Symposium on the Application of Geophysics to Environmental and Engineering Problems

Underwater Munitions Mapping Current & Future Directions

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Munitions Threat & Extent in the U.S. and Europe
Emerging Technologies
Munitions Response Surveys & International Collaboration
Challenges & Discussion

Underwater UXO contamination caused by military engagement, weapons testing and training, accidents, and by dumping

- **Threats caused by the presence of underwater munitions:**
  1. Direct physical contact with either chemical or conventional munitions resulting in threats to human health.
  2. Contamination of marine organisms and the environment in the vicinity of dumped munitions and the consequent potential for some concentration of toxic contaminants entering the wildlife and human food chains.
  3. Spontaneous explosions which can be both directly life threatening, but also have the potential to spread material away from the dump sites so increasing the potential for more of it to come into direct physical contact with individuals.

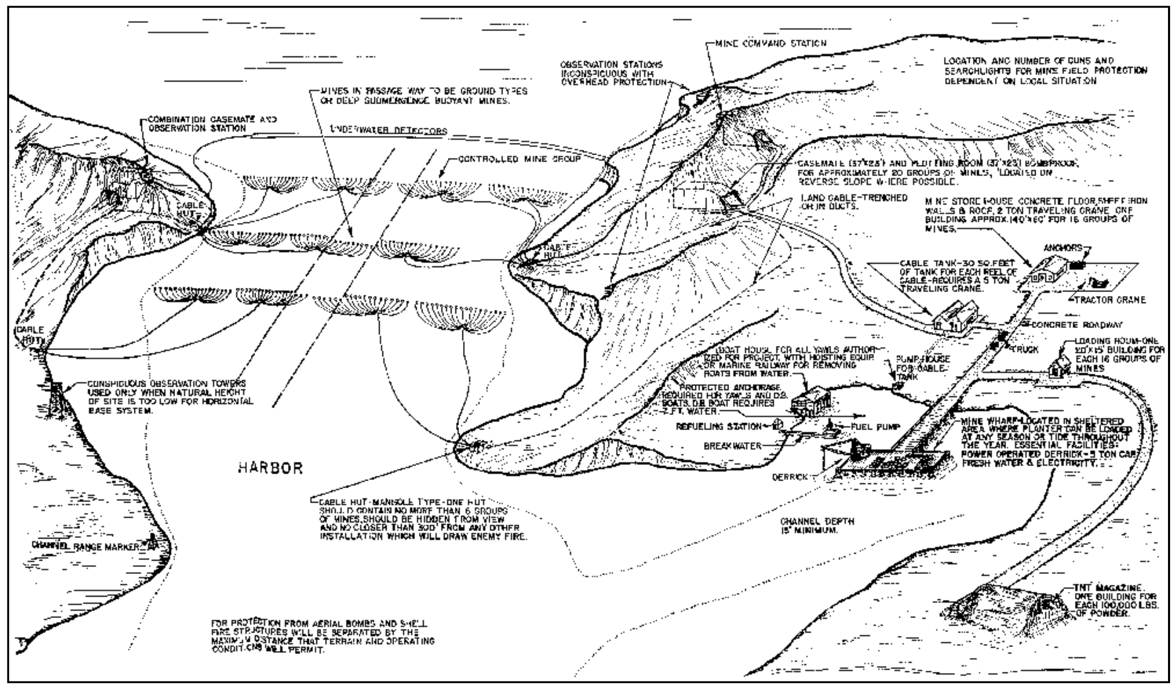
  Beddington, J., Kinloch, A.J., *Munitions dumped at sea: A literature review*, Imperial College London, 2005.

- Direct physical contact or disturbance of munitions can occur through activities such as **fishing**, **laying cables and pipelines**, **construction**, **dredging**, and **diving**, with the former accounting for more than half of encounters.
- **Driving UXO Mitigation**: Growing population and economic activity adjacent to coastal areas; Increasing utilization of maritime environment for food (fisheries), energy production (offshore oil and gas, wind farms, tidal power), commerce (harbor construction and extension, seabed pipelines and telecommunication cables), and recreation.

- In the U.S. many active and former military installations, some dating as far back as the 18th century, have artillery/bombing/training areas that include adjacent water environments and coastal ocean areas.
- U.S. Army Corps of Engineers has identified ~200 underwater Formerly Used Defense Sites potentially contaminated with munitions
- U.S. Navy Munitions Response Program manages more than 50 closed and active sites potentially contaminated with munitions

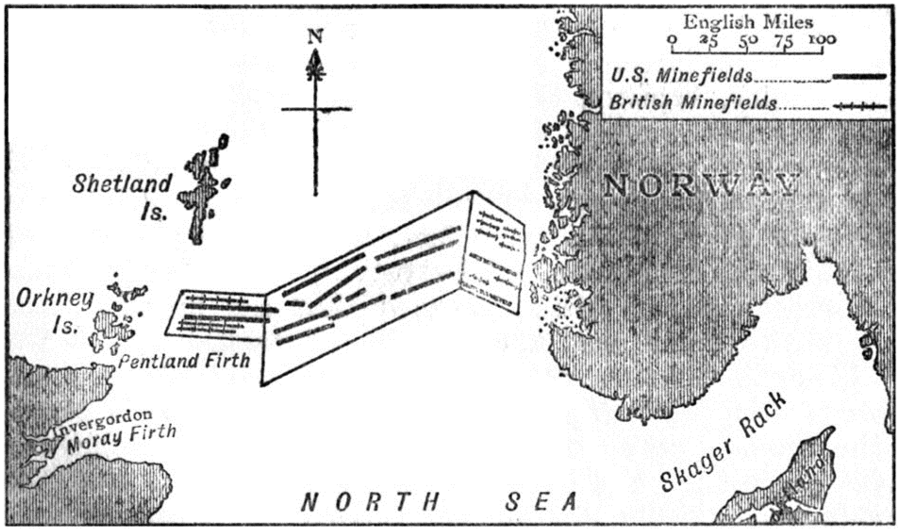
NAVFAC Naval Facilities Engineering Command

U.S. Coastal Defense: Early 20th Century



North Sea Mine Barrage

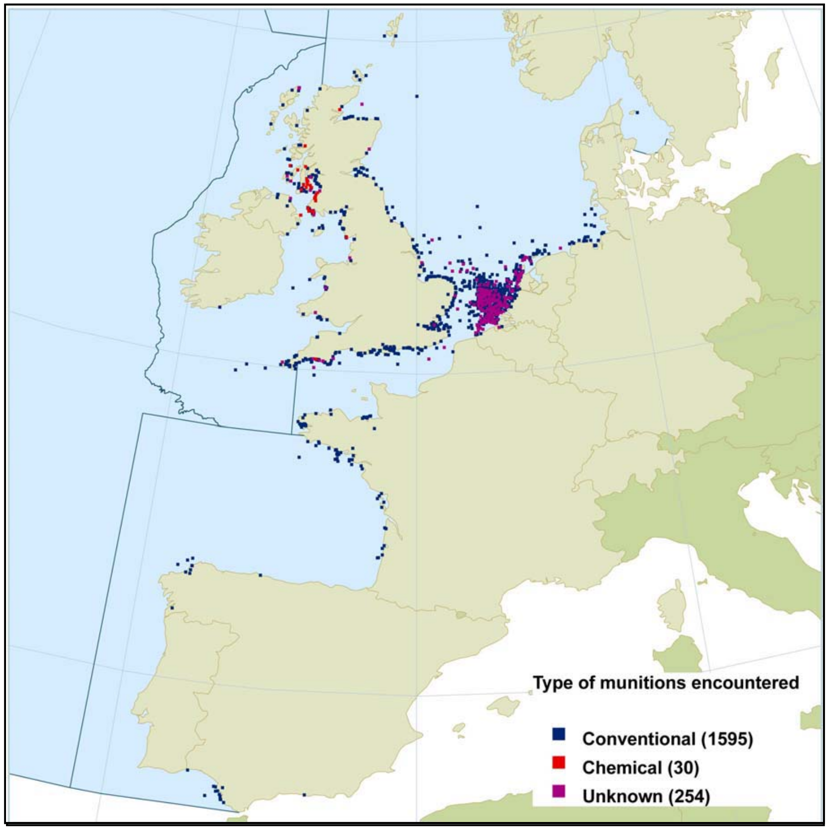
In the North & Baltic Seas, approximately 700,000 mines laid during the two World Wars, many unrecovered and regularly encountered to this day.



