OCEAN AND RESOURCES ENGINEERING

IN THE SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY AT THE UNIVERSITY OF HAWAI'I AT MĀNOA

Fusing data from near-shore and long-range sensors in a multi-layered network

Kai Gemba
Department of Ocean and Resources Engineering
University of Hawai'i at Mānoa

Danielle Holden, Hasan Shahid, Fatima Diop, Hector Pacheco, Brandon Gorton
Daniel Reynolds, Samuel Otu-Amoah, Tyler Hee Wai, Enrique Questell

DEPARTMENT OF HOMELAND SECURITY NATIONAL CENTER OF EXCELLENCE AT STEVENS INSTITUTE OF TECHNOLOGY

PORT SECURITY

The National Center for Secure & Resilient Maritime Commerce

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SRI Objective and Architecture

2011 DHS, COE, CSR Summer Research Institute

To study and address the threat of pirated ships in the MTS being used as a dirty bomb

Consequence Assessment

Sensor and Technology Applications in Port Security

Define the strengths and limitations of sensor technologies to detect, classify, and track vessels in, near, and approaching the urban port environment

Long Range Technologies

Satellites, HF Radar, AIS

Near Shore Technologies

Acoustics, Electro-optics

Decision Support Methodology

Vessel categorization, threat assessment

Transportation & Security

- Purchasing Power
  - Trends and markets of the future
- Maritime Transportation System (MTS)
  - Access to worldwide markets (85% of all goods)
  - System of Systems (Bigger responsibility on the legs, i.e. loading, railroad, etc)
- Security & Resilience
  - Protected by cost guard, military, etc
  - S<u>ecurity vs. Operation</u> (i.e. Containers)

Presentation Outline

- Technology Overview
  - –Near Shore Systems:
    - Acoustics and Electro-Optics
  - –Long Range Systems
    - Satellites, AIS, HF Radar
- Data Collection & Layered Architecture
- Tracking Examples
- Decision Support
- Acoustic integration for Hawai'i (Oahu)

  →My current research & plans

Stevens' Research Vessel,
RV Savitsky on Hudson River

Acoustic Data Collection & Processing

In Water System

SPADES
Stevens Passive Acoustic Detection System

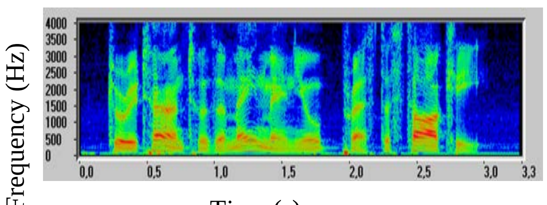
Data from hydrophone acquired and recorded

Data pre-processed in underwater system and transmitted digitally

SPADES GUI

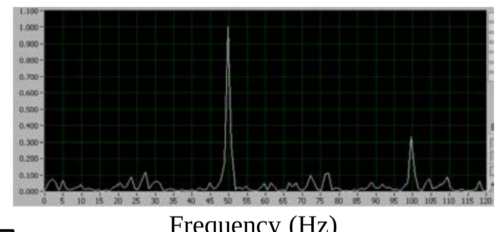
Land based system

Spectral Analysis



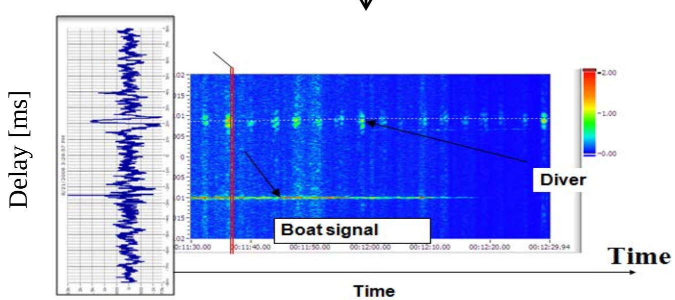
Spectrogram

Signature Analysis

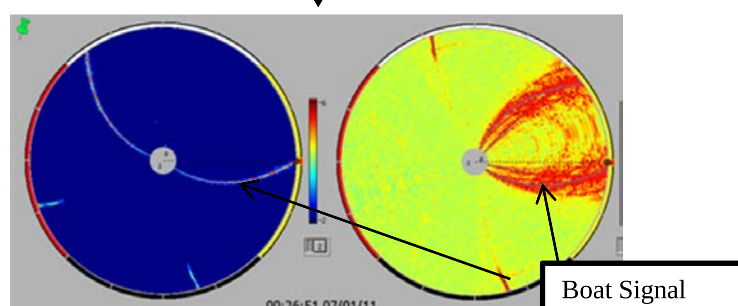


Demon Spectrum

Cross-Correlation Analysis



Cross-Correlogram



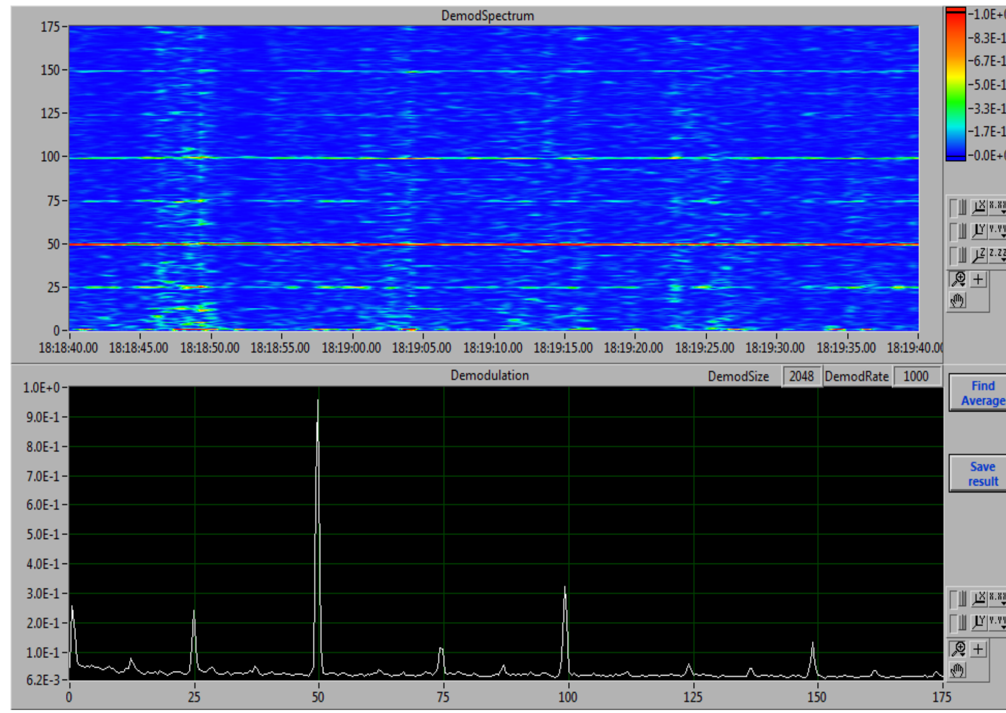
Circular Cross-Correlation

DEMON Analysis

- **De**tection of **E**nvelope **M**odulation on **N**oise
- Allows for classification by demodulating vessel specific noise
- Demonogram (top) shows how the spectral density of a vessel characteristic signal varies with time
- Demon Spectrum (bottom) shows the time averaged (60 s) representation of a vessels signal in the frequency domain

Demonogram and DEMON Spectrum

Frequency (Hz)



Frequency (Hz)

Infrared vs. High-resolution video

Video taken on July 4, 2011 from Maritime Security Laboratory

Infrared Image

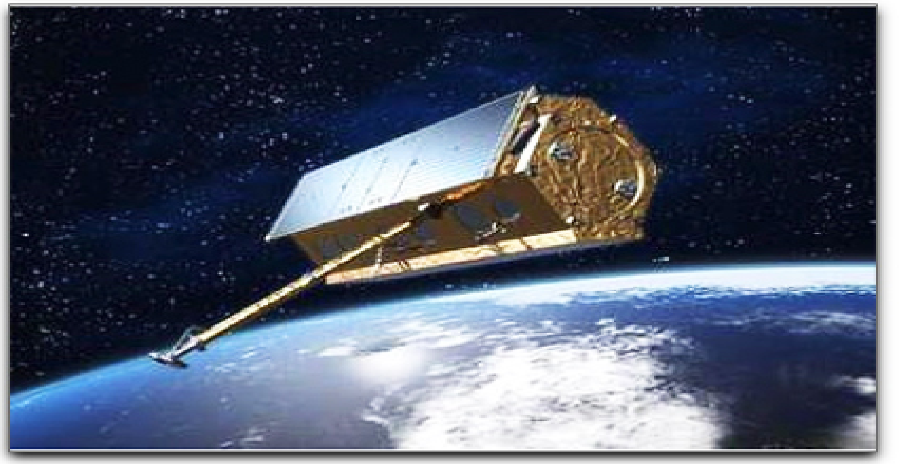
-Thermal image does not change
-Vessels can be tracked independently of light source

Optical Image

-Vessels are hard to track as natural light decreases (use their self lightening)
- Vessels are impossible to track w/o own light

Satellites - Introduction

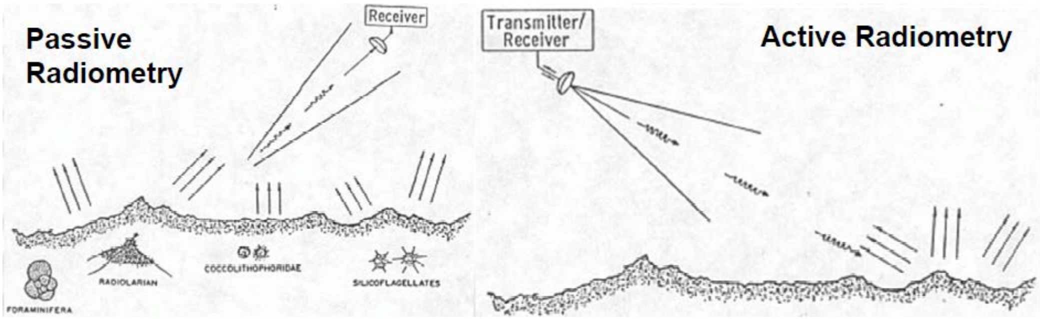
SAR image of NJ, Manhattan and Brooklyn



TerraSAR-X-Satellite (EADS-Astrium)

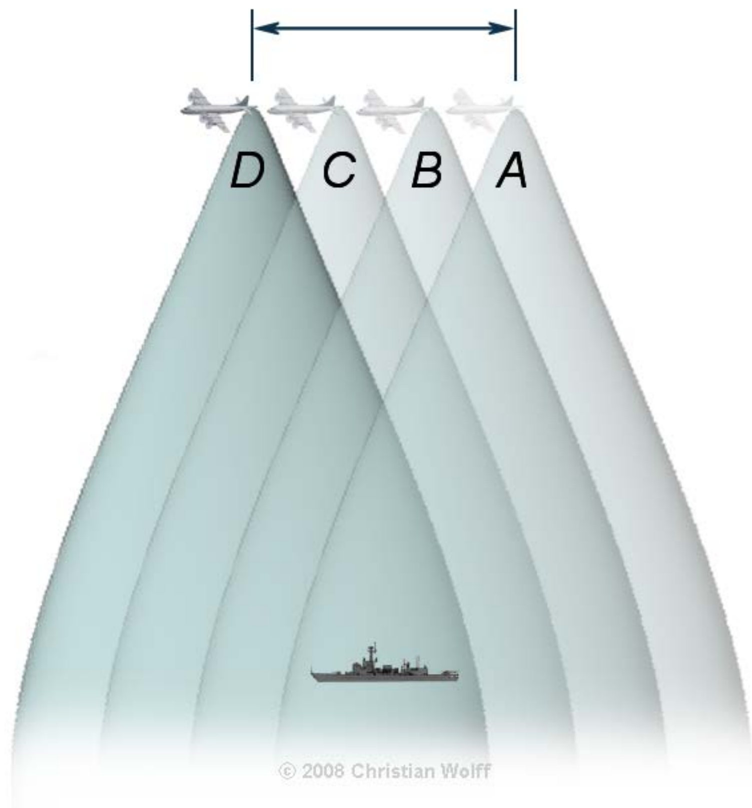
Early detection
- Low to high resolutions
- Monitor environmental conditions
- Limited availability
- Required trained personnel to operate
- High operational cost
- Processing time depends on orbit, post-processing, and image download time

Types of Satellite Imaging



Optical

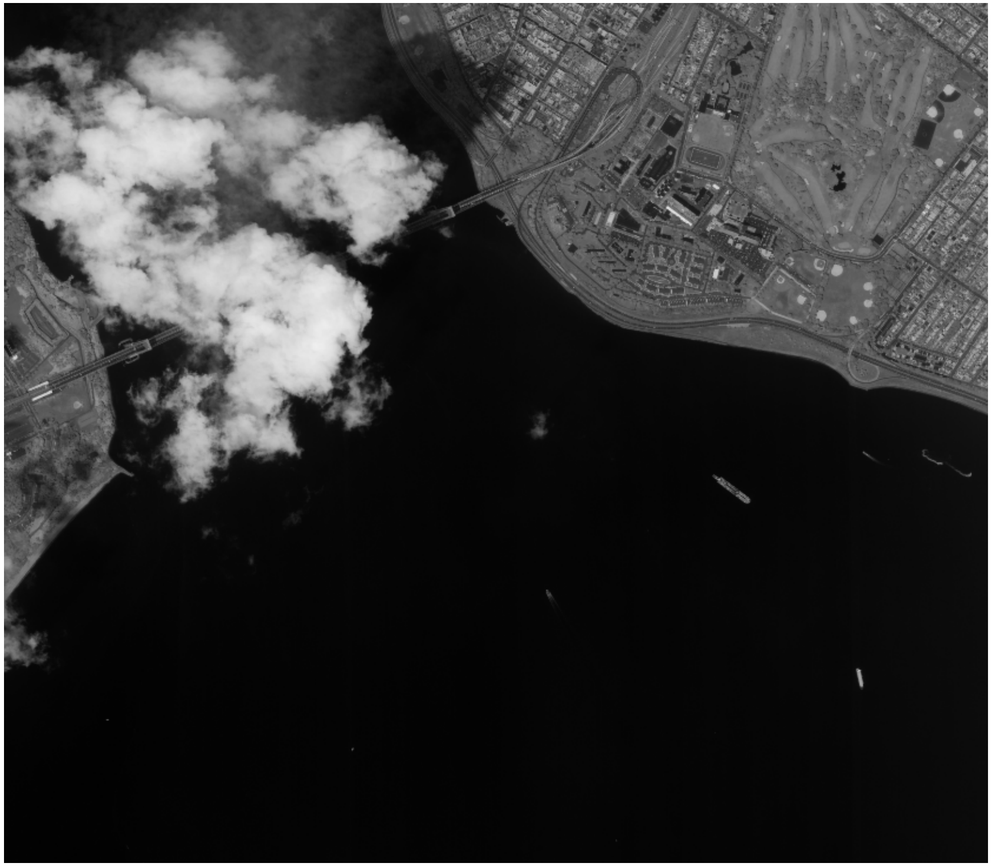
- Uses visible and infrared light
- Passive detection
- No image distortion



Synthetic Aperture Radar (SAR)

- Uses radio waves
- Active detection
- Higher resolution images, covering larger areas
- Flight path simulates large antenna (phase corrected signal summation)
- Images are distorted
- Can look through clouds
- Study Internal waves
- Thermal expansion of buildings

Satellite image comparison: Optical vs. SAR



EROS-B at 18:57:00 GMT on 7/11/2011

- Clouds covering bridge
- Wakes of vessels barely visible

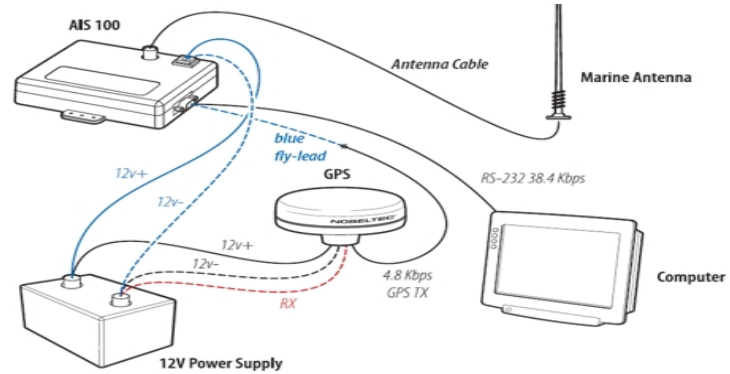
COSMO-SkyMed at 22:49:02 GMT on 7/11/2011

- No clouds
- Wakes of vessels visible
- Buildings leaning to right

Automatic Identification System (AIS)

