A Model for the First-order Doppler Spectrum for Bistatic HF Radar Surface Wave Sea Scatter

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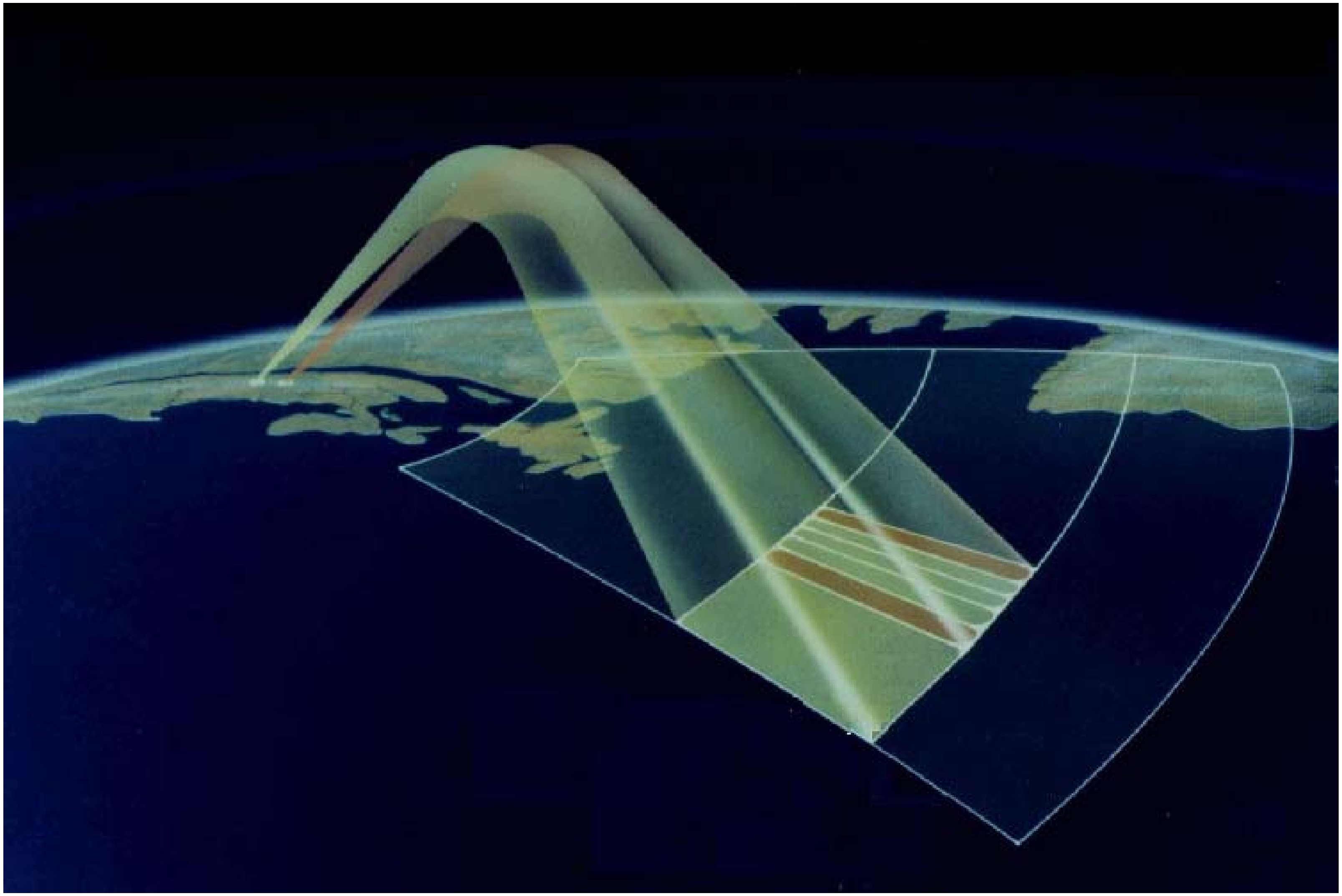
Motivation: OTH Radar Applications, with bistatic LOS reception

