KRAKEN
ROBOTIC SYSTEMS, INC.

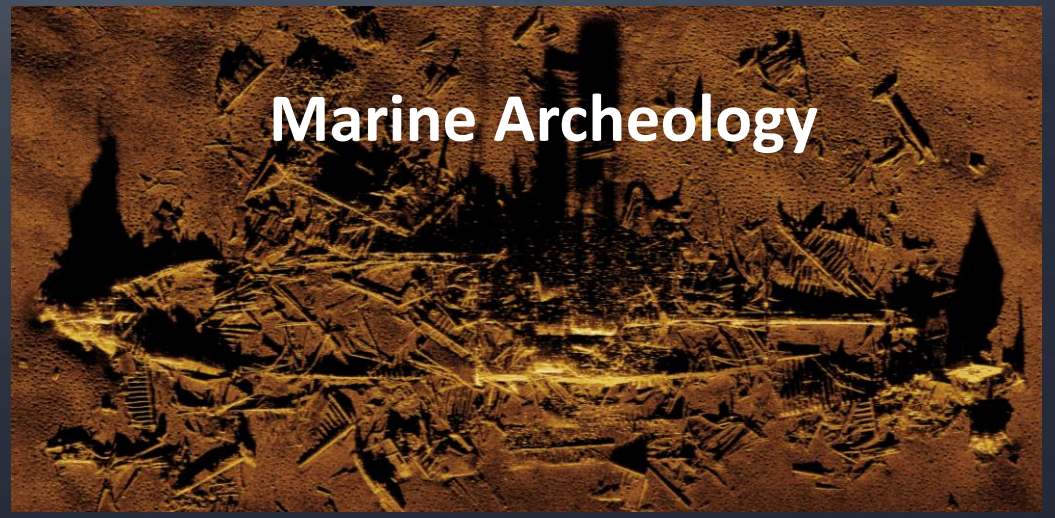
Shannon-Morgan Steele
Sonar Scientist

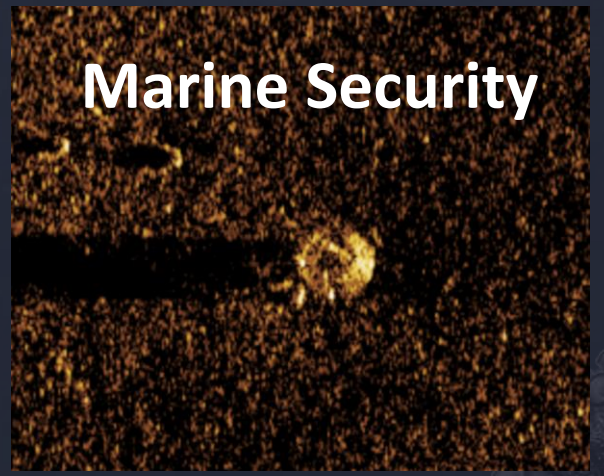
Square Synthetic Aperture Sonar

OCEANS 2022 Chennai

February 21-24, 2022

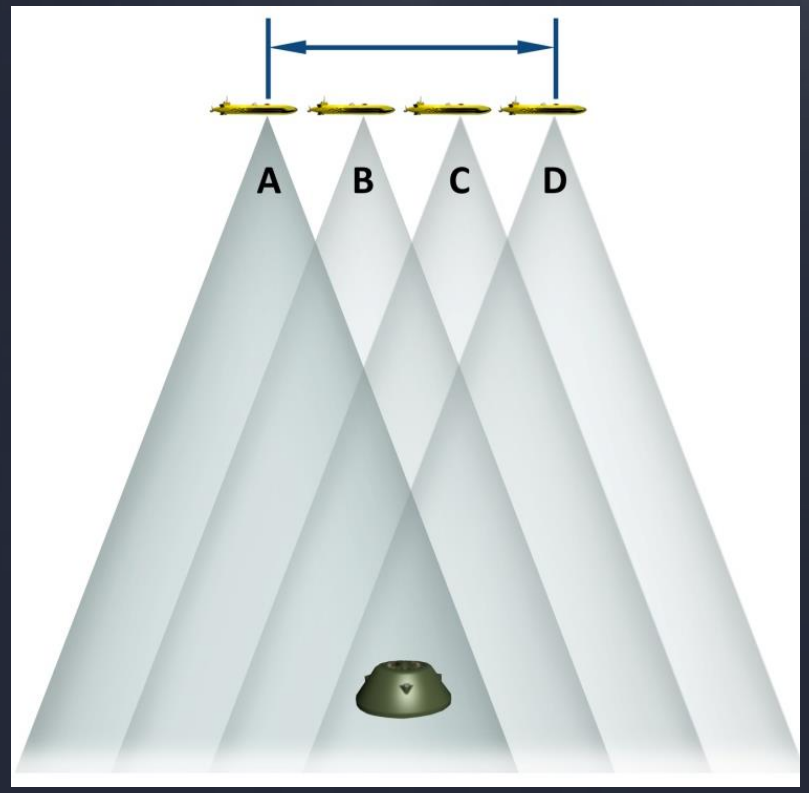
Seabed Imaging is required for many applications…