AIS Vessel Display, Hudson River

Rutgers AIS, Port of NY Entrance



Vessel Identification

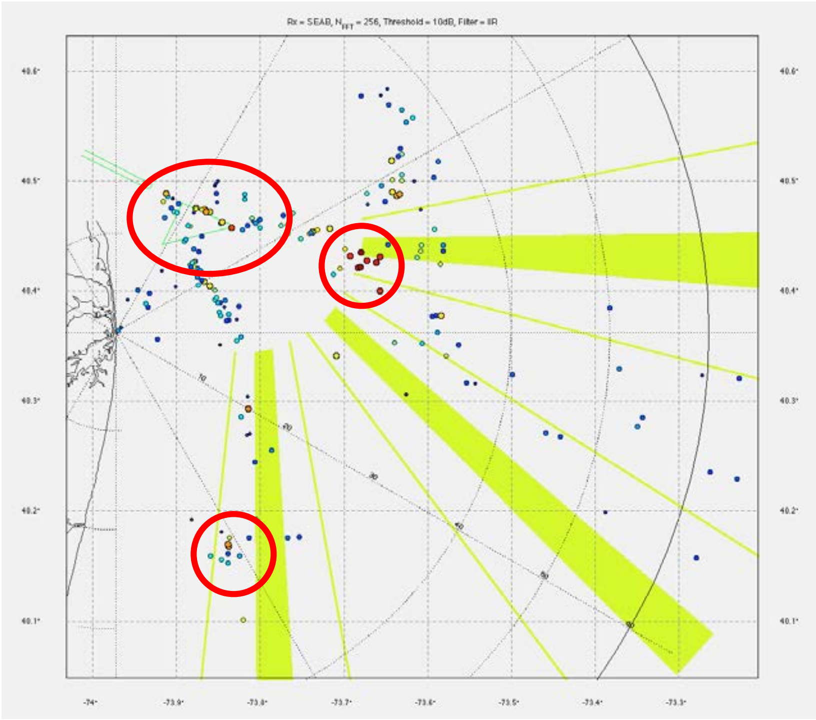
-Tracks time and location of vessels
-Provides name, type of vessel, MMSI #, country of origin
-Class A and Class B
-Stevens, Rutgers, and Coast Guard receivers
-Compatible with Google Earth
-Only effective when AIS transmitter is turned on in vessels

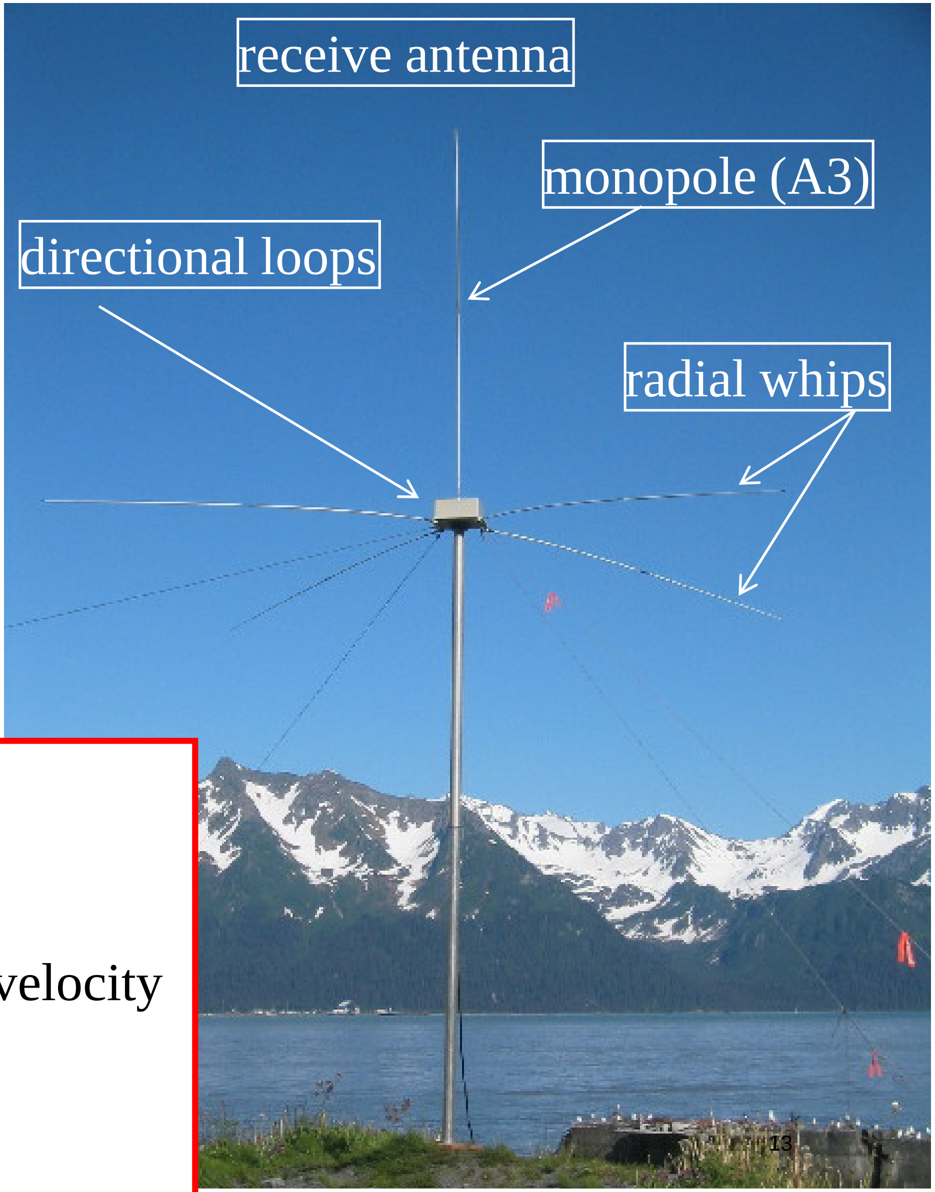
Ship Identification-AIS

- Comparison of SAR Satellite image and AIS Google overlay
- SAR image taken by TerraSAR-X on 10:56:19 GMT on 7/12/2011
- Vessel's Details
  - Speed recorded (Max): 10.2 knots
  - Call Sign: WDD5445

Source: marinetraffic.com

HF Radar - Introduction





Vessel Detection

-Detection range: 0 to 70 km

-3 to 30 MHz or 100 - 10 m wavelength

-Detects vessels trajectory, distance and velocity

-Cannot characterize type of vessel

-Effective in fog and rain

-Requires surface disturbance

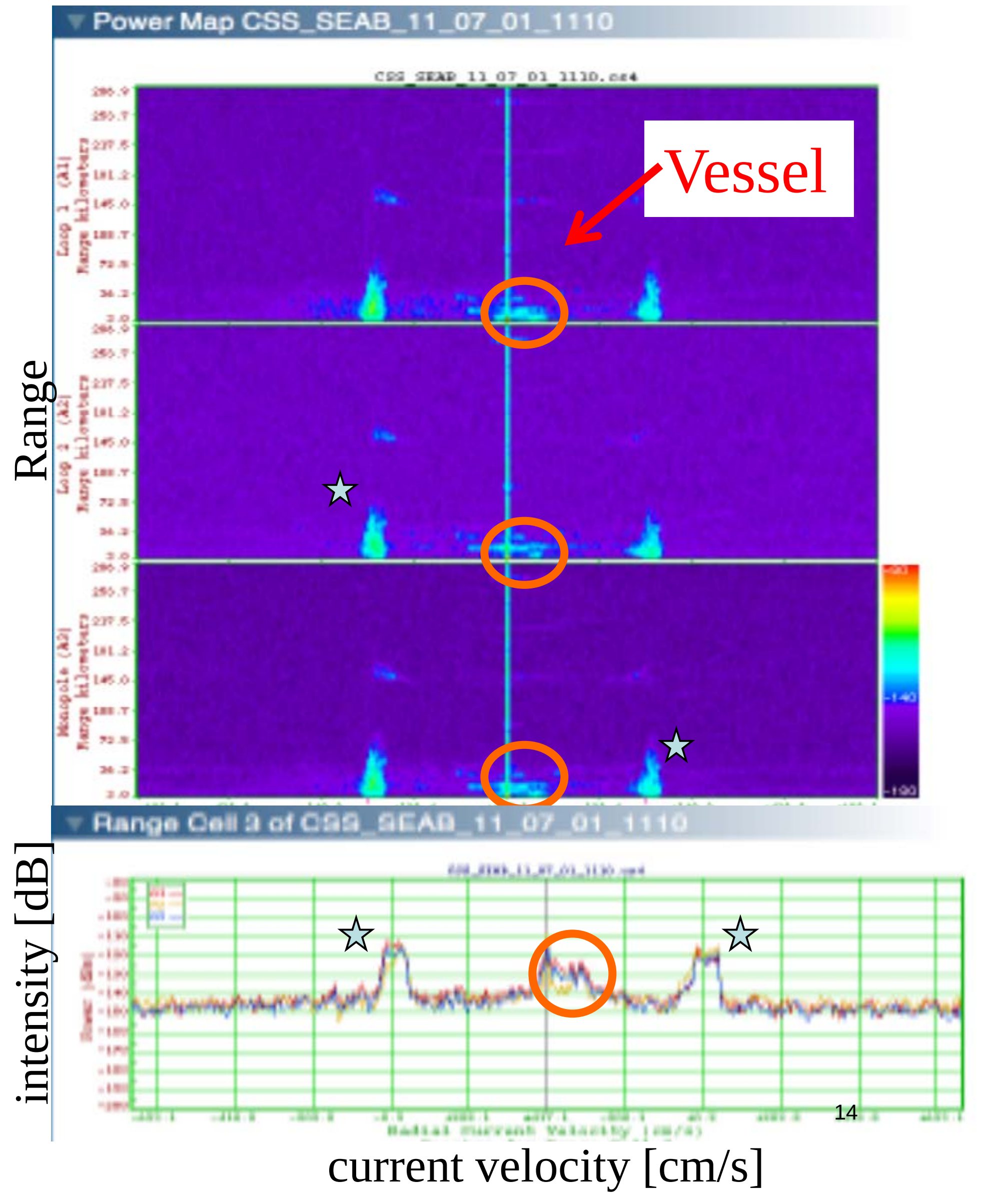
HF Radar - Introduction

Cross Spectral Image

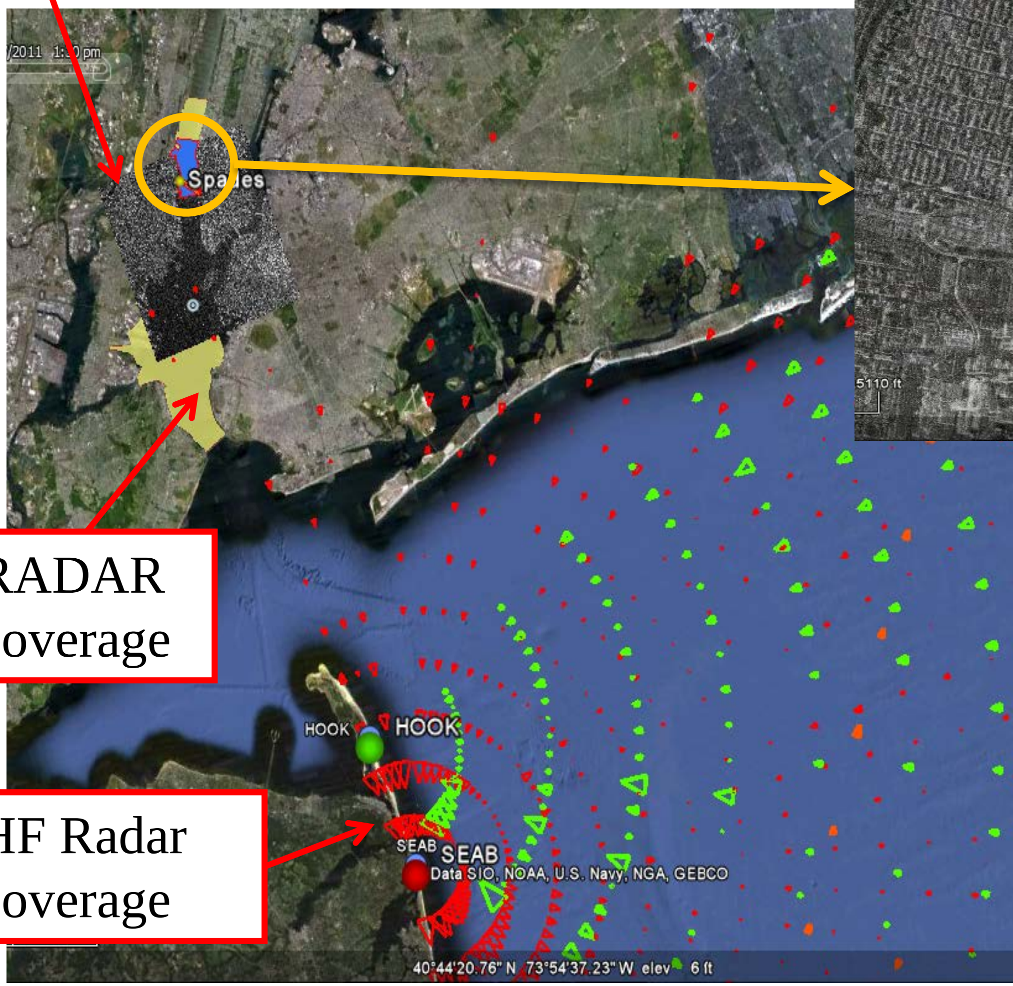
- Three plots show 2 directional loops and monopole
- Doppler spectrum determines vessels direction and speed
- Bragg Waves: ☆ A measure of radar signals scattered by waves

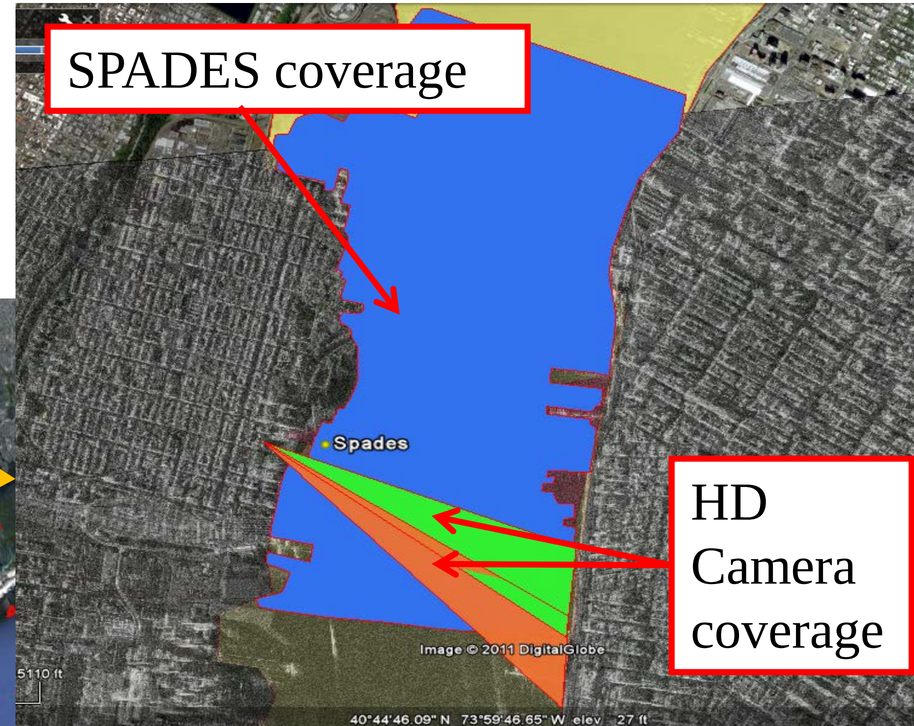
Range Cell Image

- 95 range cells with each range cell being ~3 km long
- Three colors represent three loops, or antennae on the radar



Layered Architecture





- SPADES

- max detection range: 2.5 km

- usual detection range: 1.2 km

- Coverage hole in the layer between SPADES and HF Radar

Data Collection Process

Sea - Seek

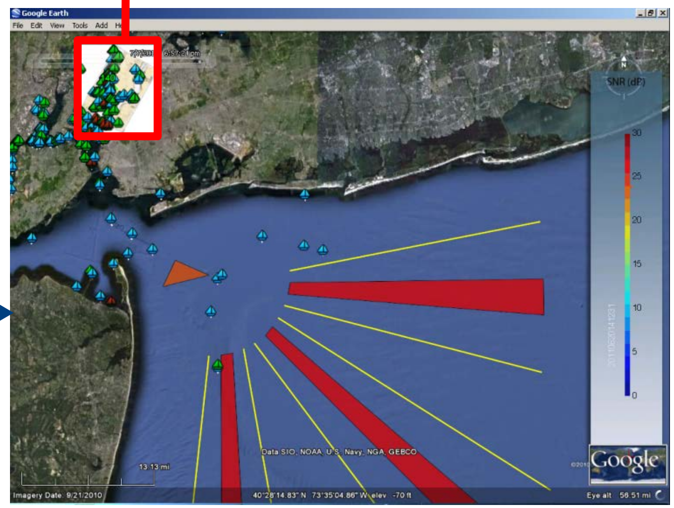
AIS

RADAR

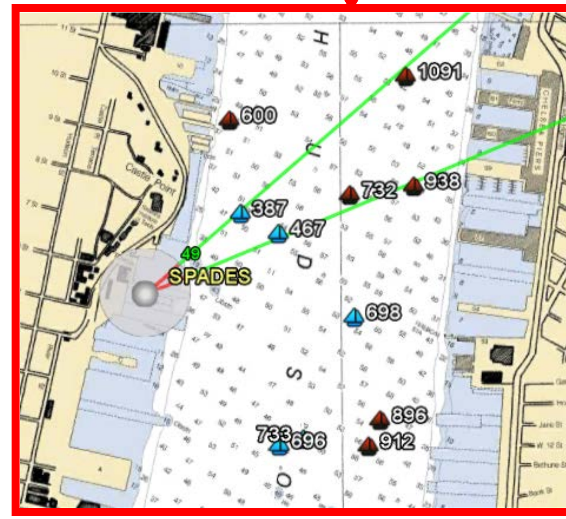
SPADES

HF Radar

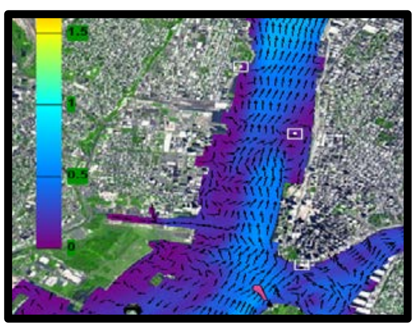
Satellite



HF Radar Map (Google Earth)



