Broadband Adaptive Beamforming

Motion Mitigation in the Littoral Environment by Frequency Averaging

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
14 MAR 2001	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Broadband Adaptive Beamforming Motion Mitigation in the Littoral Environment by Frequency Averaging	**F19628-00-C-0002**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Robert Greene**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SAIC 1710 SAIC Drive McLean, VA 22102**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See ADM001263 for entire Adaptive Sensor Array Processing Workshop.

14. ABSTRACT
See briefing charts.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**18**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

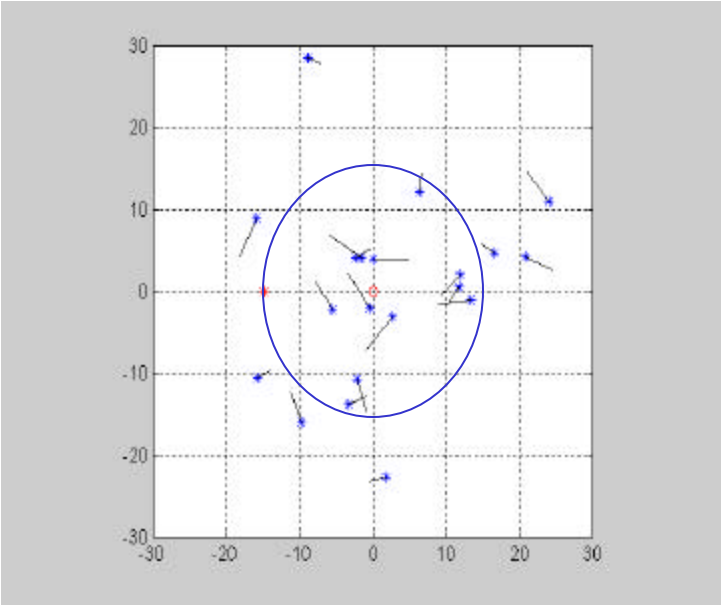
Single Wavenumber Adaptive Processing

SWAP Improves ABF performance vs dynamics

- Increases degrees of freedom
- Improves convergence of covariance matrix
- Exploits vertical arrival structure
- Exploits broadband signature

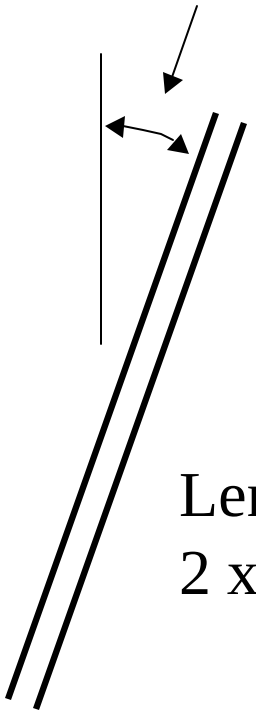
200 m Twin Line Simulation

188 - 200 Hz



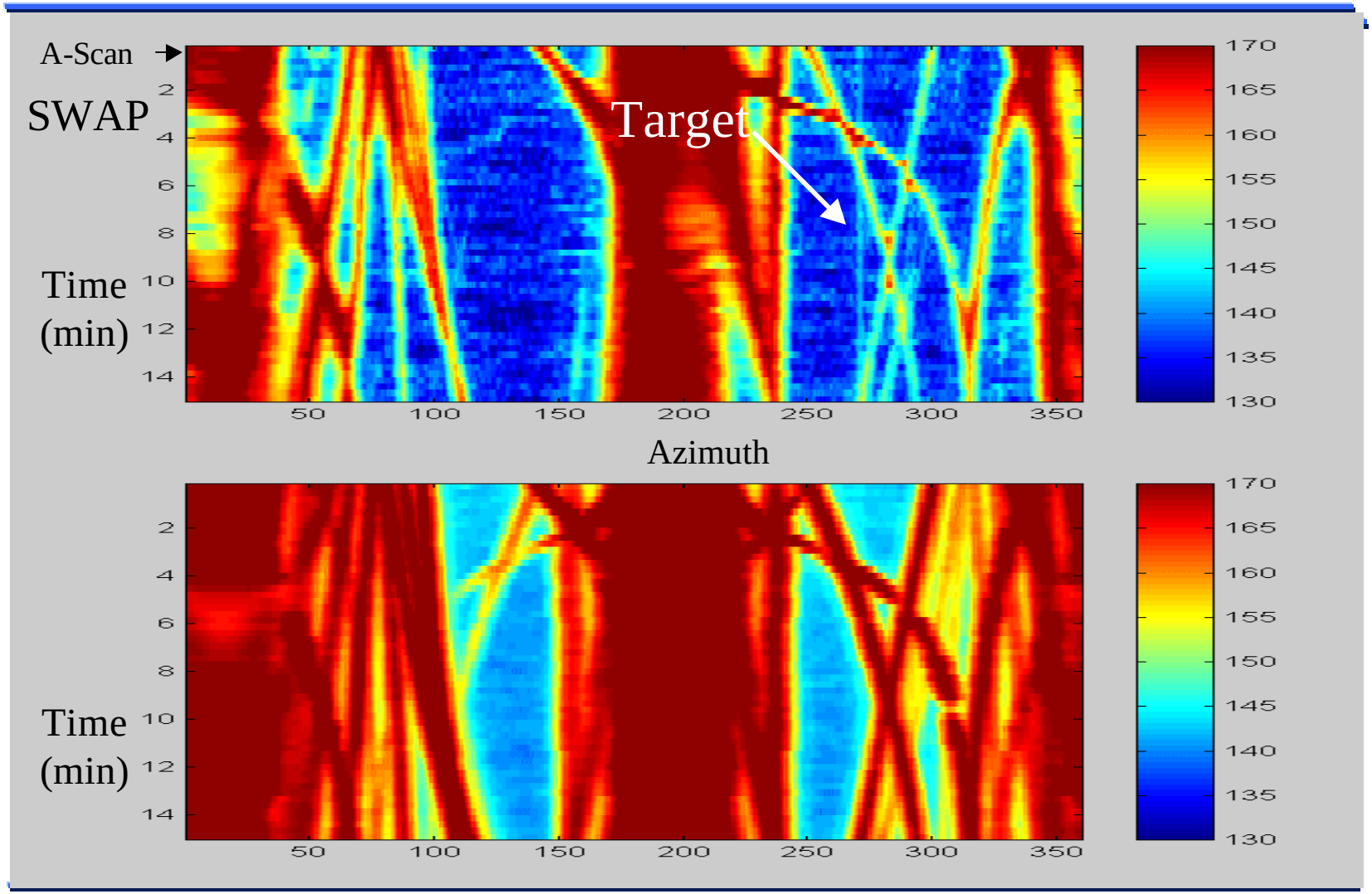
Average phone level 115 dB
Ambient white noise 65 dB
Average TL at 15 km 64 dB

