

**AD-A285 944**



**CLEARED  
FOR OPEN PUBLICATION**

**ARPA PROGRESS REPORT**

**OCT 26 1994 12**

**DIRECTORATE FOR FREEDOM OF INFORMATION  
AND SECURITY REVIEW (OASD-PA)  
DEPARTMENT OF DEFENSE**

**D. MIKLOVIC**

**REVIEW OF THIS MATERIAL DOES NOT IMPLY  
DEPARTMENT OF DEFENSE INDOORSEMENT OF  
FACTUAL ACCURACY OR OPINION.**

**26 AUGUST 1993**

**DTIC  
ELECTE  
NOV 03 1994**

**CONTRACT NO.: MDA972-91-C-0063**

*SSA*

**94-34199**

**ARS-235-037-B**



**94 11 2 084**

**DTIC QUALITY INSPECTED 3**

**Areté Associates**

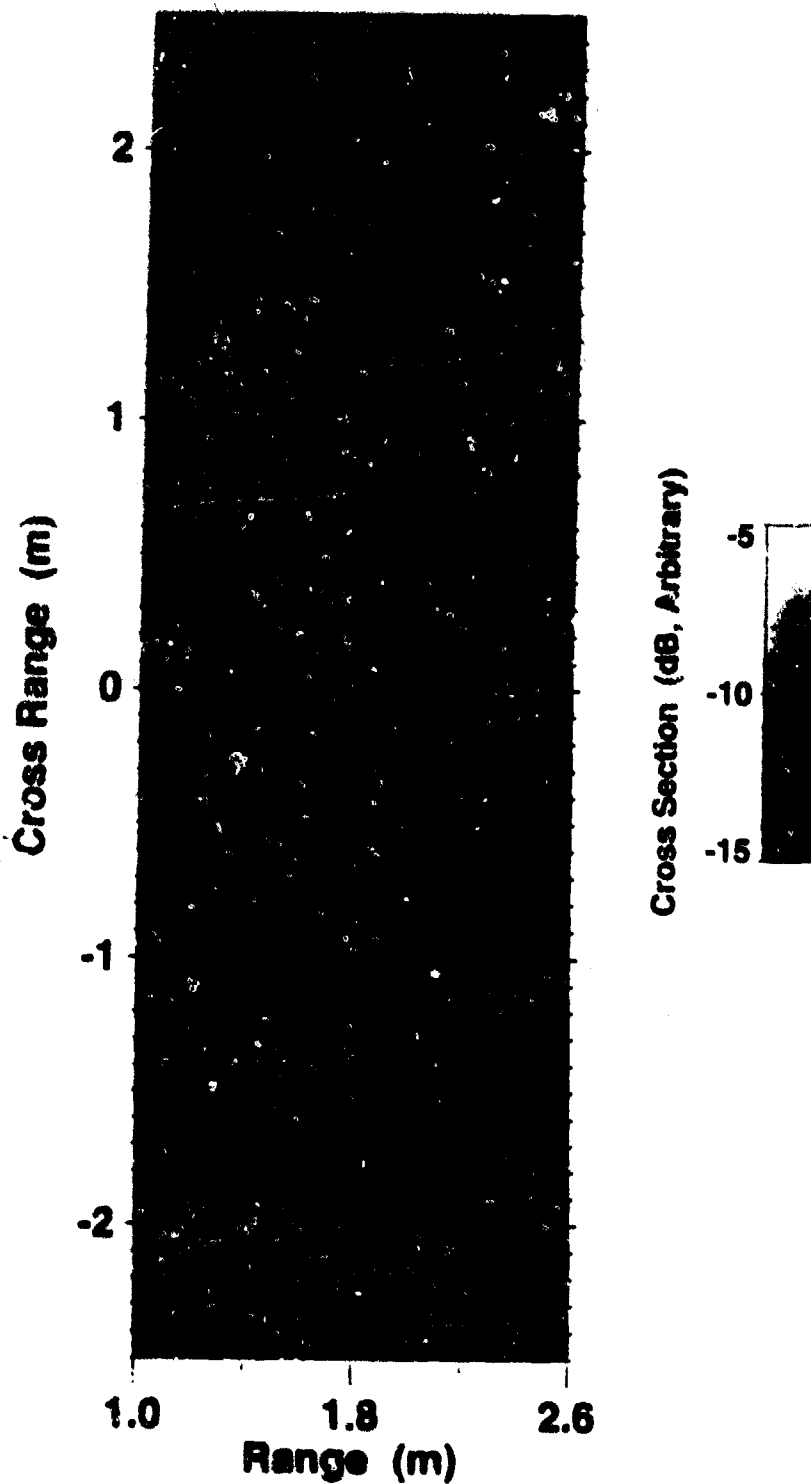
**P.O. BOX 8050, LA JOLLA, CALIFORNIA 92038**

## TOPICS

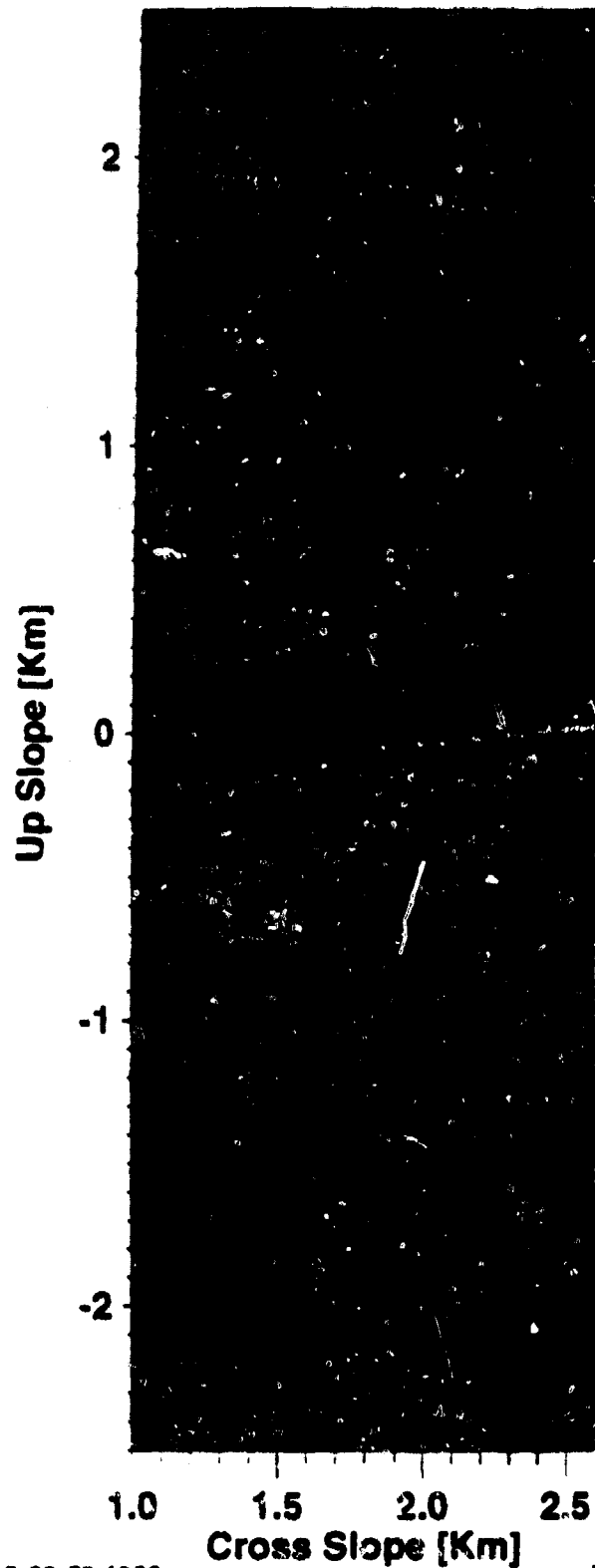
- **Exploitation of Acoustic Color for Classification**
  - / Explosive sources
  - / Multiple transmitters
  
- **Broadband Detection Assessment**
  - / Optimal detector design
  - / Measurement based predictions
  - / Model based predictions
  
- **Image Looping**
  - / System motion
  - / Environmental interpretation
  - / Tracking
  
- **Auto-coherence with Near Field Point Sources of Uncertain Location**
  - / Fixed large aperture arrays
  - / Free floating sonobuoys
  
- **Auto-coherence for Moving Arrays**
  - / Left-right resolution
  - / Incoherent ping combination
  
- **Processor Throughput Status**

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
<b>A-1</b>	

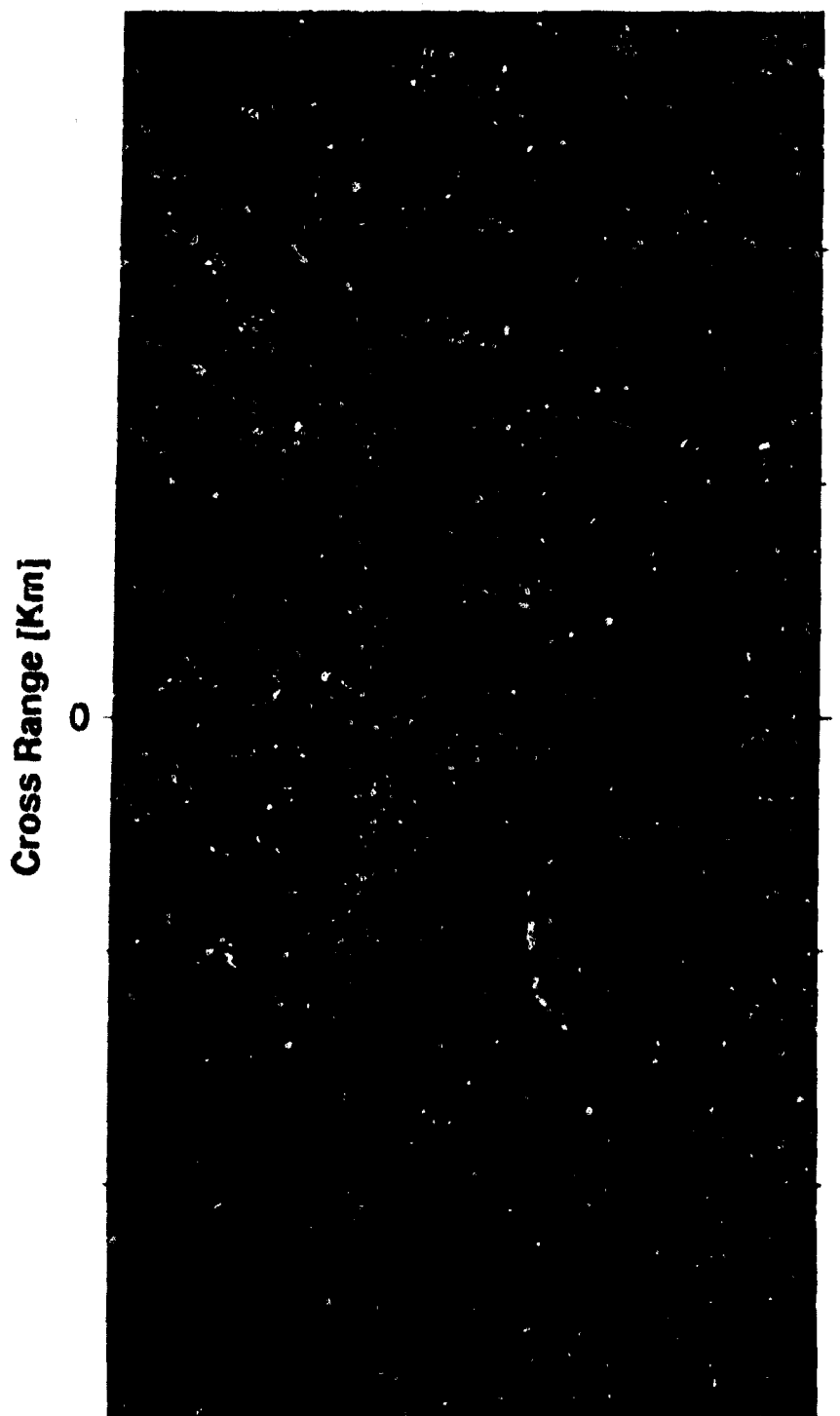
# CST7, Low Wind (4 m/s) Sum of Three Passbands



# Surface Reverberation Spectral Color Low Wind (4 m/s), CST7



# Acoustic Color For Bottom Clutter Depth: 80 Fathoms



1.5

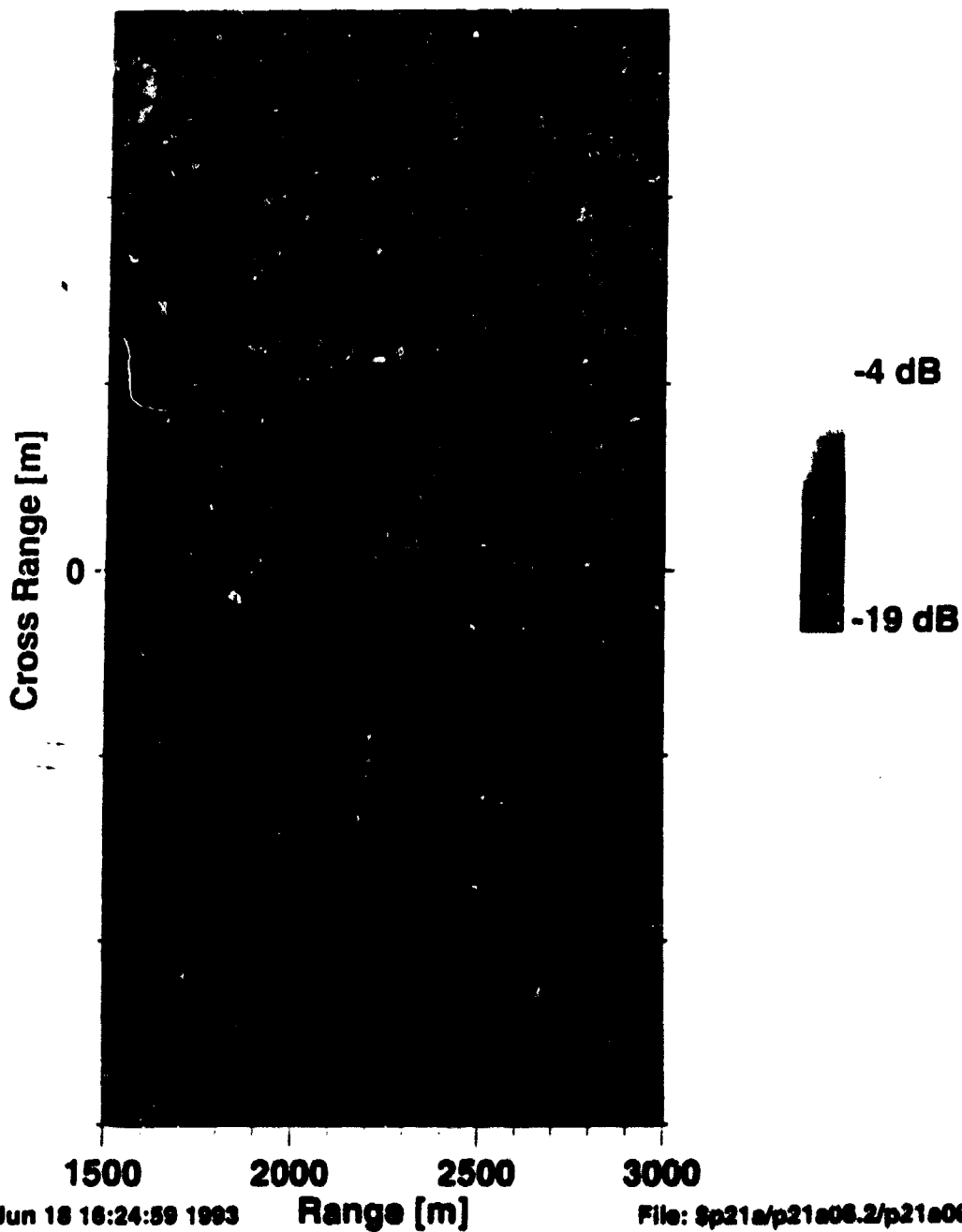
2.0

2.5

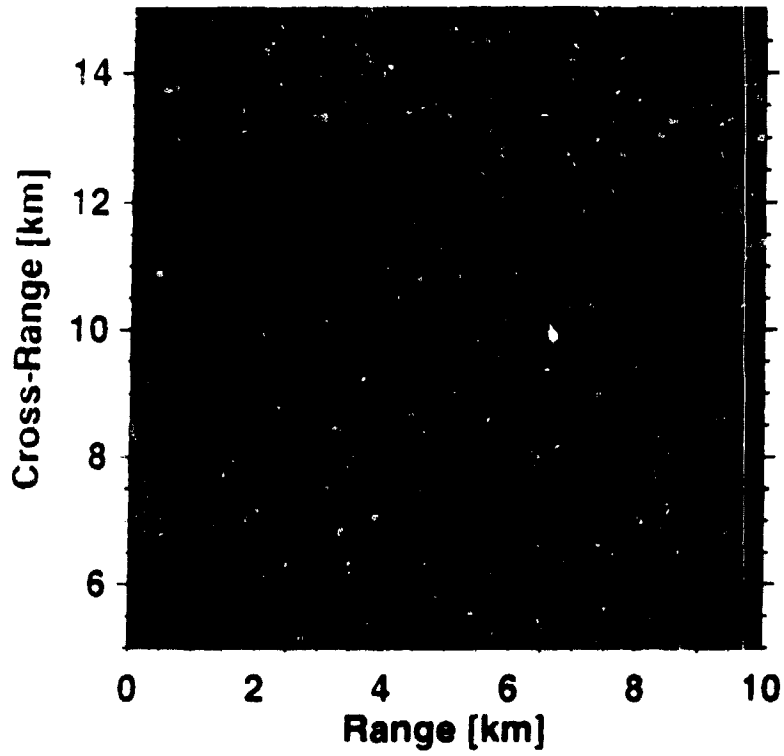
3.0

Range [Km]

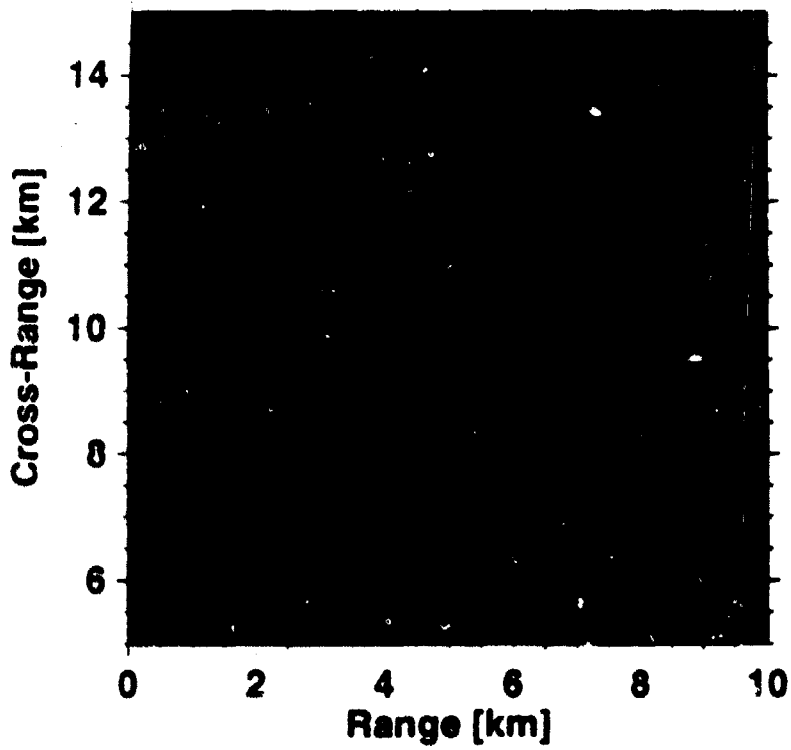
# Broadband Image For Bottom Clutter Depth: 80 Fathoms