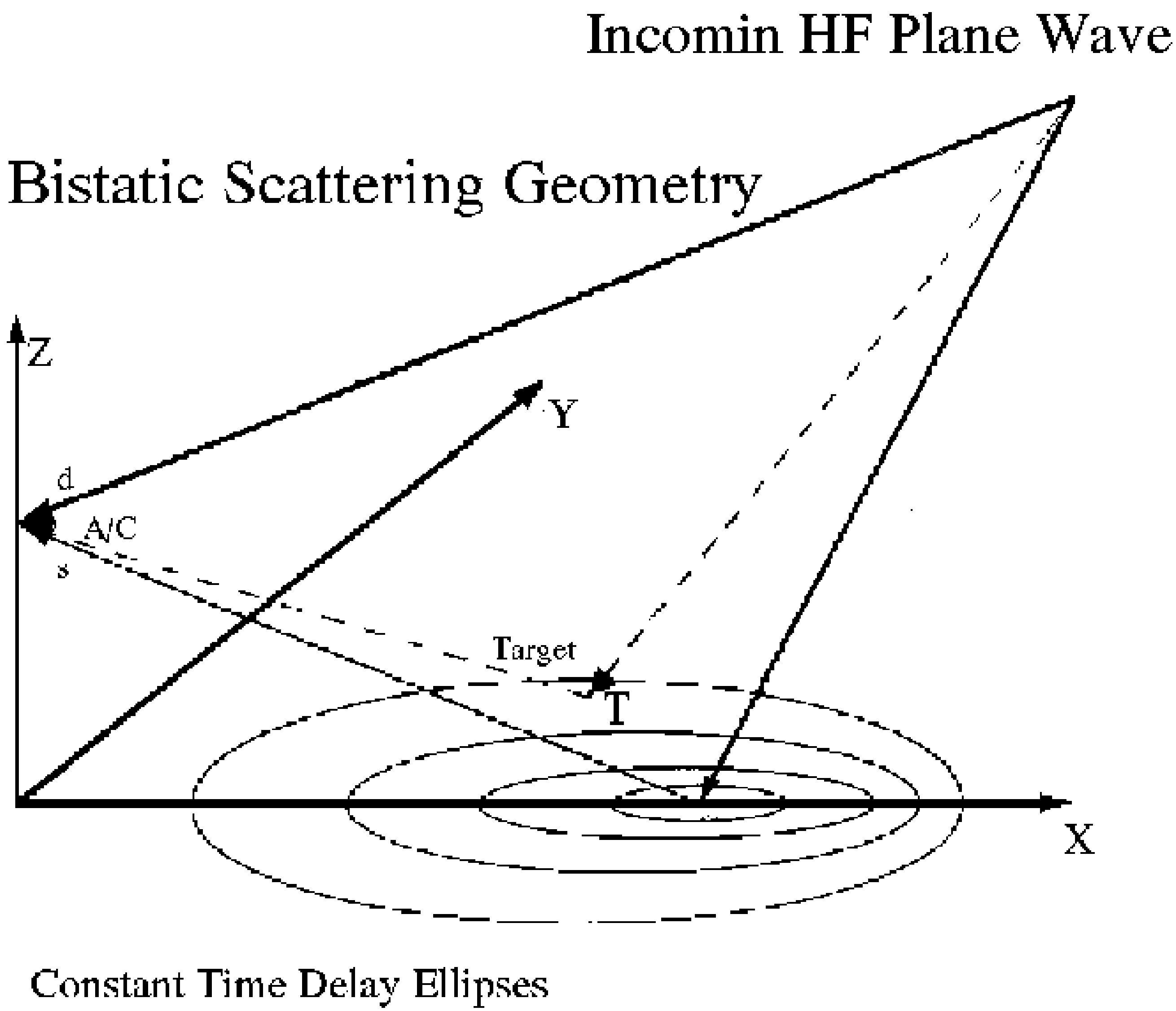


Background

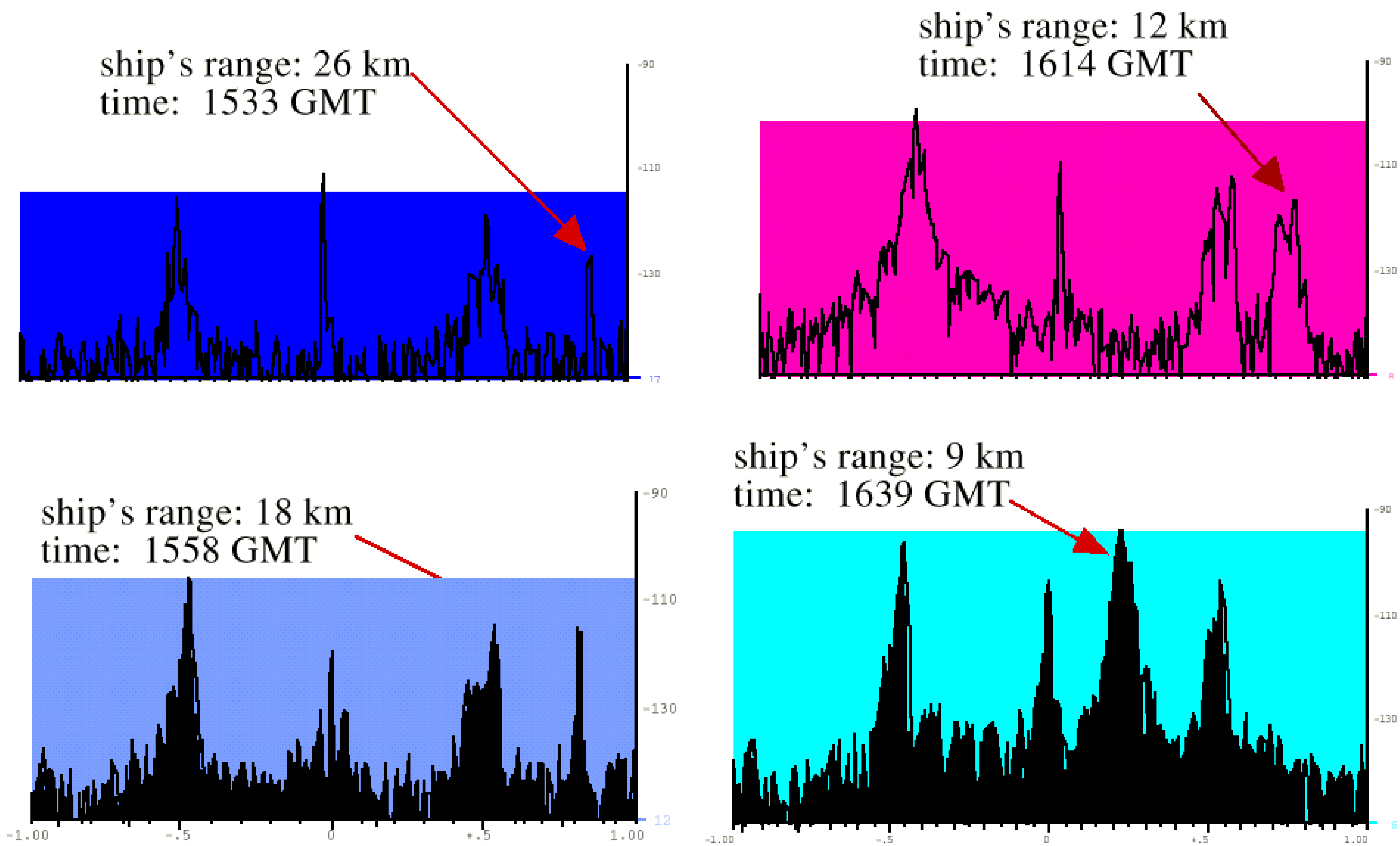
Bistatic operation is possible with an OTH radar such as ROTHR (Relocatable OTH Radar) using an airborne receiver, and offers the following advantages:

- **R_2^2 losses are far less than for Monostatic OTH operation**
- **Sea clutter can be weaker due to illumination considerations**
- **Ship Radar cross section maximizes for ‘broadside equivalent’ illumination, allowing prediction of optimal illumination geometries**

