Outline

• What is CODAR?
• Doppler shift
• Bragg scatter
• How CODAR works
• What CODAR can tell us
What is CODAR?

Coastal Ocean Dynamics Application Radar

Land-based HF radar system used to measure coastal ocean surface currents and waves
HF waves are 3-30 MHz in frequency (10-100 meters in wavelength)
HF Radar

- HF Radar can travel for long distances (beyond line of sight)
- HF Radar can travel through rain and fog
- There are about 1 billion microwave radar sensors in operation
Doppler Shift

Describes the perceived change in frequency as the distance between the source and the observer changes

http://www.colorado.edu/physics/2000/applets/doppler2.html (requires sound)
How Doppler Shift Works

http://astro.unl.edu/classaction/animations/light/dopplershift.html
Doppler Shift Math

on the blackboard!
Doppler Shift

Doppler radar gives us the radial velocity of the target (velocity of the target as it’s moving toward or away from the observer)
Bragg Scatter

- Electromagnetic radiation is scattered (in this case by sea surface waves caused by wind stress)
- The direction in which the radiation is scattered depends on the wavelengths of the radiation and the sea surface waves
- There is a certain frequency (the resonant frequency) at which the scattering is exactly in the incident direction
Bragg Scatter

Resonant Bragg scatter occurs when $\lambda_r = 2 \lambda_s \cos(\theta)$

$\lambda_r$ = radar wavelength
$\lambda_s$ = sea surface wavelength
$\theta$ = incident angle
How CODAR Works

- Active sensor, transmitting in the HF band
- Depending on the CODAR frequency, certain sized waves on the ocean surface reflect this frequency back to the CODAR sensor (Bragg scatter)
How CODAR Works

The CODAR sensor is very close to the sea surface, so
\[ \lambda_r = 2 \lambda_s \cos(\theta) \]  as \( \theta \) approaches 0 becomes

\[ \lambda_r = 2 \lambda_s \]
Transmission in the range of 3-50 MHz, which corresponds to wavelengths of 6-100 meters

<table>
<thead>
<tr>
<th>Transmission Frequency</th>
<th>Transmission Wavelength</th>
<th>Corresponding Ocean Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 MHz</td>
<td>12 m</td>
<td>6 m</td>
</tr>
<tr>
<td>12 MHz</td>
<td>25 m</td>
<td>12.5 m</td>
</tr>
<tr>
<td>5 MHz</td>
<td>60 m</td>
<td>30 m</td>
</tr>
</tbody>
</table>

Waves in this range have periods of about 1-5 seconds
How CODAR Works

The amount of signal returned is the strongest in the radial direction.
Back to Doppler Shift

- Since the ocean wave has a component moving toward or away from the CODAR sensor (radially), this creates a doppler shift.

- Observed doppler frequency shift includes the theoretical wave speed (calculated from the dispersion relation) PLUS the influence of the underlying ocean current on a radial path.

- Bragg scatter measurements are for the upper meter of the water column (2.5 meters if using the low frequencies).
Dispersion Relation

Gives phase speed ($c$) as a function of wavelength ($\lambda$)

\[ c = \sqrt{\frac{g\lambda}{2\pi}} \tanh \frac{2\pi h}{\lambda} \]

$h =$ water depth

This means that if we know the wavelength, we know the wave speed, so we can calculate the speed of the surface current in the radial direction.
Combining all of this, we now can measure surface currents. If we combine multiple CODAR sensors, we can measure the total surface current velocity. Want the bearing angle to be as close to 90 degrees as possible (doesn’t work for less than 20 degrees).
Example

One of the most active centers for CODAR research is...
Figure 2: The radial data grids for the 5MHz system (dark gray) and the 25 MHz system (light gray). The locations of the ADCPs are also shown.
What can CODAR do for us?
What can CODAR do for us?

**Search and rescue:** “Probability of success is increased through the improvement in the estimation of search areas based on real time data and modelling”.

**Marine protection:** “Hindcast and nowcast analysis of surface currents help to identify land and sea origin of spills and organize operations efficiently. Combined with other data sources and technologies (meteorology, satellite) and air and sea surveillance it helps to organize response in case of emergency or accident. Current data can be assimilated in all kind of forecast models”.

**Safe navigation:** “HF Radar delivers data which are important for the development of crisis management studies and procedures. Decision support tools based on modelling and real time data can help to take objective decisions in crisis situation”.

**Coastal engineering, fisheries and beach management:** “Coastal studies related to sediment transport, bloom events and water quality need surface current monitoring in order to improve the understanding of natural processes and take management decisions”.

**Marine sciences:** “HF RADAR not only delivers current data but also wave parameters (significant wave height, period and direction). These data are integrated into long time databases which are available for multidisciplinary studies”.

