Kongsberg Maritime

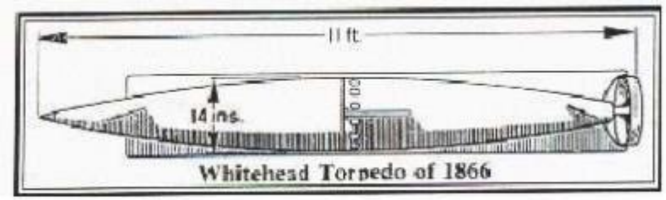
Autonomous Underwater Vehicles

HUGIN AUV Configured for Underwater Mining Applications

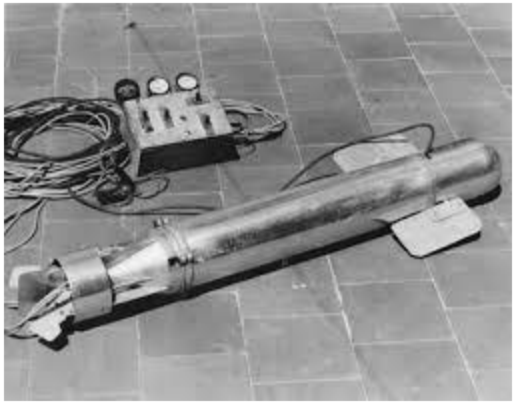
Richard Mills

Director Sales Marine Robotics

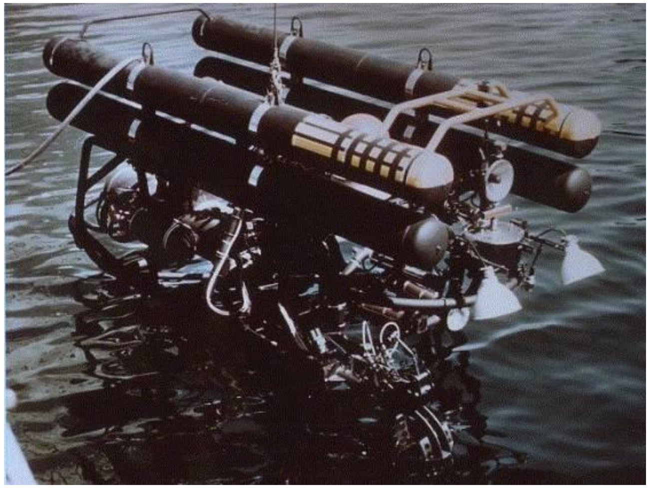
Underwater Vehicles: The Introduction of ROVs