Bistatic HF Skywave Geometry, SAR Processing

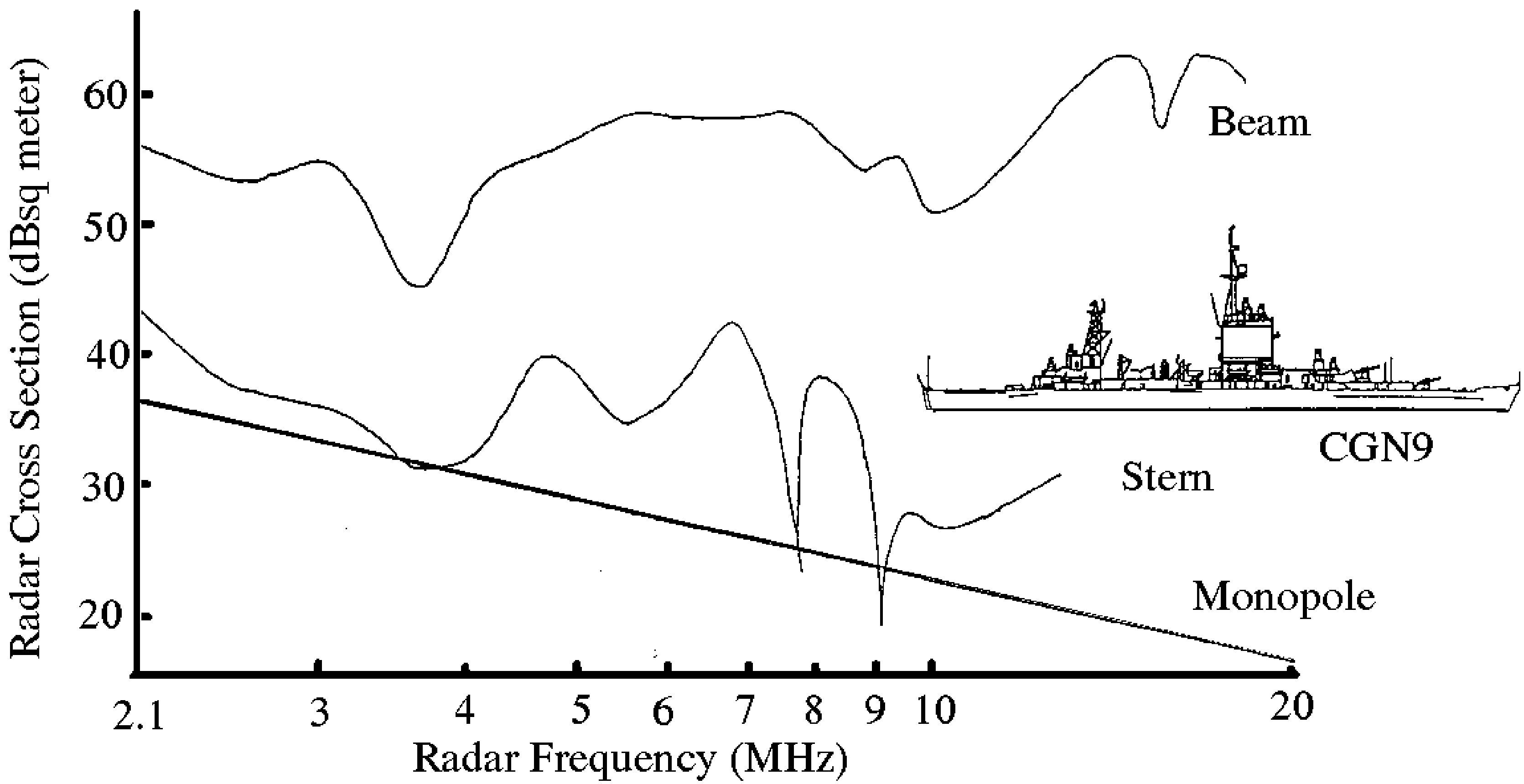


Fernandez, et al, examples of ship targets relative to Bragg lines



Monostatic Ship RCS varies dramatically with aspect

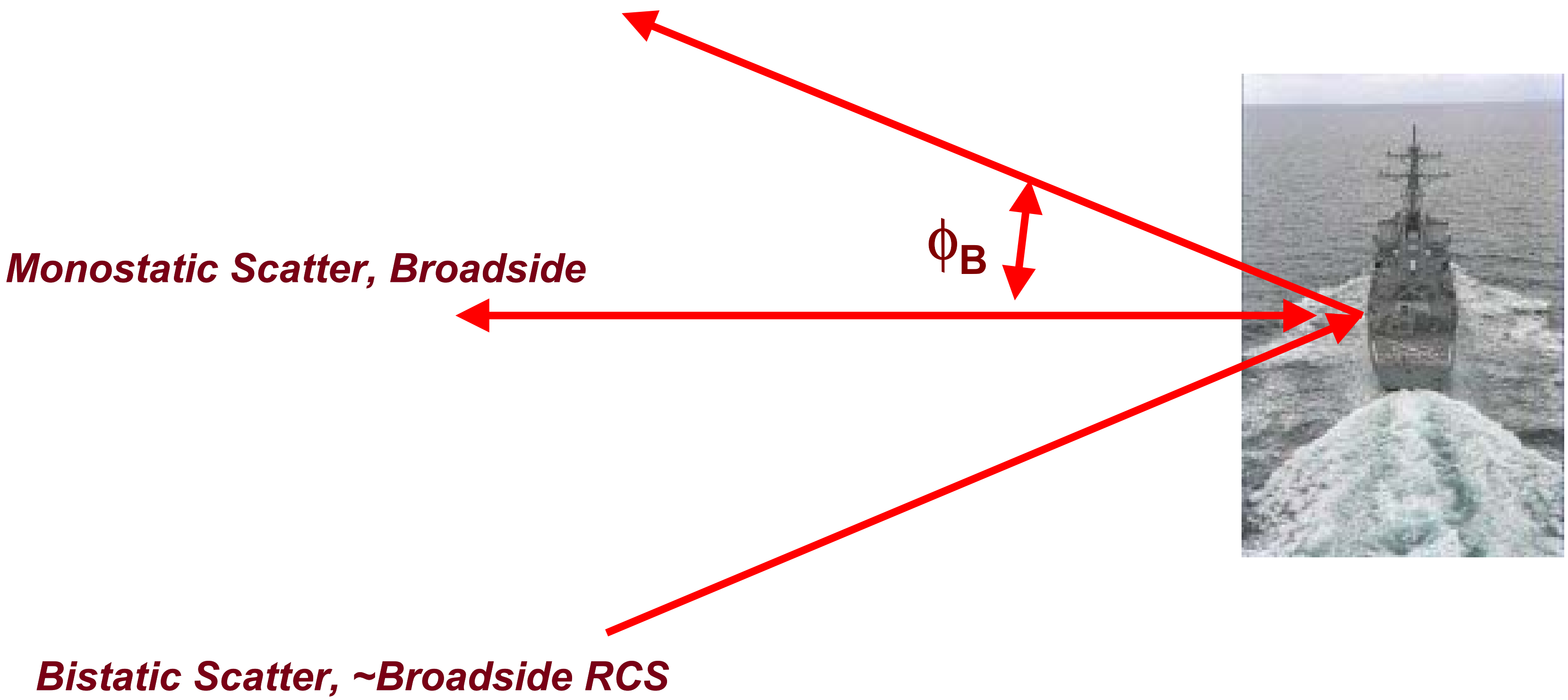
Stern/Bow vs. Beam-aspect RCS ratio is 20 dB or more



Smoothed curves of beam and stern RCS for CGN9 (Headrick & Rachuba, unpub. manuscript).