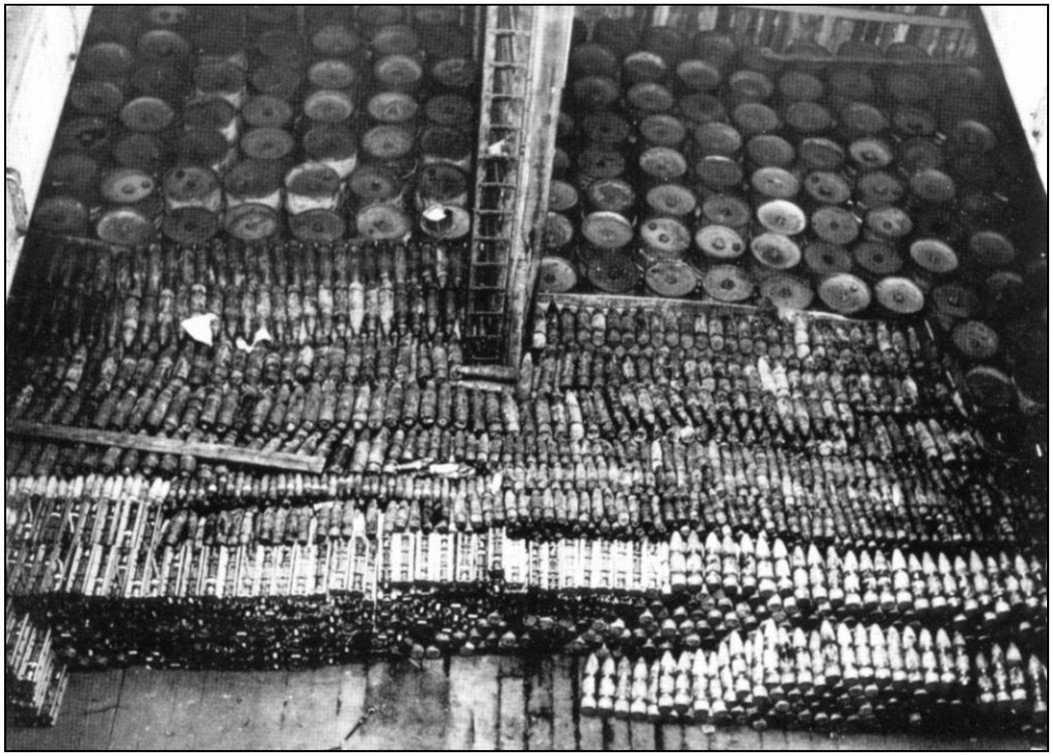
- Post-War, millions of tons of conventional and chemical munitions were dumped by many nations along an oceanic arc spanning from Spain to the Baltic States.
- Underwater munitions disposal was stopped in 1972 when international agreements were reached to regulate the dumping of material at sea.

OSPAR Commission, *Assessment of the Impact of Dumped Conventional and Chemical Munitions*, 2009

Types of Munitions Encountered



Loading of a Post WW-II Munitions Ship for Scuttling

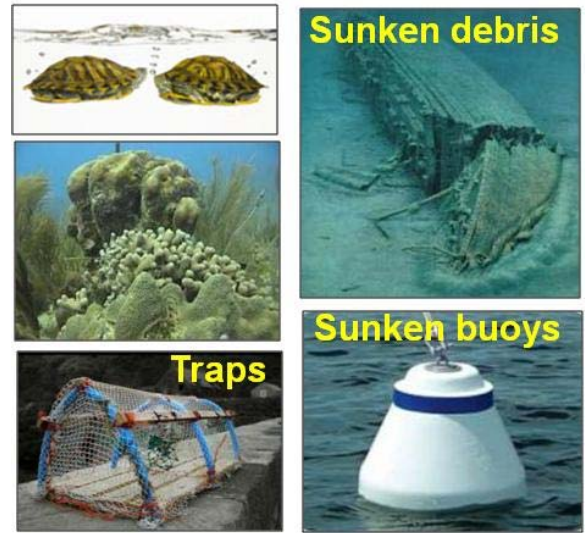


Arison III H L (2013), European Disposal Operations: The Sea Disposal of Chemical Weapons

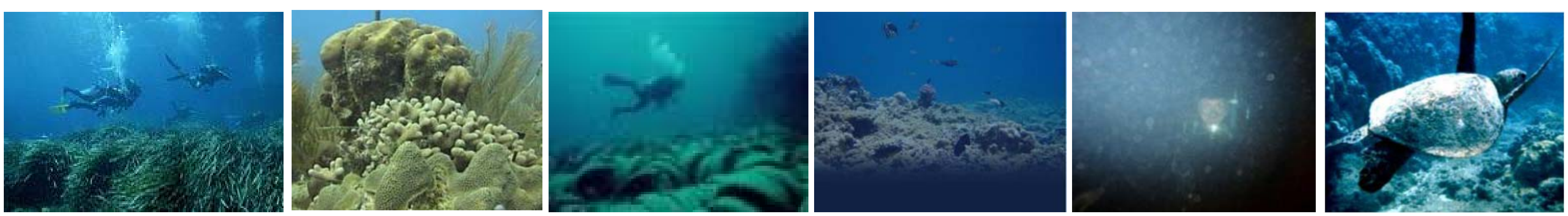
Inherent Challenges

- Poor or non-existent documentation of threat
- Broad size distribution with diverse composition
- Encrustation, fragmentation, burial
- Environmental complexity
  - Bottom types vary from mud to sand to rock
  - Water-sediment interface varies from smooth to rough to rippled modulated by the impacts of fishing activity and bioturbation
- Platform-challenging hydrodynamic conditions
- Platform challenges navigating and localizing sensed munitions in underwater (GPS-denied) environments

Biologic/Man-Made Clutter



Environmental Challenges



Concealed by Grasses/Kelp | Obscured by Crustaceans/Coral | Obscured by Edges/Rocks | Partial/Complete BURIAL | Poor Visibility | Ridges, Valleys, Outcrops

Inherent Challenges (Object - Examples)

Artillery shells found in North Sea & Baltic Sea:

Air Burst Grenade, 2016

Rusted British Cartridge Case, 2015

Grenade - embedded in concrete, 2013

UXO may or may not resemble original (expected) shape

Bio-fouled mine

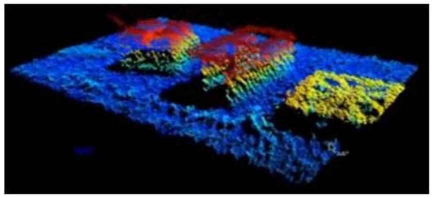
corroded mine

buried mine

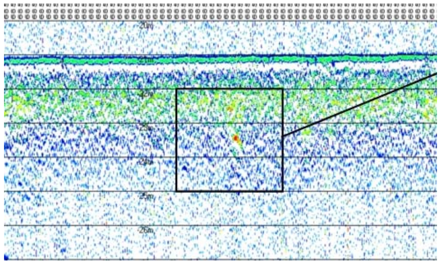
Sonars for UXO Detection/Classification

- High-frequency sidescan sonar
  - Imaging seafloor texture and objects that lay proud on the seabed
  - Agile, fine resolution that degrades with range, bathy, inexpensive

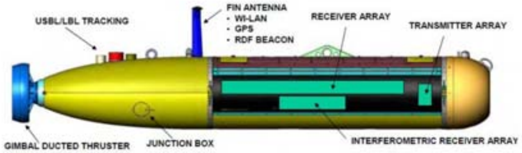
- High-resolution multi-beam sonars / Acoustic cameras
  - Fine detail 3D imagery/bathy



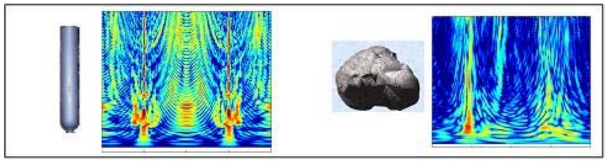
- Sub-bottom profilers and parametric sonars
  - Sediment penetration, Detection of small buried objects



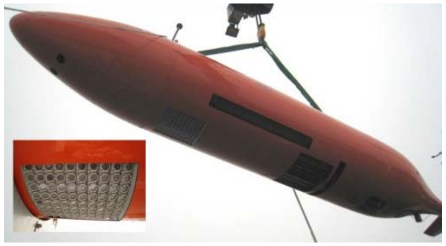
- Synthetic aperture sonar
  - Fine- constant- resolution imaging of texture and objects at long range



- Acoustic spectroscopy
  - Information on object structure and composition



Electro-optics, Magnetics, Electro-magnetic Induction

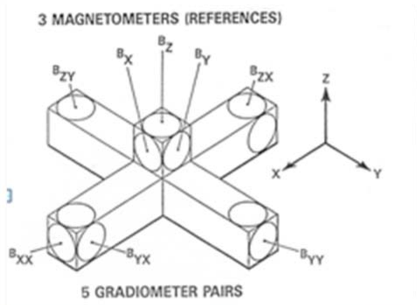


- Light-attenuating turbidity limits range of most **COTS camera systems**, used primarily for close target identification. **Active electro-optic systems** developed for greater range and fields of view

