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The SeaSonde proved its utility in directing ship and AUV sampling operations, and improving circulation model forecasts, during the summer of 1998 off New Jersey. A high standard of SeaSonde surface-current measurement accuracy was established by ADCP comparisons.

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SeaSonde Is Integral to Coastal Flow Model Development

The Rutgers University Long-term Eco-system Observatory (LEO-15) is an instrumented natural laboratory located on the inner continental shelf off Tuckerton, New Jersey in approximately 15 m of water. LEO-15 was developed to study coupled physical, optical, biological, chemical and sediment transport processes by maintaining a continuous observational presence in a 30 km x 30 km coastal region. The numerous remote sensing, shipboard, and underwater observing systems at LEO-15 transmit their measurements in real time to a central shore station in Tuckerton where they are made available via the World Wide Web (http://marine.rutgers.edu/mrs) for research, education and recreational purposes.

The first in a four-year series of Coastal Predictive Skill Experiments was conducted last summer at LEO-15. The July 1998 experiment was sponsored by the National Ocean Partnership Program (NOPP), the Office of Naval Research, and the Mid-Atlantic Bight National Undersea Research Center. The purpose of these experiments is to evaluate a new coastal-ocean forecast model and the influence of sub-surface adaptive sampling in a data- and process-rich environment. The processes studied focus on the development of recurrent coastal upwelling centres along the New Jersey coast and how they influence phytoplankton concentrations and dissolved oxygen levels. Assimilation datasets for the forecast model include spatially-extensive surface current as mapped by the SeaSonde HF radar, temperature distributions from NOAA satellites, and limited subsurface currents and temperature profiles from ships, moorings and Autonomous Underwater Vehicles (AUVs). A major goal is to optimise the usefulness of the expensive subsurface observations by adapting shipboard and AUV sampling strategies to the present oceanographic conditions based on the real-time data and previous model forecasts. The desired end result is a validated coastal forecast model which can be relocated to other regions with knowledge of what surface and subsurface datasets are required to maintain a specific level of forecast accuracy.

Using large phased array antennas on San Clemente Island, CA, Barrick and his colleagues established the utility of HF radars for coastal surface-current mapping over 25 years ago[1]. HF radar signals propagate beyond the horizon and backscatter from short waves (e.g., 6 m whose periods are 2 s). The current speed toward or away from a single radar is measured