**Tsunami early warning:** “HF Radar is an integral part of Tsunami Early Warning Systems as a complement of seismographic information and DART buoys. Its contribution consists in the reliable identification of the Tsunami wave 100 km away from the coast based on its characteristic orbital velocity pattern.”
Advantages of CODAR

- Very broad spatial coverage (360 degrees)
- Very long range
- Velocity measurements accurate to within 4 cm/s
- Cheap (when compared to satellites, anyway)
Limitations of CODAR

- Relies on theory (dispersion relation)
- Decreased range and resolution with frequency
- REALLY noisy
## CODAR range and resolution

<table>
<thead>
<tr>
<th>Transmission Frequency</th>
<th>Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6 MHz</td>
<td>160-220 km during daytime</td>
<td>3-12 km</td>
</tr>
<tr>
<td>12-14 MHz</td>
<td>50-70 km</td>
<td>2-3 km</td>
</tr>
<tr>
<td>24-27 MHz</td>
<td>30-50 km</td>
<td>1-2 km</td>
</tr>
<tr>
<td>40-44 MHz</td>
<td>10-20 km</td>
<td>300-1000 m</td>
</tr>
</tbody>
</table>

4-6 MHz range: There is a lot more background noise at night
Actual Mechanisms of CODAR

- First need to determine range to target (distance of the wave from the device)
- Then determine speed of target
- Then need to determine the direction in which the signal is traveling (along which radius the wave is traveling)
Range to Target

Uses FM (frequency modulated) signal - frequency increases with time

Can’t just measure how long it takes for a wave to return back to the sensor
**Speed of Target**

Doppler shift is calculated and averaged over ~4 minutes to give velocity accuracy to within 4 cm/s.
Figure 3: The four cells used in the interpolation. Their relative weights are indicated within each cell.
History of HF Radar

HF Radar -- Is It New Technology?

- British 25-MHz "Chain Home" built 1938 to detect German bombers
- "Bragg" sea echo from English Channel mistakenly labeled "jammer"
- These systems preceded microwave radars by several years

http://en.wikipedia.org/wiki/Chain_Home for further reading
History of HF Radar

The Beginnings
Large Phased Arrays on San Clemente Island, CA

- **Microwave vs. HF -- what's the difference?**: (about three orders of magnitude!)
- **Example**: 500-m half-rhombic array built by DoC (Barrick) in 1972 -- SCI, CA

**But Why HF?**
- Beyond the horizon
- Scatter from water waves is simple
- 1 billion microwave radars exist
- Only 300 HF radars exist in the world, 250 done by CODAR
- HF radars not good for much except sea scatter
And now for some actual examples of CODAR...
East Sea Site 2
Transmit
Antenna
Long Range SeaSonde
-6 km Range Resolution
Radials Produced to ~190 Km

Standard SeaSonde
1.5 km range resolution
Radials Produced to ~50 Km
Countries Presently Operating SeaSonde Networks

- United States
- Canada
- Mexico
- Brazil
- Norway
- Spain
- Portugal
- Italy
- Croatia
- Japan
- Korea
- China
- Taiwan
- India
- Egypt
- Israel
- Jordan
- Russia
National HF Radar Plan

- Over 100 Sites Participating (including all 26 MARCOOS systems)
- 3 Data Nodes (Rutgers, Scripps, NDBC)
- NOAA IOOS to fund development of a National Plan (coordinated through ACT)
  - Design, Budget, Metrics
Hourly CODAR Current Maps of Hudson River Plume

RU COOL Raw Velocities (HFR) 2005/04/11 0700 GMT

Wind data from NOAA NDBC station at Ambrose Light
A storm moving up the New Jersey coast on October 16, 2002
RUC Wind and Pressure Analysis

CODAR Surface Currents

Spatial Maps
10/16/2002 0700 GMT

Contour resolution – 1 mb
10/16/2002 1500 GMT

RUC Wind and Pressure Analysis

CODAR Surface Currents

Contour resolution – 1 mb
10/16/2002 1800 GMT

RUC Wind and Pressure Analysis

Contour resolution – 1 mb

CODAR Surface Currents

Surface Velocity (cm/s)
10/17/2002 0000 GMT

RUC Wind and Pressure Analysis

CODAR Surface Currents

Contour resolution – 1 mb

992 mb
Live Examples

http://bragg.oce.orst.edu/

http://www.smast.umassd.edu/OCEANOL/codar.php

http://marine.rutgers.edu/cool/codar/real-time/
  real_time_lr.html

http://marine.rutgers.edu/cool/codar/real-time/
  real_time_std.html