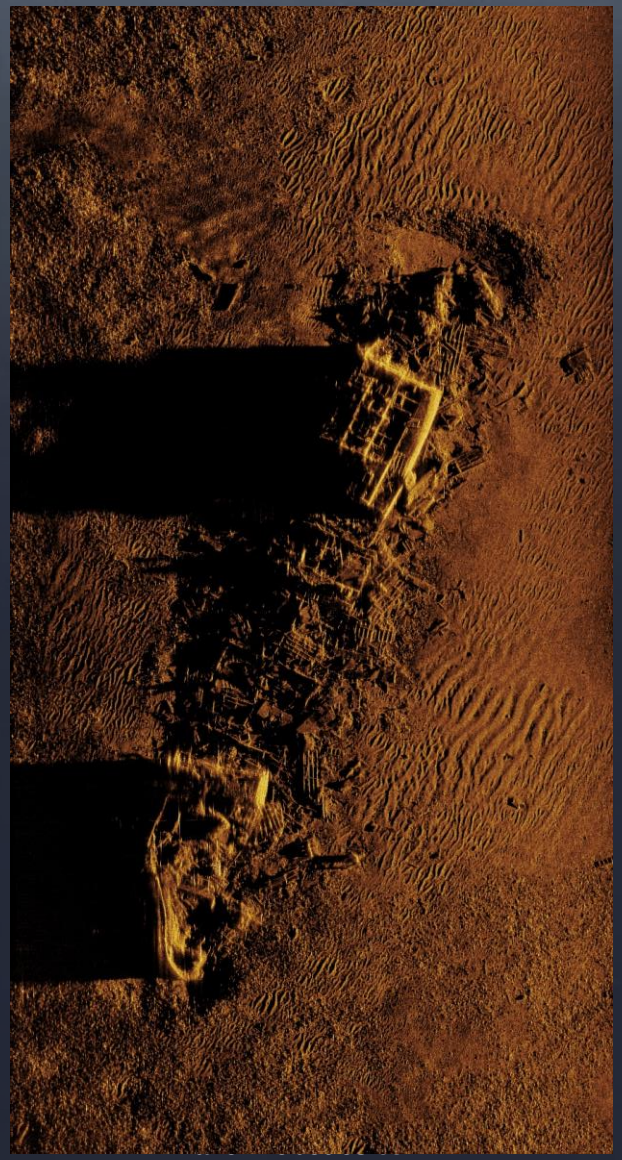




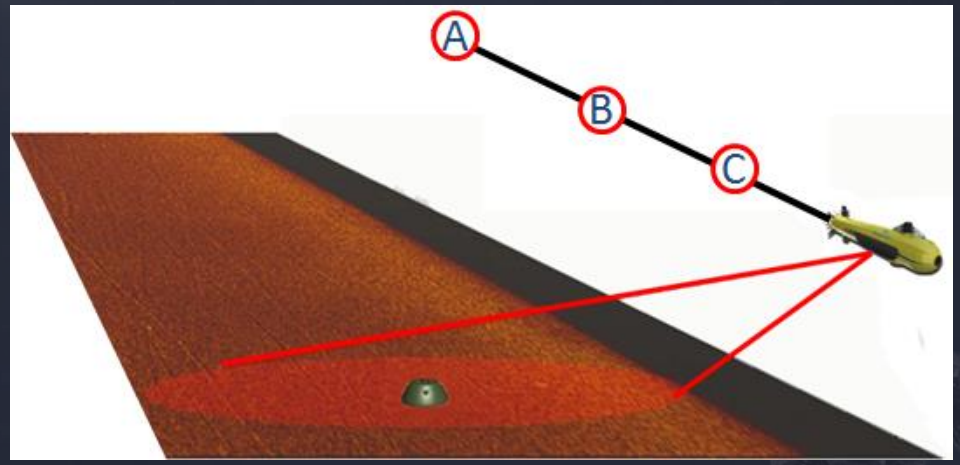
Synthetic Aperture Sonar (SAS)

Produces a synthetic aperture equal to the platform distance traveled.