AIS, Radar, and Spades Map



NYHOPS

Record and review

Optical and IR Camera

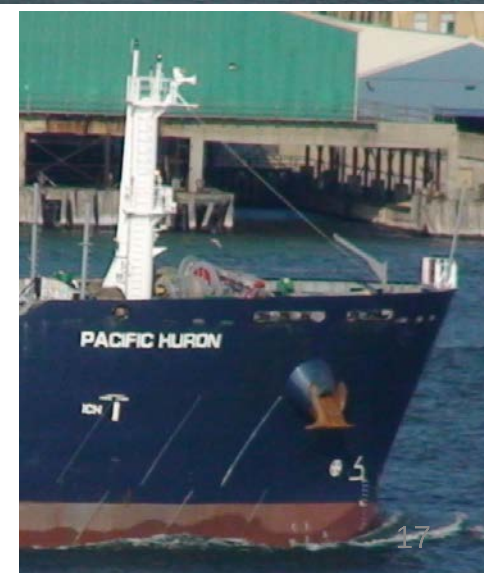
135

22:49:02 GMT on 7/12/2011
Pacific Huron

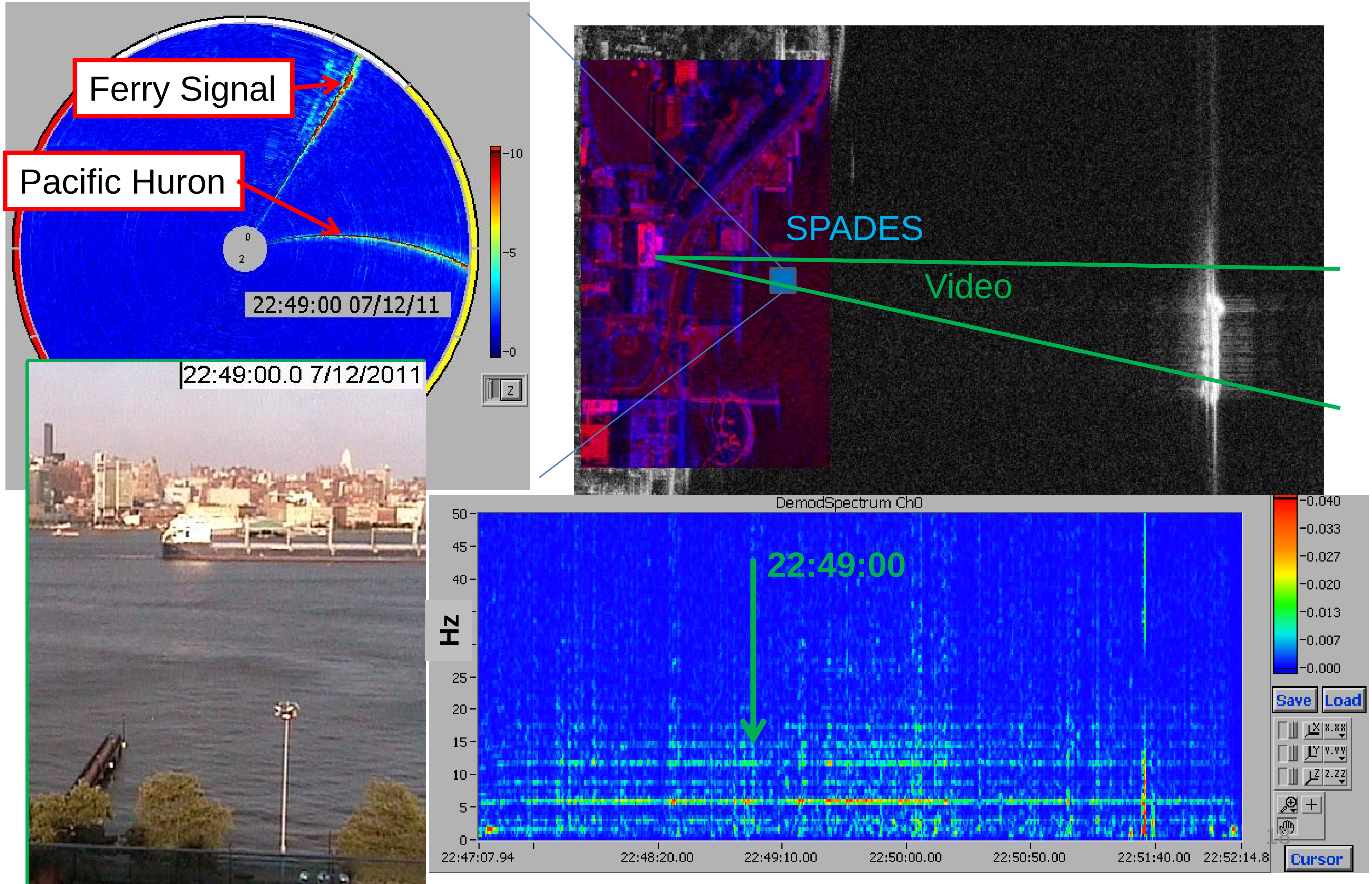
- Example of acoustic layered architecture
- AIS ID: 305535000
  - Ship Type: Cargo
  - Length x Breadth: 190 m X 25 m
  - Flag: Antigua Barbuda [AG]

Sensor Type	Time (GMT)	Distance* (m)
Acoustic detection	22:41	2023
Video detection	22:46	872
Satellite	22:49	646
Video loses contact	22:52	944
Acoustic loses contact	22:55	1475

*Distance measured from SPADES



135 Tracking Redundancy: Pacific Huron



Detection Distances

- Acoustic detection depends on several factors
  - background noise (bridges, rain)
  - interferences from other targets (coherent noise)
- Maximum detection distance for SPADES bounded by two ferry terminals (2.5 km N, 750 m S)

Carnival Miracle: Cruise Ship
Detection : 1200 m, Loss: 1200 m

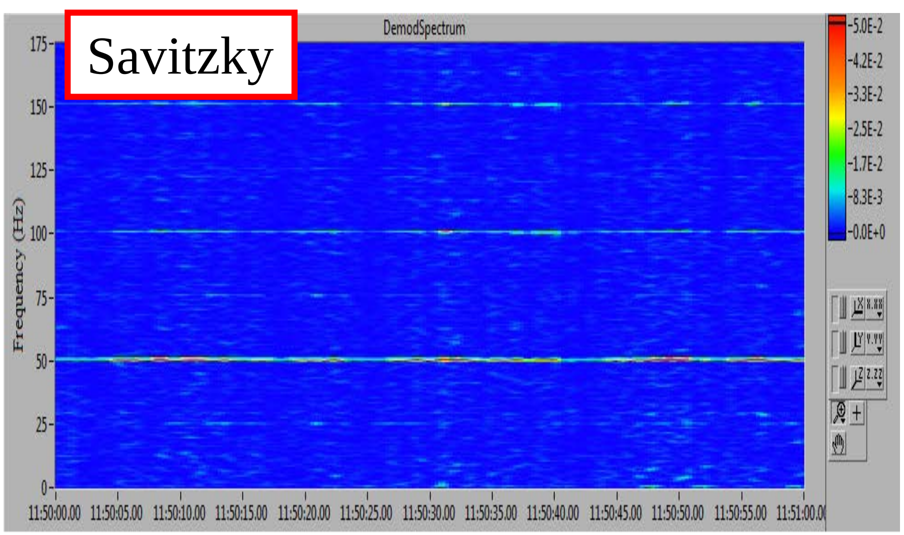
Thomas D. Witte: Tug Boat
Detection: 550 m, Loss 1000 m

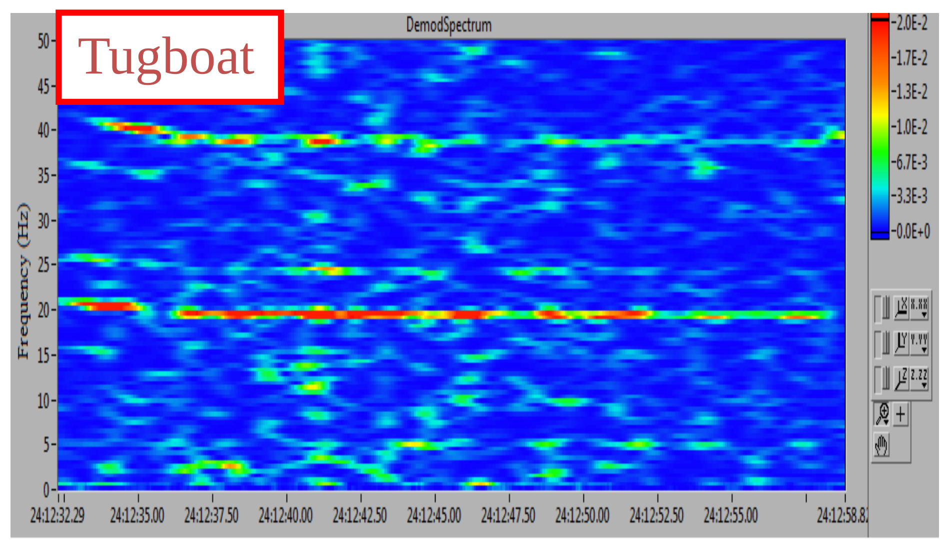
Small Pleasure Craft
Detection: 450 m, Loss 800 m

Robert Fulton: NY Ferry
Max Detection Distance: 2500 m

Acoustic Classification

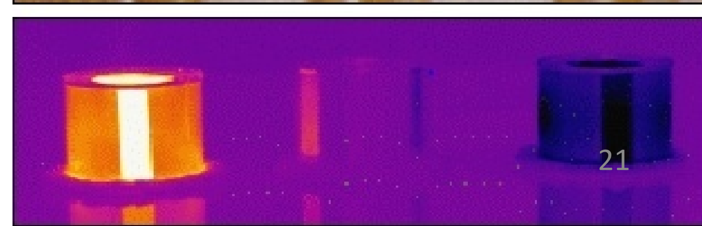
Vessel type	Fundamental Frequency range [Hz]	1st Harmonic [Hz]	2nd Harmonic [Hz]	3rd Harmonic [Hz]	Other frequency [Hz]
Tanker	4-6	8-12	n/a	n/a	n/a
Tugboat	14-20	28-40	n/a	n/a	n/a
Pleasure boat	88-97	n/a	n/a	n/a	154-172
34 foot Zurn	81	n/a	n/a	n/a	141,222
Jet Ski	26	53	79	105	n/a



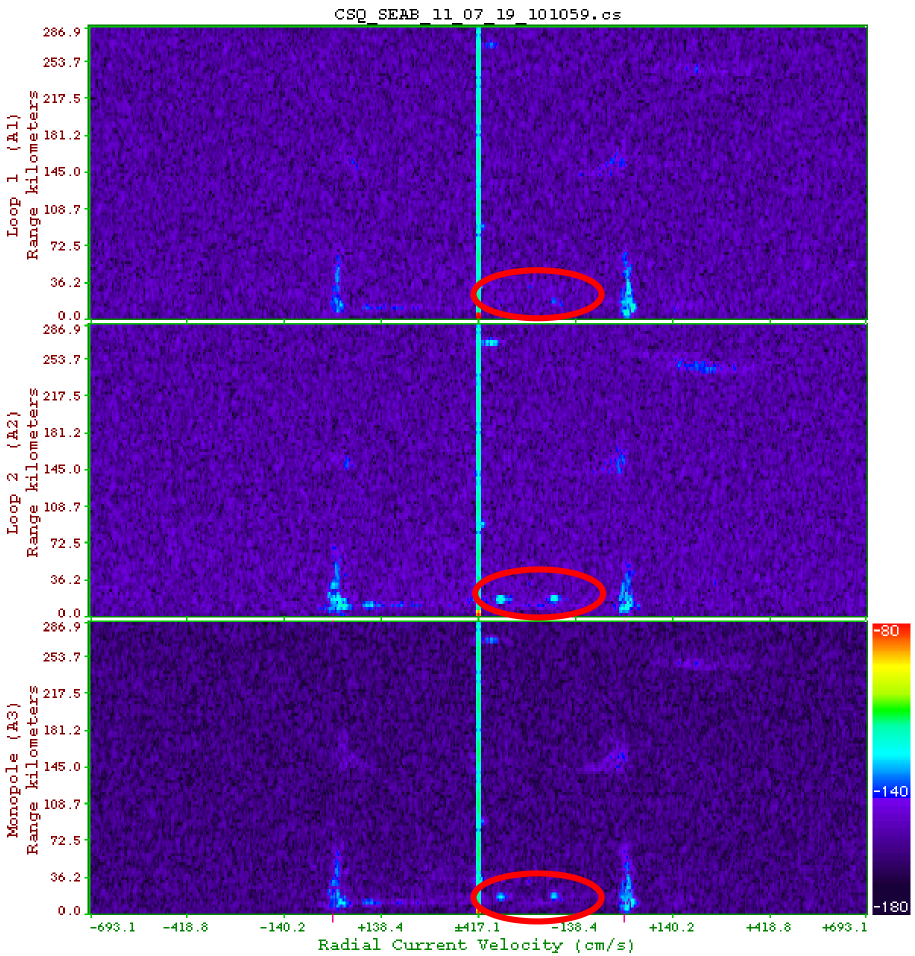


Near Shore Technologies

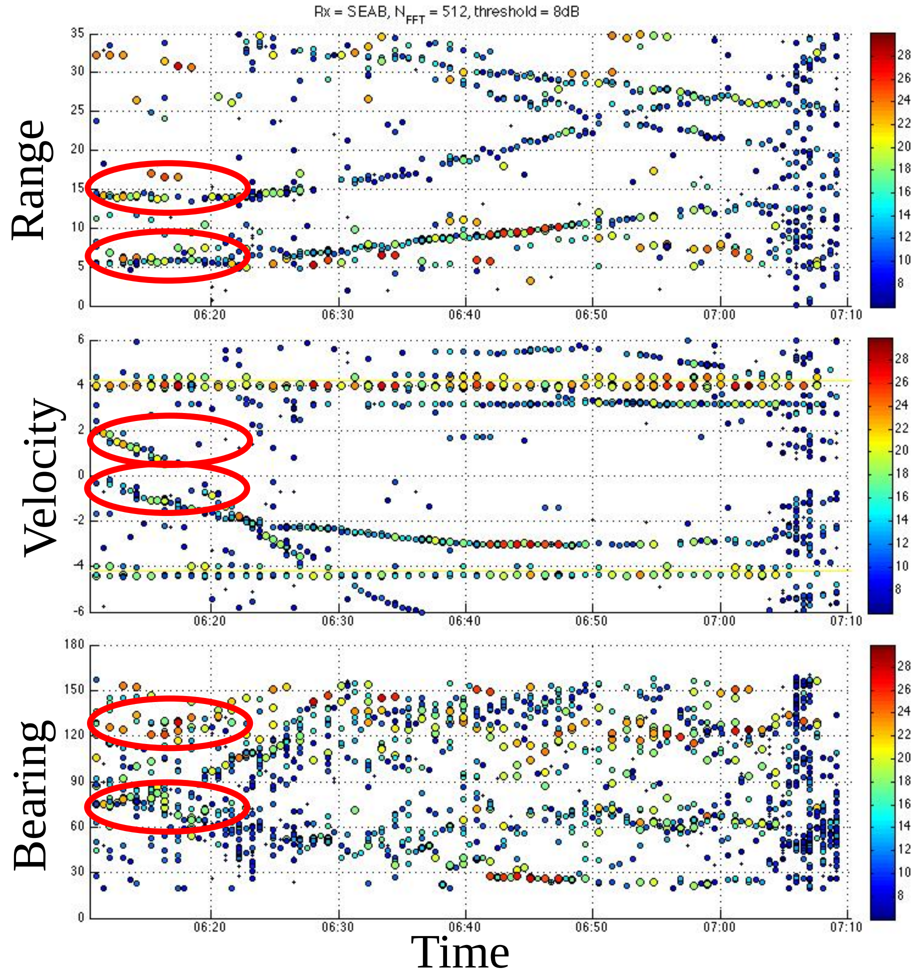
- Conclusions
  - **Acoustics** is a reliable system in tracking vessels of interest (real time!) in the absence of dominant noise (i.e. other vessels or rain)
  - Successful in detection, tracking and classification but more complicated (changing environment)
  - Additional technologies (underwater optics, gliders, floats..)
  - **Electro Optics** can be used as detection and validation tool (requires operator)
  - IR limitations have to be considered (reflectivity & emissivity)