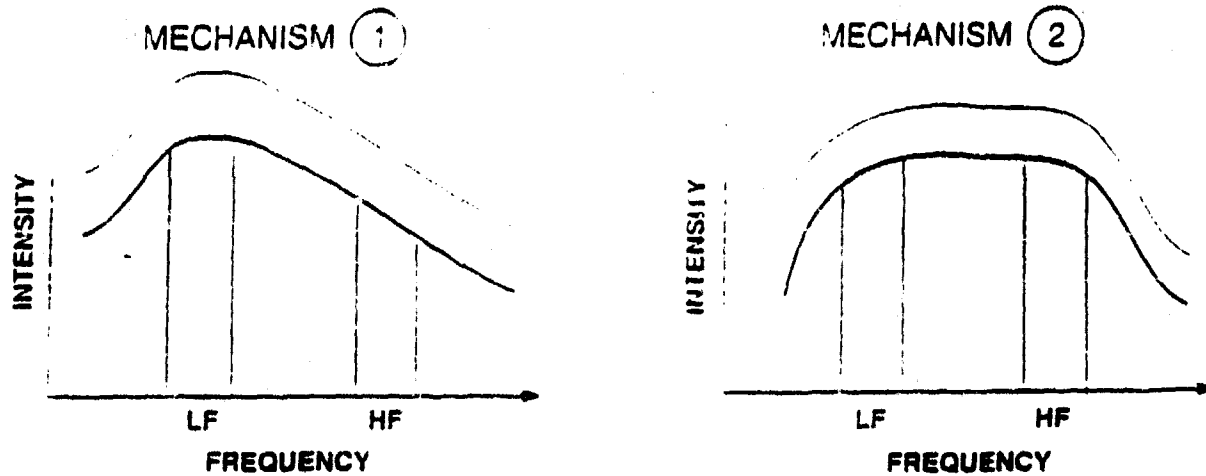
**Broadband Image**



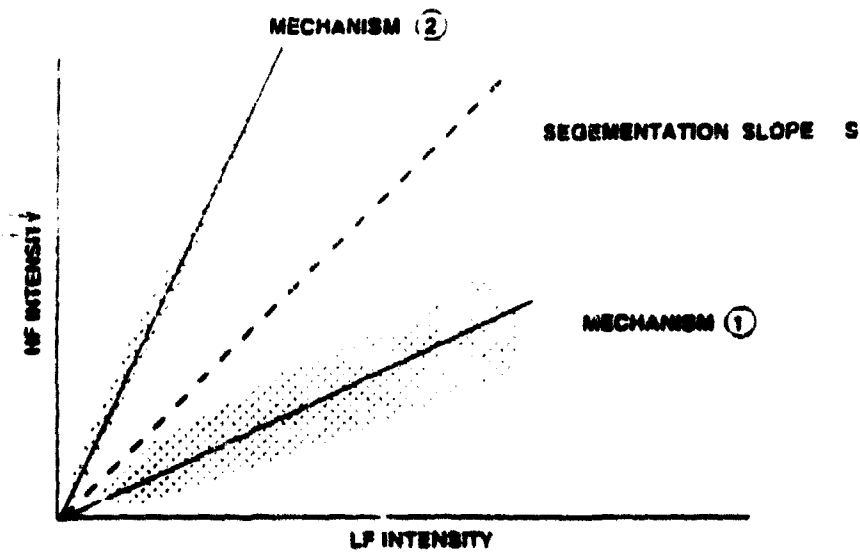
**3 Band Acoustic Color**



## SCATTERING MECHANISM SEGMENTATION BASED ON SPECTRAL SHAPE



### MULTIBAND PIXEL SCATTERGRAM



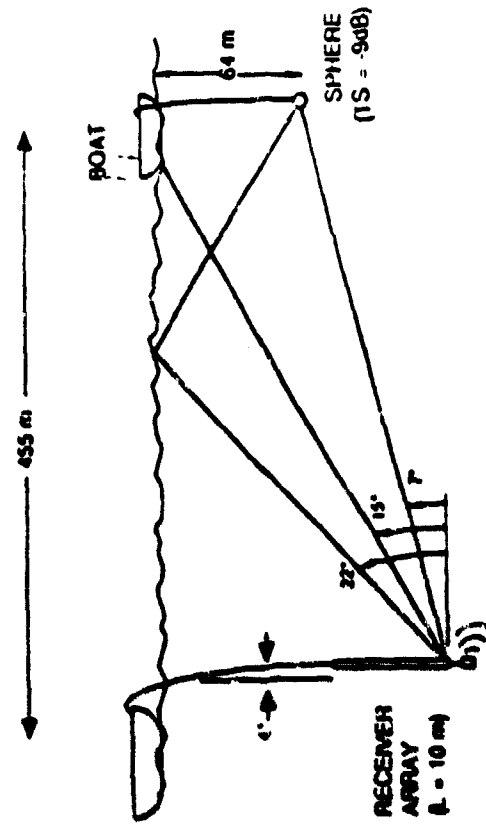
$\frac{HF}{LF} < S$  Classify as ①

$\frac{HF}{LF} > S$  Classify as ②



# TARGET DISCRIMINATION USING BROADBAND SIGNALS

## BOATSPHERE SCATTERING GEOMETRY



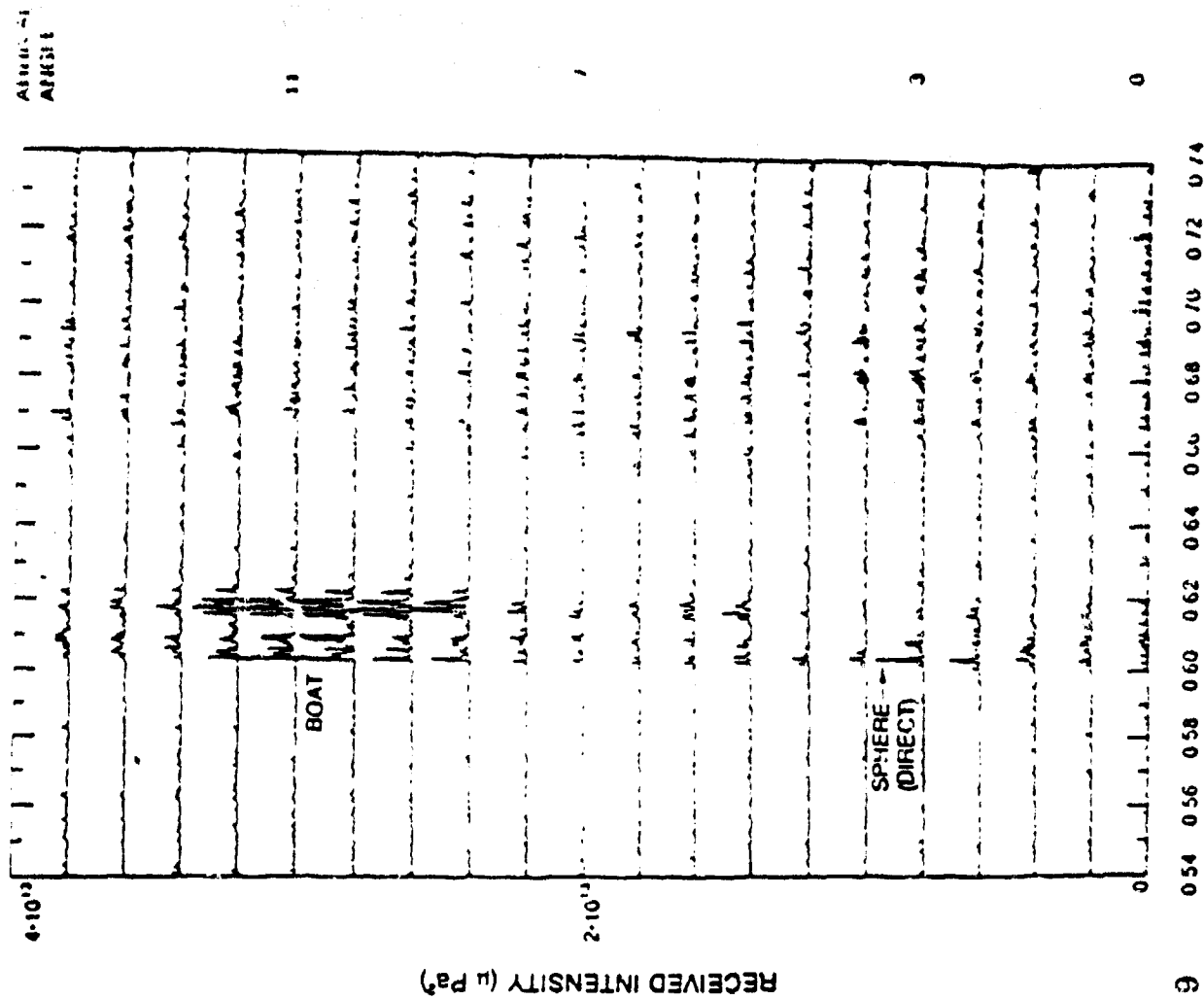
## ARRAY RESOLUTION

N = 8 HYDROPHONES, L = 10 m,  $\Delta\omega = 5$  kHz

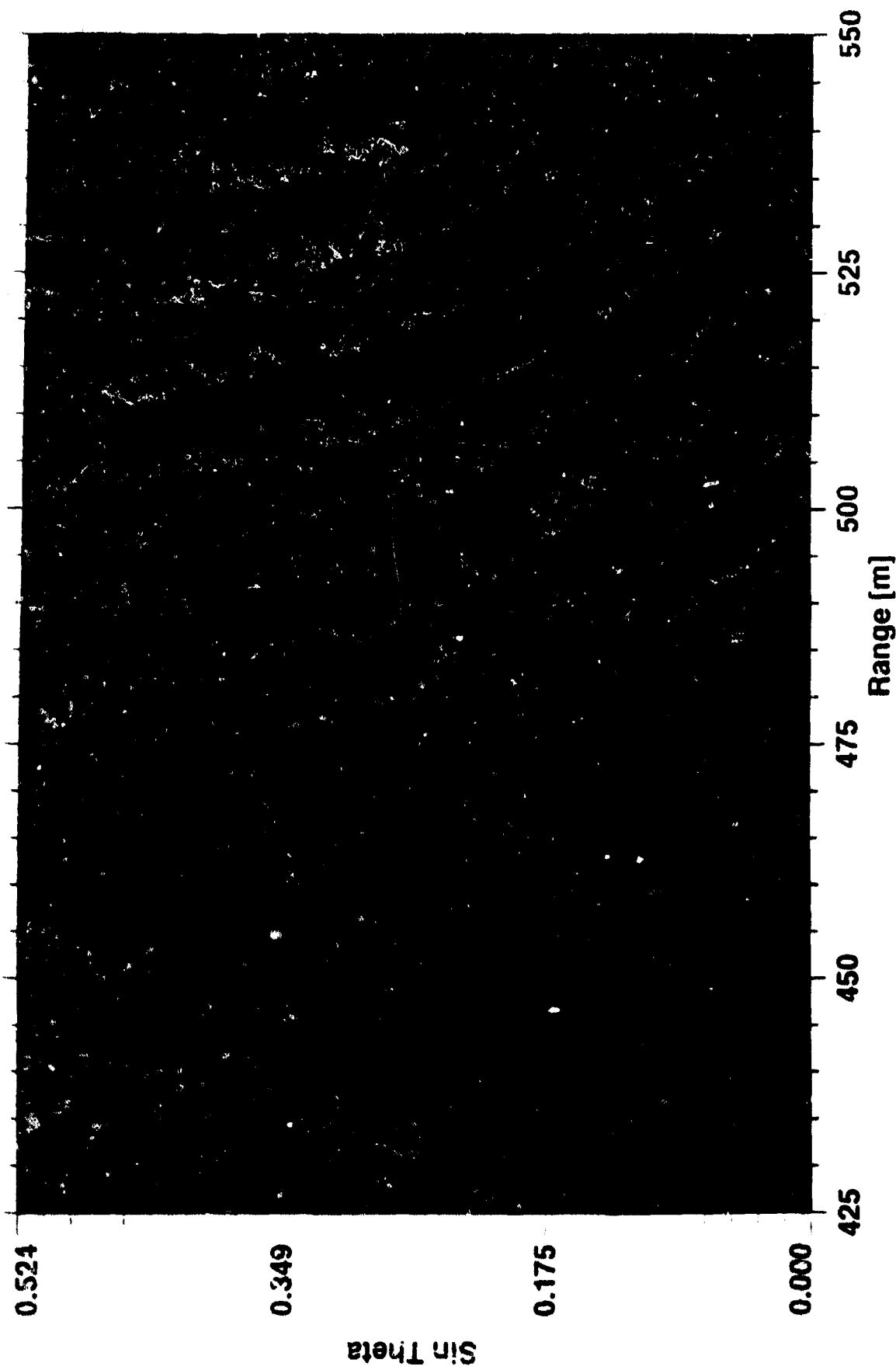
NARROW BAND:  $\Delta L = 14^\circ$

BROADBAND:  $\sqrt{2} \frac{c}{L \Delta\omega} = 2.4^\circ$

## TIME ANGLE ARRIVAL STRUCTURE



# Spectral Color Imaging



## NARROW BAND VS. BROADBAND DETECTION

### Relevant Parameters

noise (all non-target fluctuations) PSD:	$P_n(\omega)$
signal ESD:	$E(\omega)$
signal spread:	$T$

### Narrowband

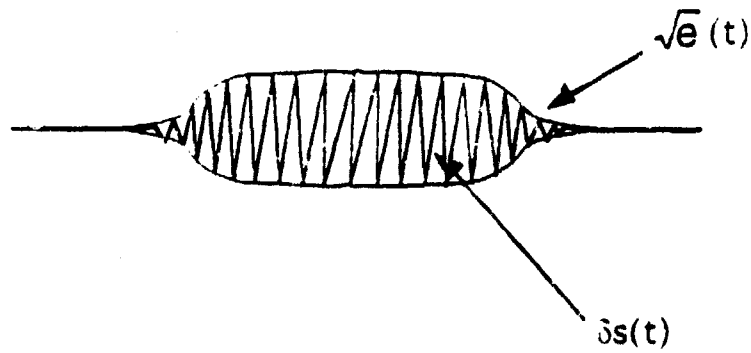
- No signal spread  $\Rightarrow \Delta\omega T = 1$
- intuitively SNR is ratio of powers

$$\text{SNR} = \frac{2P_s \Delta\omega}{2P_n \Delta\omega} = \frac{E \Delta\omega}{T P_n \Delta\omega} = \frac{E \Delta\omega}{P_n}$$

### Broadband

- Parameters vary with frequency so that optimal combination of frequencies is an issue.
- $\Delta\omega T > 1$  due to target spread, so this must be factored into performance.

## SIGNAL MODEL



Signal :  $s(t) = \sqrt{e}(t - a)\delta s(t)$

$\delta s(t)$  - colored Gaussian process with known PSD  $P_s(\omega)$

$e(t)$  - deterministic "slowly varying" signal energy envelope

$a$  - unknown signal position

## OPTIMAL BROADBAND "ENERGY" DETECTOR

Likelihood ratio test on measurement  $m(t)$  leads to the following optimal energy detector:

a weighted square-law detector:

$$d(a) = \int_{-\infty}^{\infty} m_f^2(t) e^{t-a} dt$$

with the linear filter:

$$m_f(t) = \int \frac{M(\omega)}{P_n^{1/2}} \left( \frac{P_s}{P_s + P_n} \right)^{1/2} e^{i2\pi\omega t} d\omega$$

$$M(\omega) = \int m(t) e^{-i2\pi\omega t} dt$$

$P_n$  = noise PSD ,  $P_s$  = signal PSD

The filter power transfer function is

$$|H|^2 = \frac{1}{P_n} \cdot \frac{P_s}{P_s + P_n}$$

NOISE WHITENER                      OPTIMAL FREQUENCY WEIGHTING

## SNR FOR THE OPTIMAL DETECTOR

Standard detector power SNR is  $\frac{d_{s+n} - d_n}{\text{var}(d_n)}$ .

This can be expressed exactly as

$$\text{SNR}_E = \frac{1}{2T} \frac{\left( \int \frac{E^2(\omega)}{P_n(P_s + P_n)} d\omega \right)^2}{\int \left( \frac{E(\omega)}{P_s + P_n} \right)^2 d\omega}$$

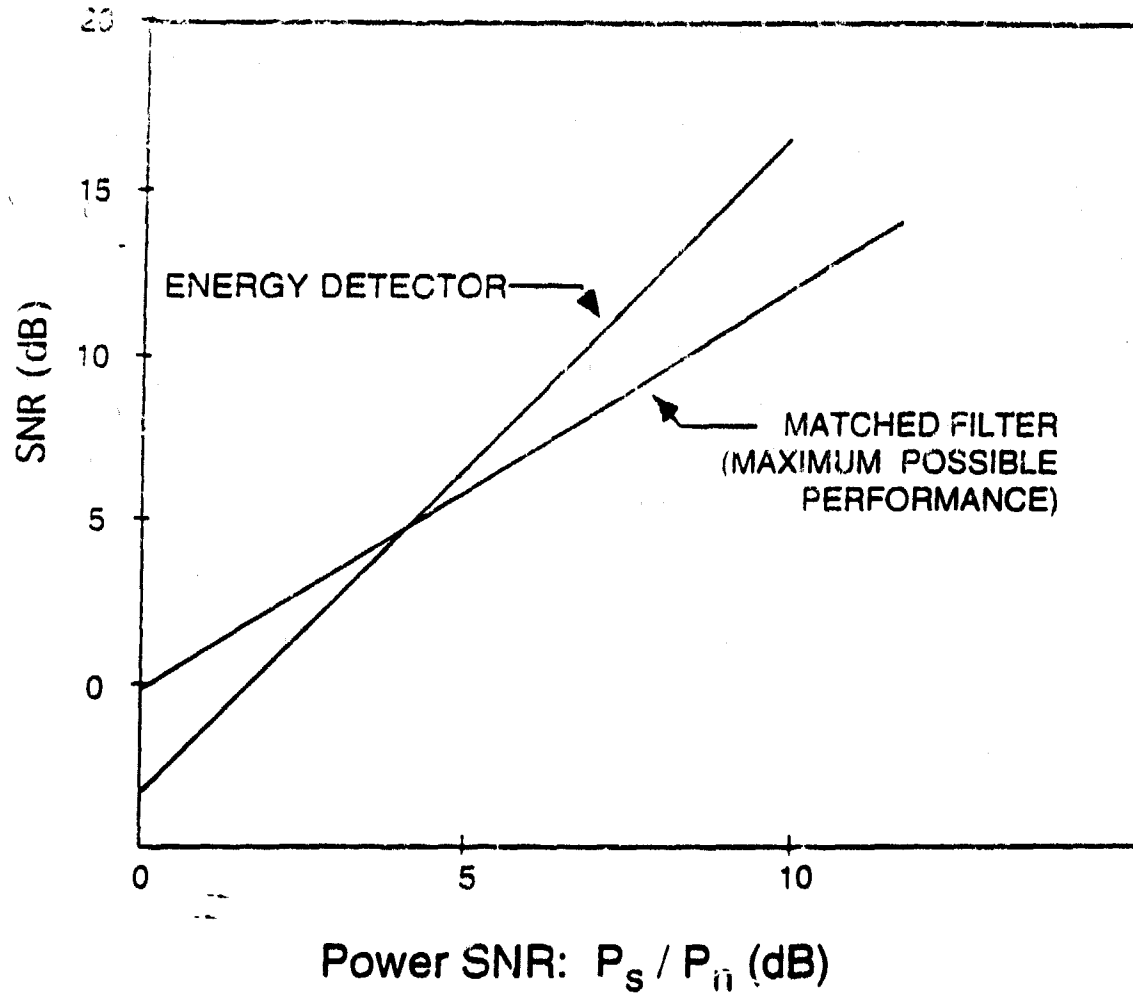
where

$$T = \frac{(\int e dt)^2}{\int e^2 dt} \quad P_s = \frac{E}{T}$$

for small signal power, and small bandwidth

$$\text{SNR}_E \rightarrow T \Delta\omega \left( \frac{P_s}{P_n} \right)^2$$

The usual result for energy detection (e.g. Urick case II).

**DETECTOR SNR VS. POWER SNR**

⇒ energy detector SNR poor measure of performance for  $P_s / P_n \geq 0$  dB.

## FIGURE OF MERIT

- A figure of merit must be interpretable in terms of ROC performance.

- A useful bound is:

$$\text{for } P_D \equiv 1/2, \quad P_{FA} \leq e^{-\lambda_1} P_D$$

where  $\lambda_1 = \langle \log\text{-likelihood in signal and noise} \rangle$ .

- For the classical matched filter

$$\lambda_1 = 1/2 \text{ SNR}$$

therefore  $2\lambda_1$  is the appropriate SNR-like figure of merit.