Heading 15 degrees



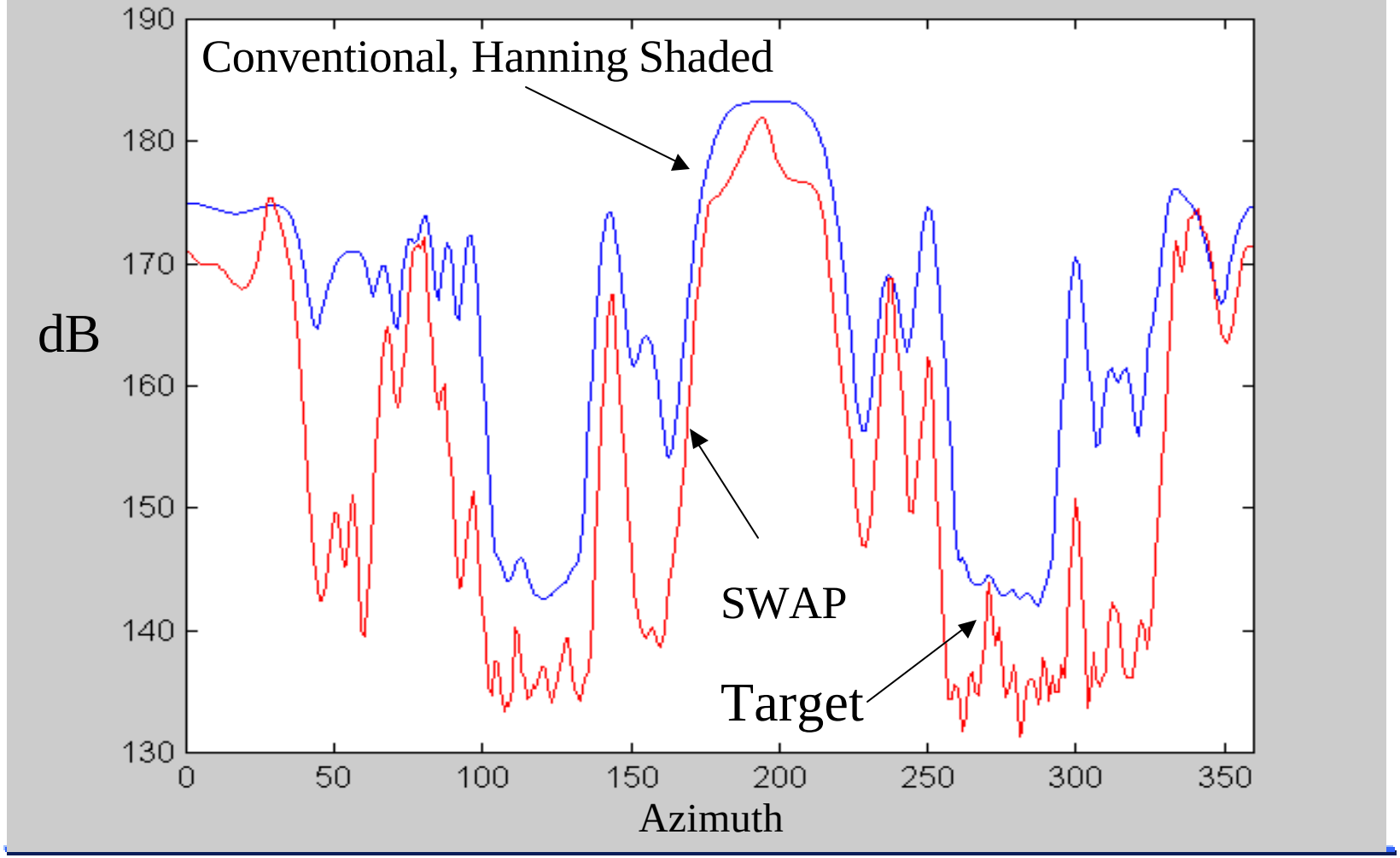
Length 200 m
2 x 65 phones

SWAP vs Conventional BTR



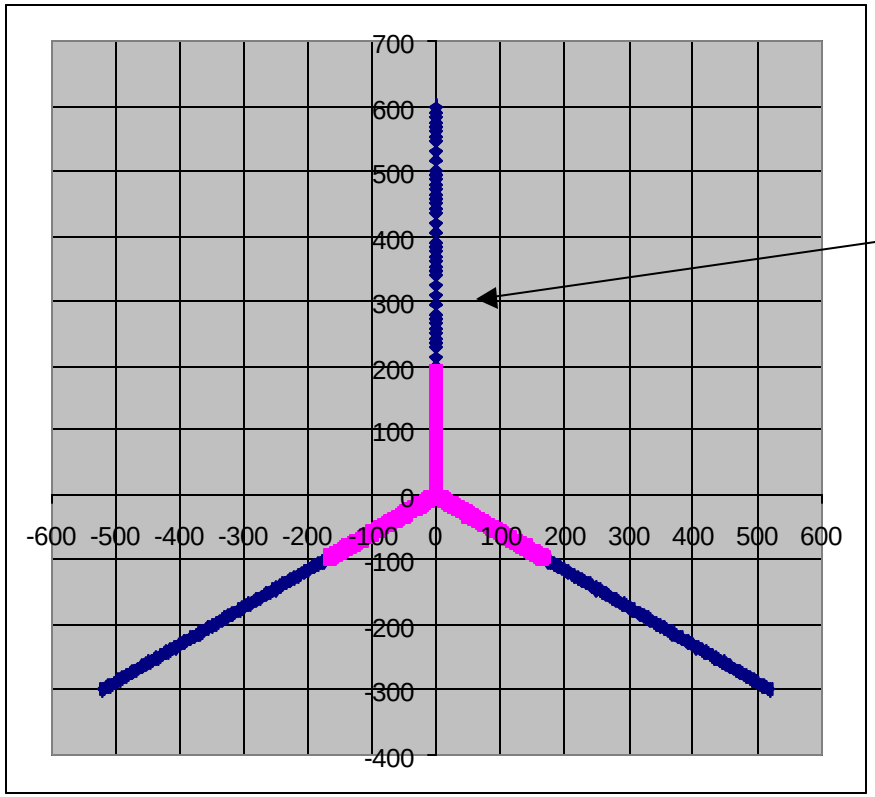
Conventional, Hanning Shaded

A-Scan at T = 16 sec



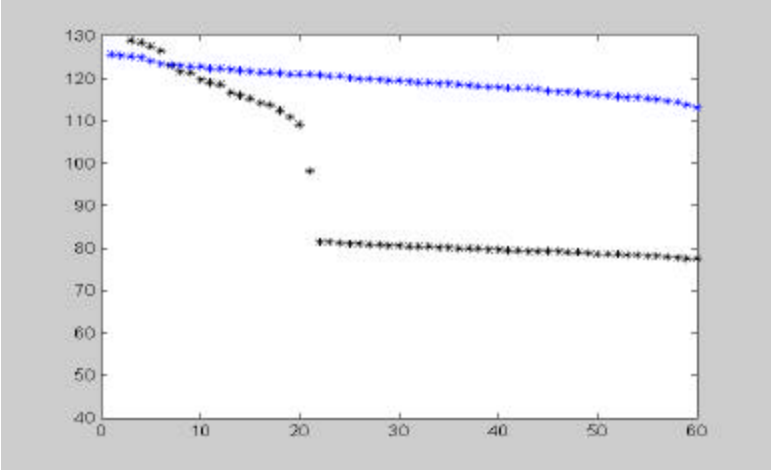
Large Aperture Example

Ocean Acoustic Observatory Study

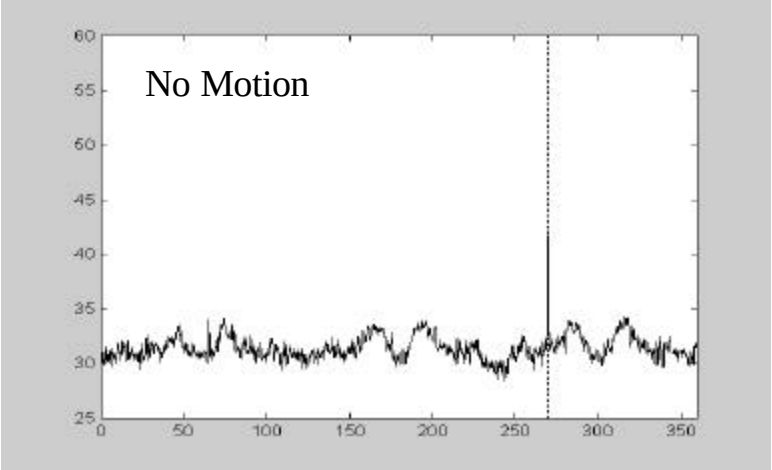


Ship Motion Causes Smearing

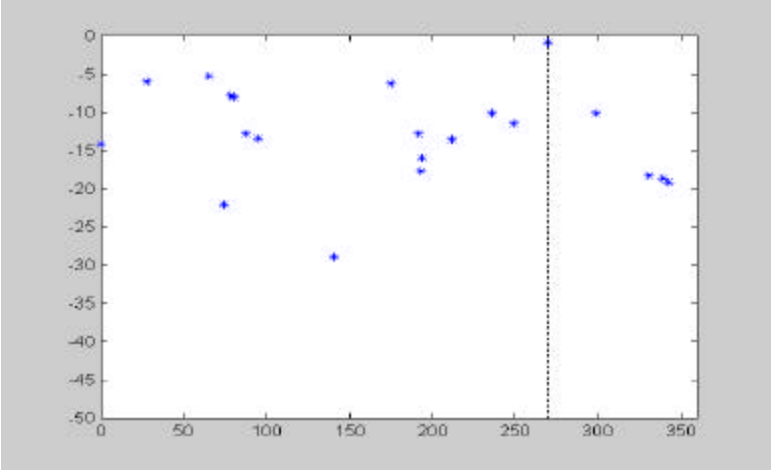
Eigenvalues, No Motion, Motion



