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# Broadband Adaptive Beamforming

## Motion Mitigation in the Littoral Environment by Frequency Averaging

Robert Greene  
1710 SAIC Drive  
McLean, VA 22102  
tel: (703) 676-5975  
email: [greener@osg.saic.com](mailto:greener@osg.saic.com)

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# Single Wavenumber Adaptive Processing

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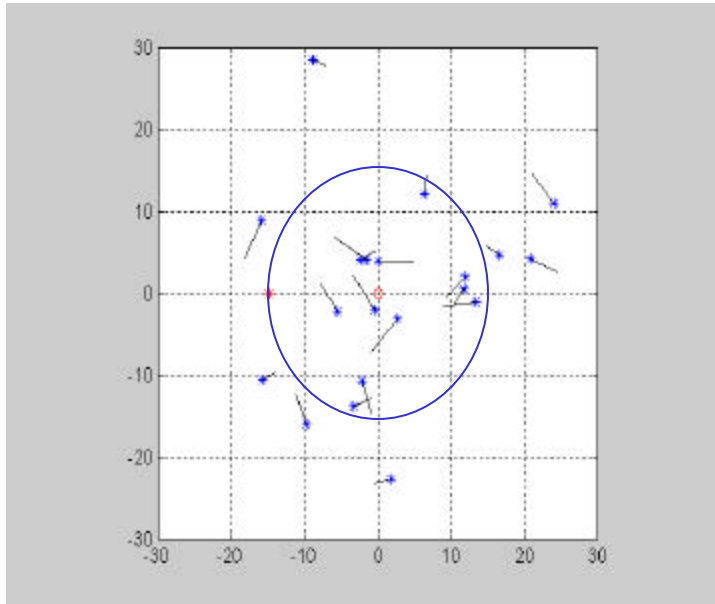
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## SWAP Improves ABF performance vs dynamics

- Increases degrees of freedom
  - Improves convergence of covariance matrix
  - Exploits vertical arrival structure
  - Exploits broadband signature
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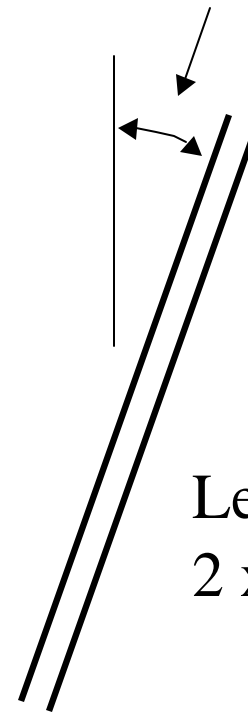
# 200 m Twin Line Simulation

188 - 200 Hz



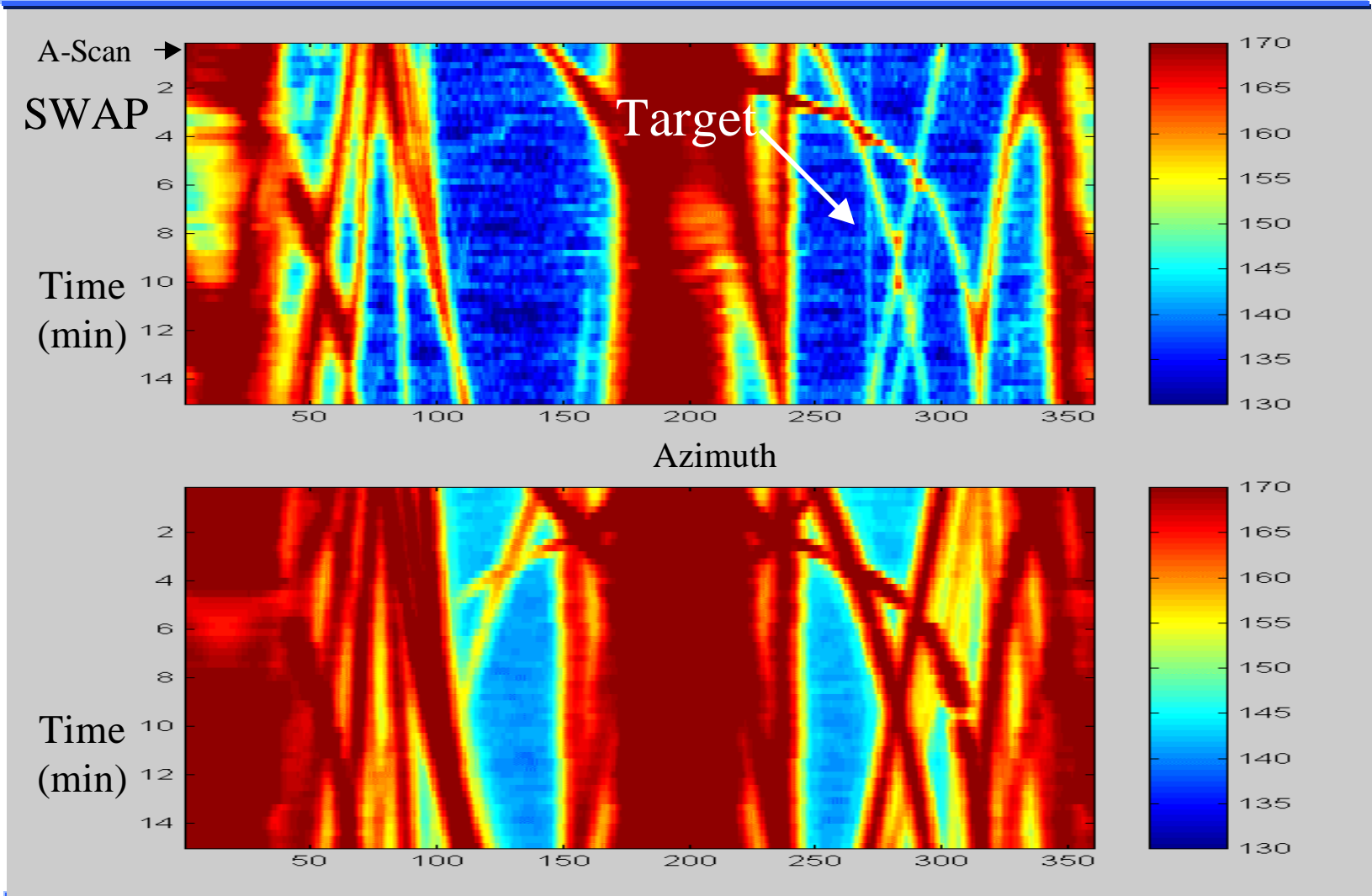
Average phone level 115 dB  
Ambient white noise 65 dB  
Average TL at 15 km 64 dB