1864-66 Whitehead Luppis



1953 Dimitri Robikoff: Poodle ROV



1966 Cable-Controlled Underwater Recovery Vehicle (CURV-I)

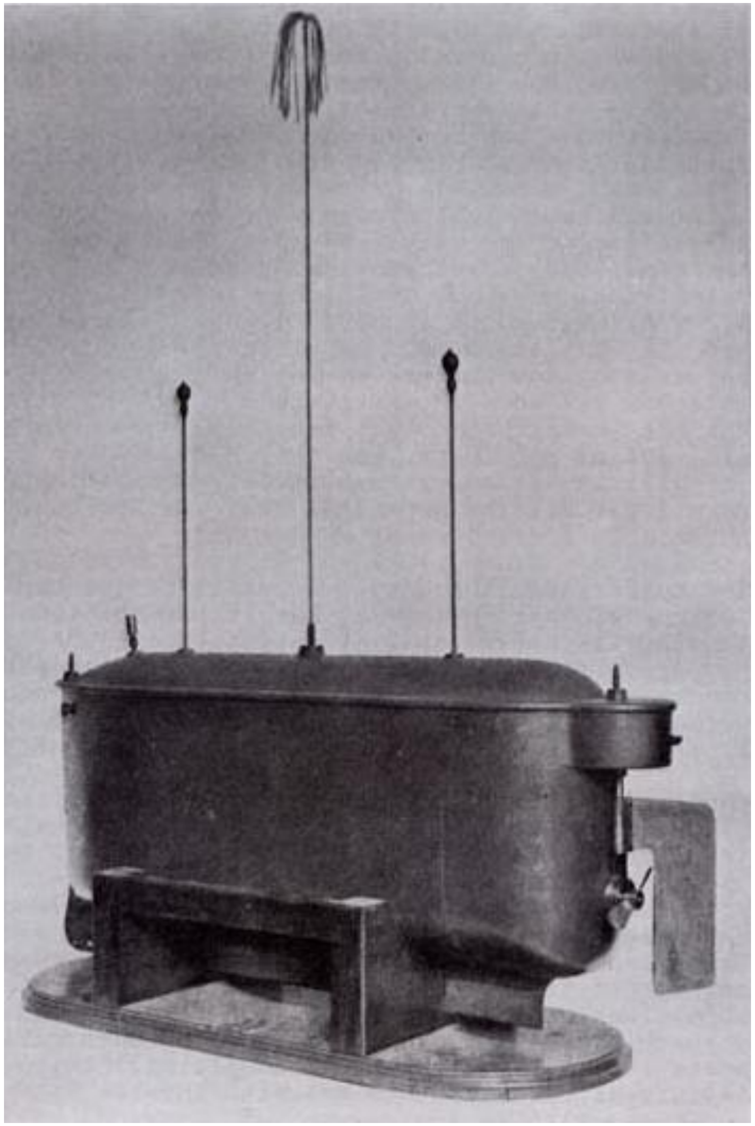
1970s TROV Commercial ROV

- First controlled underwater vehicle developed in 1864
- Designed to access inhospitable areas and reduce risk to people
- Military applications came first
  - Torpedo recovery
  - Observation etc.
- Commercial tasks followed in the 1970s:
  - Pipeline inspection
  - Well head intervention etc.

Tetherless Evolution

1898: Nikola Tesla demonstrated a remote controlled boat at an exhibition at Madison Square Gardens.

In typical Tesla style, he convinced his audience they could control it with their thoughts!



Underwater Vehicles: Becoming Autonomous

1957 University of Washington Special Purpose Underwater Research Vehicle (SPURV)

- First tether-free controlled underwater vehicle developed in 1957
- Universities lead the way
- Research gave way to defence applications in the early 1980s

- First AUV developed by commercial company 1983 (ARCS)
- First commercial surveys in 1990s
- Defence still accounts for more than 60% of all AUVs