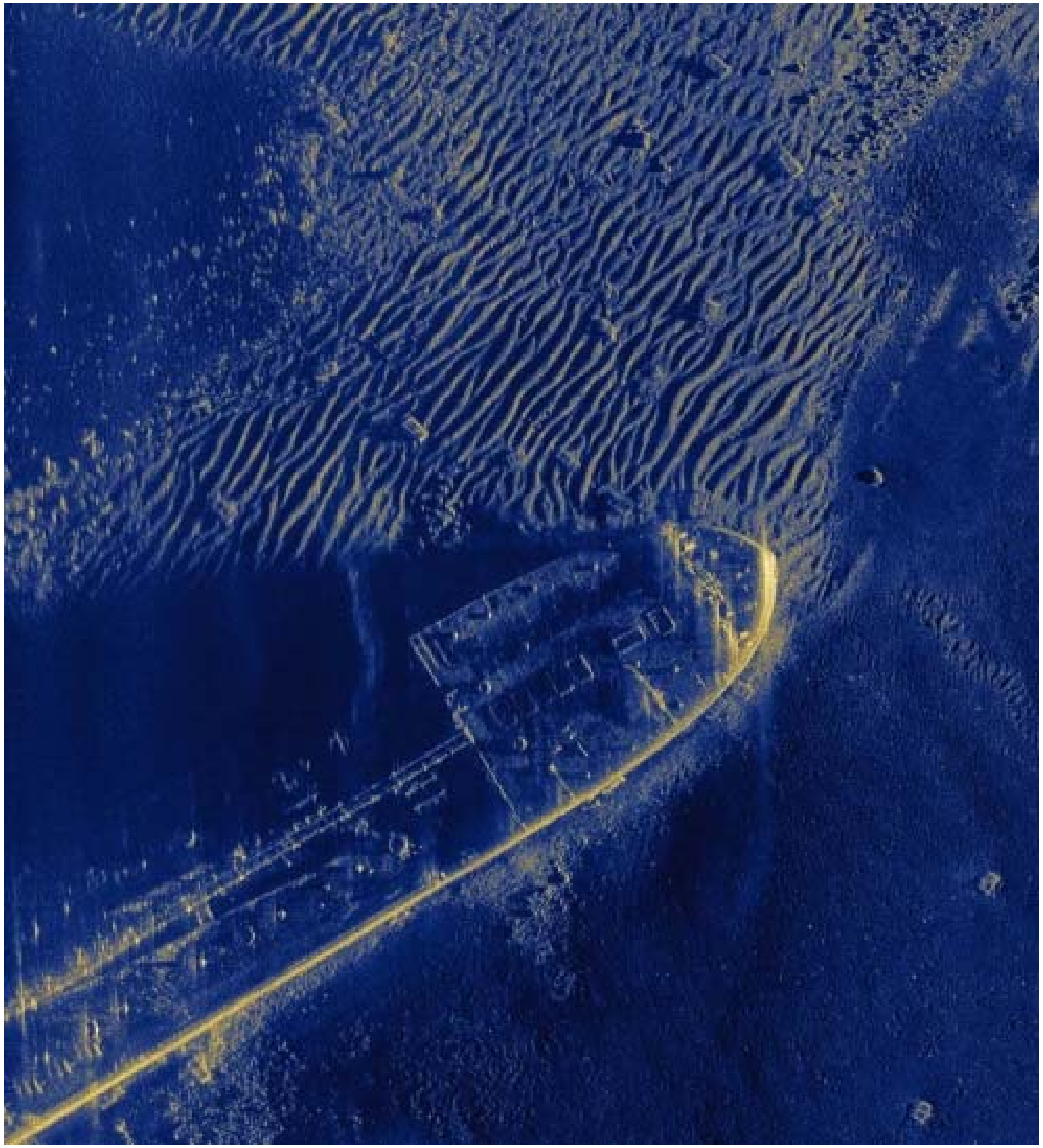
- **Passive magnetic systems** (e.g. Total Field Magnetometers Arrays, Magnetic Gradiometers) detect ferrous UXO on top of or buried in the sediment, with some systems inverting for target location, size, and burial depth.
- Limitations include short stand-off distances and electromagnetic interference emanating from the platform

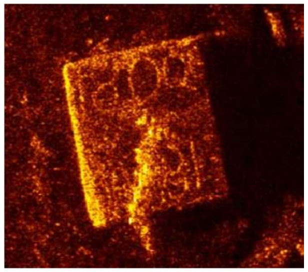
- **Electro-magnetic Induction** (EMI) used to detect ferrous & non-ferrous materials, though range further constrained
- High confidence classification of buried munitions enabled by combining information from sonar (e.g. shape from imagery) with magnetic characteristics