Heading 15 degrees



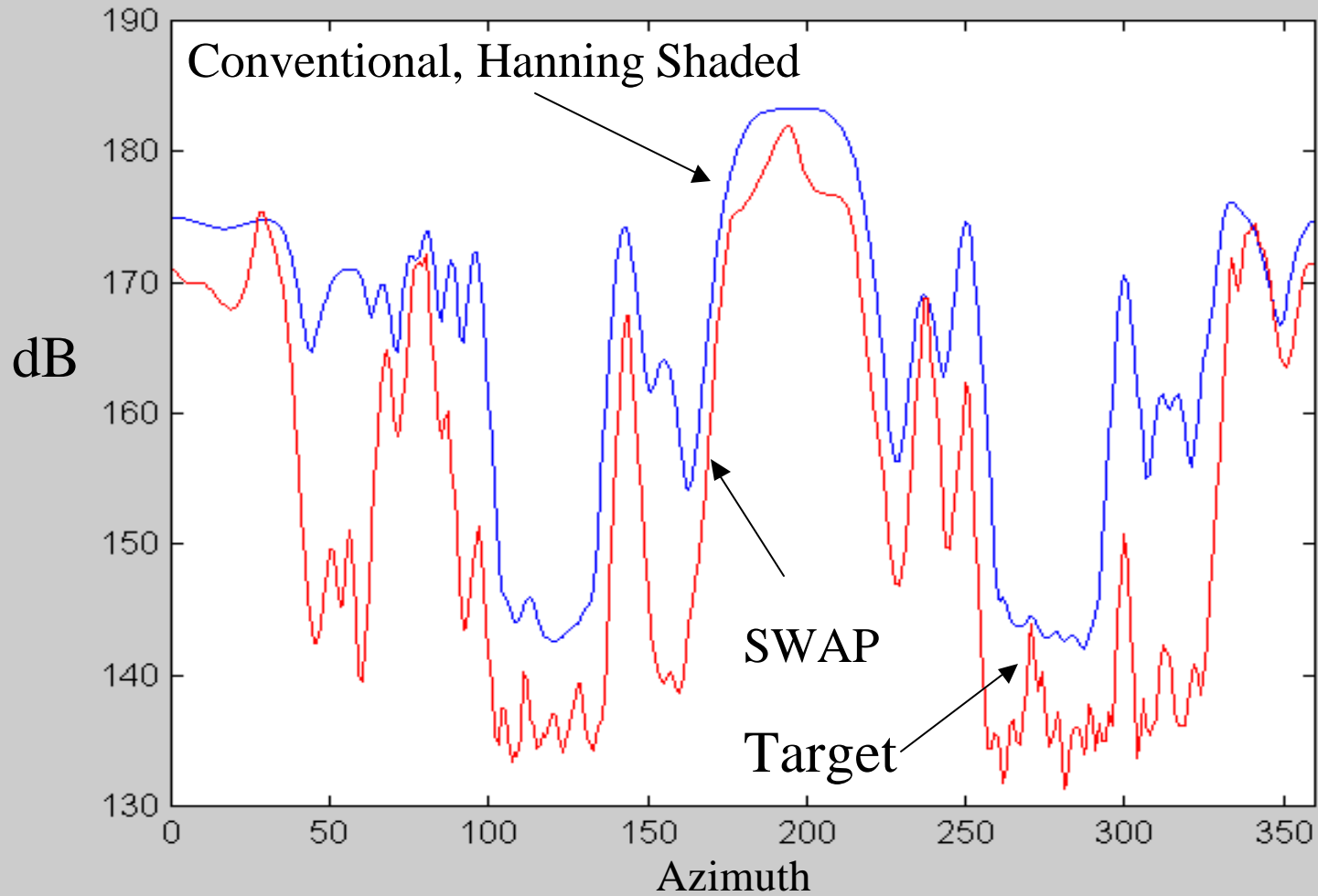
Length 200 m  
2 x 65 phones

# SWAP vs Conventional BTR



Conventional, Hanning Shaded

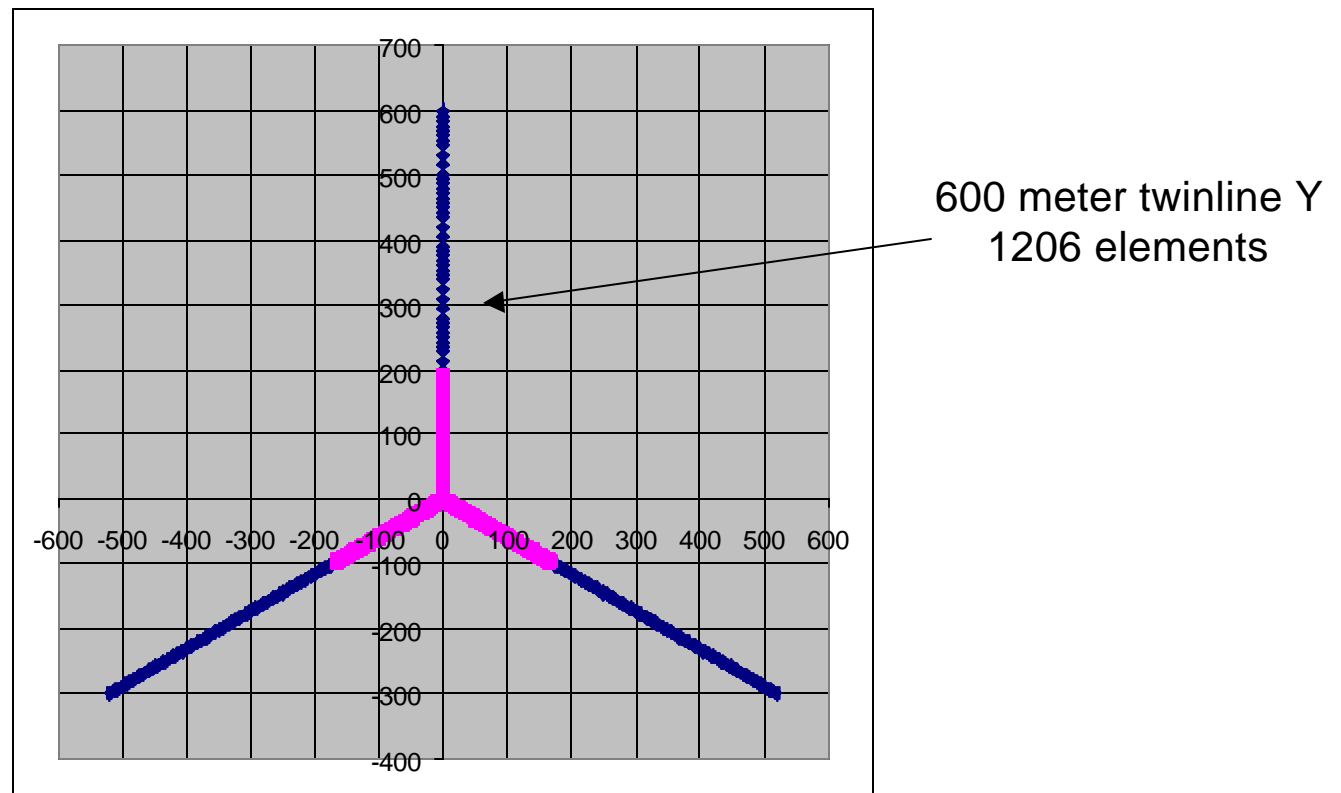
# A-Scan at $T = 16$ sec





# Large Aperture Example

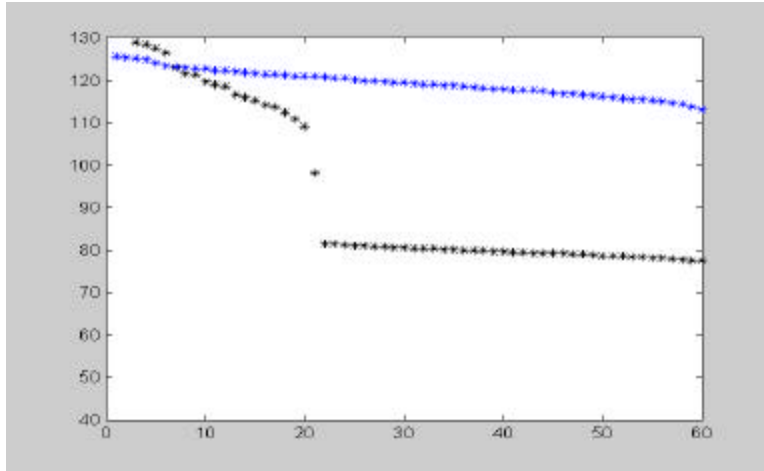