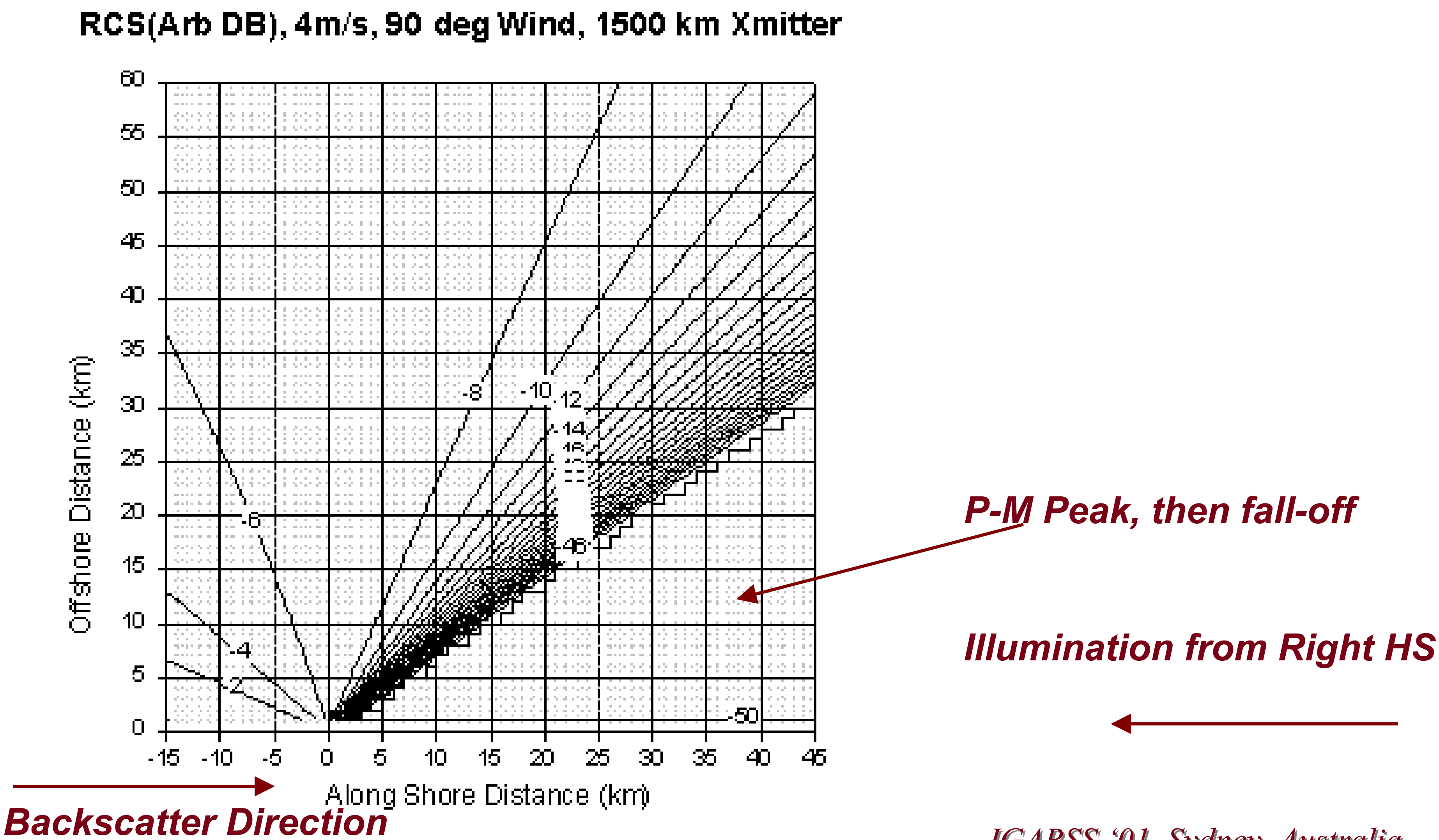
Bistatic Ship Cross Sections

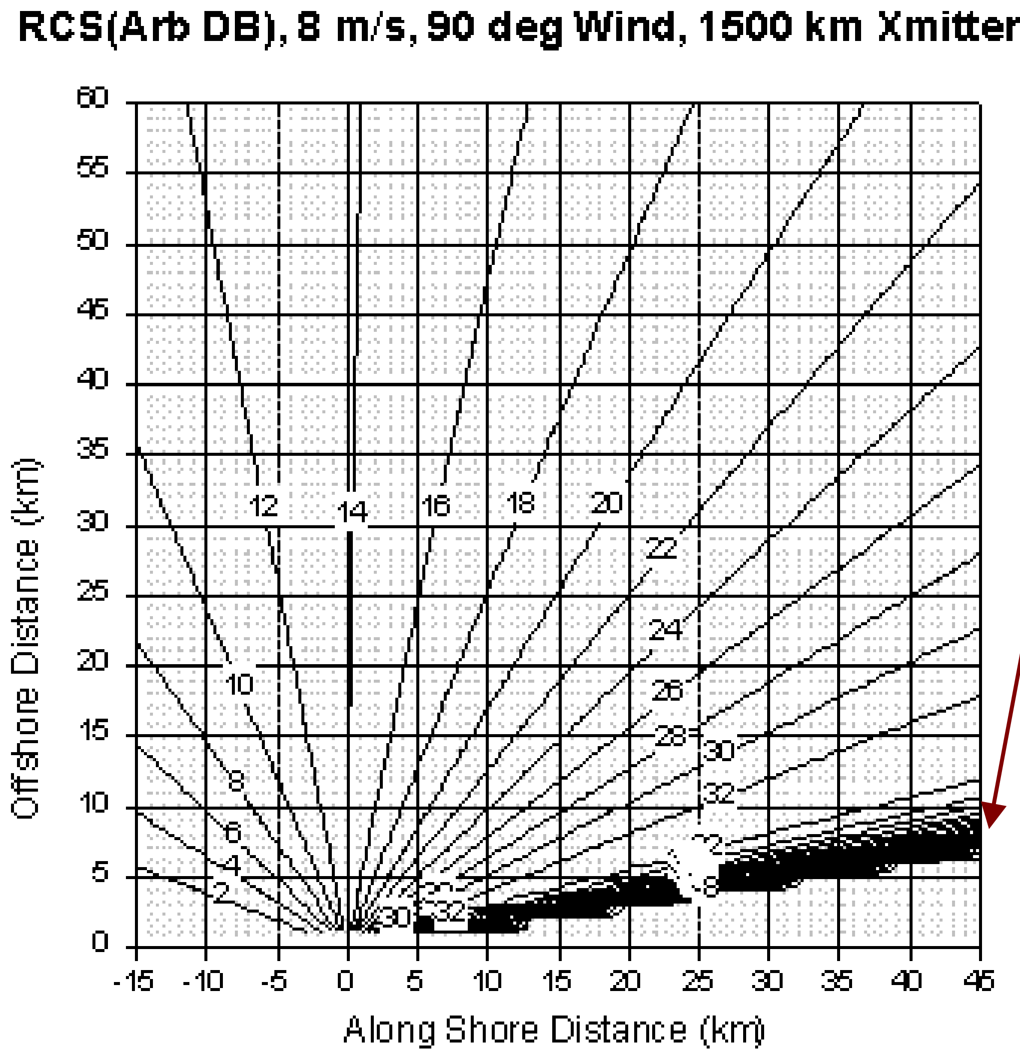
Use of the bistatic theorem predicts enhanced RCS when the bisector of the incidence-scatter angle is normal to ship's beam ~ = broadside RCS.



Bistatic Bragg Model Characteristics:

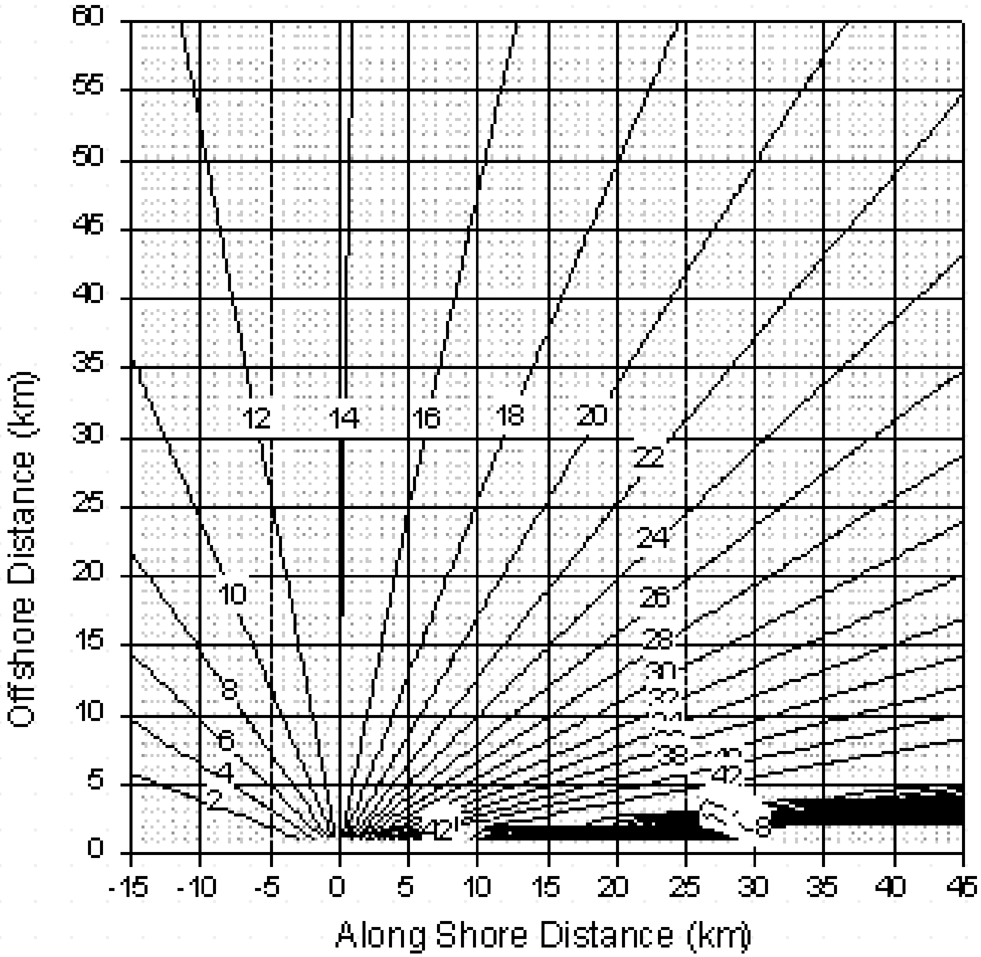
- **Determine coverage of Bragg SNR vs. Spectrum**
  - **Use P-M K-Spectrum with Long-Trizna spreading Function**
  - **25-MHz Operating Frequency**
  - **Sky Wave Path Loss not accounted for yet**
  - **Normalized to minimum RCS in Area, not Noise at this point**