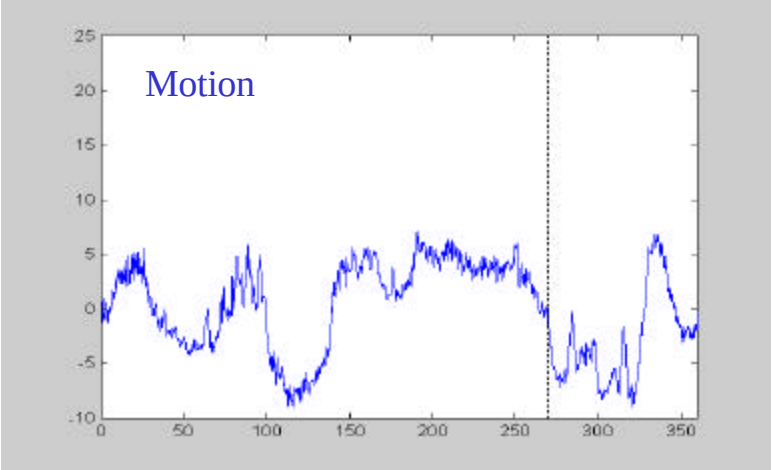
ABF Response at R = 15 km, Z = 100 m



Mismatch R = 15 km, Z = 100 m



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



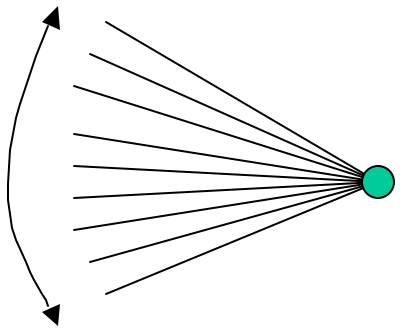
Use the Environment

SWAP Exploits Special Property of Shallow Water Propagation

Surface

Signals from each source arrive in a continuous fan of angles

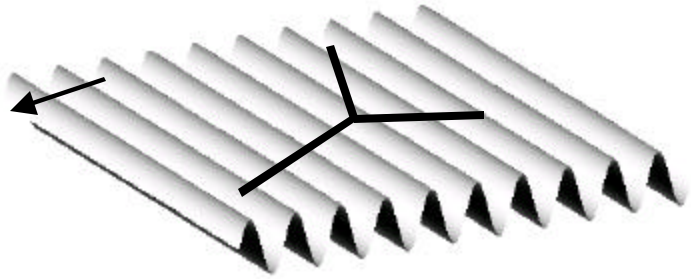
([-20, 20] degrees for OAO)