Long Range Tracking: HF Radar



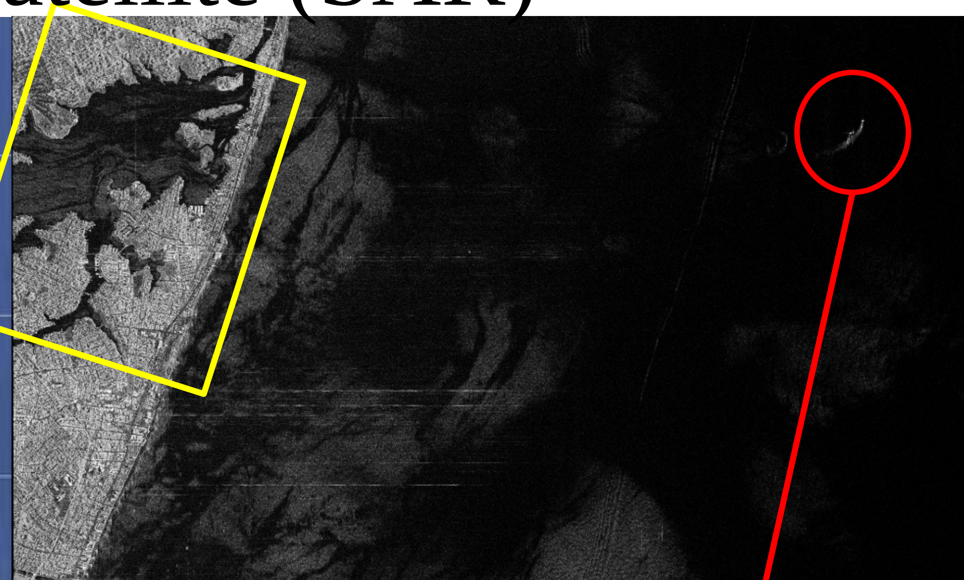
Cross-spectra, 10:10:59 GMT on 7/19/2011



Ship Detection GUI, 10:20:00 GMT to 11:10:00 GMT on 7/19/2011

Long Range Tracking: AIS and Satellite (SAR)

AIS data overlaid onto Google Earth, 10:13:45 GMT on 7/19/2011

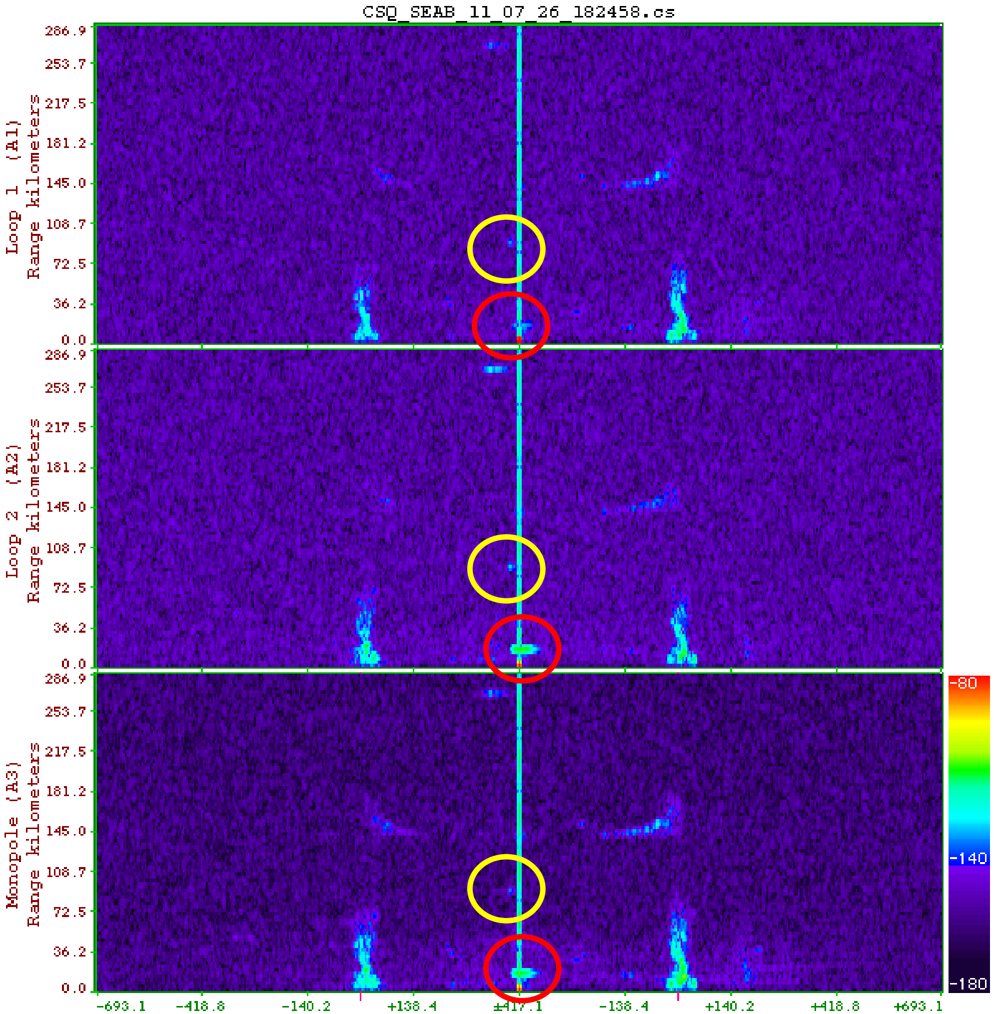


Satellite image taken by COSMO-SkyMed, 10:13:06 GMT on 7/19/2011

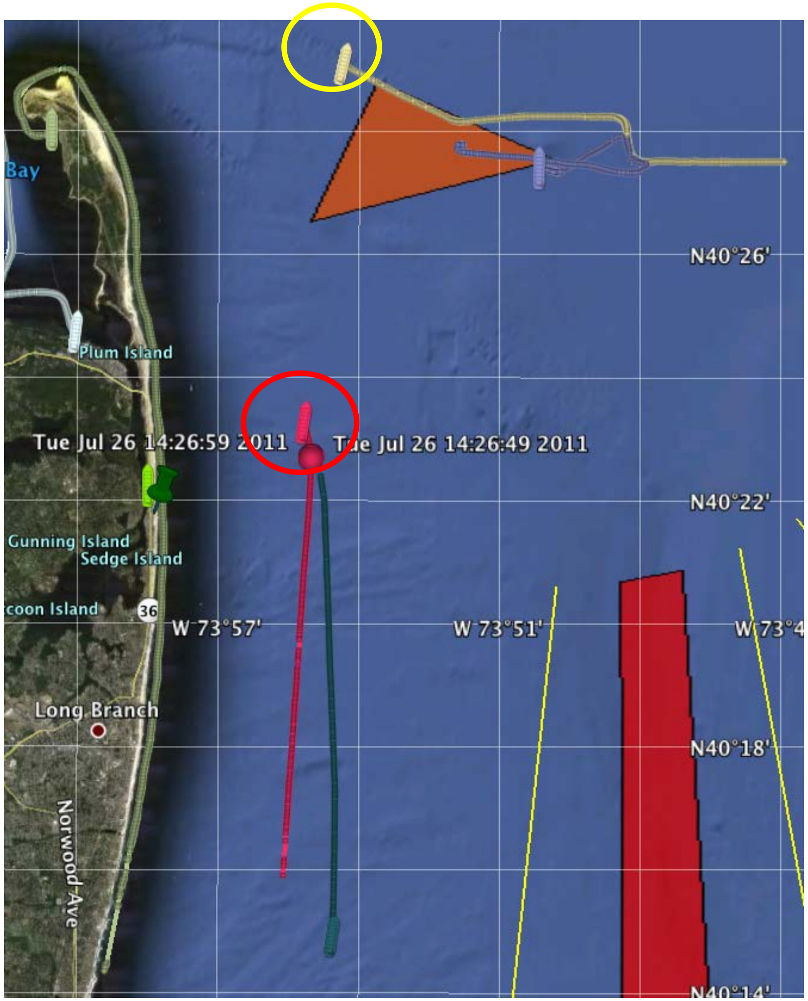
Joan Moran (MMSI # 368669000)

Miss Gill (MMSI# 367122680)

Long Range Tracking: Complimenting HF Radar with AIS



Cross-spectra, 18:24:58 GMT on 7/26/2011



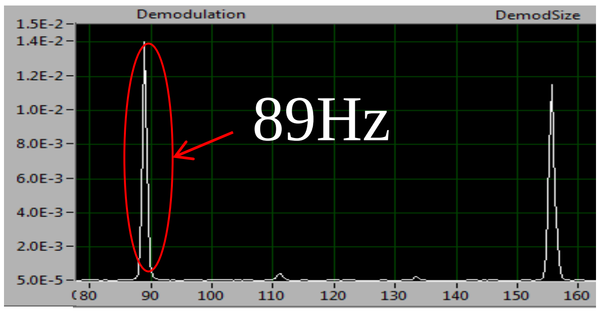
AIS data overlaid onto Google Earth, 18:26:59 GMT on 7/26/2011

Long Range Technologies

- Conclusions
  - Best used in a layered approach
  - Successful in detection, not identification
  - Good for port security because:
    - Satellite gives a large overview of the area
    - Good tools to display post effects (i.e. oil spill)
    - HF Radar can see over the horizon
  - HF Radar
    - Best used for surface currents (Search and Rescue)
    - Hard to clearly detect vessels
    - Individual stations can be synched to a network

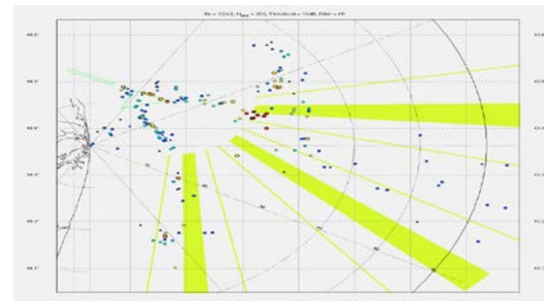
Multisource Data Interpretation:

How do you get from this…

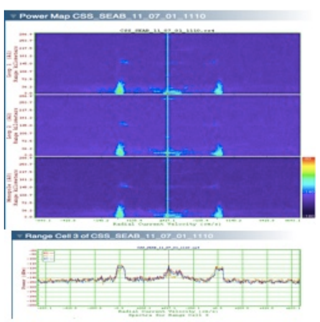


Characteristic Frequency

Blurry Camera

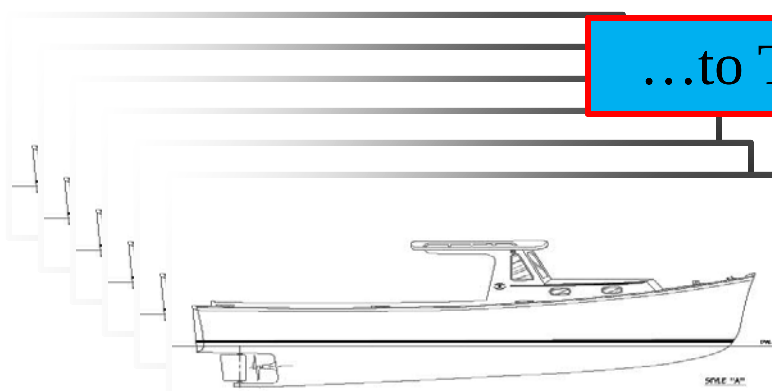


HF Radar Screen



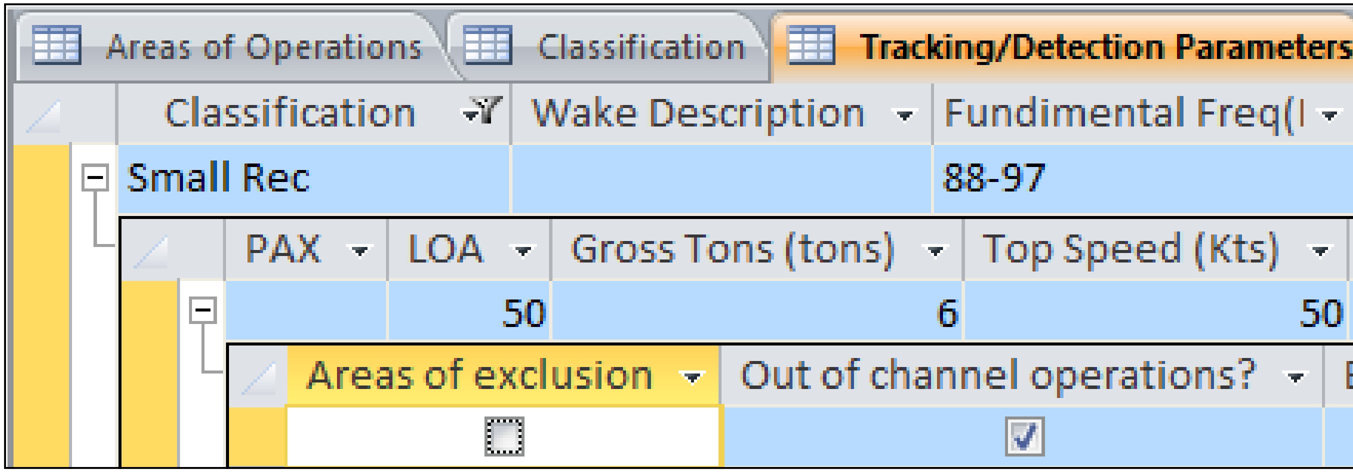
HF Radar,
Speed and Range

…to This?



Vessel Specifics

Process Breakdown:



Contact:

Fundamental Frequency: 88Hz

Small Recreational Vessel

Vessel Info:
-Length: 20-50'
-Draft <4'
-Beam: 6'

Suspicious:
-Should It be Broadcasting AIS?
-Is it Where Expected?
-Is it Acting as Expected?

MAGELLO GUI

- http://www.stevens.edu/csrmagello/

Acoustic Network in Hawaii

- Real time data collection and processing
  - Simplicity & robustness
- Export processed data to a GUI (.kml)
  - Simple and intuitive display for layering technologies
- Interaction with other technologies:
  - Record position and signature → provide acoustically relevant information about a source
  - complete time history

Next Steps

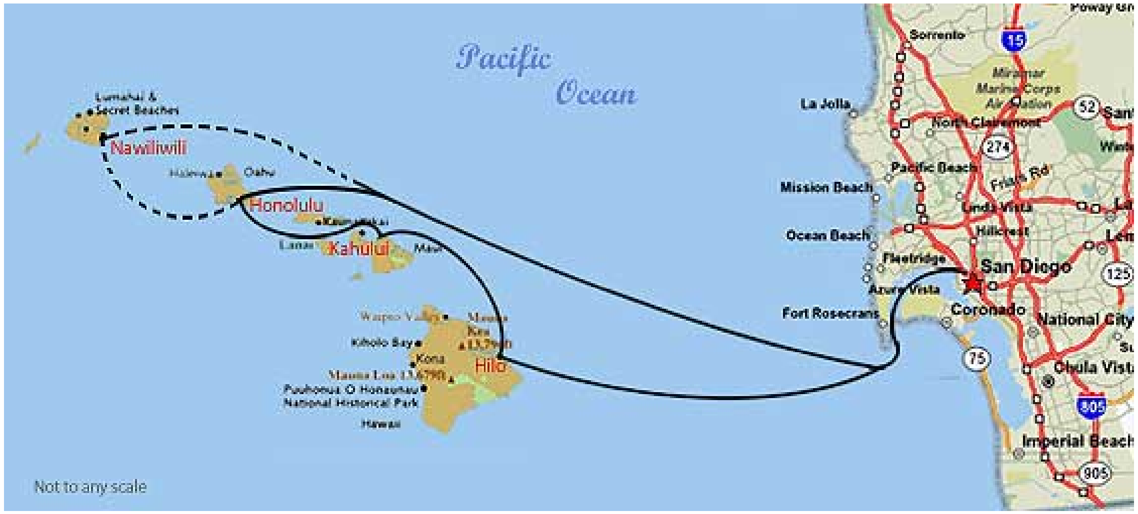
- Design and conduct an acoustic experiment on the south shore of Oahu this Fall
  - 10+ hydrophones, arranged in 2-3 clusters with both TDOA and Beamforming capability
  - Record Diver Signatures
    - Diver detection (breathing rate & frequency band)
    - Extraction of equipment specific frequencies
  - Vessel of opportunity / Diver tracking
    - Optimize with custom weights / UKF

Thank you for your time!

Are there any questions?