RCS(Arb DB), 4m/s, 90 deg Wind, 1500 km Xmitter
Offshore Distance (km)
Along Shore Distance (km)
0
5
10
15
20
25
30
35
40
45
50
55
60
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
-2
-4
-6
-8
-10
-12
-14
-46
-50
P-M Peak, then fall-off
Illumination from Right HS
Backscatter Direction



4->8 m/s Wind Increase causes smaller null area, larger amplitudes elsewhere

RCS(Arb DB), 12m/s, 90 deg Wind, 1500 km Xmitter



8->12 m/s Wind Increase forces just a sliver area of null scatter, greatly increase RCS elsewhere

Results for 1500 km-separation Sky Wave Case:

- Significant & continuous increase in Bragg RCS with increasing Azimuth off backscatter direction
- Rapid drop to zero at Critical Azimuth related to peak of P-M spectrum
  - Corresponds to P-M spectral shift to lower frequencies
  - Higher Wind speed generates longer waves, Critical Angle shift
- Deep null in Bragg RCS in specular/forward scatter direction
  - May allow SAR processing without Doppler processing needed normally to suppress Bragg lines in regions of nulls near forward scatter

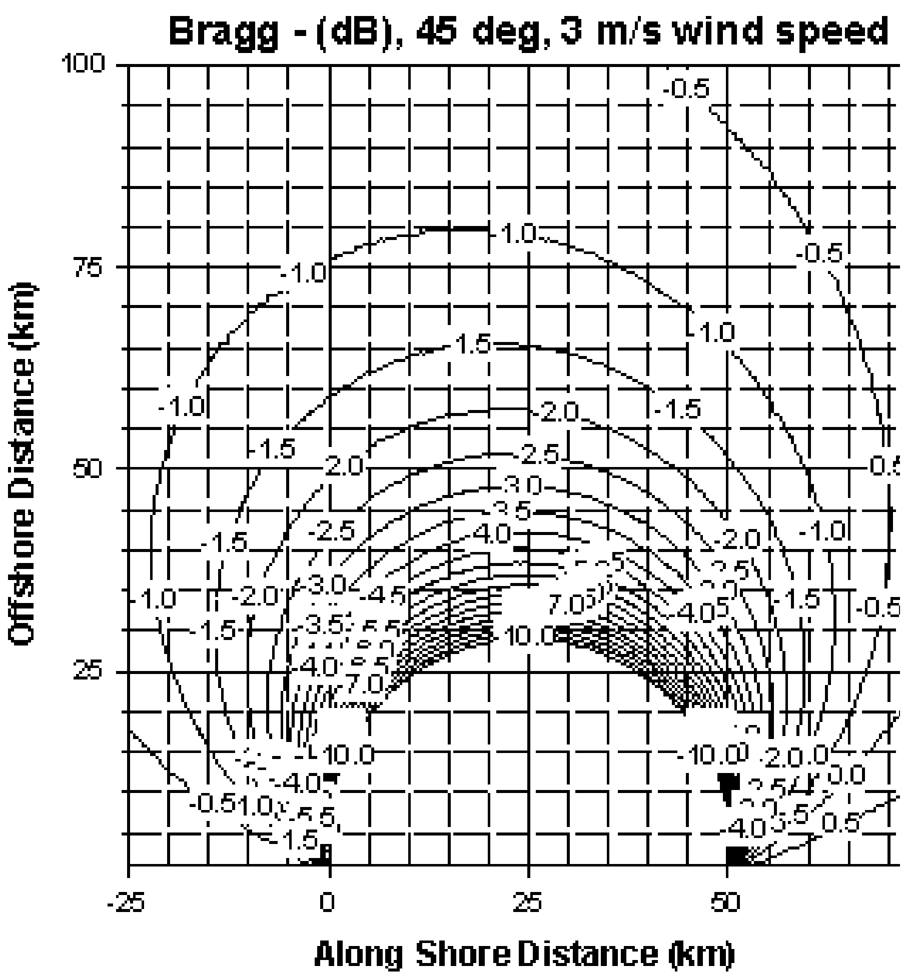
Utility of model to HF remote sensing of oceanic currents

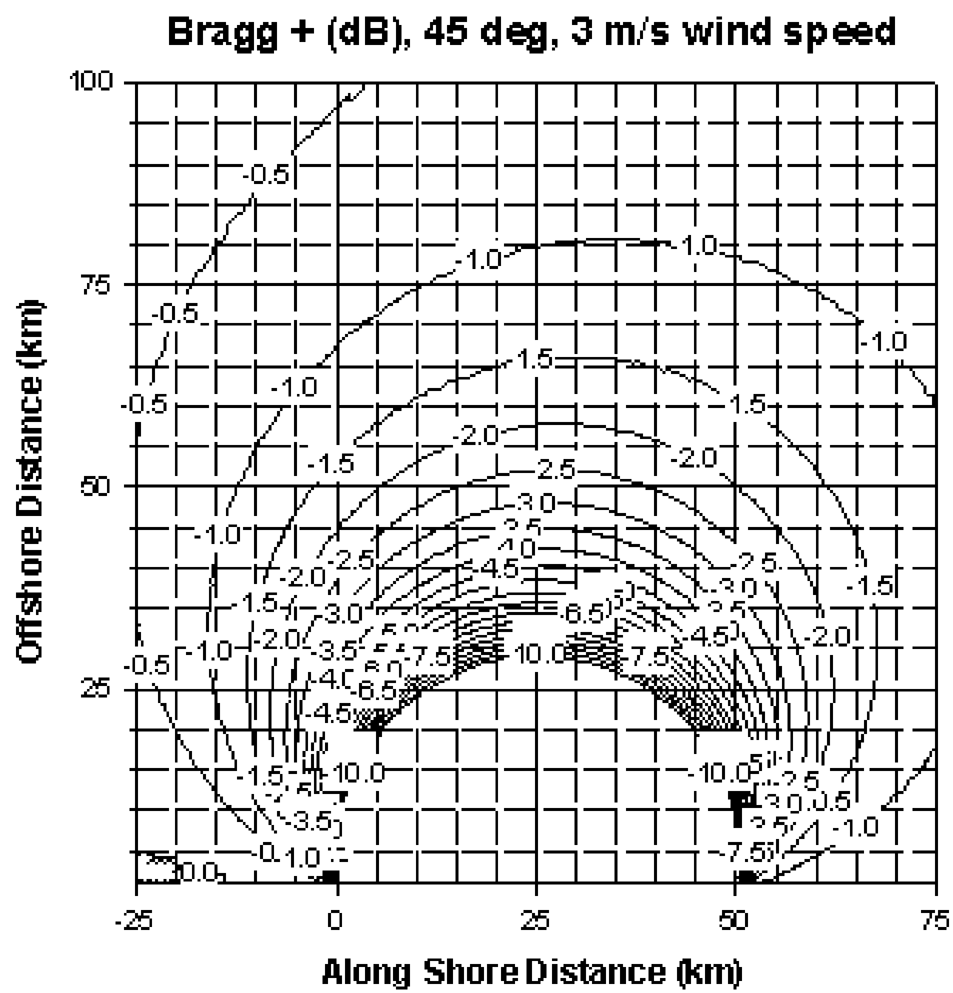
- **Model used to map Doppler shifts for surface wave operation**
- **Transmit/Receiver separation an order of magnitude less**
- **RCS and Bragg Doppler shifts vary strongly now**
- **Current depths sensed change with azimuth**
  - **offers opportunity for current shear measurement with a single radar frequency**

