The World's First Triple Nested HF Radar Test Bed for Current Mapping and Ship Detection

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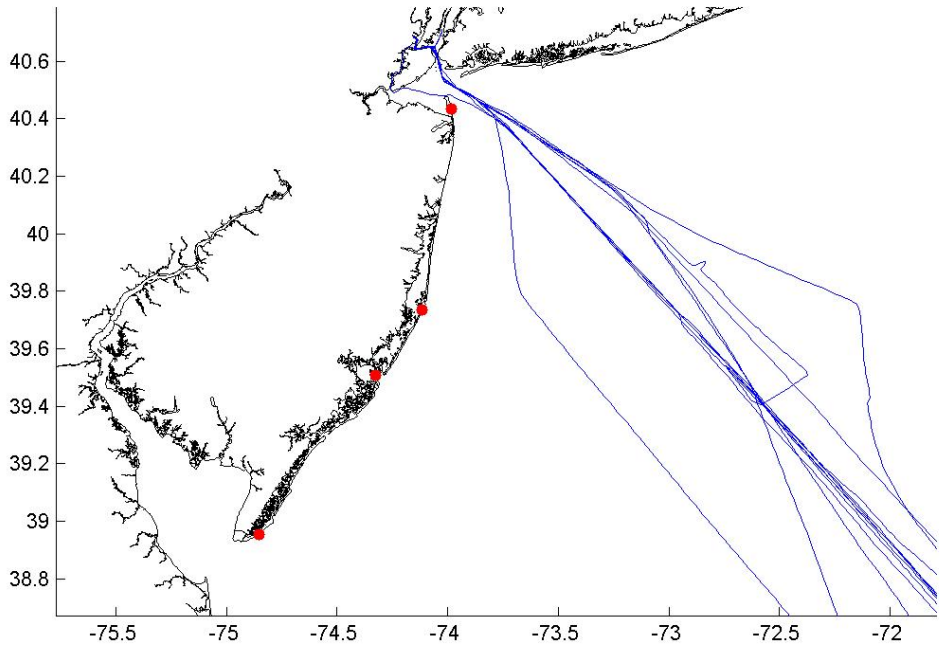
FUTURE WORK (ROW4)

System Performance in Varied Environments

- Based upon the shown work, optimal settings have been set at all long-range sites for multi-static dual use operations
- Now focusing on a long term data set , M/V Oleander sails New York to Bermuda on a weekly basis providing ship tracking opportunities while the network continues to provide surface current maps to the Coast Guard for Search & Rescue Demonstrations.



Multiple Frequencies

•Sandy Hook: 5, 13 and 25 MHz

Multiple Sites

•Sandy Hook

•Loveladies

•Tuckerton &

•Wildwood

Ship Tracking Throughout Rutgers HF Radar Network

Detection Time Period	Ship	Ship Length/Height	Tracked from	Frequency	Raw Data Archived & Distributed	Detection Files Generated	Kalman Filter Solution Generated
June 18-24,2001	Endeavor ①	185'/84'	Sandy Hook	5 MHz	√	√	√
June 19-23, 2001	Oleander ②	387'/98'	Sandy Hook	5 MHz	√	√	√
November 22-24, 2002	Oleander ②	387'/98'	Sandy Hook & Loveladies	5 MHz	√	√	√
December 16-19, 2002	Coast Guard Finback ③	82'/48'	Wildwood	5 MHz	√	√	√
March 26,2003	Sea Tow Greg④	25'/13'	Tuckerton	5 MHz	√		
April 21, 2003	Sea Tow Greg ④	25'/13'	Tuckerton	5 MHz	√		
May 7, 2003	Rosemary Miller ⑤	95'/32'	Sandy Hook & Loveladies	5 MHz	√		
May 20, 2003	Sea Tow Mike ⑥	20'/13'	Tuckerton	5 MHz	√	√	√
July 30, 2003	Sea Tow Joe ⑦	41'/20'	Tuckerton & Loveladies	5 MHz	√		
September 3-4, 2003	RV Connecticut ⑧	70'/50'	Sandy Hook & Loveladies	5 MHz	√		
September 26-29, 2003	Royal Caribbean Serenade of the Seas ⑨	962'/13 decks	Sandy Hook	5 MHz	√		
October 7, 2003	Sea Tow Greg ④	25'/13'	Loveladies	5 MHz	√		
October 7, 2003	Sea Tow Greg ④	25'/13'	Brant Beach	25 MHz	√		
October 8, 2003	Sea Tow Greg ④	25'/13'	Loveladies	5 MHz	√		
October 8, 2003	Sea Tow Greg ④	25'/13'	Brant Beach	25 MHz	√		

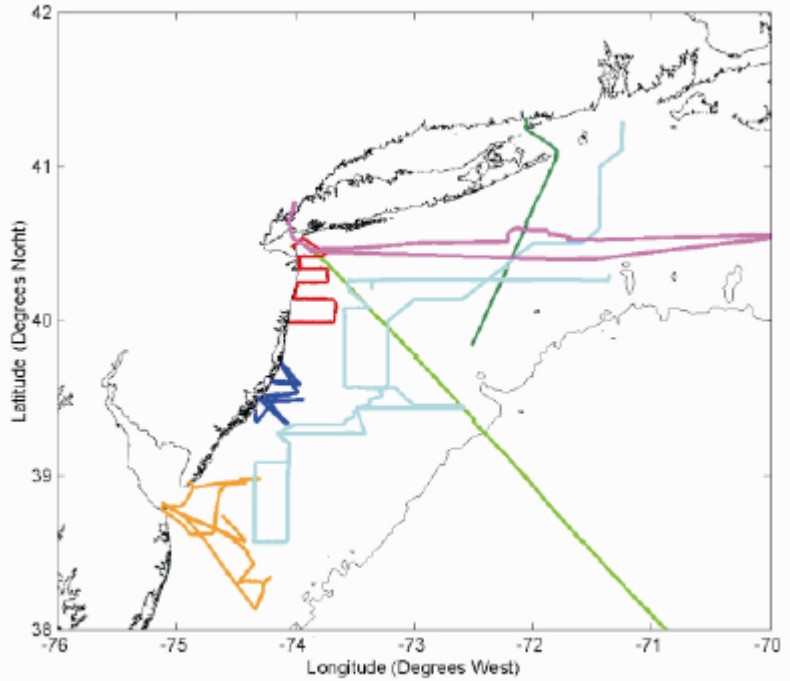
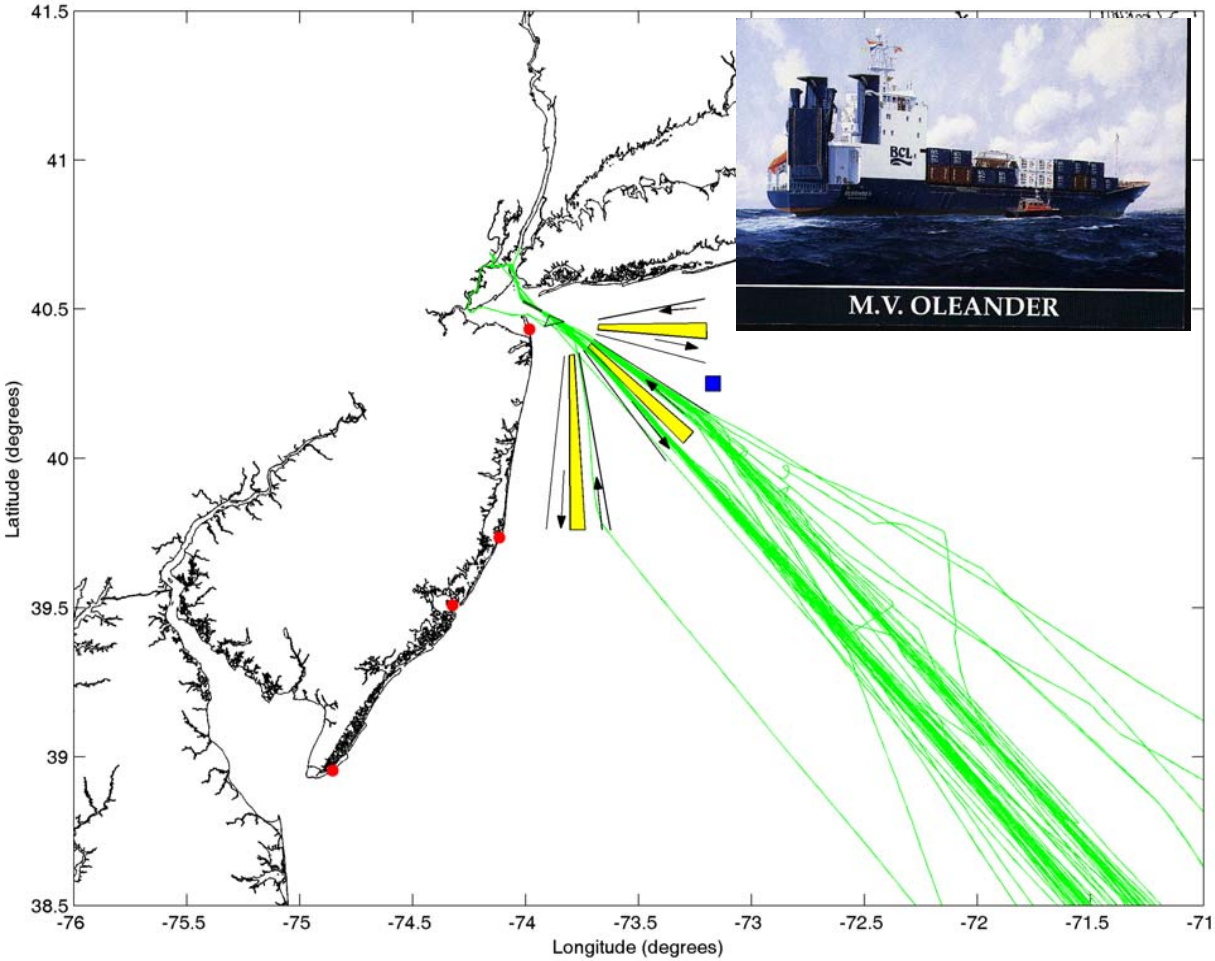


Figure 1. GPS tracks for vessels tested in year 1.