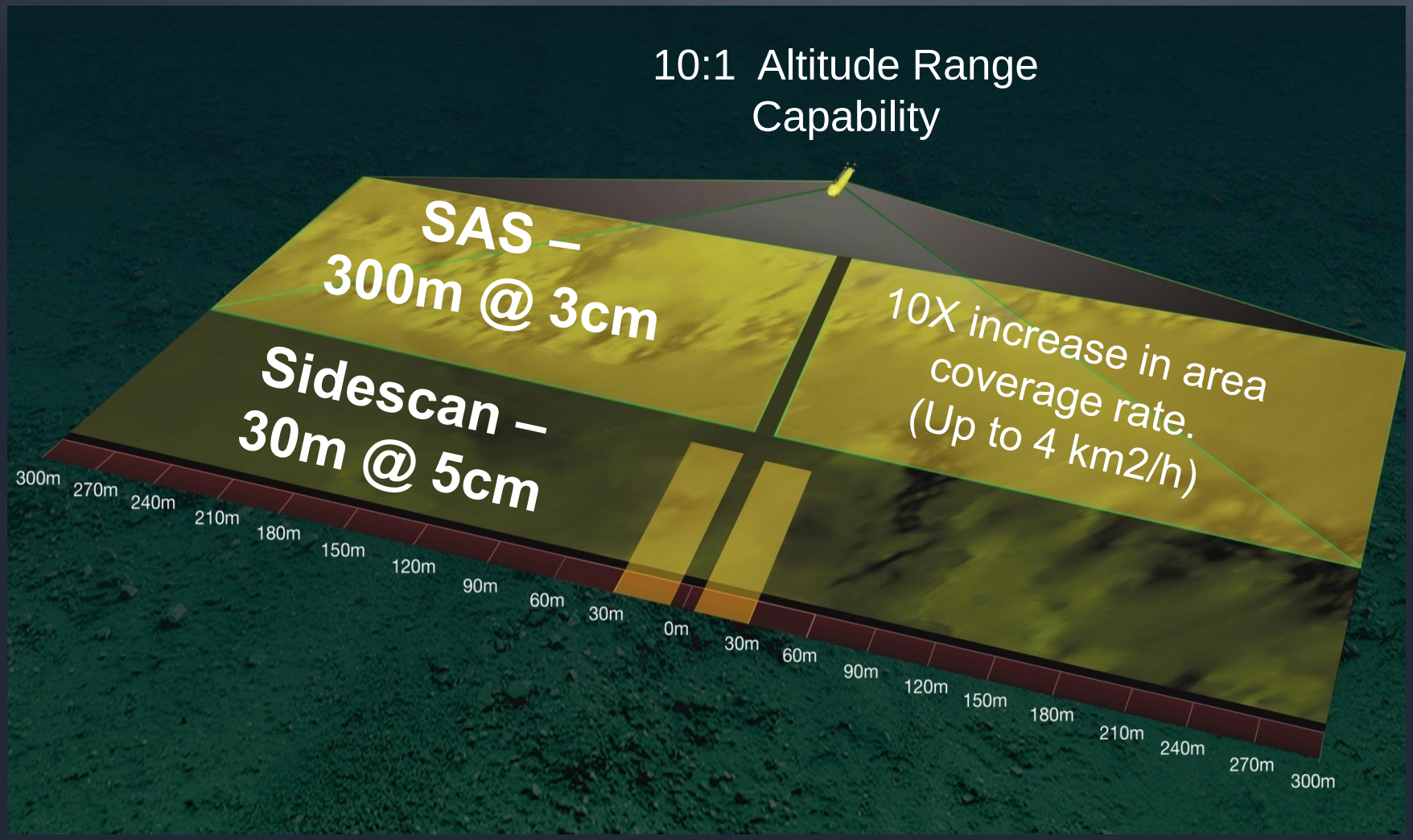


SAS coherently combines acoustic pings to create ultra-high resolution images.