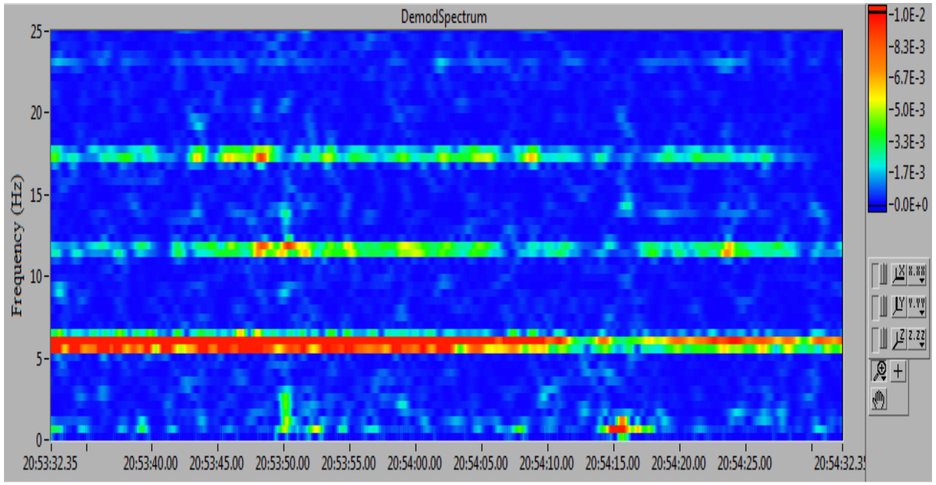
This material is based upon work supported by the U.S. Department of Homeland Security under Grand Award Number 2008-ST-061-ML0002.
The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Monitoring Early Vessel Traffic

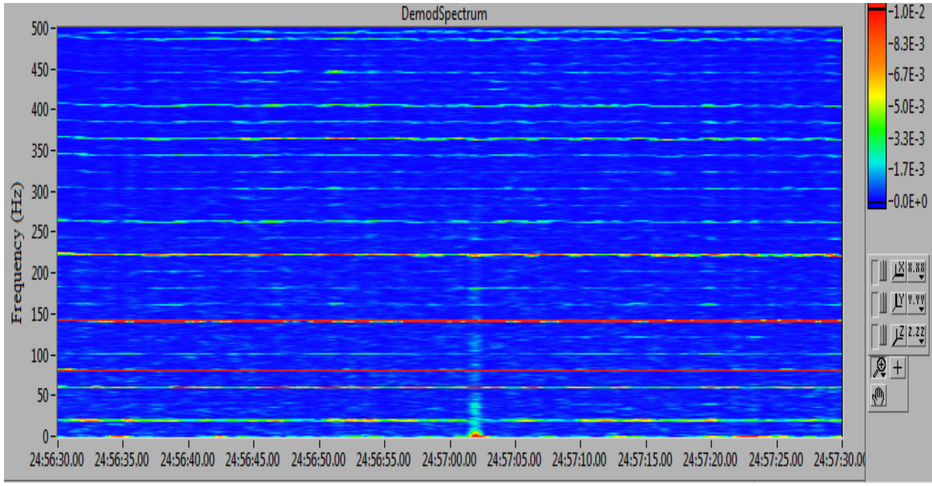


Long Range detection and tracking within major shipping lanes might be accomplished with 4 hydrophones

DEMON Spectra Classification



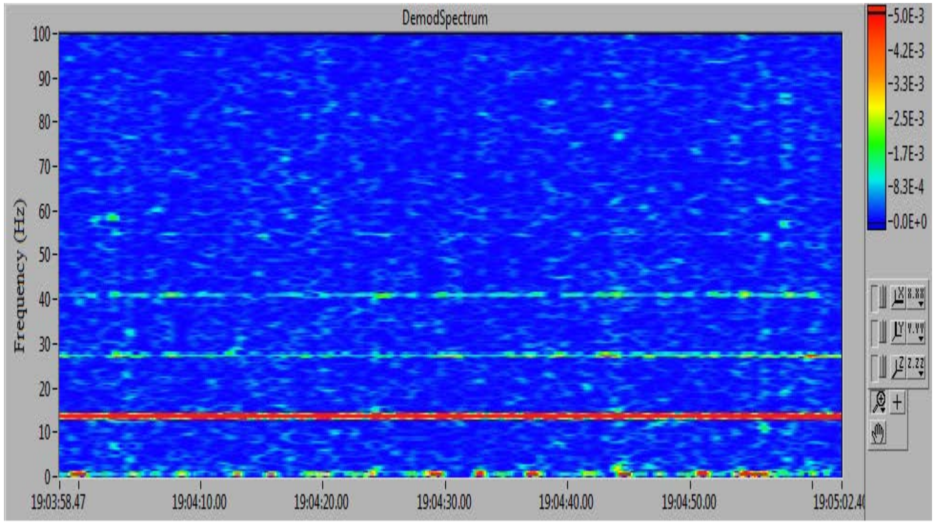
Circle Line Cruise Ship



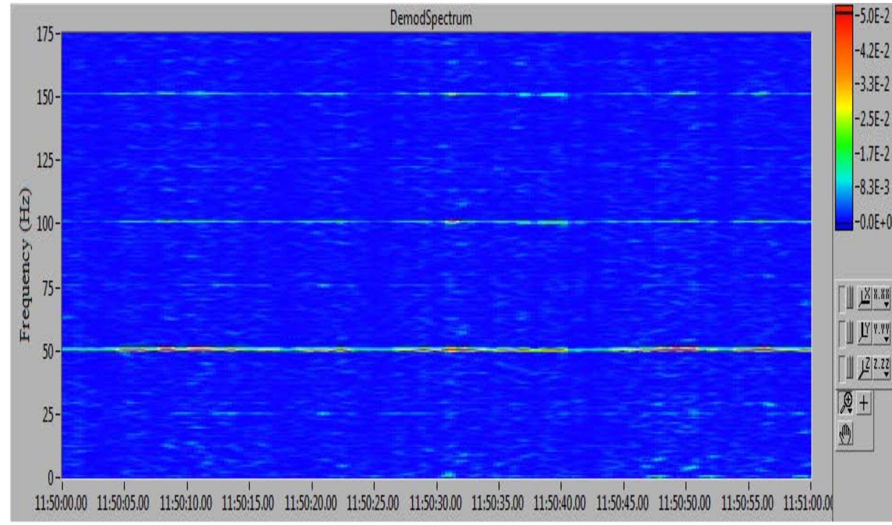
34 Foot Zurn Yacht

Vessel type	Fundamental Frequency range	1st Harmonic	2nd Harmonic	3rd Harmonic	4th Harmonic	Other frequency
Small cruise	5-6	10-12	15-18	n/a	n/a	n/a
Ferry	10-12	n/a	n/a	30-36	40-48	n/a
Tanker	4-6	8-12	n/a	n/a	n/a	n/a
Tugboat	14-20	28-40	n/a	n/a	n/a	n/a
Savitsky	47-54	95-109	143-163	n/a	n/a	n/a
Small pleasure boat	88-97	n/a	n/a	n/a	n/a	154-172
34 foot Zurn	81	n/a	n/a	n/a	n/a	141
Jet Ski	26	53	79	105	n/a	n/a

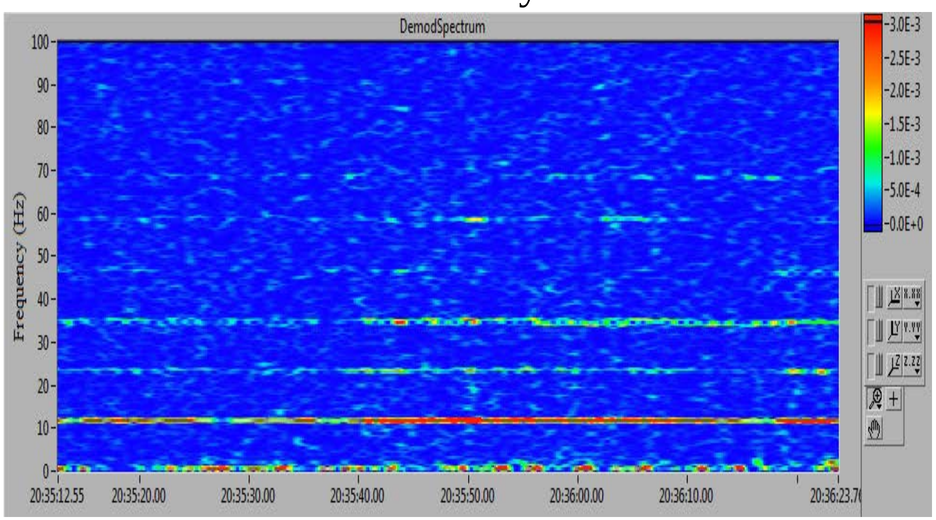
Stability of Demonogram

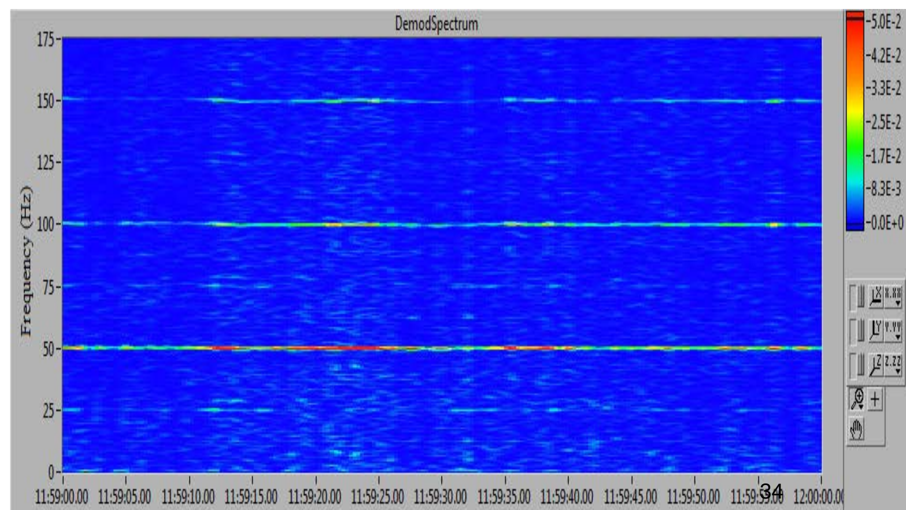


Abraham Lincoln Ferry 7/11 19:04



Savitsky 7/11 11:51

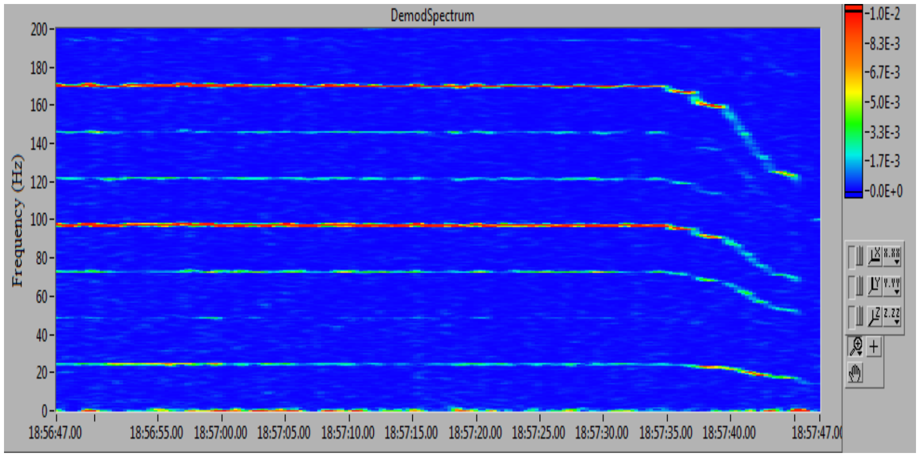




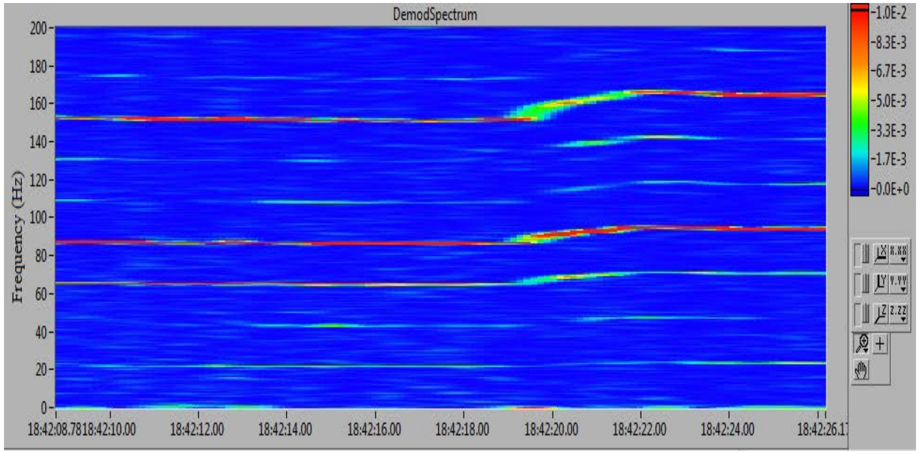
Douglas B Guarin Ferry 6/30 20:34

Savitsky 7/11 11:59

Engine Speed Effects on DEMON Signature



Unknown Boat 6/30 18:57.
Peaks change by a factor of .72



Unknown Boat 6/30 18:42.
Peaks change by a factor of 1.08

- DEMON analysis gives us a signal which is dominated by the engine and propellers
- As the engine speed changes, the DEMON spectra will as well
- Signatures show that the vessel dependent frequencies change proportionally when the engine speed changes

Appendix 1: Acoustic Classification

Vessel type	Fundamental Frequency range	1st Harmonic	2nd Harmonic	3rd Harmonic	4th Harmonic	Other frequency
Small cruise	5-6	10-12	15-18	n/a	n/a	n/a
Ferry	10-12	n/a	n/a	30-36	40-48	n/a
Tanker	4-6	8-12	n/a	n/a	n/a	n/a
Tugboat	14-20	28-40	n/a	n/a	n/a	n/a
Savitsky	47-54	95-109	143-163	n/a	n/a	n/a
Small pleasure boat	88-97	n/a	n/a	n/a	n/a	154-172
34 foot Zurn	81	n/a	n/a	n/a	n/a	141
Jet Ski	26	53	79	105	n/a	n/a

Vessel type	Fundamental Frequency range [hz]	1st Harmonic	2nd Harmonic	3rd Harmonic	4th Harmonic	Other frequency
Small cruise	5-6	10-12	15-18	n/a	n/a	n/a
Ferry	10-12	n/a	n/a	30-36	40-48	n/a
Tanker	4-6	8-12	n/a	n/a	n/a	n/a
Tugboat	14-20	28-40	n/a	n/a	n/a	n/a
Savitsky	47-54	95-109	143-163	n/a	n/a	n/a
Small pleasure boat	88-97	n/a	n/a	n/a	n/a	154-172
34 foot Zurn	81	n/a	n/a	n/a	n/a	141
Jet Ski	26	53	79	105	n/a	n/a

Appendix 2: Stability of Savitsky Signal

Savitsky 1	Peak	49.8 Hz	99.1 Hz	148.9 Hz
	Relative Intensity	1	0.342	0.151
Savitsky 2	Peak	54.7 Hz	109.4 Hz	163.1 Hz
	Relative Intensity	1	0.406	0.16
Savitsky 3	Peak	47.9 Hz	95.2 Hz	143.1 Hz
	Relative Intensity	1	0.418	0.207
Savitsky 4	Peak	50.3 Hz	100.6 Hz	150.9 Hz
	Relative Intensity	1	0.366	0.204
Savitsky 5	Peak	49.8 Hz	100.1 Hz	149.9 Hz
	Relative Intensity	1	0.433	0.218

Appendix 3: Engine Speed Effects

		1st Frequency (Hz)	2nd Frequency (Hz)	3rd Frequency (Hz)
1	Initial peak	25	100	175
	Final peak	18	78	137
	Ratio (Final/Initial)	0.76	0.78	0.78
2	Initial peak	66	200	400
	Final peak	56.5	170	340
	Ratio (Final/Initial)	0.86	0.85	0.85
3	Initial peak	65	87	152
	Final peak	70	94	165
	Ratio (Final/Initial)	0.93	0.93	0.92
4	Initial peak	97	169	
	Final peak	70	123	
	Ratio (Final/Initial)	0.72	0.73	

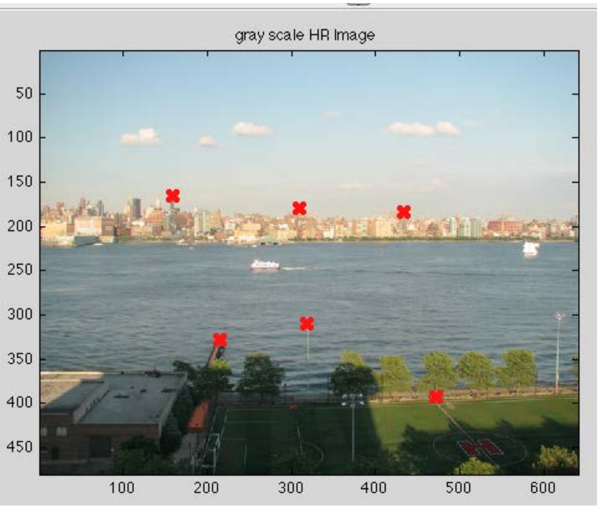
5	Initial peak	83.5	146.5
	Final peak	89	156
	Ratio (Final/Initial)	0.94	0.94
6	Initial peak	78.5	138
	Final peak	97	171.5
	Ratio (Final/Initial)	0.81	0.8
7	Initial peak	98	172
	Final peak	82.5	144.5
	Ratio (Final/Initial)	0.84	0.84
8	Initial peak	92	161
	Final peak	81.5	143
	Ratio (Final/Initial)	0.89	0.89
9	Initial peak	79.5	139
	Final peak	88	154
	Ratio (Final/Initial)	0.9	0.9