- This can be expressed analytically

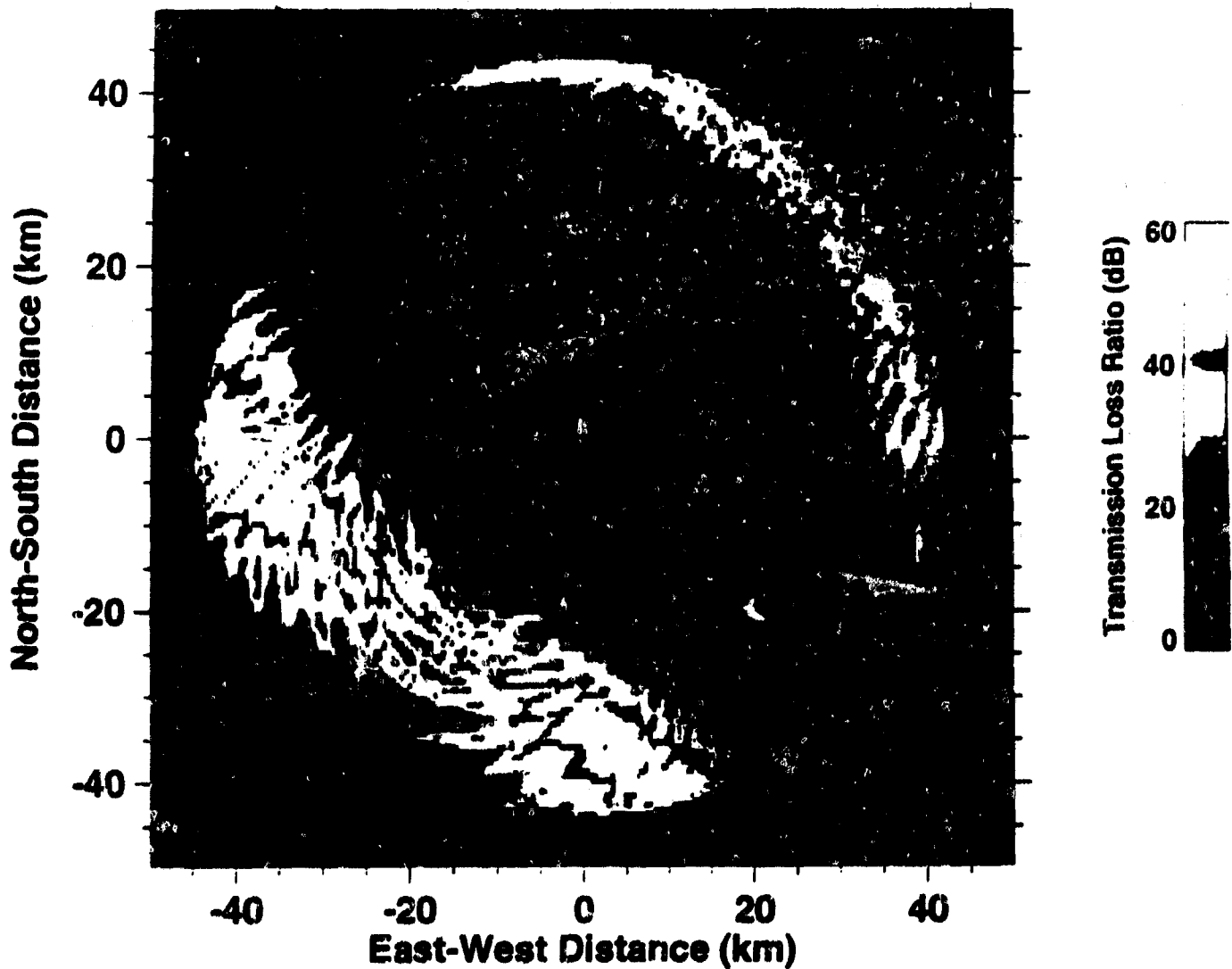
$$2\lambda_1 = T \int \left[ \frac{P_s}{P_n} - \log \left( 1 + \frac{P_s}{P_n} \right) \right] d\omega$$

where

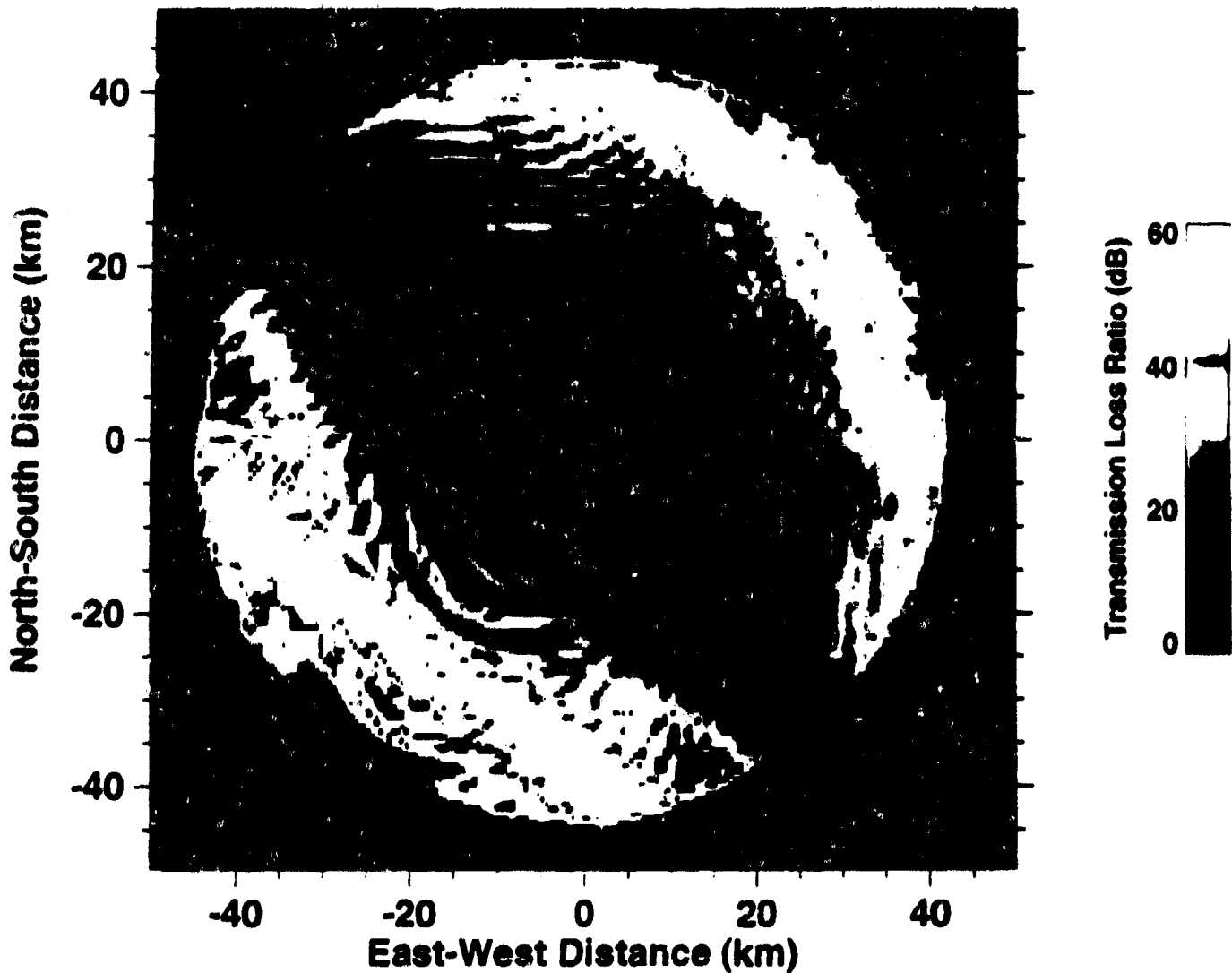
$$T = \frac{(\int e dt)^2}{\int e^2 dt} \quad P_s = \frac{E}{T}$$



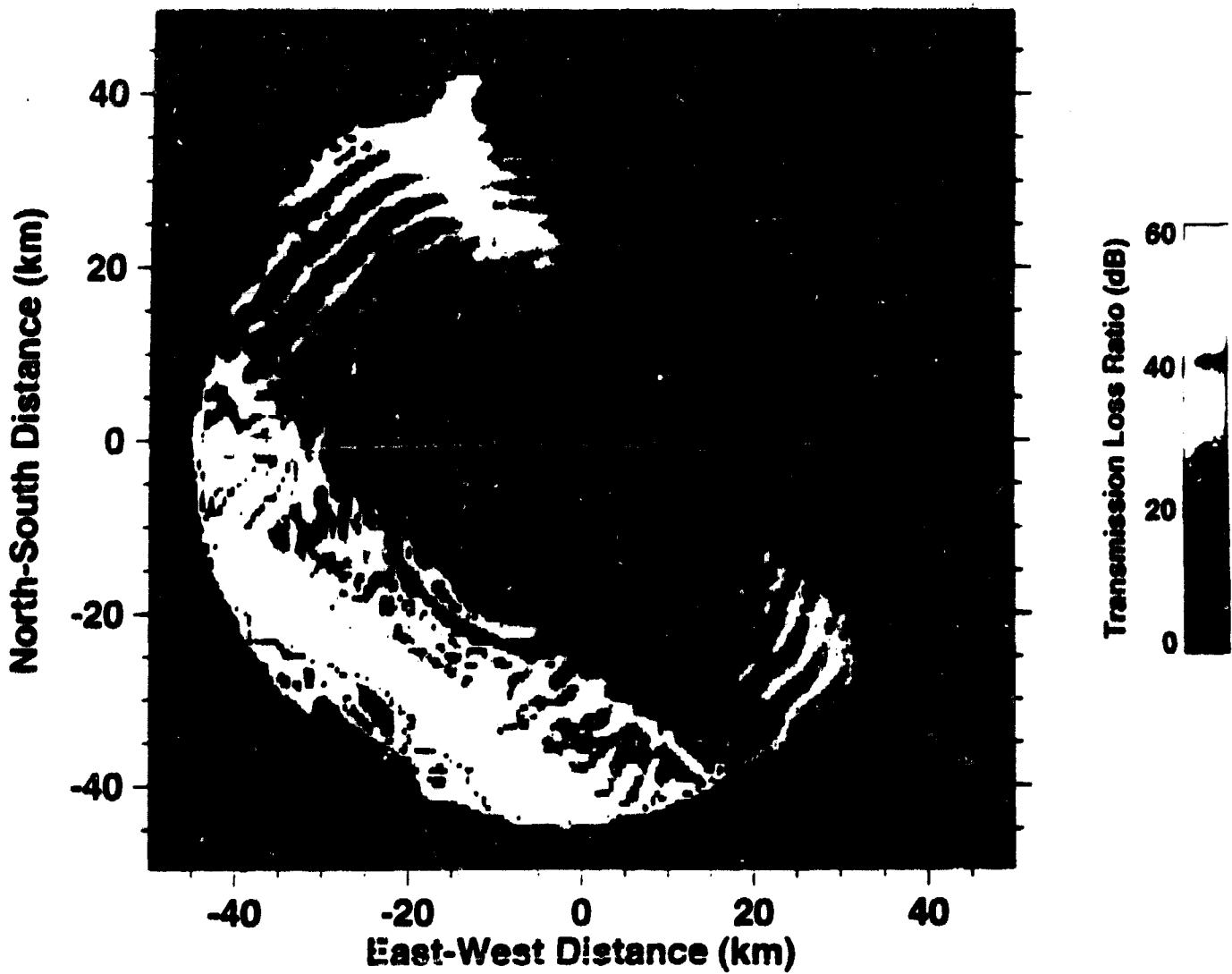
**ACT1 Simulation: Ratio of Target TL to Bottom TL**  
**200 Hz Omni Source, Bottomed Array**  
**20 m Target Depth**



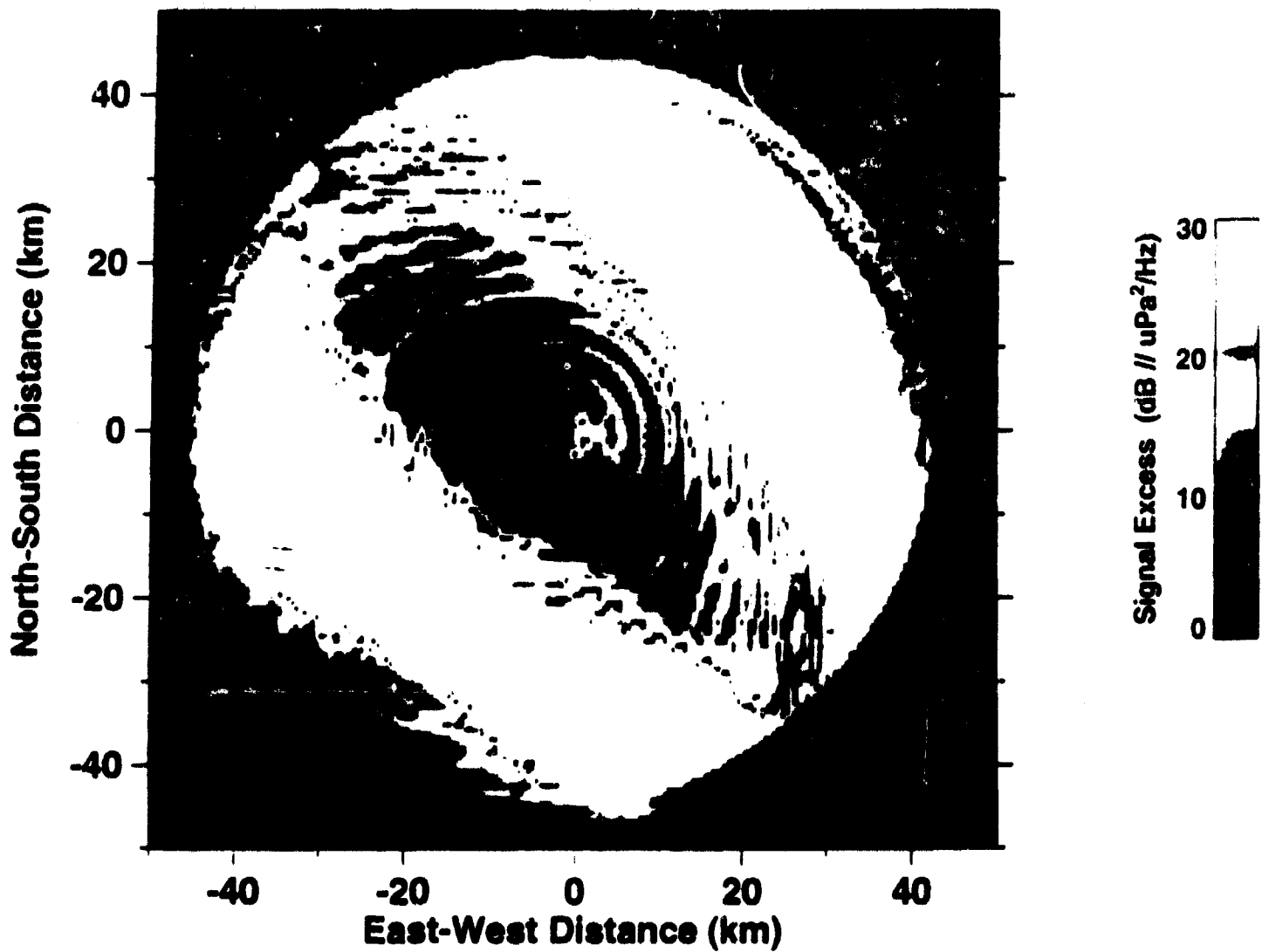
**ACT1 Simulation: Ratio of Target TL to Bottom TL**  
**200 Hz Omni Source, Bottomed Array**  
**40 m Target Depth**



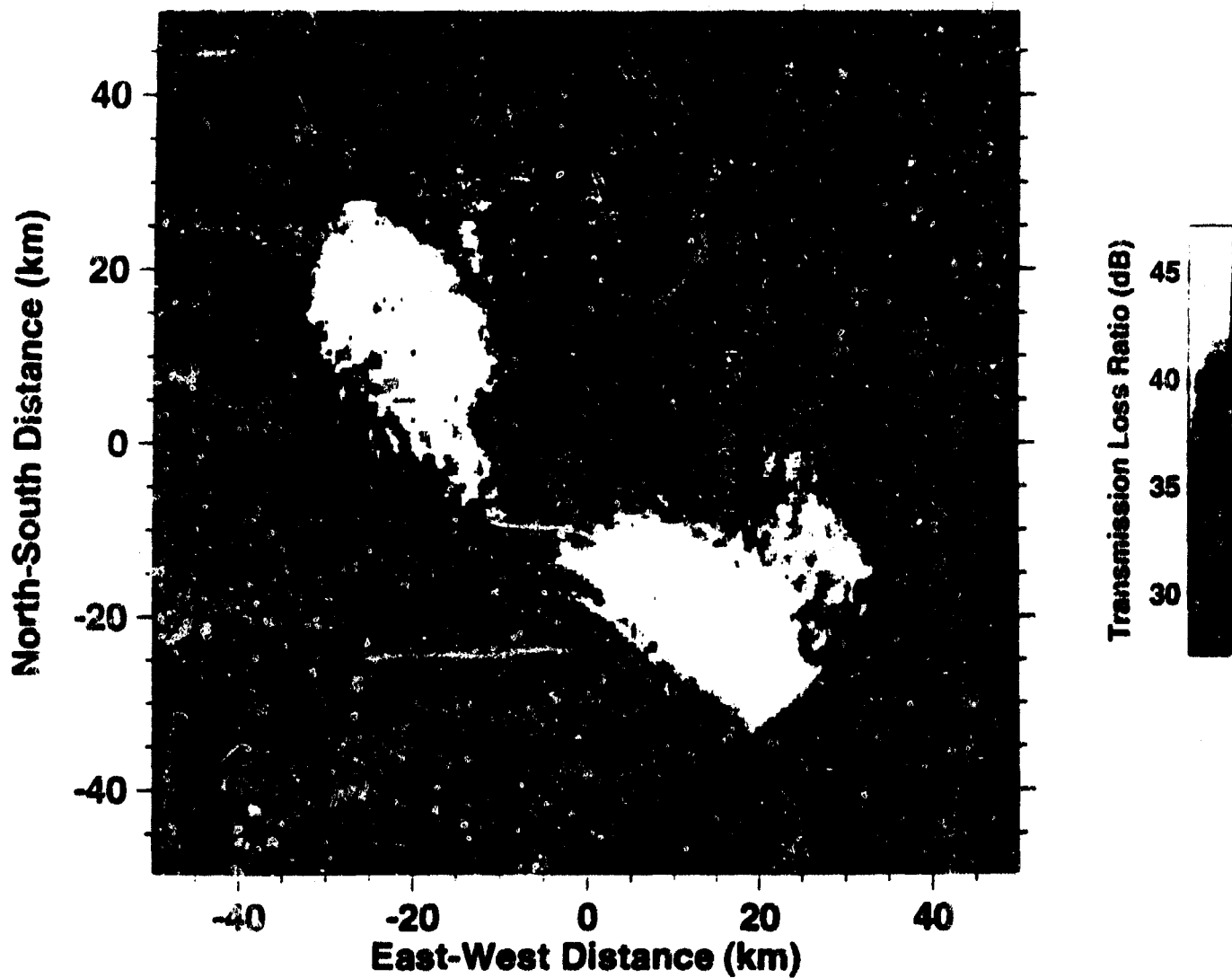
**ACT1 Simulation: Ratio of Target TL to Bottom TL**  
**200 Hz Omni Source, Bottomed Array**  
**80 m Target Depth**