Bottom

SWAP Signal Model

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



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

Horizontal wavenumber = k_0, ϕ in [0, 20] degrees

Example at 200 Hz

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

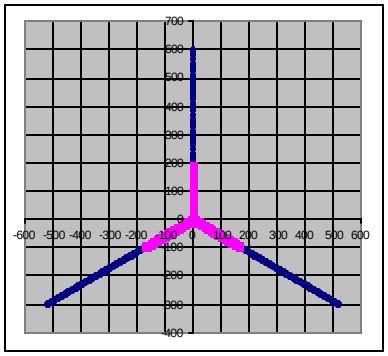
The same plane wave replica:

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

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

At 200 Hz, ϕ = 0 degrees
At 188 Hz, ϕ = 20 degrees

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

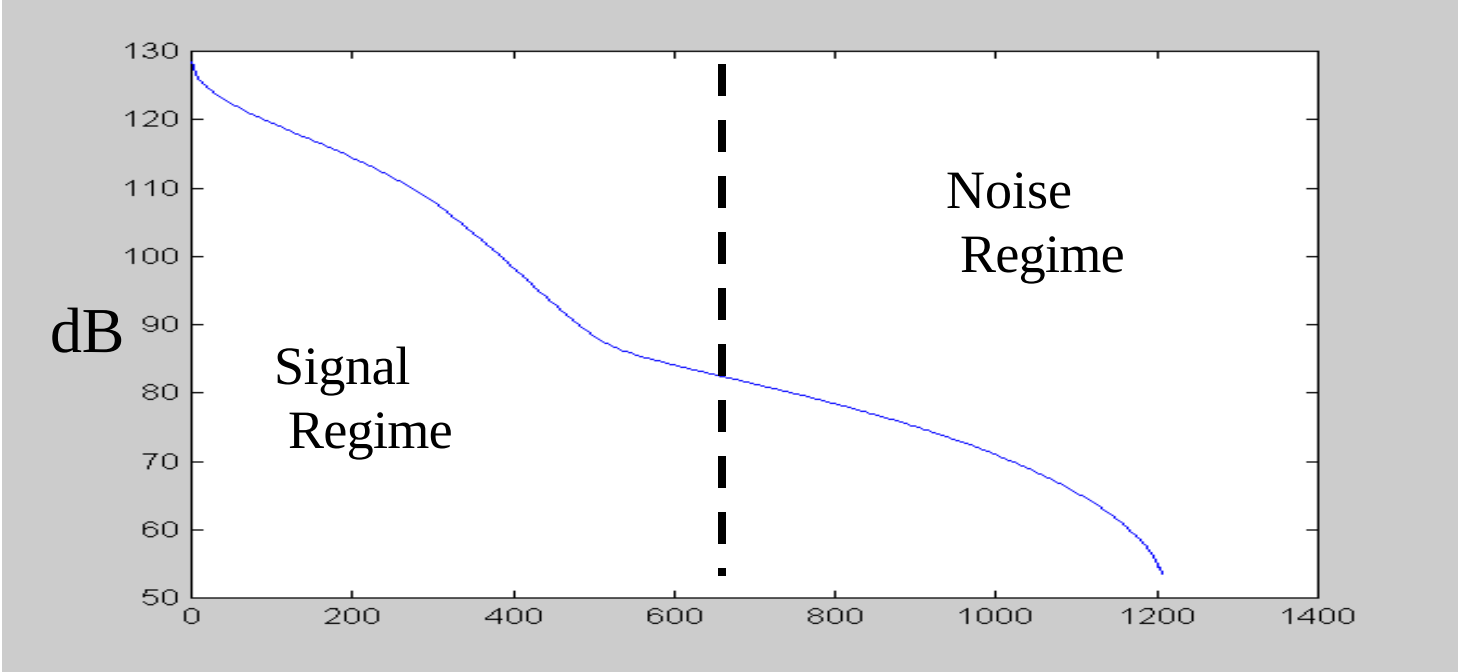
$$BF_{Output} = \Sigma_{j=1,\,1536} \left| w_0^{H} \cdot Data(f_j) \right|^2$$

