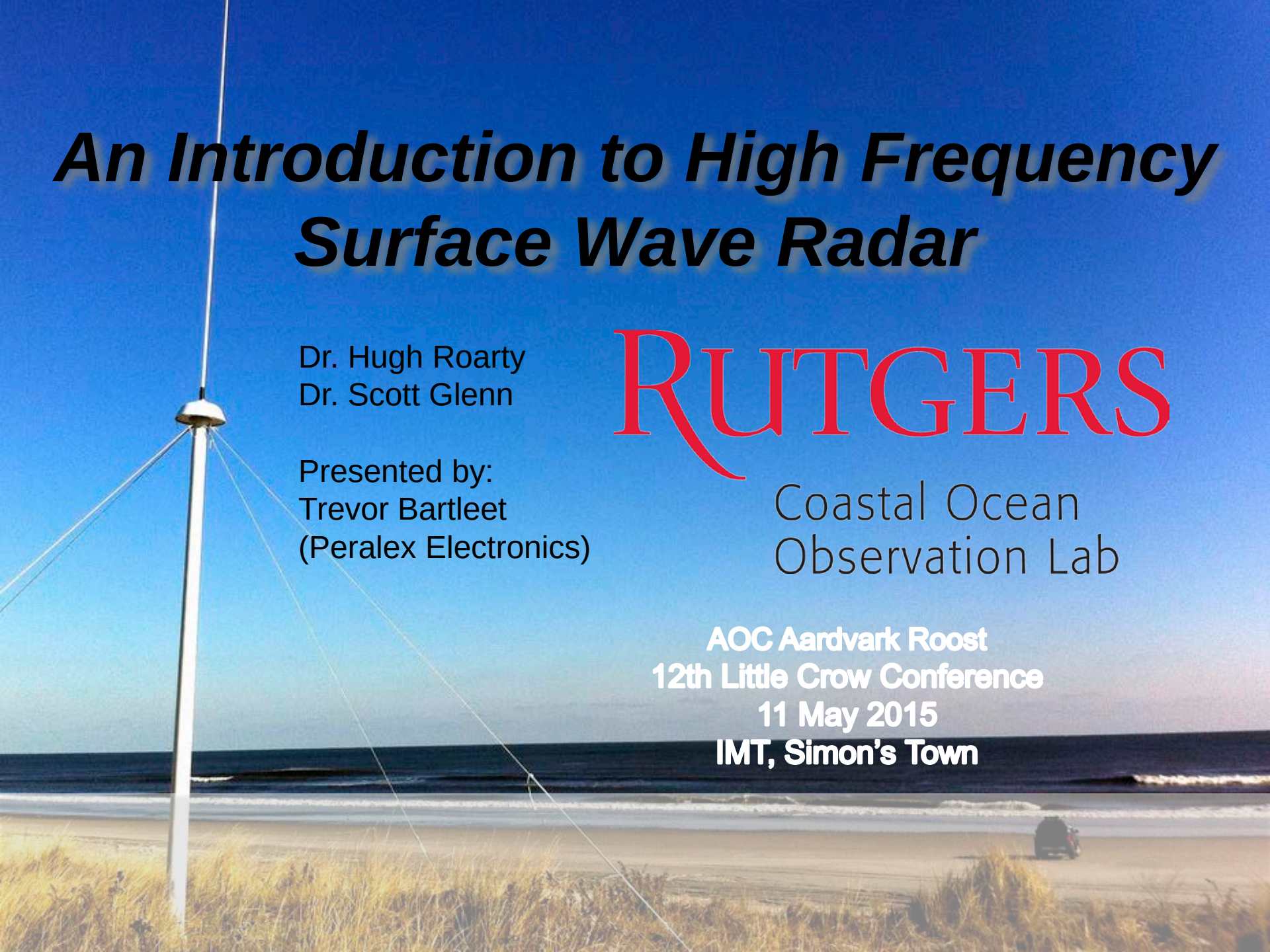


An Introduction to High Frequency Surface Wave Radar

Dr. Hugh Roarty
Dr. Scott Glenn

Presented by:
Trevor Bartleet
(Peralex Electronics)

RUTGERS
Coastal Ocean Observation Lab

AOC Aardvark Roost
12th Little Crow Conference
11 May 2015
IMT, Simon's Town

UNIVERSITY OF CAPE TOWN

IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

The Radar Masters Course at UCT

http://radarmasters.co.za/

- Set up to address the growing need for skilled engineers and scientists in the challenging fields of Radar and Electronic Defence.
- The programmes are flexible, so a working engineer can pursue the degree over a two or three year period.
- Students focus on relevant theory, technologies and applications of radar and ED/EW, with coursework and project components.
- Programme had first intake of students in February 2011

Subjects

- Core subjects include:
  - Mathematics for Radar and EW
  - Introduction to Radar
  - Introduction to EW
  - Radar Signal Processing
  - Radar Systems Modelling
  - Microwave Components & Antennas
  - Microwave Filters Design
  - Applications of Imaging Radar

- Specialised subjects
  - HF Surface Wave Radar

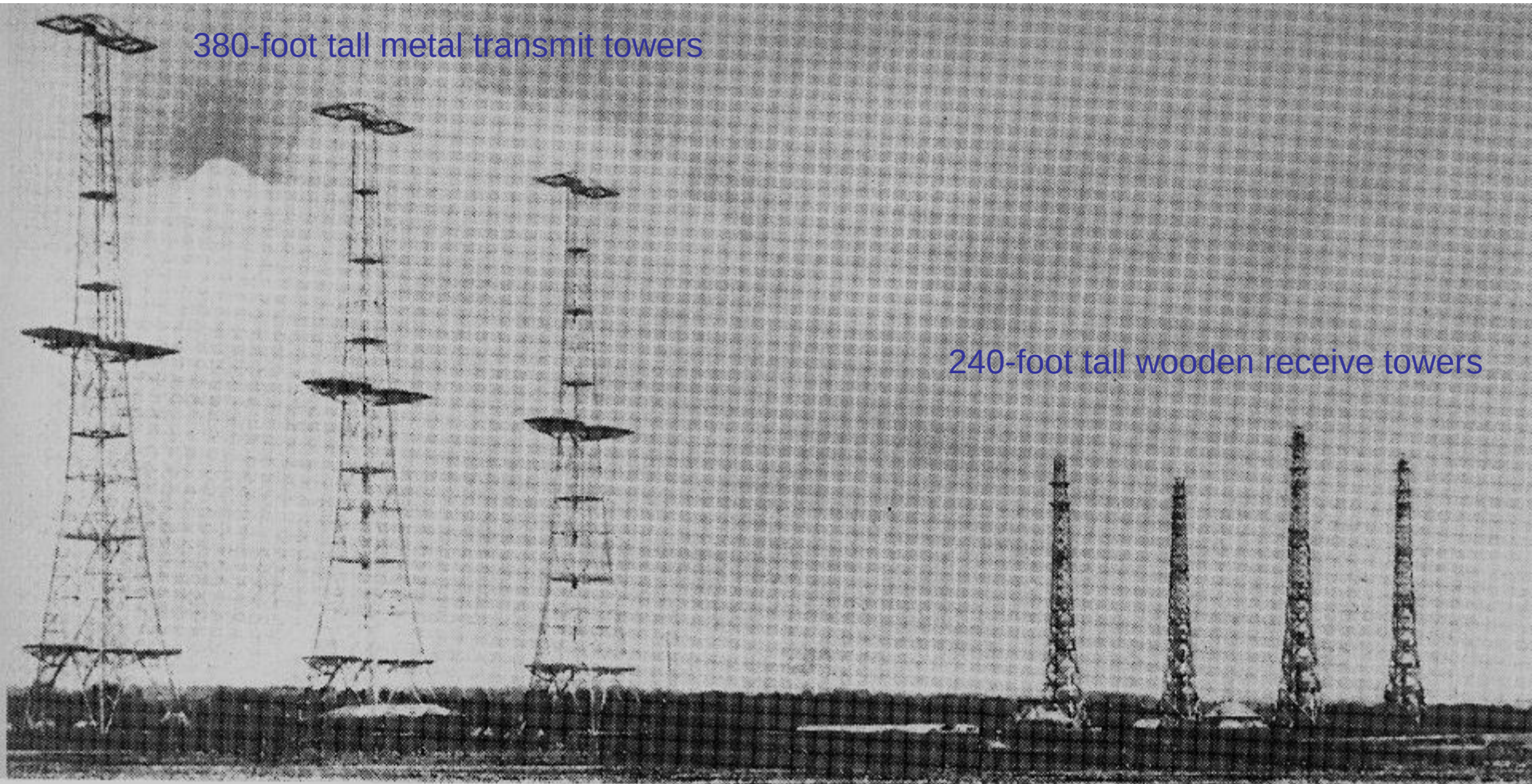
The Challenger Glider Mission:
A New Generation of Student Based Discovery

"The Ocean is Our Classroom"

HISTORY OF HIGH FREQUENCY RADAR

HF Radar -- Is It New Technology?

- British 25-MHz "Chain Home" built 1938 to detect German bombers
  - "Bragg" sea echo from English Channel mistakenly labeled "jammer"
  - These systems preceded microwave radars by several years



Crombie (1955)

Dominion Physical Laboratory, Lower Hutt, New Zealand.

Letters to Nature 175, 681 - 682 (16 April 1955)

Doppler Spectrum of Sea Echo at 13·56 Mc./s.

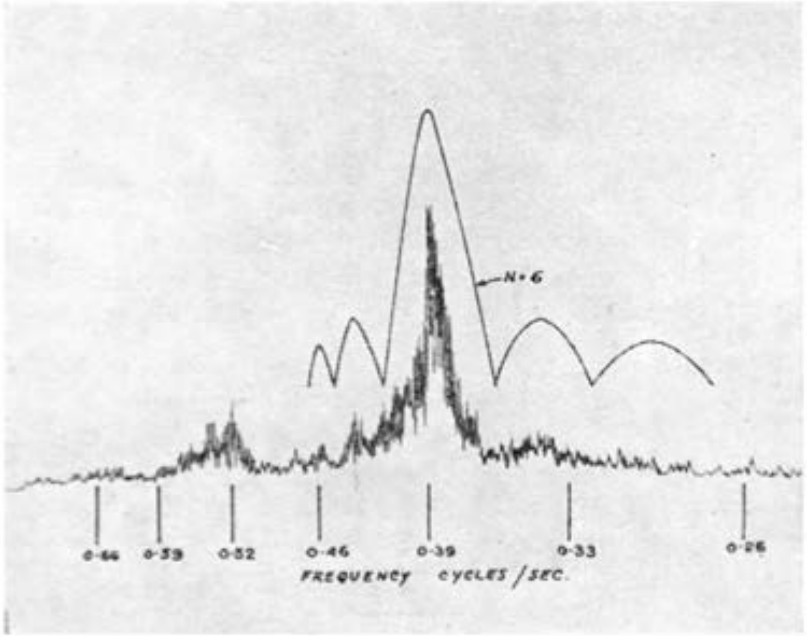
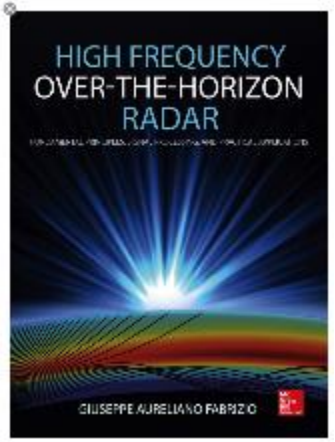


Fig. 2

HOW HIGH FREQUENCY RADAR WORKS

Horizon Calculation



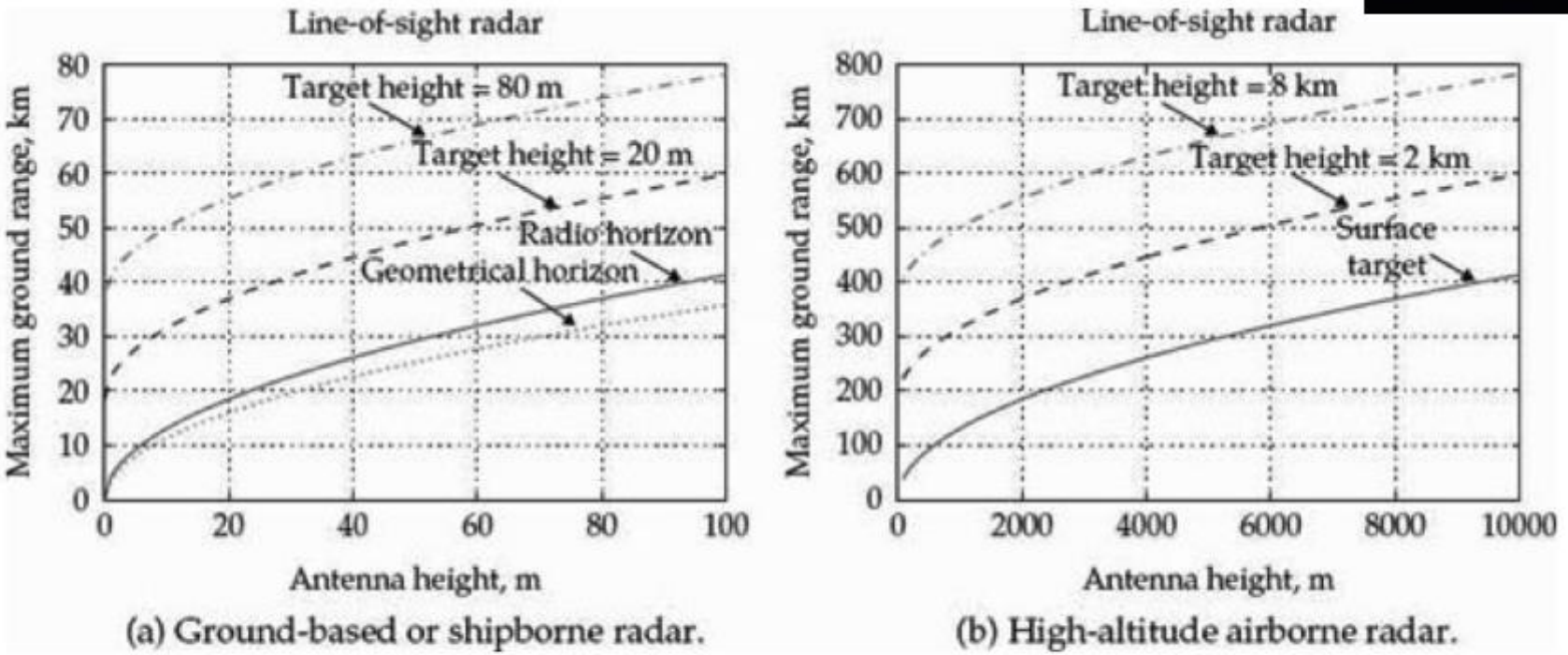


FIGURE 1.3 Nominal ground range coverage limitation of a line-of-sight radar system due to the Earth's curvature as a function of antenna height and target altitude.

Speed of Light

- Speed of Light,

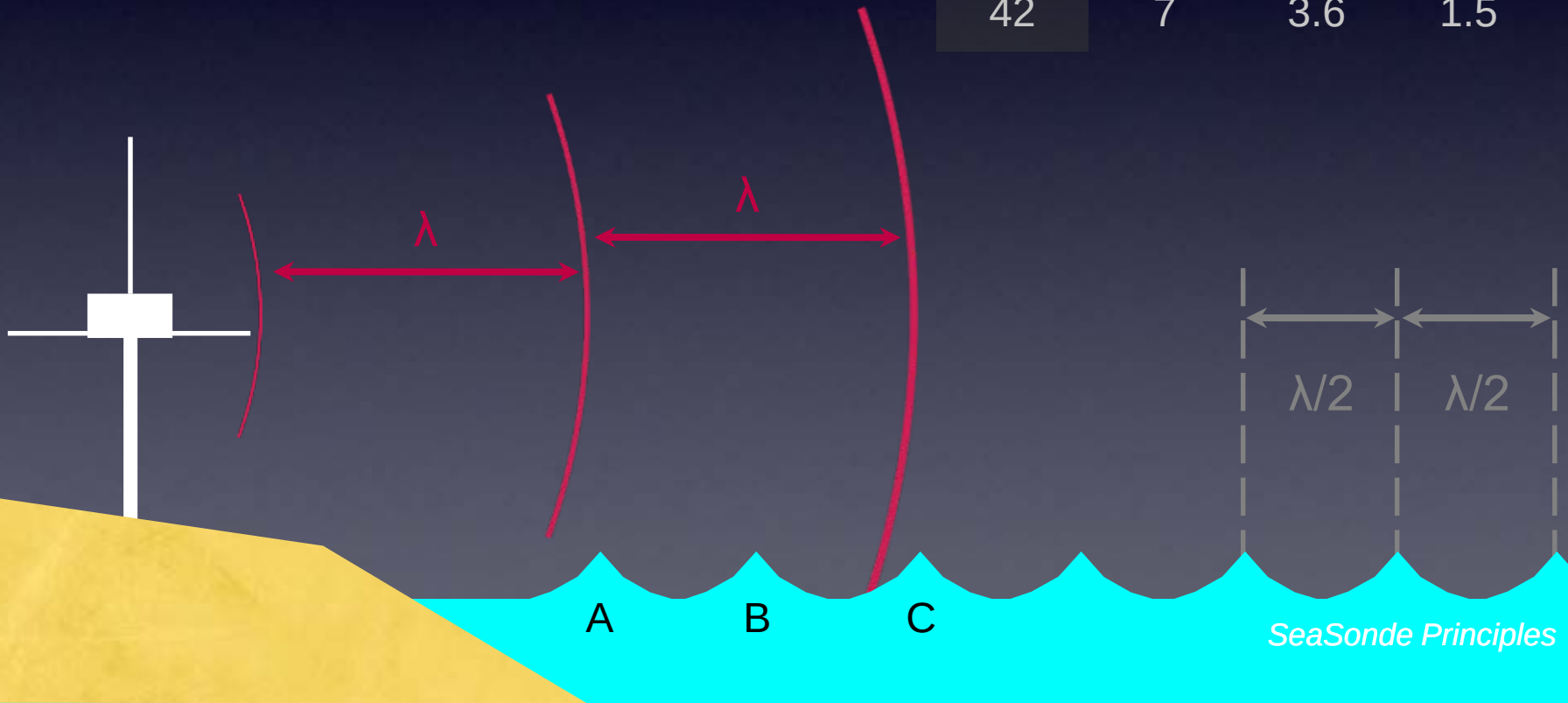
  c = 299,792,458 m/s

- $c=f\lambda$
- Approximation is $300/f_{MHz}$ = Radio Wavelength (m)

Radio Frequency (MHz)	Radio Wave-length (m)	Ocean Wave-length (m)	Effective range (km)
5	60	30	180
13	23	12	80
25	12	6	30
42	7	4	

Bragg Sea Echo

Freq mhz	λ meters	λ/2 meters	T seconds
5	60	30.0	4.4
13	23	11.5	2.7
25	12	6.0	2.0
42	7	3.6	1.5



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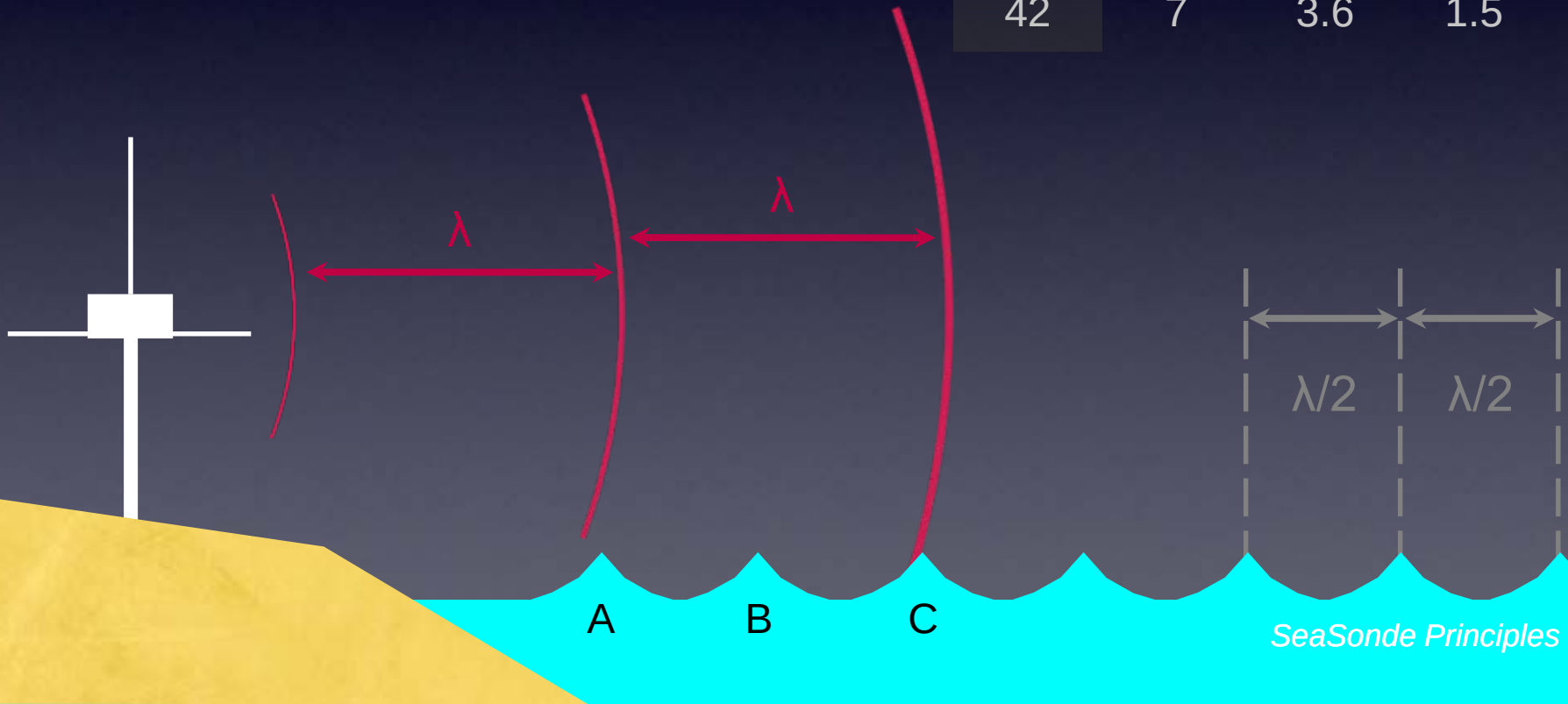