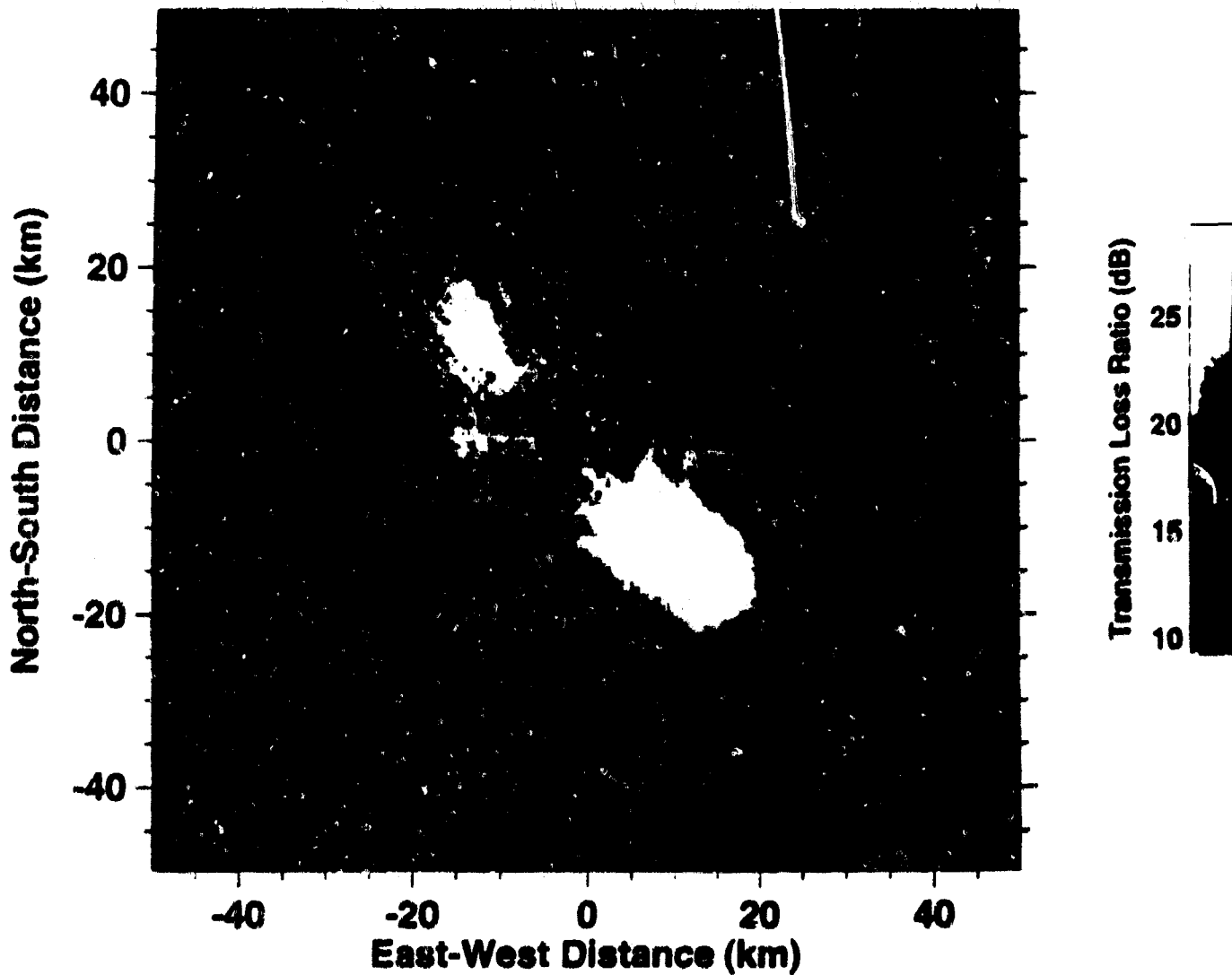
**ACT1 Figure of Merit Simulation  
Omni Source  
Target Depth=40 m, Target Strength=5 dB**



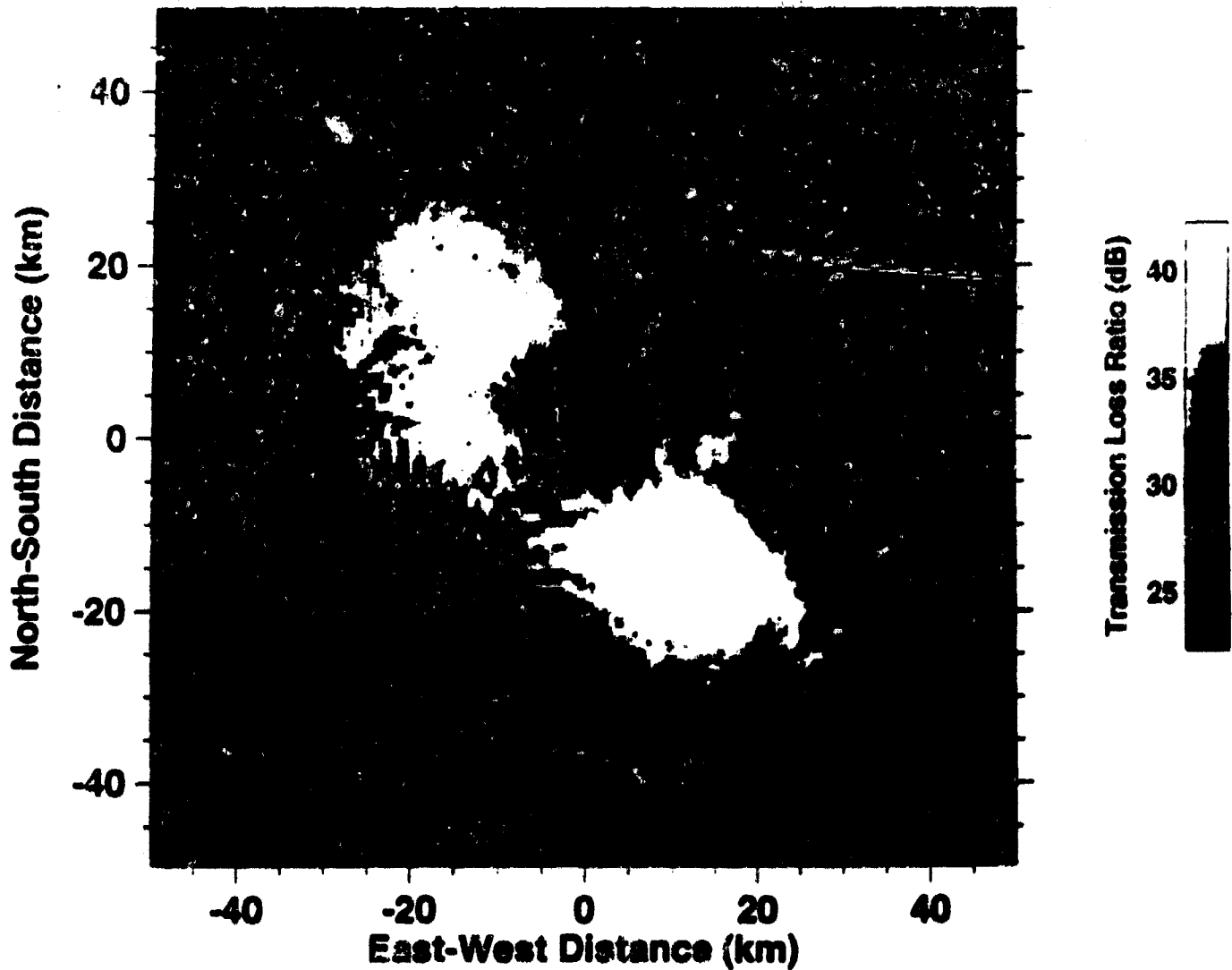
**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 50 Hz**  
**Includes Spherical Spreading Correction and Backscatter**



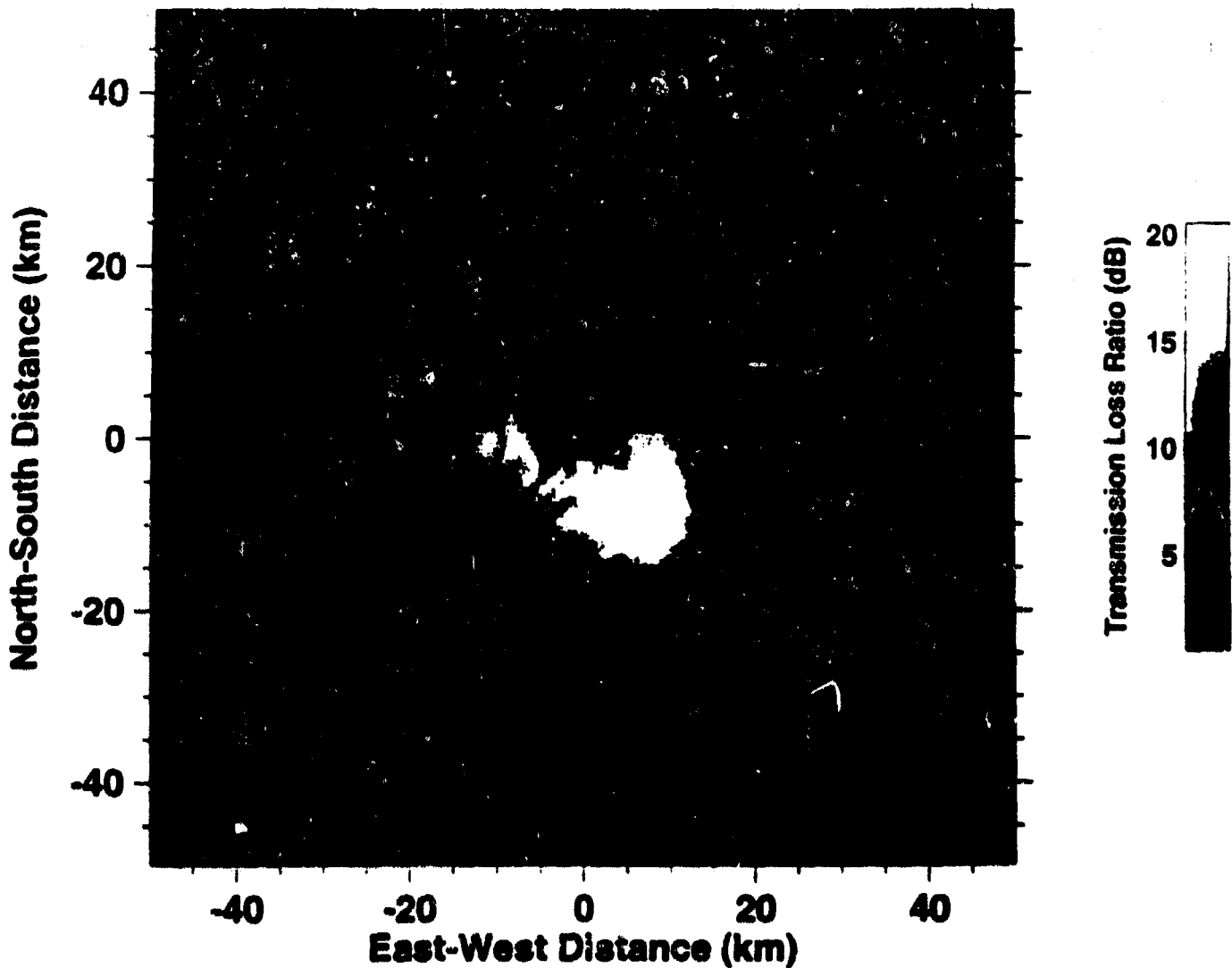
**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 200 Hz**  
**Includes Spherical Spreading Correction and Backscatter**



**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 100 Hz**  
**Includes Spherical Spreading Correction and Backscatter**

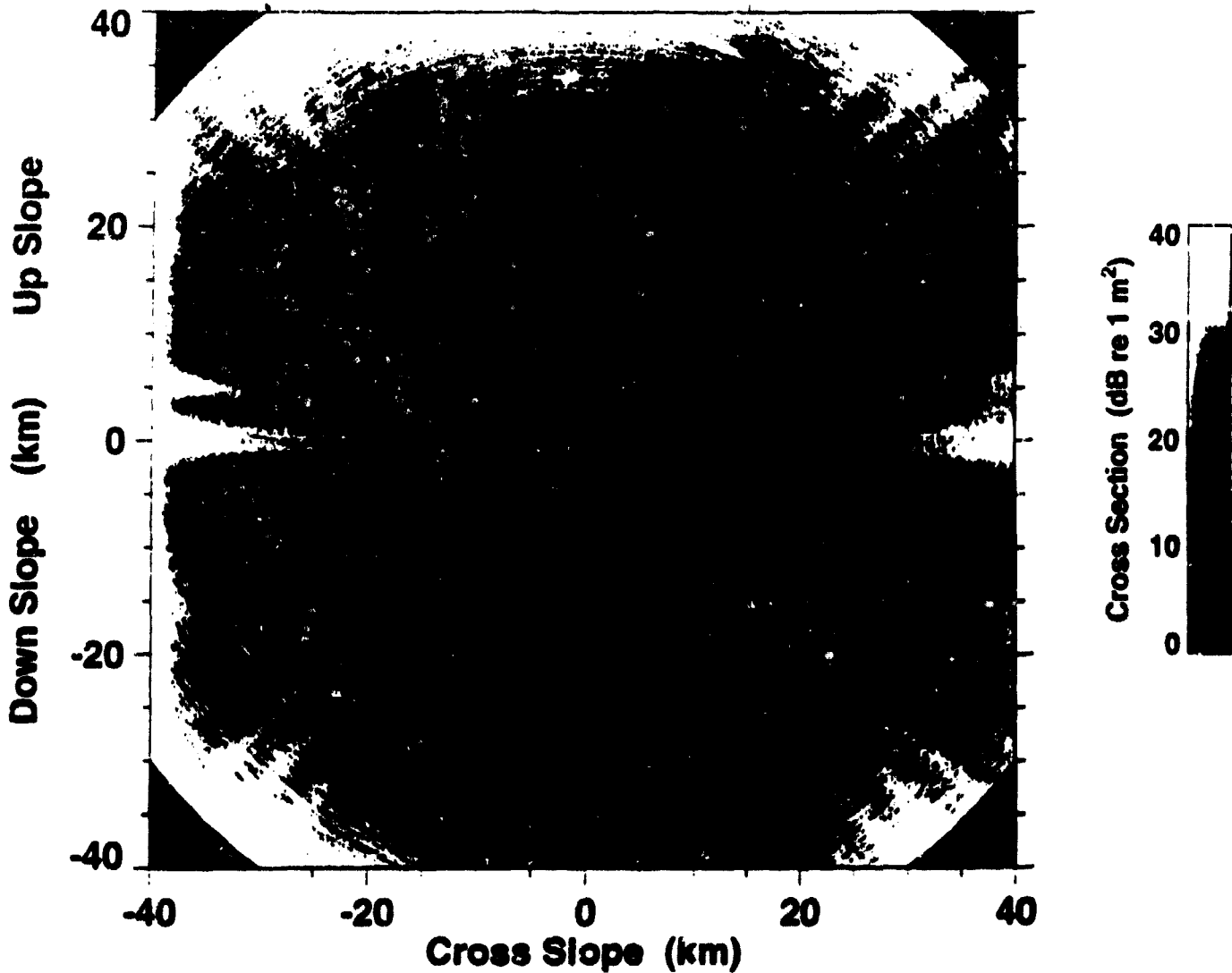


**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 400 Hz**  
**Includes Spherical Spreading Correction and Backscatter**

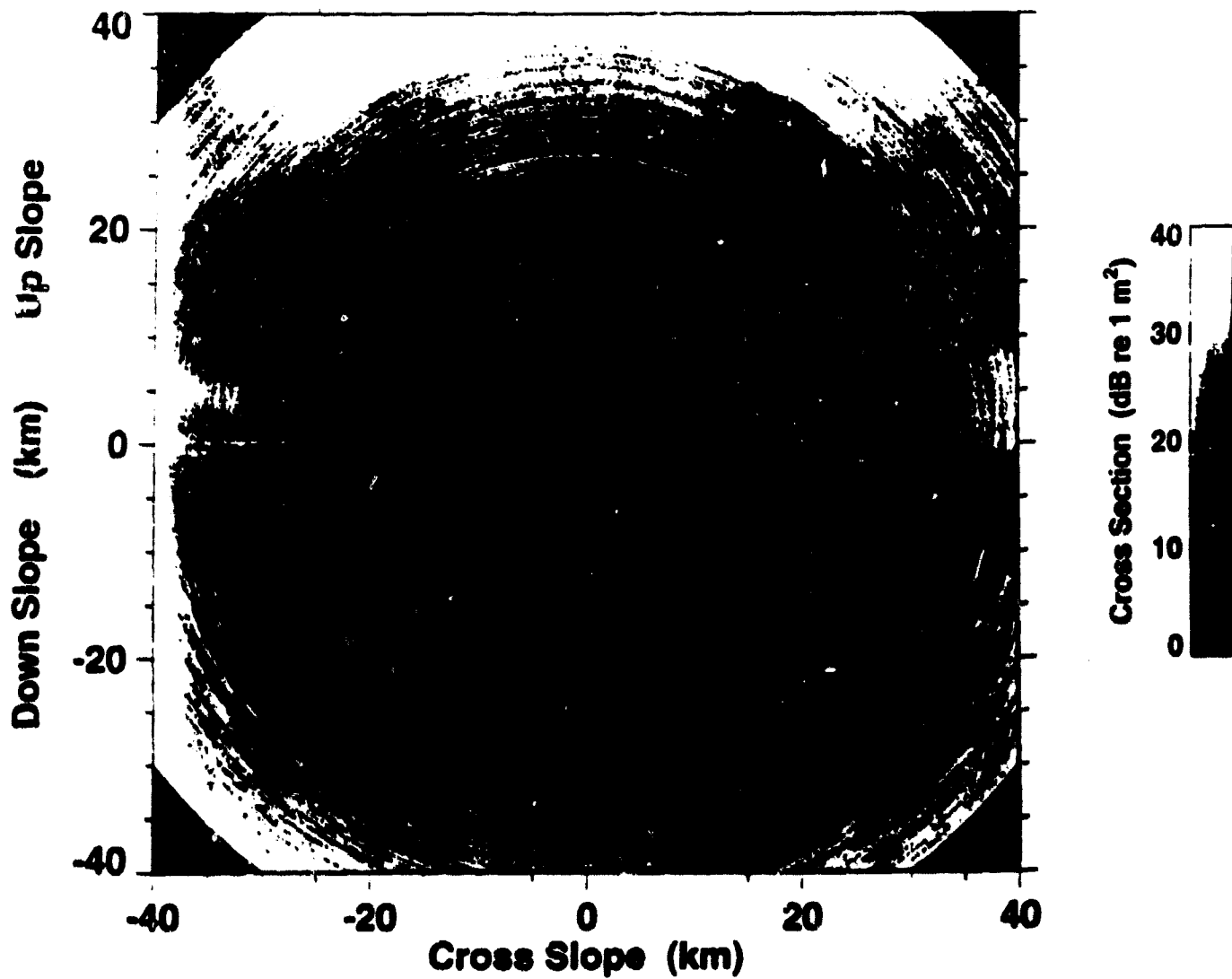




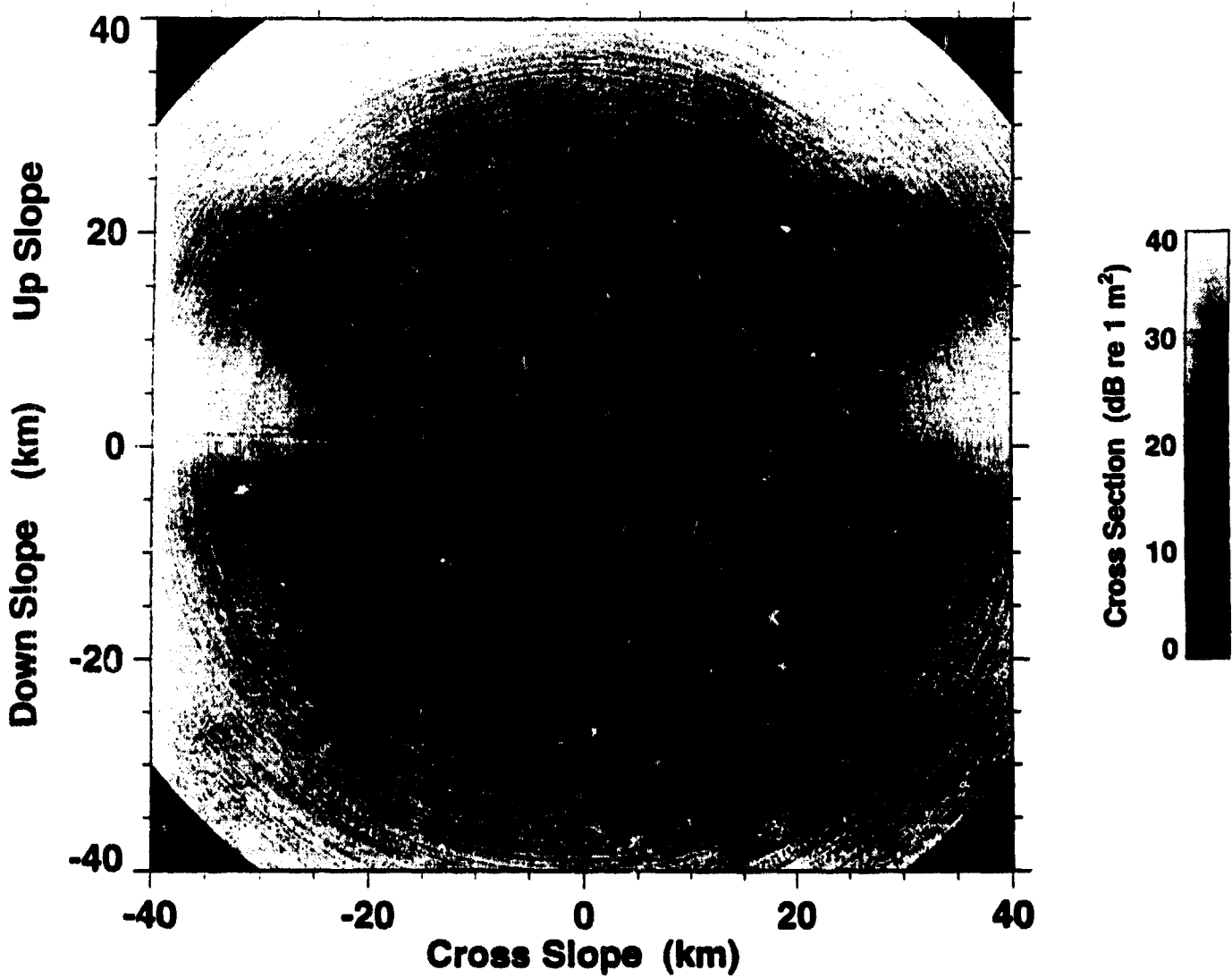
# ACT1, Event mr1h13, Omni Source, Bottomed Array 1 Octave Band Centered on 400 Hz