1980 Ifremer Epaulard

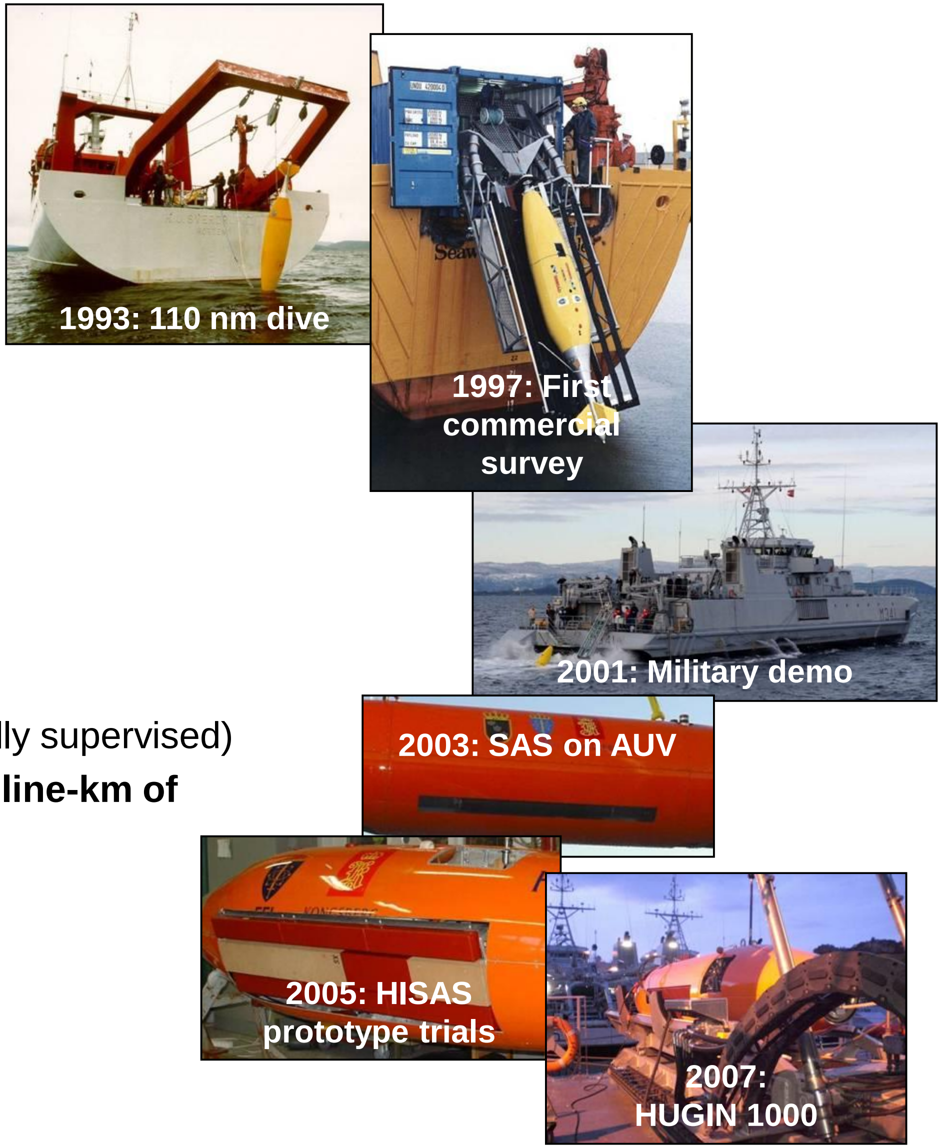
Kongsberg Maritime and AUVs

1993: **H**igh-precision **U**ntethered **G**eosurvey and **IN**spection system
HUGIN 1, a joint KM, Statoil, Royal Norwegian Navy and FFI development

Kongsberg Maritime and AUVs

Key Milestones: *KM AUV Development*

- 1993: 110 nautical mile dive
- 1997: First commercial survey
- **2000: First commercial sale**
- 2001: First Military demonstration
- 2003: SAS prototype on HUGIN
- **2005: 5 AUVs sold**
- 2005: HISAS prototype on HUGIN
- 2007: Introduction of HUGIN 1000 model
- **2010: 27 AUVs sold**
- 2015: Depth record for HUGIN 4449 m (fully supervised)
- **2016: 55 AUVs sold, more than 800,000 line-km of commercial survey completed**