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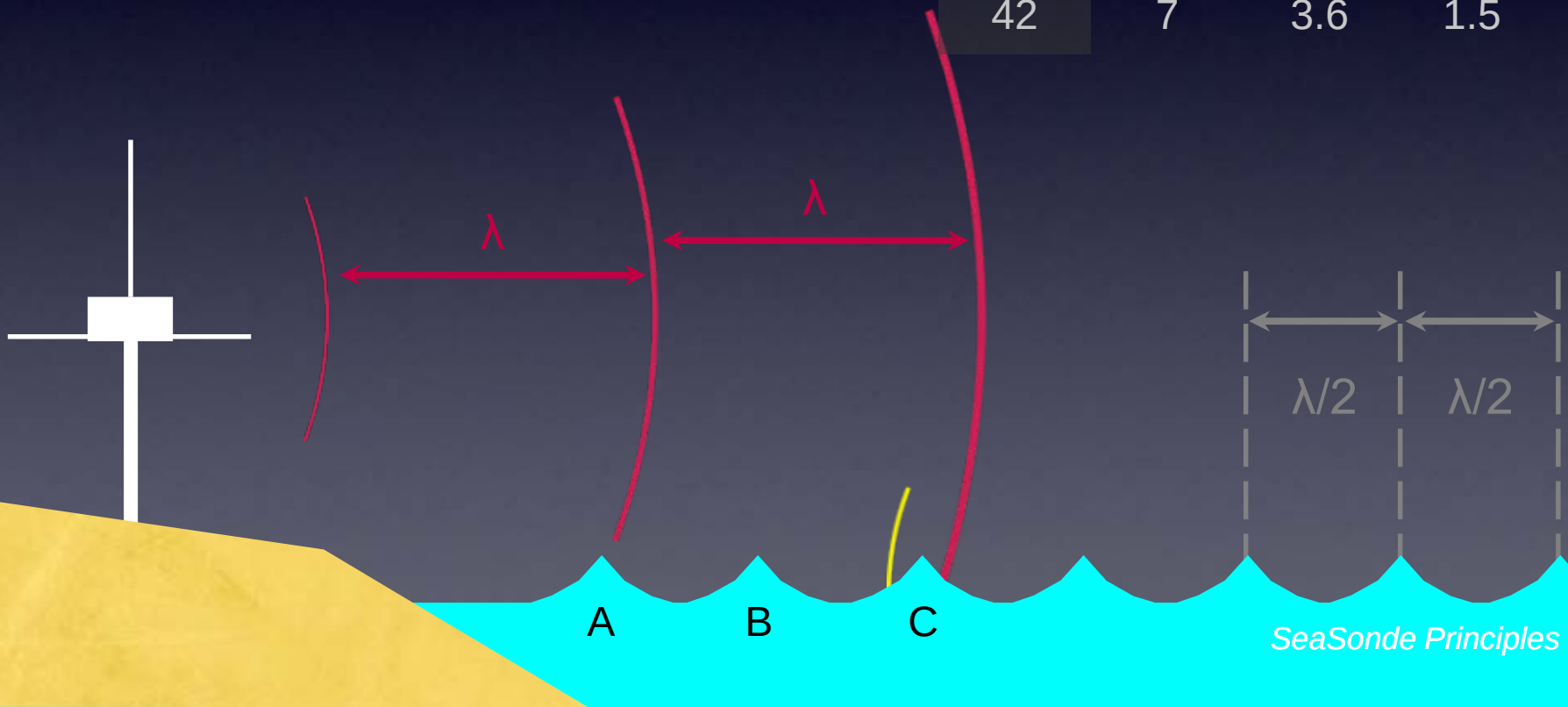

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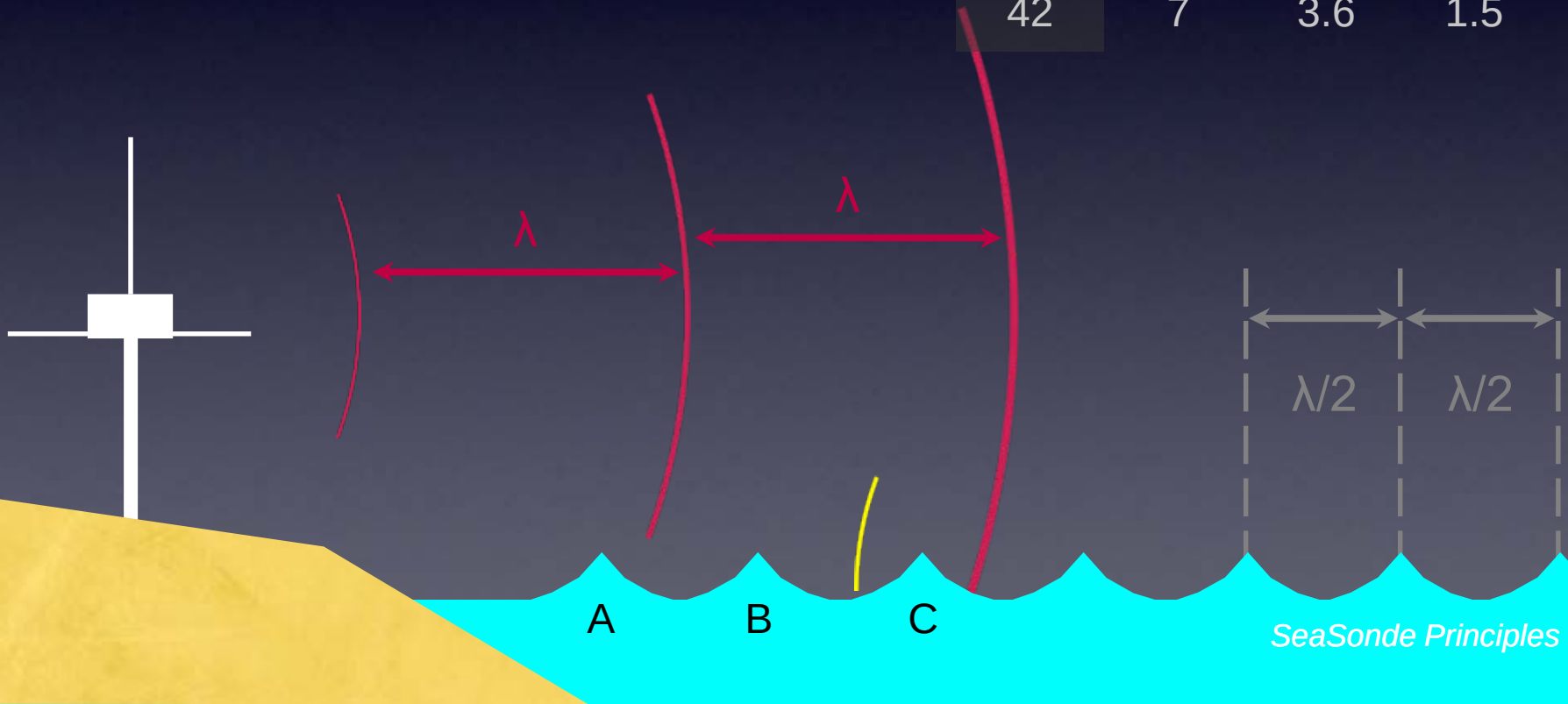

Bragg Sea Echo

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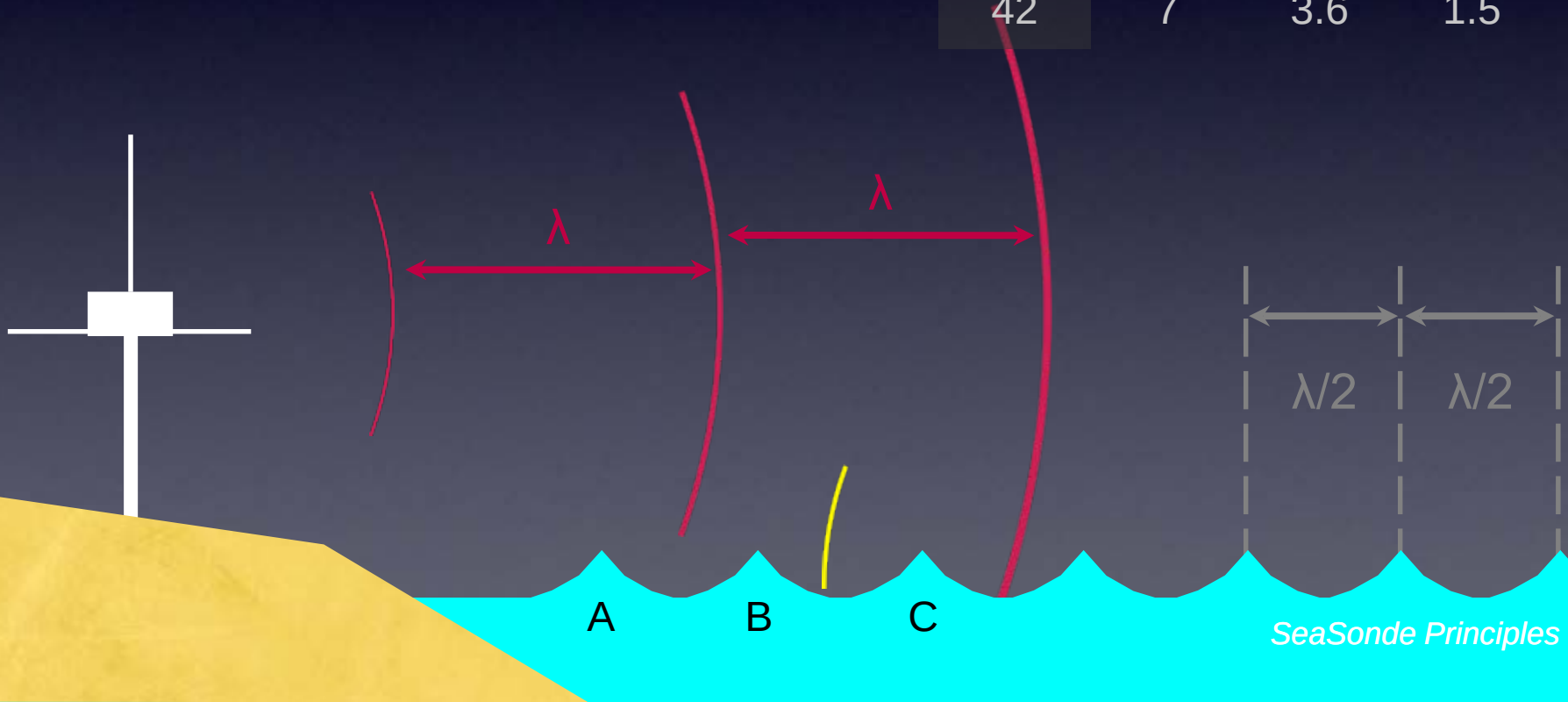

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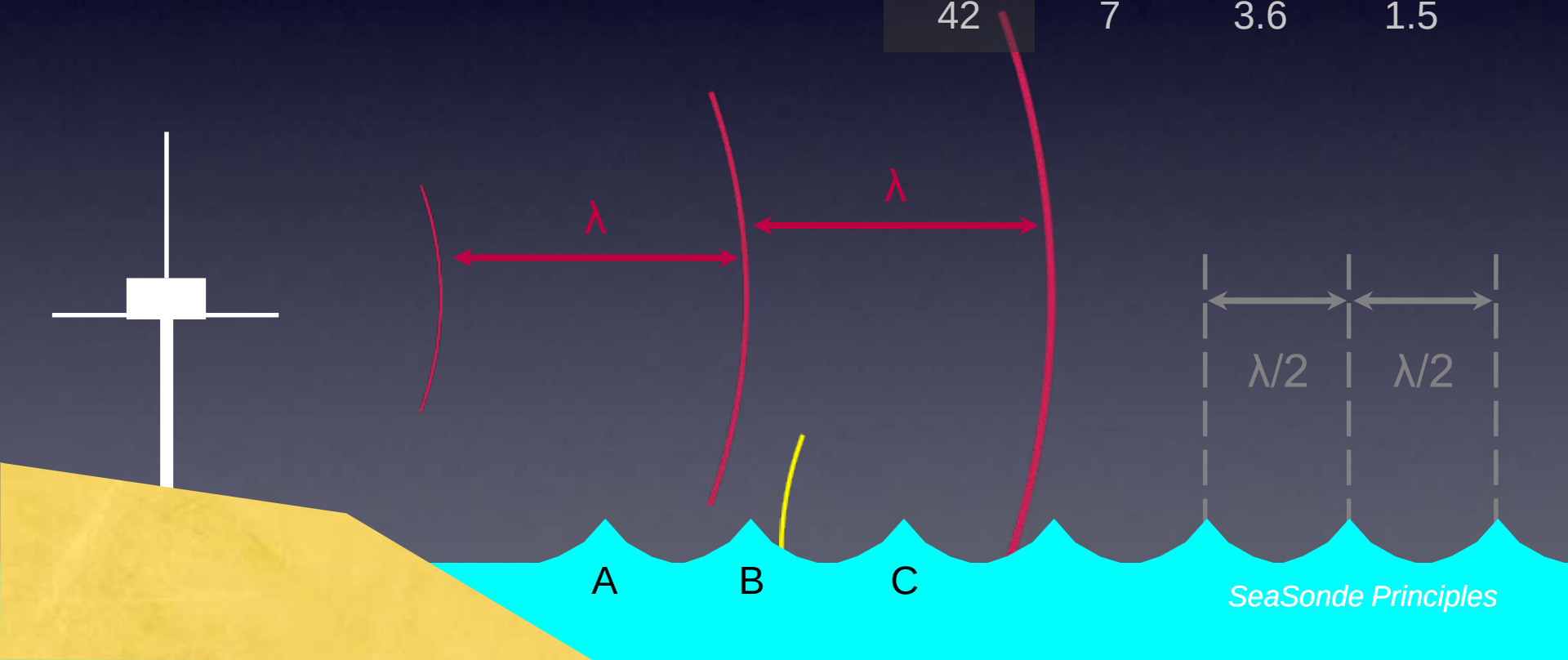

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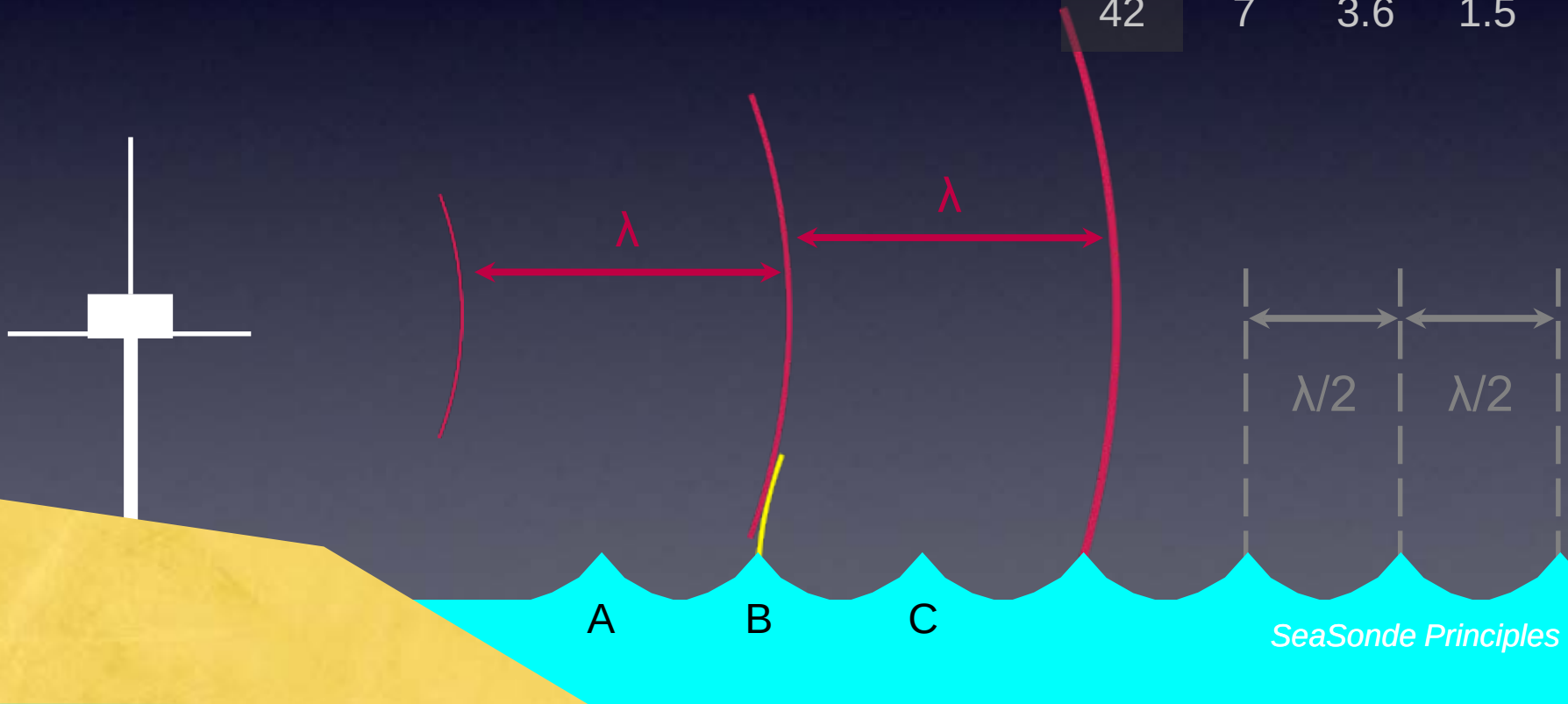