## Ocean Acoustic Observatory Study



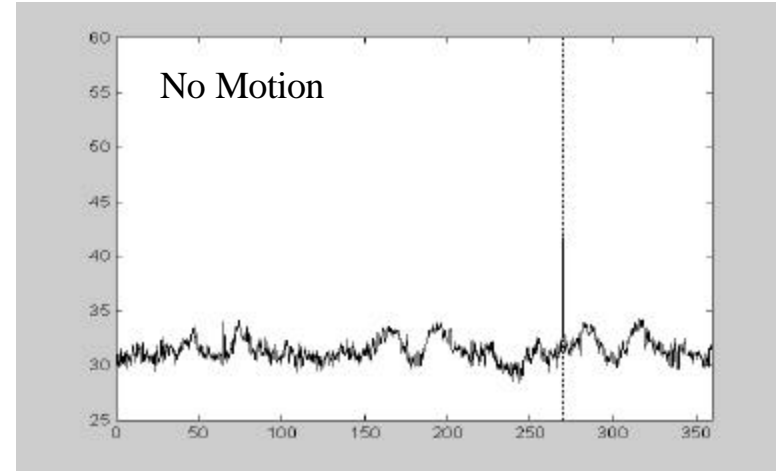


# Ship Motion Causes Smearing

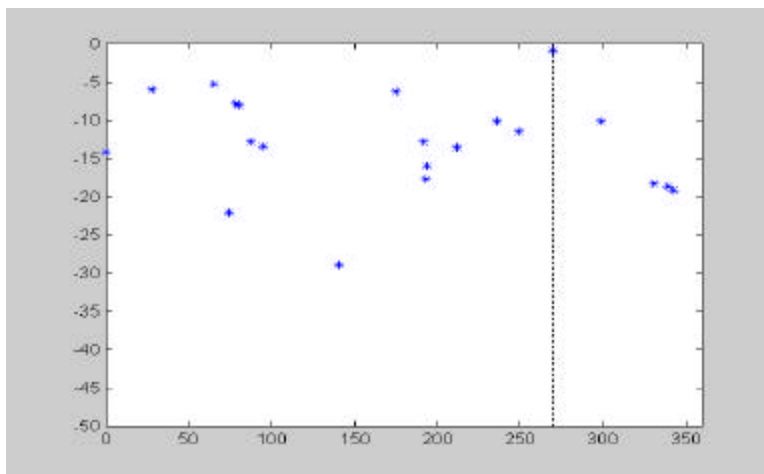
Eigenvalues, No Motion, Motion



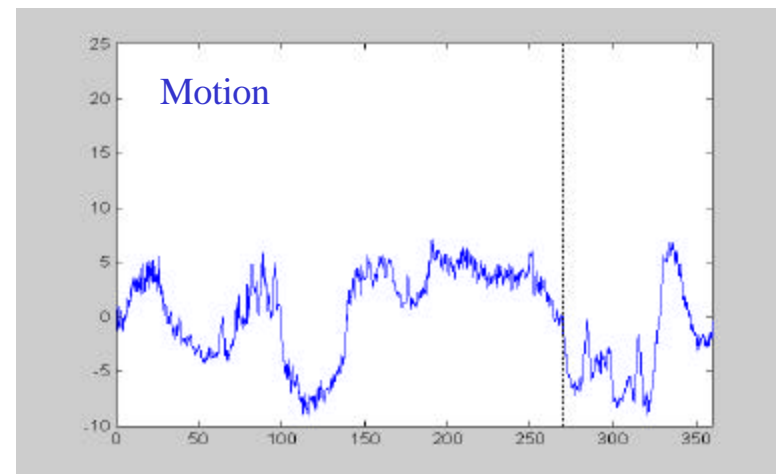
ABF Response at R = 15 km, Z = 100 m



Mismatch R = 15 km, Z = 100 m



ABF Response at R = 15 km, Z = 100 m



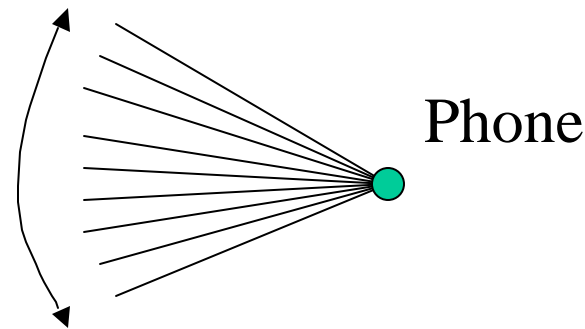


# Use the Environment

SWAP Exploits Special Property of Shallow Water Propagation

Signals from each source  
arrive in a continuous fan  
of angles

([-20, 20] degrees for OAO)