Introducing Digital Image Processing

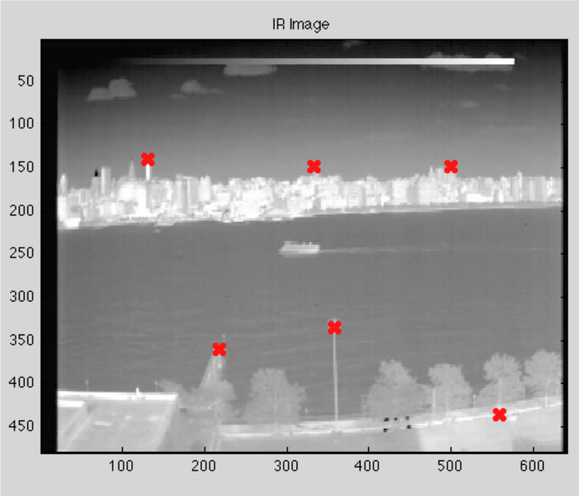
- Set of computational techniques for analyzing, enhancing, compressing and reconstructing images
- Applications:
  - Image Subtraction: pixel by pixel intensity subtraction between two images to form a better contrast image with the potential target
  - Image Overlay: Alignment of overlapping HR and IR images to construct one seamless composite image with more detail
  - Noise and glare reduction
  - Edge and corner detection

Example Image Overlay

Original HR Image

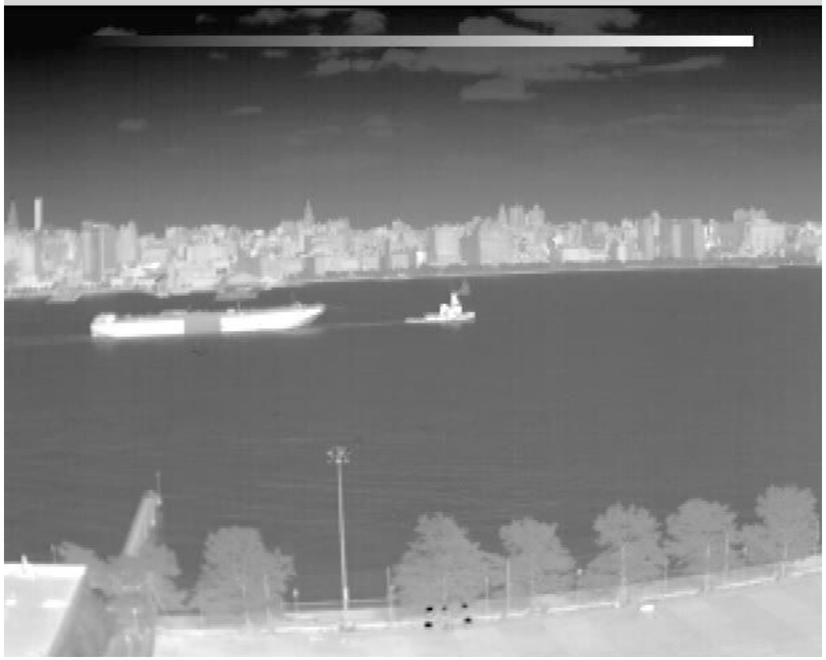


Original IR image



Overlaying Image

Image Processing for Detecting Multiple Targets



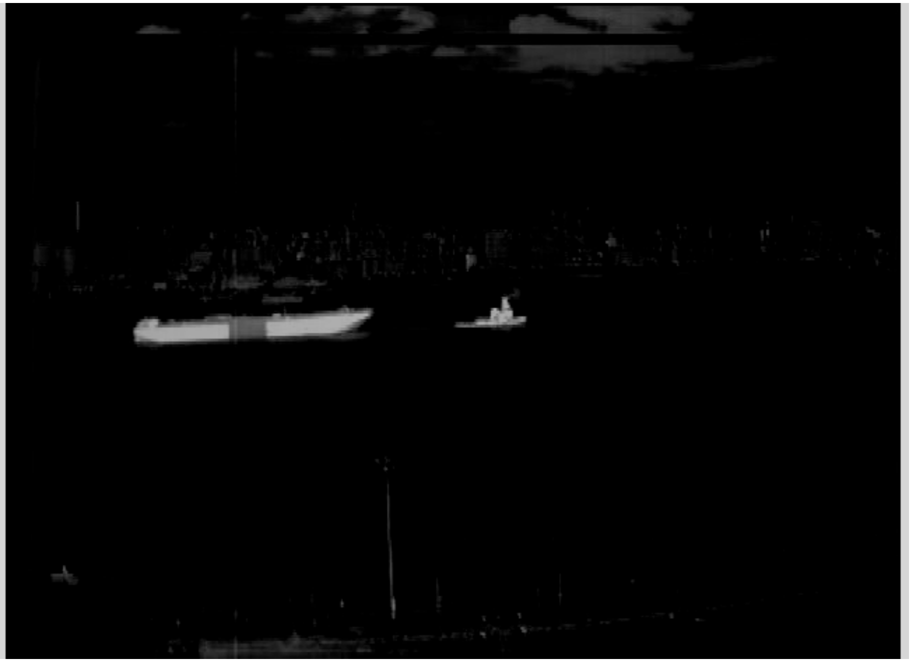
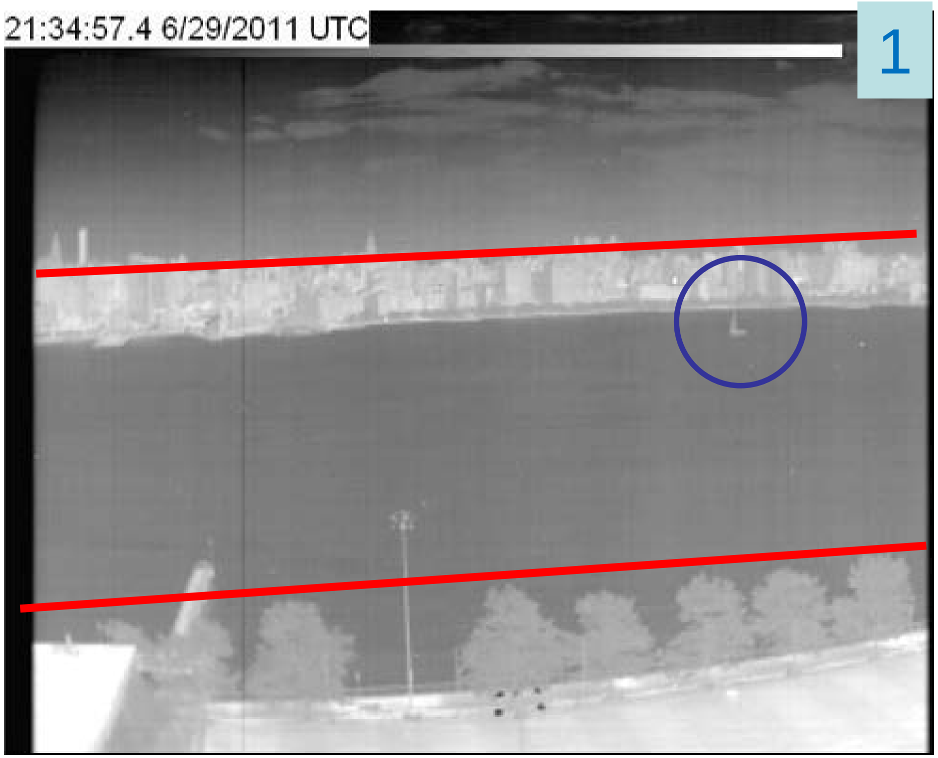


Image Subtraction

Goal: contrast enhancement (for edge detection)



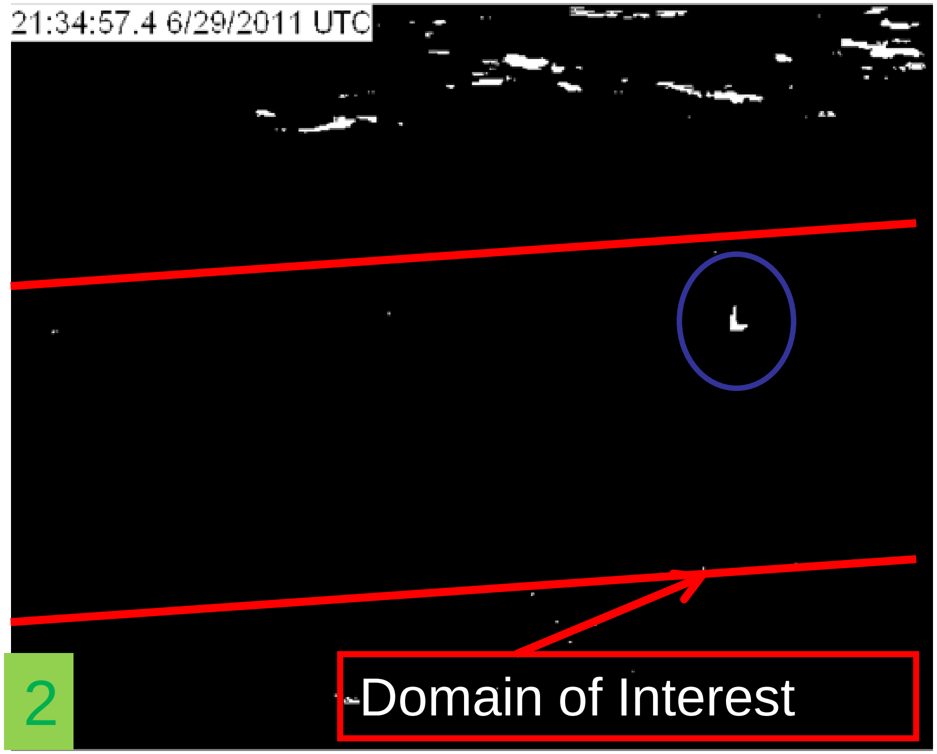


Image of interest (l) is subtracted from a time averaged reference image

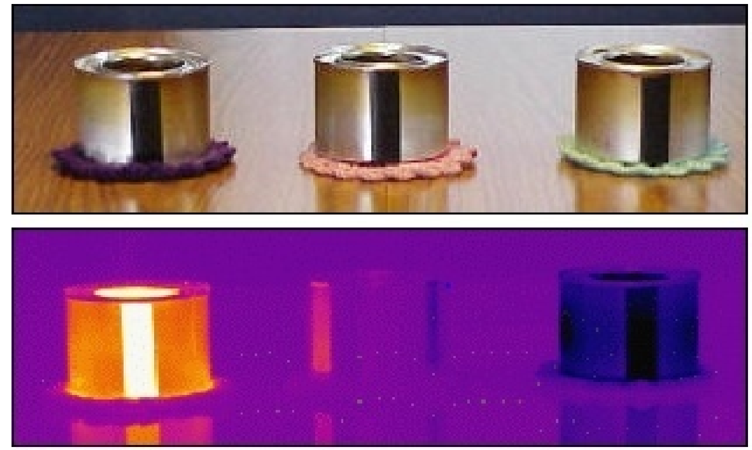
Resulting image (2) is the contrast enhanced image
→ eases operator decision
→ further processing

Image Processing

- Conclusions
  - Image subtraction was established as a viable surveillance technology
  - You can detect things better & nice for further processing
  - Suggests automation
- Recommendations
  - Create a database of background images sorted by significant changes in the environment
  - Fully automate the algorithm so it continually analyzes IR images
  - Make the algorithm do successful image vessel classification
  - **Create a fully-functional GUI that could be integrated into a surveillance system such as BOOM**

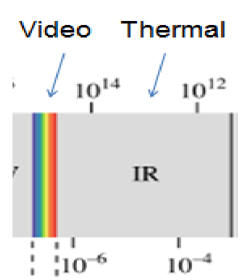
IR Imaging Overview

- All objects radiate thermal energy
  - As the temperature increases, the amount of thermal energy increases while the peak wavelength of the radiated energy decreases
- IR cameras detect radiated energy, NOT Temperature
  - Heat energy is emitted by the object so no light or heat source is needed
  - Emissivity is a characteristic of the material. Two objects at the same temperature can emit a different amount of energy and thus appear different on an IR image



Three aluminum cans with partially oxidized surfaces and a strip of black electrical tape. The can on the left is hot, middle can is ambient and right can is cold.

Aluminum emissivity of 0.1,
Electrical tape emissivity of 0.95.

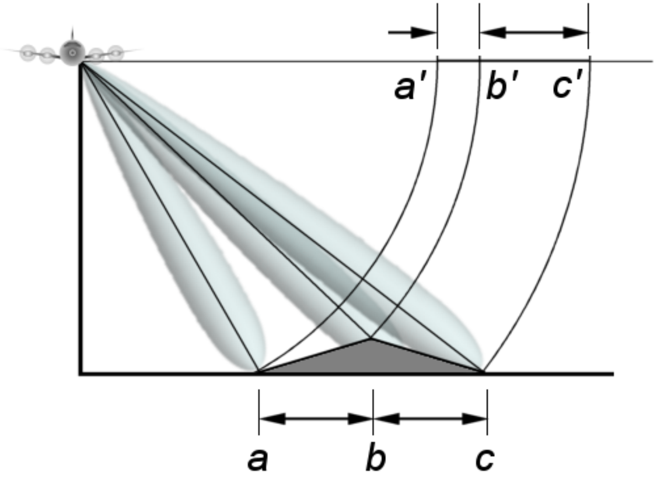


IR represents the wavelengths slightly longer than visible

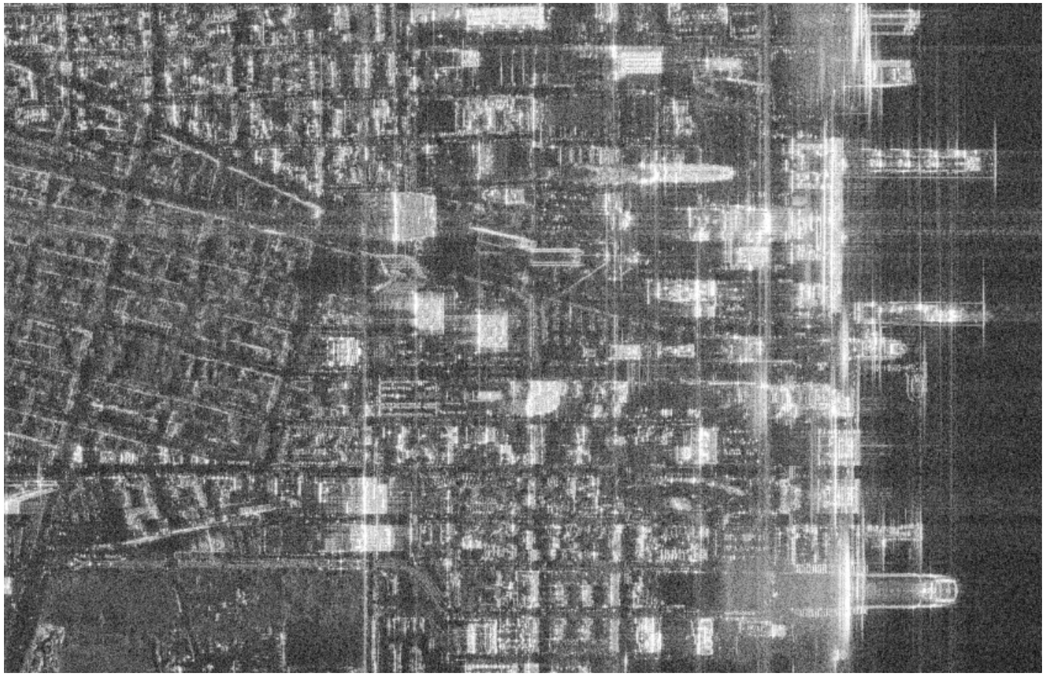
Satellite Flyovers

Date	Time (GMT)	Satellite	Type
7/11/2011	10:23:24	COSMO-SkyMed	SAR
	11:01:30	COSMO-SkyMed	SAR
	11:13:25	TerraSAR-X	SAR
	18:57:00	EROS-B	Optical
	22:49:02	COSMO-SkyMed	SAR
7/12/2011	10:56:19	TerraSAR-X	SAR
	11:01:28	COSMO-SkyMed	SAR
	18:40:00	EROS-B	Optical
	22:49:00	COSMO-SkyMed	SAR
	23:04:06	COSMO-SkyMed	SAR