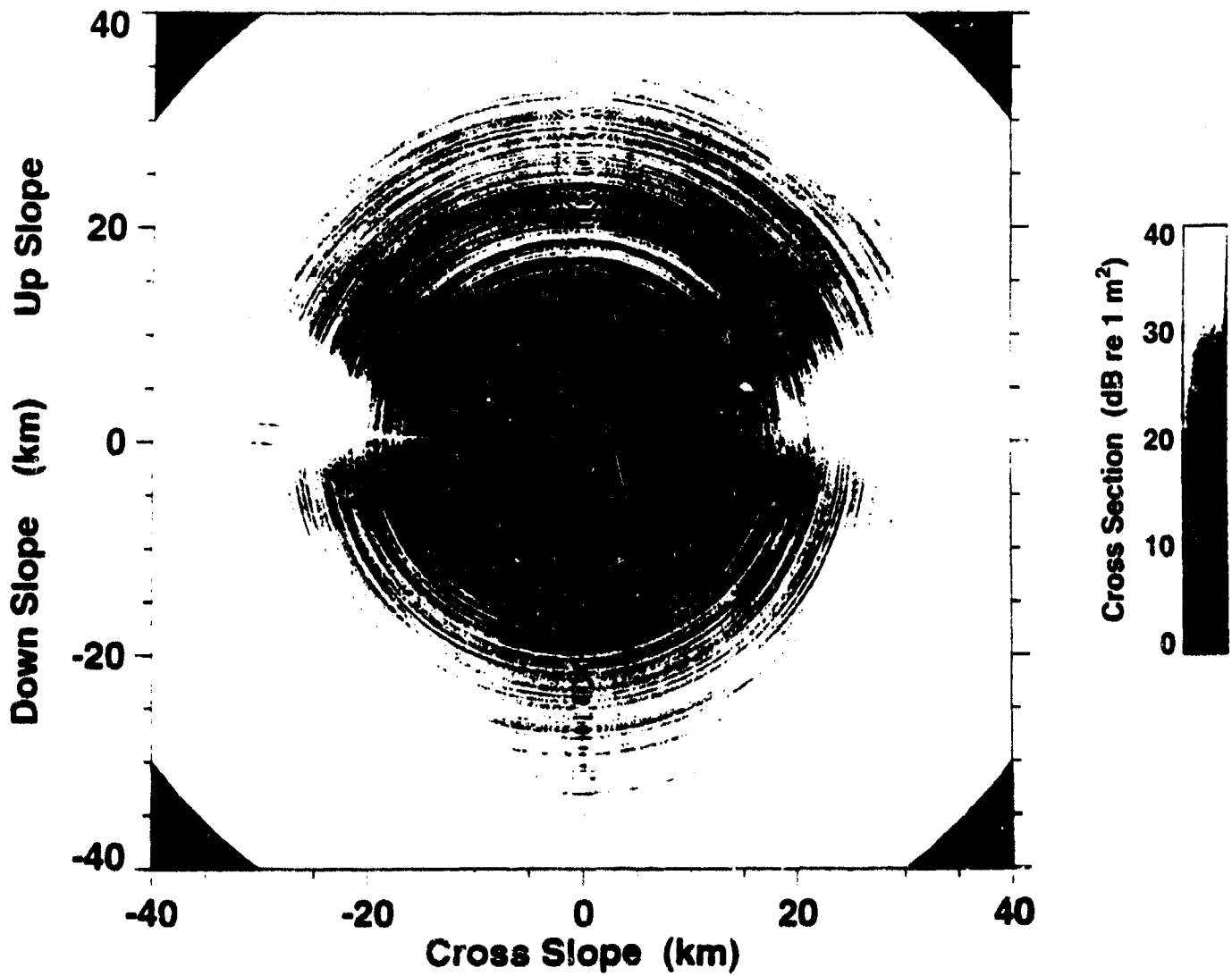
# ACT1, Event mr1h13, Omni Source, Bottomed Array 1 Octave Band Centered on 200 Hz



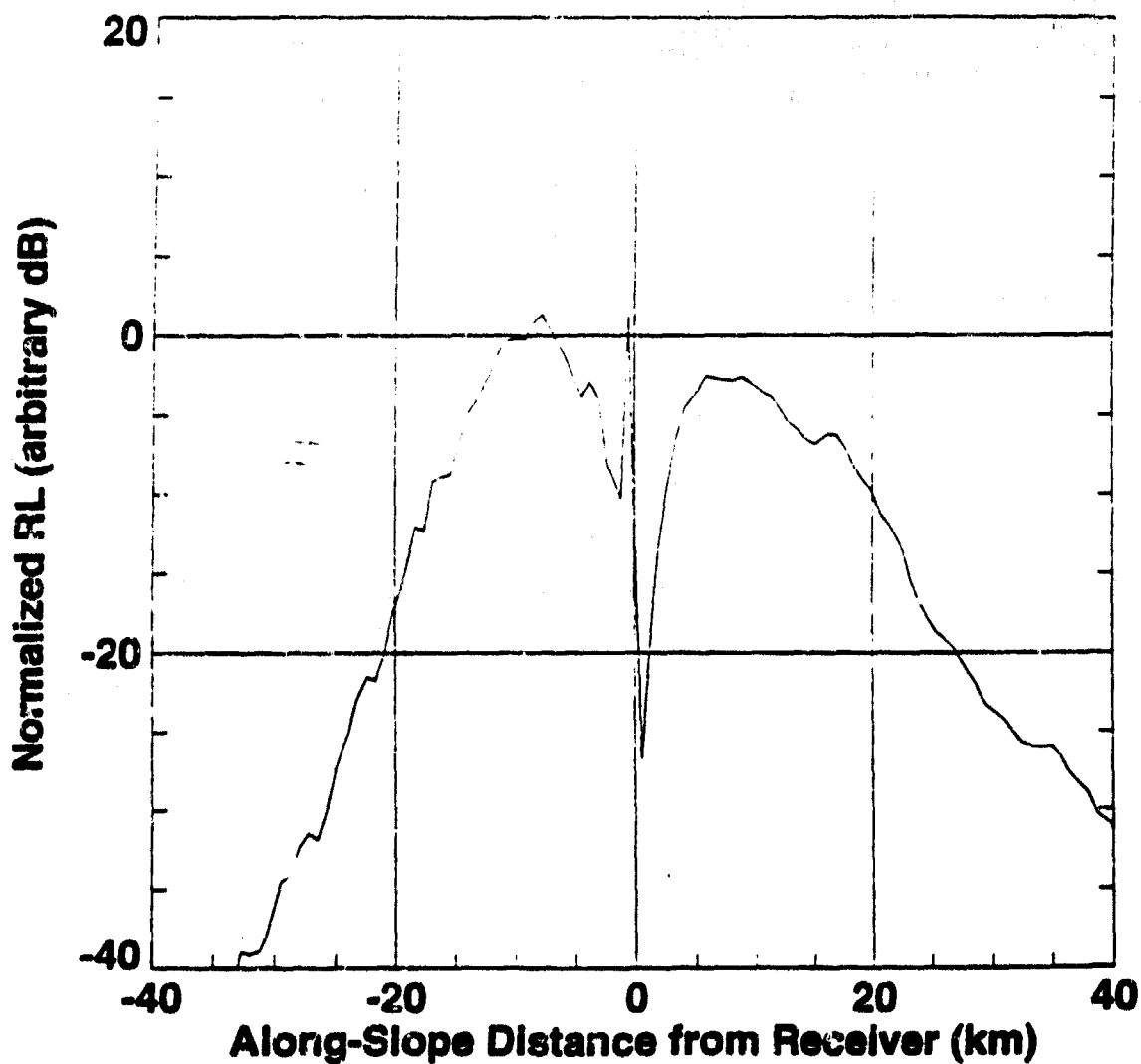
# ACT1, Event mr1h13, Omni Source, Bottomed Array 1 Octave Band Centered on 100 Hz



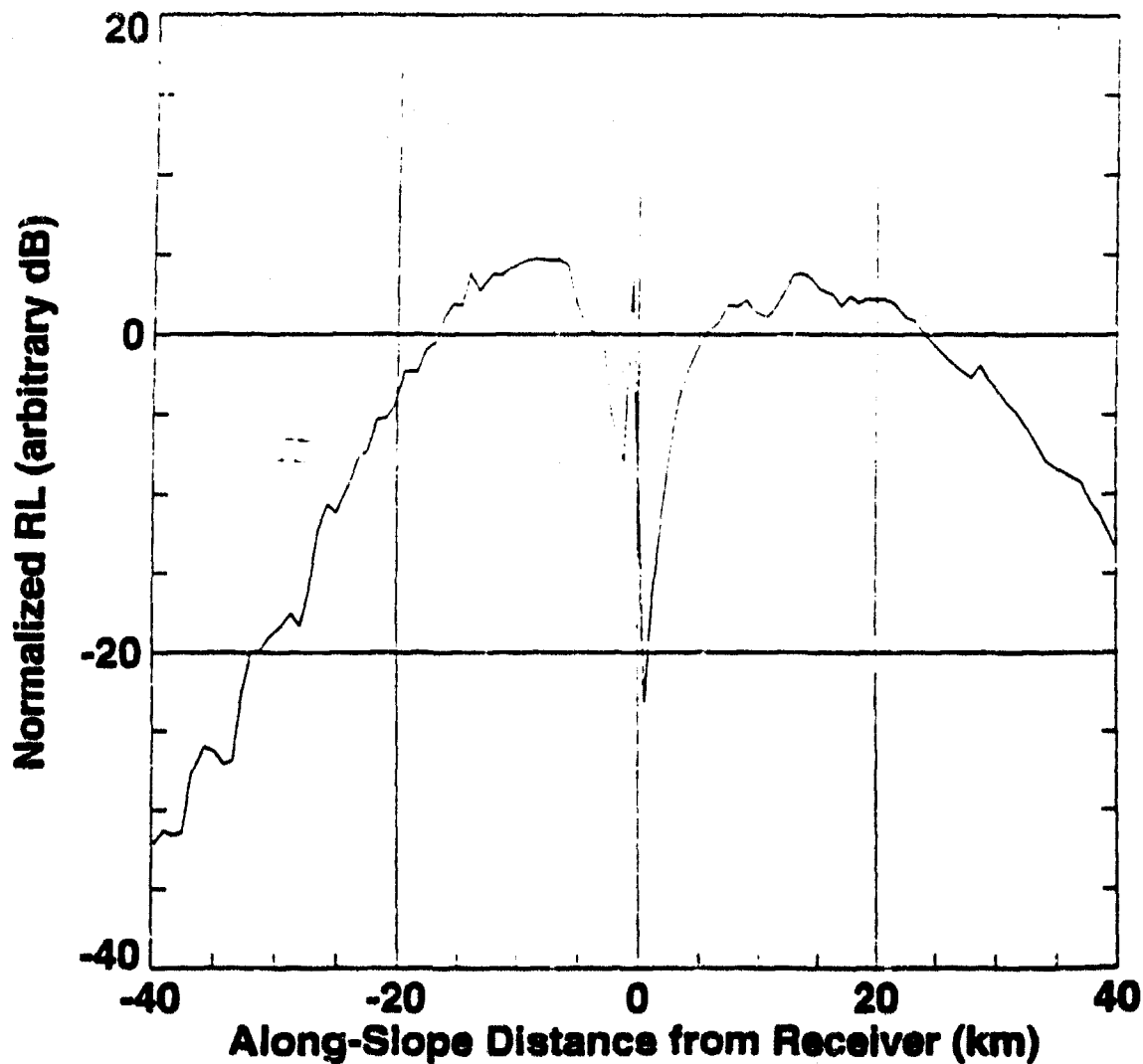
# ACT1, Event mr1h13, Omni Source, Bottomed Array 1 Octave Band Centered on 50 Hz



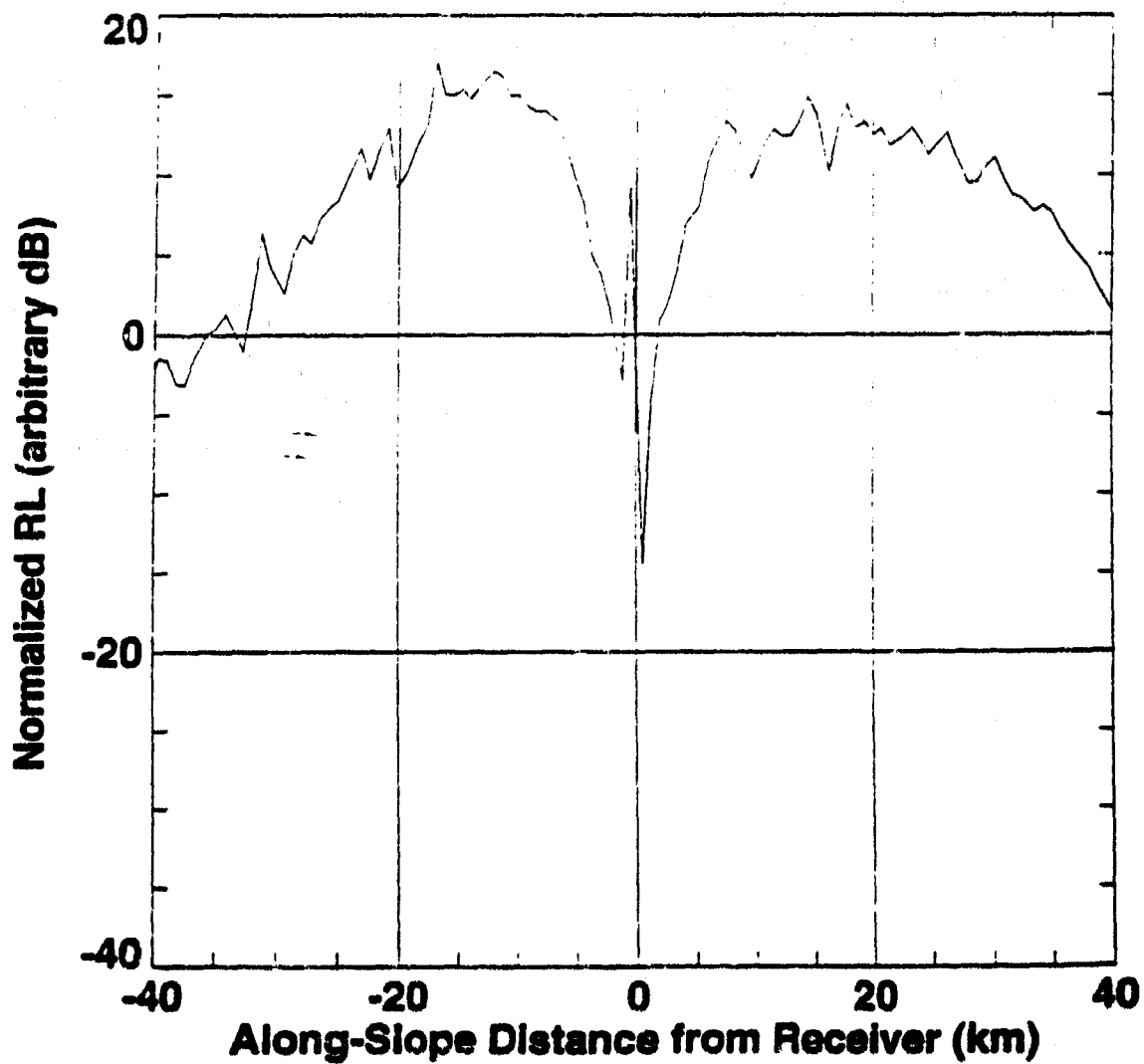
**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 400 Hz**  
**Includes Spherical Spreading Correction and Backscatter**



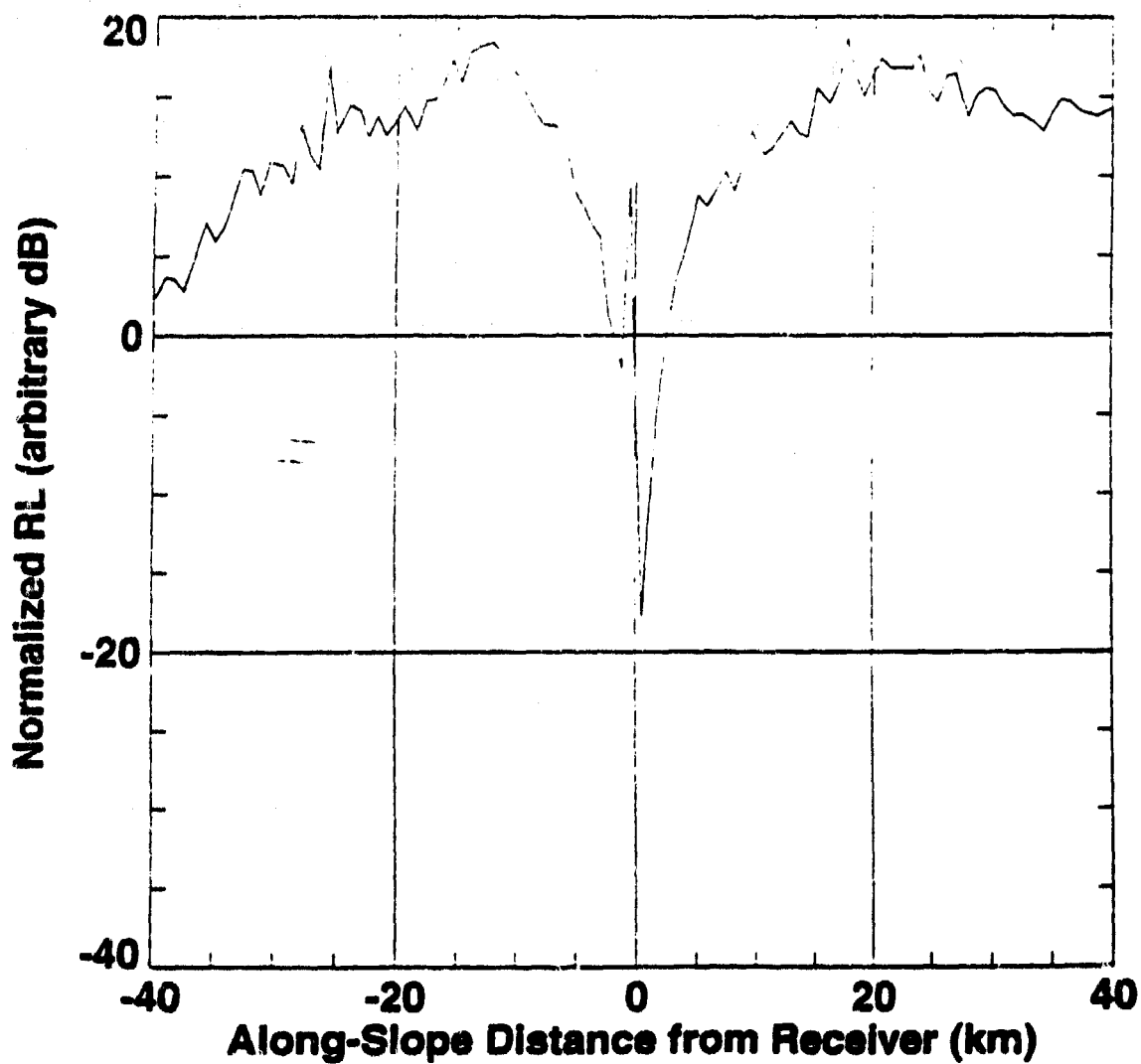
**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 200 Hz**  
**Includes Spherical Spreading Correction and Backscatter**



