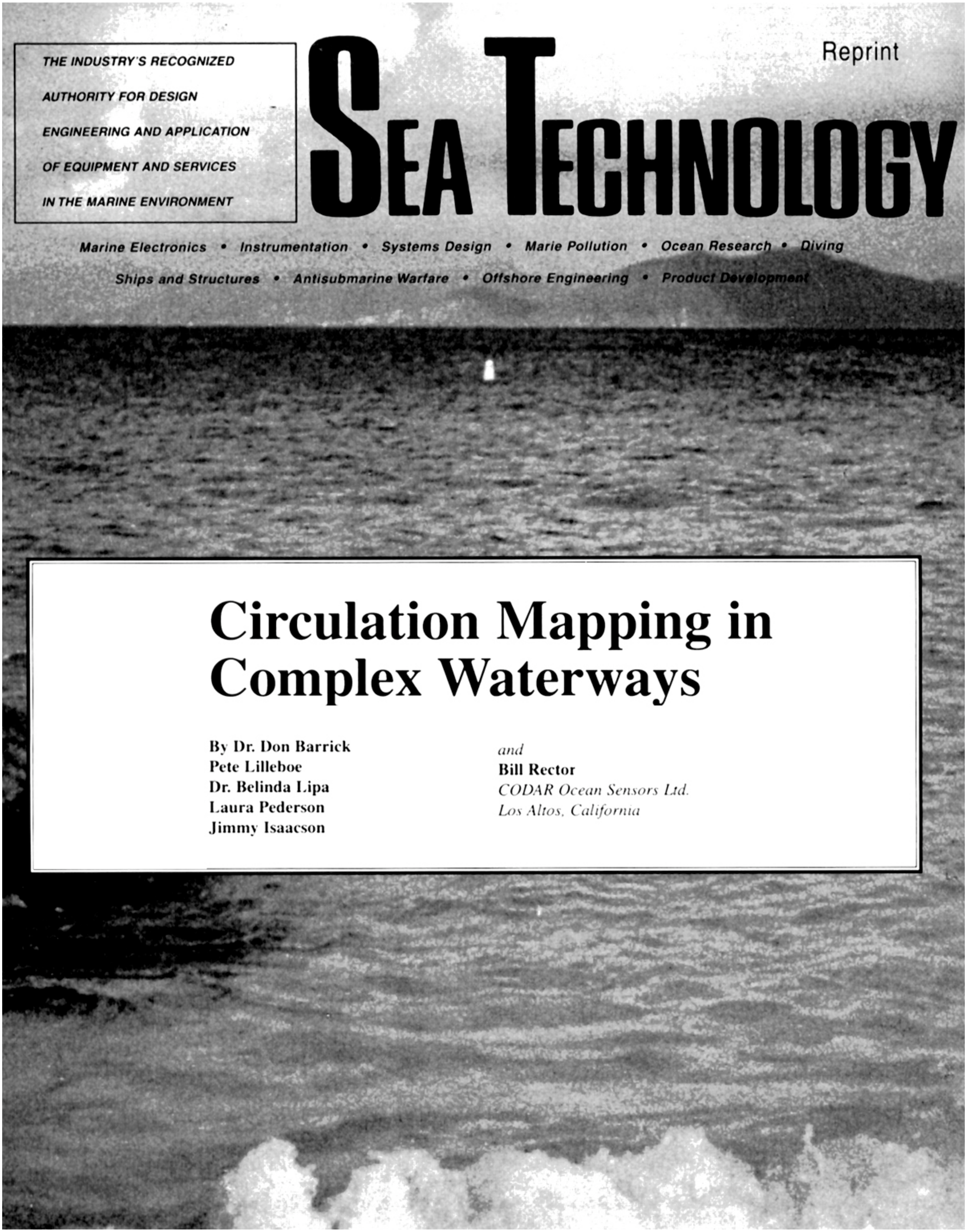
THE INDUSTRY'S RECOGNIZED
AUTHORITY FOR DESIGN
ENGINEERING AND APPLICATION
OF EQUIPMENT AND SERVICES
IN THE MARINE ENVIRONMENT