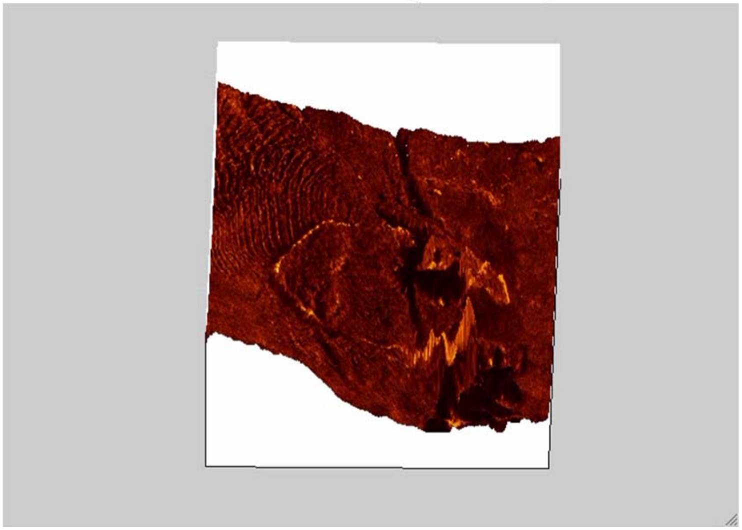
MFAM



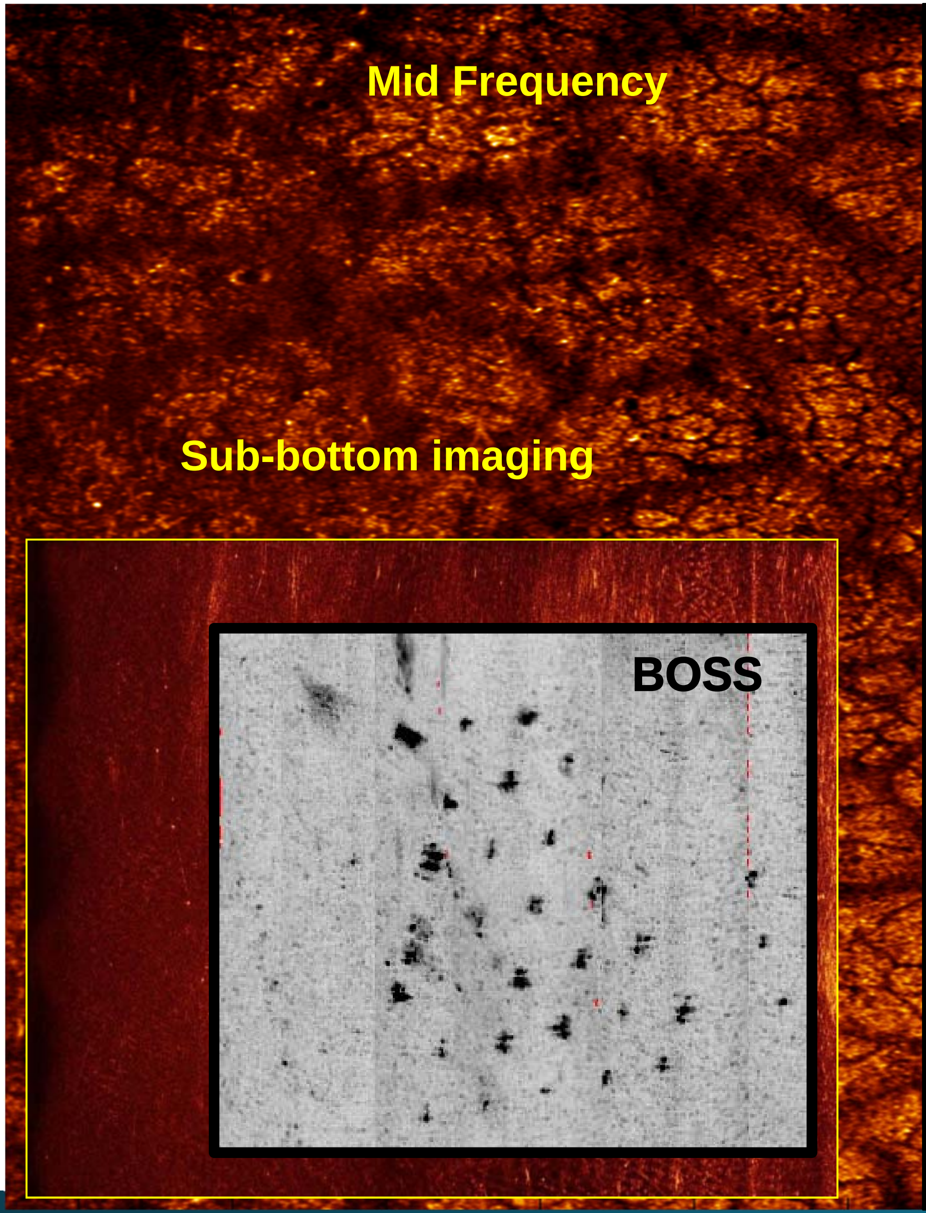
High-Frequency SAS Imagery

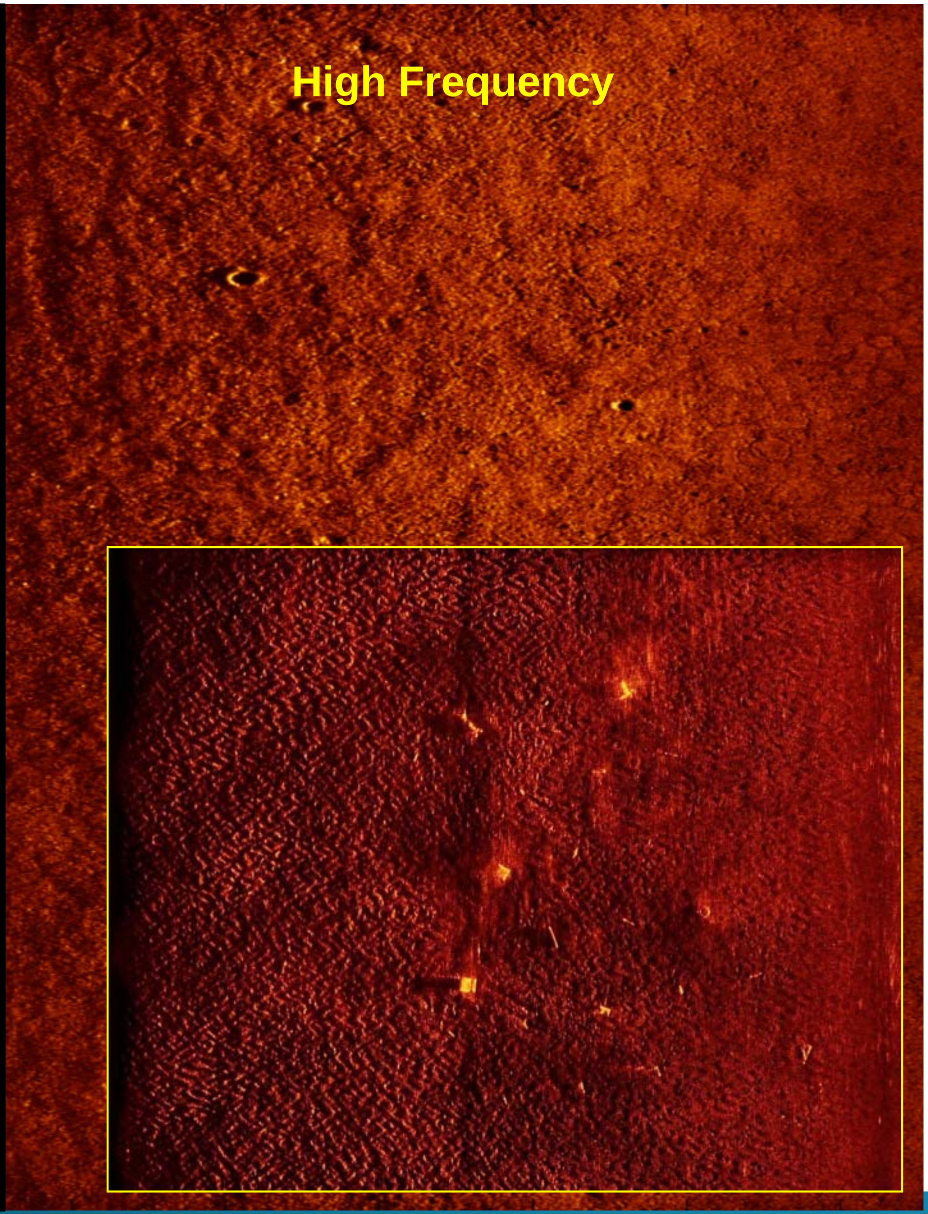




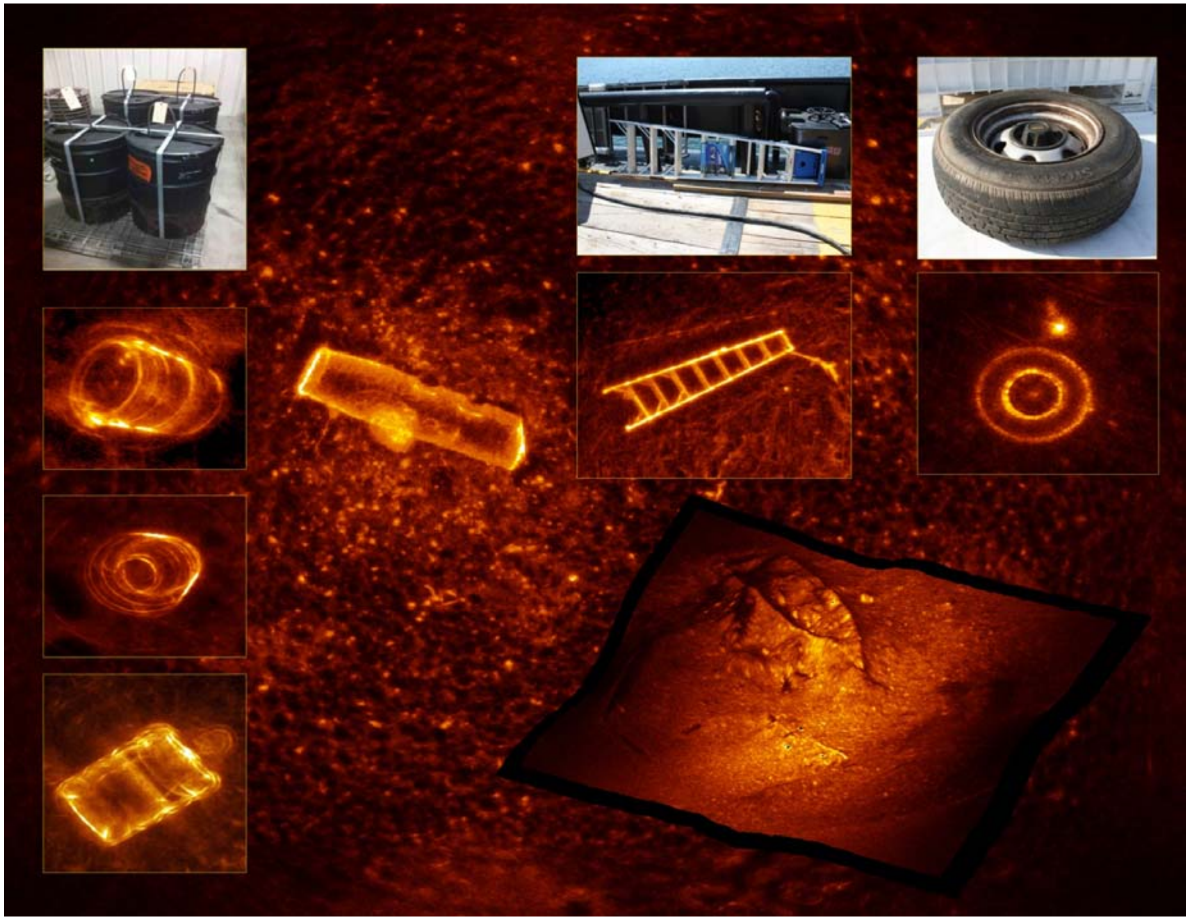


Advantages of Multi-band SAS

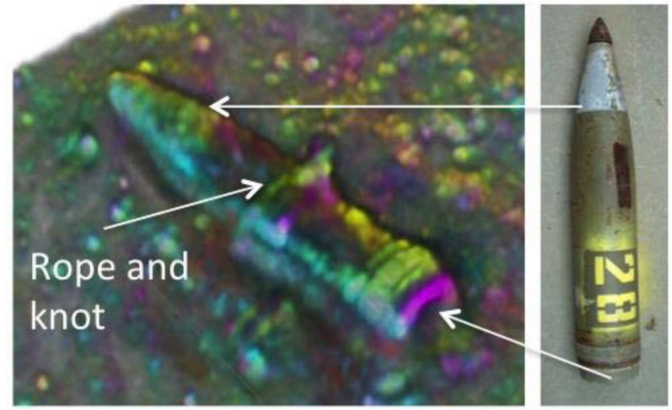




Circular SAS Imaging (2012)