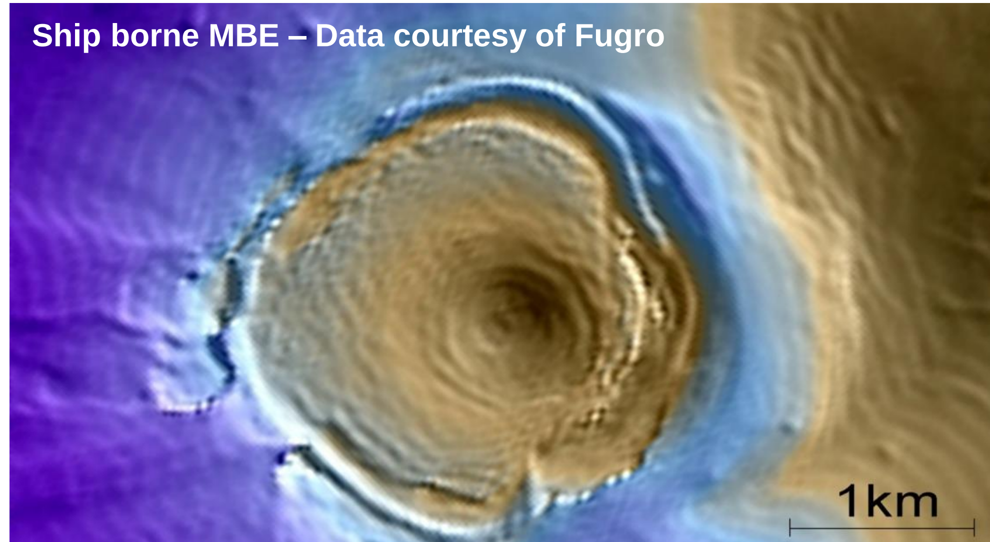


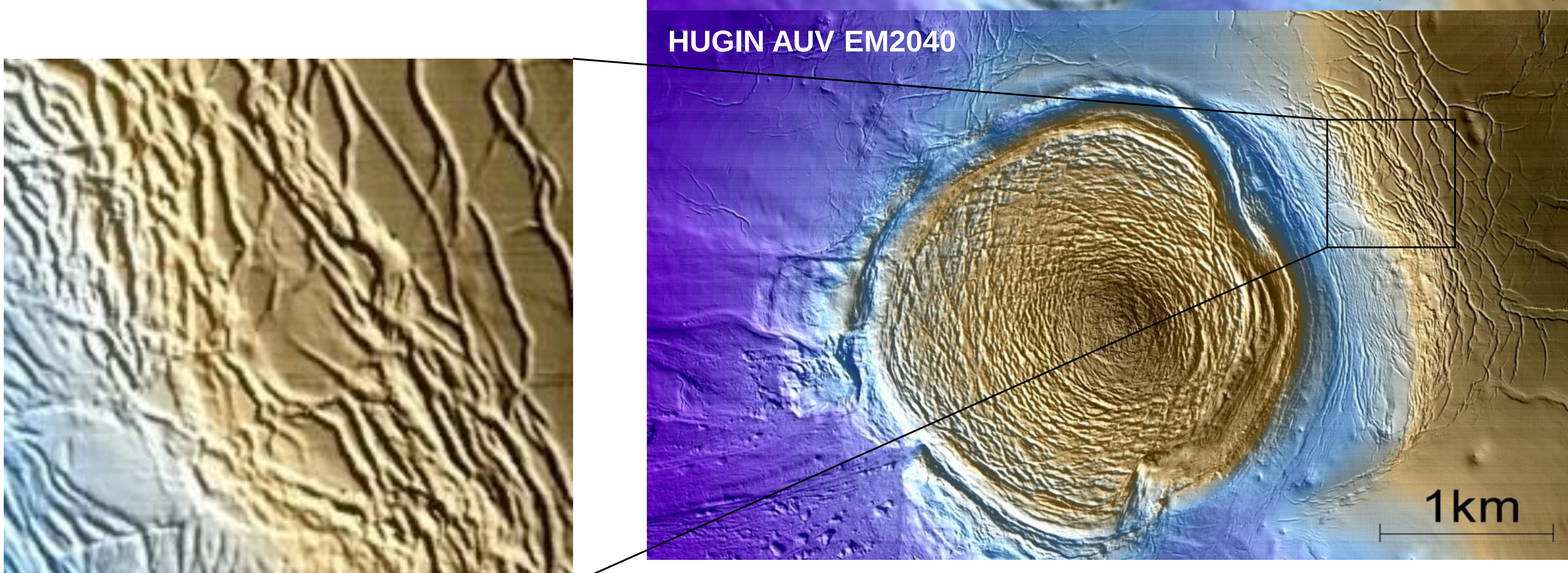
Successes!

- **HUGIN is the most productive commercial AUV ever**
- **More than 800,000 line km of commercial survey**
- **Operations in Europe, Asia, Africa, Americas and Arctic**

Benefits of Using AUVs

- Better Data
  - Get the sensor closer to the target
  - Higher resolution
  - Less noise
  - More stability = less gaps
  - Multiple data sets from a single pass
- Faster than ROV or other traditional methods
- Better positioning and more stable than towed bodies





The State-of-the-Art Survey Class AUV?

