HF- radar for coastal erosion application

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CODAR Ocean Sensors, Ltd.
The Leader in HF Surface-Wave Radar Ocean Monitoring

• Company principals have been continuously involved in HFSWR for 40 years
  - Patented CODAR Hallmarks:
    • Compact antenna system -- small footprint offers unobtrusive coastal presence
    • Unmanned, real-time operation
    • Low power -- both radiated and required input supply
    • GPS-synchronized multiple-radar and multi-static operation at same frequency

• Currents mapped to 200 km with Long-Range backscatter SeaSondes

• Bistatic augmentation by CODAR demonstrates coverage extension to 330 km

• Over 300 CODAR SeaSondes manufactured and sold -- 85% of all HFSWRs
  - Systems logged over 5 million operating hours to date

• Recent "Dual-Use" objectives being pursued to examine ship detection/tracking
  - Robust, multiple-look at same target defies evasion

• HFSWR is CODAR’s only product -- provides us unparalleled focus of direction

• Local waveheights and direction
Why HF radar for coastal erosion?

To be able to understand coastal erosion and design effective wave breakers oceanographic data such as:
- Wave height
- Wave period
- Wave direction
- Current speed
- Current direction

are needed.

HF-radar is the only instrument measuring all the parameters over a large area without anything in the water.
Coastal erosion is the retreat of the shoreline due to water currents, waves, wind and increasing sea level. It is a natural process that can be influenced by human activities.

The public perception of coastal erosion is of a sandy beach being washed away, threatening nearby houses with the same fate.
Waves

Waves are the main cause of soft-coast erosion. On sandy beaches the sand is often transported just offshore, but on coarser gravel beaches erosion may occur when waves carry gravel inland.

High waves erode sediment, while flatter waves deposit it.
Similar to how a police radar measures car speed, HF radars measure ocean surface current speed by precisely measuring the Doppler shifts produced by the radar signal bouncing off the moving object.

Realize, radar can only measure the movement directly towards or away from the radar.
Why Use HF?

• HF => High Frequency (radio spectrum between 4 - 50 MHz, λ between 6 - 75 m).

• Signals travel well beyond the horizon, much farther than microwave signals that are limited to line-of-sight (Ham radio operators use HF for same reason).

• Only HF signals respond to ocean waves in a very predictable manner, hence allowing us to derive ocean surface current, wave, and hard target information.

• Advantages of CODAR SeaSonde HF Radars:
  • Operate from shore, without any instrumentation in water!
  • Provide wide area surveillance, up to 340 km from shore
  • Automated operation, with continuous coverage
  • Very little maintenance required, low operating costs

• What Is Observed or Measured?
  • The SeaSonde HF radar detects surface currents movement in speed and direction, and tsunami-induced current signature
  • It also provides local wave conditions
What Does a SeaSonde® Look Like?

The antennas are placed at the coast, connected via cables to electronics that operate within an environmentally controlled shelter (as shown on right).

An additional computer located at your office allows for remote modem access to and control of radars, as well as automatic data retrieval.
Measuring Currents in Monterey Bay, California
Surface Current Vector Map Of Monterey Bay, California
Observation of Complex Flow -- Only Possible with HF Radar

CODAR SeaSonde current map overlaid on satellite-derived sea temperature (color). This view of the Monterey Bay shows the cold California Current traveling south with a shocking double gyre carrying some cold water into the Bay.

No other instrument can measure complex surface current movement like HF radar.

# SeaSonde Configuration

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Standard</th>
<th>Hi - Res</th>
<th>Long - Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial Range</strong> (typical)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alongshore:</td>
<td>20-60 km</td>
<td>15-30 km</td>
<td>100-220 km</td>
</tr>
<tr>
<td>Offshore:</td>
<td>20-75 km</td>
<td>15-20 km</td>
<td>140-220 km</td>
</tr>
</tbody>
</table>

- Ranges achieved vary with environmental conditions and antenna placement. Note: Two radars are normally required for creating 2-D surface current maps of direction and speed.

### Range Resolution

- Resolution is user selectable

### Angular Resolution:

1-5 degree grid: user selectable.

### Current Accuracy:

Varies with environment. Comparisons with ADCPs located in close proximity to the surface are typically < 7 cm/s of the total current velocity and 1-2 cm/s of the tidal component.