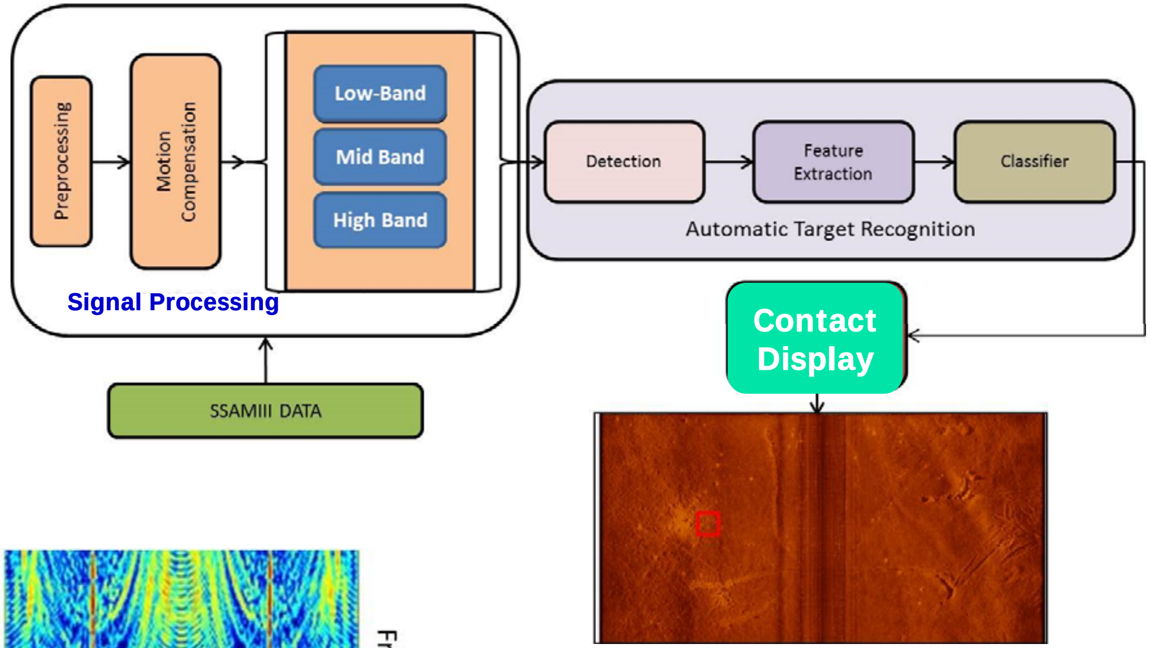
Spiral SAS Imaging

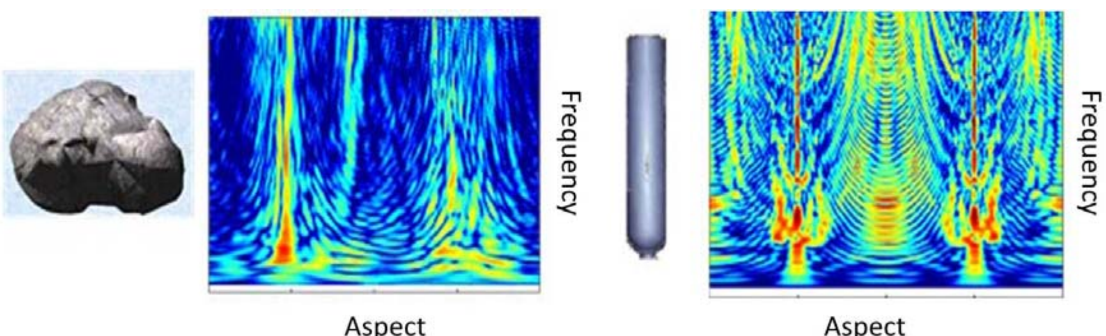


T. M. Marston, J. L. Kennedy, *Volumetric acoustic imaging via circular multi-pass aperture synthesis*, IEEE JOE 41(4), pp. 852-867, 2016

Multi-modal ATR

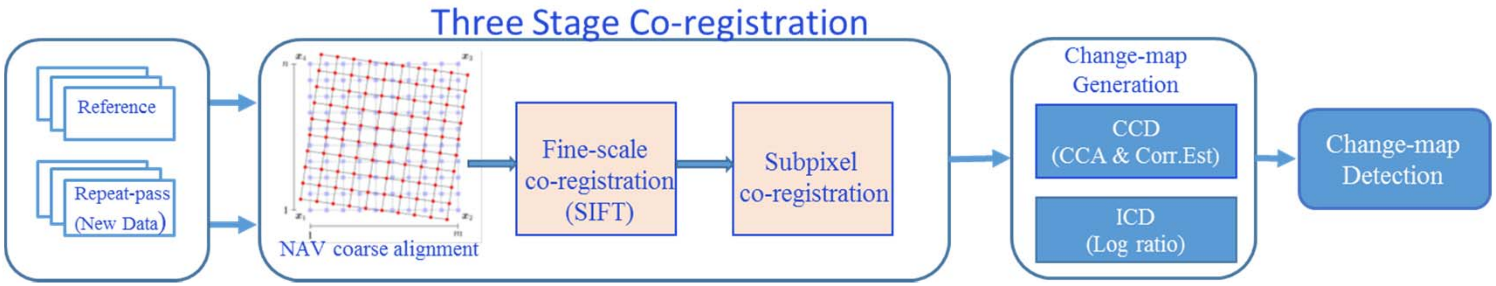
- The availability of multiple acoustic bands allows ATR via combination of image and non-image based features





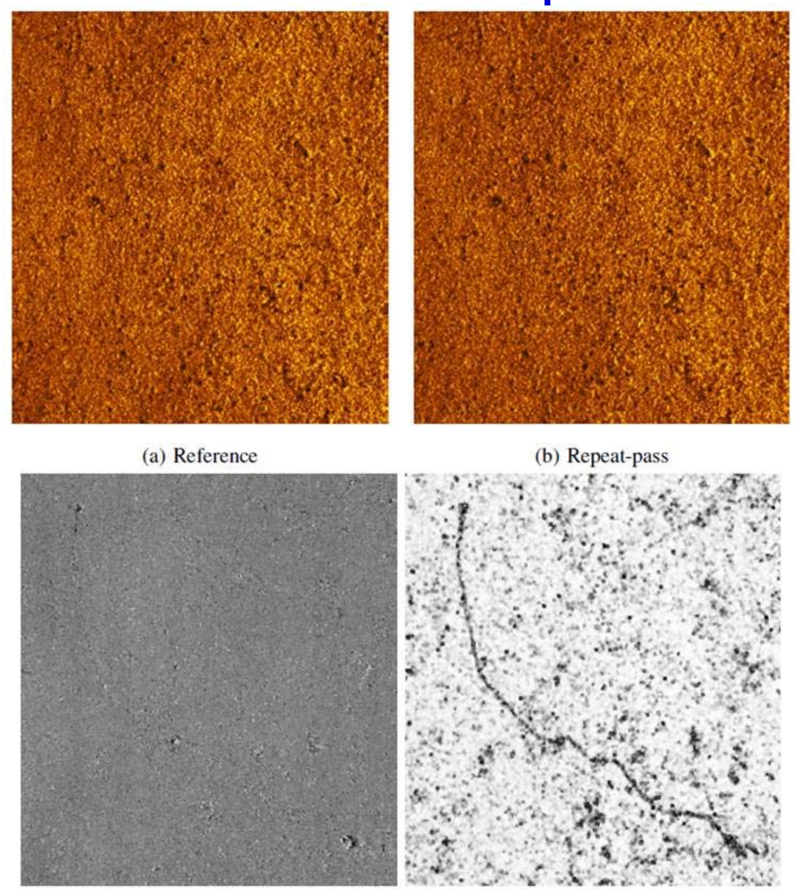
- The wide field of view and broad bandwidth of SAS systems provides alternative detection, classification, or identification modalities
- E.g. interrogation of target strength as a function of frequency vs. aspect

Automated Detection of Seabed Changes



- Sonar applications include
  - Firing Range Monitoring
  - Mine Countermeasures
  - IED Defeat
  - Seabed Surveillance (Q-routes, SLOC)
  - Port and Harbor Security
  - Resource Management

New Sonar Example

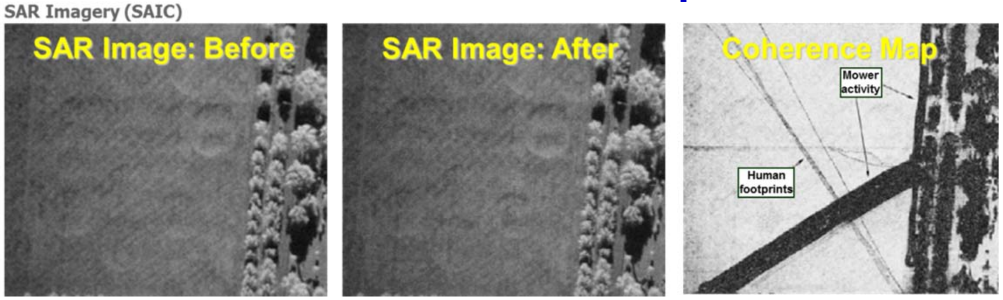


(a) Reference (b) Repeat-pass

(c) Incoherent Change Detection (d) Coherent Change Detection

Historical Radar Example

SAR Imagery (SAIC)



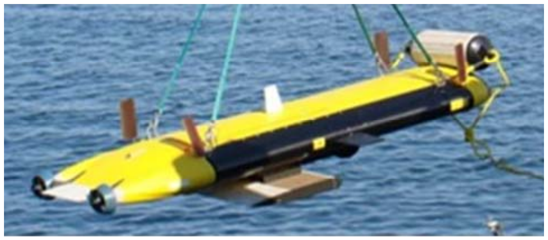
More details: T. G-Michael, B. Marchand, J.D. Tucker, T.M. Marston, D.D. Sternlicht and M.R. Azimi-Sadjadi, *Image-based Automated Change Detection for Synthetic Aperture Sonar by Multi-Stage Co-Registration and Canonical Correlation Analysis*, IEEE Journal of Oceanic Engineering, Vol. 41, No.3, pp. 592-612, July 2016