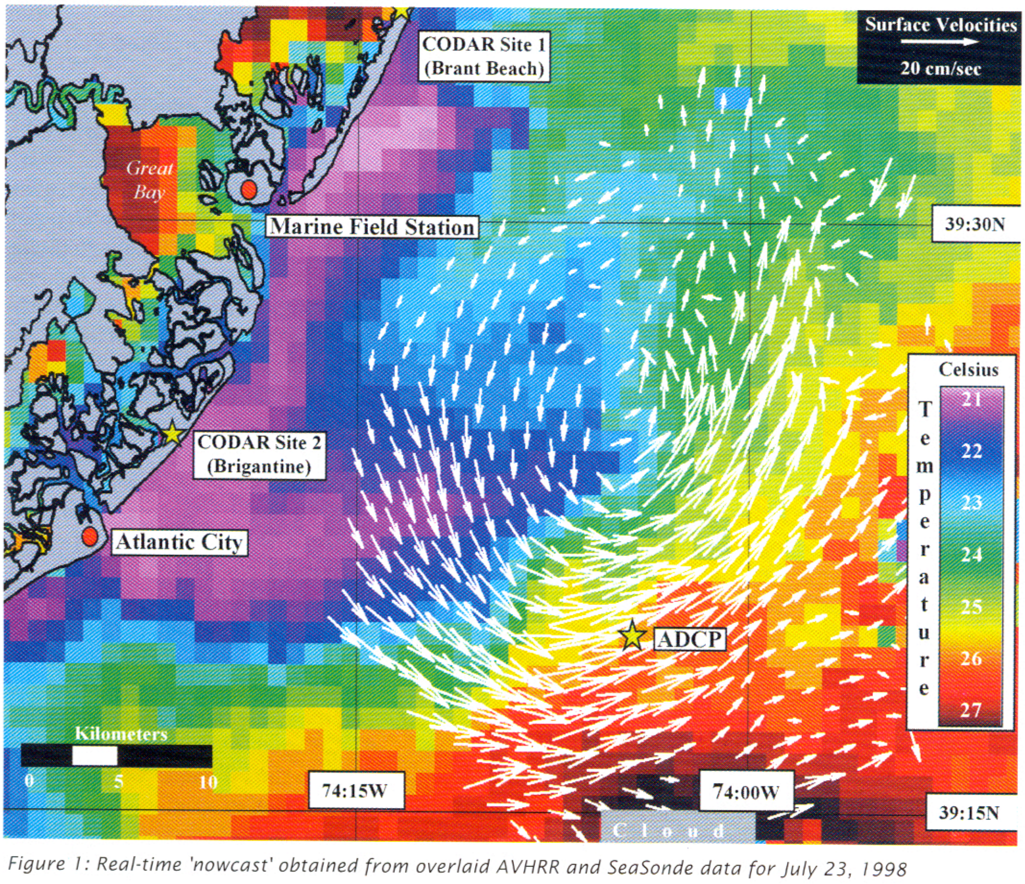


Figure 1: Real-time 'nowcast' obtained from overlaid AVHRR and SeaSonde data for July 23, 1998

as the Doppler shift of the echo signal. Because a single radar detects only the radial speed toward or away from its site, normally two or more radars are deployed to synthesise a total horizontal current vector at each point on their common map area. Ranges out to 70 km and spatial resolutions as good as 300 m are achieved by choice of operating frequency and waveform. The information from a pair of HF radars is equivalent to that of thousands of closely spaced drifters which would need to be released every day.

The major impediment to widespread HF radar use has been their large phased-array antenna sizes, demanding at least 100 m of coast per site, not including their transmit antennas. Besides high costs, this was a major inconvenience factor that often limited access to points with desirable views. This obstacle was overcome by inventions at U.S. NOAA's research laboratories headed by Barrick in the 1970s. Compact direction-finding antennas replaced the large beam-forming phased arrays. The SeaSonde is its commercial culmination. Its compact antenna can be kept out of reach, either on posts or building rooftops. Along with a unique, highly efficient waveform, this low-power compact system allows unmanned real-time operation which at some sites has continued for six years uninterrupted. But it is also suited for quick-response deployments because of its small size and ease of set-up.

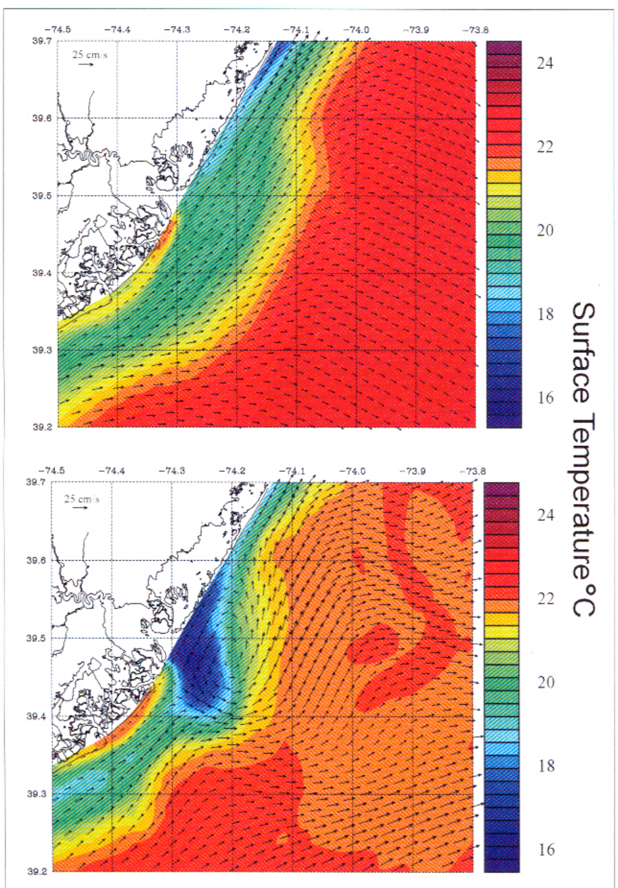


Figure 2: Ocean model outputs for July 17, 1998 both with (lower) and without (upper) SeaSonde data assimilation. Model fails to predict observed eddy without SeaSonde input