SAR: Image Distortion

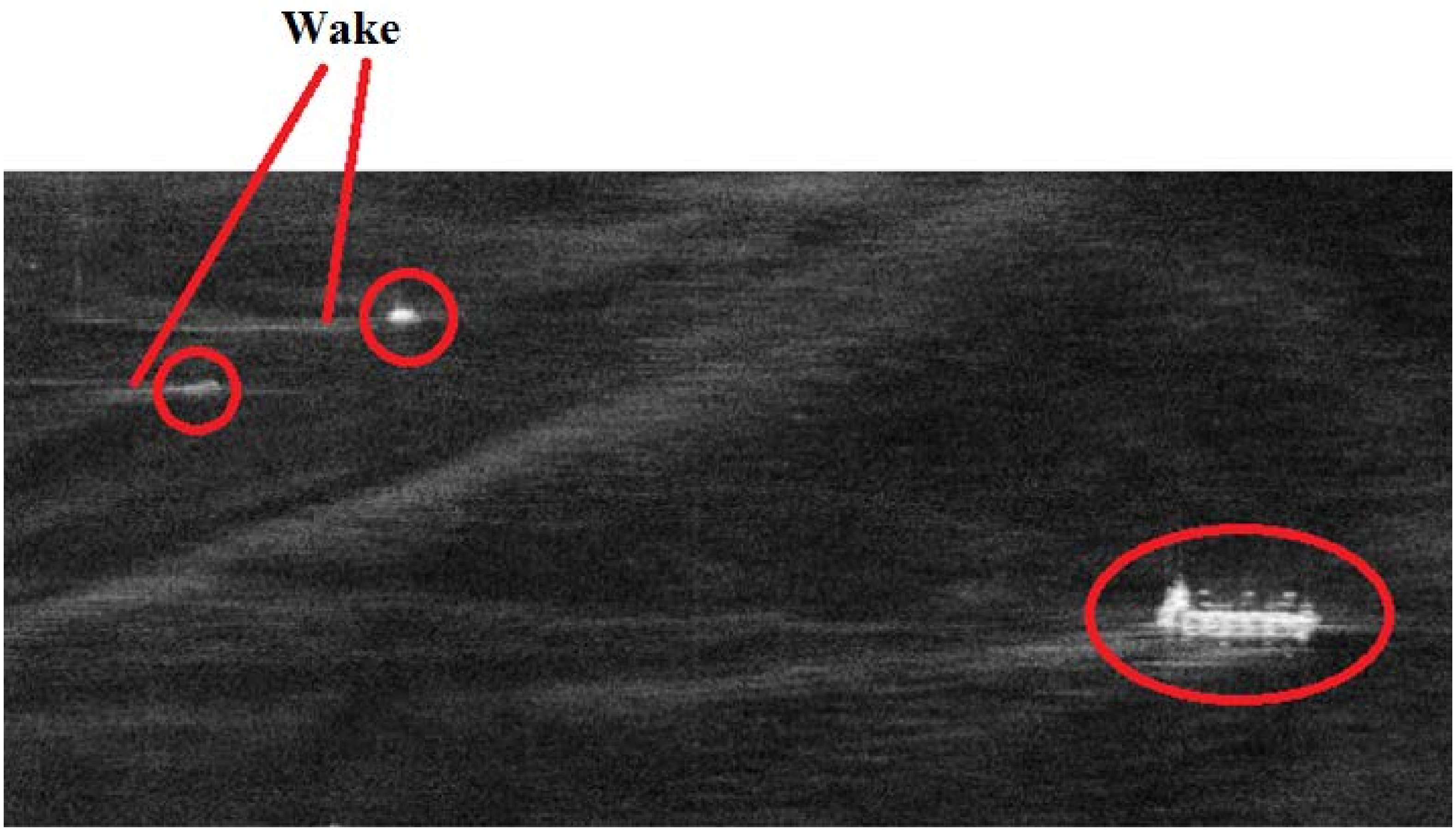


- Beam reaches top of target before it reaches its bottom
- Image appears compressed



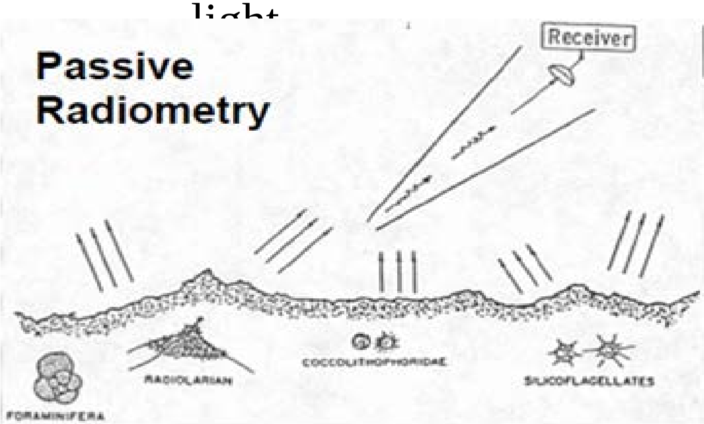
Ship Identification-Wakes

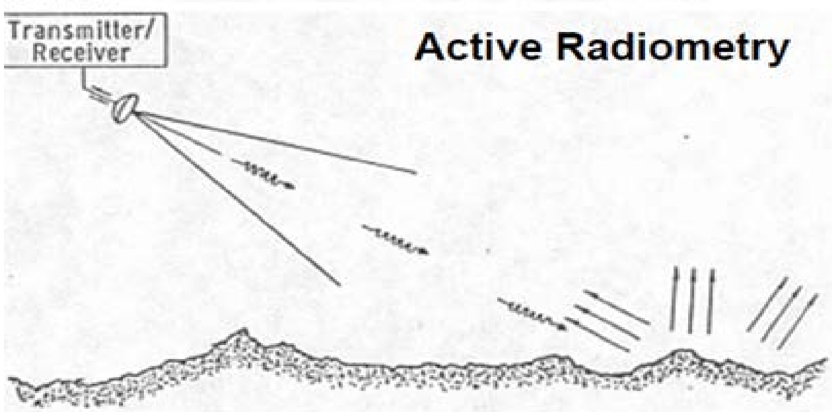
- Large vessels are easy to see



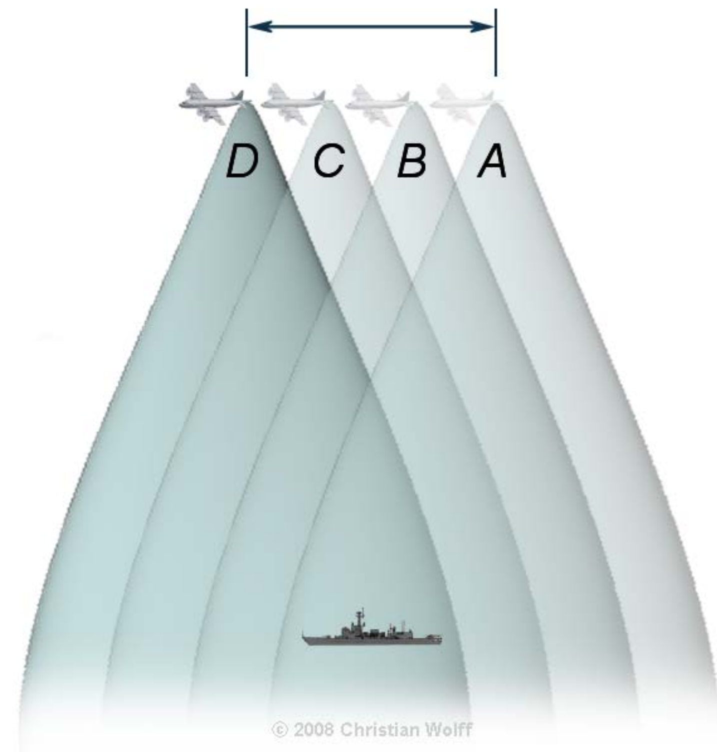
Types of Satellite Imaging

- Optical
  - Passive
  - Uses visible and Infra-Red light





- Synthetic Aperture Radar (SAR)
  - Active
  - Flight path simulates large



Simulation Results - GPS Tracking route

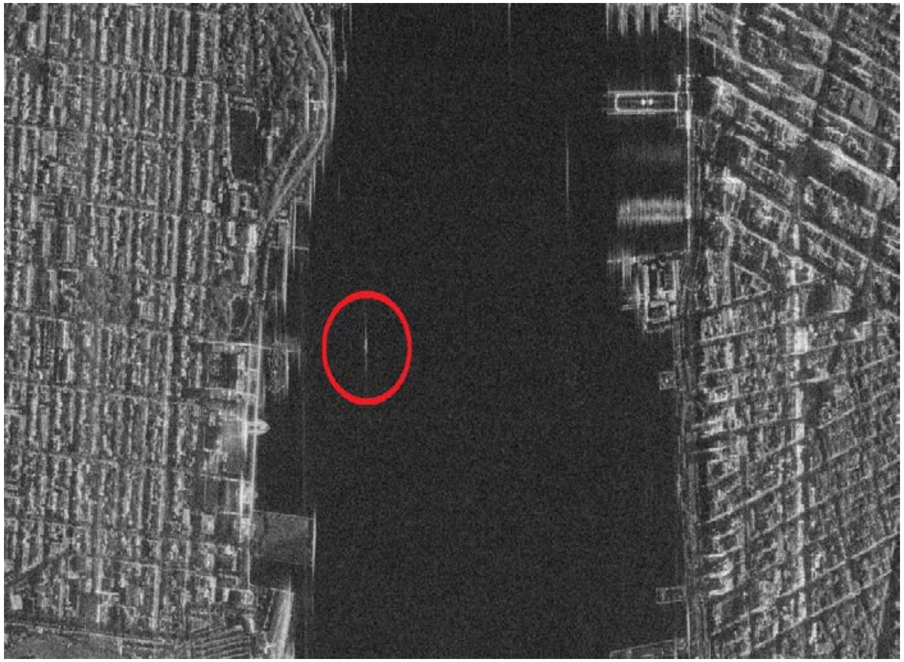
- Pin ups represent Savitzky's positions at time of Satellite images
- Routes also confirmed with SPADES and Video

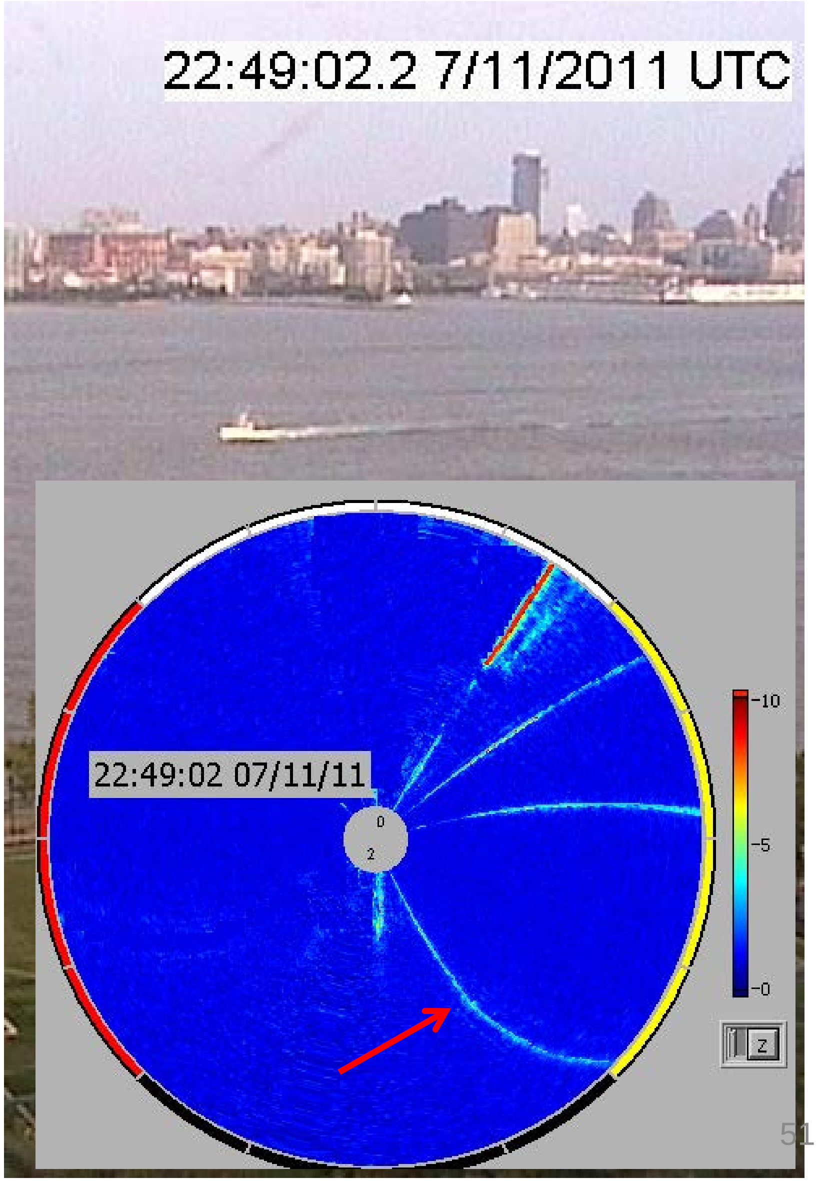
Savitzky confirmed with satellite image

Savitzky not confirmed on satellite image

Savitzky's explosion site (confirmed)

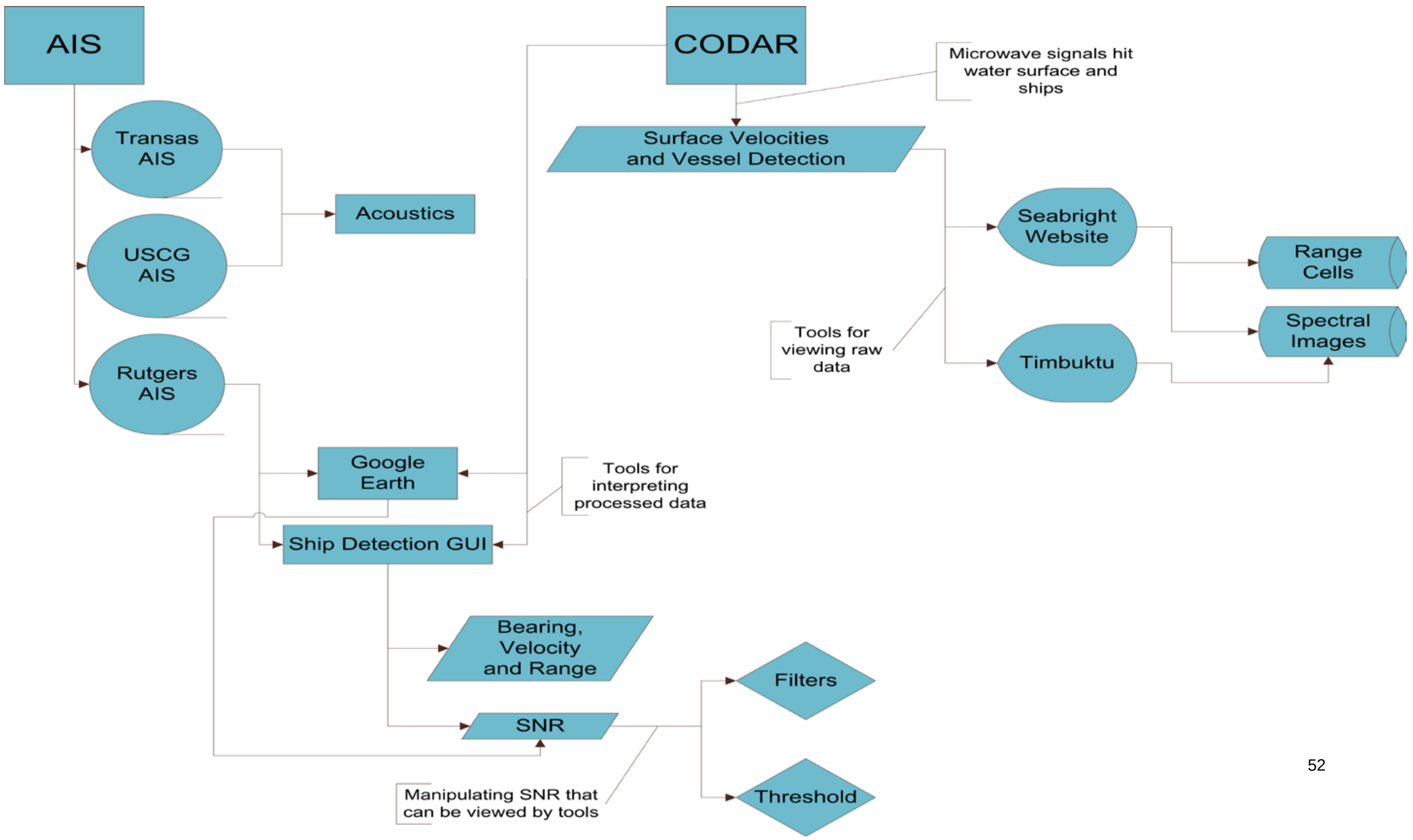
130 22:49:02 GMT on 7/11/2011 - RV Savitsky





Acoustic detection distance:
550 m at 22:48:00 GMT
Acoustics loses contact:
460 m at 22:50:50 GMT due to ferry noise from the north

Long Range Flow Chart



Threat ID: Check For Normal Behavior

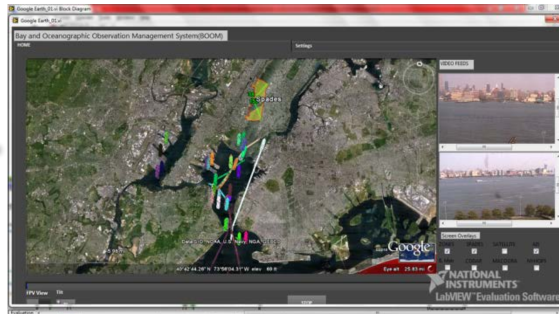
Tracking/Detection Parameters | Areas of Operations | CAM Info | Classification