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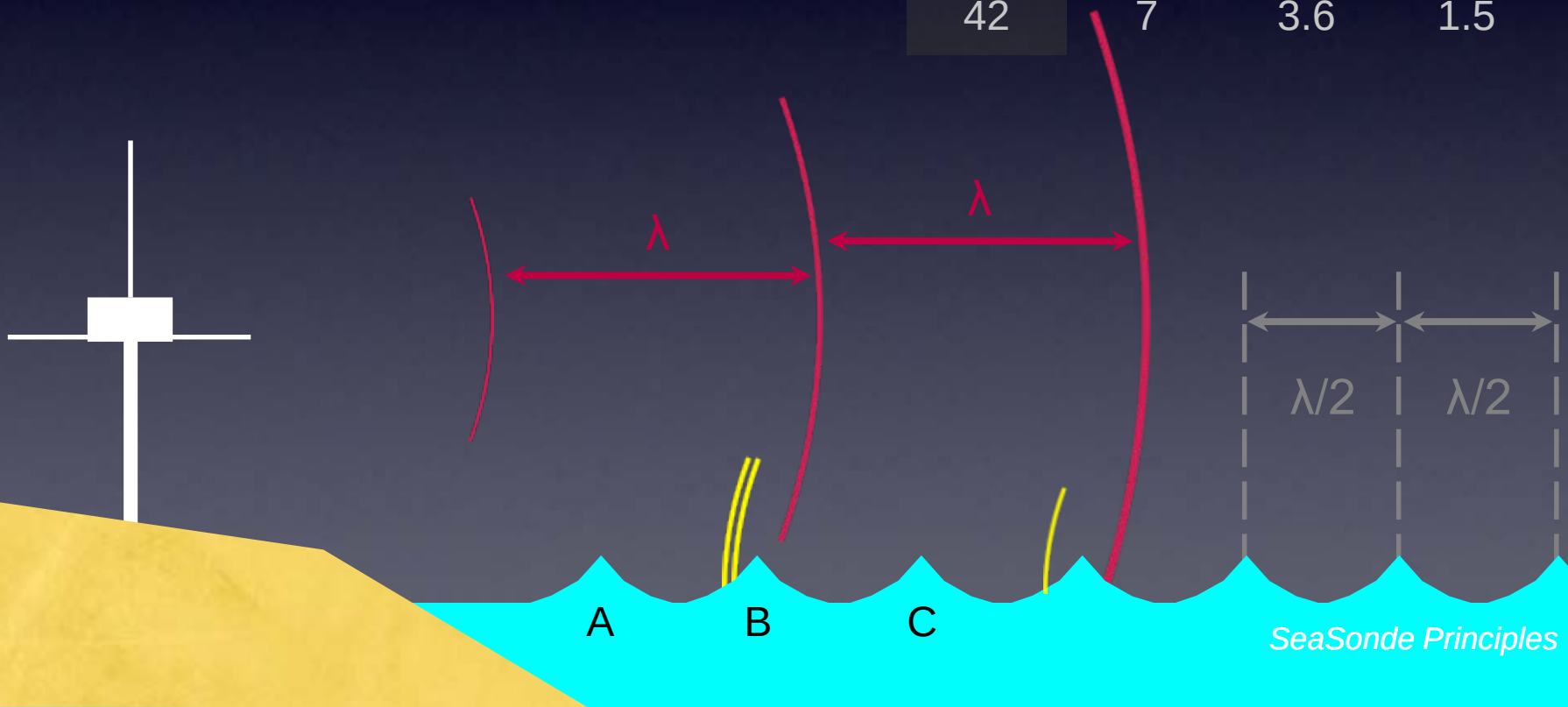
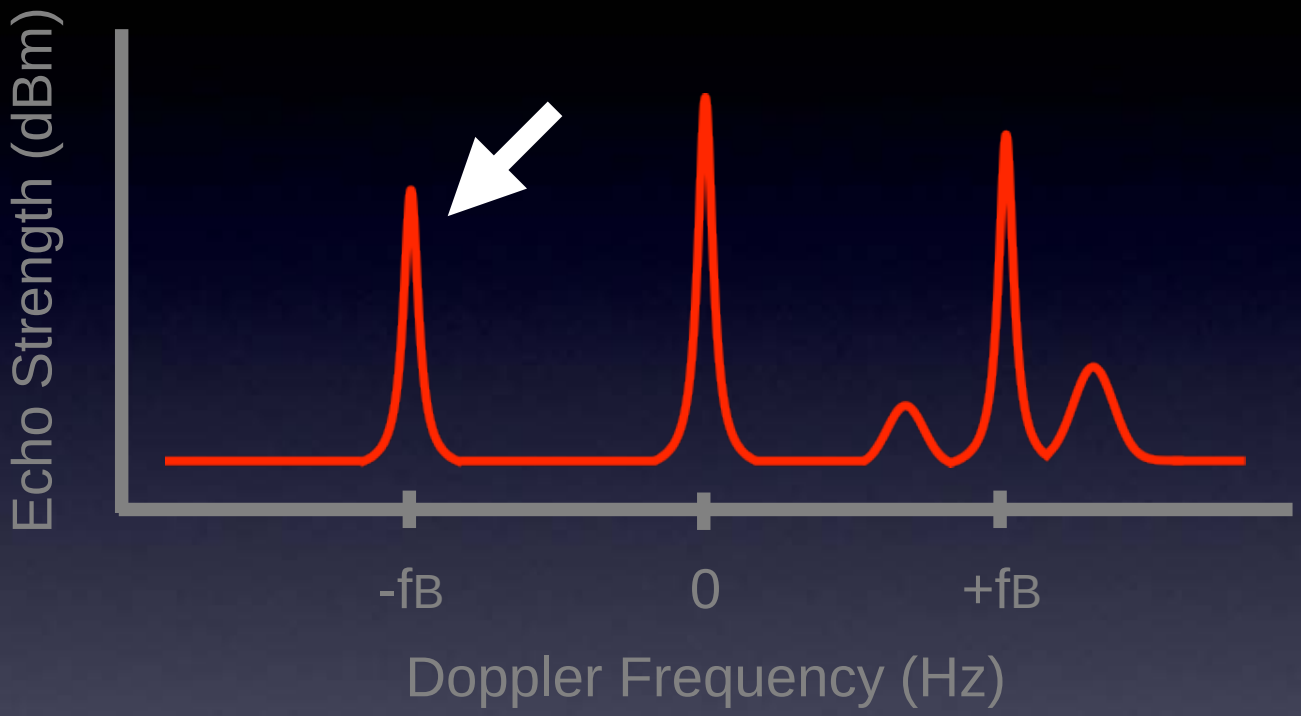
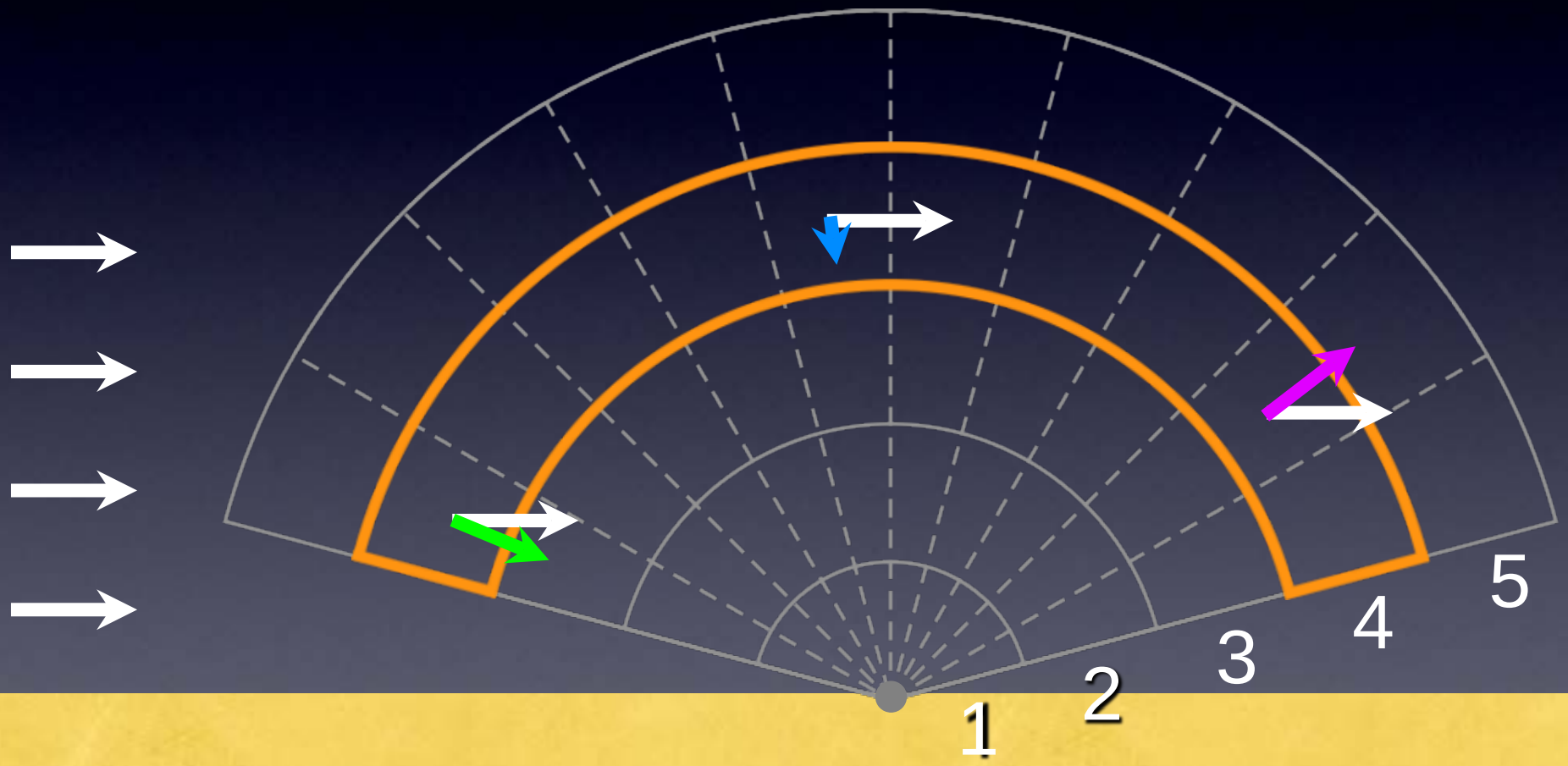


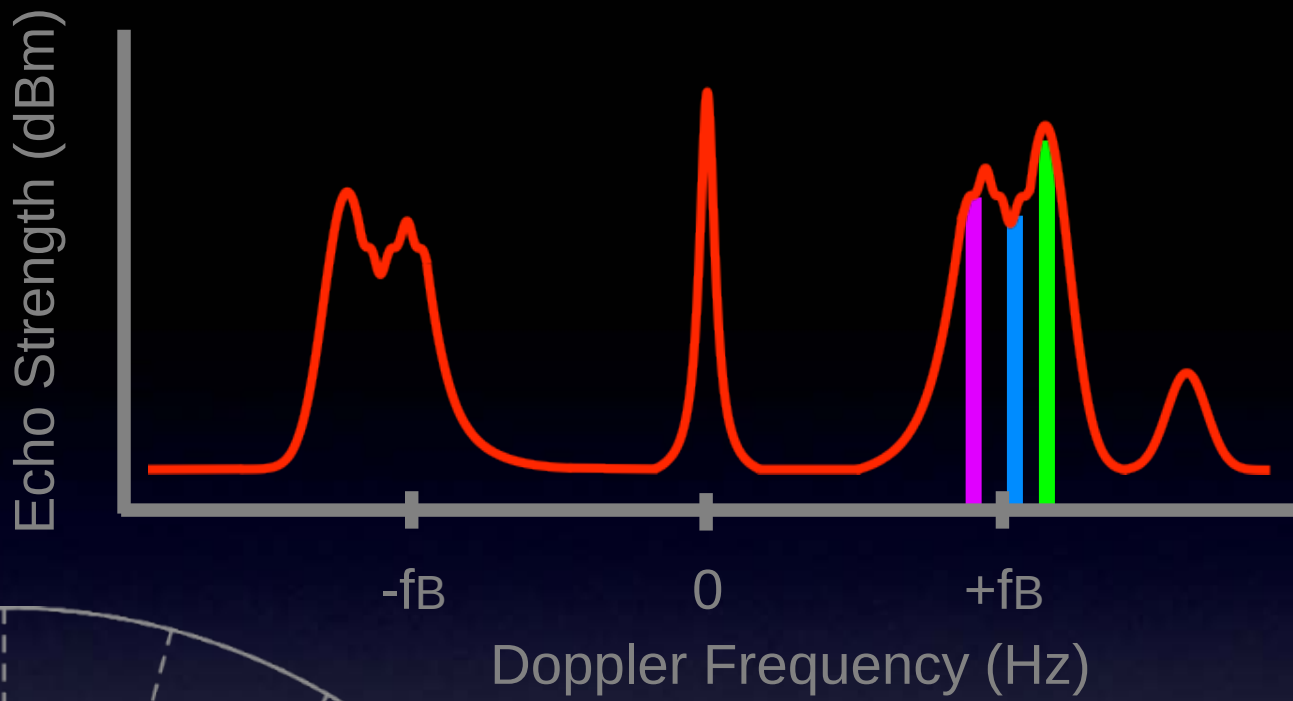
Doppler Spectrum

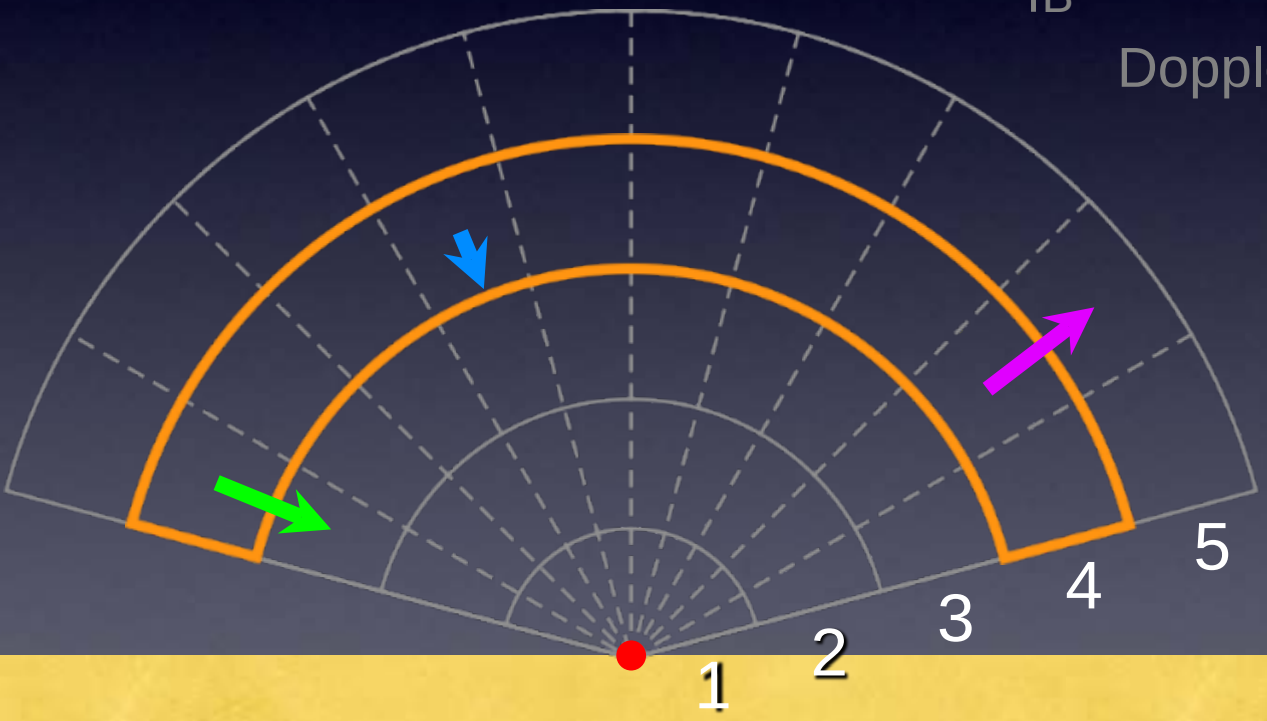


Radial Currents

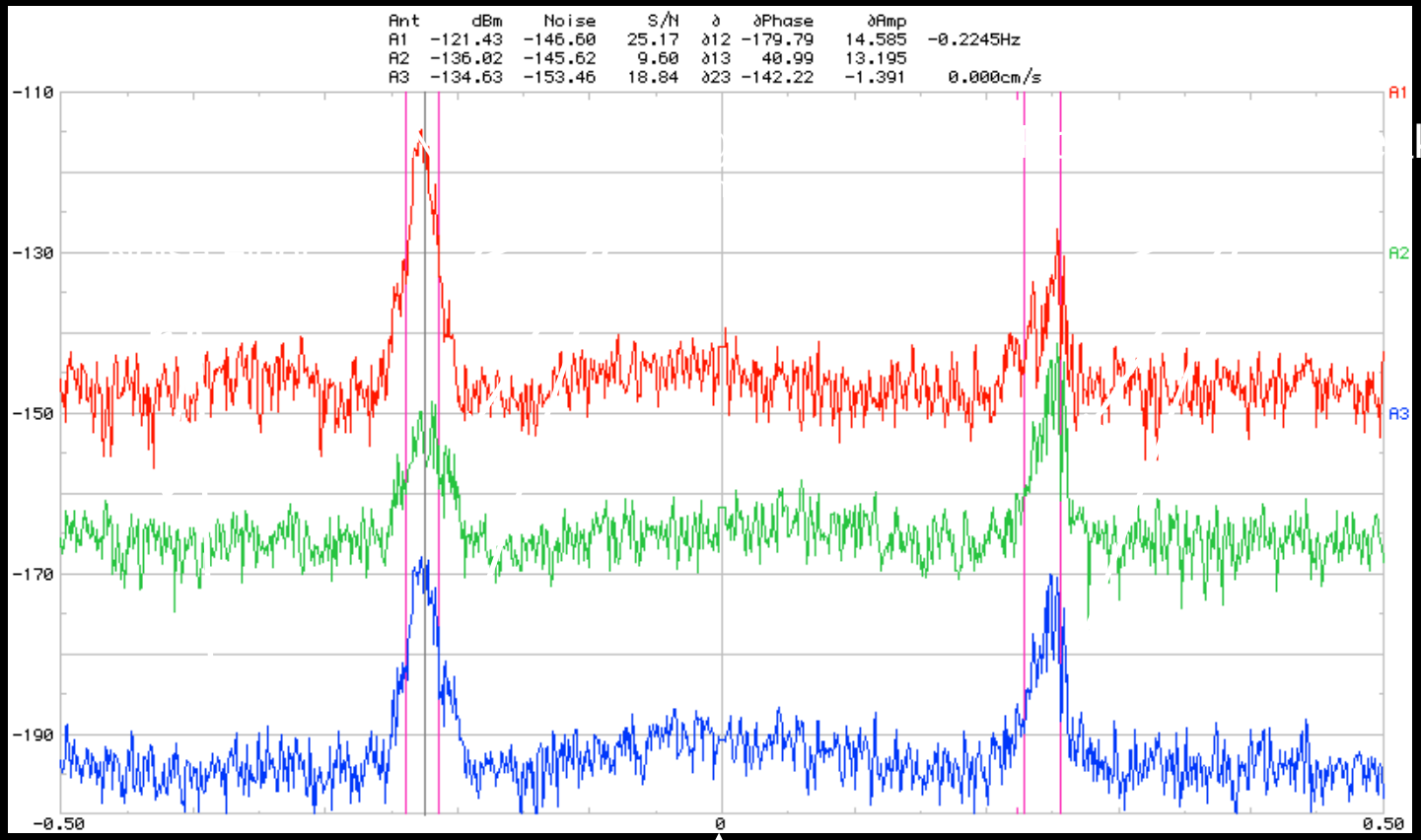


Radial Currents





The Doppler Spectrum



Loop 1 (A1)

Loop 2 (A2)

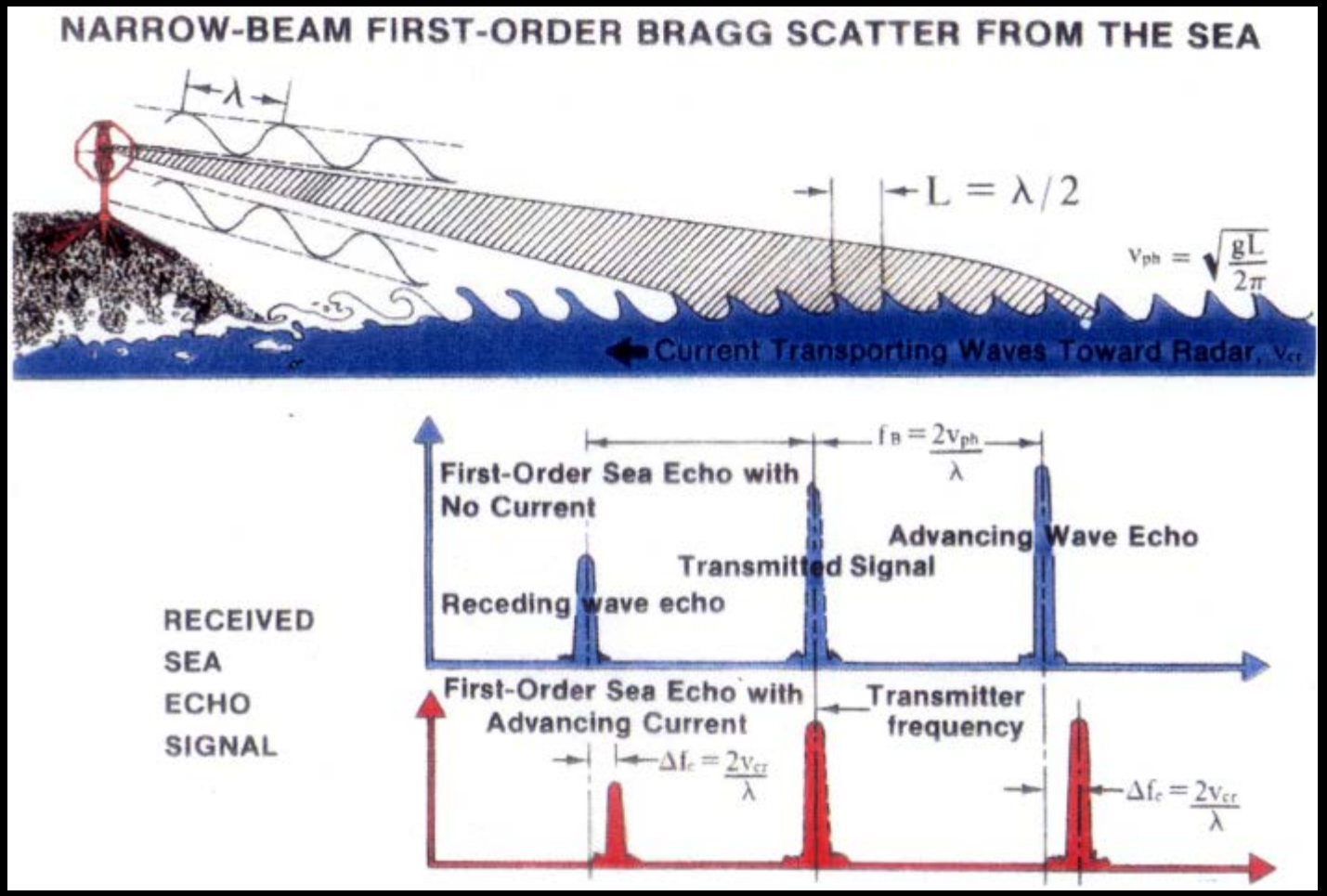
Monopole (A3)