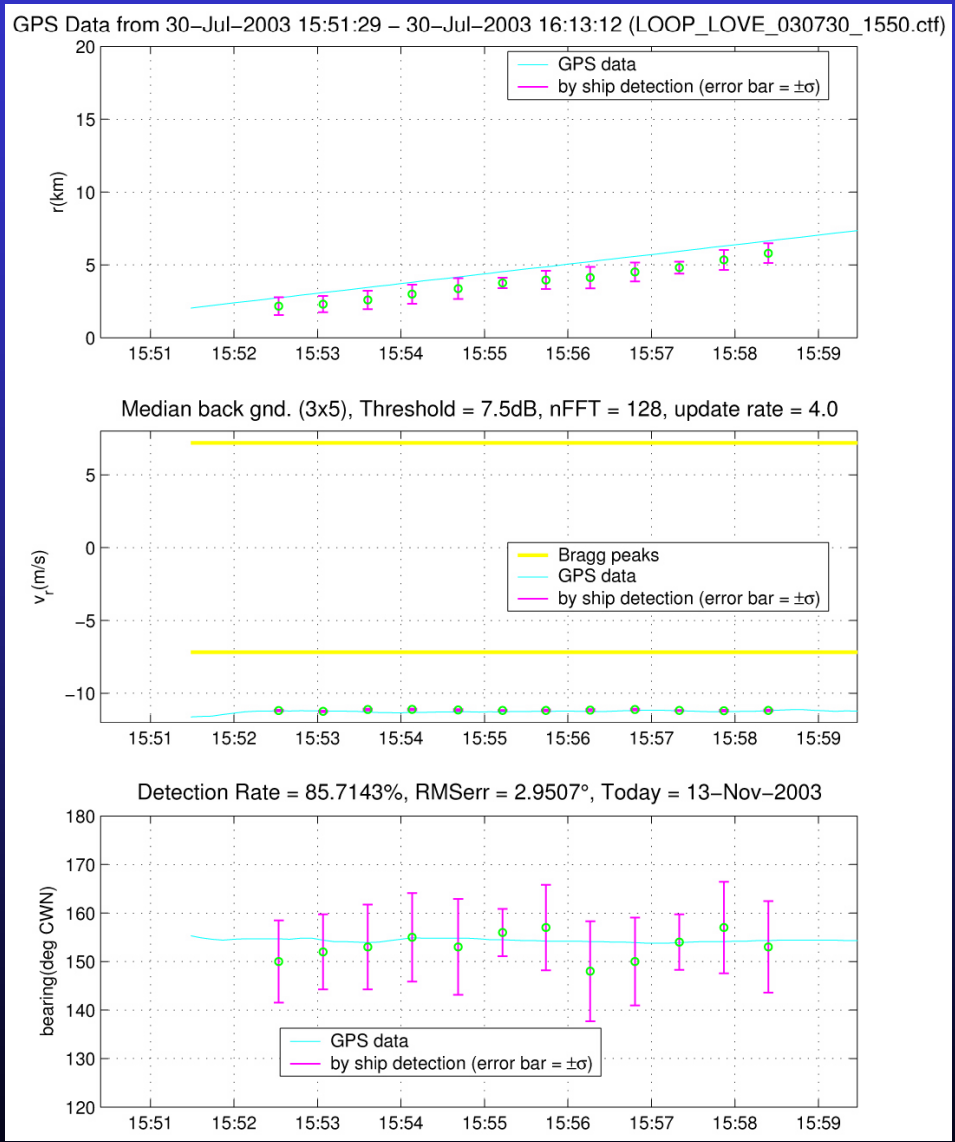
60 Transits of Oleander in 2005



New Jersey Installations Used for Oleander Tests

Detection Algorithm

- Simultaneous multiple sliding window FFTs in Doppler processing
- Two types of background calculation --- median and IIR
- 3D background (Time, Range and Doppler) varying with sea echoes
- Thresholding of peaks --- local SNR of monopole or at least one of the two dipole antennas have to be above the threshold
- MUSIC algorithm used to determine bearing
- Bearing precision determined by SNR (~1/sqrt(SNR))



Oleander Detections

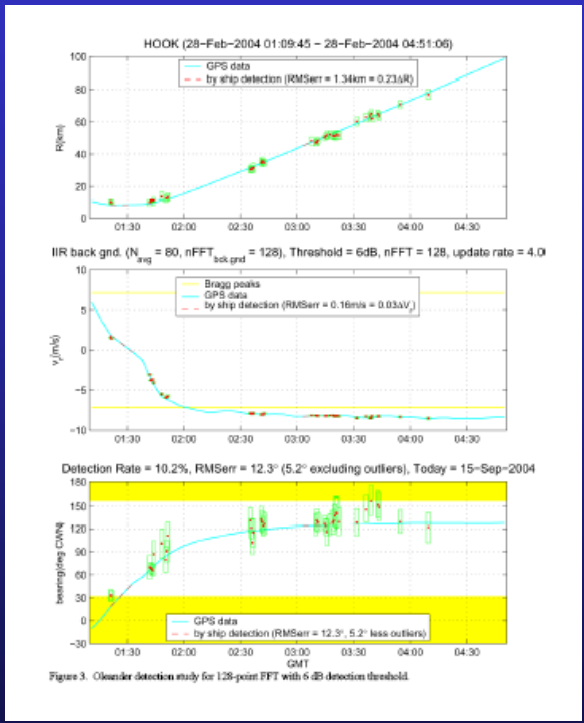


Figure 3. Oleander detection study for 128-point FFT with 6 dB detection threshold.

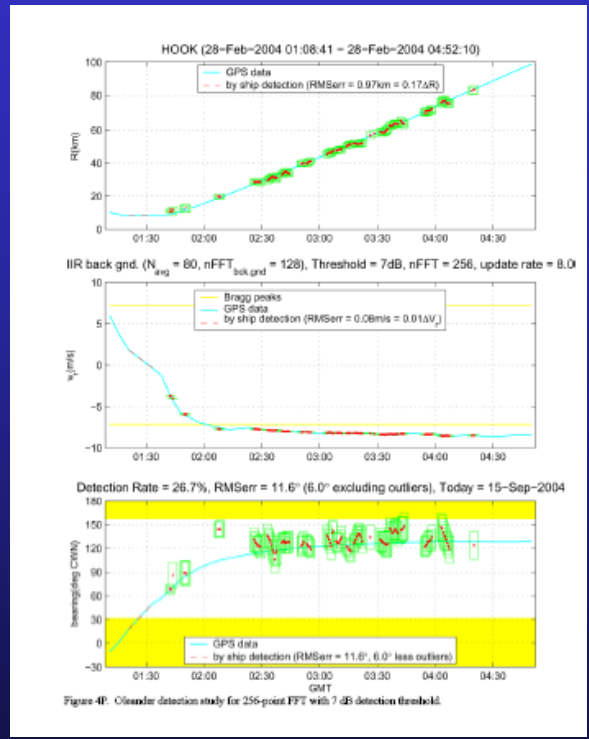


Figure 4P. Oleander detection study for 256-point FFT with 7 dB detection threshold.

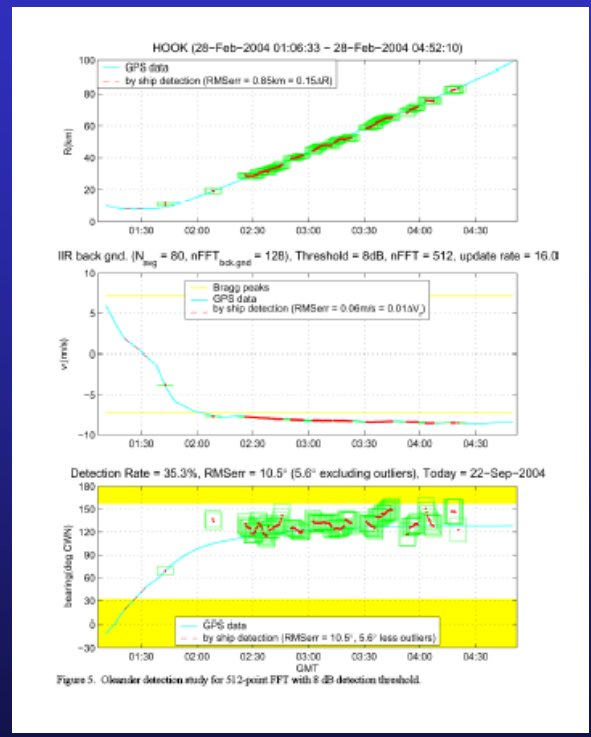


Figure 5. Oleander detection study for 512-point FFT with 8 dB detection threshold.

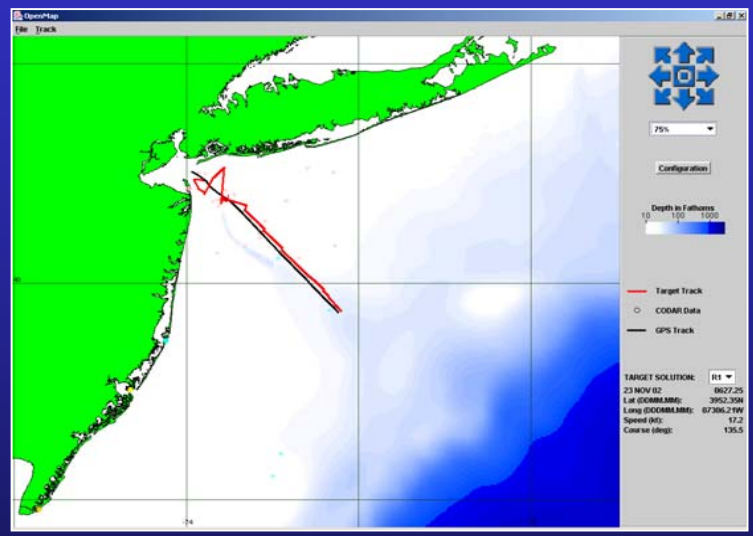
128 point FFT
6 dB Threshold

256 point FFT
7 dB Threshold

512 point FFT
8 dB Threshold

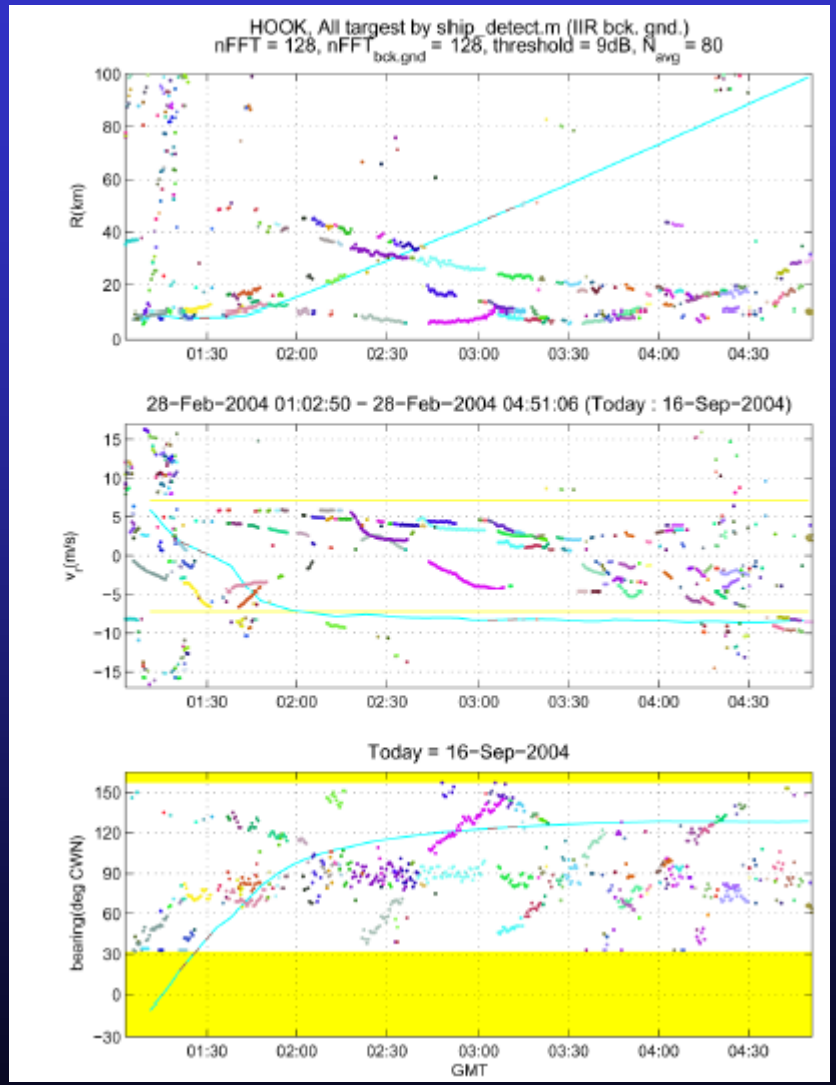
Ship Tracking Algorithm

- A Kalman Filter provides a recursive solution to the least squares problem.
- Assumptions include linear target motion and normally distributed measurement errors.
- Tracker inputs are time; radar transmitter and receiver positions; range, bearing, and range rate; and range, bearing, and range rate uncertainties.
- Tracker outputs are target position; velocity; and estimates of position and velocity uncertainties (covariance matrix).
- Target Maneuver Test: a statistical test is used to estimate whether a combination of two straight tracks fit the data better than a single straight track.