Classification	PAX	LOA	Gross Tons (tons)	Top Speed (Kts)	Draft (Ft)	Beam (Ft)	Hight	MR (1-10)	Payload (Tons)	AIS Required? (Y/N)	Model Ship
PWC	3	10	0.25		0.5	4			1	☐	
Small Rec		50	6	50	2	6				☐	
Small F/V		50	8	25	5	10	20		6000	☐	Holland 32
Small Sail		40	8		8	10				☐	
Small P/V	40	100	18	30	4	15			30	☐	P/V Atlantic Seal
Medium Rec		80	30	30	4	17				☐	50' Viking Convertible
Pilot		55	50	30	5	17				☑	Hunt Designed Chesa
Medium P/V	100	150	95	18	9	36			50	☑	P/V Staten Island
Tug(unhitched)		180	194	10	20	40	70			☑	M/V Delta Billie
Medium F/V		100	200	10	8	28			153	☐	F/V Time Bandit
Large Rec											
Large Sail											
Tug& Tow											
Cruise Ship											
Large P/V											
Large F/V											
Small Tanker (handymax)											
Small Cargo (handymax)											
Medium Cargo (panamax)											
Super Cruise											
Large Tanker (aframax)											
Large Cargo (Suezmax)											

Tracking/Detection Parameters | Areas of Operations | CAM Info | Classification

Classification	Areas of exclusion	Out of channel operations?	Erradic Operations Expected?	Expected areas of Operations
Container Large	☐	☐	☐	
Container Medium	☐	☐	☐	Upper Bay, Red Hook or Port E.
Container Small	☐	☐	☐	
Cruise Ship	☐	☐	☐	
Large F/V	☐	☐	☐	
Large P/V	☐	☐	☐	
Large Rec	☑	☑	☐	
Large Sail	☑	☑	☑	
Medium F/V	☐	☐	☐	
Medium P/V	☑	☐	☐	
Medium Rec	☑	☑	☑	
Pilot	☐	☐	☐	
PWC	☐	☐	☐	
Small F/V	☐	☐	☐	
Small P/V	☑	☑	☑	
Small Rec	☑	☑	☑	
Small Sail	☑	☑	☑	
Super Cruise	☐	☐	☐	
Tanker Large	☐	☐	☐	
Tanker Small	☐	☐	☐	
Tug& Tow	☐	☐	☐	
Tug(unhitched)	☐	☐	☐	

Bay and Oceanographic Observation Management System (BOOM)



Acoustic

HD cameras

CODAR

RADAR

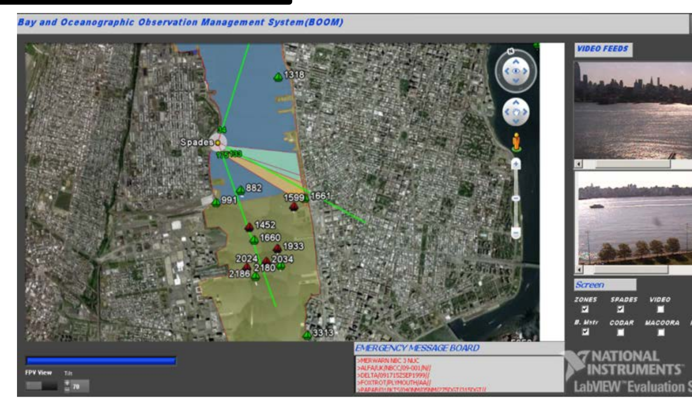
Law enforcement official

BOOM

DETECTION SYSTEMS

Integration of sensor displays

Data Fusion

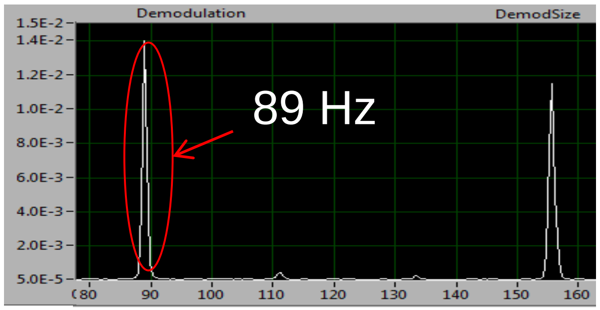


Laboratory setting

Single Integrated display

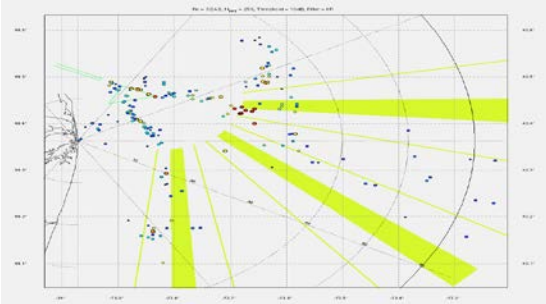
User Information Tools

How do you get from this…

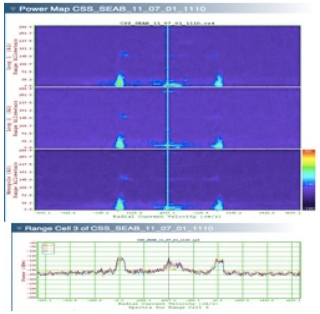


Demon Spectrum

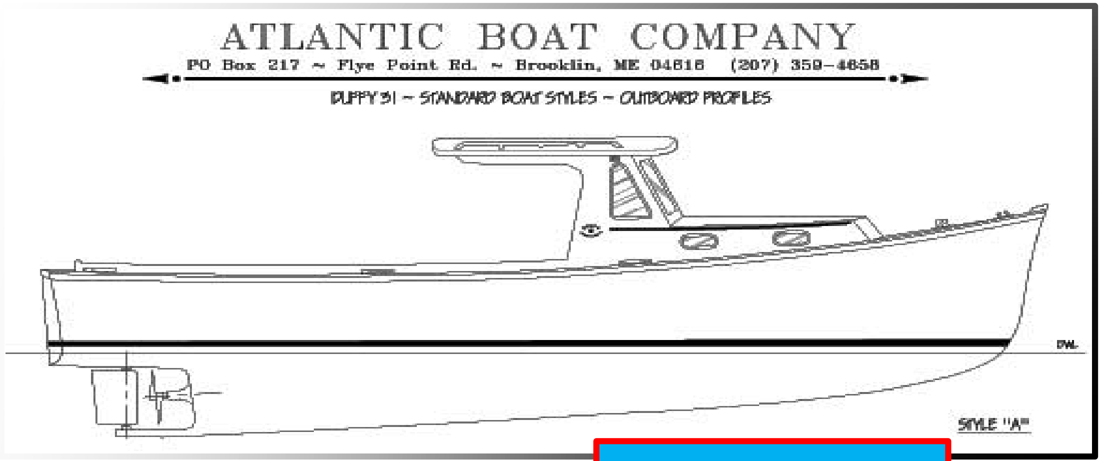
Blurry Camera Image



HF Radar Screen

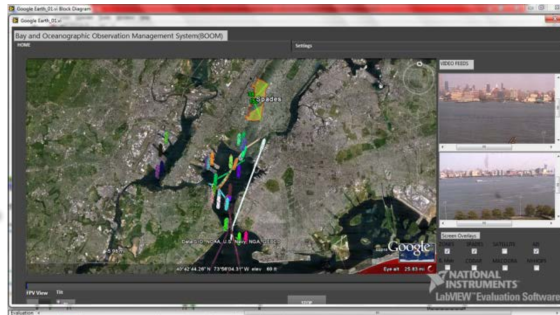


HF Radar –
Speed and Range



…to This?

Bay and Oceanographic Observation Management System (BOOM)



Acoustic

HD cameras

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Integration of sensor displays

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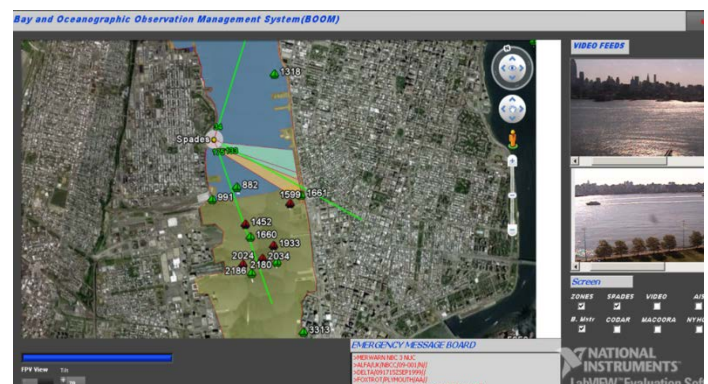


Laboratory setting

Single Integrated display

Acoustic Data Collection and Processing

Stevens Passive Acoustic Detection System (SPADES)

In Water System

Passive Acoustic Detection with four hydrophones

Data from hydrophone acquired and recorded

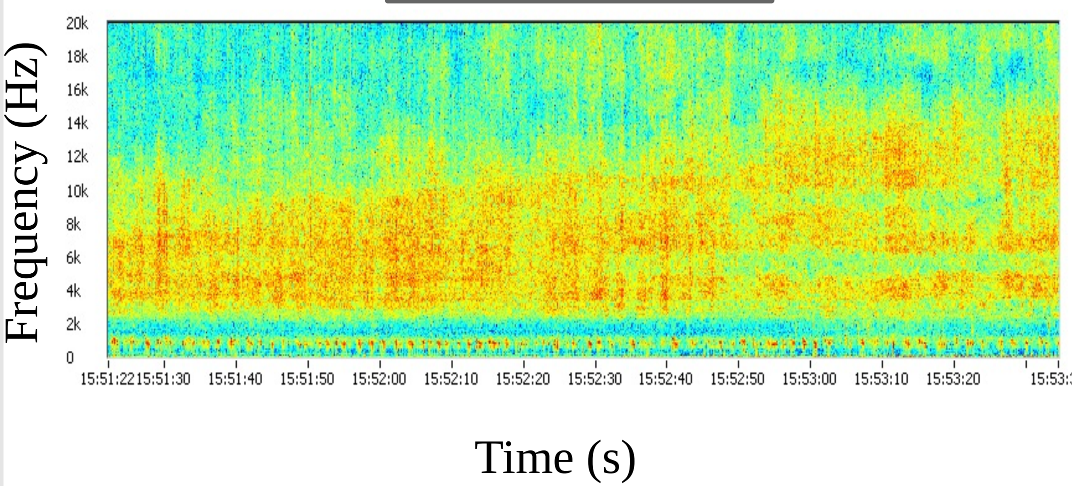
Data pre-processed in underwater system and transmitted digitally

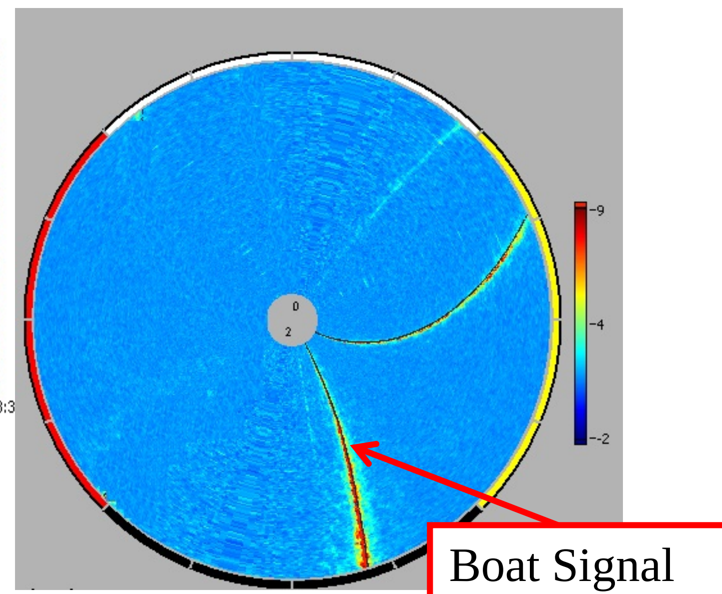
SPADES GUI

Spectral Analysis

Cross-Correlation Analysis

Land based system





Who Uses Sensor Networks?

Law Enforcement:
United States Coast Guard

Problem:
Vessels without AIS

Needs:
-Tracking
-ID or Classification

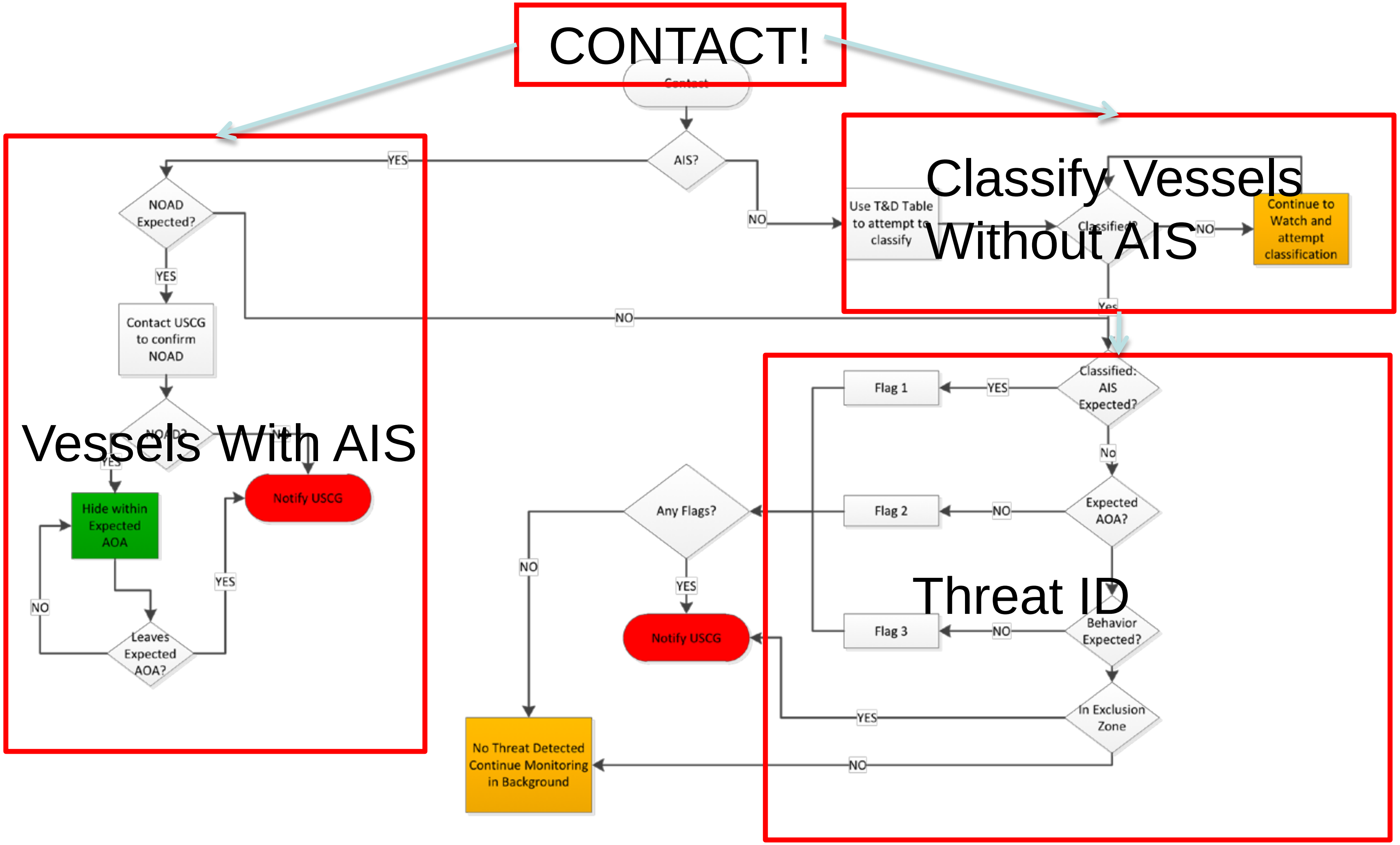
Emergency Response:
OEM & First Responders

Problem:
No Modeling Input Data

Needs:
-Visual Information
-Vessel Information

CLASSIFICATION

Contact ID and Assessment Process



SRI Objective and Architecture

2011 DHS, COE, CSR Summer Research Institute

To study and address the threat of pirated ships in the MTS being used as a weapon of terror

- **Consequence Assessment**
- **Sensor and Technology Applications in Port Security**

  Define the strengths and limitations of sensor technologies to detect, classify, and track vessels in, near, and approaching the urban port environment

  - **Long Range Technologies**

    Satellites, HF Radar, AIS

  - **Near Shore Technologies**

    Acoustics, Electro-optics

  - **Decision Support Methodology**

    Vessel categorization, threat assessment

BOOM!: Interactive **B**ay and **O**ceanographic **O**bservation **M**anagement System

- AIS
- SPADES
- NYHOPS
- MACOORA
- RADAR
- Satellite
- Coverage Zones
- Live Feeds