Summer '98 Findings

A SeaSonde radar pair was deployed on the New Jersey coast in the vicinity of LEO-15 to measure surface currents associated with coastal upwelling. Historically, LEO-15 has been an area of strong upwelling characterised by uniform offshore flow. After the initial winds relax, the cold upwelled water concentrates into distinct upwelling centres characterised by a cold eddy surrounded by a northward flowing jet. Hourly SeaSonde surface-current maps complemented many other instruments, including moored, towed and AUV-mounted ADCPs, in an intense sampling of upwelling during the month of July 1998.

The SeaSonde data were initially detided using a least squares fit of regional tidal constituents. The detided data were then filtered using a low pass filter with a cut off frequency of thirty hours. The filtered data showed expected upwelling features, including strong offshore flow and eddy development. This data set was used to plan daily cruise transects and to improve numerical model forecasts through assimilation.

Real-time SeaSonde-derived vector fields were used to plan daily transects near LEO-15 as an alternative to past operations which used an arbitrary cross-shore line. During July of 1998, SeaSonde maps coupled with AVHRR imagery allowed researchers to develop a 'nowcast' of the upwelling area and identify specific areas of interest. The 'nowcast' obtained each morning enabled the in situ sampling to concentrate on these critical areas. For example, the data illustrated in Figure 1 prompted sampling along transects drawn through the centre of the eddy. This efficient sampling regime coupled the surface-current maps with subsurface profiles providing a more complete representation of upwelling dynamics.

The HF radar data were also assimilated into a numerical model to improve weekly forecasts. To test this assimilation, the model was initiated both with and without the surface-current information. The assimilated model depicted the development of an upwelling eddy while the non-assimilative model did not (Figure 2). The assimilations based on the SeaSonde data led to predictions of common flow features associated with upwelling, thus providing a more accurate forecast.

Use and Validation of SeaSonde

Besides differing from deeper currents in their direct response to the surface winds, the highly important surface flows also have greater spatial variability over small scales.

Nonetheless, the assimilation of HF radar data with that from other instruments into models requires one to establish how they relate to one another, i.e., comparisons. Since each radar directly feels the radial component of the surface current, it makes most sense to relate this radial speed to the velocity component from the other instrument directed toward the radar. This way, a comparative assessment for each radar is established separately, before the two data sets have been combined into a total vector.

An example of a raw time series at hourly increments over one week is shown in Figure 3. Here the South SeaSonde radial component at the ADCP location (shown in Figure 1 located ~29 km directly out from this radar site) is compared to its own radar-directed component from the bin 4.5 m below the mean surface. This is the closest measurable bin to the surface. Also shown is a scatter plot between these two raw measurements, but over a 30 day time period during July 1998 (a total of ~720 data points). The rms difference between the two (i.e., $\mathrm{Avg}[\sqrt{(v_a - v_r)^2}]$) is 6.7 cm/s.

This difference has four causes: (i) residual random variability due to a finite ensemble average of the sensor signals; (ii) the different nature of the two measurements; (iii) error in the ADCP used for the comparison; (iv) error in the HF radar measurement. Careful studies examining the partitioning of these errors have been done elsewhere for phased-array HF radar systems, e.g., Chapman and Graber[1]. Finding upper bounds in total rms velocity of 10-15 cm/s, those studies concluded that the portion due to the HF radar might be 6-7 cm/s. Since our total rms difference is 6.7, our radar error at the radial level must be less by several cm/s than this number.

The tidal part of the currents measured by different instruments at the same location is expected to agree more closely, with the short-term wind and wave effects near the surface removed. Only those components at the known tidal frequencies are extracted, using a least-squares filter over a long time period (30 days). Remaining differences include any real depth and spatial variations, as well as long-term errors due to inherent instrument biases. Examples of the tidal time series over one week are shown in Figure 4 for both sites. Again, the SeaSonde radial tidal speeds at the ADCP are compared to the component which points toward each of the two radar sites. The degree of overlay suggests little bias. The rms differences between these radial tidal components over the entire 30-day period are 2.5 cm/s and 2.4 cm/s for the North and South sites, respectively.