### Wavefield Products (measured at each radar):

Local on-shore wave conditions in ring centered ~3 km from coast around each radar. Significant Waveheight: typical accuracy: 7-15%; Dominant On-Shore Direction: typical accuracy: 5 degrees -12 degrees; Dominant Wave Period: typical accuracy: 0.6 s; Other spectral wave parameters available. Wave information is limited by environmental conditions and operating frequency.
Resolutions obtained by the SeaSonde

*In distance:*
Determined by the bandwidth \( \sim c/2B \)

- 25 KHz bandwidth gives a resolution of 6 km
- 50 KHz: 3 km
- 100 KHz: 1.5 km
- 500 KHz: 300 m

*In bearing:*
More complicated signal processing \( \sim 2 \) degrees

*In speed:*
Doppler measurements, typical accuracy \( \sim 5-10 \) cm/s
Physical Mechanism Behind Current Mapping from First-Order Doppler Sea-Echo Spectral Peaks

- **Upper Doppler Spectrum:** Bragg scatter peaks from resonant waves in absence of currents -- positions are fixed and known from wave dispersion relation

- **Lower Doppler Spectrum:** Peaks are shifted to right (upward in frequency) by advancing current
Extraction from Second-Order Physical Mechanism Behind Wave Doppler Sea-Echo Spectral Side bands

SECOND-ORDER ECHO EXPLAINED BY LONG-WAVE ORBITAL PHASE MODULATION

NARROW-BAND PHASE MODULATION $\Rightarrow$ 2 Sidebands around Bragg Peaks
Sideband Positions: $\pm f_B \pm f_i$
Sideband Powers: $\sim a_i^2$

24 Oct. 1980, 0930 EST (ARSLOE)
Wind Toward Radar

25 Oct. 1980, 2130 EST (ARSLOE)
Wind Away From Radar

Short/Long Wave Frequencies

$f_s = f_B = \sqrt{\frac{g}{2\pi L_s}} = \frac{g}{\pi \lambda}$

$f_i = \sqrt{\frac{g}{2\pi L_i}}$
Close-Up of SeaSonde Receive Antenna
SeaSondes at 2008 Olympic & Paralympic Sailing Games in Qingdao
Project managed & maintained continuously through Olympics by China State Oceanic Administration-North Sea Branch

An all-in-one combined transmit-receive SeaSonde antenna operates atop building, with microwave radio communication link positioned to left of building

SeaSonde #1
Qingdao
SeaSonde #2

View of Dagong Island. SeaSonde antenna is within the yellow circle on small building.

SeaSonde antenna at Dagong Island. SOA engineering team are at left.
Typical 13 MHz Installation
Nordøy, Norway

Shelter for people & electronics
Receive antenna
Transmit antenna
Pictures of SeaSondes at Nyhamna

- SeaSonde Antenna
- Equipment Shed
- Inside of Shed
Typical 5 MHz Installation

Cabo Frio, Brazil
Compact electronics can be placed in a small footprint enclosure.
San Clemente Island, California
Most SeaSondes operate from permanent sites, but they are relocatable.

Texas A&M Univ. has been developing portable trailers and peripherals for rapid response capability—sponsored by TGLO.
Mobile Units Developed by NOAA

Key Largo, Florida
SeaSondes in the Americas

* Each network typically consists of 2-10 SeaSonde units.
Norsk Hydro Uses 25 MHz SeaSonde inside Confined Fjord at Nyhamna, NO

Entrance to Fjord: Long-period waves from North Sea are hazardous for large tankers.

Blow up of region covered by SeaSonde radars at oil company Gas plant.
The Nyhamna SeaSonde HF Radar Network: Essential Information for Vessel Operations

Objectives

- Produce robust, real-time maps of currents in fjord at gas plant
- Provide robust, redundant wave information in fjord at gas plant
  - Significant Wave period
  - Concentrate on long period waves important to vessel operations
- Create easy-to-use web interface to port data to:
  - Show real-time graphic map & data outputs to port operators
  - Allow password-protected internet display anywhere
Currents in the Nyhamna Fjord at Gas Plant

Currents at Ebb Tide

Currents at Flood Tide
Wave Height Comparisons Nyhamna
January 30 - February 4, 2007

- Waveheights do not vary significantly among the three radars
- Buoy and radars capture the same higher-wave events
- More radars give redundant wave data
  - Each radar is an independent & robust wave monitor

Waveheights at all three radars

Average radar & buoy waveheights
Wave Period Comparisons at Nyhamna
January 30 - February 4, 2007

- Wave period from radar & buoy are obtained differently
- Yet wave periods from buoy & radar show agreement
- Radar periods show little variation vs. range and radar site
- Redundancy is good
  - Each radar is an independent & robust wave monitor

Period for different radars at different ranges

Comparison of radar and buoy periods
Example Web Current Displays: Raw & Tidal Currents