$$= w_0^{H} \cdot [\Sigma_{j=1,\,1536}\, Data(f_j)\, Data(f_j)^{H}] \cdot w_0$$

Covariance Matrix, R

Spectrum of R Matrix

Form R_S by zeroing out noise eigenvalues



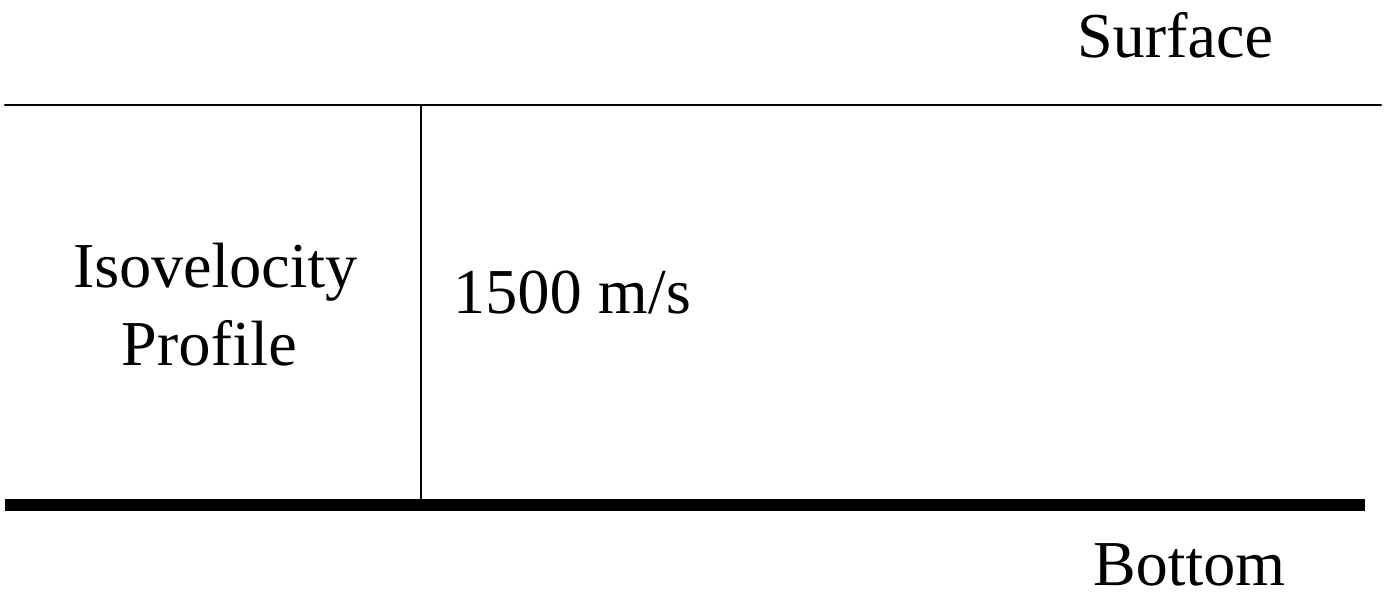
SWAP Algorithm

Single Wavenumber Adaptive Processing

$$\frac{\left[w_0^{H} \cdot R^{-1} \cdot R_S \cdot R^{-1} \cdot w_0 \right]}{\left[w_0^{H} \cdot R^{-1} \cdot w_0 \right]^{2}}$$