Conclusions

Adaptive sampling programmes at LEO-15 before 1998 relied solely on satellite-derived sea-surface temperature fields for mission planning. Overhead passes from the operational NOAA AVHRR satellites are only available four times per day, and unfortunately the satellite's view of the ocean surface can be obscured by clouds or fog. During the July 1998 experiment, 9 out of 27 days were completely obscured from view by dense cloud cover. Since fog often develops over the cold upwelling centres and does not burn off until late in the day, the upwelling centres often were not visible even on relatively clear days until after the adaptive sampling ships and AUVs had left the dock.

In contrast, continuous SeaSonde surface current fields were available every hour in real-time regardless of the weather conditions. The continuous nature of the SeaSonde observations allowed us decompose the observed current fields into tidal and low frequency components, the latter clearly revealing the wind-driven upwelling centres. Real-time maps that showed regions of surface convergence and divergence expedited our biological adaptive sampling operations. We also found convincing evidence that assimilation of SeaSonde currents into the numerical model will improve weekly forecasts; without these surface inputs, the model often failed to predict the observed eddies produced by cold upwelling features. Finally, ADCP comparisons support the conclusion that radar error in radial current measurement near the centre of the coverage area is better than 6 cm/s. Future plans for the SeaSonde under NOPP will see expanded versatility and coverage.

Over the next two years, a 'bistatic' capability is to be added to the SeaSonde.

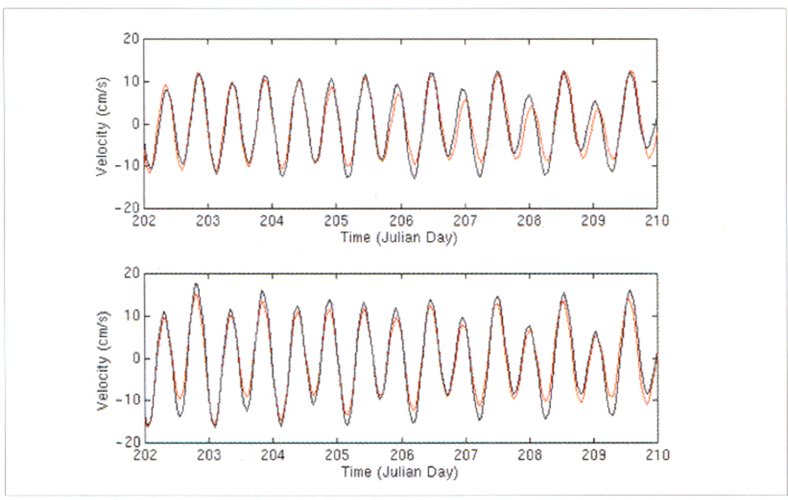


Figure 4: Tidal time series comparison over one week for North-site (upper) and South-site (lower) SeaSonde radial currents and ADCP radar-directed velocities