Efficient

IHO Grade

Repeatable

Accurate

Low Downtime

Flexible

Reliable

Endurance

Supported

Varied Payload

HUGIN AUV Configured for Underwater Mining Applications

Dimensions:

- Length: ~6.2 m
- Diameter: 87.5 cm

Depth Rating:

- 6000 m

Power Supply:

- Rechargeable and swappable Lithium Polymer batteries

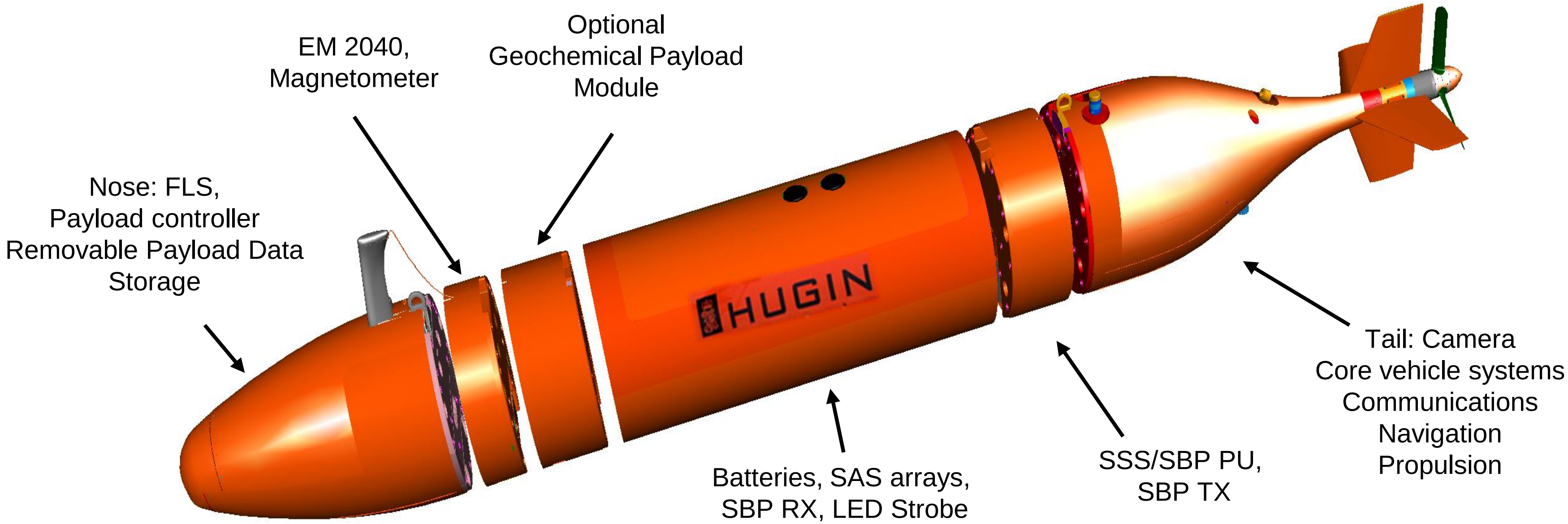
Endurance:

- 55+ hours

Payload Sensors:

- HISAS
- EM2040 MBE
- EdgeTech SBP
- Magentometer
- CathX Ocean Colour Still Image Camera