Short physical aperture ensures no gaps in along track coverage

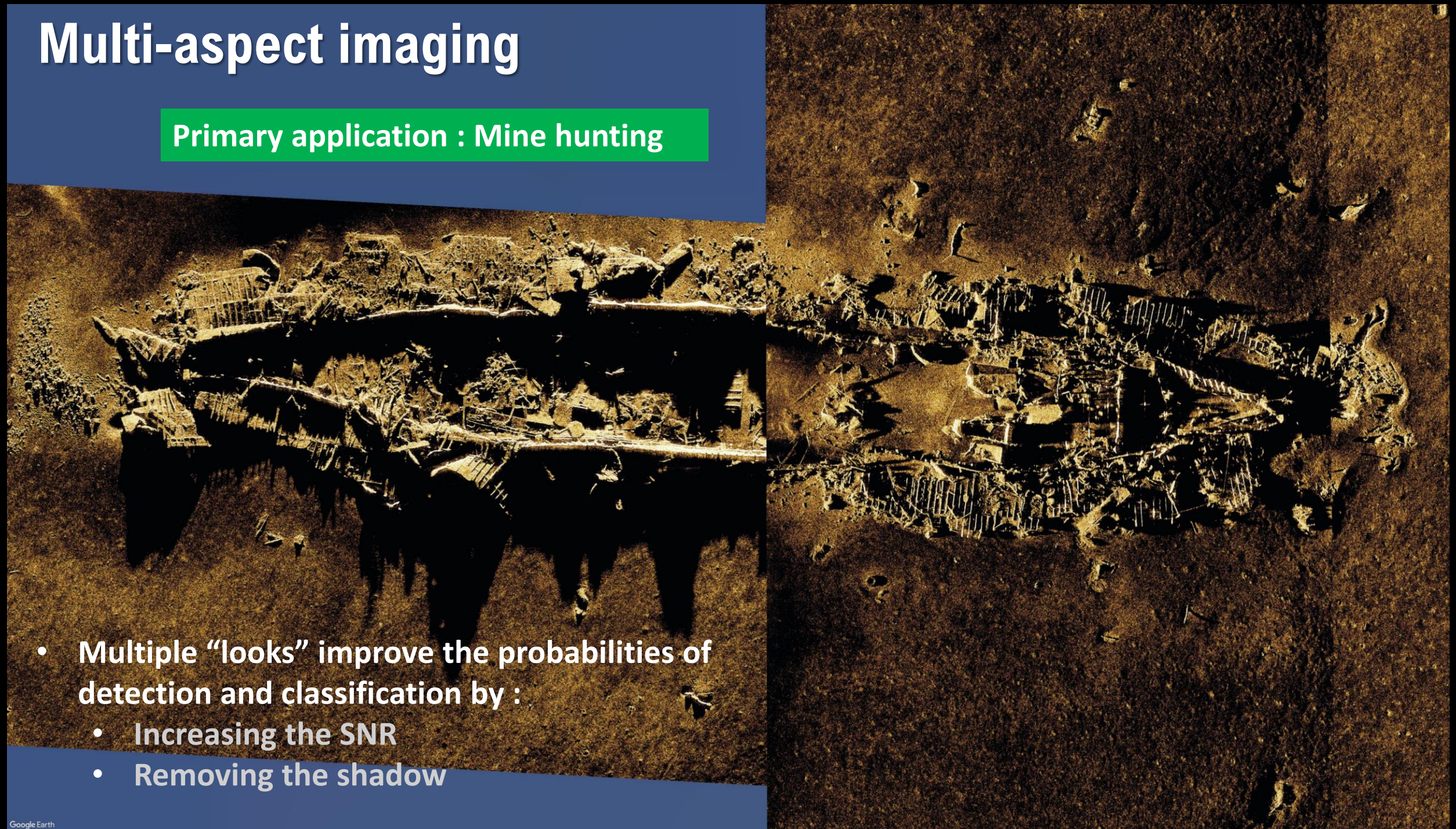
Synthetic Aperture Sonar (SAS)



SAS provides a solution to both the array length limitation and the degrading resolution with range.