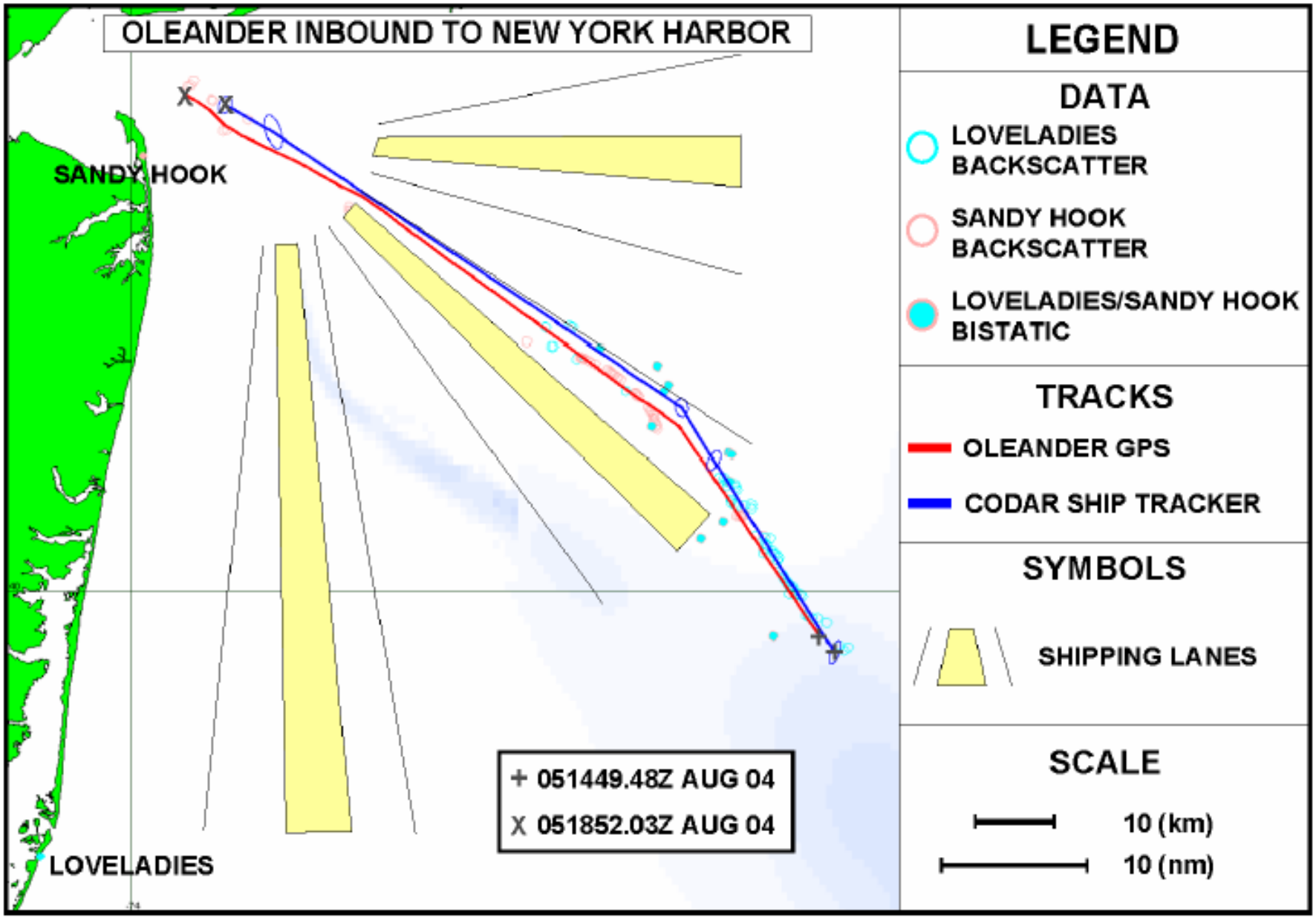


Oleander Constant Course and Speed Tracker Solution Using CODAR Detections from 23 November 2002

Pepper Plots



- All targets detected 9 dB above background


OLEANDER INBOUND TO NEW YORK HARBOR
SANDY HOOK
LOVELADIES
+ 051449.48Z AUG 04
X 051852.03Z AUG 04
LEGEND
DATA
LOVELADIES BACKSCATTER
SANDY HOOK BACKSCATTER
LOVELADIES/SANDY HOOK BISTATIC
TRACKS
OLEANDER GPS
CODAR SHIP TRACKER
SYMBOLS
SHIPPING LANES
SCALE
10 (km)
10 (nm)

Present Focus

- **Hardware Improvements**
  - **13 MHz Codar SeaSonde, December 2004**
  - **13 MHz Codar Superdirective System, July 2005**
- **Software Improvements**
  - **SIFTER Algorithm**

Sandy Hook Facility March 2004

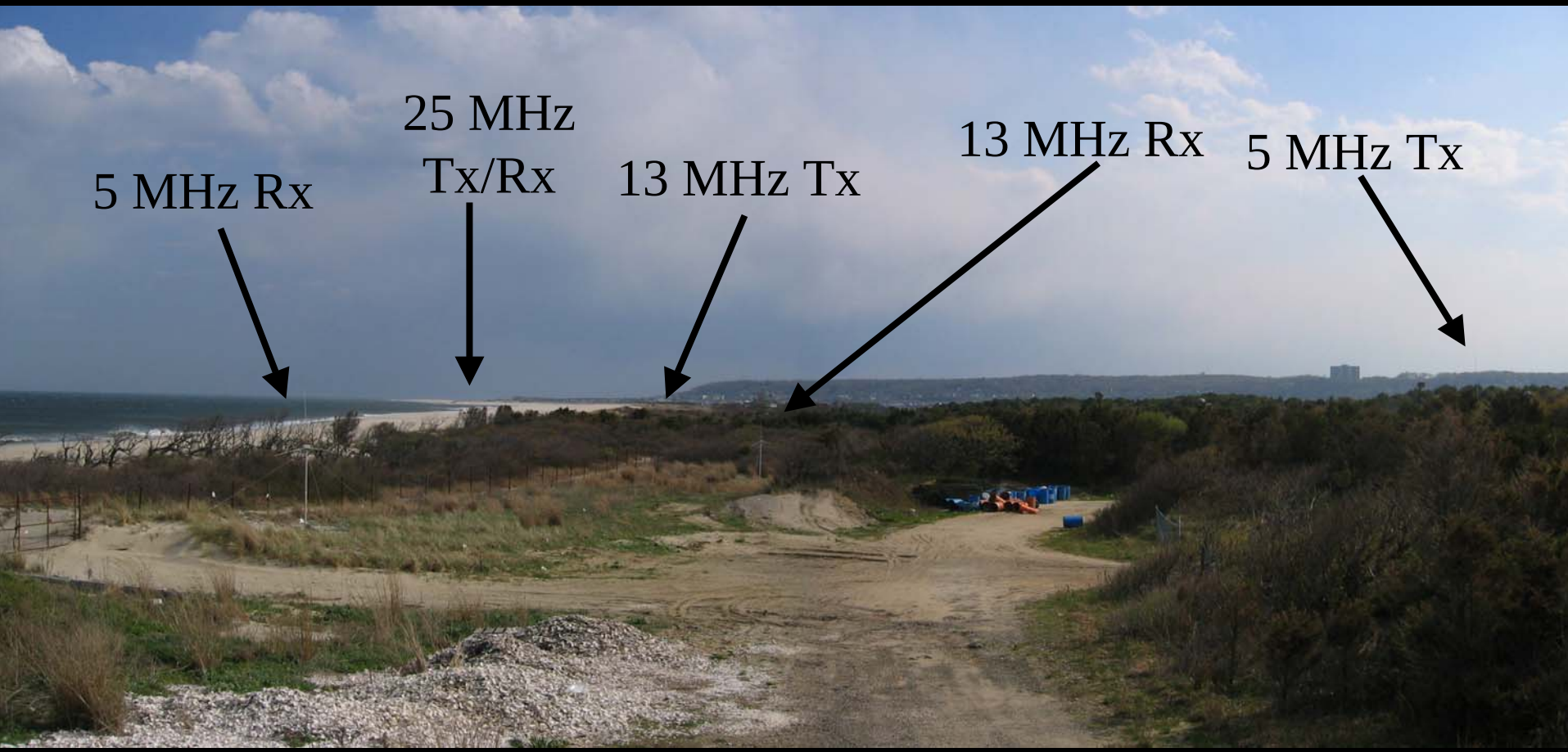
Continuous Operation Since July 2001

Sandy Hook

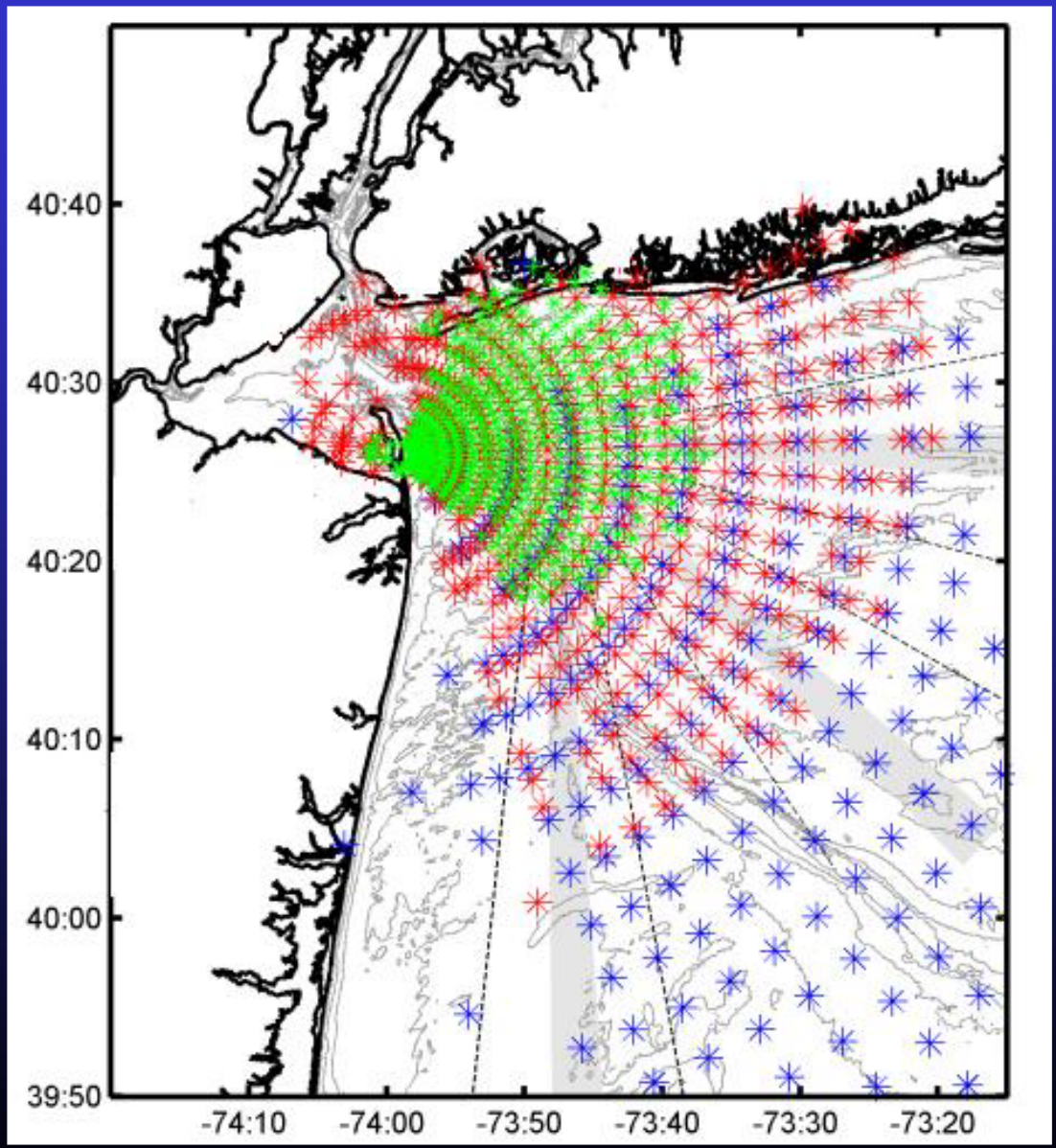
Test Bed

Present Day

- 25 MHz system installed March 2004
- 5 MHz Transmit Antenna moved 1 wavelength back from shoreline
- 13 MHz System Installed December 2004