Negative Doppler:
Targets moving
away from Antennas

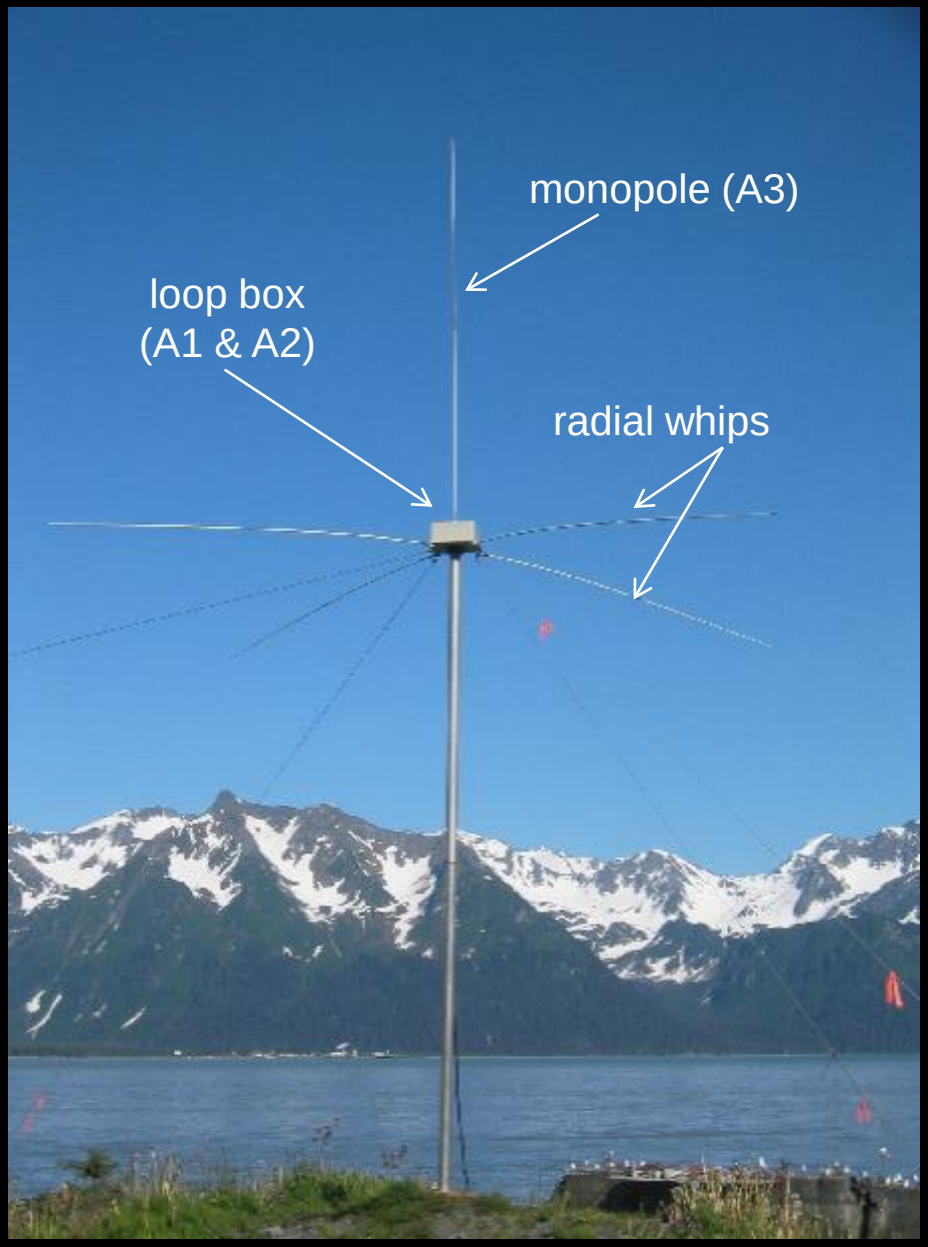
0 Hz
Doppler Offset
a.k.a. “DC”

Positive Doppler:
Targets moving
towards Antennas

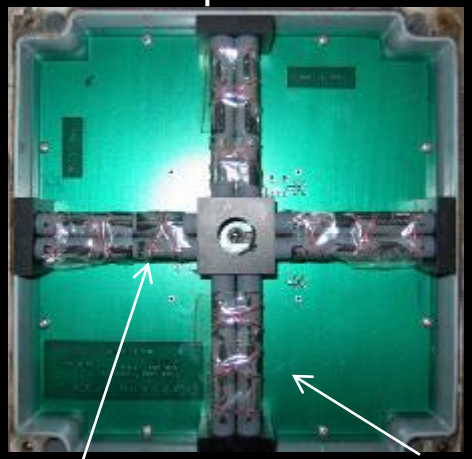
Physical Mechanism Behind Current Mapping from First-Order Doppler Sea-Echo Spectral Peaks

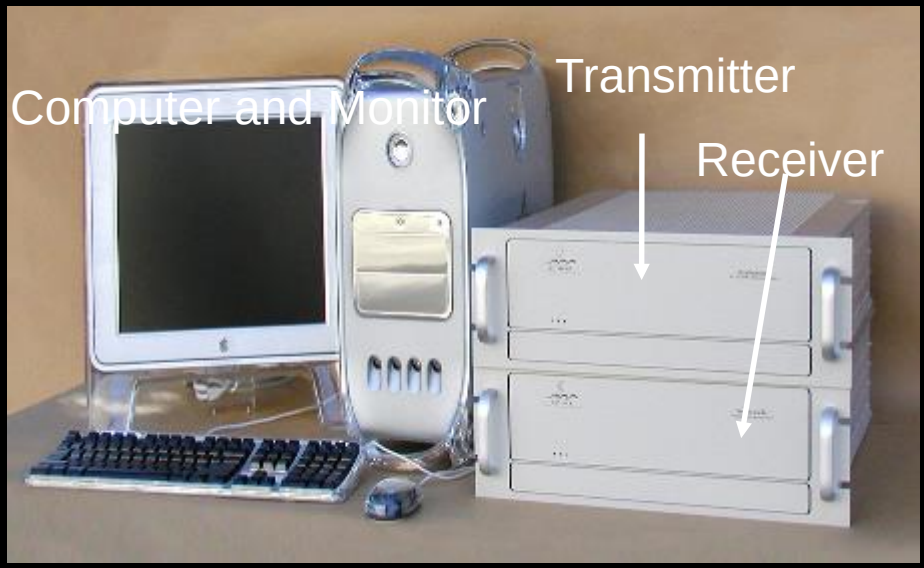


What does an HF RADAR consist of?

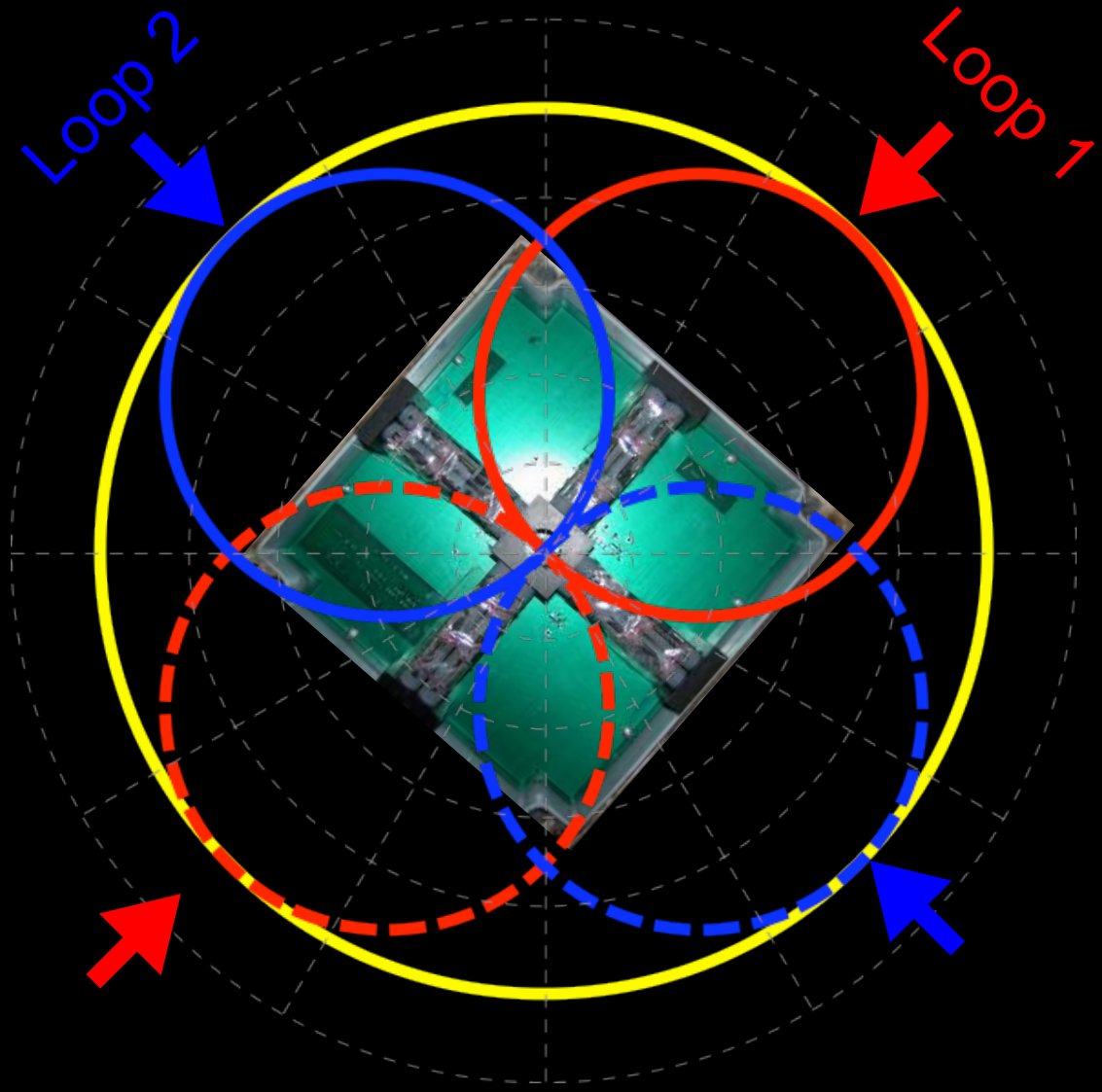


loop box

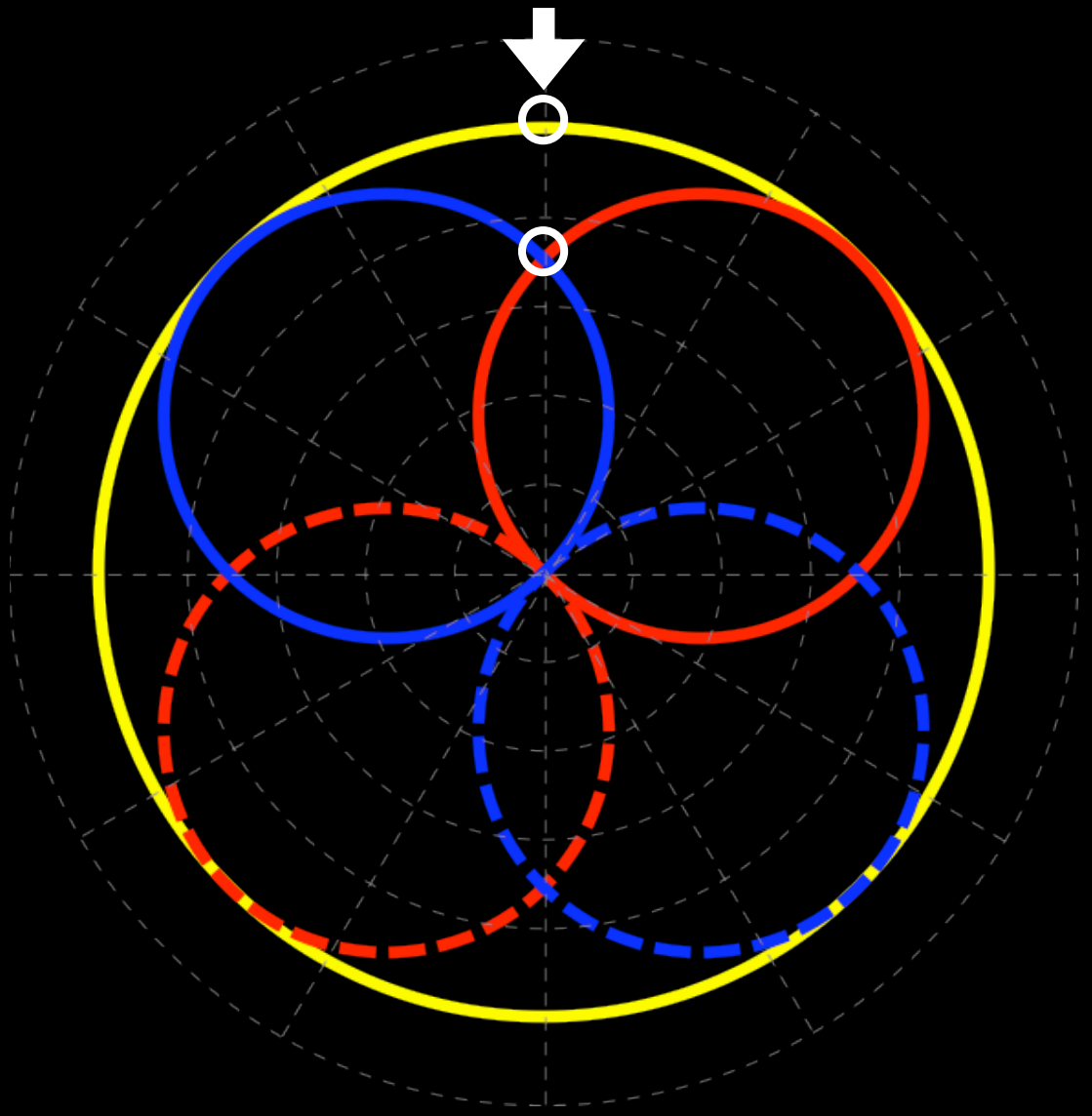





13 MHz Transmit and
Receive Antenna
4 meters

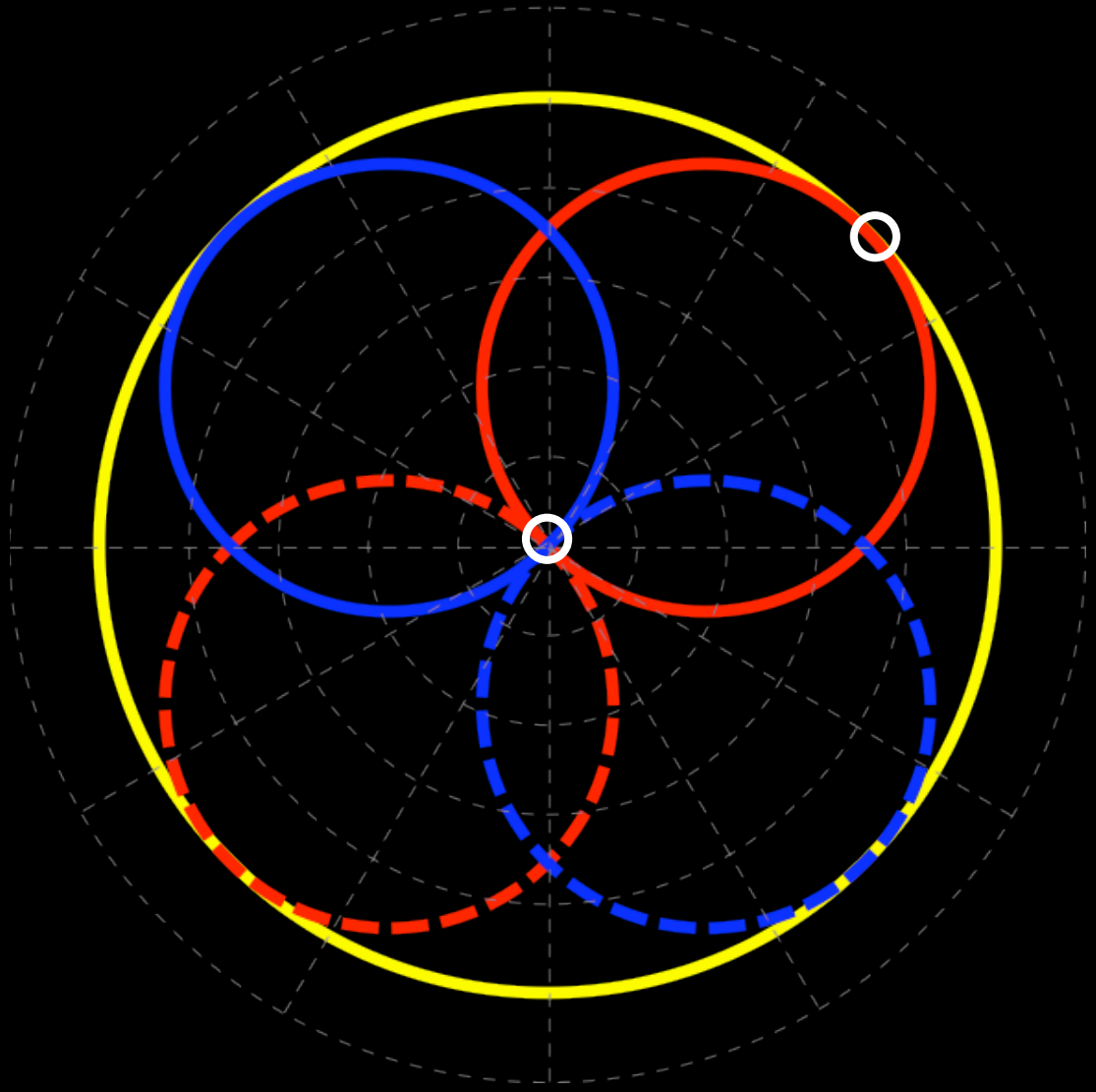

Loop 2
Loop 1

Direction Finding



	Amplitudes		Phases	
	A1/A3	A2/A3	P1-P3	P2-P3
0	0.707	0.707	0	0
15	0.866	0.5	0	0
45	1	0	0	0
75	0.866	0.5	0	180
90	0.707	0.707	0	180
120	0.259	0.966	0	180
180	0.707	0.707	180	180