EdgeTech

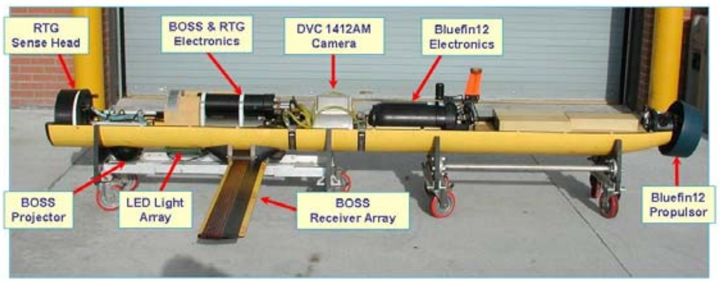
Emerging Capabilities in Identifying Buried Munitions

Combining acoustics, magnetics and complementary sensors to reduce false alarm rate

3 Sizes of BOSS



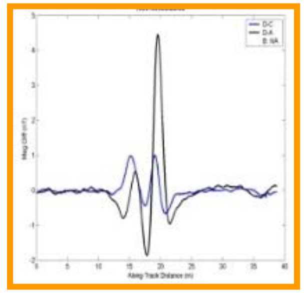
RAZOR Highly Maneuverable Platform



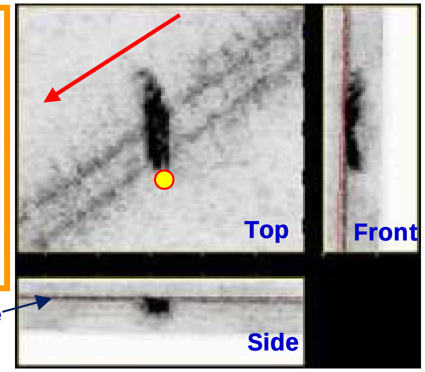
Bluefin 12

ATLAS Seahorse

Magnetic Gradiometer Time Series

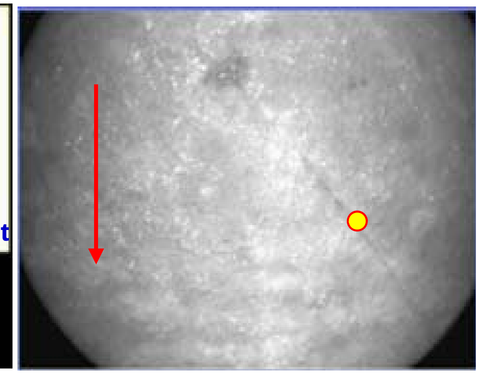


Buried Object Scanning Sonar (BOSS) 3-D Image Projections

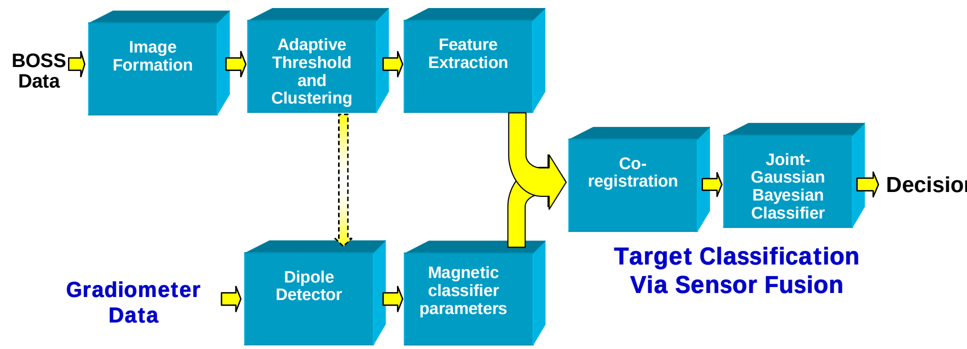


Sediment Interface

Optical Image of Sediment



o Magnetic Localization



Target Classification Via Sensor Fusion

Development of systems to reacquire, identify, and precisely localize buried underwater munitions

- **Multi-modal sensor suites integrated onto highly maneuverable AUVs**
- **3D Bottom-Penetrating Acoustics, High Sensitivity Magnetics, Electro-optics**

Munitions Response Surveys

International Collaboration

U.S. East & West Coasts

Baltic Sea

North Sea

Advanced MCM Systems for UXO Surveys

U.S. NSWC PCD

SMALL SYNTHETIC APERTURE MINEHUNTER
- High-frequency for high resolution imagery
- Broad-band for detection of buried objects

BOSS/BLUEFIN12
- Buried Object Scanning Sonar (BOSS)
- Electro-Optic (EO) Imager

BLUEFIN SEALION
- Marine Sonics MSTL Sidescan
- Electro-Optic (EO) Imager

LSG/REMUS 600
- Laser Scalar Gradiometer (LSG)
- EdgeTech Sidescan
- Electro-Optic (EO) Imager
- EdgeTech Sub-bottom Profiler

LSG/REMUS 600
- Configured for Operations < 4 m

MAGNUM/REMUS 100
- MAGNetic Underwater Minehunter (MAGNUM)
- Marine Sonics MSTL Sidescan

SURFSENSE FoS
- Survey in waters < 4 meters
- UROC, ASDP, Hydronaulix USVs
- Geonics EM-61 S HP
- Blueview P900/2250

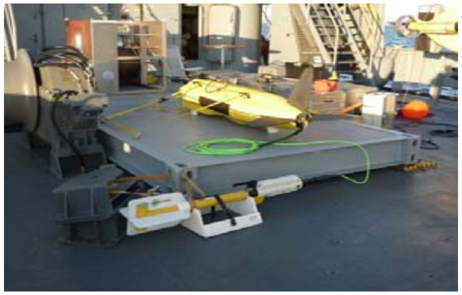
SURVEYS

NAS Pax River, MD	APR 2012
NSA Panama City, FL	AUG 2012
MCB Quantico, VA	OCT 2012
TREX, FL	MAY 2013
Fort Story, VA	JUL 2013
NWS Earle, NJ	AUG 2013
West Point, NY	DEC 2014
Dahlgren, VA	JUN 2015
Baltic Sea	SEP 2016
Aleutian Islands	JUN 2017
Potomac River	SEP 2017
San Diego	NOV 2017

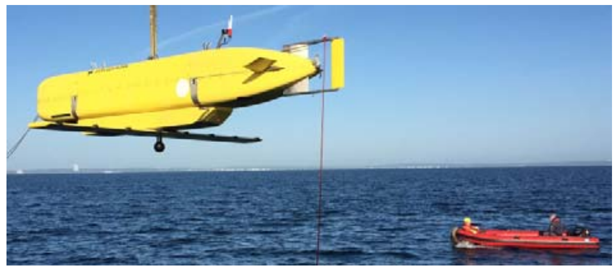
Advanced MCM Systems for UXO Surveys

Germany WTD71 / Norway FFI

Conventional Side Scan, Multi-beamer and Magnetometers
- ➢SOAM
- ➢Survey in waters >5 meters



AUV with R2Sonic & BOSS Sonar
- ➢SeaHorse (SOAM)
- ➢Survey in waters >5 meters



Parametric Sonar (INNOMAR)

AUVs with SAS Sensor
- ➢SeaOtter MK II
- ➢HUGIN 1000

AUV with Sniffer
- ➢Raman
- ➢Electro-chemical

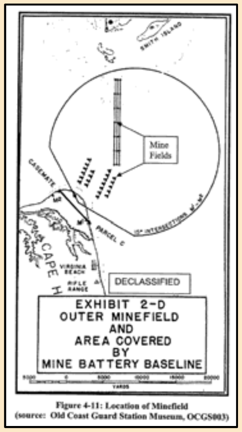
ROV with camera

SQUID (IPHT / WTD 71)

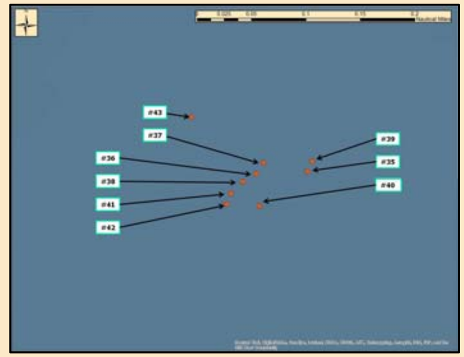
MAGRAY (SENSYS)

WWII Era Coastal Defense Mines Found by NSWC PCD During 2013 NAVFAC Munitions Response Wide Area Assessment of Chesapeake Bay Entrance