HUGIN AUV System



Key Navigation System Components


Forward Looking Sonar


Inertial Measurement Unit

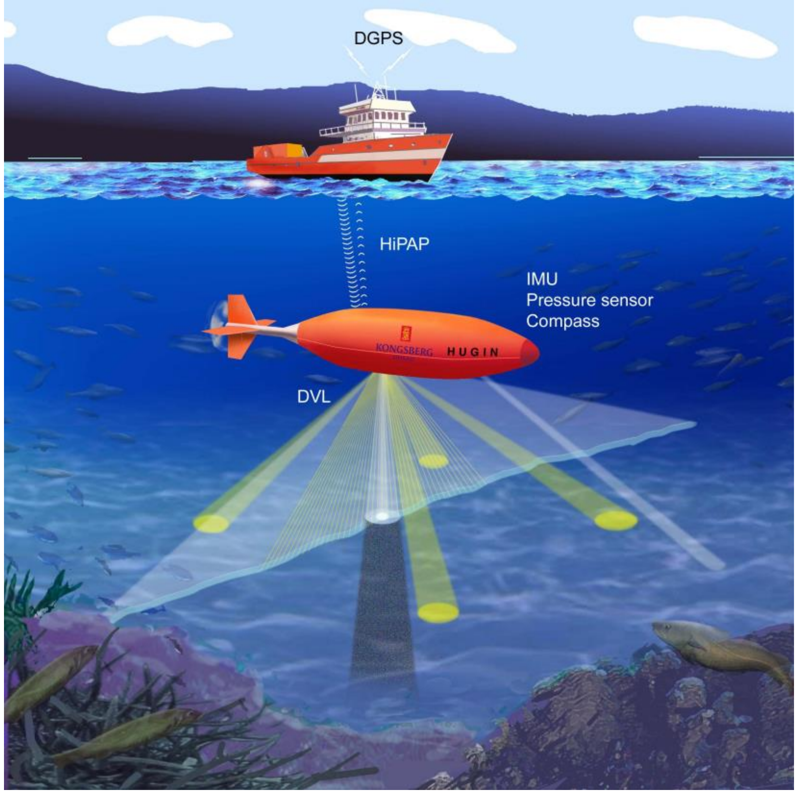

Doppler Velocity Log


cNODE Transponder

HUGIN AUV Navigation at Depth

DVL Aided Inertial:

- Autonomous operations using IMU & DVL only
- Accuracy: 0.1% of distance travelled n a straight line over a flat bottom (2 D, 1σ)
- GPS fix on the surface prior to dive
- Unaided free-inertial during descent induces most drift



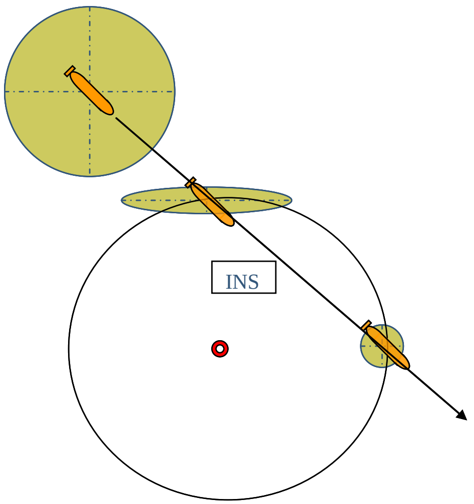
HiPAP Aided Inertial:

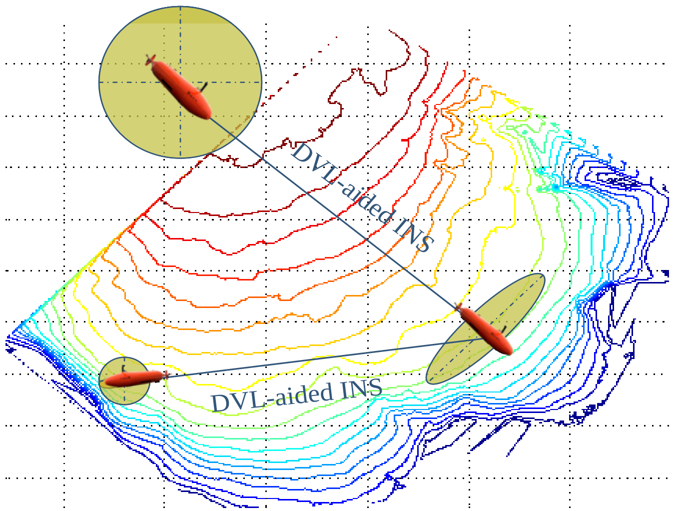
- Supervised Operations
- Real-time aiding
- Accuracy (1σ):
  - 0.5 - 6 m real-time
  - 0.5 - 4 m post-processed
- Depends on quality of GPS feed to HiPAP, plus depth

HUGIN AUV Navigation at Depth

Underwater Transponder Protocol (UTP):

- Similar to sparse LBL, up to 1 km useful range
- Needs only one transponder on the seafloor
- Error ellipse reduces every time the AUV makes contact
- Accuracy (1σ):
    - Real-time: 5 m
    - Post mission 1 - 3 m

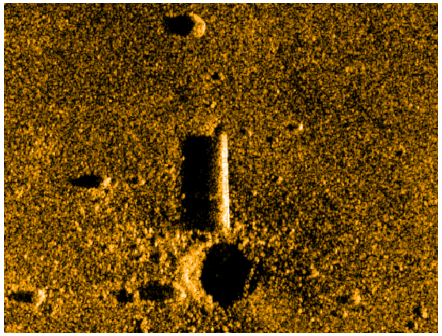




Terrain Navigation:

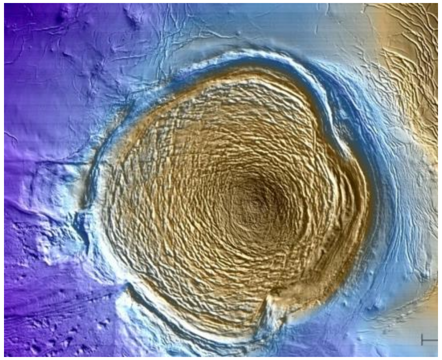
- Can run autonomously
- Requires:
    - Bathymetric sensor (EM2040 or even just DVL)
    - Known bathymetry (Digital Terrain Model) loaded onto HUGIN
    - Terrain must have some vertical variation
- Accuracy (1σ):
    - 0.5 - 5 m
    - Dependent on resolution of the DTM

HUGIN AUV Payload Sensors



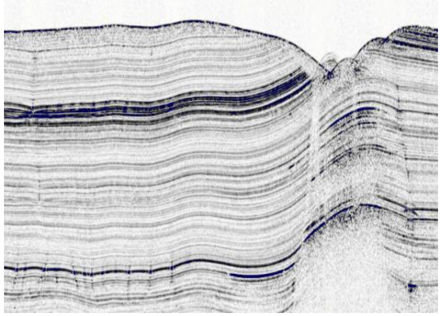
Synthetic Aperture Sonar: *HISAS 1032*

- Range up to 300 m either side
- SAS Imagery theoretical resolution 2 x 2 cm, 4x4 cm in practice
- Interferometric bathymetry across entire swath
- File formats: .SASI, .XTF and .ALL



Multibeam Echosounder: *EM2040*

- Frequency: 200, 300 & 400 kHz
- Single receiver arrangement
- Beam angle: 0.7º x 0.7º
- Swath: 140º (single Rx)



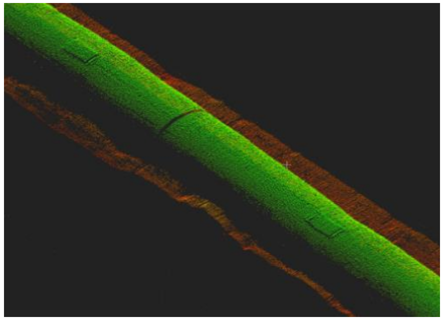
Sub-Bottom Profiler: *EdgeTech Chirp SBP*

- Frequency: 1-6 kHz
- Resolution 15-25 cm
- Penetration 15-150 m (coarse calcareous sand to clay)
- PVDF receivers for cleaner return signal

HUGIN AUV Payload Sensors

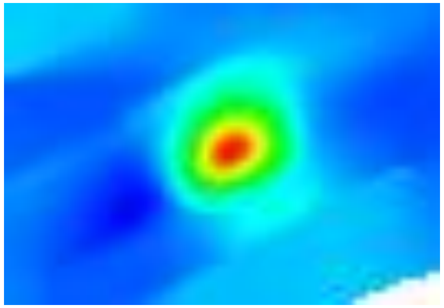
Camera: *CathX Ocean UHD Color Still Image Camera*

- 12.5 Megaixel, UHD 1080p resolution
- Color still image camera
- 2 x LED panels on underside of main body section
- Data timestamped for georeferencing



Laser Profiler: *CathX Ocean Laser Profiler*

- Ultra-high resolution bathymetry
- Up to 30 lines per second
- 2048 samples per line
- Creates x, y, z point cloud