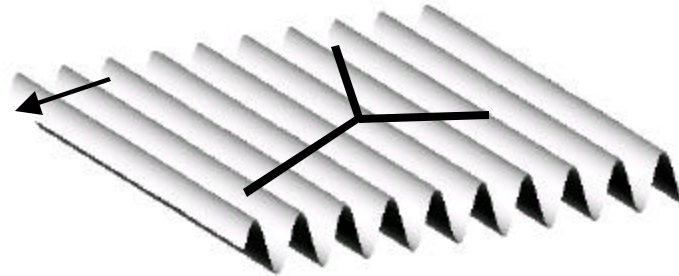
Bottom

# SWAP Signal Model

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- Range-focused plane wave replica
- Vertical arrival angle  $\phi$  is free parameter
- Choose  $\phi$  so horizontal wavenumber is constant



$$\exp (2 \pi i [f \cos(\phi)] (\cos(\theta), \sin(\theta)) \cdot (x_j, y_j))$$

↑  
Horizontal wavenumber =  $k_0$ ,  $\phi$  in  $[0, 20]$  degrees

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# Example at 200 Hz

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$$f \cos(\phi) = 200$$

The same plane wave replica:

$$\exp(2 \pi i [f \cos(\phi)] (\cos(\theta), \sin(\theta)) \cdot (x_j, y_j))$$

is valid over the frequency range [ 188 Hz, 200 Hz ]

At 200 Hz,  $\phi = 0$  degrees

At 188 Hz,  $\phi = 20$  degrees

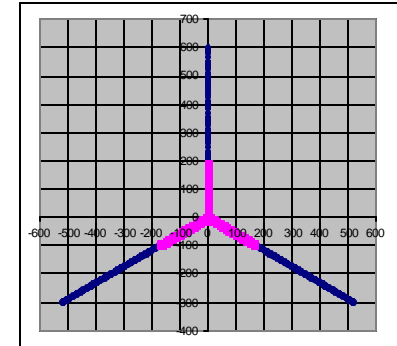
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# Example: 600 m Twinline Y

Take 128 seconds of data from each phone

Fourier transform

Frequency resolution 1/128 Hz



12 x 128 = 1536 frequencies in [ 188, 200 ] Hz band

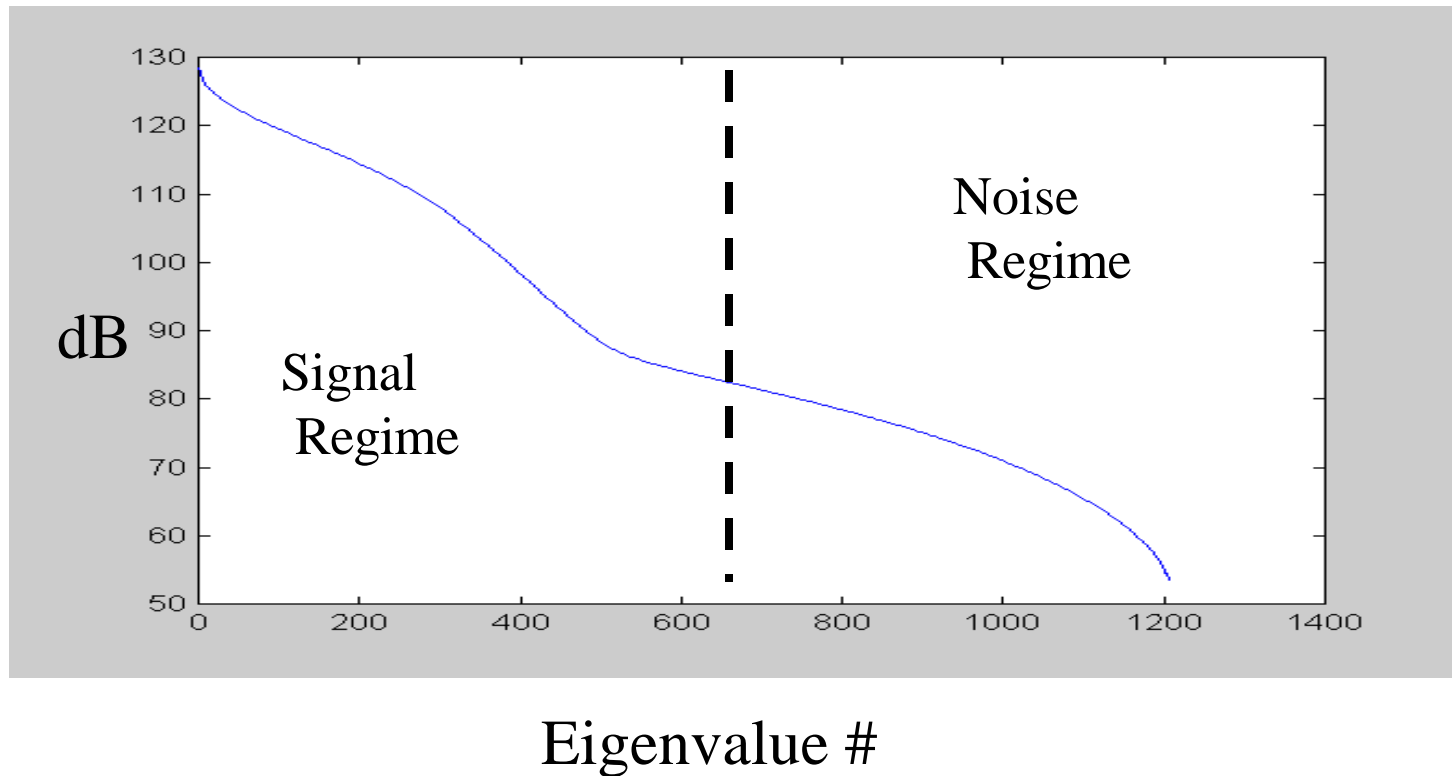
$$\text{BF}_{\text{Output}} = \sum_{j=1, 1536} | w_0^H \cdot \text{Data}(f_j) |^2$$