Multi-aspect imaging

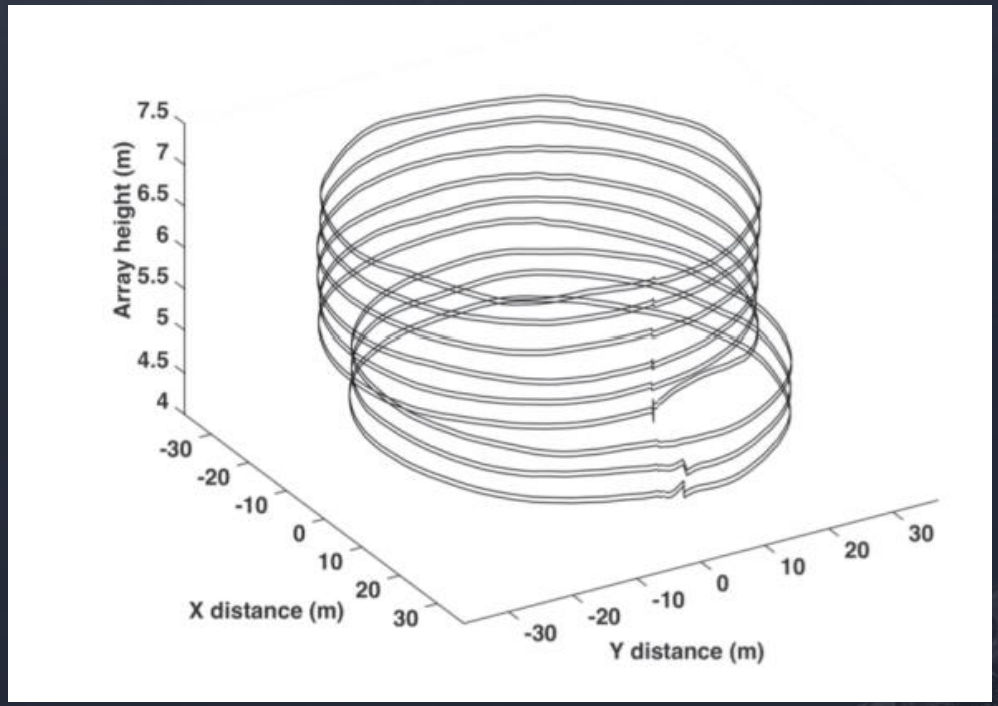
Primary application : Mine hunting



- **Multiple “looks” improve the probabilities of detection and classification by :**
  - **Increasing the SNR**
  - **Removing the shadow**

Multi-aspect imaging

- **Full azimuth coverage is possible by flying circular or spiral trajectories with the target within the sonar beam**
  - **Possible to do with an AUV**
  - **Difficult with a towed sensor**



Towed Sensors

Tow cable dynamics make circular navigation challenging.

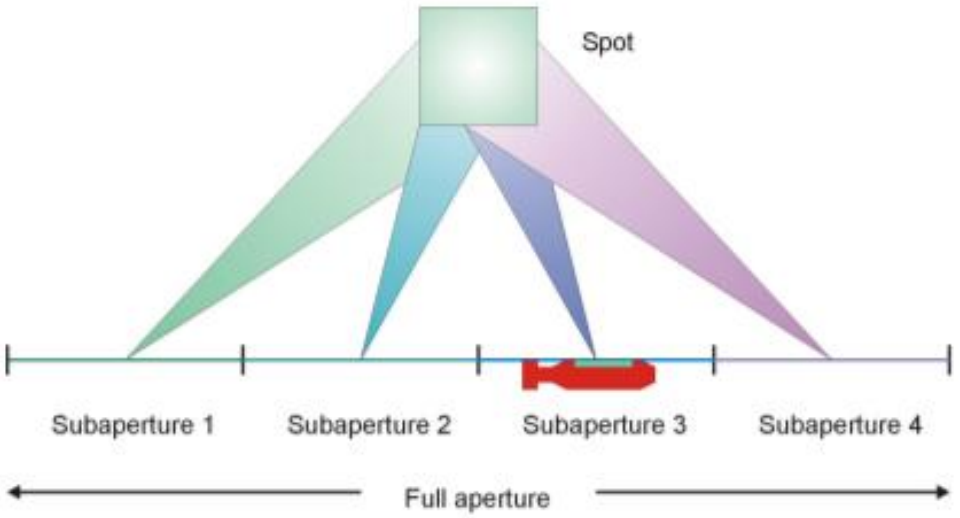
Towed sensors are preferred because they have:

- **High ACR (even in shallow water)**
- **Long endurance**
- **Rapid transit capabilities**
- **Ample electrical power for real-time processing**
- **High bandwidth telemetry**