Bistatic/Monostatic Relative RCS Levels

25-MHz Approach/Recede Line RCS

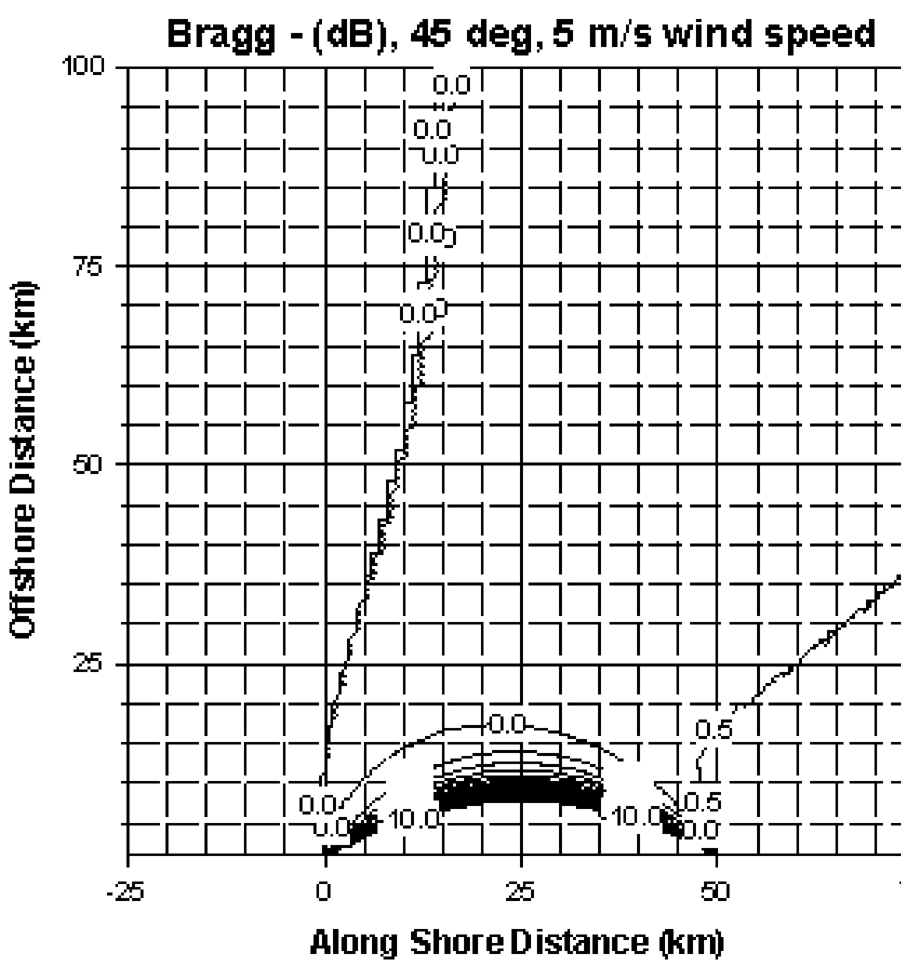
3 m/s Winds: Deep Hole at Short Range - No long wave spectral energy