SEA TECHNOLOGY

Reprint

Marine Electronics • Instrumentation • Systems Design • Marie Pollution • Ocean Research • Diving
Ships and Structures • Antisubmarine Warfare • Offshore Engineering • Product Development



Circulation Mapping in Complex Waterways

By Dr. Don Barrick
Pete Lilleboe
Dr. Belinda Lipa
Laura Pederson
Jimmy Isaacson
and
Bill Rector
CODAR Ocean Sensors Ltd.
Los Altos, California

Circulation Mapping in Complex Waterways

SeaSonde High Frequency Radar System Breaks Resolution Barrier from Kilometers to Only Hundreds of Meters; 30-Year-Old Con-

By Dr. Don Barrick
Pete Lilleboe
Dr. Belinda Lipa
Laura Pederson
Jimmy Isaacson
and
Bill Rector
CODAR Ocean Sensors Ltd.
Los Altos, California

High-frequency radar (HF) proved its effectiveness for measuring surface currents nearly 30 years ago. The past 15 years of product research has seen great reductions in size along with many signal advances and processing improvements. Today, more than 30 compact, unobtrusive, and unmanned coastal SeaSonde® radar systems around the world are mapping current patterns in real time, each with information content equivalent to thousands of surface drifters deployed daily.

This, along with recent breakthroughs that allow very fine user-selectable spatial resolution to 100 meters, allows the mapping of highly complex flows in enclosed waterways such as the San Francisco Bay in 1999 discussed here.

Evolution of HF radars to remotely sense water currents began in NOAA's Environmental Research Laboratories (Boulder, Colorado) in the early 1970s. The first tests at San Clemente Island employed conventional phased-array antennas that spanned more than 100 meters of coastal frontage.

Because such systems–with their complex antenna equipment and large required coastal footprint–were too obtrusive and expensive for practical application, author Barrick led a NOAA thrust to replace that antenna system with a compact design. Called CODAR, this patented approach abandoned electronic beam forming and scanning used with the large phased arrays in favor of direction finding to determine the bearing angle to the scattering patch.

In the mid-1980s, Barrick and his group left NOAA to commercialize this CODAR technology. They (1) reduced antenna size further; (2) invented a unique, efficient, low-power, digitally synthesized waveform that allows the user to select from a wide range of radar cell sizes and frequencies; and (3) adapted desktop PC platforms for all radar control, real-time processing, and modem communication to the unmanned field site from anywhere in the world.

These advances–the result of lowering the price while increasing robustness and utility–have opened the door to use of this important current-mapping technology to a wide market of research and operational customers.

Introducing SeaSonde

The first two decades of tests and development led to the SeaSonde, a mid-range, mid-resolution unit that looks out from a coastal site onto an open sea. Typical resolutions were 1-3 kilometers with maximum distances from 40-80 kilometers. Recent CODAR discoveries in antenna technology, as well as in signal waveforms and their digital generation and processing, expanded the SeaSonde family to products that now reach out to long ranges of 300 kilometers at one end with systems at the other end with 100-meter spatial resolutions suitable for operation in bays and harbors.

The latter variation–and its first tests–comprise the focus of this article.