Direction Finding



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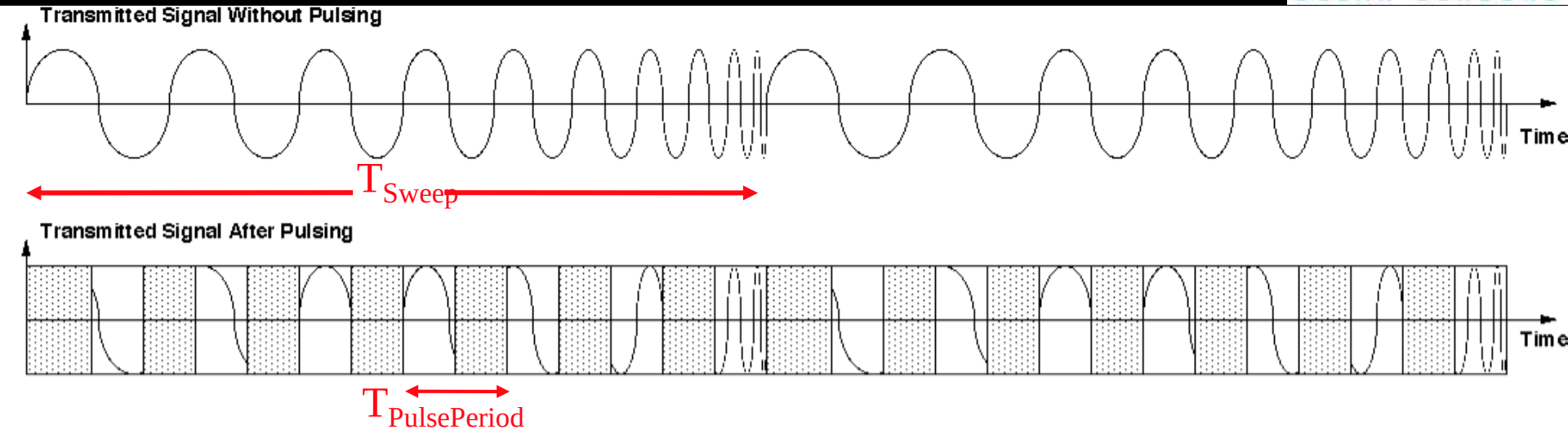
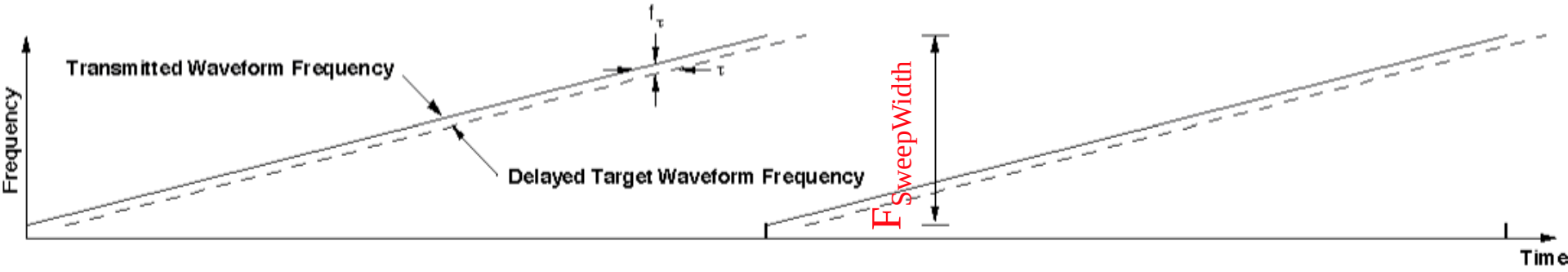
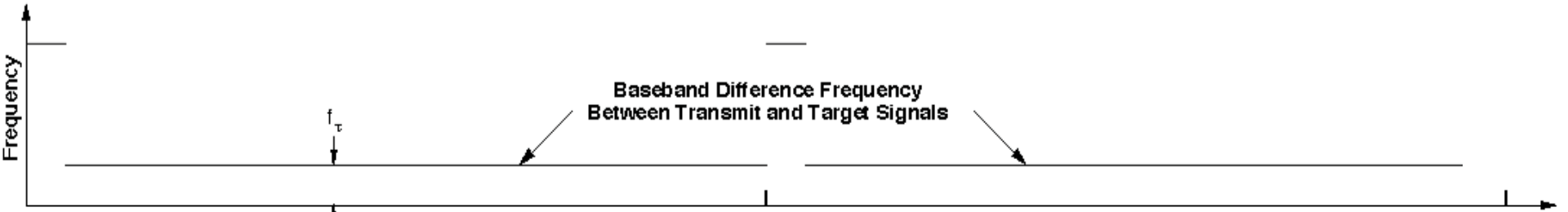
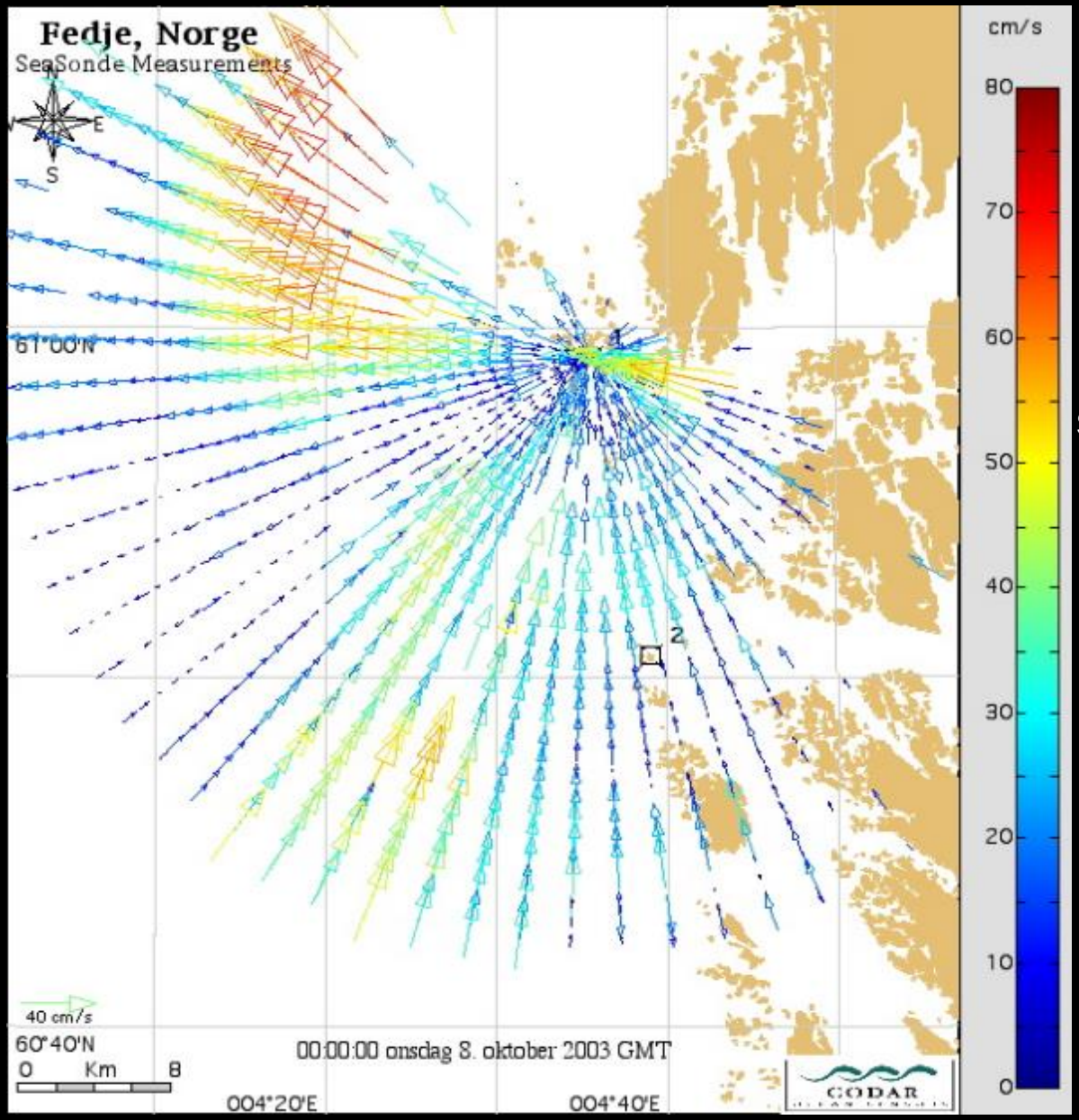
SeaSonde Waveform







Radial Vector Output of MUSIC Processing



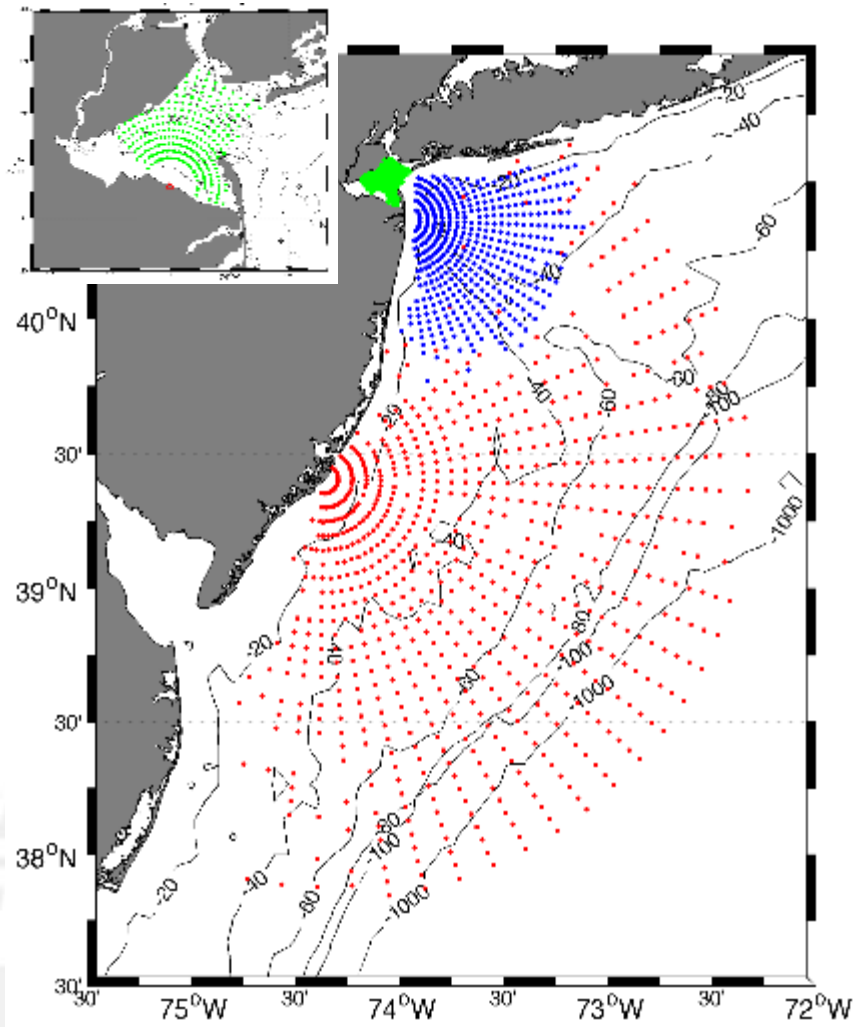
Output of MUSIC processing: radial vectors

Vectors are in polar coordinate system centered at receive antenna

1 radial map per averaged cross spectra file into one hourly map

APPLICATION: OCEANOGRAPHY, SEARCH AND RESCUE, OIL SPILLS

Surface Current Mapping Capability



25 MHz

Radar λ: 12 m Ocean λ: 6 m

Range: 30 km Resolution: 1 km

13 MHz

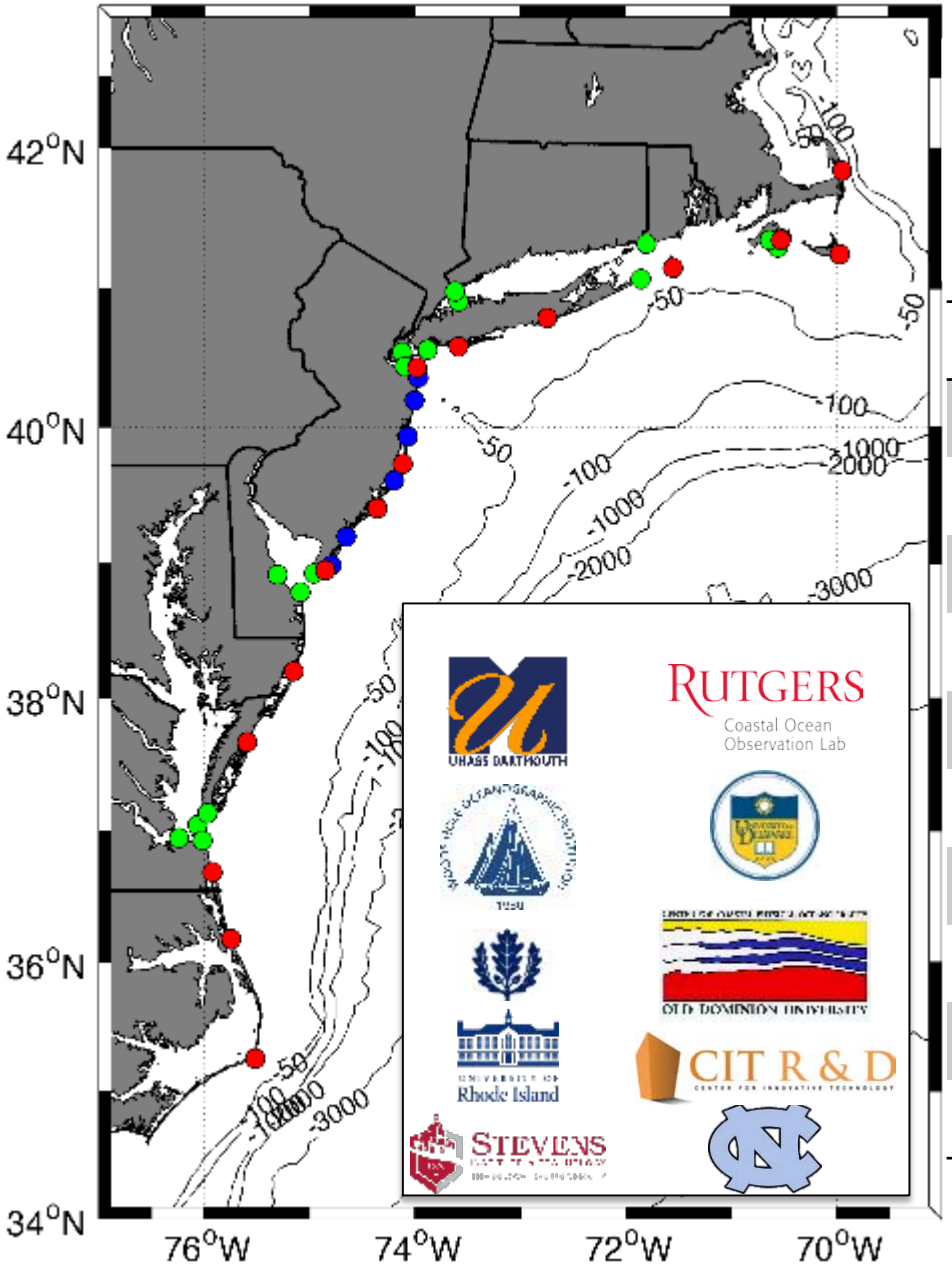
Radar λ: 23 m Ocean λ: 12 m

Range: 80 km Resolution: 3 km

05 MHz

Radar λ: 60m Ocean λ: 30 m

Range: 180 km Resolution: 6 km

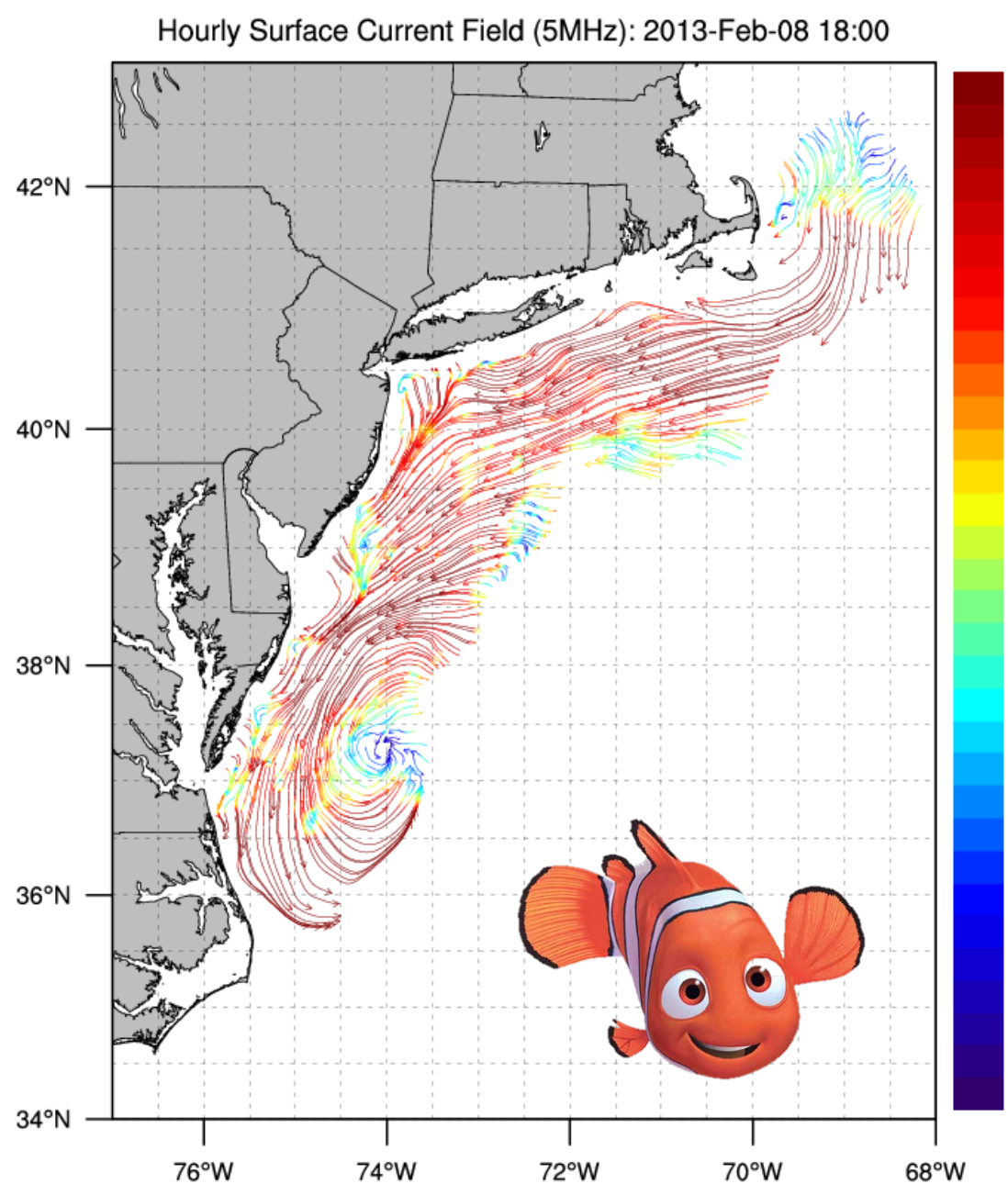


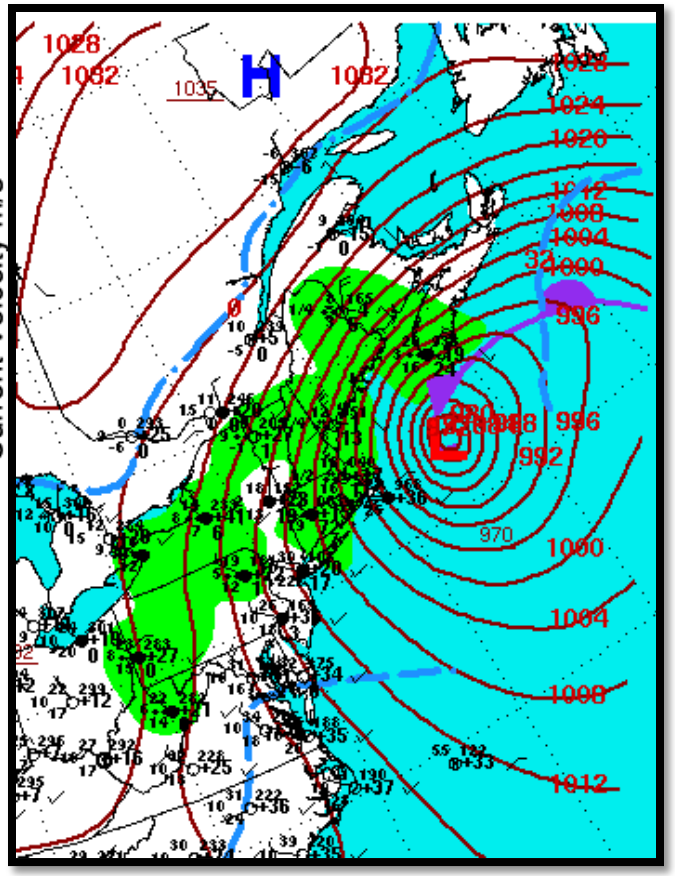
MARACOOS HF RADAR NETWORK

	5 MHz	13 MHz	25 MHz
U Mass	●		
WHOI			●
U Conn			●
URI			●
Stevens			●
Rutgers	●	●	●
Delaware			●
ODU/CIT	●		●
UNC	●		
9	17	8	17

41 Stations in Total

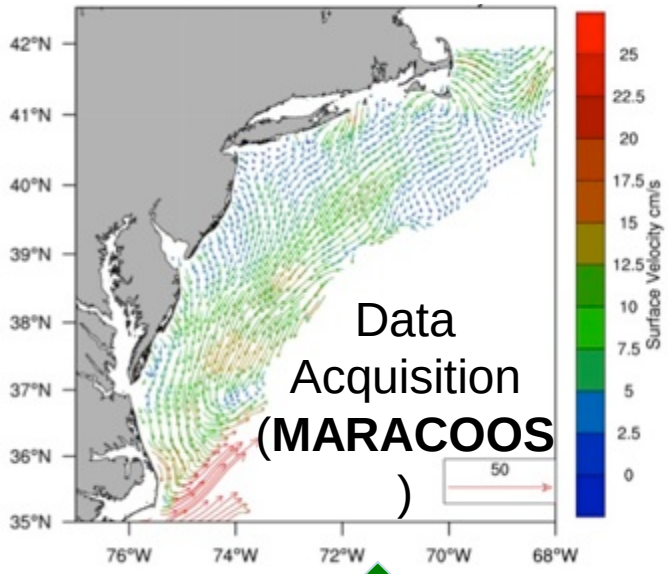
Winter Storm Nemo





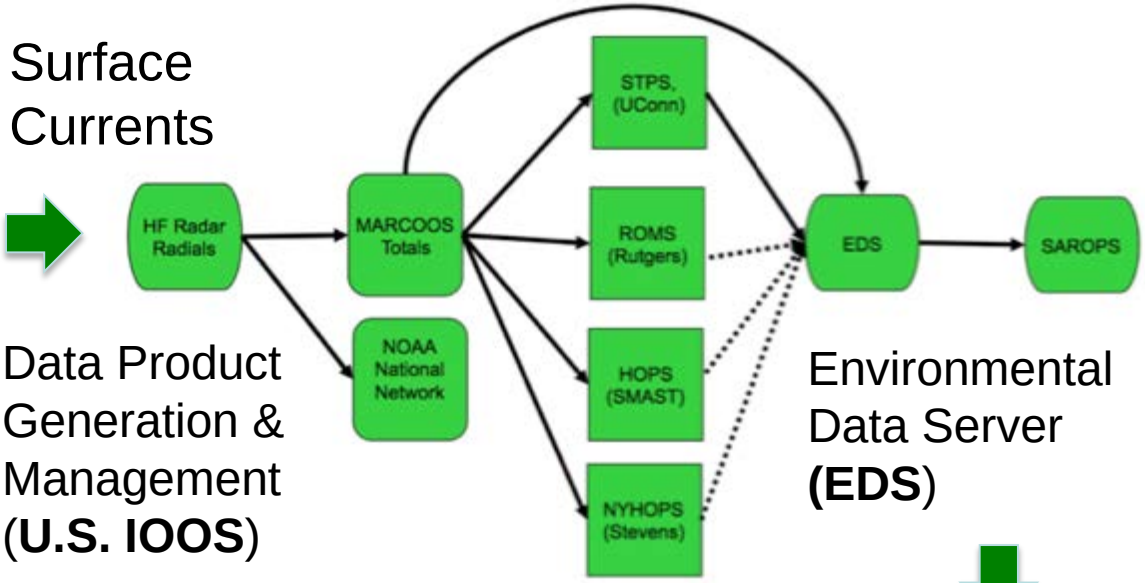
February 9, 2013

<u>Transition</u> Objective –
Operational Use of HF Radar Surface Currents for Search And Rescue