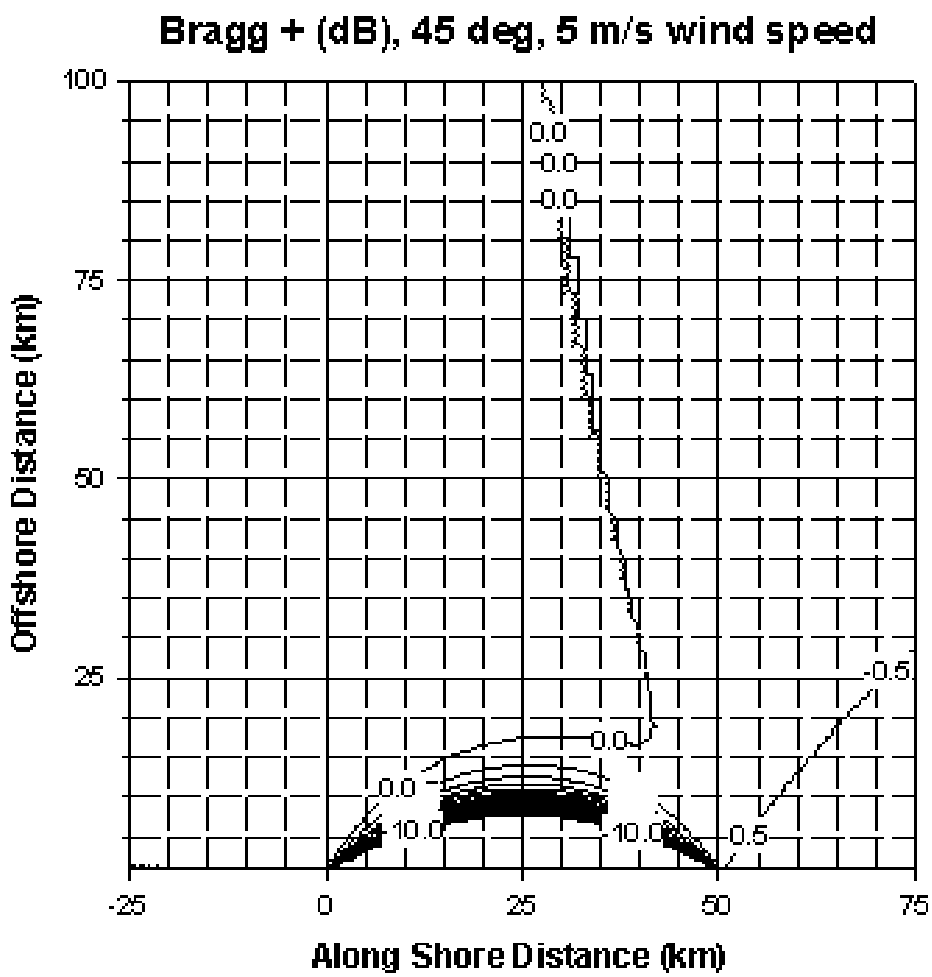




Bistatic/Monostatic Relative RCS Levels

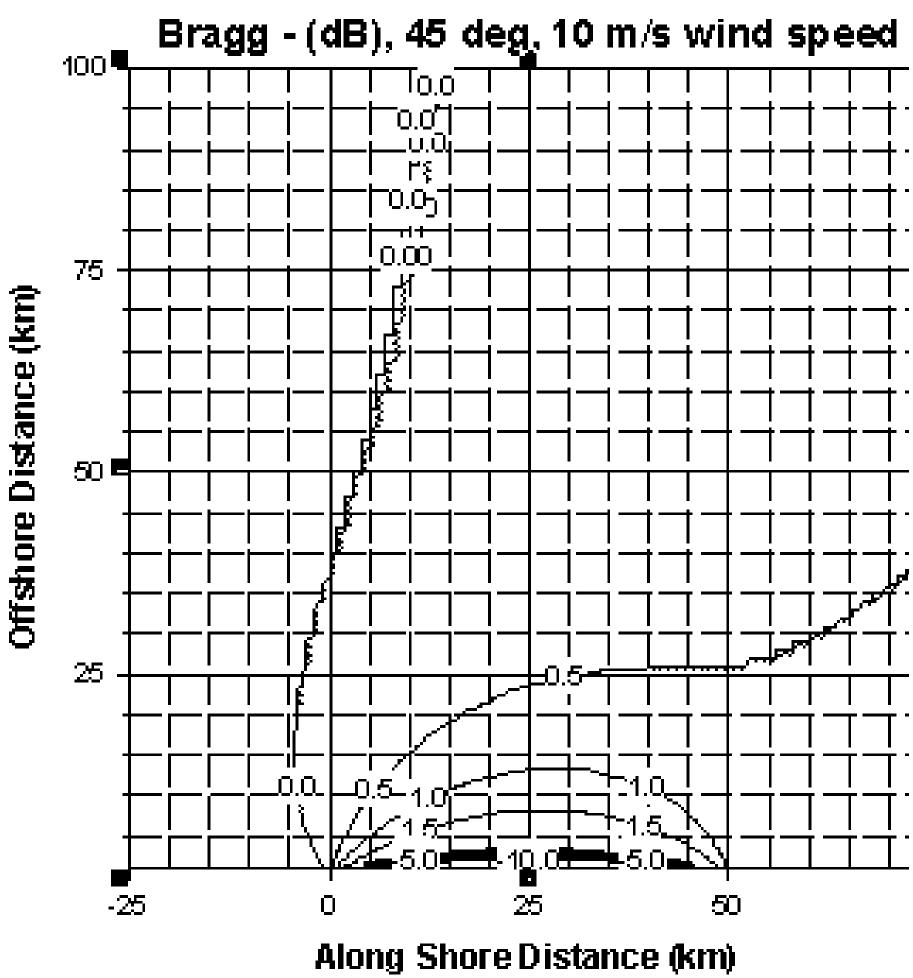
5 m/s Winds: Hole fills a shorter ranges

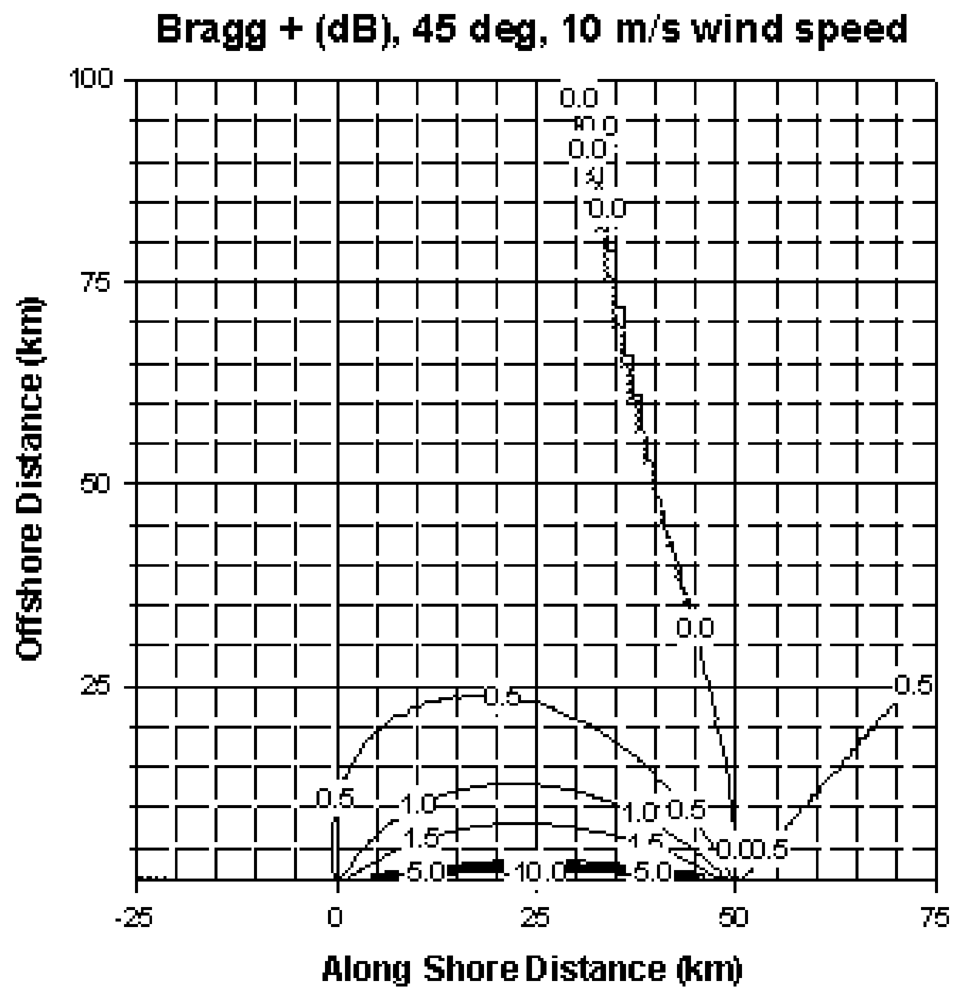




Bistatic/Monostatic Relative RCS Levels

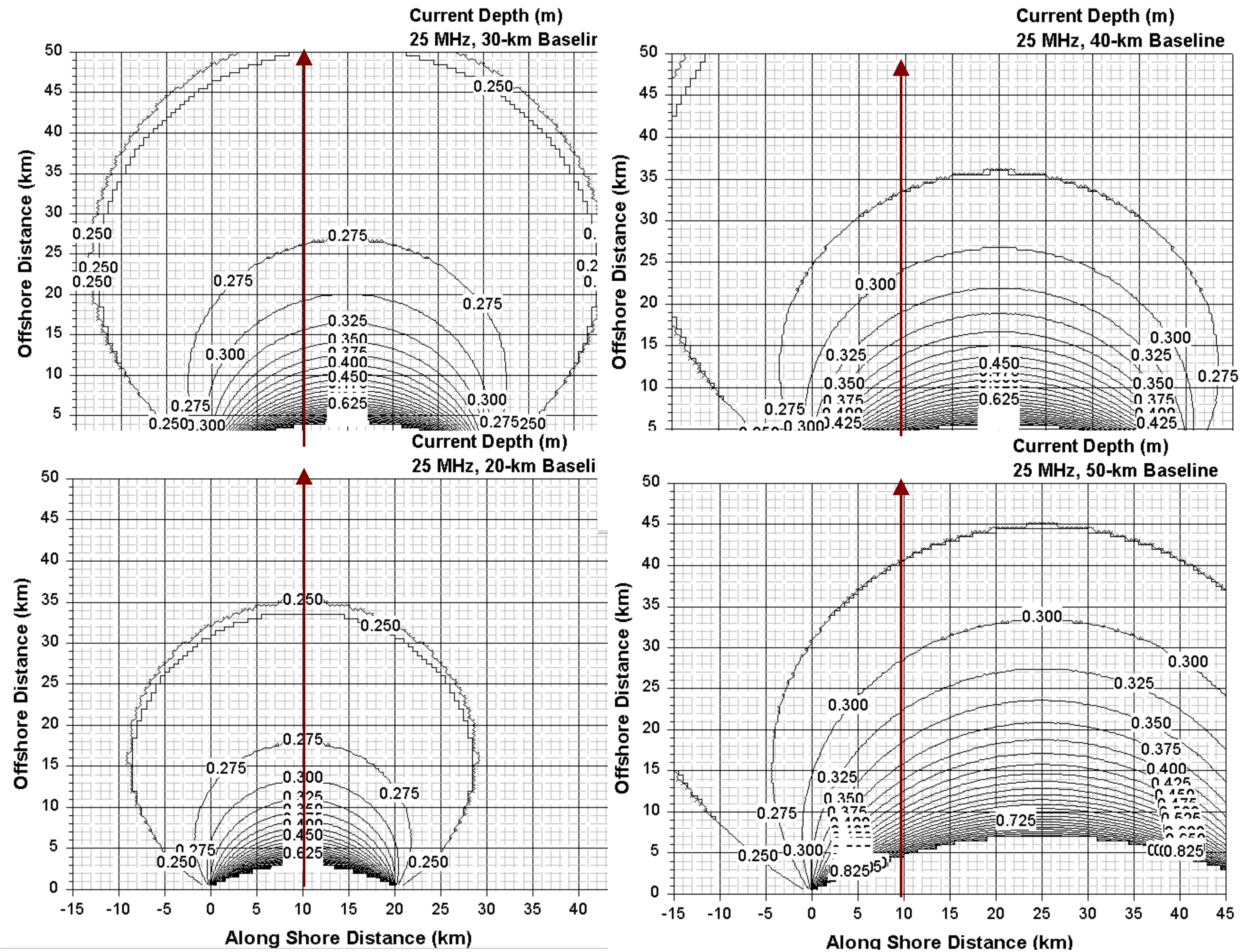
10 m/s Winds: Hole fills even further, little or no null scatter now