**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 100 Hz**  
**Includes Spherical Spreading Correction and Backscatter**

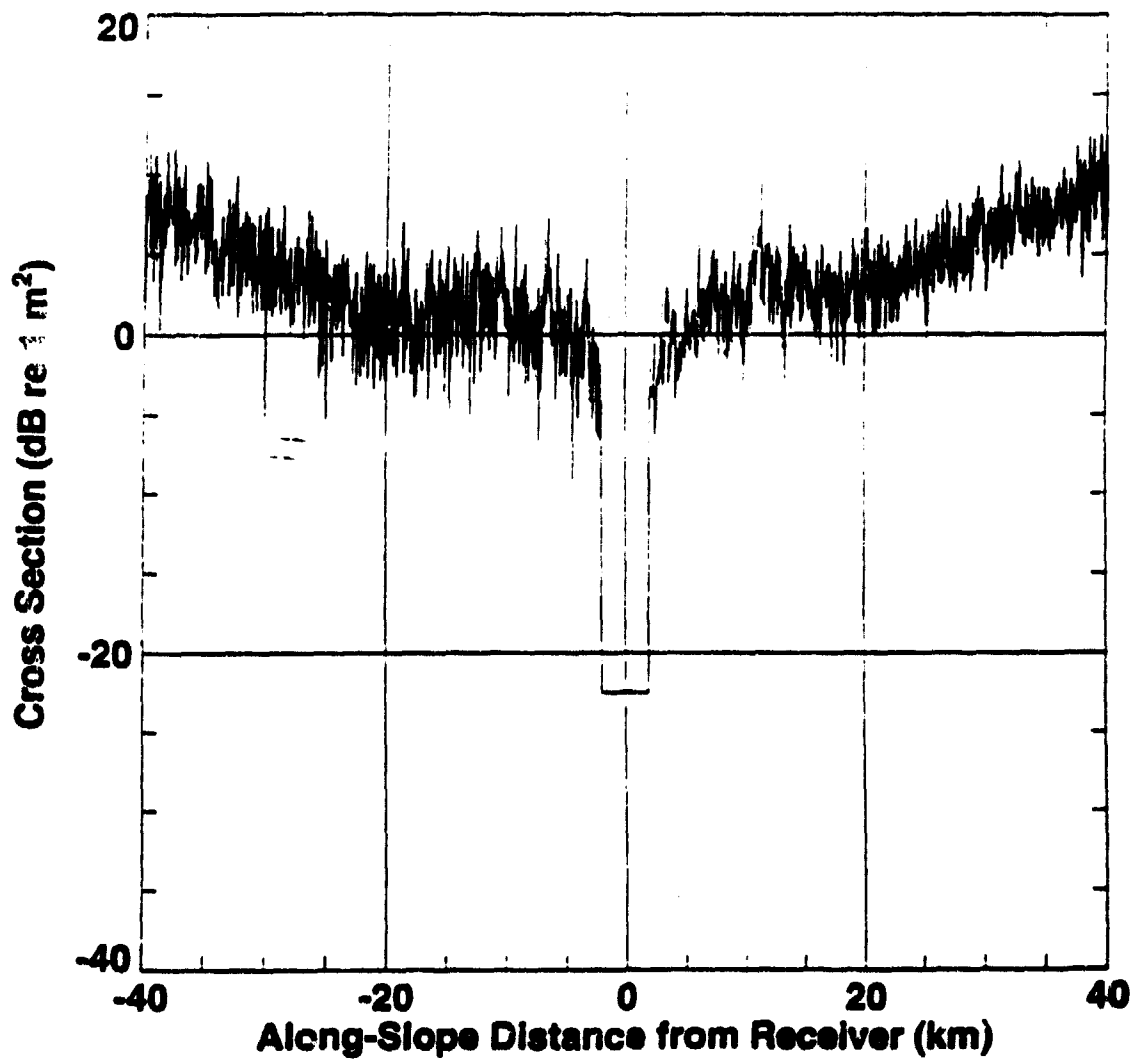


**ACT1 Bottom Reverberation Level Simulation**  
**Omni Source, Bottomed Array, 50 Hz**  
**Includes Spherical Spreading Correction and Backscatter**

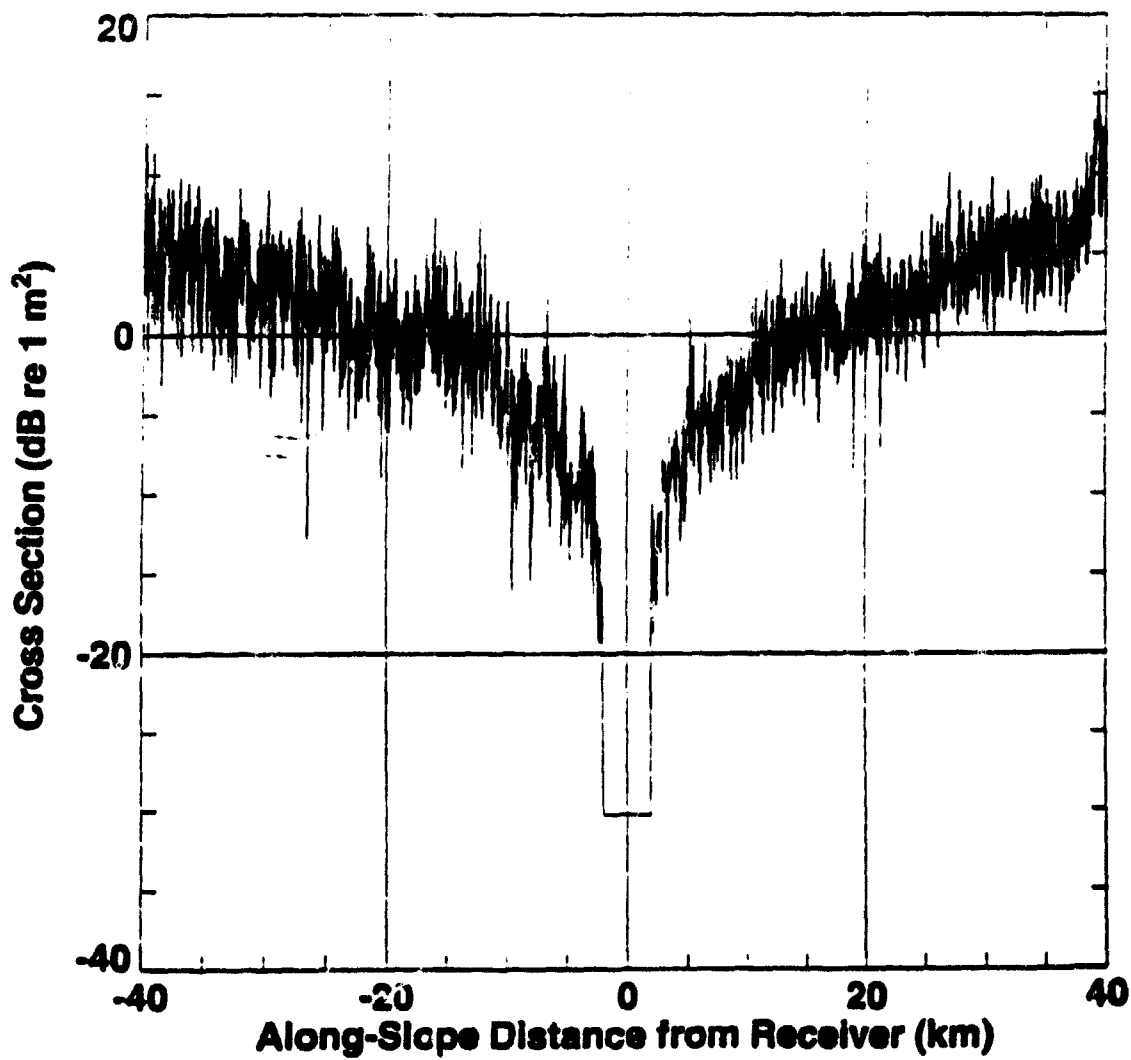




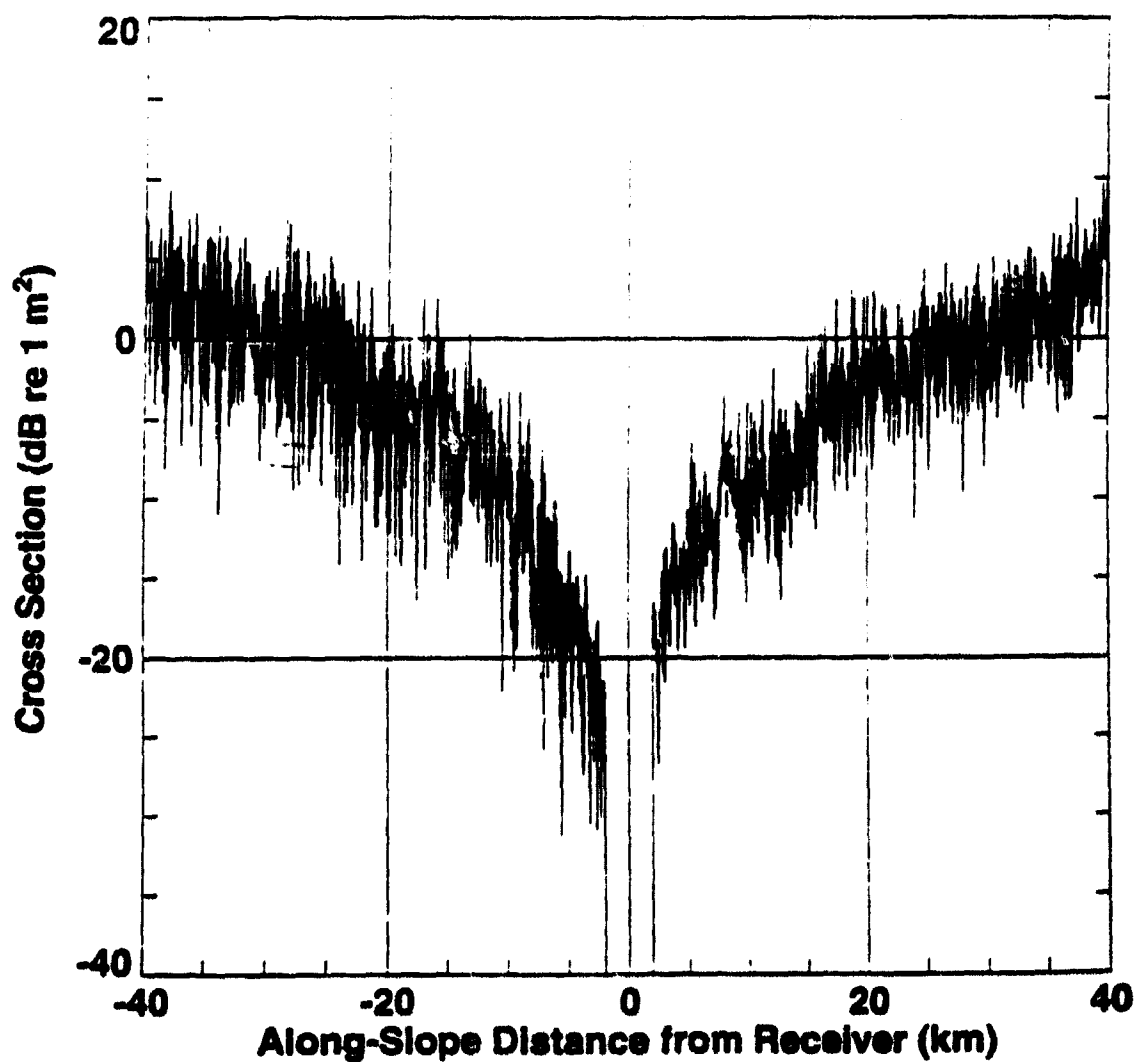
**ACT1, Event mr1h13, Omni Source, Bottomed Array**  
**1 Octave Band Centered on 400 Hz**  
**Cut Through Image Along Slope**



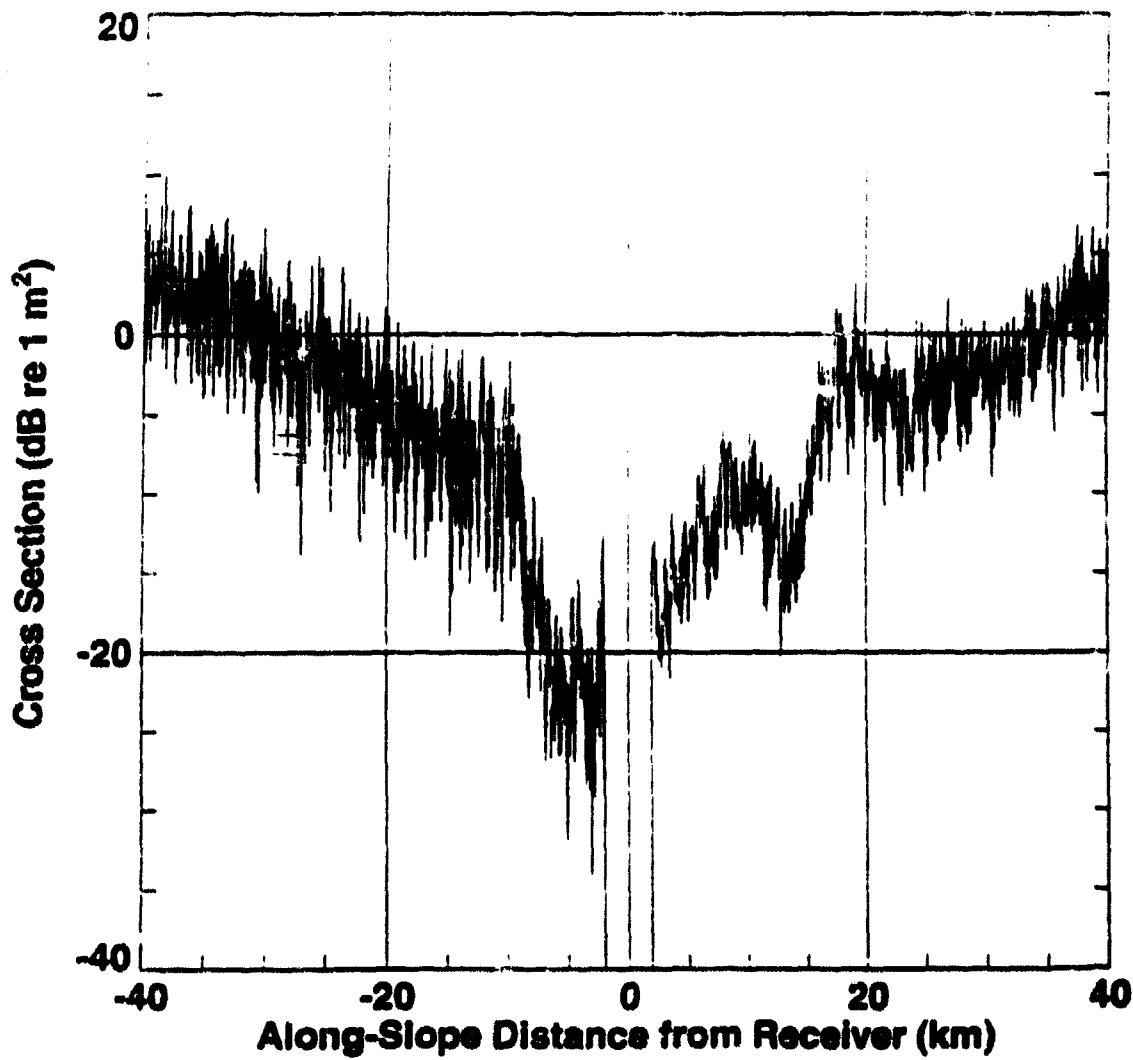
**ACT1, Event mr1h13, Omni Source, Bottomed Array**  
**1 Octave Band Centered on 200 Hz**  
**Cut Through Image Along Slope**



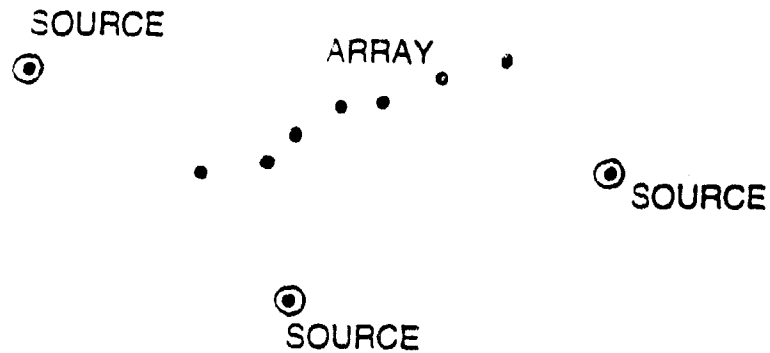
**ACT1, Event mr1h13, Omni Source, Bottomed Array**  
**1 Octave Band Centered on 100 Hz**  
**Cut Through Image Along Slope**



**ACT1, Event mr1h13, Omni Source, Bottomed Array**  
**1 Octave Band Centered on 50 Hz**  
**Cut Through Image Along Slope**



## AUTO-COHERENCE WITH NEAR FIELD POINT SOURCES OF UNCERTAIN LOCATION



N phones

$\Rightarrow 2N + 2M$  unknowns

M sources

MN measured arrival times

For  $M \geq 3$ ,  $N$  large, there are many more measurements than unknowns

/ This can be solved in principal for all relative positions.

## AUTO-COHERENCE WITH NEAR FIELD POINT SOURCES OF UNCERTAIN LOCATION (continued)

- / The obvious least error minimization approach is intractable:
  - a 12<sup>th</sup> degree expression must be minimized in  $(2N + 2M)$  dimensions.
- / A unique reduced expression has been derived which is 6<sup>th</sup> degree in 5 unknowns.
- / An algorithm has been developed and tested exploiting this expression which works with modest computational requirements.

