations,” accepted for presentation (preprint available) at the 2nd American Meteorology Society Conference on Coastal Atmospheric and Ocean Processes, Phoenix AZ, Jan.

Vesecky, J. F., C. C. Teague, R. G. Onstott, J. M. Daida, P. M. Hansen, D. M. Fernandez, N. Schnepf and K. Fischer, 1997. “Surface current response to land-sea breeze circulation in Monterey Bay,” California as observed by a new multifrequency HF Radar, 1-6 on CD-Rom, *Proc. Oceans '97 Conf*., IEEE Press, Piscataway NJ.