5 MHz Rx
25 MHz
Tx/Rx
13 MHz Tx
13 MHz Rx
5 MHz Tx

Three Frequency Coverage

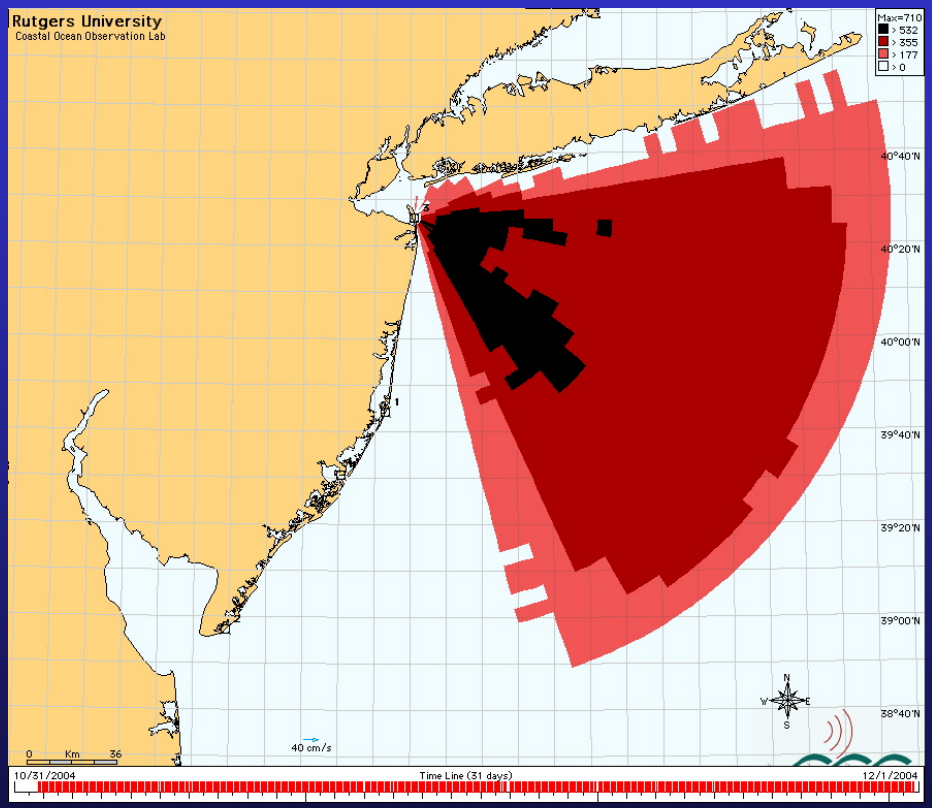


- 5 MHz
- 13 MHz
- 25 MHz

How did the move of the Transmit Antenna Affect Radial Coverage?