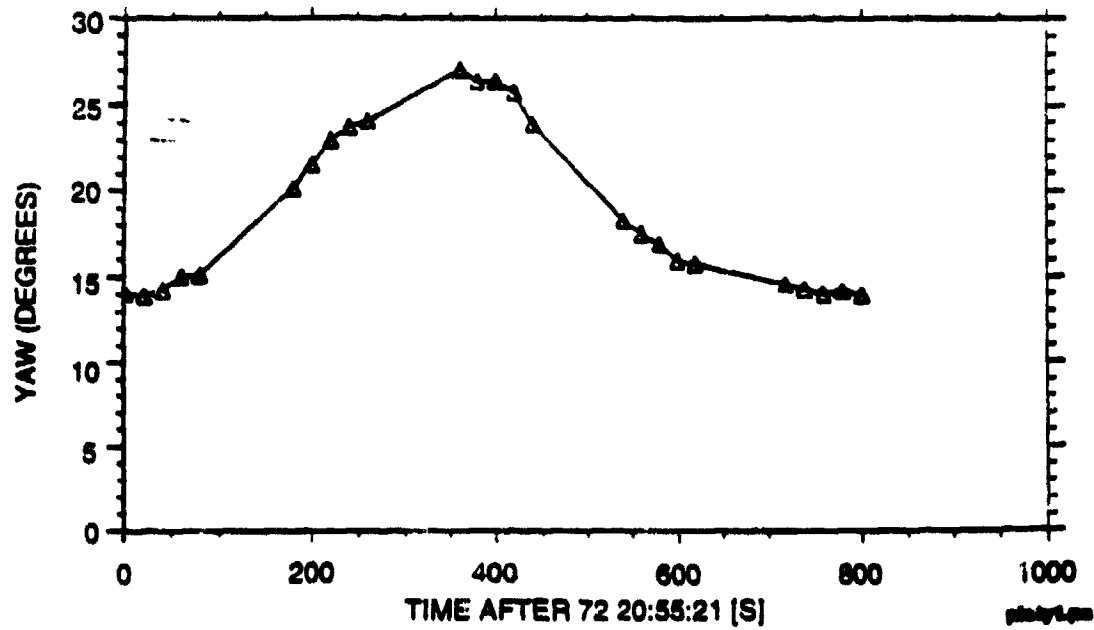
For ACT 1 (3 sources, 25 phones)

Computer	Run Time
HP 9000/735	~ 20 minutes
SPARC Station 2	~ 6 hours

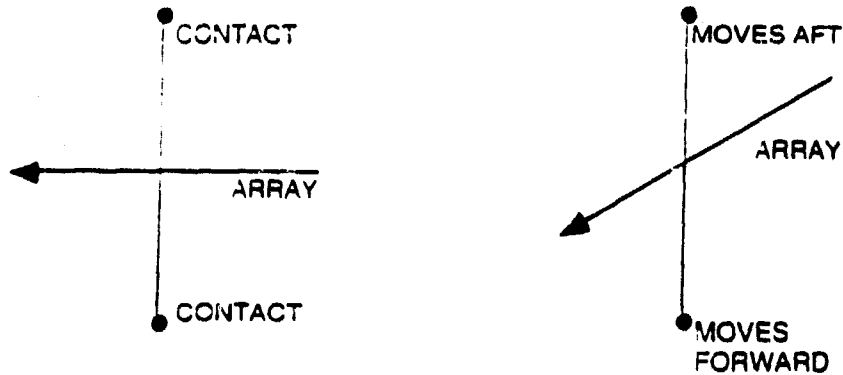
## ARRAY YAW MEASURED DURING ARPA PHASE OF CST 7



- / Limited sensitivity
- / Cannot separate vertical and horizontal



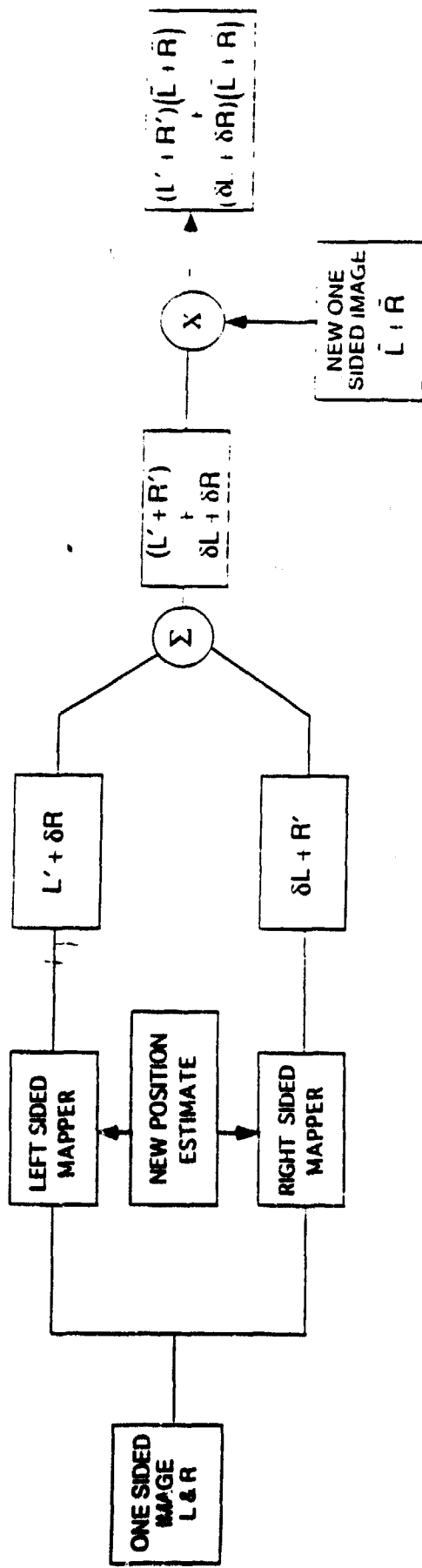
## ARRAY MOTION AND ITS EXPLOITATION



- This can cause many apparent moving contacts if not accounted for.
- This distortion can in principle provide
  - / Actual array motion
  - / Unambiguous and stationary left-right views.



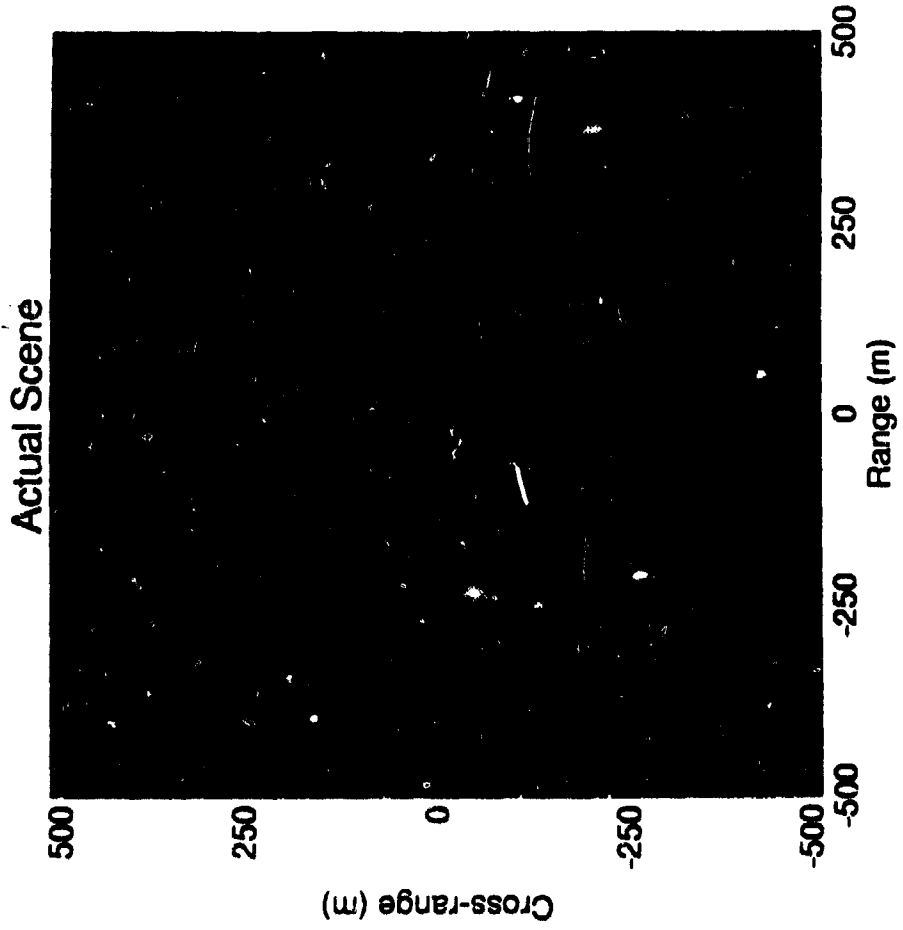
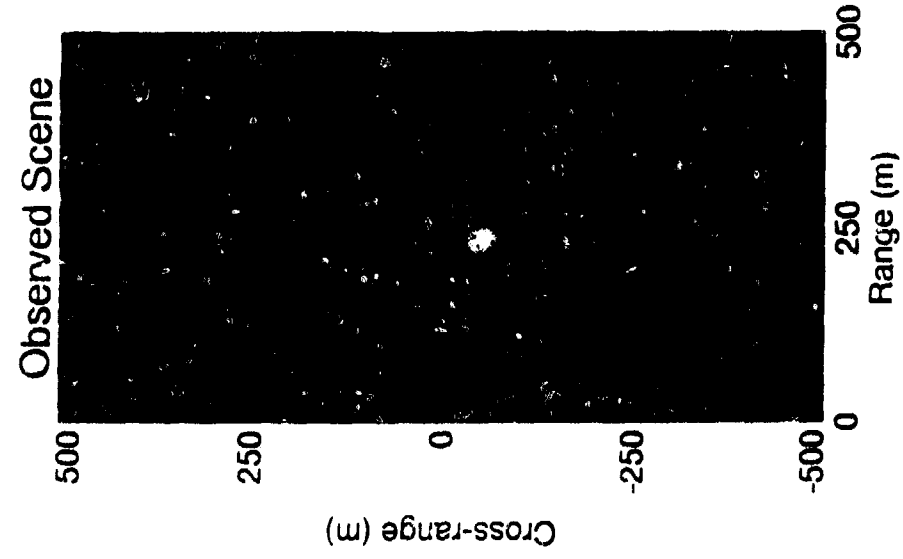
# CONCEPT FOR MULTI-IMAGE REGISTRATION AND LEFT-RIGHT RESOLUTION

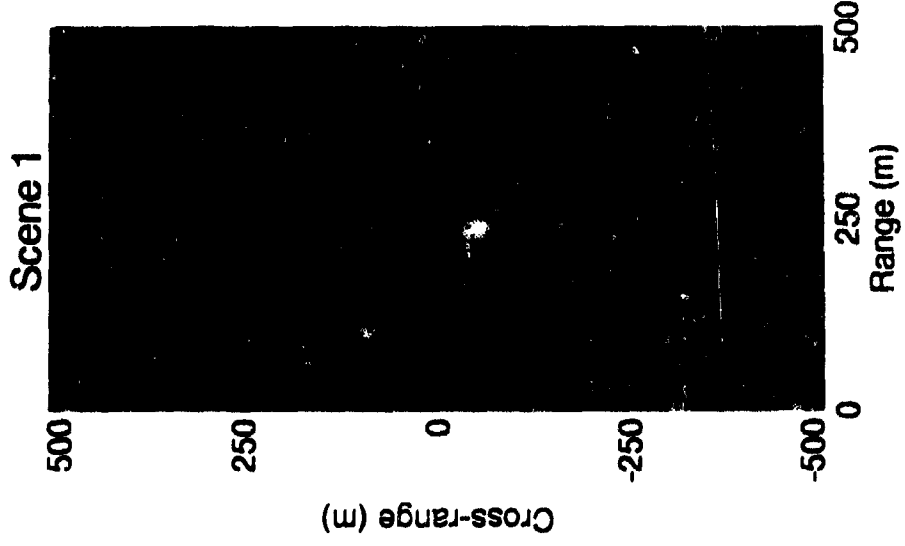


Map all images to a common frame:

$$\text{Estimate Left} = \frac{1}{N} \Sigma (L + \delta R)$$

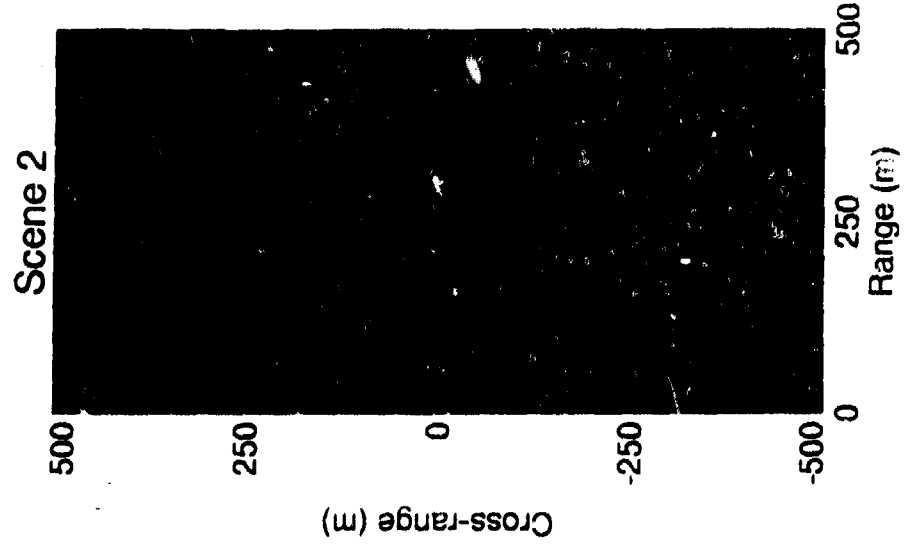
$$\text{Estimate Right} = \frac{1}{N} \Sigma (\delta L + R)$$





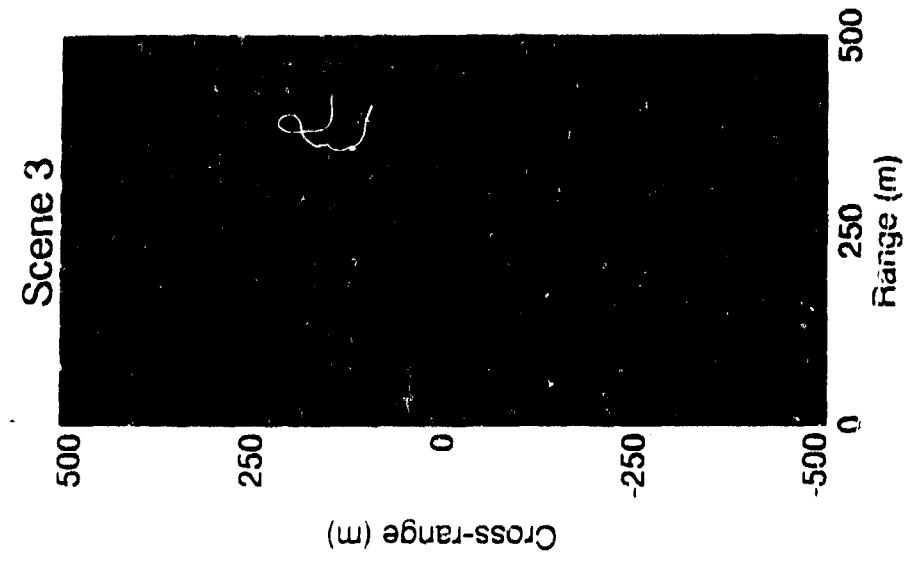
Array Position: ( 0.0 , 0.0 )

Array Angle: 0. deg.



Array Position: ( 126.7 , 181.0 )

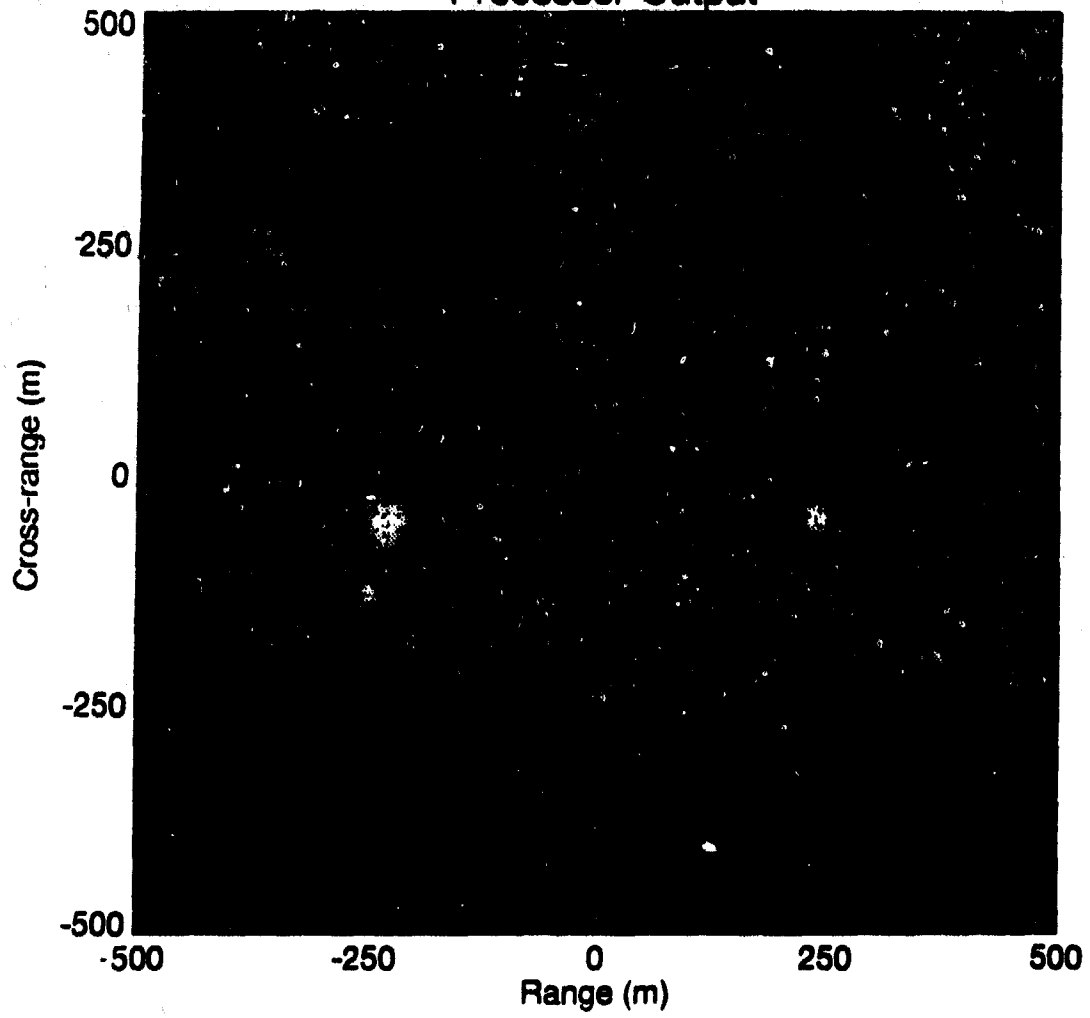
Array Angle: 10. deg.

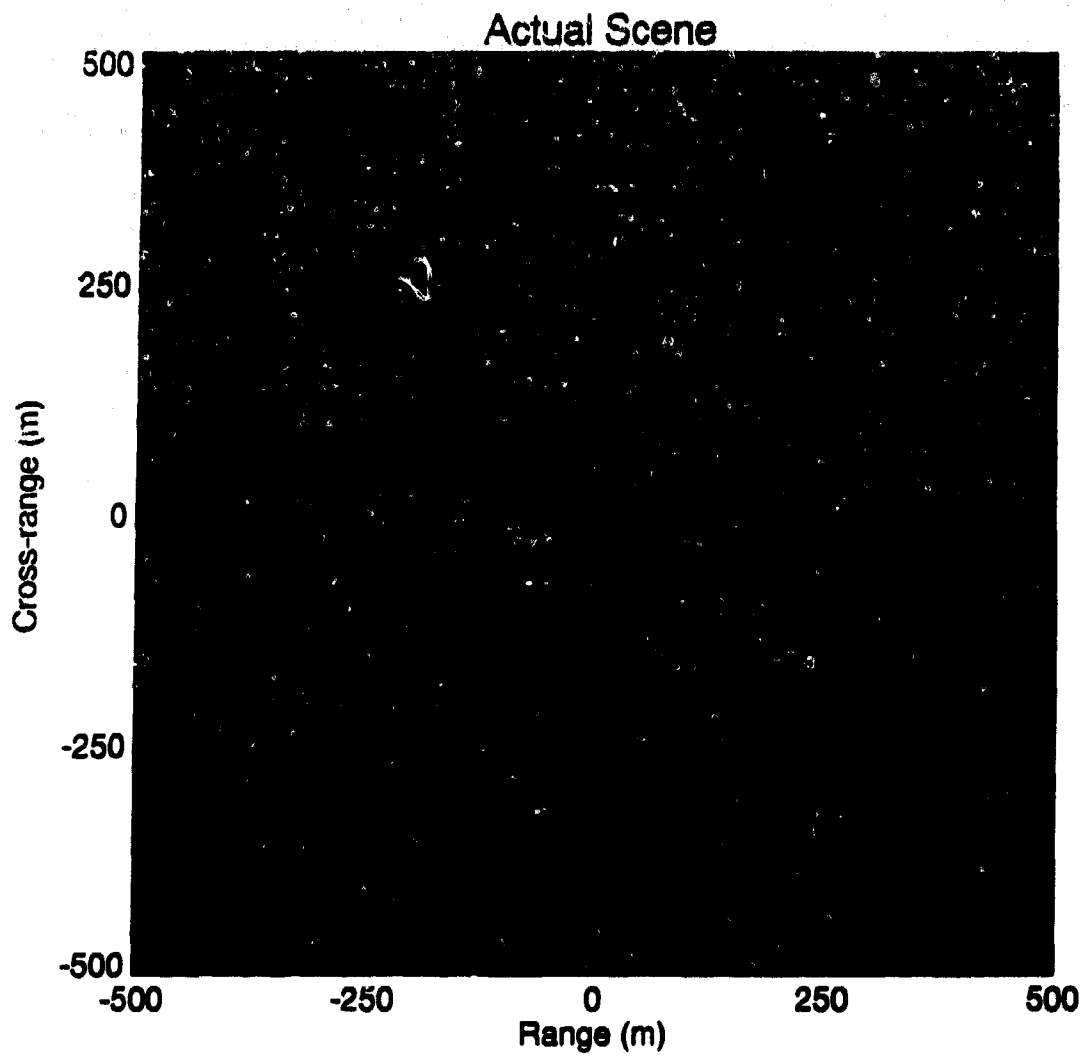


Array Position: ( 177.7 , 229.7 )

Array Angle: 5. deg.