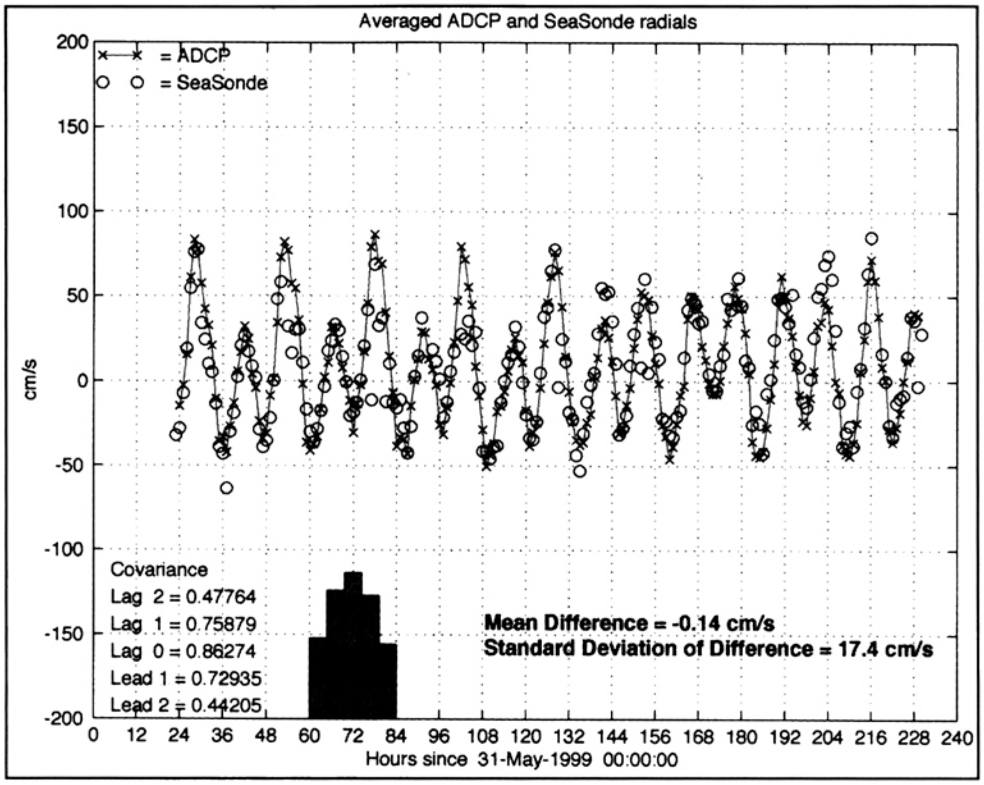
'Hi-Res' = Finer Resolution

Dubbed the "Hi-Res" SeaSonde, it operates at higher frequencies (24-50 MHz) to provide fine resolution at the expense of decreased maximum range. Attention was given in its design to reducing its presence further as the shores of bays are even more crowded with human activity (buildings, cities, and ports) along with higher potential radio interference.

All HF radars depend on Bragg scatter for current sensing from short water waves (~6 meters long with ~2-second periods) that resonate with the radar wave. The Doppler shift from these waves, as transported by the underlying currents, gives the current speed toward and away from the radar at each map point in range and bearing angle. The speed is measured to a resolution between 2 and 5 centimeters/-second with an accuracy better than 10 centimeters/second. Two or more such radars are usually deployed so that any desired point can be observed simultaneously at different angles to produce a total horizontal current vector. Antenna height is not important at high frequencies as their radio waves propagate beyond the visible horizon.

Although microwave radars are more compact and widespread, after 50 years of attempts they have never proven successful for current monitoring. The reason is that their short waves see too many unrelated, confusing small-scale, near-surface effects that obscure the underlying current signature. Occasionally currents are seen, but more often they are not.

A "sometimes" system is hard to



Comparison of current time series over nine days at NOAA ADCP position near Richmond (5 kilometers from the Tiburon SeaSonde site). The raw radial current vector measured by the radar is compared to the ADCP vector component pointing toward the radar. Difference standard deviation is 17.4 centimeters-/second. SeaSonde provides areal measurement over ~200 meter radius circle within upper 1-meter layer; ADCP provides point measurement whose distance from bottom is fixed but depth from surface varies between 1 and 3 meters depending on tidal phase. Both data sets are averaged over 1 hour. Histogram shows that best correlation between two data sets is obtained at the same times (zero lag).