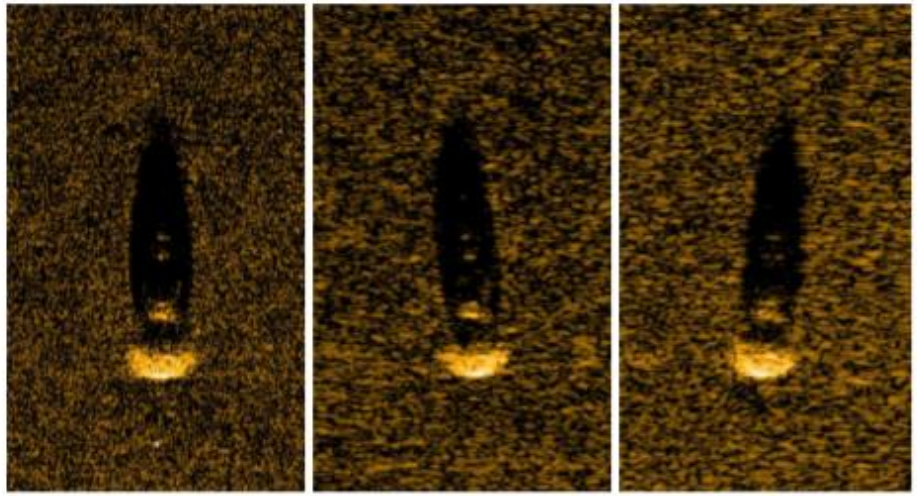
Linear multi-aspect Imaging

- A partial multi-aspect capability can be obtained on a linear path either by processing SAS data in along-track sub-apertures or by using a squinted transmitter
  - These typically result in degraded resolution and image contrast

Sub-apertures



Center | **Max squint left** | **Max squint right**



R. E. Hansen, H. J. Callow, T. O. Sæbø, P. E. Hagen, and B. Langli,"High fidelity synthetic aperture sonar products for target analysis,"Proc. OCEANS 2008 Quebec City, 200

Square SAS

- Multi-aspect Imaging for towed sensors
- Fuse imagery from piecewise linear survey lines having an azimuthal extent of at least ±90 degrees
  - Includes an arbitrary number of piecewise linear survey lines such as hexagonal or octagonal configurations
    - But there is a trade off between number of target views and data acquisition time

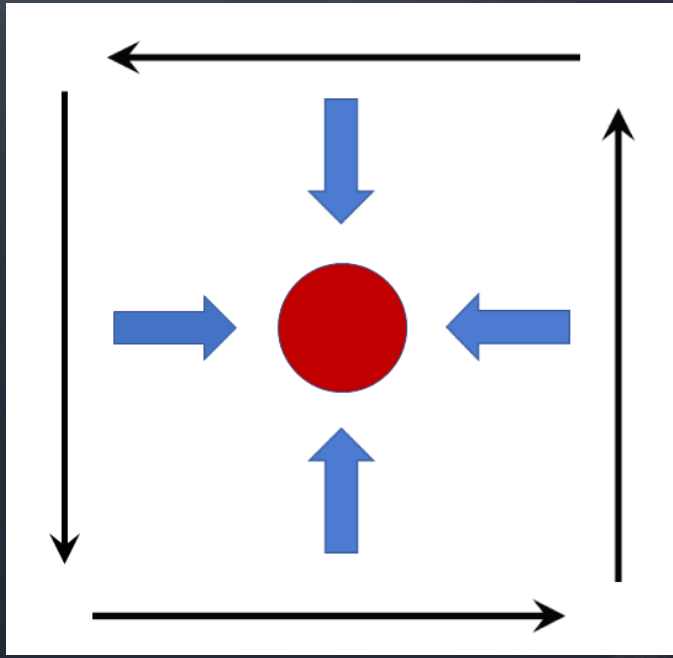
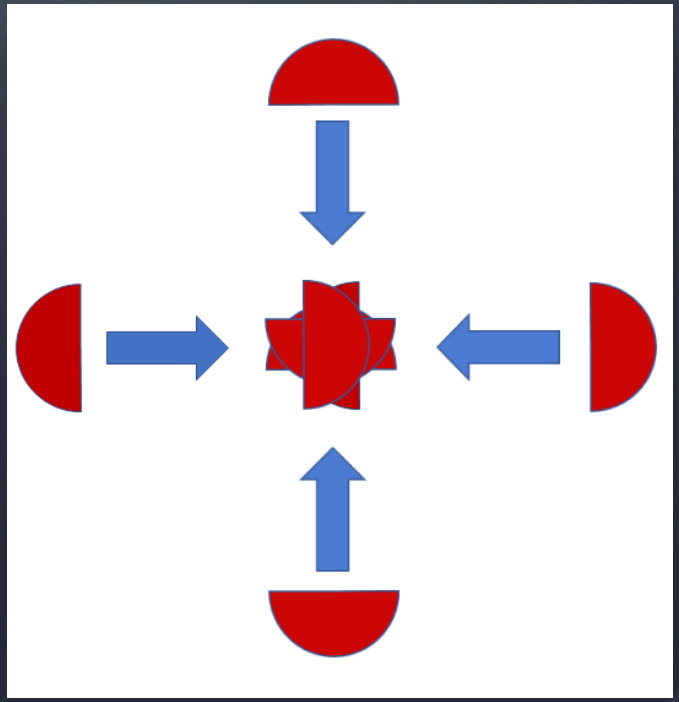


Image Registration for Image fusion

Image registration aims to estimate the transformation required bring multiple images into alignment.