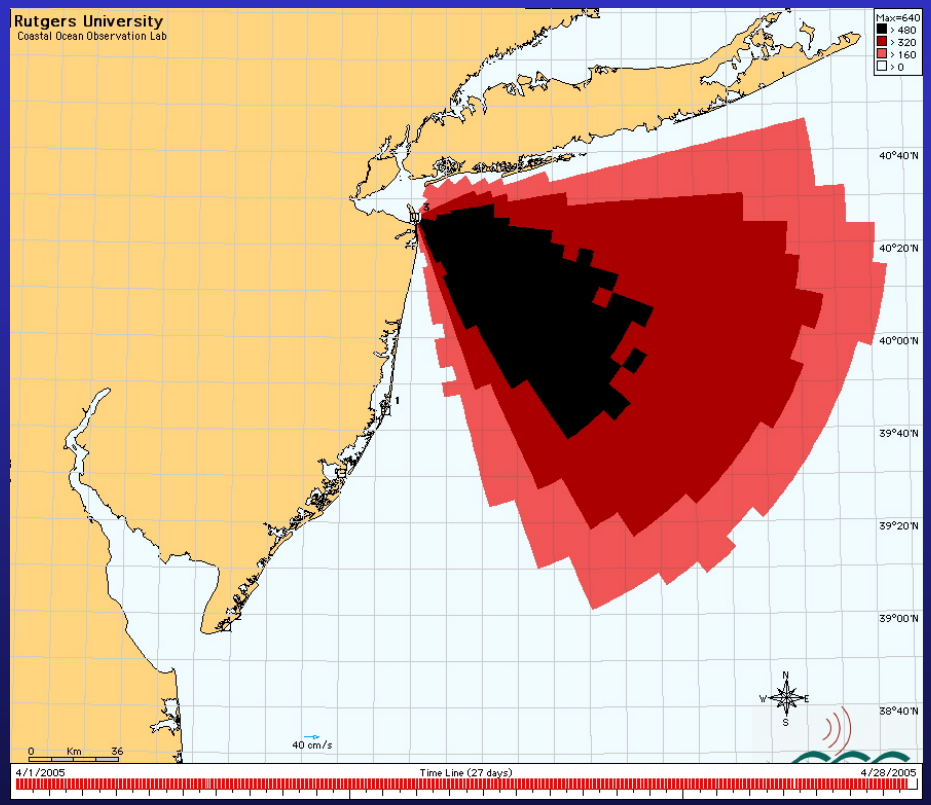
5 MHz Transmit Antenna Move

BEFORE



Radial Distribution
November 2004

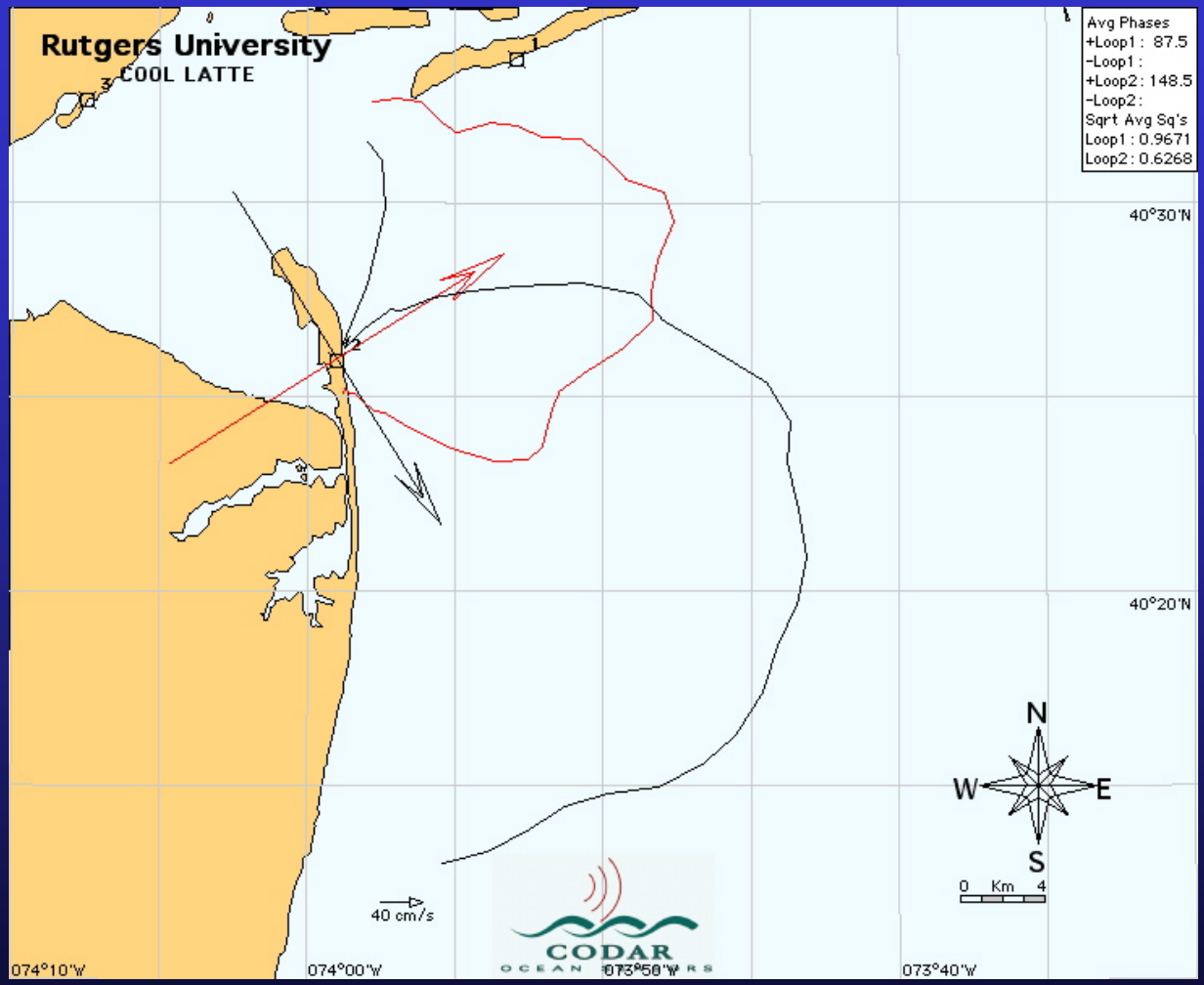
AFTER



Radial Distribution
April 2005

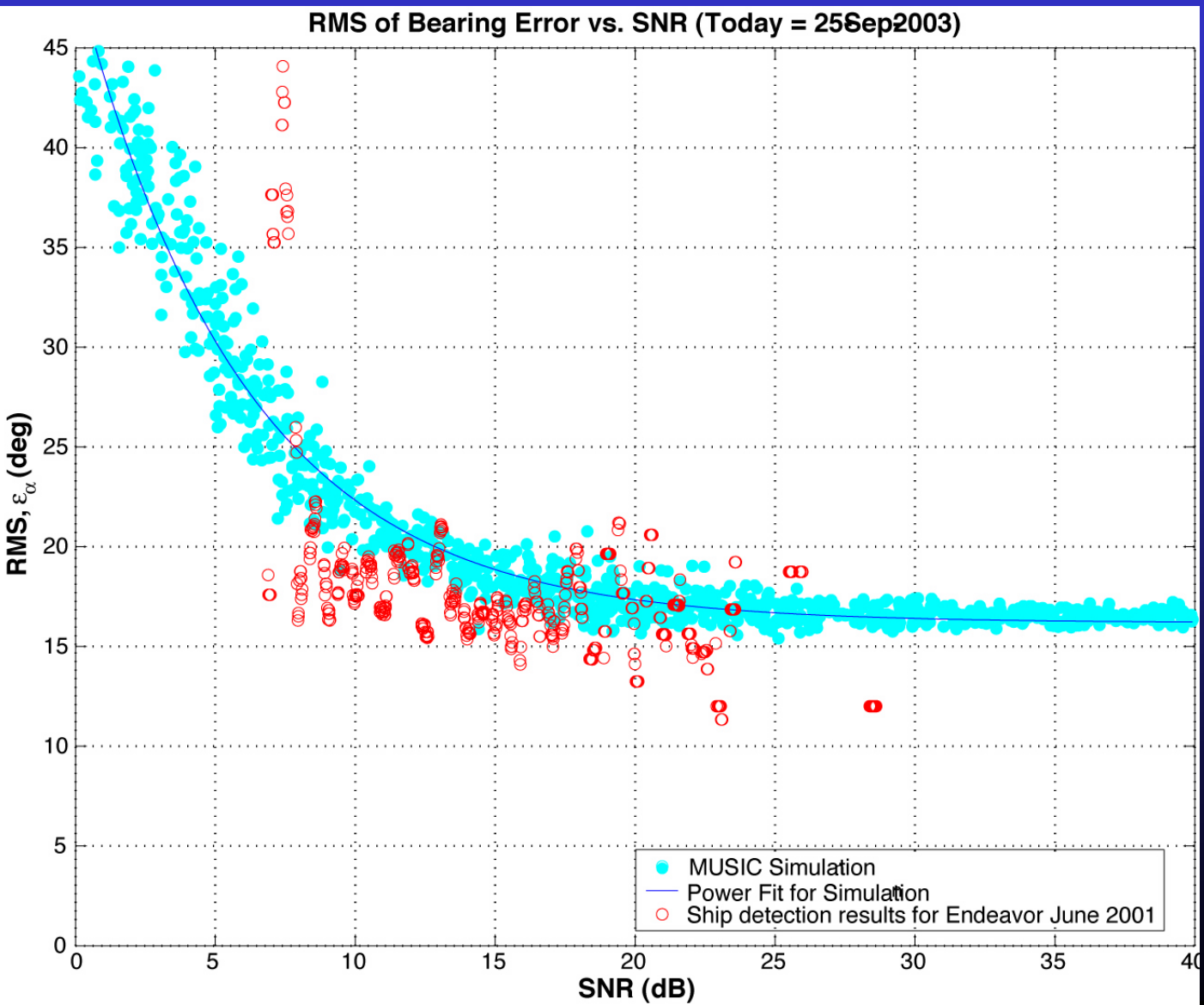
5 & 13 MHz Receive Antennas in "Cluttered" Environment

5 MHz HOOK



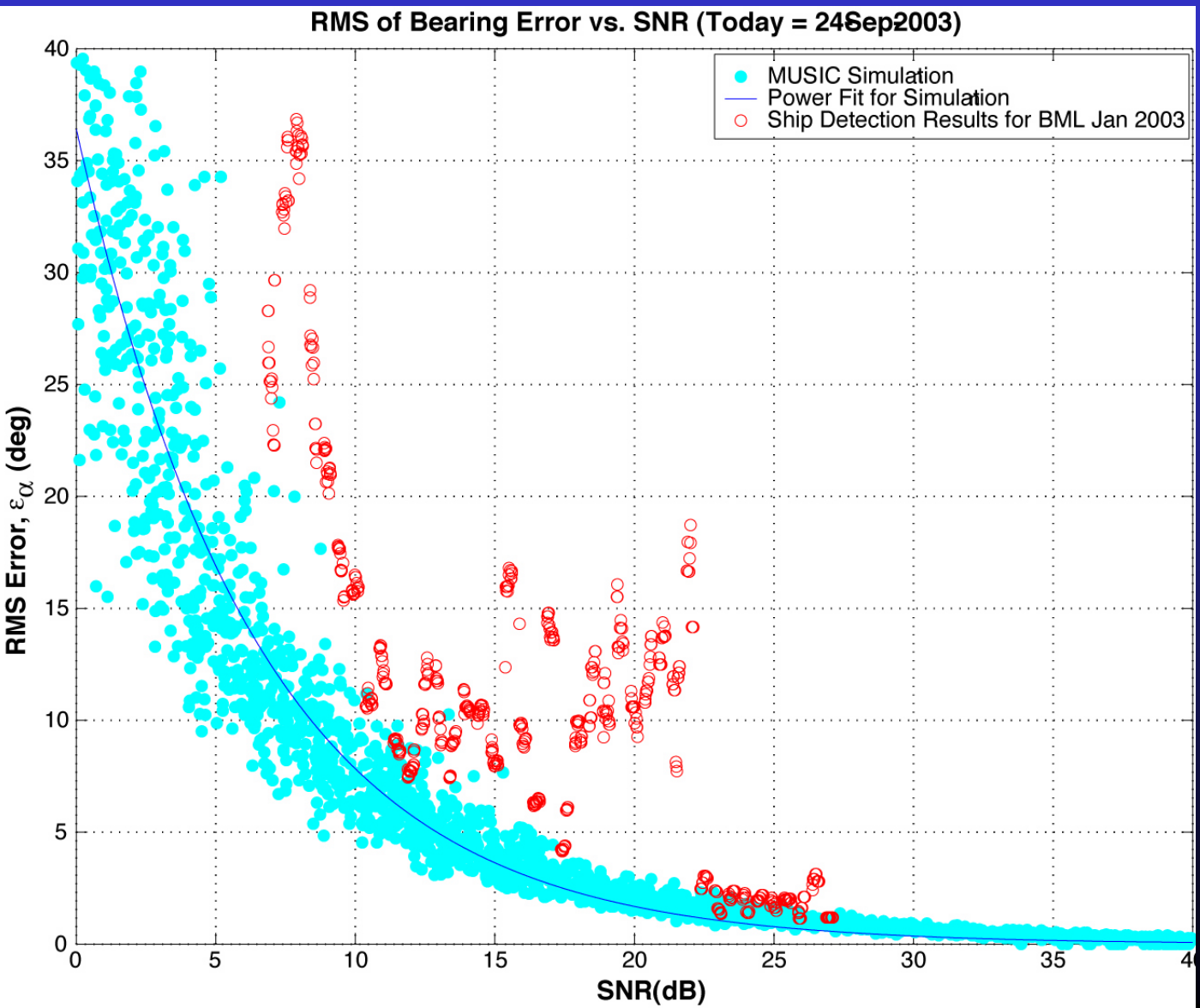
Pattern Measurement

Simulated Bearing Error with Added Bias from Improper Antenna Pattern Compared with Real Ship Bearing Data



- For Simulation:
  - Measured distorted pattern inputted
  - Ideal pattern used to recover echo
- Expected power-law fit is offset by 16°
- Ship is also offset when inappropriate ideal pattern is used

Simulated Bearing Error with Distorted, Measured Antenna Patterns Compared with Real Ship Bearing Data



- Simulated points follow power law:

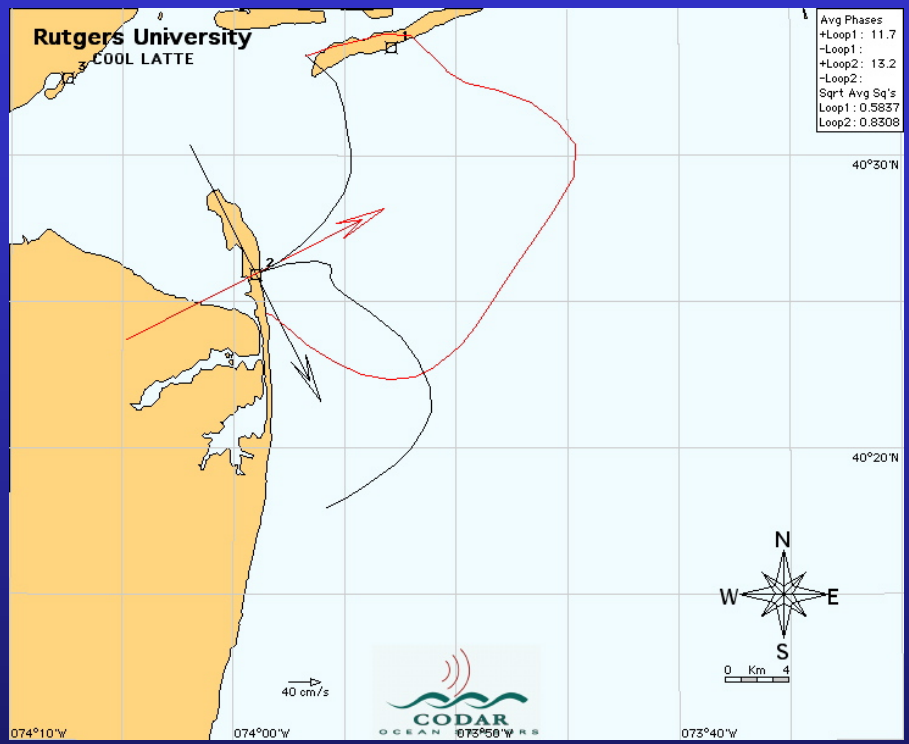
$$\sigma_B = \frac{36.4}{SNR^{0.67}}$$

- Compared to:

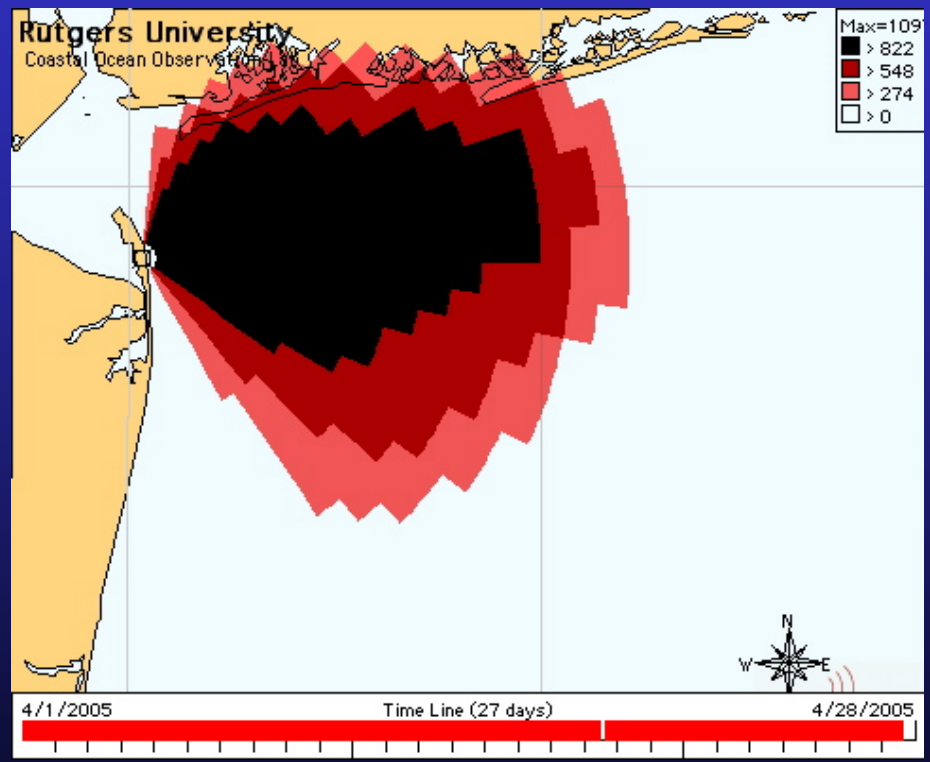
$$\sigma_B = \frac{40}{SNR^{0.5}}$$

- Ship detections at lower SNRs may differ because:
  - Noise peaks are mis-identified as ships
  - "Noise" near peak contains ship signal, i.e., it is too high