$$= w_0^H \cdot \left[ \sum_{j=1, 1536} \text{Data}(f_j) \text{Data}(f_j)^H \right] \cdot w_0$$

←  
Covariance Matrix, R

# Spectrum of R Matrix

Form  $R_S$  by zeroing out noise eigenvalues



# SWAP Algorithm

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## Single Wavenumber Adaptive Processing

$$[ w_0^H \cdot R^{-1} \cdot R_S \cdot R^{-1} \cdot w_0 ]$$

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$$[ w_0^H \cdot R^{-1} \cdot w_0 ]^2$$

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# OAO Scenarios

Based on broadband ray-based simulation

Surface

Isovelocity  
Profile

1500 m/s

Bottom

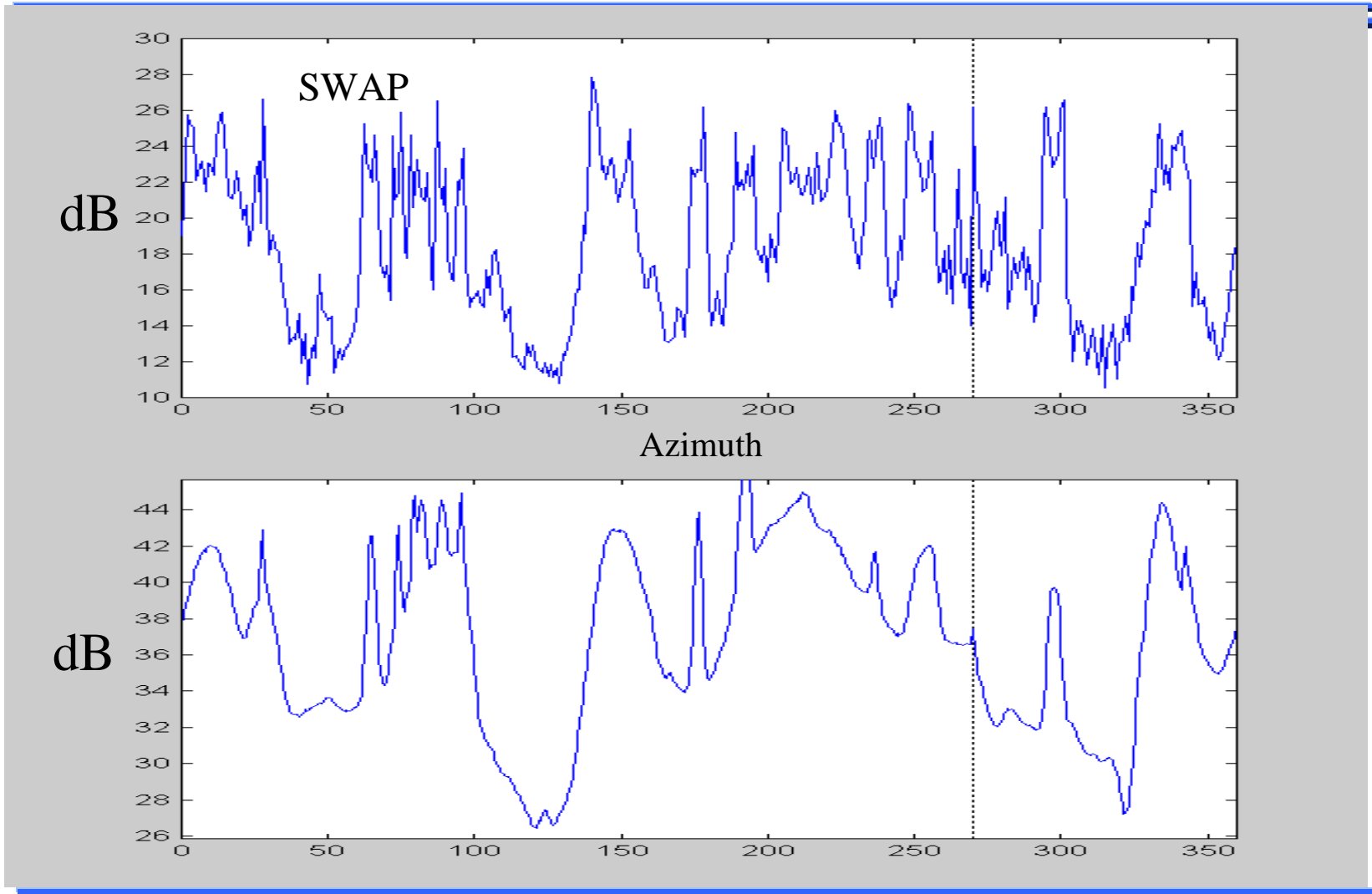
Continuous doppler by warping time series