Monomodal Registration

- Acquisition of multiple images from a single sensor
- Extracts features from the image and then performs cross-correlation to match the feature locations
- Requires collected imagery to have similar brightness, contrast, noise statistics, and sensor-to-object orientation.



Doesn't work : cross-correlation aligns feature centroids rather than the shapes

Multimodal Registration

- Data acquisition with multiple sensor types.
  - Example: CT and MRI scans

- Maximizes the mutual information between image pairs using a multi-resolution pyramid scheme with iterated evolutionary optimization .
- The mutual information of images A and B is the distance between probability distributions using the Kullback-Leibler measure

joint distribution of A and B

$$I(A,B) = \sum_{a,b} p_{AB}(a,b) \log \frac{p_{AB}(a,b)}{p_A(a)\, p_B(b)}$$

Complete statistical independence distribution

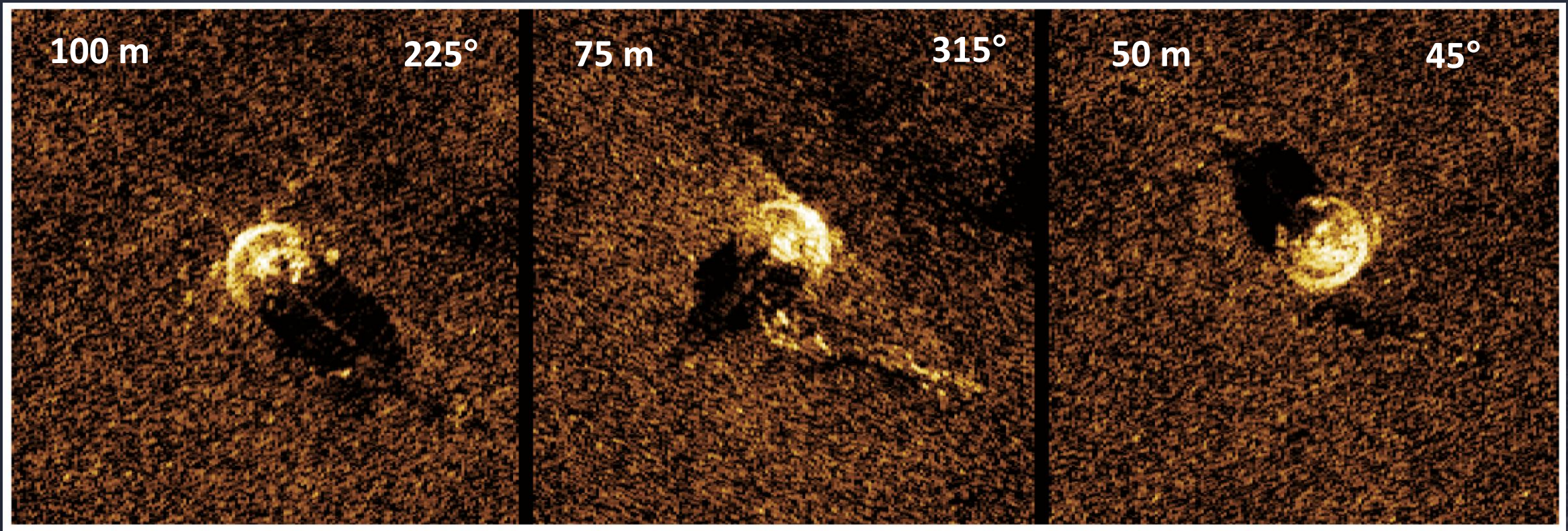
Data Collection and processing

- Collected from the R/V Ocean Seeker, a 20 m twin-hull catamaran equipped for seabed surveying, which includes:
  - A KATFISH high speed, actively stabilized towfish equipped with a MINSAS
  - fully unmanned launch and recovery system