13 MHz HOMR



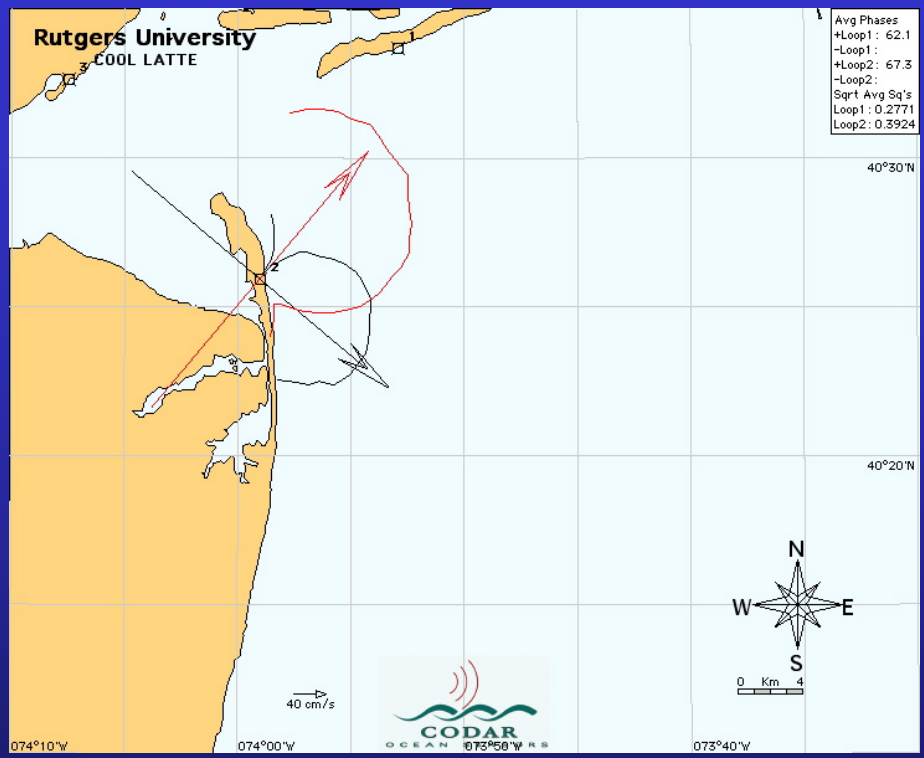
Pattern Measurement



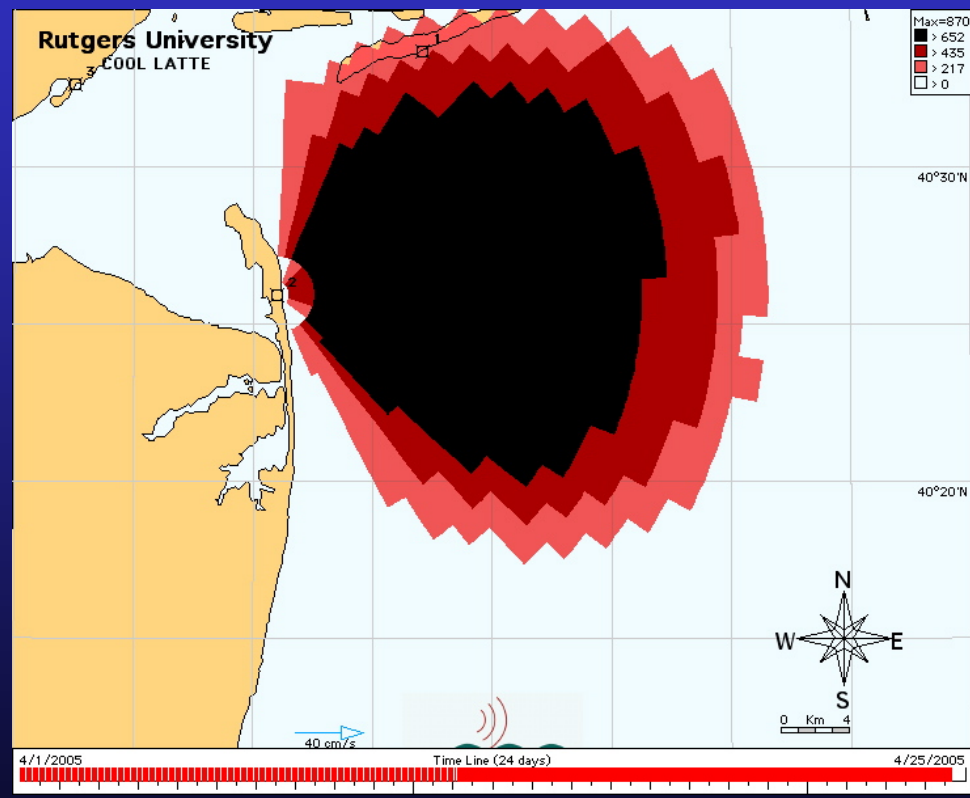
Radial Distribution

25 MHz System in Clear Environment

25 MHz HOSR

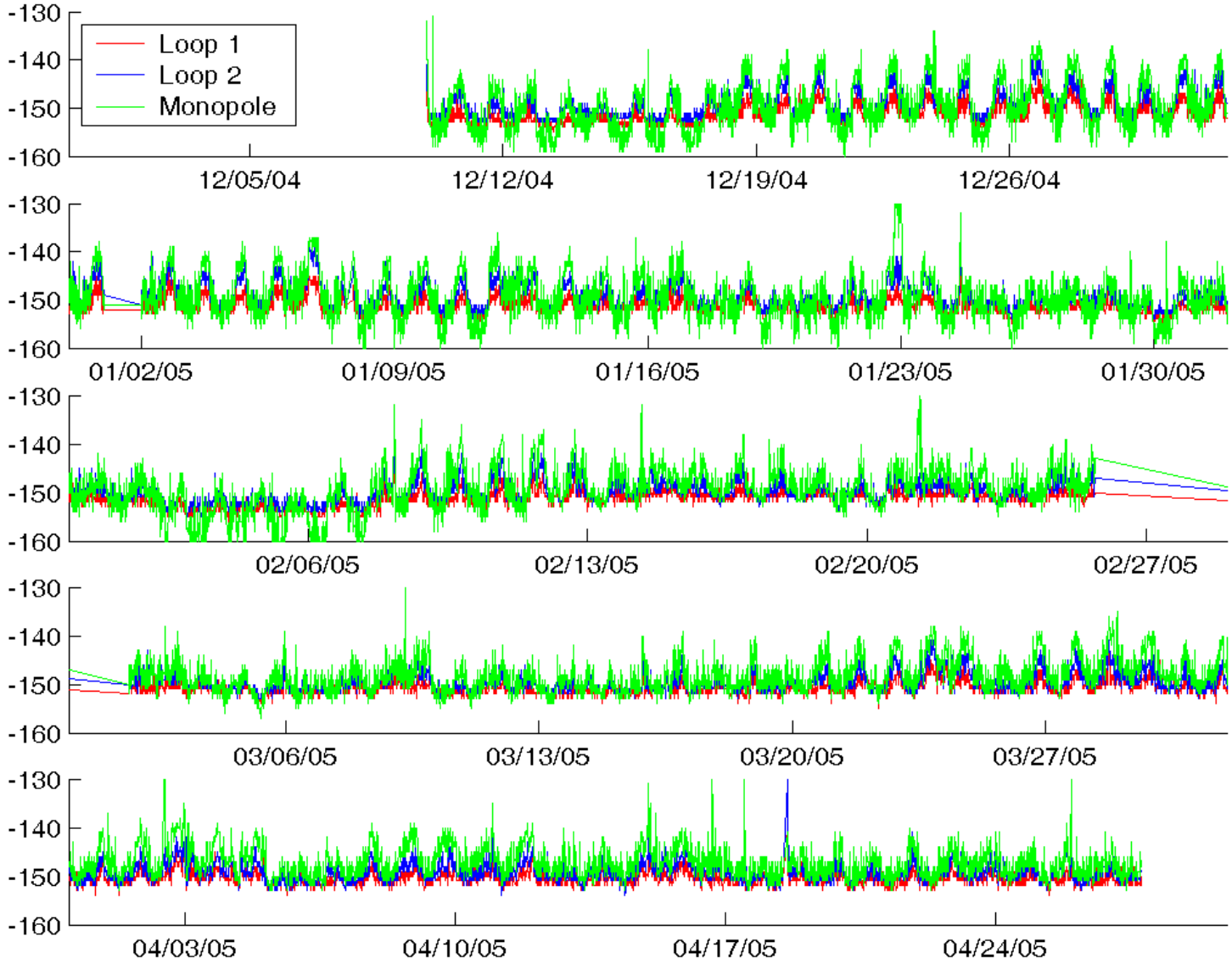


Pattern Measurement



Radial Distribution

Noise Floor Measurements (dBm) for 13 MHz Codar System at Sandy Hook, NJ



Sandy Hook

Test Bed

Future

- 13 MHz SuperDirective System Installation July 2005

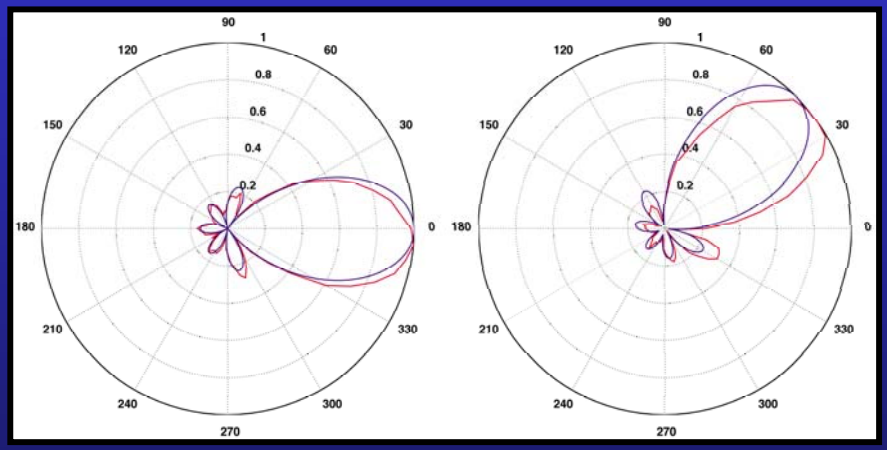
SuperDirective System

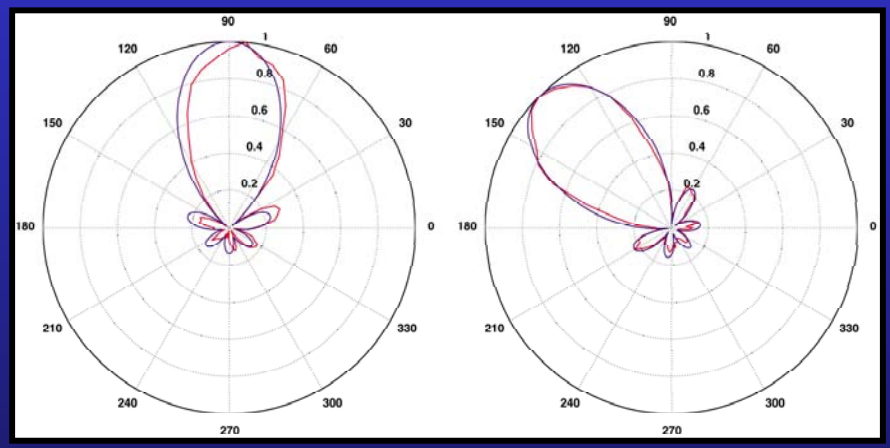
13-MHz Heptagonal Array Being Built and Tested at CODAR