- User can select any time period for display from archives
- Animations below allow visualization for better comprehension
The First of Its Kind -- New Challenges Were Encountered at Nyhamna and All Have Been Successfully Resolved

- Three radars are operating simultaneously without interference in very confined area (2 km across fjord)

- Highest spatial resolution ever obtained with HF radars at 25 MHz (i.e., 300 meters requiring 500 kHz bandwidth -- no problems)
The Web Interface:  Password-Protected Real-Time Data Displayed Anywhere with Internet Access
Example of Wave Outputs from SeaSondes

- User-selectable graph history displays
- Local on-shore wave information is extracted
- Shallow water linear transformations employed in inversion, if appropriate
- Limitations:
  - High waves
  - High interference/noise
  - Strong nearshore currents
  - Shallow water
Long-Range SeaSonde® Wave Output--

Winter 2001 Storm Produces Wave Heights to 42 Feet on Oregon Coast

Data courtesy of Oregon State University

Hs = 42 ft (13 m)
User-Developed Products Available
According to the Department of Marine and Coastal Resources, Thailand loses about 5-20m of shore each year along its 2,677km coast. The country now has only 1.04 million rai (167,741ha), down from over two million rai (322,580ha) in 1961.

Saving seashore districts such as Bang Khun Thian is crucial to Bangkok since the area is the capital's first line of defence against rising sea levels. If the trend continues, the city will be more vulnerable to flooding and seawater contamination. As a result, local residents will be at risk, particularly those who depend on fishing and shrimp farming.
Gulf of Thailand
12 MHz SeaSonde Coverage Estimate
Gulf of Thailand
12 MHz SeaSonde Coverage Estimate

Laem Chabang

CODAR
OCEAN SENSORS
Areas of Application

Pollutant / Oil Spill Planning & Response
Fishing, Fisheries and Mariculture
Marine Sanctuary Protection & Monitoring
Weather Monitoring and Forecasting
Ship and Boater Safety
Search & Rescue
Homeland Security
Ocean Dynamics & Marine Life Research
… And More
SeaSondes Deployed Around The Globe

Over 300 systems
85% Market Share

- Brazil
- Canada
- China
- Croatia
- Egypt
- Honduras
- India
- Israel
- Italy
- Japan
- Jordan
- Mexico
- Norway
- Portugal
- Russia
- South Korea
- Spain
- Taiwan
- USA
HF radar analyses methods presently in use are based on the assumption of infinite water depth, and may therefore be inadequate close to shore where we often have shallow waters.

\[ 2\pi d/L > 0.8 \]

Codar has developed an algorithm which can treat situations when the radar echos returned from ocean waves that interact with the ocean floor which means that a HF-radar can be used to measure waves and currents when shallow water effects become significant.
Summary
Areas of Application

• Marine sanctuary mapping, monitoring, and protection
• Pollutant / Oil spill simulation
• Search and rescue
• Ocean dynamics- erosion applications
• Tsunami detection
• Wave measurements
The second order spectral energy increases relatively to the first order as water depth decreases, resulting in spectral saturation when the wavelength exceeds the limit defined by the radar transmit frequency.

Saturation limit on significant wavelength is defined approximately by the relation

$$H_{\text{sat}} = \frac{2}{k}$$

where $k$ is the radar wavenumber.

<table>
<thead>
<tr>
<th>Frequency (Mhz)</th>
<th>5</th>
<th>12</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_{\text{sat}}$ (m)</td>
<td>20</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>
New SeaSonde Receive Antenna

- Less likely to leak
- Elimination of the horizontal whip radials (ground elements) -- now reside inside the mast
- Available for all frequency bands
- Backwards compatible with older electronics
- Both separated and combined antenna configs will use the dome design
- Plan to be commercially available in late 2008.
Combined TX/RX antenna configuration

• Combined antenna configuration definition: all TX and RX antennae parts are placed together onto a single mast
• Presently combined TX/RX antenna config. available for frequency bands 24 MHz or higher (up to 50 MHz)
• 12 MHz combined antenna system in development
• Will be commercially available in early 2009, as an optional configuration.
A SeaSonde with a sweep frequency of 50 kHz measures distance in steps of 3 km. Each step is called a “range cell.”

There is usually some variation in ocean currents within each range cell. SeaSonde’s
Typical SeaSonde Network

- Remote Site 1
  - Radial Map 1
- Central Combining Station
  - Radial Map 2
  - Radial Map 3
- Remote Site 2
- Remote Site 3
- Vector Map