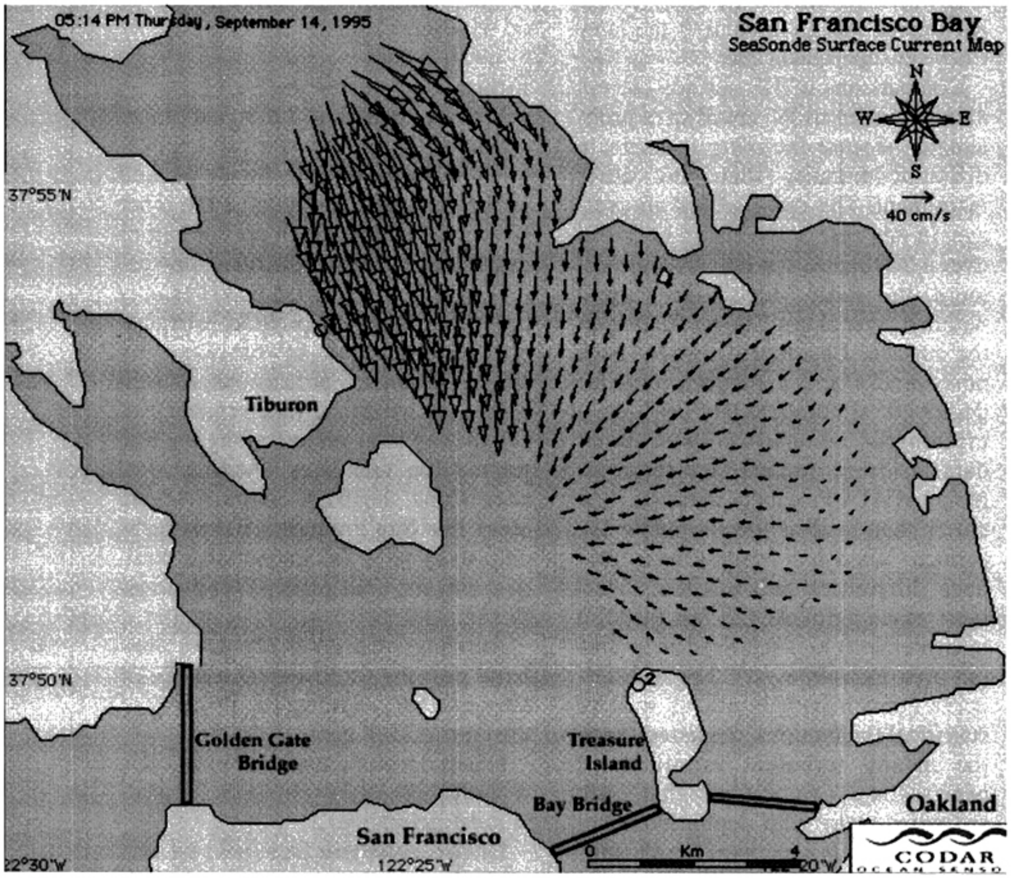
justify for operational use that people need to depend on.

HF radars use frequencies three orders of magnitude lower than microwave to overcome these obstacles; on the other hand, they have very limited uses other than sea surface monitoring. Hence, tens of millions of microwave radars have been sold (most for use in small boats for several applications) while probably less than 70 HF radars of any type have been built worldwide (nearly all by CODAR) over the past few years for sea surface surveillance.

San Francisco Bay Tests

A look at San Francisco Bay Hi-Res SeaSonde data is provided by tests done during this summer. The situation on San Francisco Bay and its tributaries is typical of a congested nesting of ports and harbors. Although the ports of Oakland and San Francisco (south of Golden Gate) are busy, the lion's share of heavy vessel traffic heads north toward Richmond and further into San Pablo Bay and on beyond to the Sacramento River Delta. Many oil supertankers dock at Chevron's Richmond refinery pier and further on, at the Tosco pier near Benicia. Safe navigation is a special concern in these areas. If a large spill occurs (as happened in 1971), it will undoubtedly impact these areas north of the Gate.

Complex flows such as eddies had been seen in the bay before the arrival of SeaSondes. Point measurements (such as bottom-mounted acoustic doppler current profilers) have missed these features, as have simplified numerical models that show only unidirectional flow along the channels. The ADCPs are too sparsely spaced in



Below is example of total vectors produced by the Hi-Res SeaSonde every hour over San Francisco Bay north of Golden Gate. This current pattern was mapped during ebb tide.

addition to having very short lifetimes; only one survives in San Francisco Bay of the dozen or more that were put out. The critical area of fastest flow through Golden Gate has seen the loss of several ADCPs within weeks of deployment–all casualties of ships, human activities, and the elements. Numerical models offer considerable promise of providing these complex flow patterns but, lacking good input data, often miss irregular features such as eddies and counterflows near shore. Examples of model accuracy improvement with SeaSonde radar input are found on the Rutgers University website (http://marine.rutgers.edu/mrs/-coolresults/1998/hernan.aslo/hernantalk.html).