OAO Scenarios

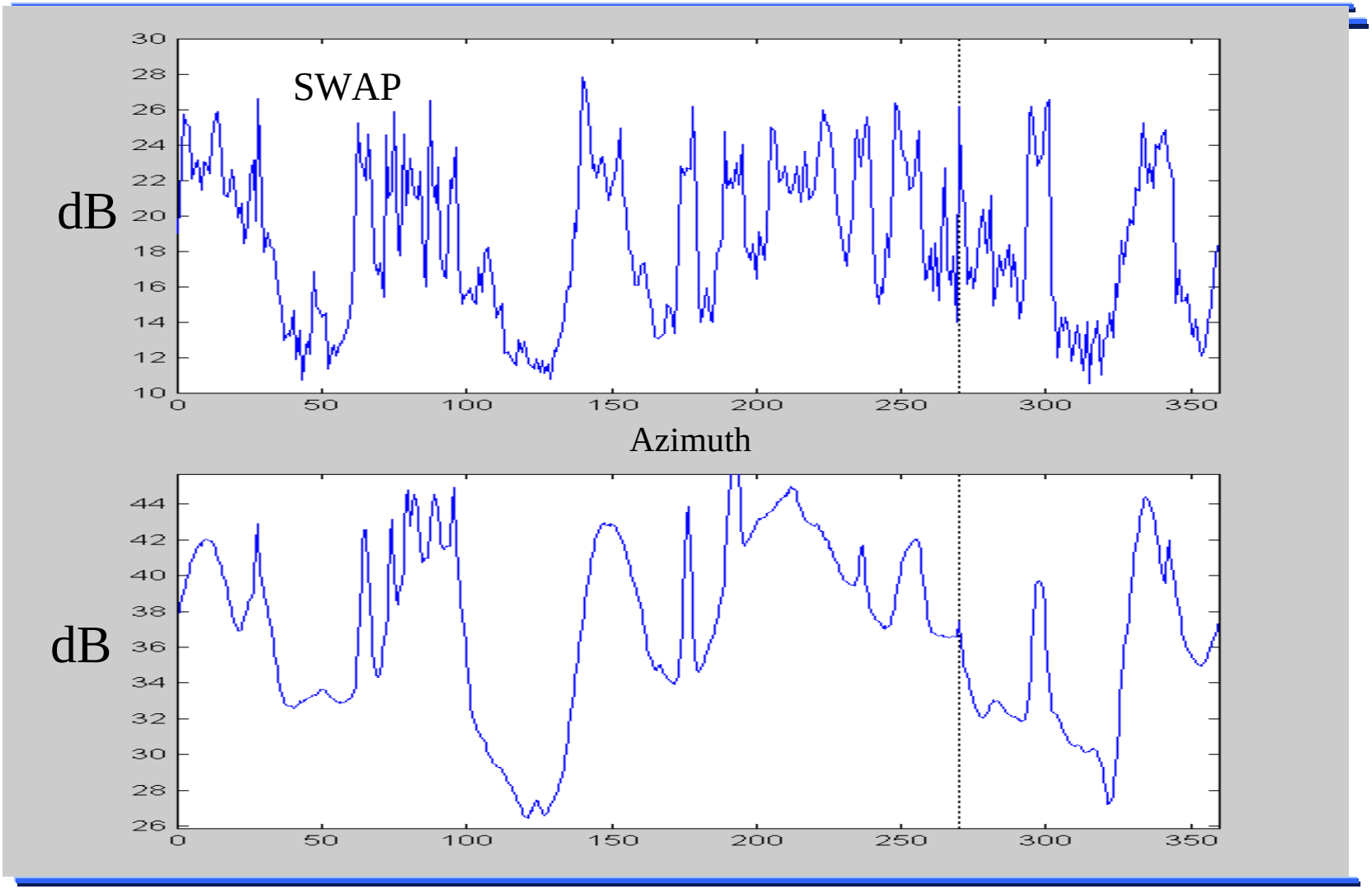
Based on broadband ray-based simulation



Continuous doppler by warping time series
Differential doppler on rays with different angles