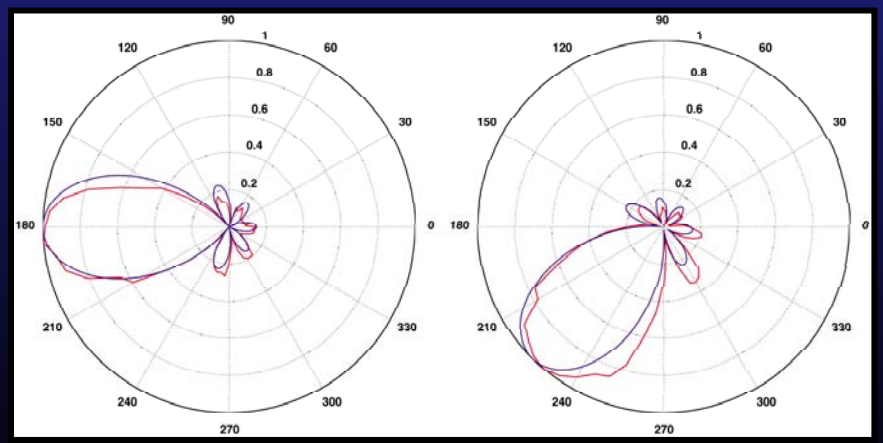
- 23-foot (7-m) high mast
- 9-foot (3-m) arms
- 8-foot (2.7-m) dipoles
- 2 masts ~21 dB directivity over ground
- -32 dB efficiency

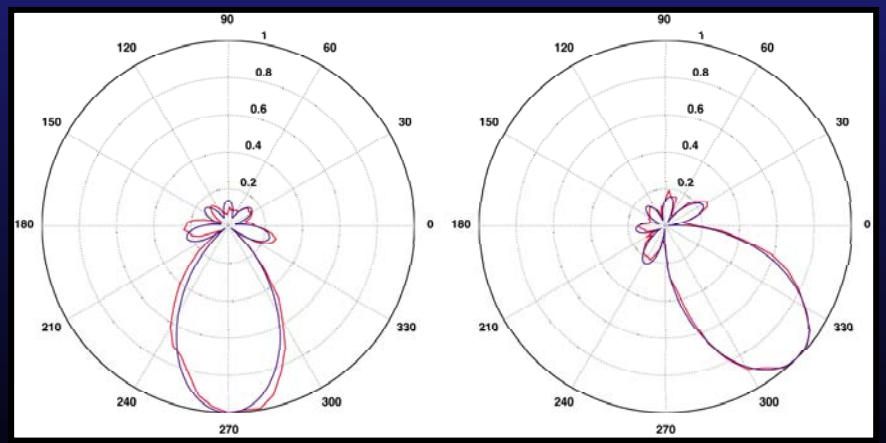
SuperDirective Beam Patterns 360 degree coverage

- Blue curve is theoretical pattern for 7-element array
- Red results from use of measured transponder pattern









SIGNAL

INVERSION

FOR

TARGET

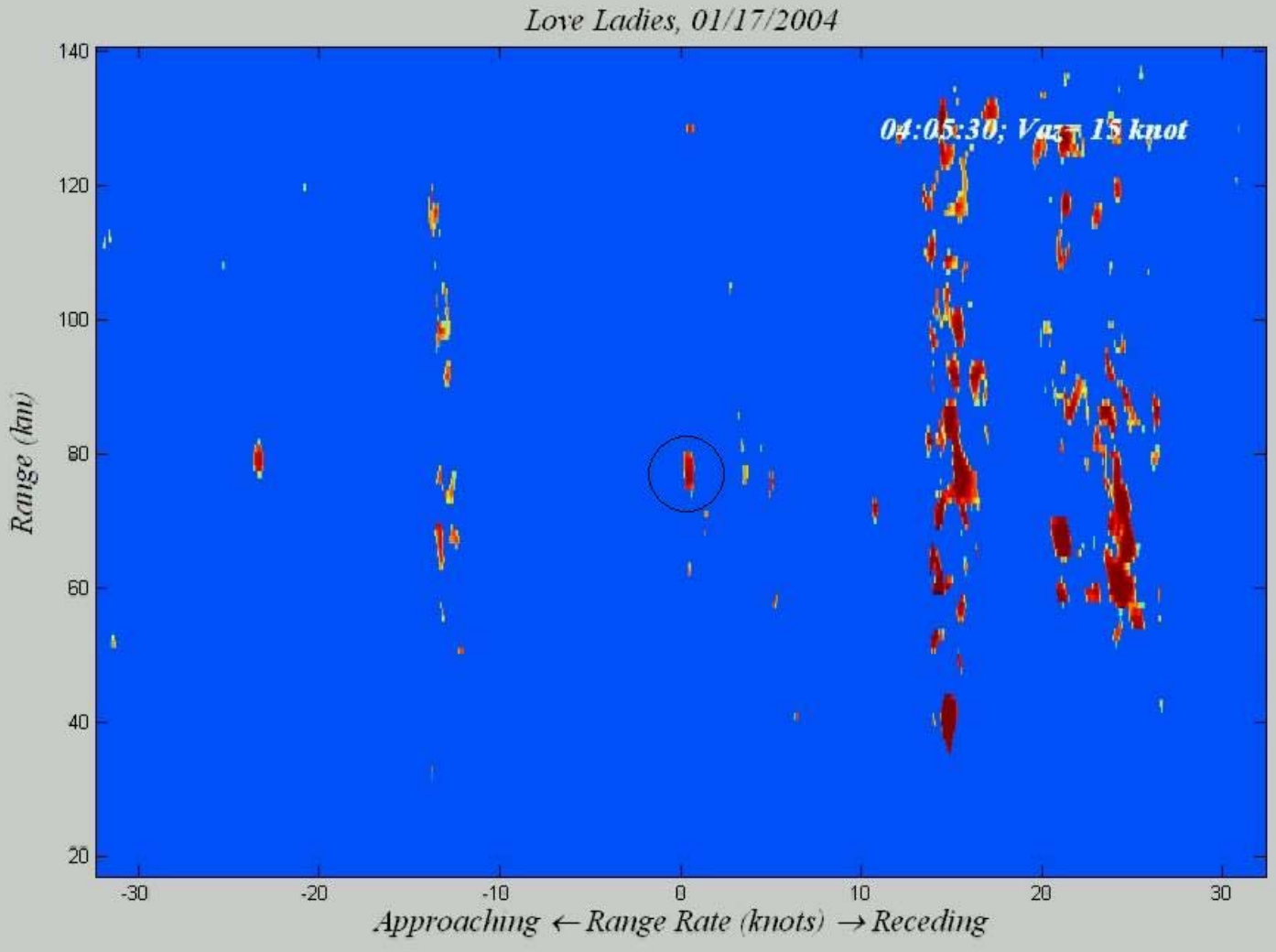
EXTRACTION

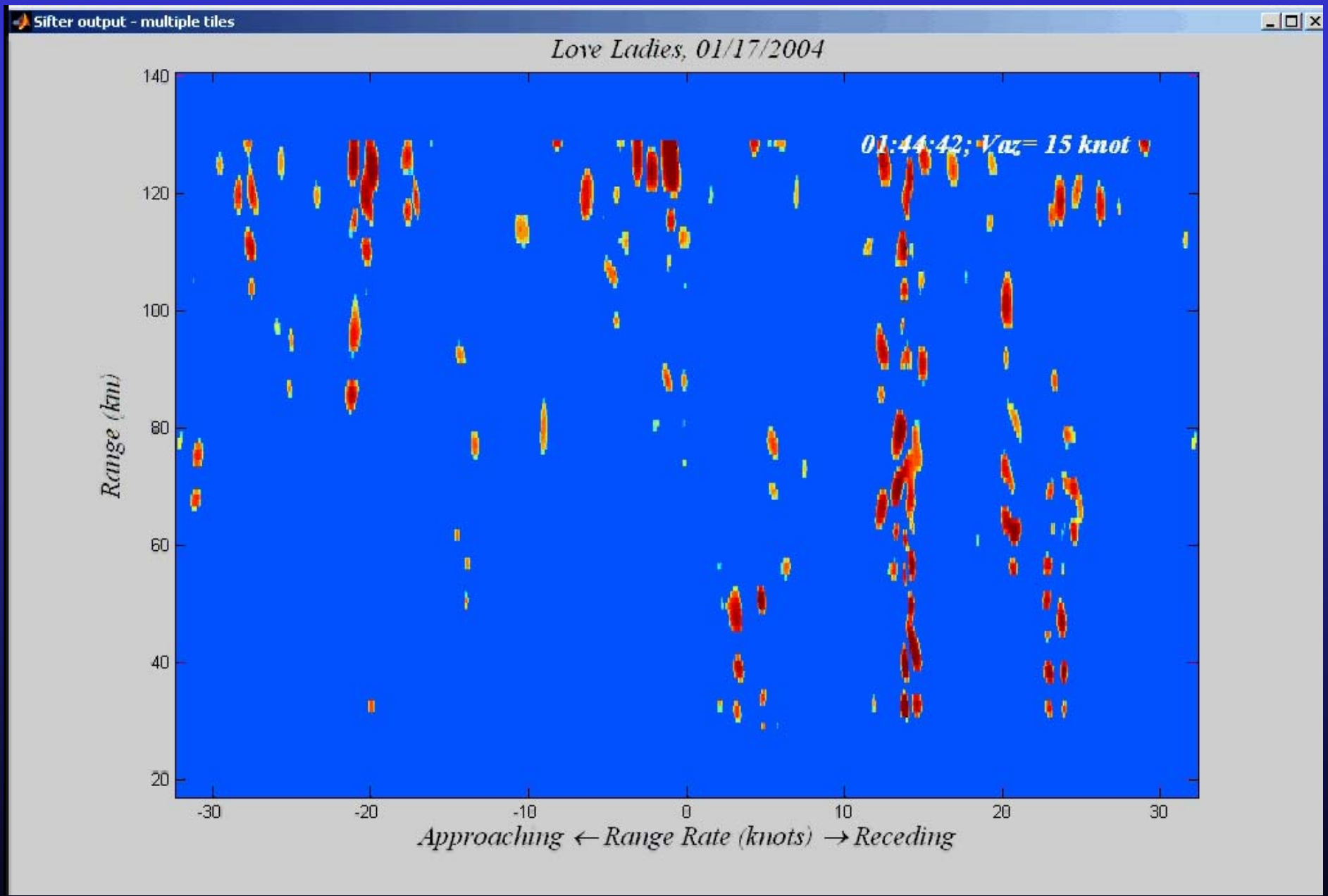
&

REGISTRATION

- Developed by Mission Research Corporation (MRC)
- Originally developed for ROTHR (Relocatable Over The Horizon Radar)
- SIFTER rejects peaks that do not move in a consistent way
- SIFTER finds “smoothest” distribution of scatterers that reproduces HFSWR or ROTHR measurements
- Targets appear as localized peaks