Differential doppler on rays with different angles



# 140 dB Target

80 dB diagonal loading



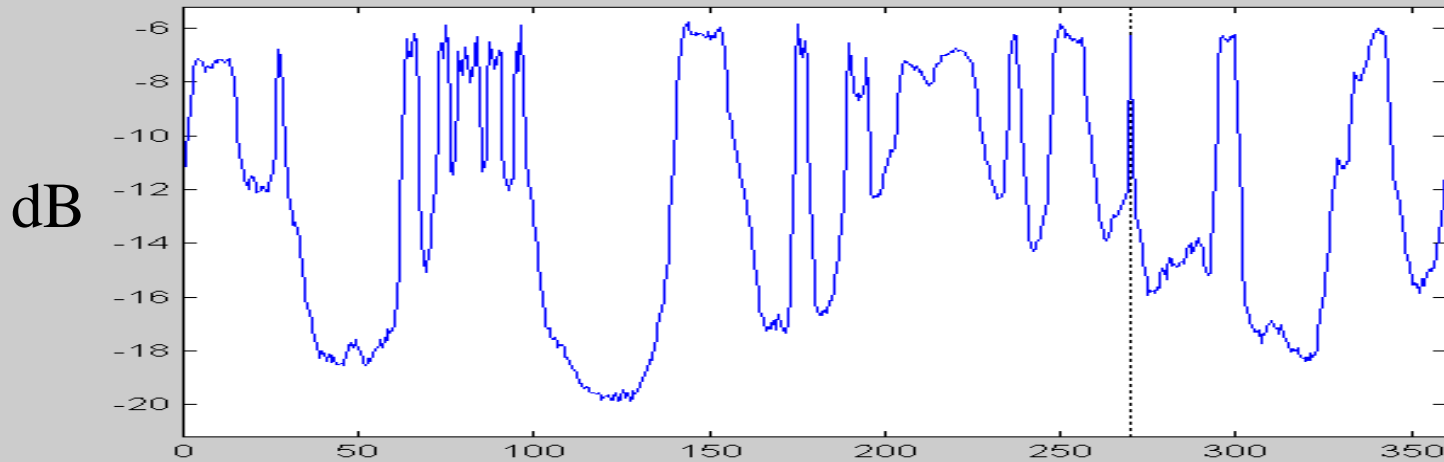
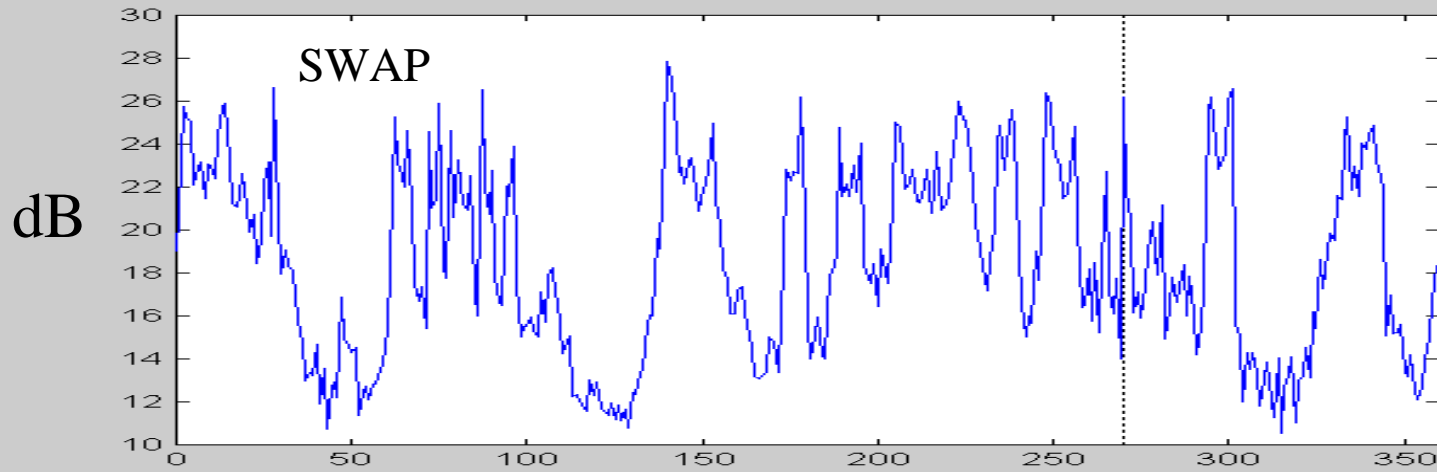
Reduced rank, narrow band MVDR, 12 Hz average