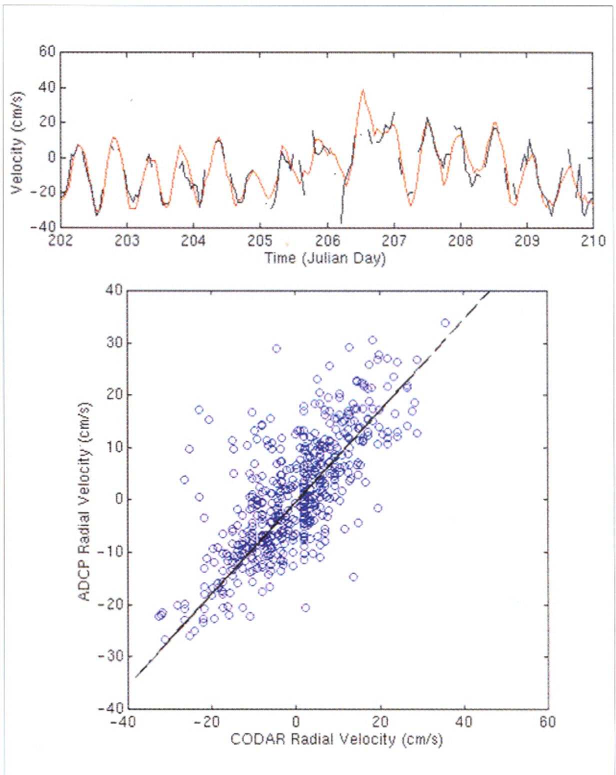


Figure 3: Raw data comparisons between South-site SeaSonde and ADCP bin at 4.5 m depth. Lower is scatter plot for month of July (6.7 cm/s rms difference); upper is one-week time series

Footnote

[1] A recommended collection of readable articles summarising the evolution and progress of HF current-mapping radars is found in a special issue of the journal Oceanography, vol. 10, no. 2, 1997

National Oceanographic Partnership Program (NOPP) is a collaboration of twelve federal agencies to promote co-operative activities among government, academia, and industry, for the advancement of ocean science, technology, and education.

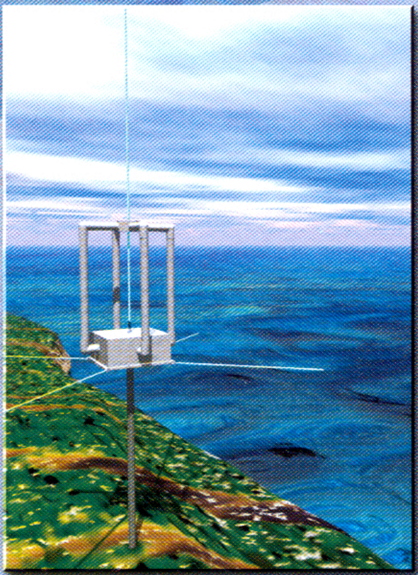
Biographies

Don Barrick is President of CODAR Ocean Sensors, Ltd., the group which invented and developed HF radar surface-current mapping over the past 25 years.

Josh T Kohut is a second year graduate student at the Rutgers University Institute of Marine and Coastal Sciences studying the coastal dynamics of upwelling.

Scott M Glenn, a Professor at the Rutgers University Institute of Marine and Coastal Sciences, is Principal Investigator for NOPP- sponsored research at LEO-15. ■

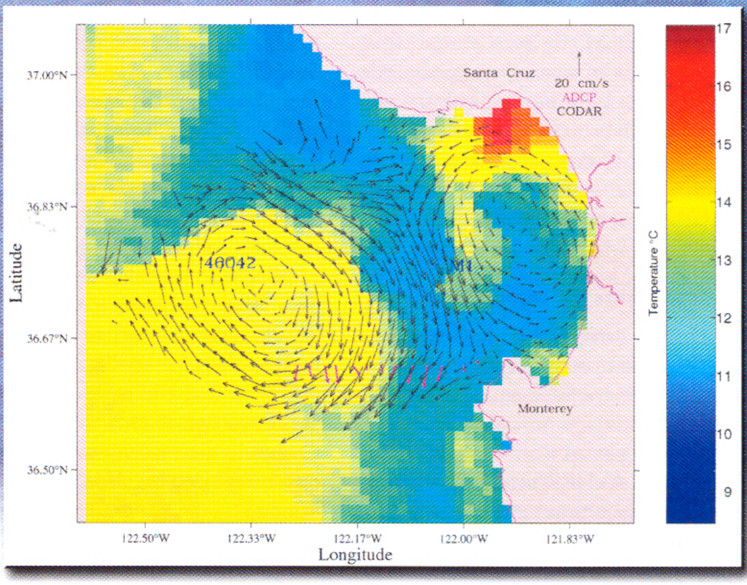
The No-Hassle Way to Map Surface Currents from Shore



Receive Antenna – Actual size less than 1m³

Actual data set from Monterey Bay showing SeaSonde® current velocity vectors, and AVHRR temperatures in colored background.

The Journal of Geophysical Research, 1996, vol. 101, by J. D. Paduan & L. K. Rosenfeld



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