WWII Cape Henry Mine Battery



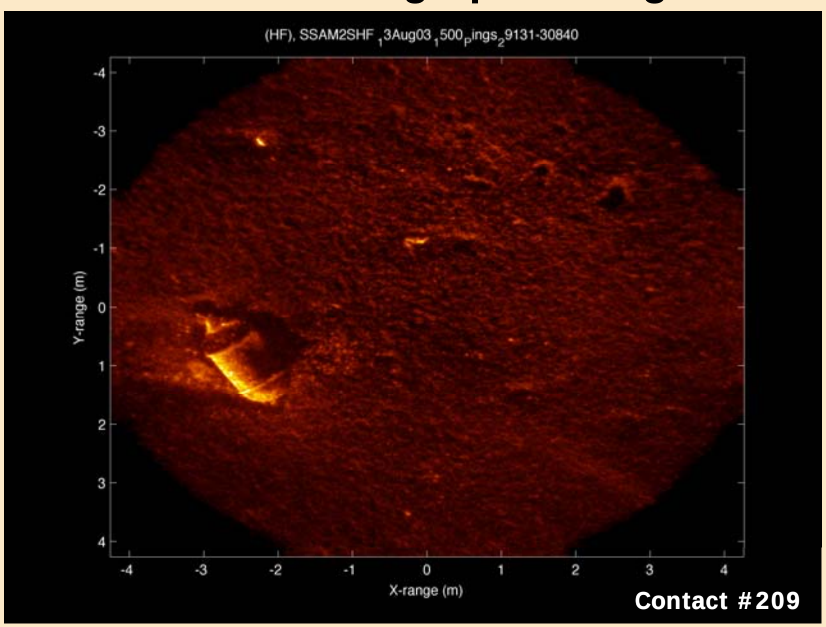
Contacts of Interest



Contacts #35-#43 acquired in single pass of SSAM

Archive Photo of Mine of Interest

SSAM Tomographic Image



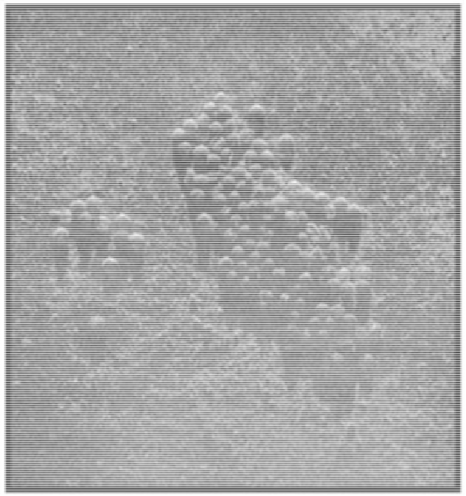
Photos of Recovered Object #209

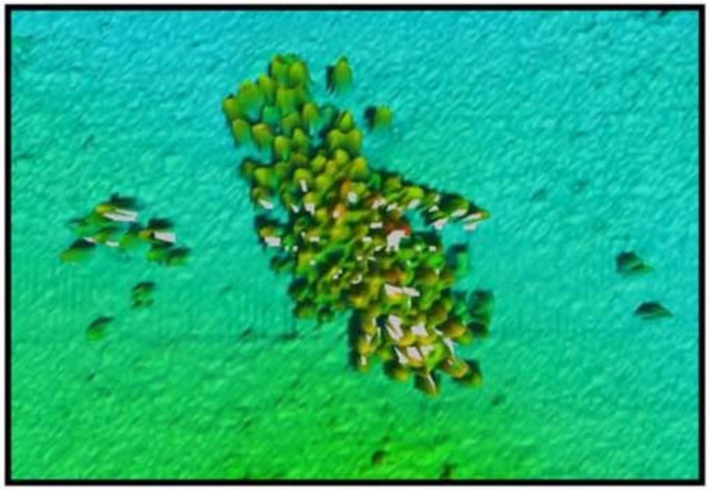
EOD visual inspection revealed 6ft cylindrical object with cable on one end, open on other end, and with sand inside. Assessed not to be an immediate hazard.

WWII Era Ammunition Found in the Baltic Sea by WTD 71

Sonar images of approximately 70 moored mines from a dumping site in Kiel Bay

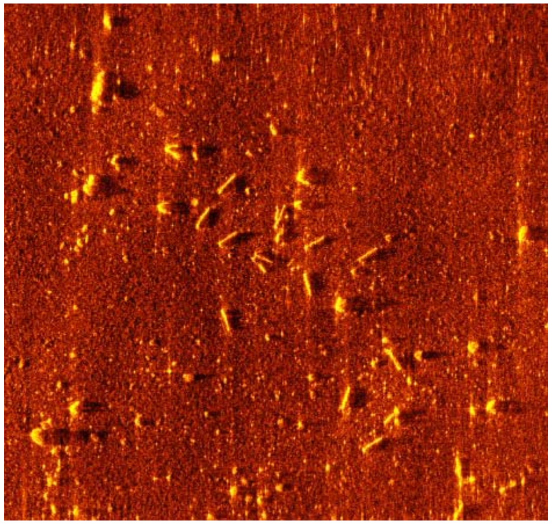
HISAS



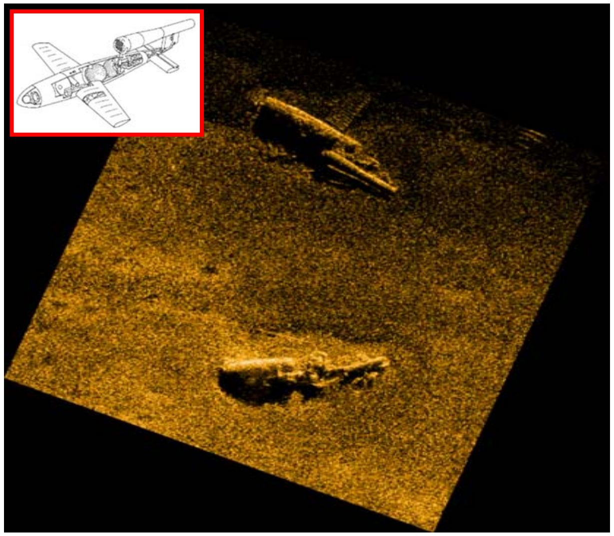


R2Sonic MBE

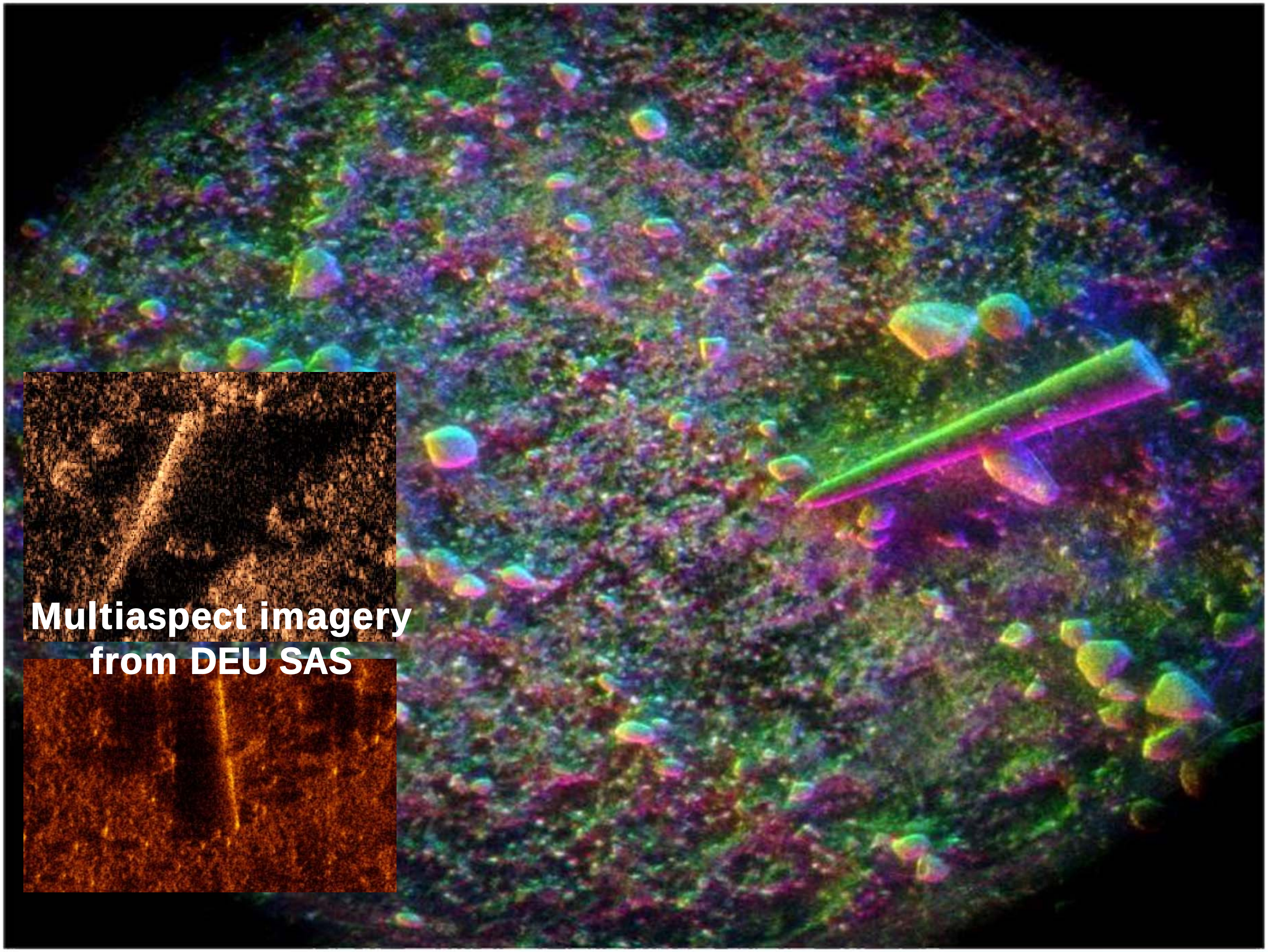
DEU SAS images of explosive craters and scattered UXO (ALMUND-U CWP Survey)