CODAR Ocean Sensors, in conjunction with the U.S. Geological Survey and San Francisco State University (SFSU), operated two Hi-Res SeaSonde radar units in this area north of Golden Gate. Deployed during summer 1999, one radar was sited at SFSU's Romberg Tiburon Center and the second on Treasure Island's north end. When the two sites were operated together and their data combined, total vector maps were produced showing surface flow at ebb tide. Winds from the northwest also drive the currents near the surface in addition to tides for this example. The coverage spans the area north of Golden Gate, up to the Richmond Bridge, including the busy Chevron supertanker pier.

Comparisons of HF surface-current data with "sea truth" are always problematic because the radar measures a different quantity than any other instrument. The radar senses an average, in this case spanning an hour and over a 200-meter spatial cell. Furthermore, the radar "feels" the current within a layer about 1 meter deep from the surface. Lagrangian drifters have noisy tracks and a number must be deployed simultaneously to get a meaningful comparison with radar data. Current meters and bottom-mounted ADCPs cannot measure flow closer than several meters below the surface. Wind and wave effects produce differences between the uppermost meaningful ADCP bin (a point measurement) and the SeaSonde data (an area measurement). These differences contain both biases as well as statistical fluctuations, the latter due to the natural turbulent variations of near-surface velocities that are smoothed away with depth. Nonetheless, the ADCP is perhaps the "instrument of choice" for comparisons.

Initial radial current data from the Tiburon SeaSonde with 200-meter spatial resolution were compared with the bottom-mounted ADCP current component pointing toward Tiburon. This NOAA ADCP is located near Richmond, about 5 kilometers north-northeast of the Tiburon radar. Here the uppermost useful ADCP bin was centered 2 meters below mean surface level and has a 2-meter tidal excursion. This means the ADCP measurement with respect to the surface fluctuates between 1-3 meters with the tidal phase. The standard deviation between the two measurements was 17.4 centimeters/second. A histogram will show that the two measurements are most strongly correlated at the same time as each "lag period" interval is one hour. Comparisons are continuing at other ADCP bottom locations as well as with a boat-towed ADCP across a large area over a period of several hours.

"Other products in the SeaSonde family achieve extended ranges beyond 200 kilometers by dropping to a much lower HF band (near 5 MHz) with the same compact antenna advantage."

Future Improvements

We are planning future improvements for both the waterway applications of the Hi-Res SeaSonde as well as for SeaSonde products at the other coverage extreme. Each port or harbor to be considered has its own site-specific peculiarities. Often two sites may not be enough to provide adequate coverage because of blockage by islands or coastal protrusions, as well as the mathematical indeterminacy of calculating total vectors along the line joining the two sites. Finding ideal sites along the busy coasts rimming areas like San Francisco Bay is difficult, even with the unobtrusive compact antenna units evolved for the SeaSonde.

Buildings and other obstacles cluttered near the receive antennas distort their patterns, reducing the accuracy of the current map data.

Under development is a concept that will alleviate these problems: a bistatic radar geometry.

One receiver will be served by several transmitters arrayed around or across the bay (local clutter distortion to patterns is not so important on transmit). These transmitters are low-power, tiny, unattended units requiring no computer control, and all operate at the same frequency with different signal codings to distinguish their echoes. Frequency approval and interference are less problematic if they all operate on a single channel. The bistatic design eliminates the need for multiple complete radars, each with transmitter, receiver, computer, and distortion-free antenna environments.

Other products in the SeaSonde family achieve extended ranges beyond 200 kilometers by dropping to a much lower HF band (near 5 MHz) with the same compact antenna advantage. Lower frequencies propagate farther over the sea, well beyond the spherical-earth horizon limit for optical and microwave frequencies. The Long-Range and SuperScan SeaSonde capitalize on this effect.

An even longer range variation–the EEZ-Sonde–also provides ship and aircraft surveillance out to 200 nautical miles, now recognized by the UN as the limit to which all countries may protect their waters. /st/