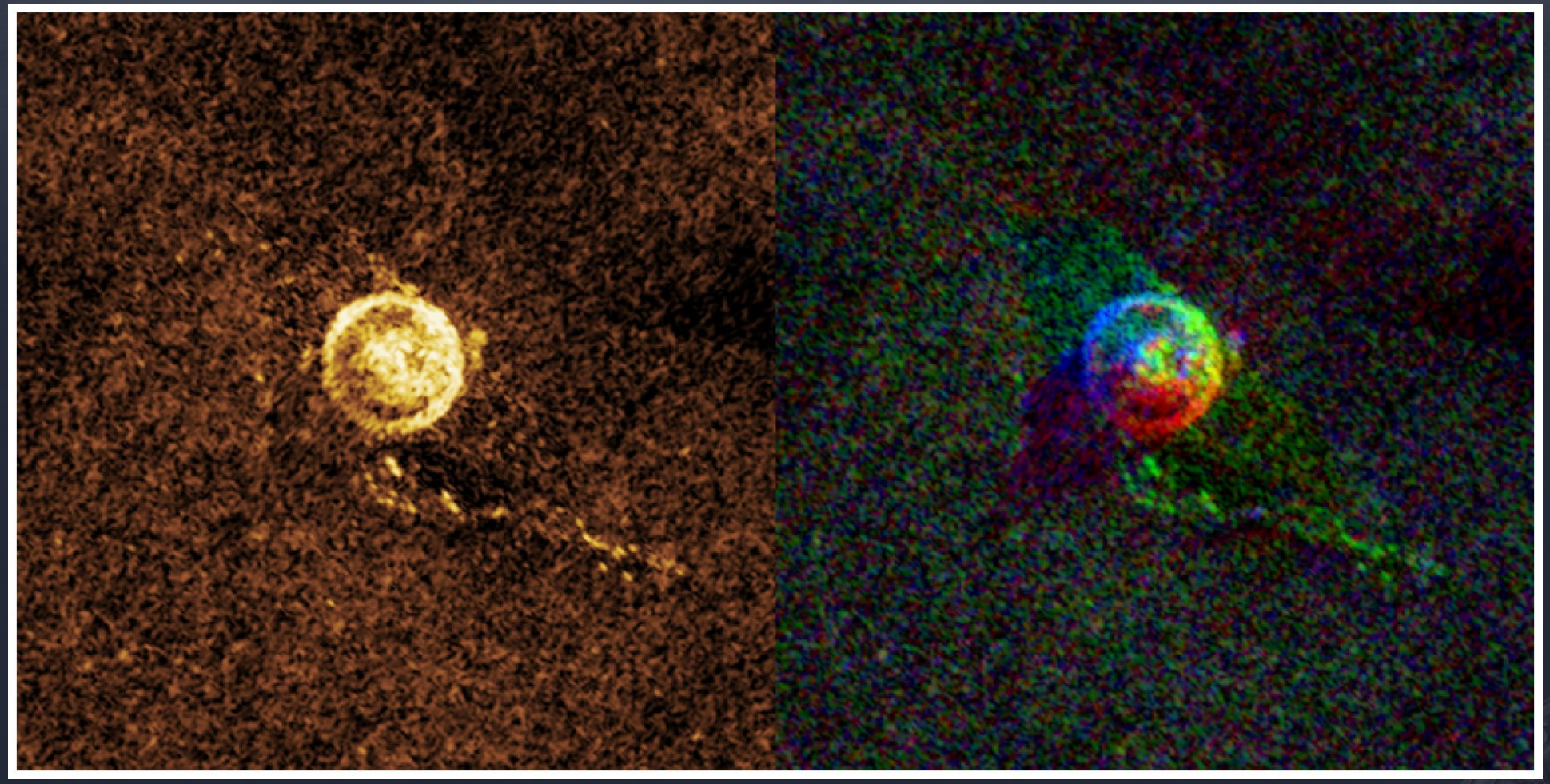
- The experiment was performed using three different ranges to test multimodal image registration when each target view has a different grazing angle

Test Data

Inert training target in Bedford Basin



Results



Summary

- The Square SAS technique fuses multi-aspect imagery from piecewise linear survey lines having an azimuthal extent of at least ±90◦
- The technique is applicable to any SAS platform but is ideal for towed systems where multiple linear passes are required
- The technique reduces speckle noise, eliminated shadow, and captures details that may only be observed from a particular view.

Future Work

- Visualization techniques for the fused image when more than three views are present
- Fuse multi-aspect imagery from larger objects such as shipwrecks