V1 Rocket (Flenburg Bay, HISAS)

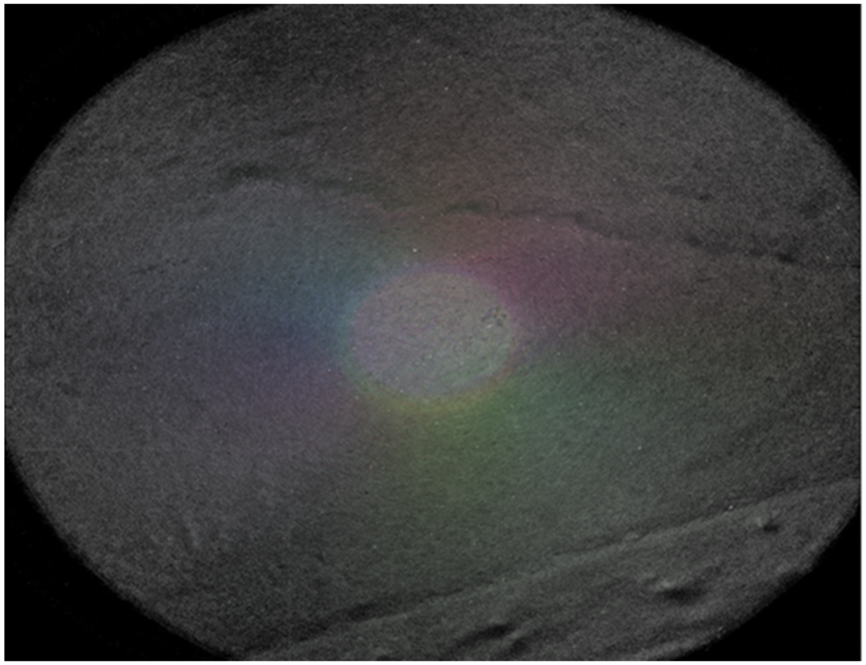


US CSAS image of ~12’ “torpedo shape” detected by DEU SAS



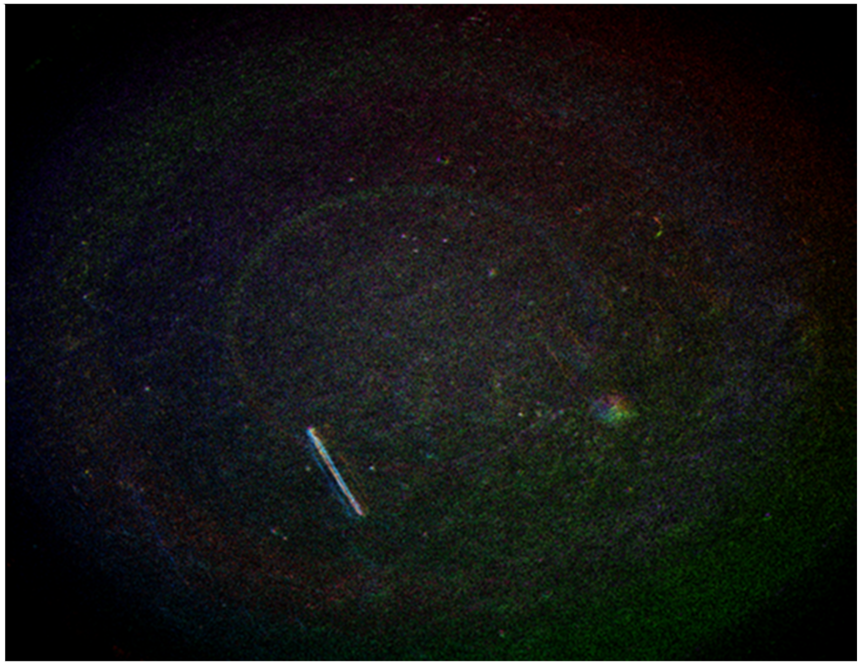
Circular SAS Image of Buried Object

HF CSAS Image

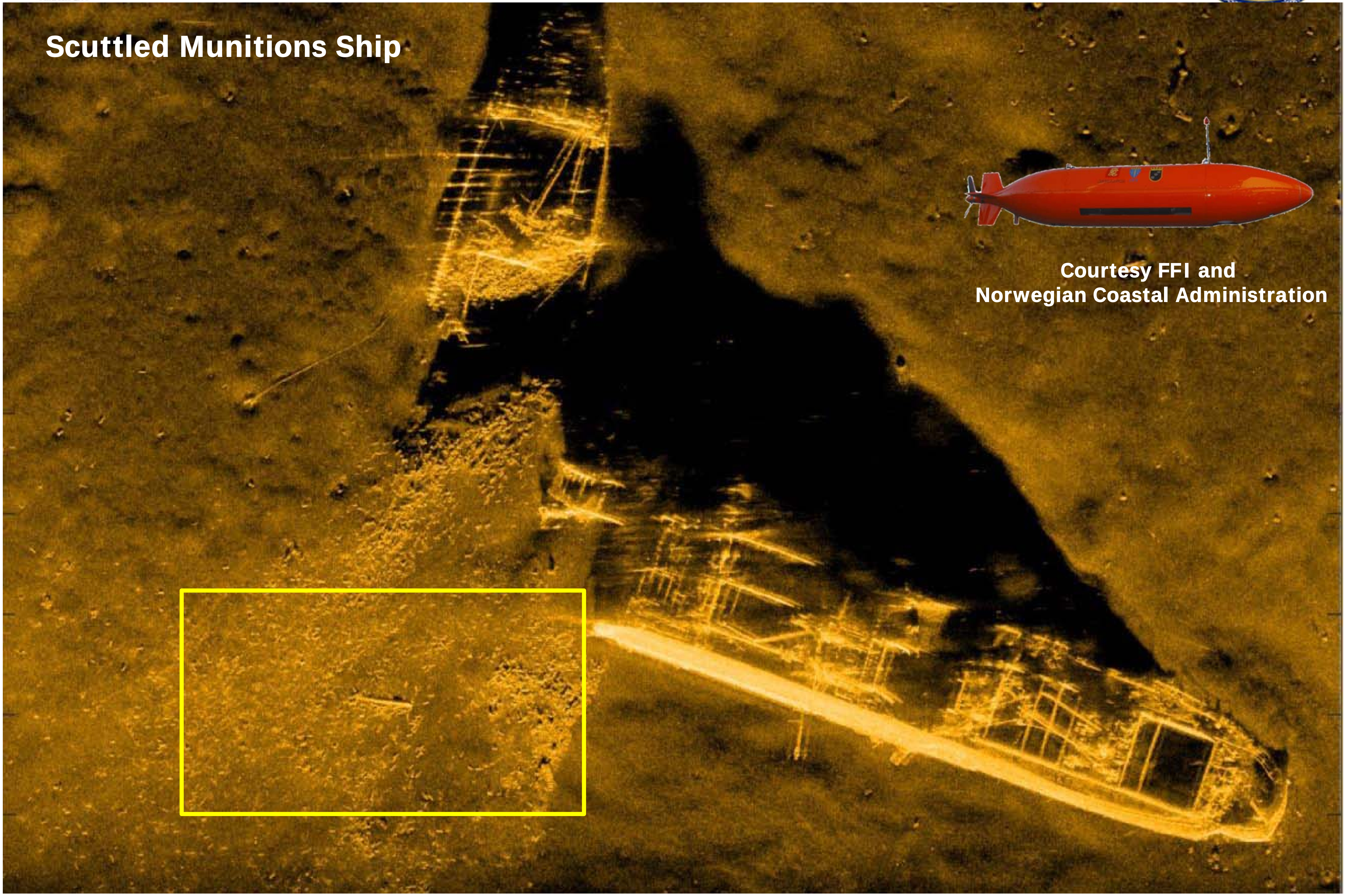


Seabed Texture

Mid-Frequency CSAS Image



Buried Object


Scuttled Munitions Ship
Courtesy FFI and
Norwegian Coastal Administration

Zoom

Technology Challenges for Wide Area Assessment and Remedial Investigation

Sensor Performance

- Resolving small and fragmented objects
- Detection ranges
- Sub-bottom sensing
- Explosives identification
- Near-shore (< 10 ft) sensing

Systems

- Near-shore vs deep water operation
- High sea states and currents
- Operations in confined areas

Data/Image Analysis

- ATR and change detection
- Multi-sensor fusion
- Simple, accurate decision tools
- Rapid end-to-end processing

Operations

- Safe management of multiple systems in simultaneous ops
- Inter-system data co-registration
- Minimized manning

Discussion

- Advances in underwater sensors, platforms, and automation will increase the efficiency of munitions classification in many areas and make munitions detection and classification possible for the first time in buried, cluttered and other challenging environments.
- Different environments lend themselves to different sensing modalities, and may require specific combinations of optic, acoustic, magnetic, electromagnetic induction, and chemical sensors.
- These advances are being evaluated and realized at an accelerated pace due to SERDP/ESTCP/ONR investments and international collaborations.
- In coming years, selection of platforms and sensors for munitions response surveys will require tradeoff studies on capabilities, concepts of employment, manning requirements, anticipated budgets, and expected price reduction of candidate technologies.