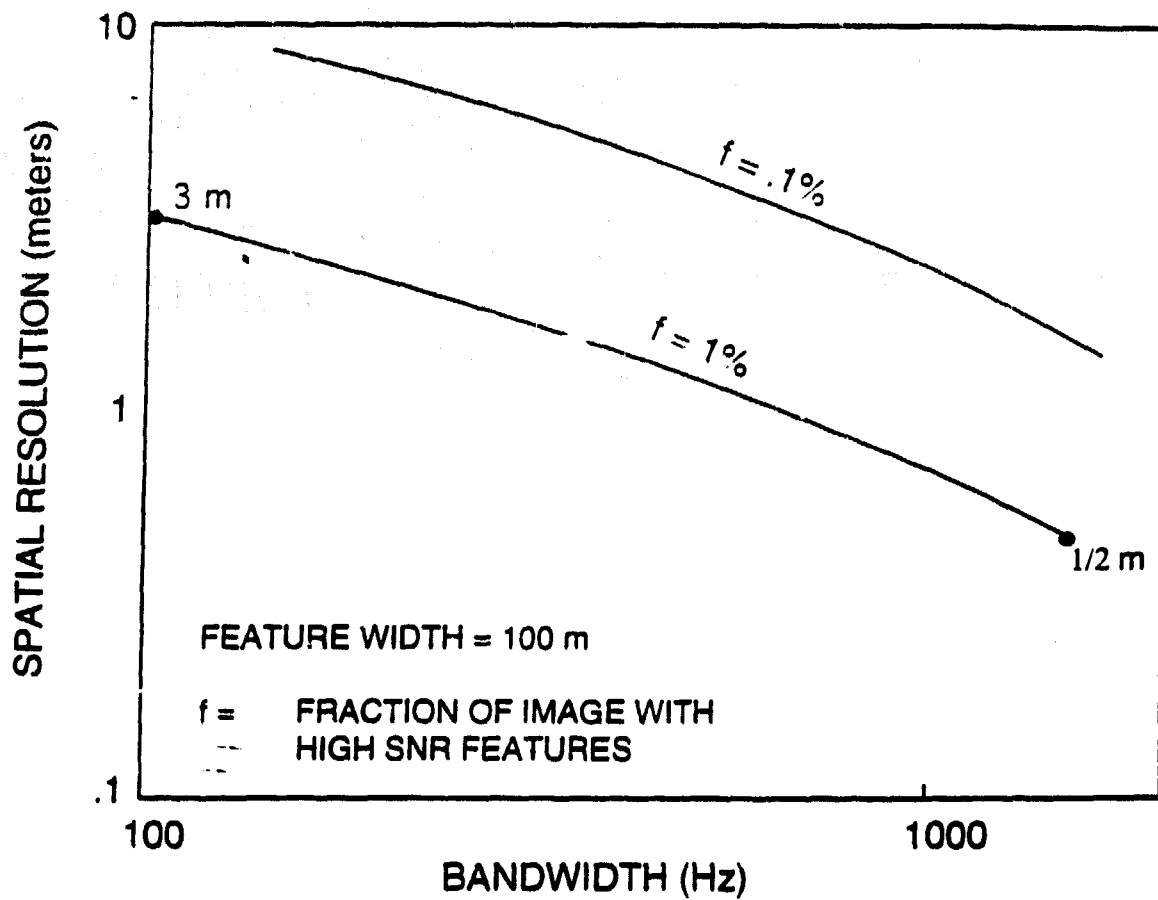
Processor Output





## SPATIAL RESOLUTION USING IMAGE REGISTRATION

CST MFA Image over 10 km range



## WASP Processor Speed Coding Progress

### Progress

- The MicroWay i860 processors are working correctly
- The VAST auto-vectorizer for C now produces correct code
- Image code is being reworked to take advantage of the pipelined architecture of the i860 chip. Time to create an ACT I image\* is estimated at 4.8 minutes. (37% duty cycle)

\* 25 sensors, 3.2K sps, 80Km range, 462 beams

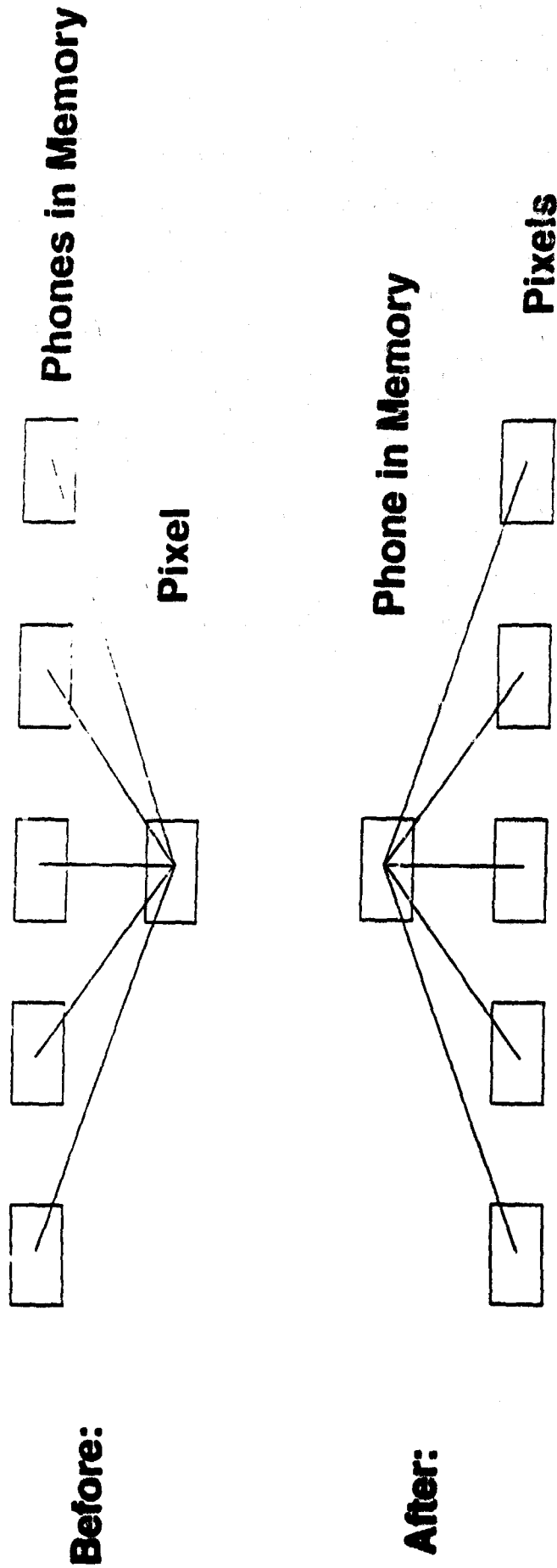
## Code Sections and Timings

<b>Section</b>	<b>Achieved to Date</b>	<b>Expected</b>
<b>Read Data from Disk</b>	<b>11 sec</b>	<b>4 sec</b>
<b>Index Creation (time delays)</b>	<b>71 sec</b>	<b>45 sec</b>
<b>Image Creation</b>	<b>193 sec</b>	<b>120 sec</b>
<b>Image Output</b>	<b>3 sec</b>	<b>3 sec</b>
	<hr/>	
	<b>288 sec = 4.8 Minutes</b>	



## Code Vectorization

Previously, each pixel was calculated individually. Since the phone data is very large, each pixel would result in widely varying memory locations being accessed. The new method determines the contribution of each phone for an entire range-bin row of pixels before moving on to the next phone. The large vectors created by this change allow the processor pipeline to be filled more often, without memory wait states as phone data is retrieved from non-cache system memory.

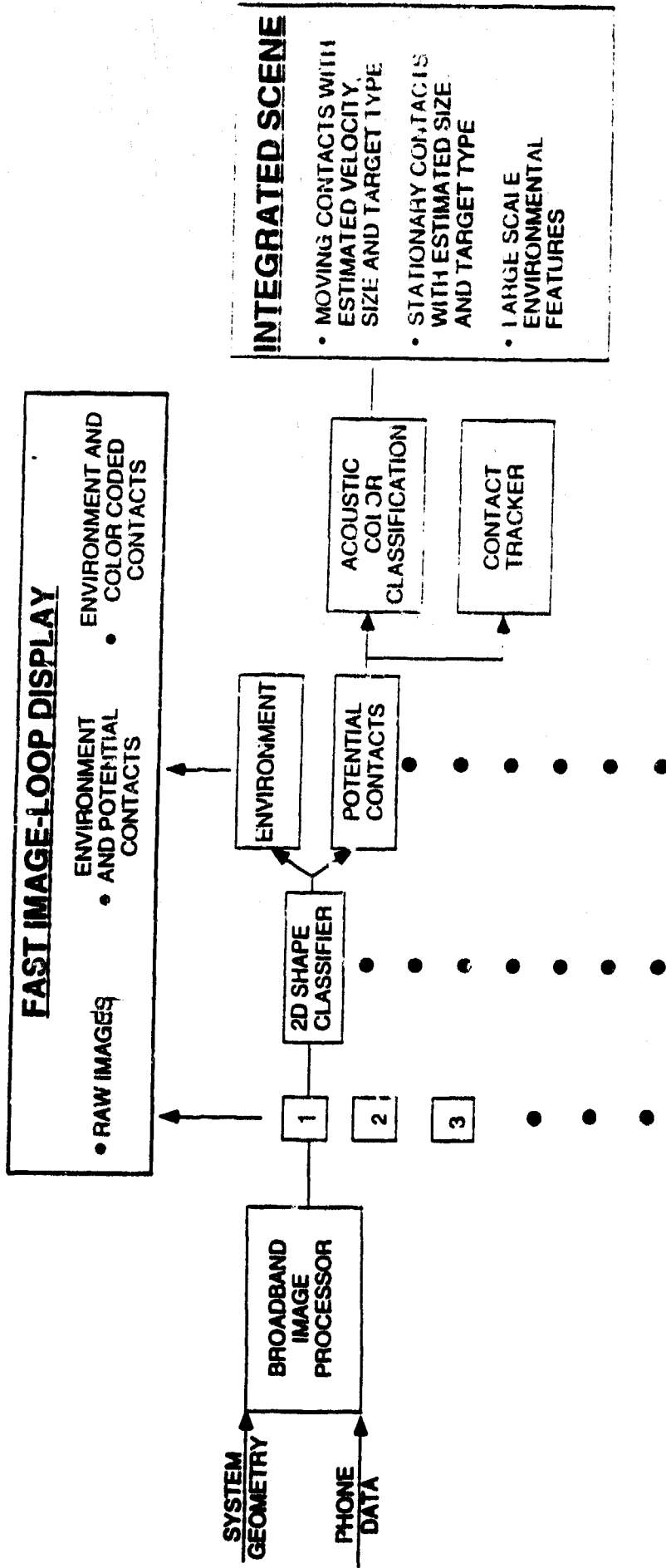


## COMPARISON OF PROCESSORS

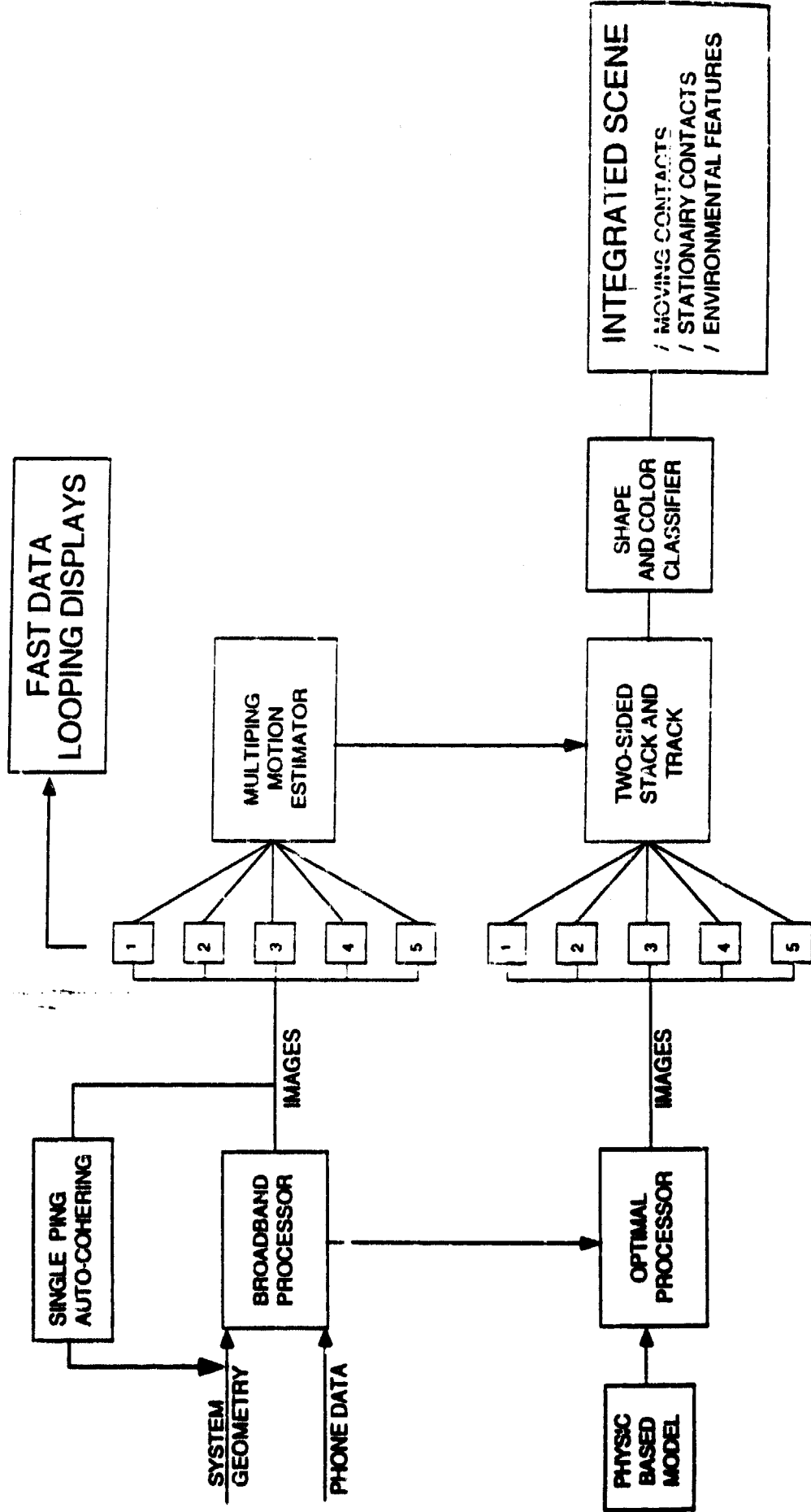
SUN SPARC II	HP 9000 735 CRX	MICROWAY*
47 min (3.8% duty cycle)	10.8 min (16.5% duty cycle)	5 X i860 4.8 min (37% duty cycle)

\* Estimate only, processor not yet fully operational and tested

# CONCEPT FOR OPERATIONAL PROCESSOR

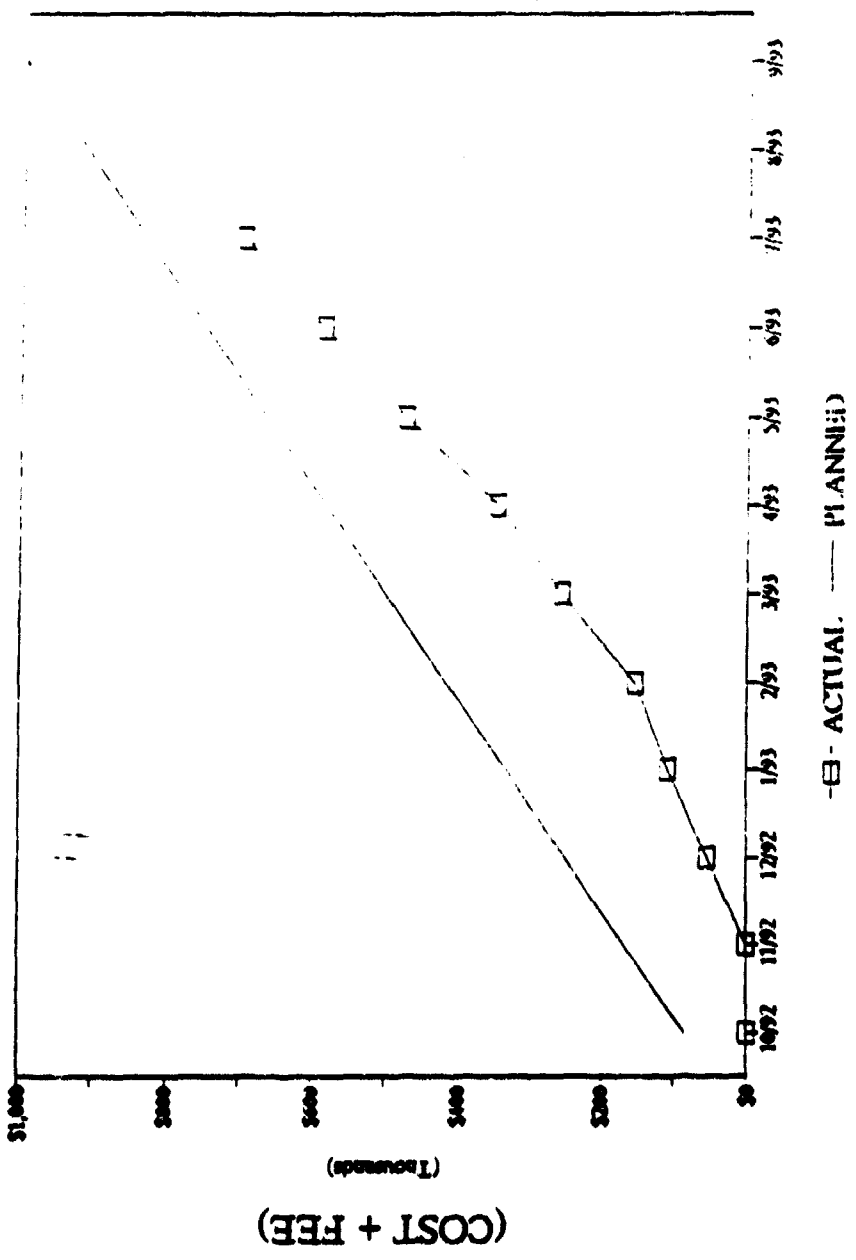


# CONCEPT FOR ADVANCED CAPABILITY PROCESSOR



# CUMULATIVE COST EXPENDITURES

JOB CODE: 3235XXX - CLIN 0003



-□- ACTUAL. --- PLANNED

# Areté Engineering Technologies Corporation

P.O. Box 8050  
La Jolla, CA 92038

4 October 1994

Dr. William Carey  
Advanced Research Projects Agency  
Maritime Systems Technology Office  
3701 North Fairfax Drive  
Arlington VA 22203-1714

Reference: MDA972-91-C-0063

Dear Bill:

Upon review of our contract files we found that copies of some quarterly reviews for CLIN 0003 on the above referenced contract were not forwarded to your office. For your convenience I have enclosed the following reports:

- 1) "High Resolution Bottom Characterization" (ARS-235-021-B), dated 4 May 1993.
- 2) "ARPA Progress Report" (ARS-235-037-B), dated 26 August 1994.
- 3) "Broadband Low-Frequency Acoustic Imaging" (ARS-235-049-B), dated 21 December 1993.

Copies of the remaining quarterly reviews for CLIN 0003 have been delivered; "DARPA Quarterly Review" (ARS-235-001-B), dated 6 January 1993, and "Nearfield Imaging During CST 7, Phase III (U)" (AS-93-0009.0), classified SECRET and dated 1 March 1994.

If you have any questions, or require more information, please call me at (619)450-1211.

Sincerely,



D. W. Miklovic, i.n.D.  
Vice President

DWM:dj  
SD-093

Enclosures: As stated above

cc: See Distribution

Dr. William Carey

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4 October 1994

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