Data Acquisition (**MARACOOS**)

Surface Currents

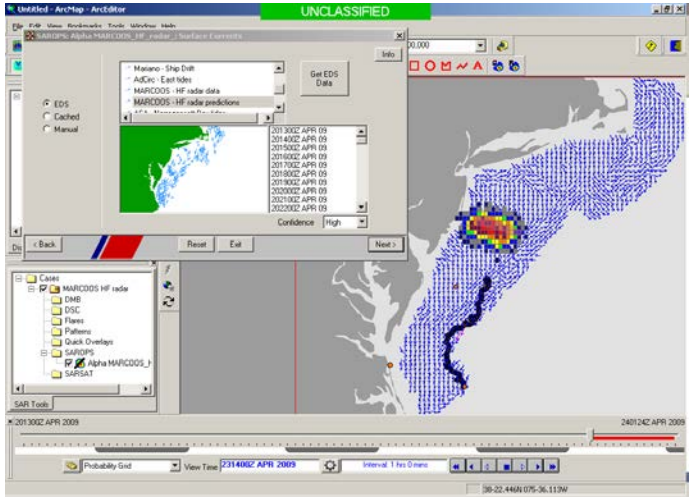


Data Product Generation & Management (**U.S. IOOS**)

Environmental Data Server (**EDS**)

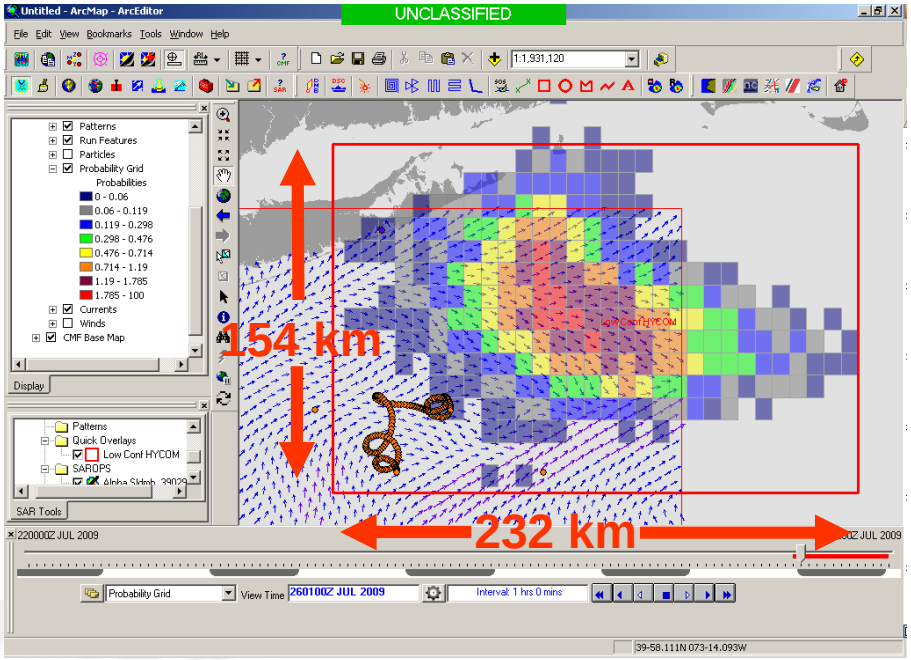
United States Coast Guard
U.S. Department of Homeland Security

Search And Rescue Optimal Planning System (**SAROPS**)



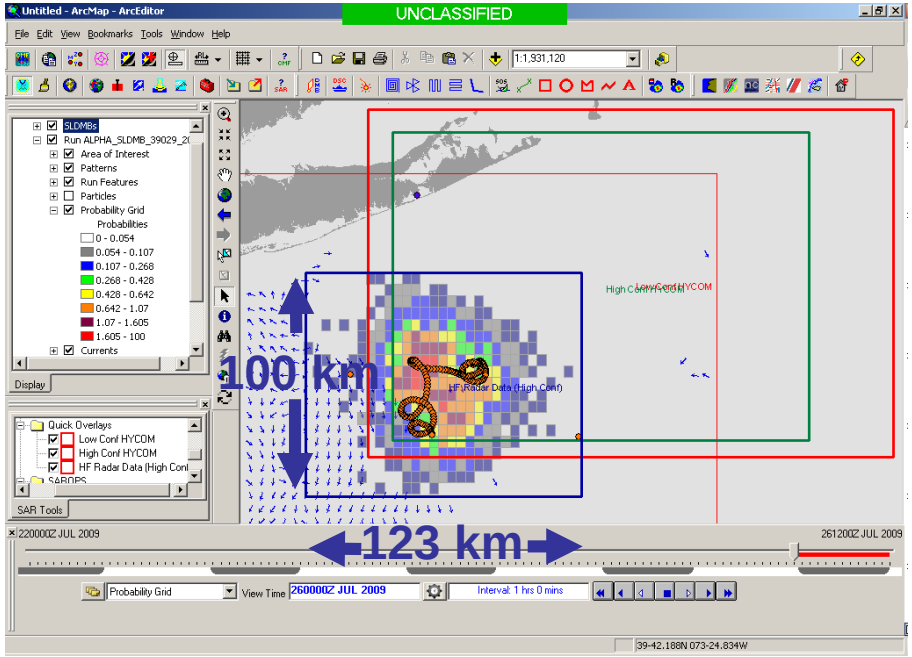
SAROPS Test Case

5000 Virtual Drifters + 1 Real Drifter (Black Line): Search Area After 96 Hours



HyCOM

36,000 km^2



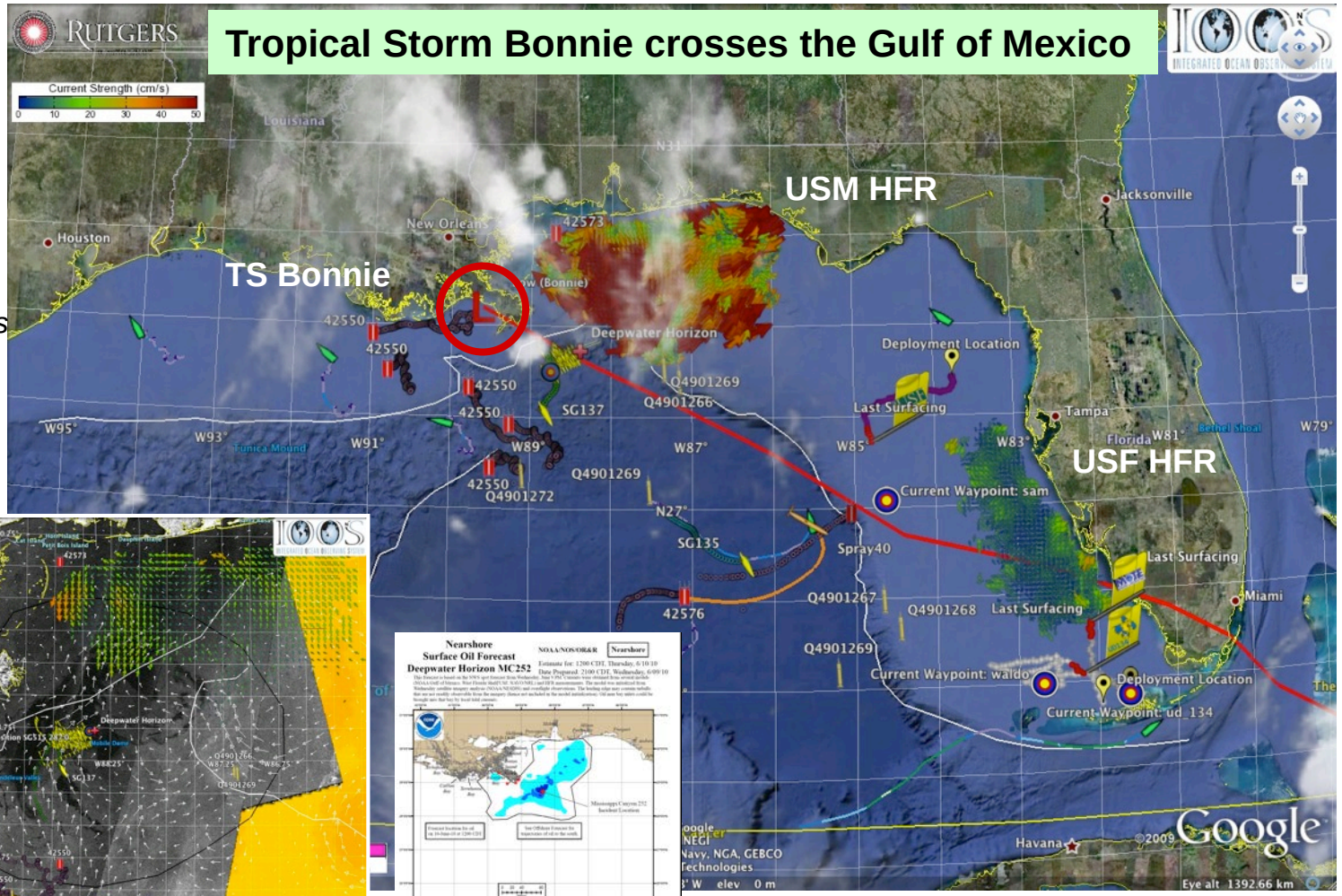
HF Radar

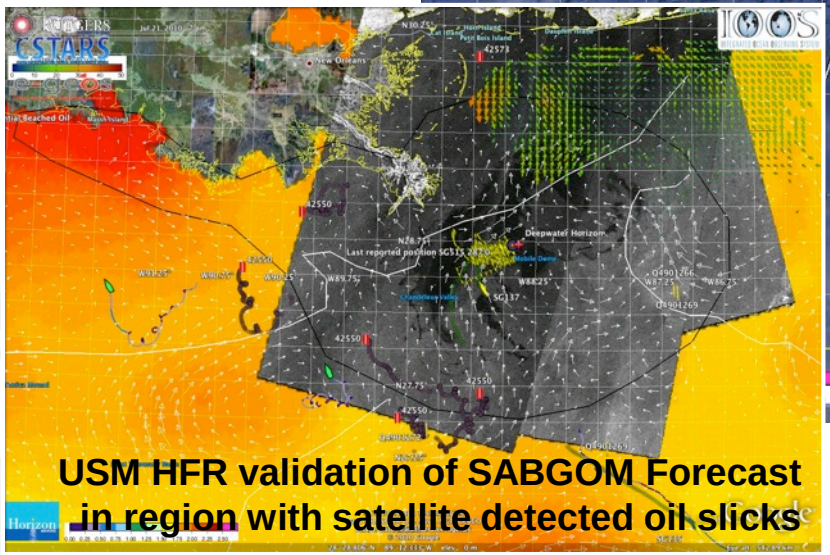
12,000 km^2

Deepwater Horizon Oil Spill: Coordinated Rapid Response

Contributed Assets:

HF Radar Networks
USF, USM
Gliders
iRobot, Mote, Rutgers, SIO, UDel, USF, Navy
Drifters & Profilers
Horizon Marine, Navy
Satellite Imagery
CSTARS, UDel, Rutgers
Ocean Forecasts
Navy, NCSU
Data/Web Services
ASA, Rutgers, SIO



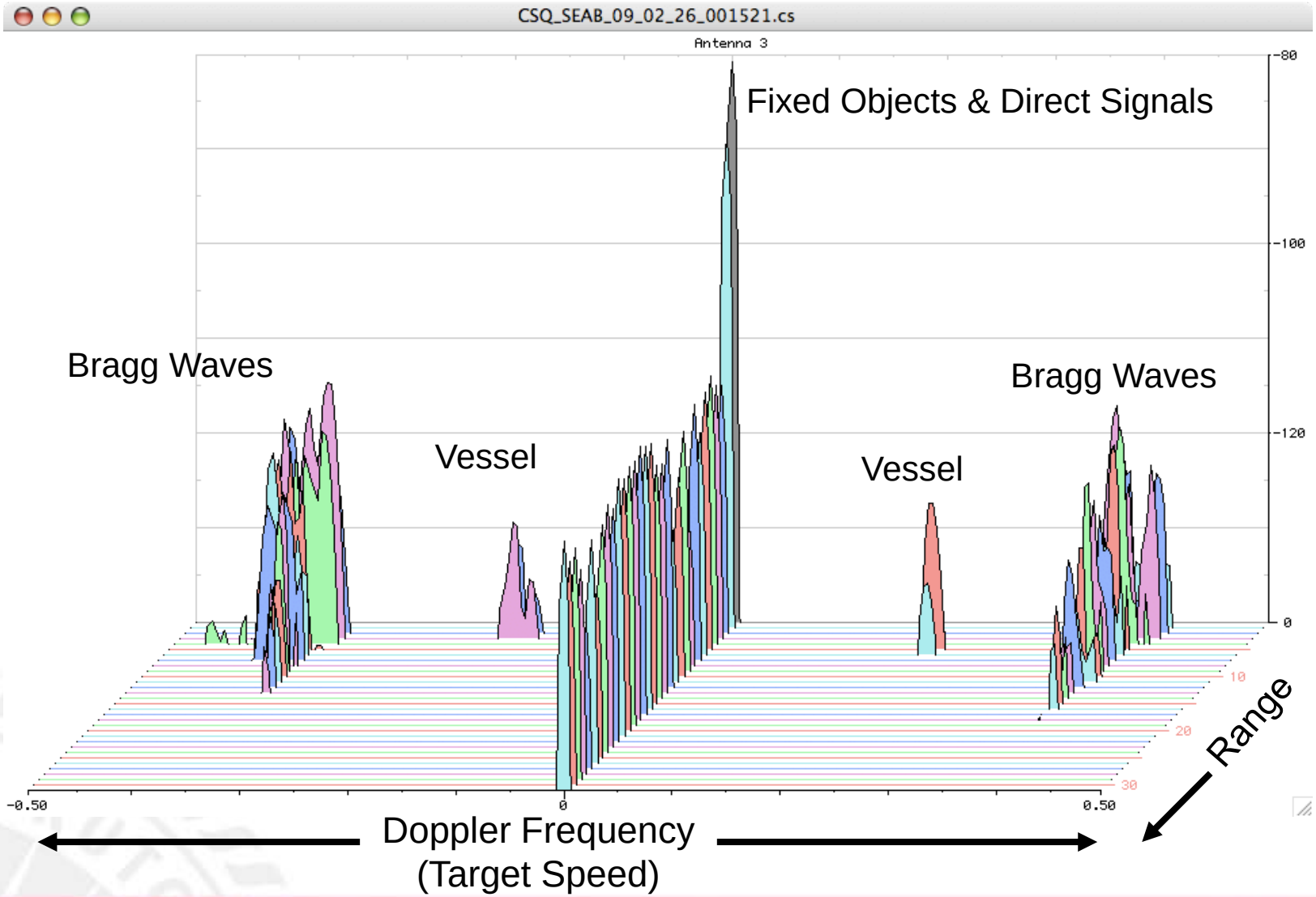


USM HFR validation of SABGOM Forecast in region with satellite detected oil slicks

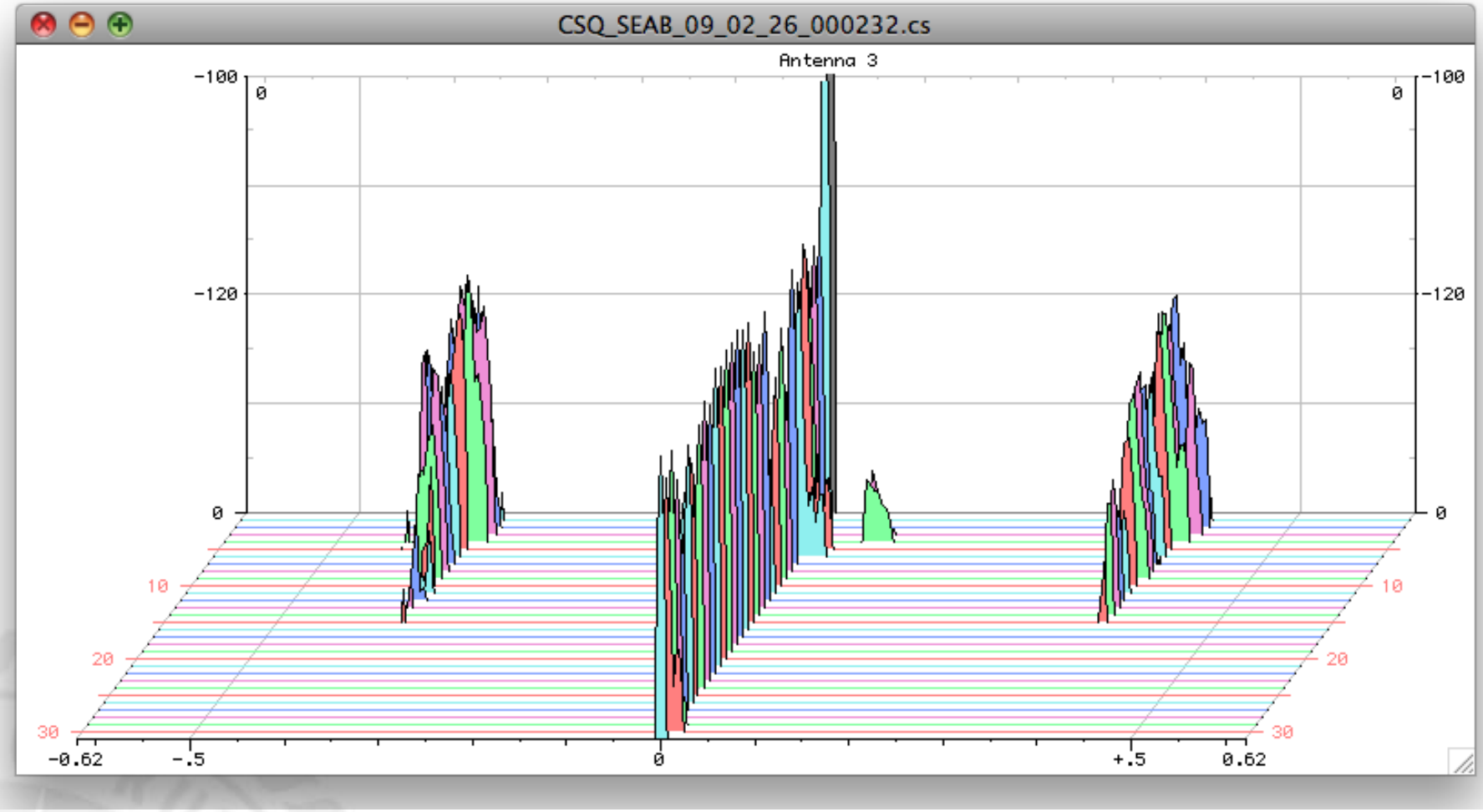
HFR used for Oil Slick Forecasts by NOAA/NOS/OR&R