140 dB Target

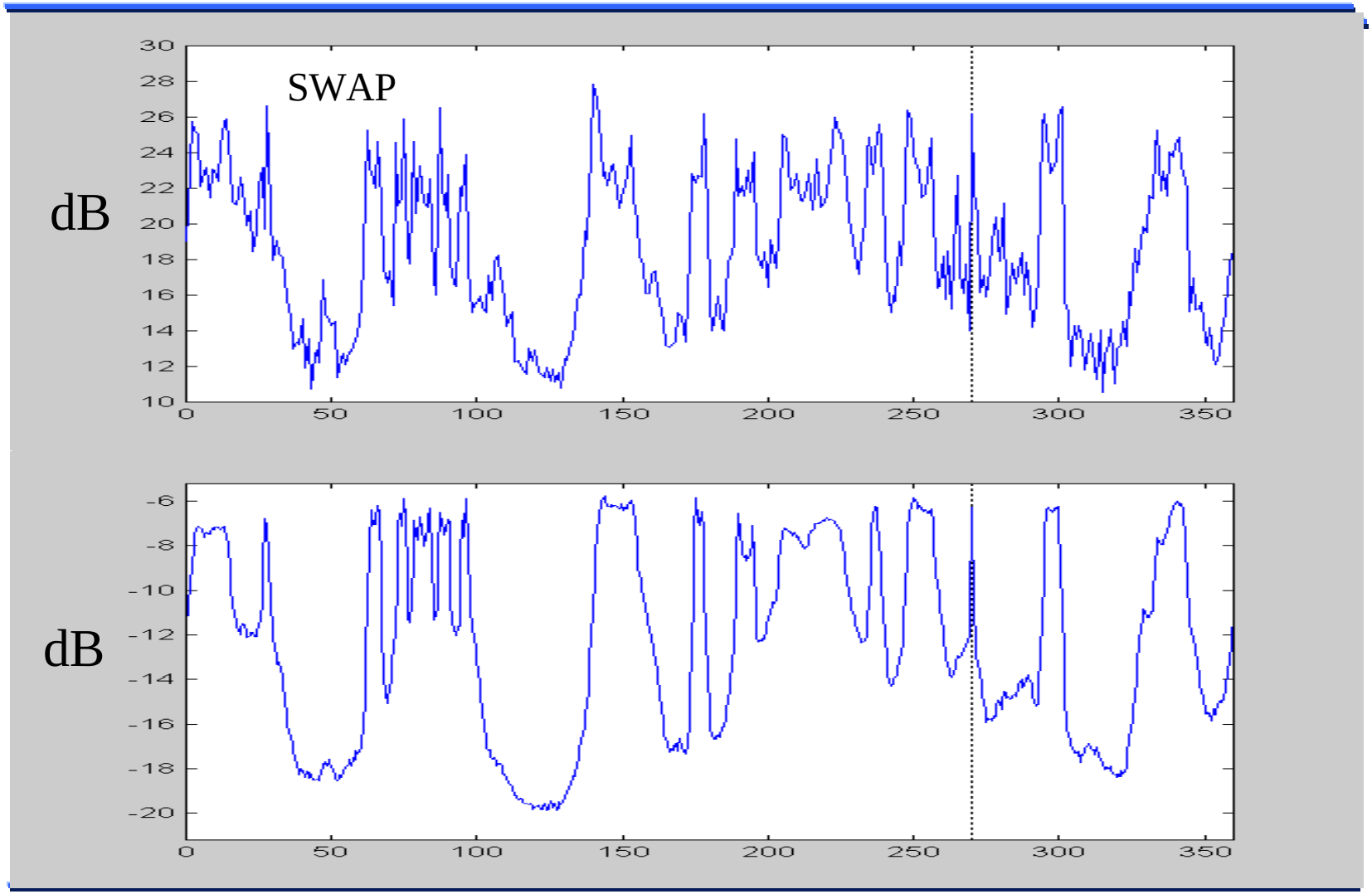
80 dB diagonal loading



Reduced rank, narrow band MVDR, 12 Hz average

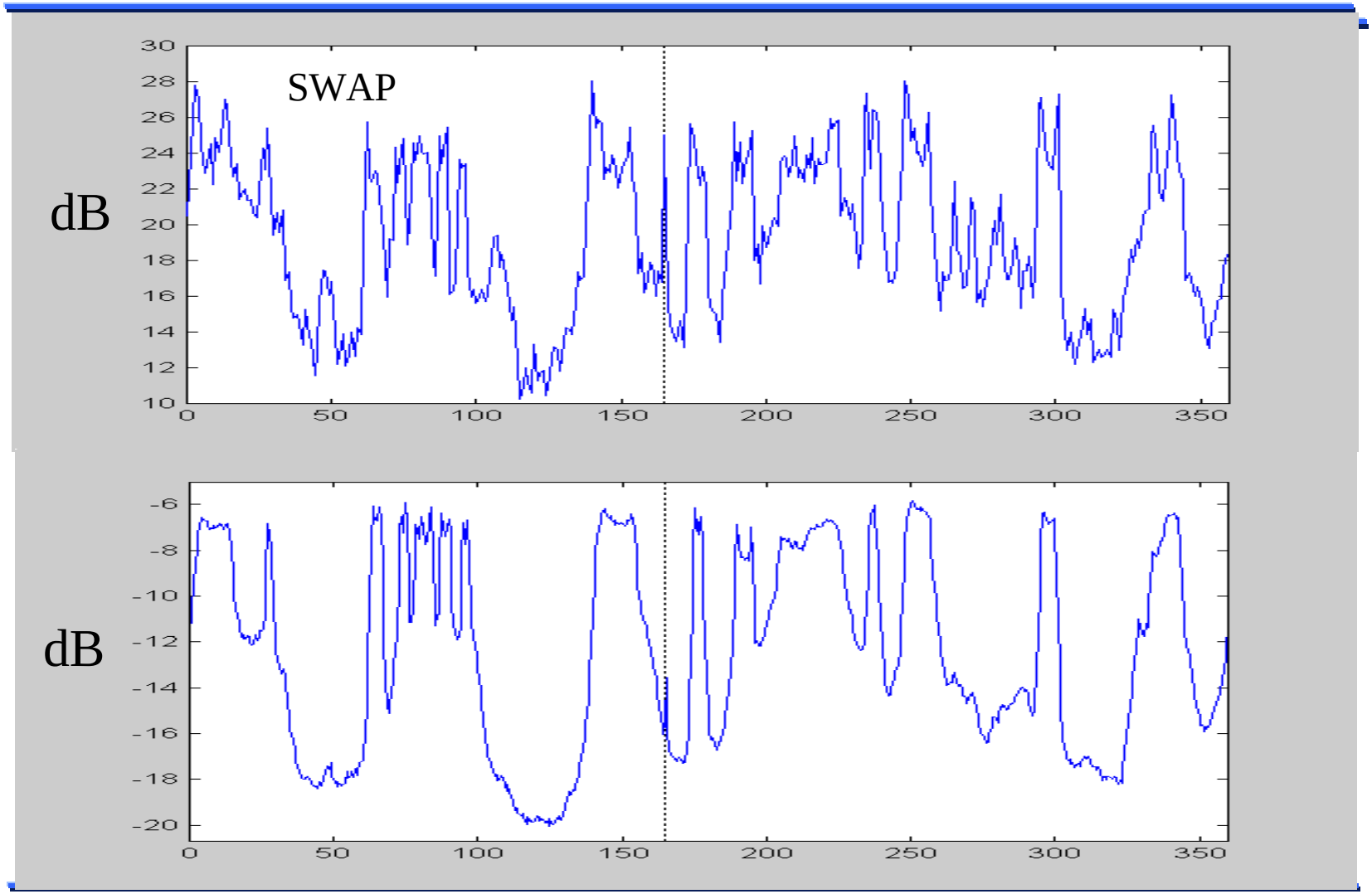
140 dB Target

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

SWAP Improves ABF performance vs dynamics

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