SIFTER Results



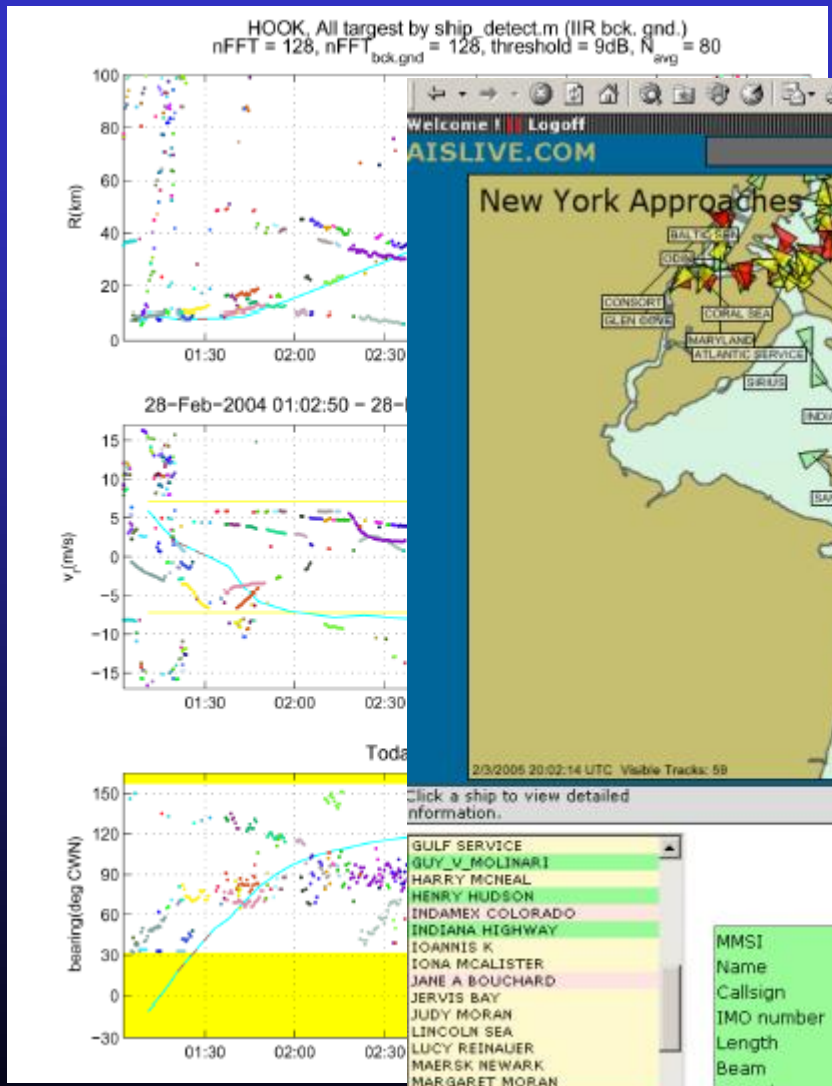

Sifter output - multiple tiles
Love Ladies, 01/17/2004
01:44:42; Vaz= 15 knot
Range (km)
140
120
100
80
60
40
20
-30
-20
-10
0
10
20
30
Approaching ← Range Rate (knots) → Receding

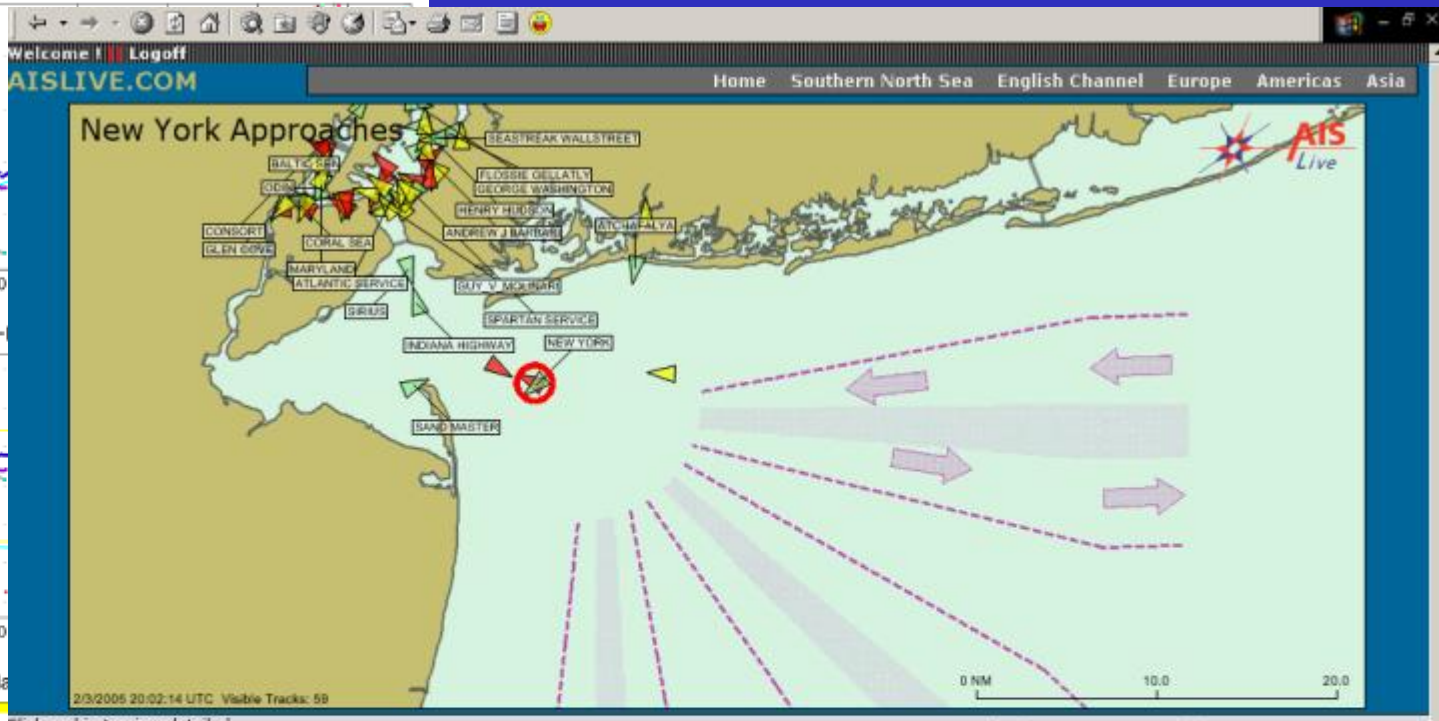
Future Work

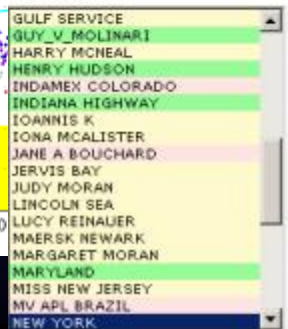
- **Utilize AIS signal to ground truth multiple ship tracks**

- **New and Different Targets**

Automatic Identification System (AIS)







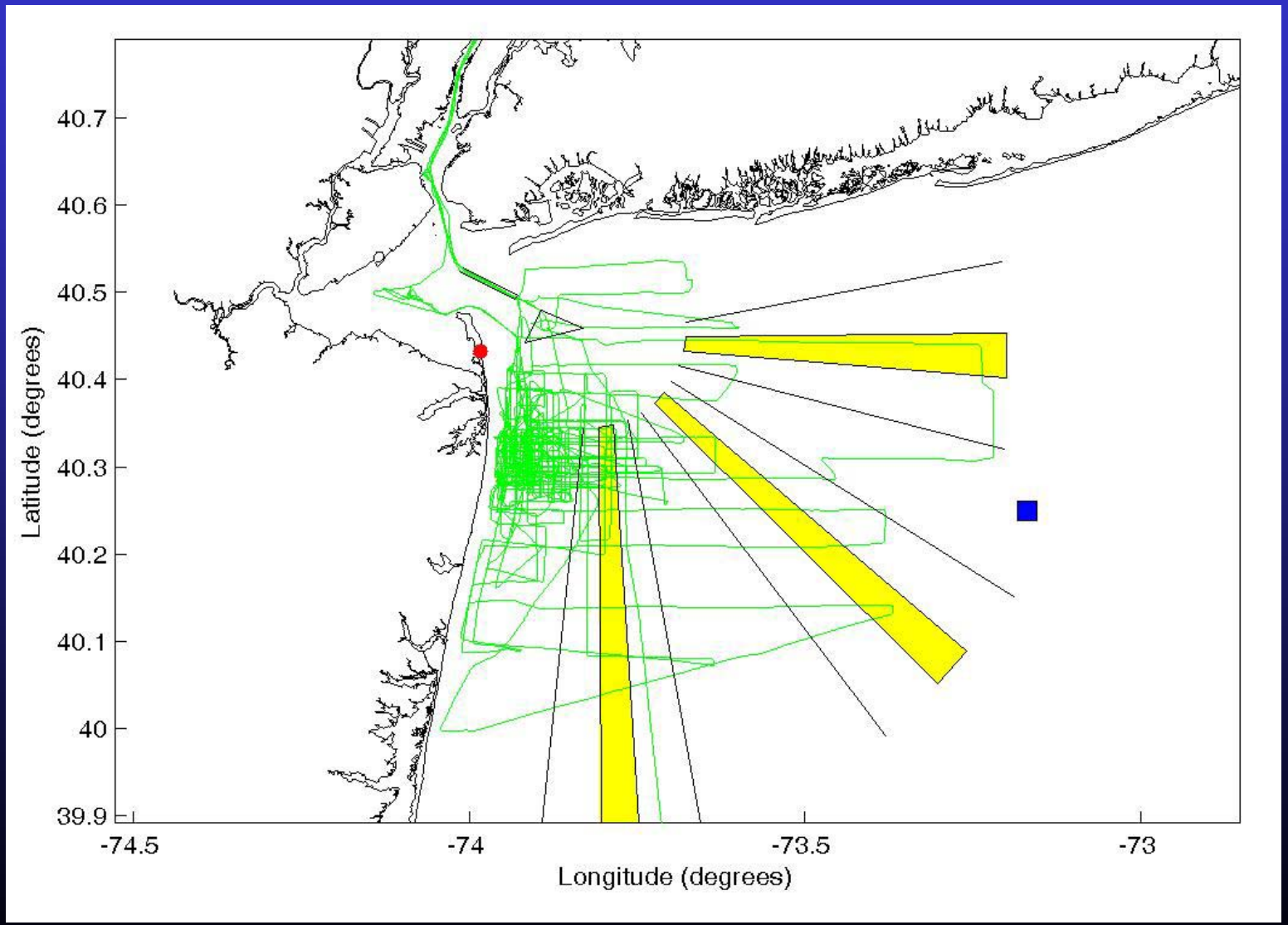
MMSI	449	Last seen at	2/3/2005 19:54:55 UTC
Name	NEW YORK	Latitude	N 40°28.541'
Callsign	WZH4694	Longitude	W 73°52.854'
IMO number	7437068	Heading	230°
Length	51 m	Speed	2.2 knots
Beam	18 m	Destination	PILOT STATION
Draught	0.0 m	ETA	31/12/9999 23:59:59 UTC
Vessel Type	Pilot Boat	Status	Under way using engine
Extra Info	N/A		

177’ R/V Oc

tal Patrol Boat

32’ Go-Fast Boat

135’ R/V Cape Hatteras

47’ Motor Lifeboat

GPS Track of RV Cape Hatteras during LATTE 2005