APPLICATION: MARITIME DOMAIN AWARENESS AND VESSEL DETECTION

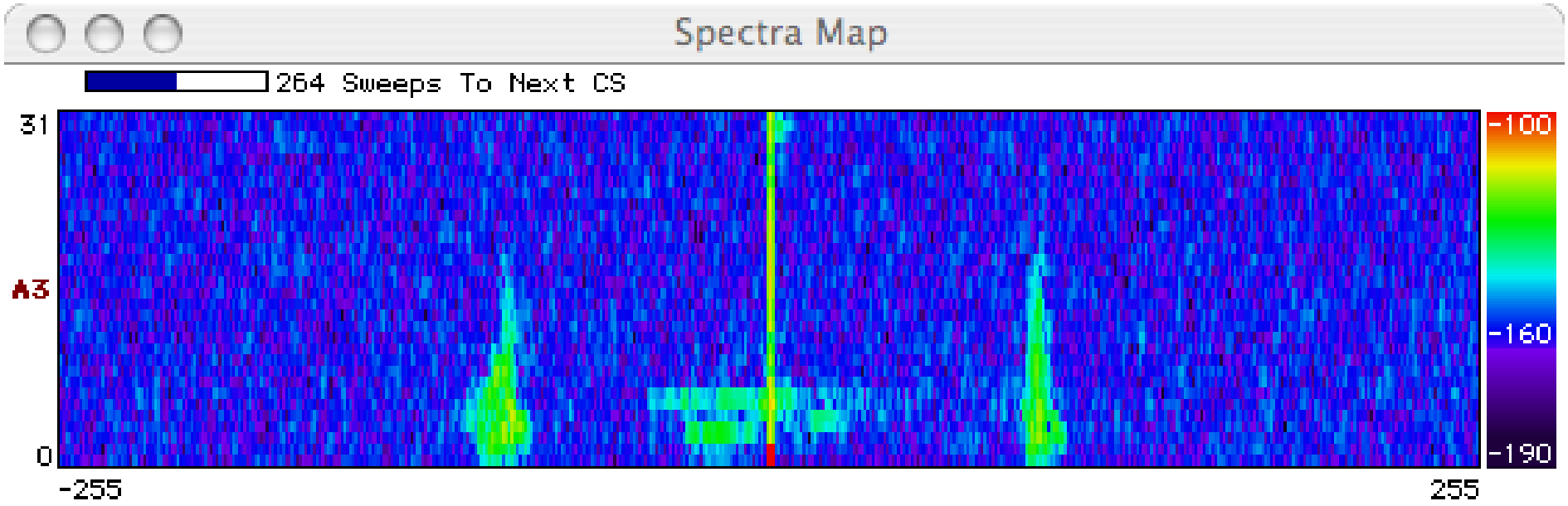
Doppler Spectra from all Range Cells with Detection Threshold above Background Applied



Ships in Spectra



Ships in Spectra



The Center for Secure and Resilient Maritime Commerce (CSR)

HF Radar Team

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Don Barrick, Pete Lilleboe, Chad Whelan Belinda Lipa, Bill Rector, Jimmy Isaacson

University or Puerto Rico – Mayaguez
Jorge Corredor, Julio Morell, Miguel Canals

Applied Mathematics, Inc -
Bill Browning

University of Alaska – Fairbanks
Tom Weingarter, Hank Statscewich

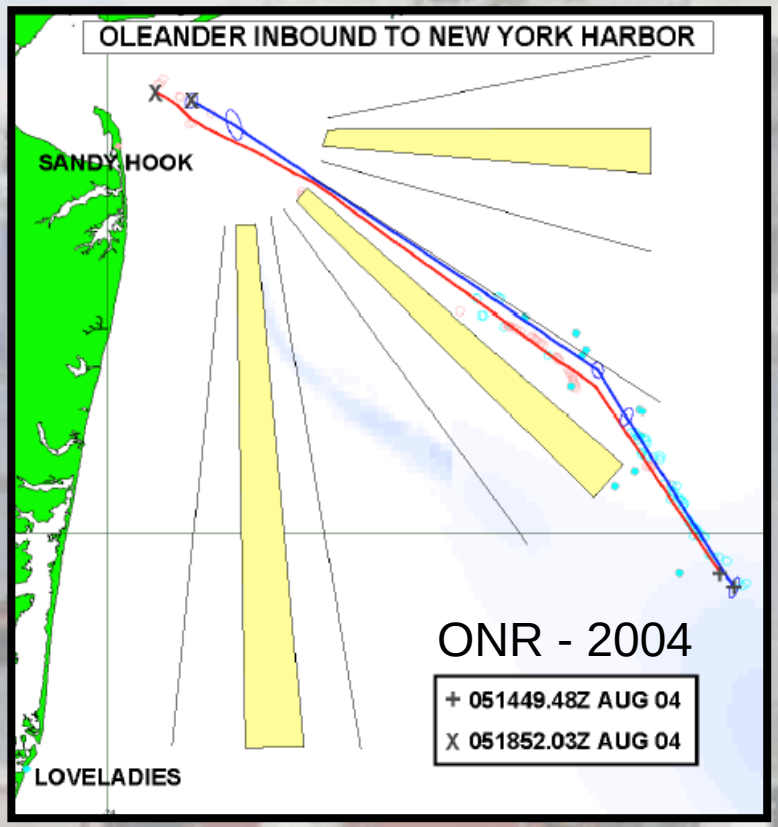
Ocean Power Technologies –
Debbie Montagna, Bruce Downie

Naval Research Laboratory
Michael Lovellette, Dan Newton

Norwegian Defence Research Establishment (FFI)
Terje Johnsen, Walther Asen

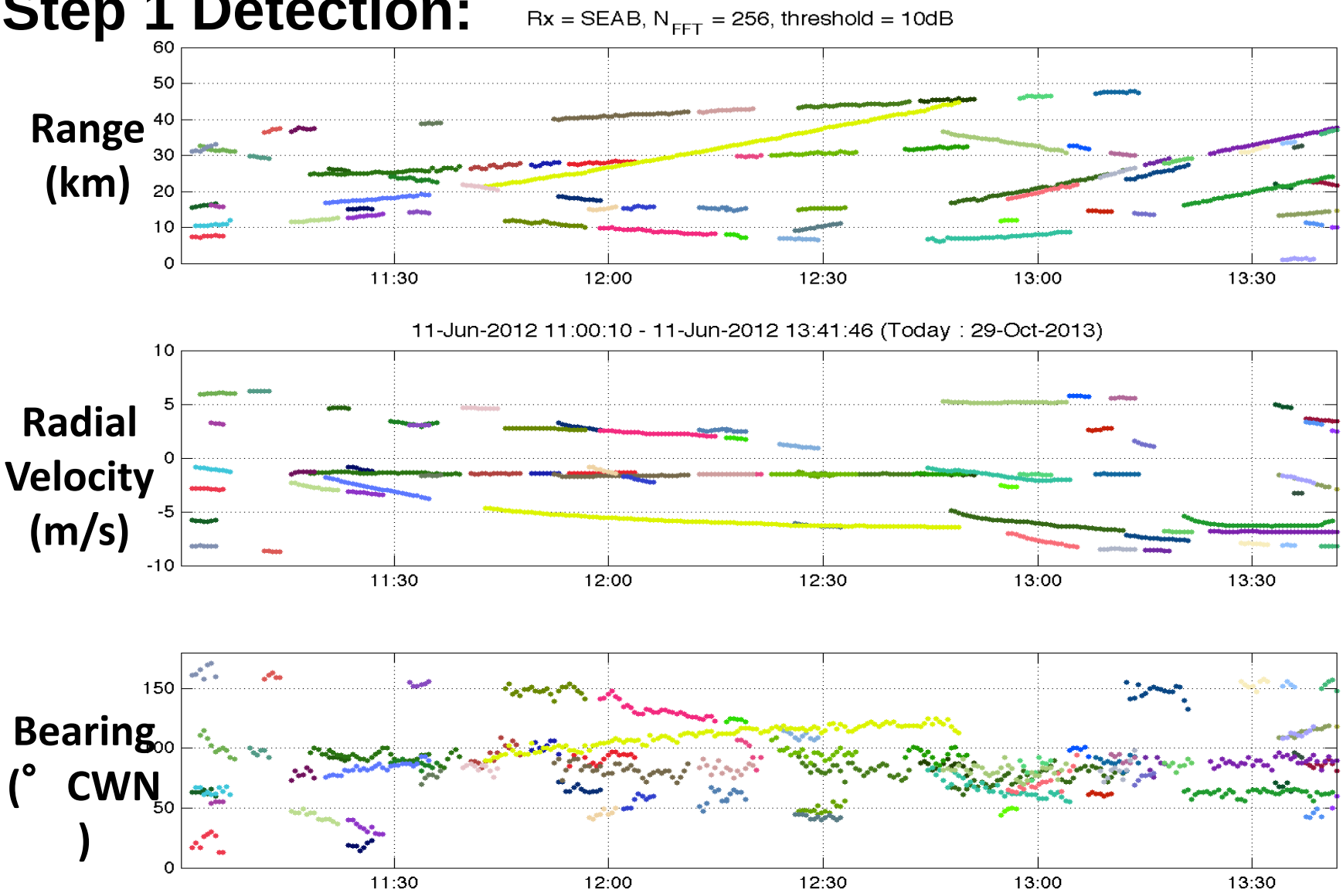
CODARNor
Anton Kjelaas

Rutgers University – CODAR Ocean Sensors
Academic – Industry Partnership since 1998

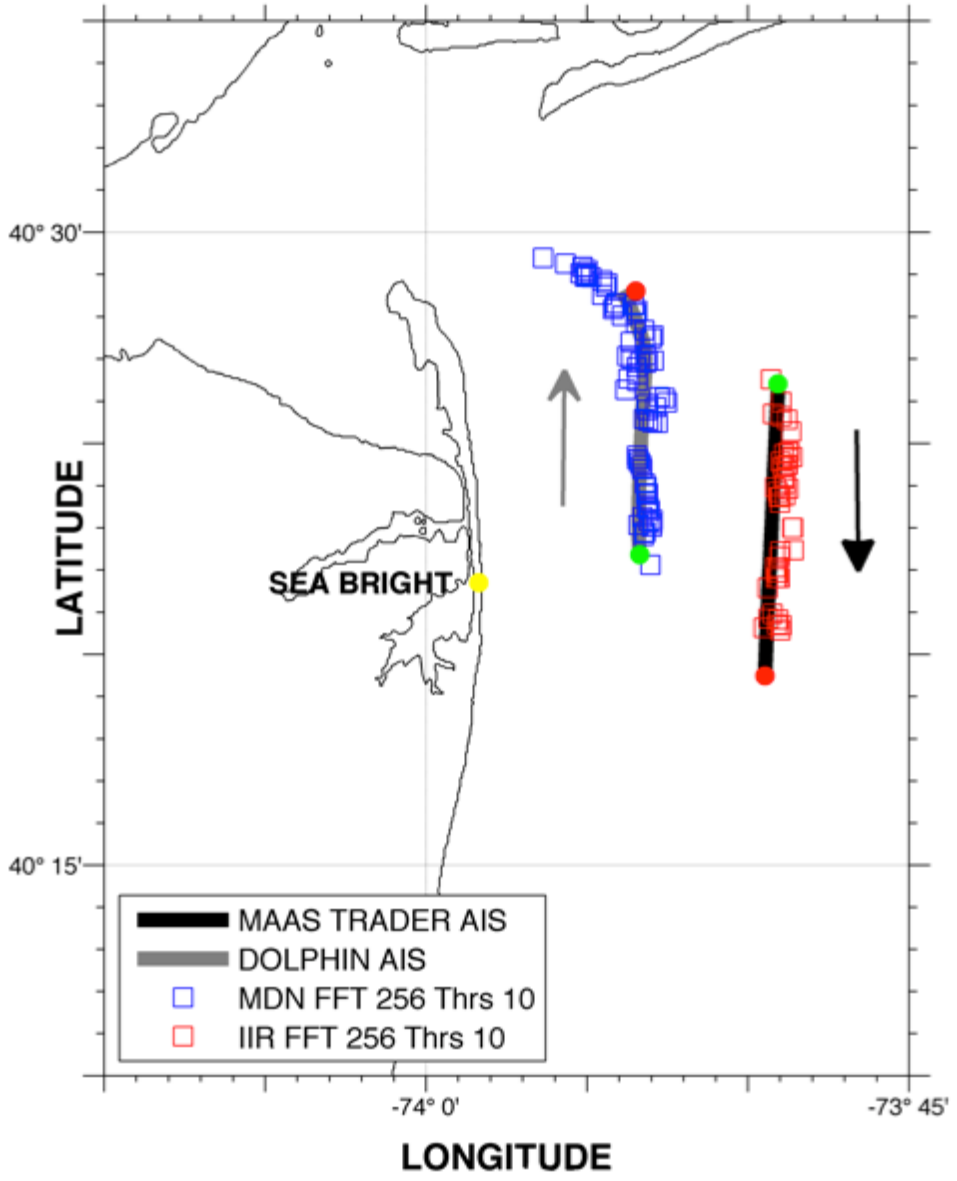


27 Researchers @ 9 Institutions

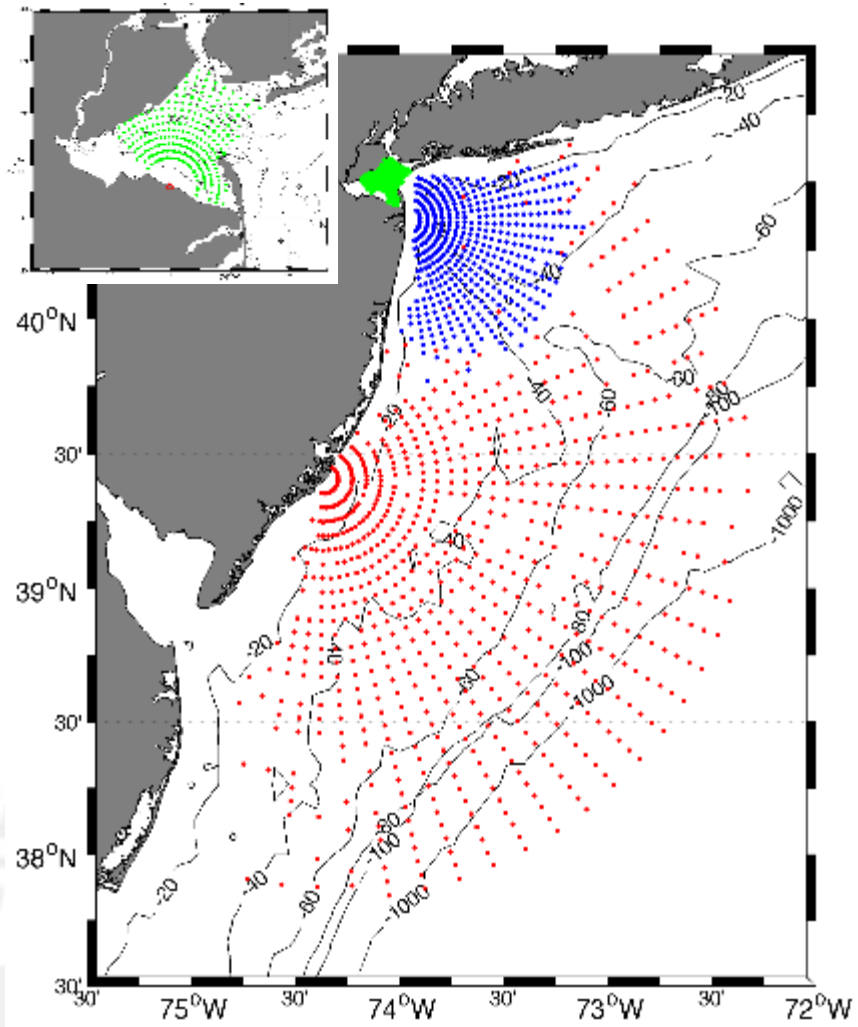
Step 1 Detection:



Step 2 Association: TRACK OF MAAS TRADER and DOLPHIN



Surface Current Mapping Capability



25 MHz

Radar λ: 12 m Ocean λ: 6 m

Range: 30 km Resolution: 1 km

13 MHz

Radar λ: 23 m Ocean λ: 12 m

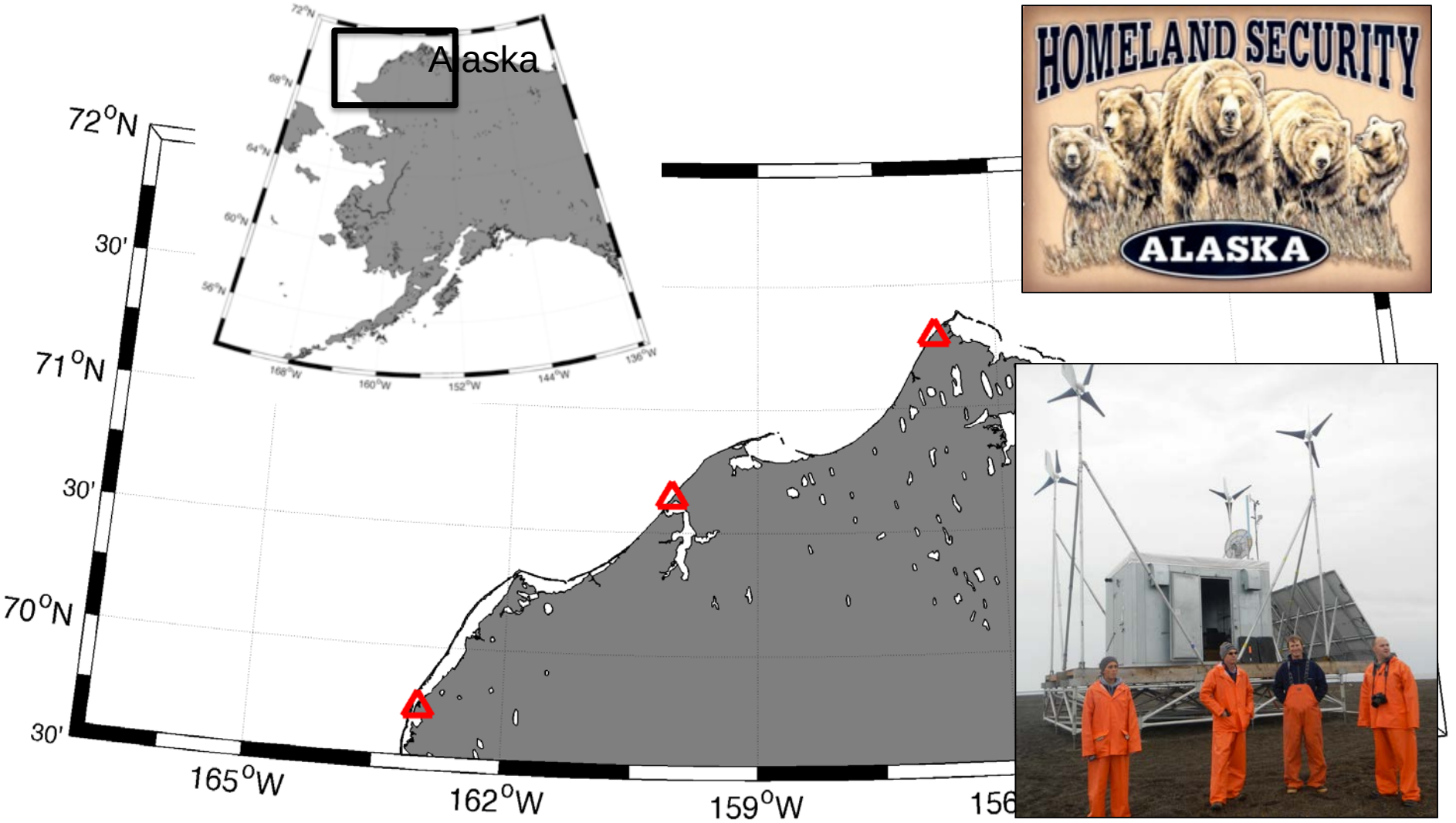
Range: 80 km Resolution: 3 km

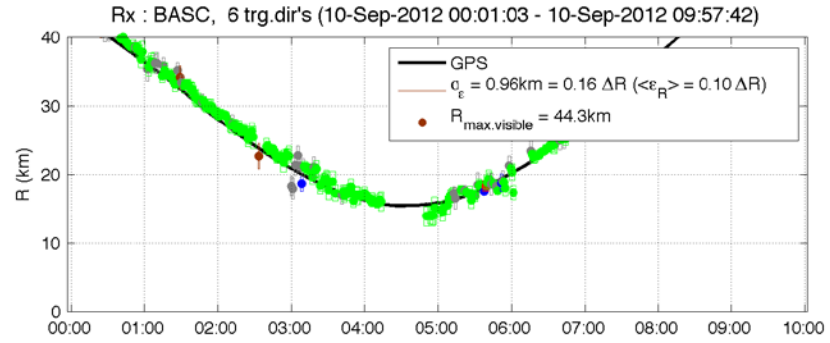
05 MHz

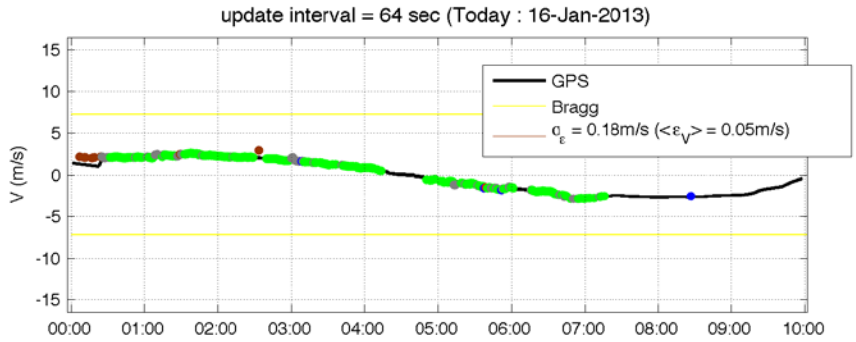
Radar λ: 60m Ocean λ: 30 m

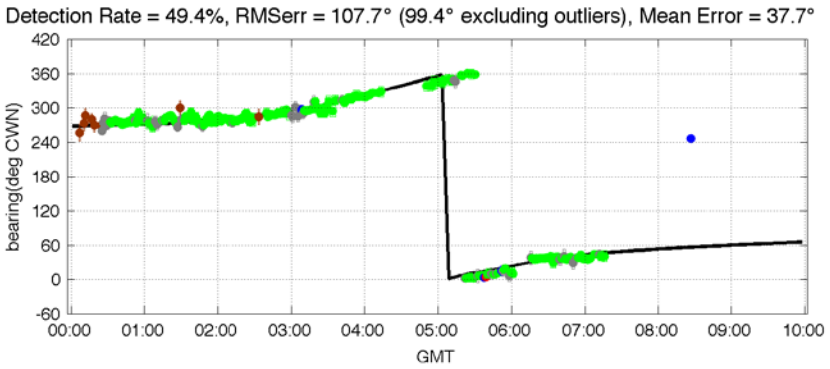
Range: 180 km Resolution: 6 km

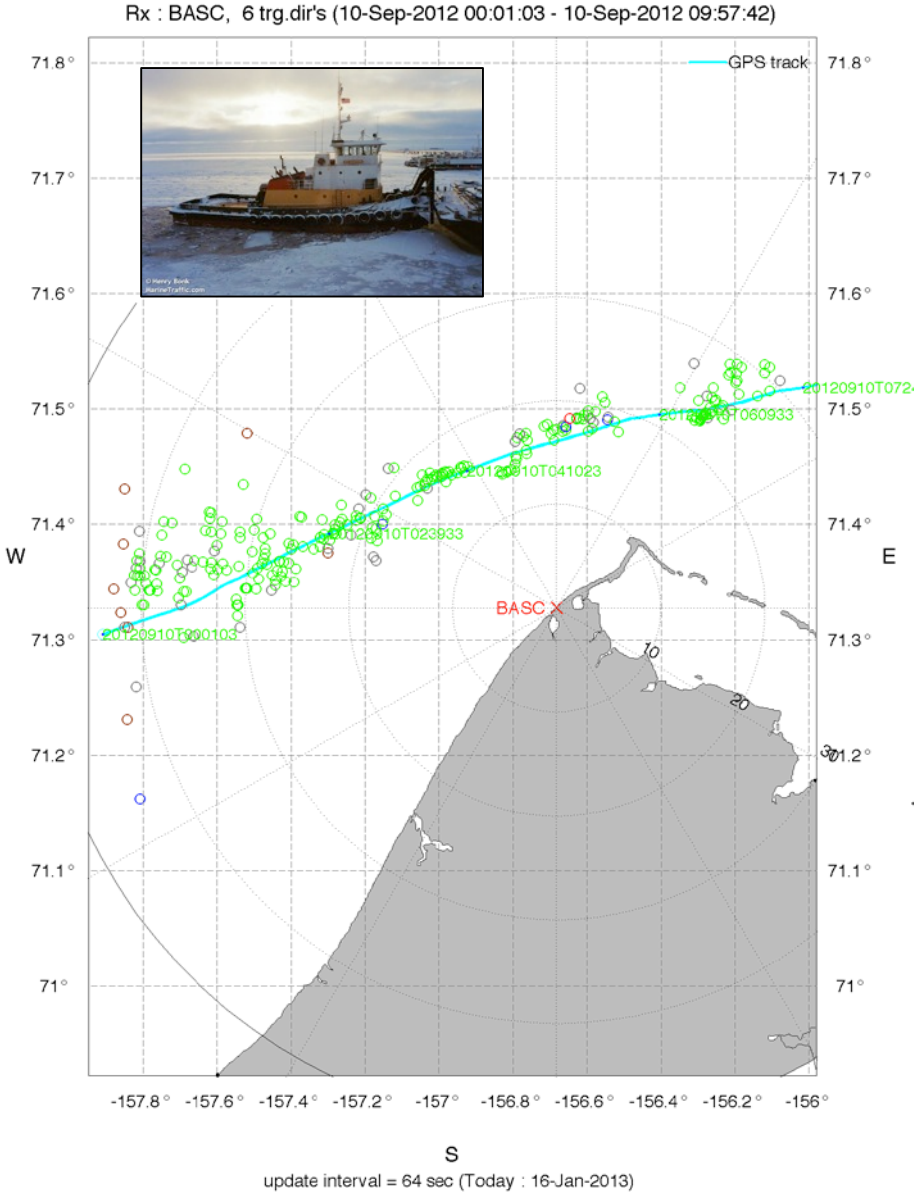
HF Radar Alaska




Rx : BASC, 6 trg.dir's (10-Sep-2012 00:01:03 - 10-Sep-2012 09:57:42)
GPS
σ_ε = 0.96km = 0.16 ΔR (<ε_R> = 0.10 ΔR)
$R_{max.visible}$ = 44.3km
R (km)
0
10
20
30
40
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00


update interval = 64 sec (Today : 16-Jan-2013)
GPS
Bragg
σ_ε = 0.18m/s (<ε_V> = 0.05m/s)
V (m/s)
15
10
5
0
-5
-10
-15
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00


Detection Rate = 49.4%, RMSerr = 107.7° (99.4° excluding outliers), Mean Error = 37.7°
bearing(deg CWN)
420
360
300
240
180
120
60
0
-60
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
GMT


Rx : BASC, 6 trg.dir's (10-Sep-2012 00:01:03 - 10-Sep-2012 09:57:42)
GPS track
BASC
W
E
S
71.8°
71.7°
71.6°
71.5°
71.4°
71.3°
71.2°
71.1°
71°
-157.8°
-157.6°
-157.4°
-157.2°
-157°
-156.8°
-156.6°
-156.4°
-156.2°
-156°
update interval = 64 sec (Today : 16-Jan-2013)

Detection of Russian Navy Ship with HF Radar

- Russian navy ship was shadowing the Research Vessel Westward Wind during its research cruise
- The Russian navy ship was within the EEZ of the United States
- Photos of the navy ship were taken on August 27, 2014 from the Westward Wind
- Position data from the Westward Wind were taken from Chukchi Science page

Westward Wind

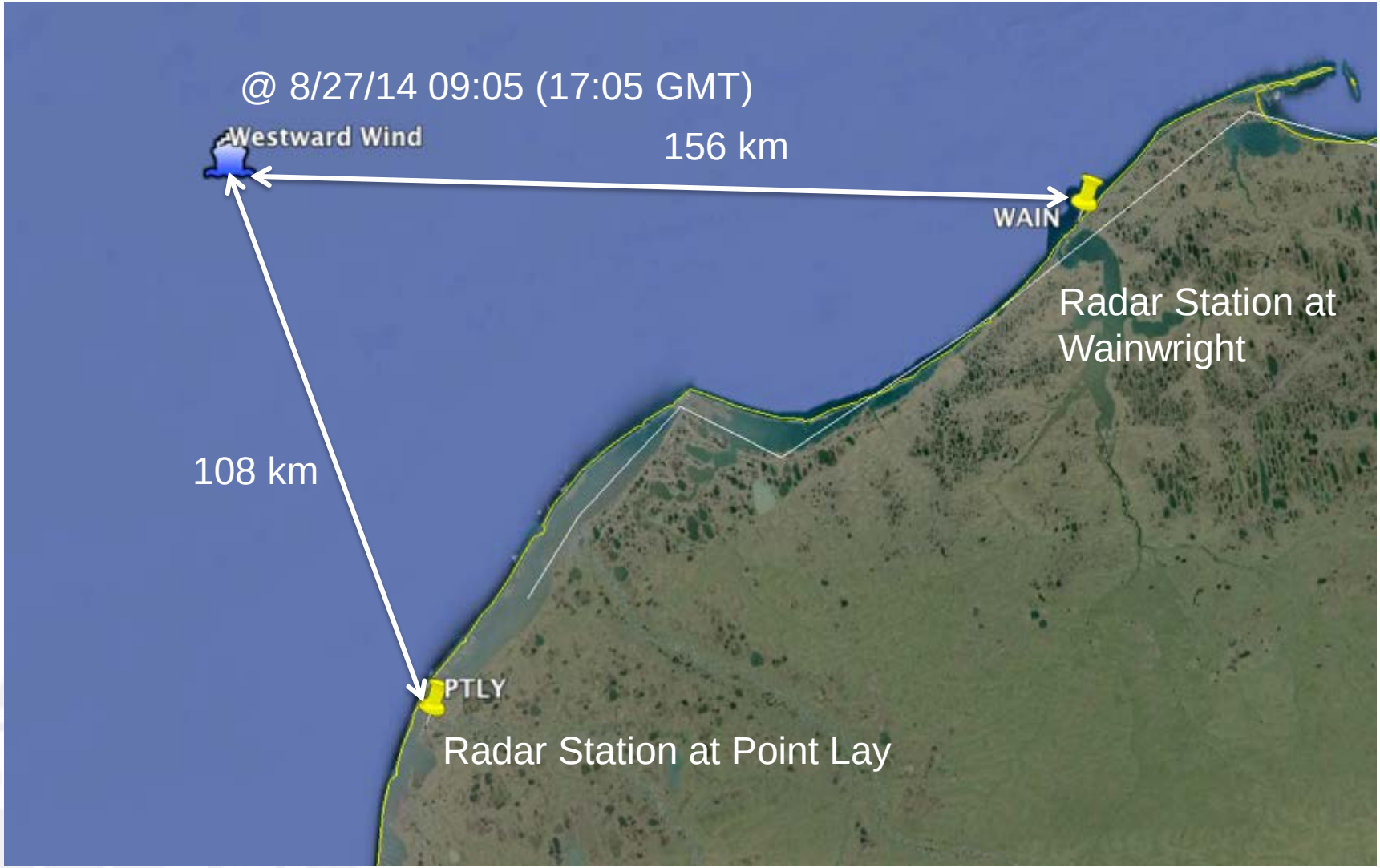
Russian Navy, Pribaltika

Photo taken from the Westward Wind at approximately 8/27/14 08:38 (16:38 GMT)

Russian Navy, Pribaltika

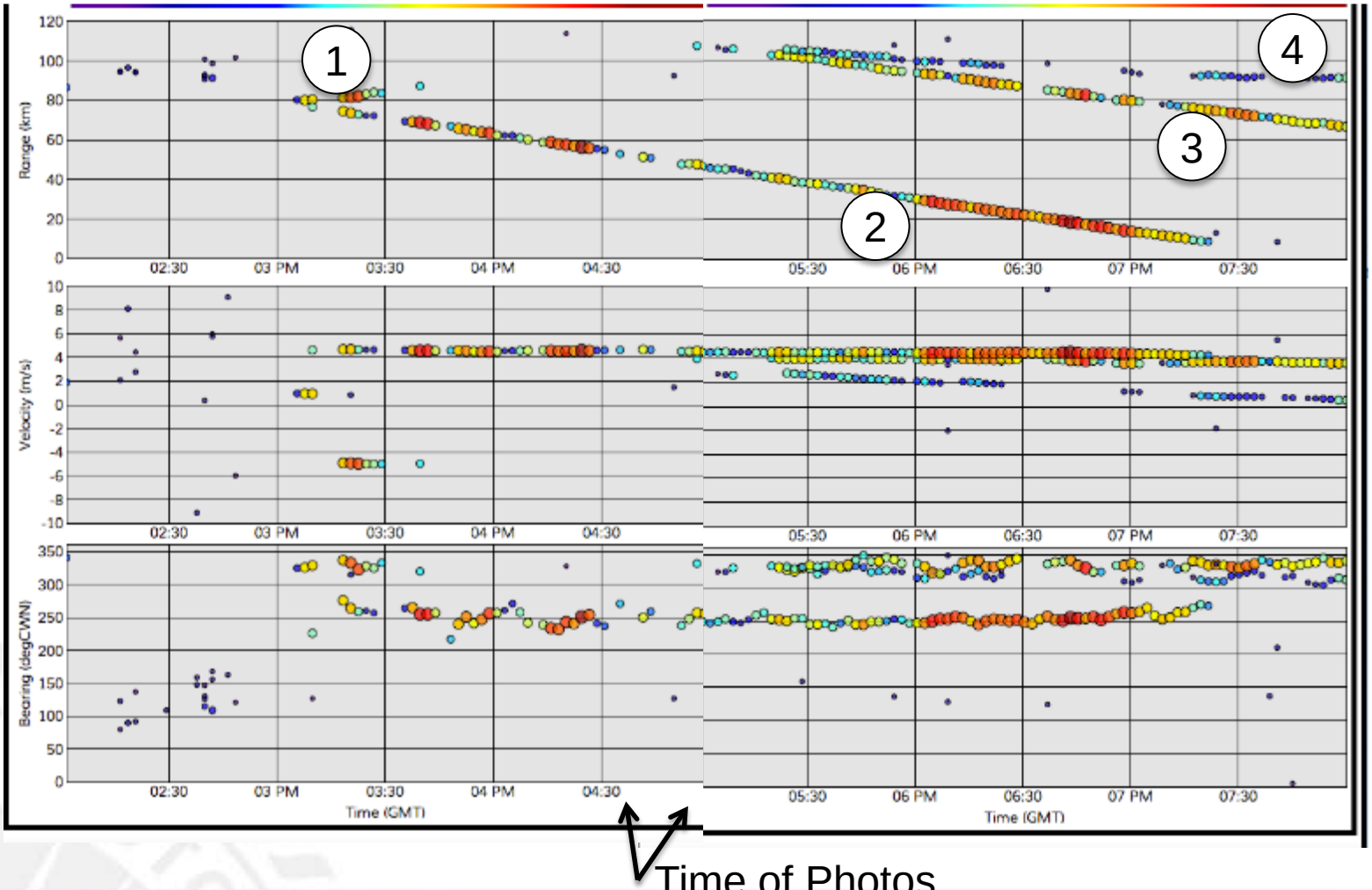
Photo taken from the Westward Wind at approximately 8/27/14 08:55 (16:55 GMT)

Location of Westward Wind



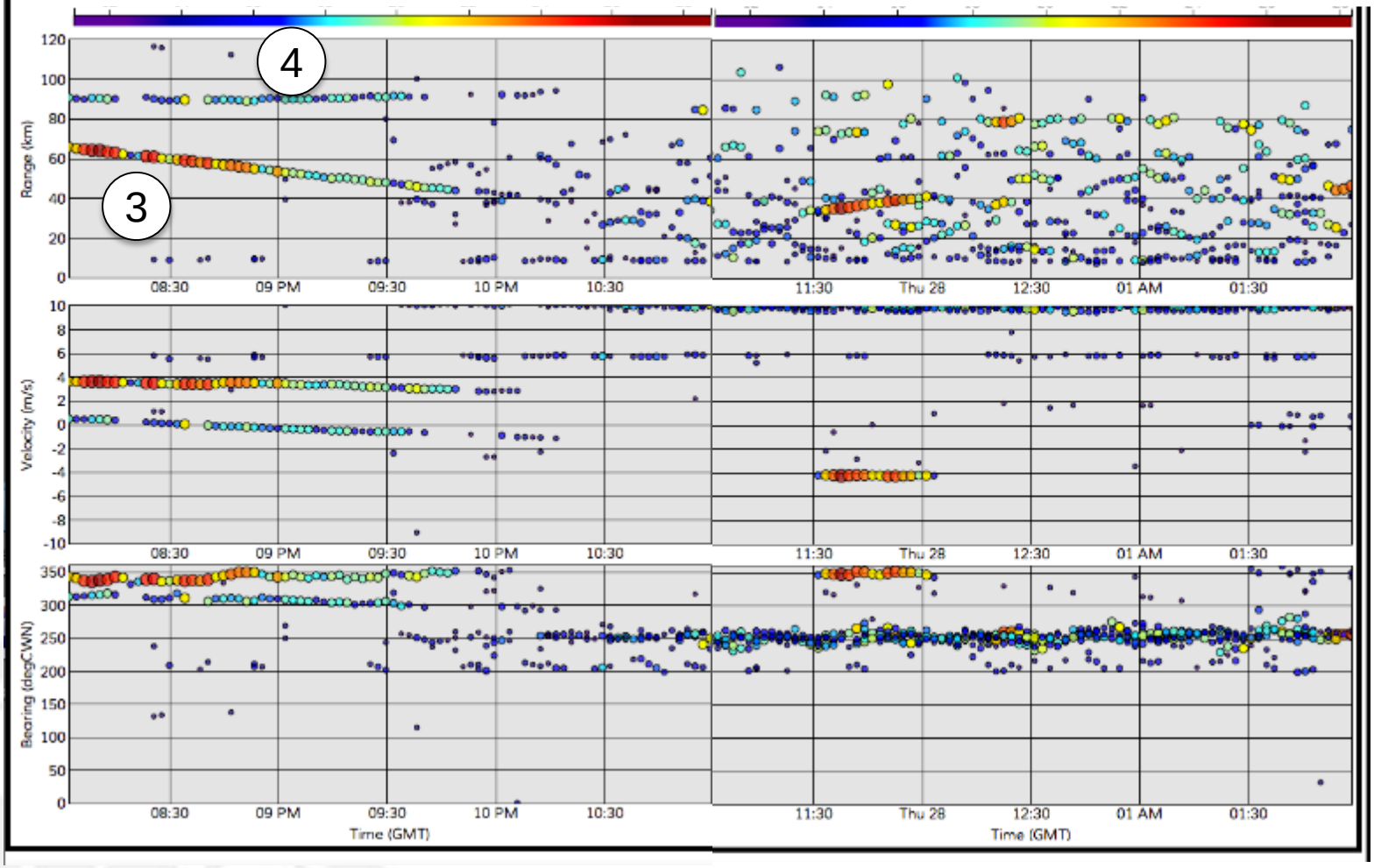
Detections by HF Radar at PTLY

14:00 -20:00 GMT

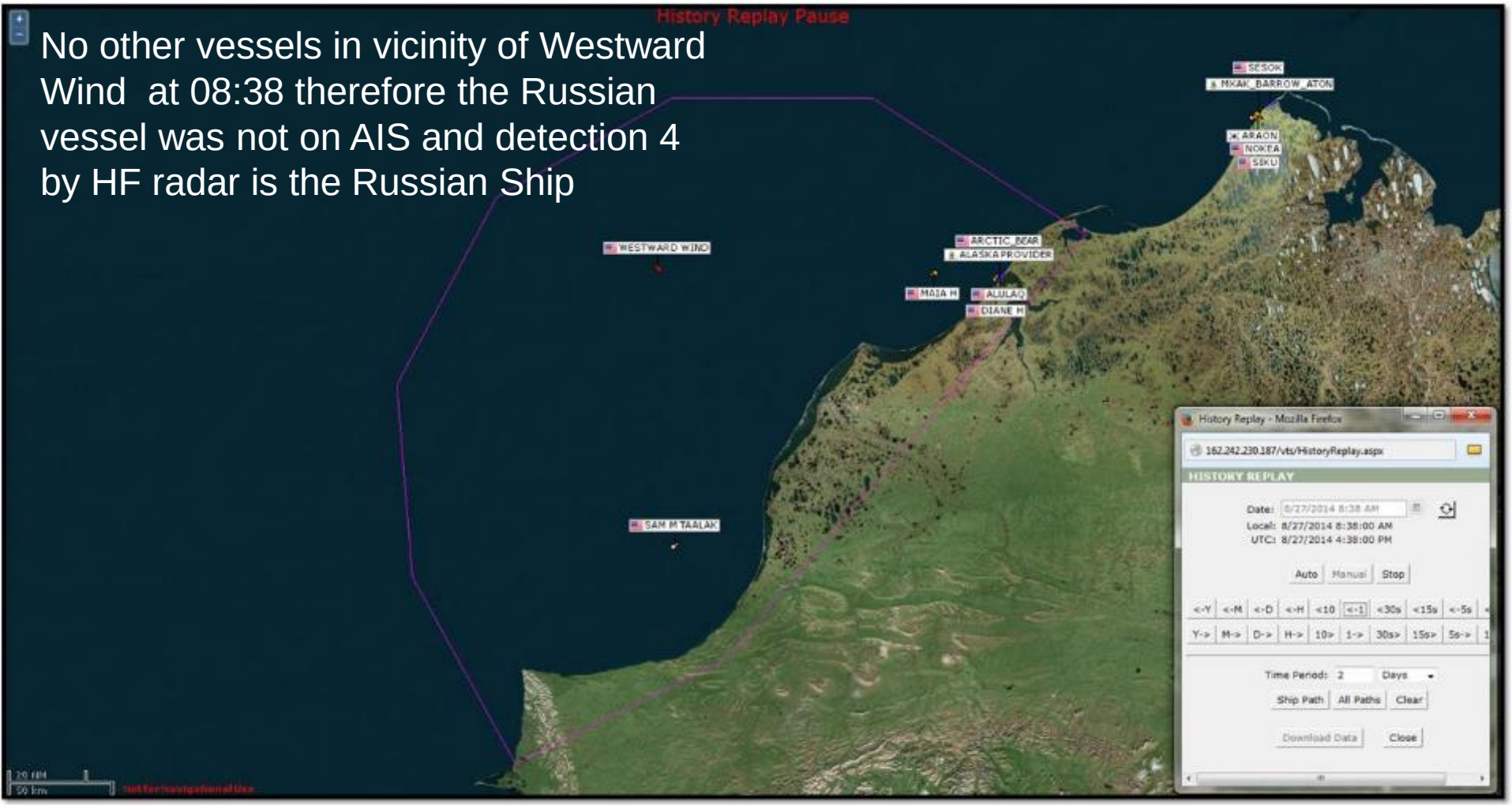


Time of Photos

Detections by Radar at PTLY 20:00-02:00 GMT



AIS at Time of Encounter with Russian Ship (08:38 am local)



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27 – 30 October 2015

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