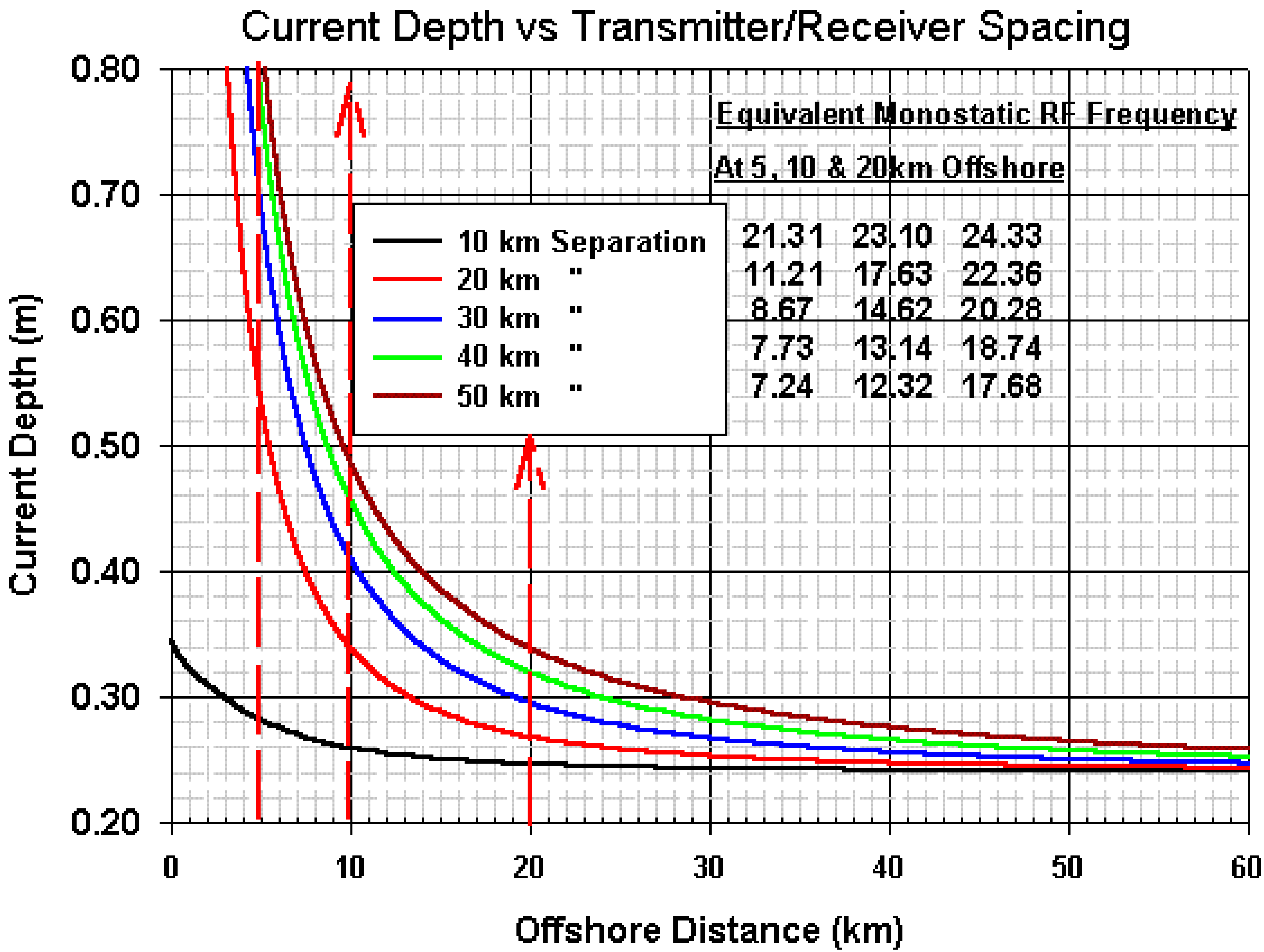




Bragg Current Depth vs Look Angle, Range Using several Transmit Sites

- **Bragg resonant ocean waves lengthen with increasing bistatic angle - all are longer than monostatic Bragg ocean wave**
- **Longer ocean waves imply deeper current averages (~.04 L)**
- **Depths predicted vs look angle, Transmitter/Receiver separation**


Current Depth (m)
25 MHz, 30-km Baselir
Current Depth (m)
25 MHz, 40-km Baseline
Current Depth (m)
25 MHz, 20-km Baseli
Current Depth (m)
25 MHz, 50-km Baseline
Offshore Distance (km)
Along Shore Distance (km)


Current Depth vs Transmitter/Receiver Spacing
Current Depth (m)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
Offshore Distance (km)
0
10
20
30
40
50
60
Equivalent Monostatic RF Frequency
At 5, 10 & 20km Offshore
10 km Separation 21.31 23.10 24.33
20 km " 11.21 17.63 22.36
30 km " 8.67 14.62 20.28
40 km " 7.73 13.14 18.74
50 km " 7.24 12.32 17.68

Summary:

Surface Wave (50-km maximujm baseline):

- **Azimuthal dependence more variable with azimuthal angle compared to OTH case**
- **Critical azimuth now a critical ellipse with Xmit/Rcv locs at foci**
- **Null region occurs at short ranges rather than over extended range as for Sky Wave case**
- **Current Depth increases compared to monostatic case**
  - **Due to Bragg resonant wavelength increase with larger bistatic angles**
    - **shorter ranges - larger bistatic angles for given X/R positions**
    - **larger Transmit/Receive Spacing - larger bistatic angles for given offshore R**
  - **as deep as 85 cm at 5 km, 50-km spacing,**
    - **Equivalent to using lower monostatic frequency ~ to 7.24 MHz monostatic**

- **Several Transmitters at a single frequency=>Current shear measure**

Future Plans:

- **Surface Wave: Bistatic experiment planned**
- **OTH: Predictive capability of optimum look angle for given ship speed, heading**