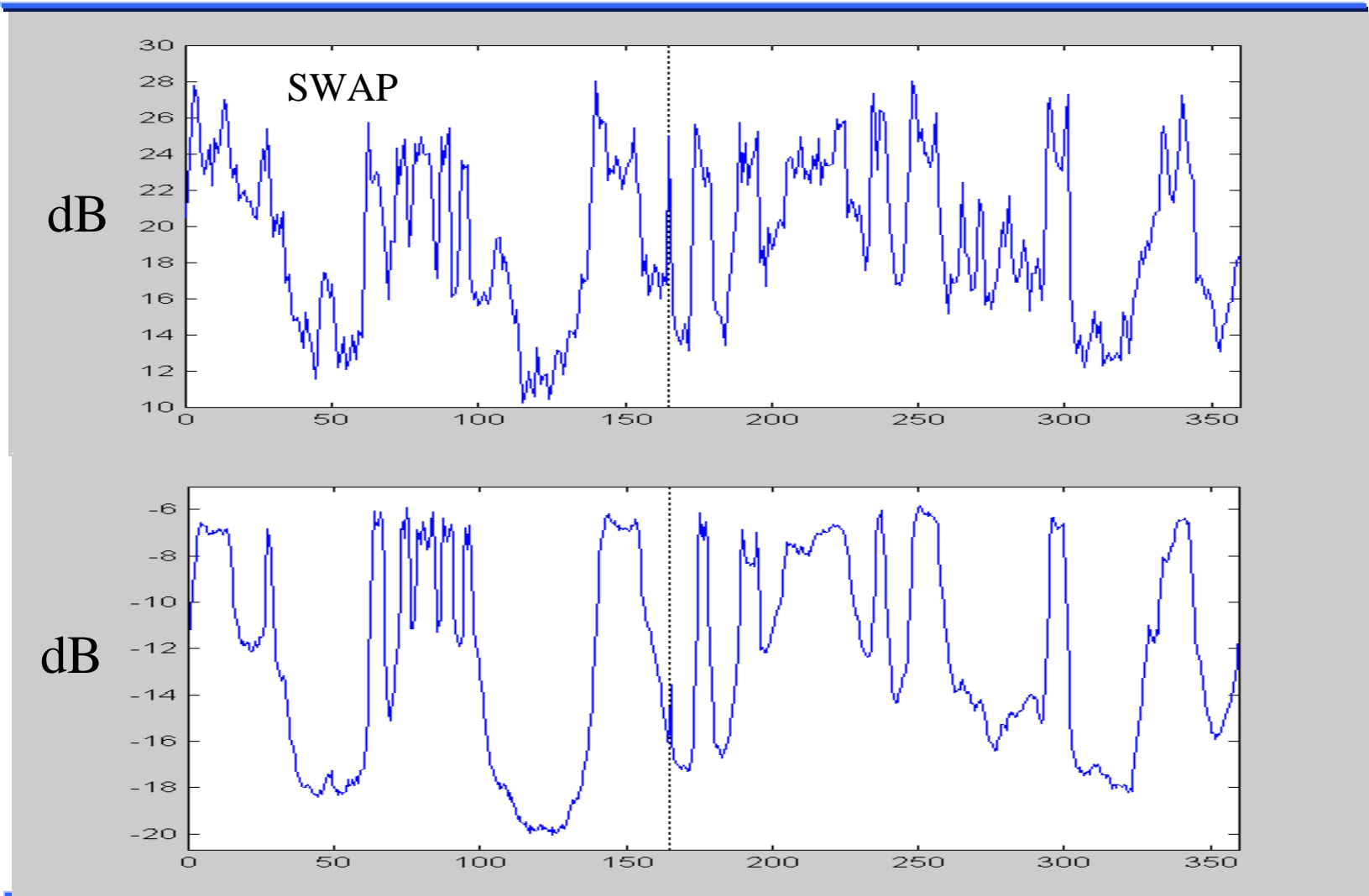
# 140 dB Target

30 dB diagonal loading



Reduced rank, narrow band MVDR, 12 Hz average

# 125 dB Target



Reduced rank, narrow band MVDR, 12 Hz average



# Single Wavenumber Adaptive Processing

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## SWAP Improves ABF performance vs dynamics

- Increases exploitable degrees of freedom
  - Has extensions to matched-field processing
  - Has extensions to vertical apertures
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