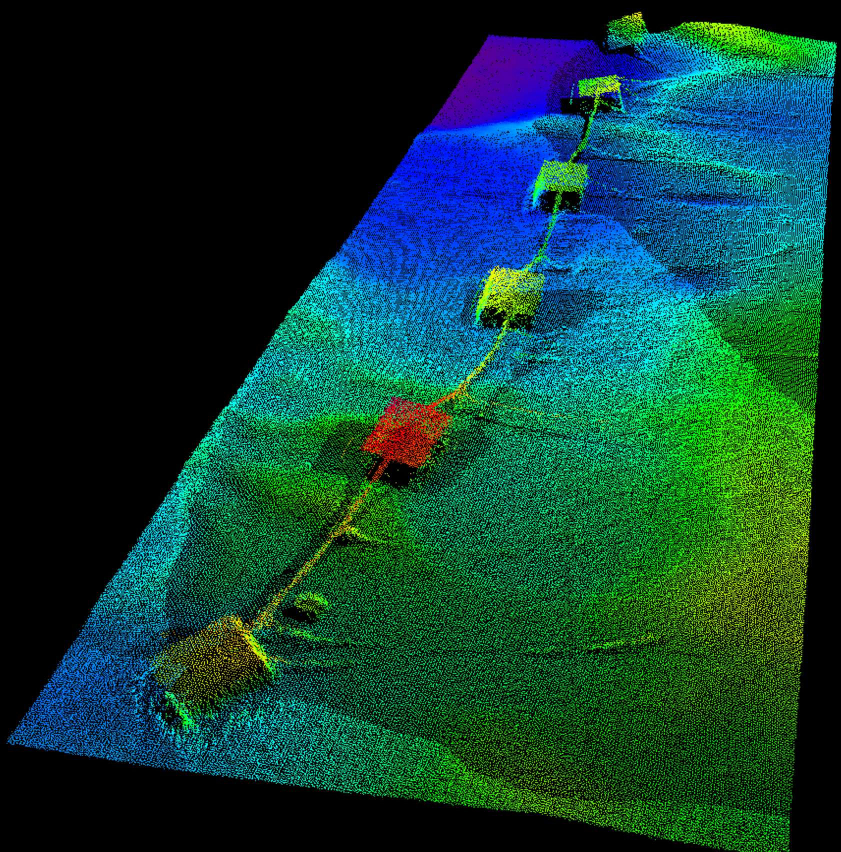


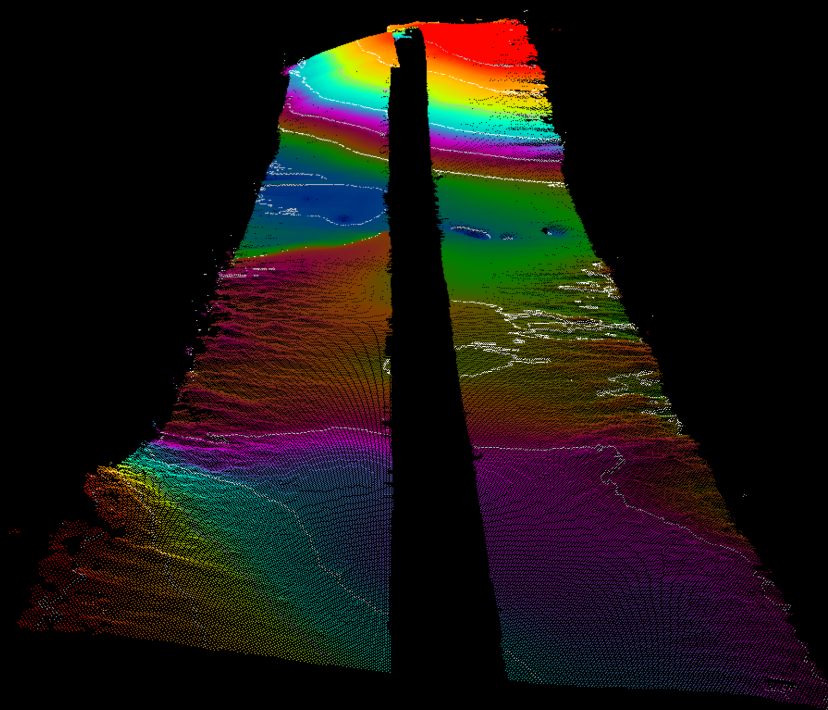
Magnetometer: *Ocean Floor Geophysics SCM*

- Dynamic Range: ±65 μT (±0.65 Gauss)
- Noise Level: ±0.5 nT (±5 μGauss) peak-to-peak
- Resolution: 0.001 mGauss
- Compensation algorithms running in real-time

Data Products

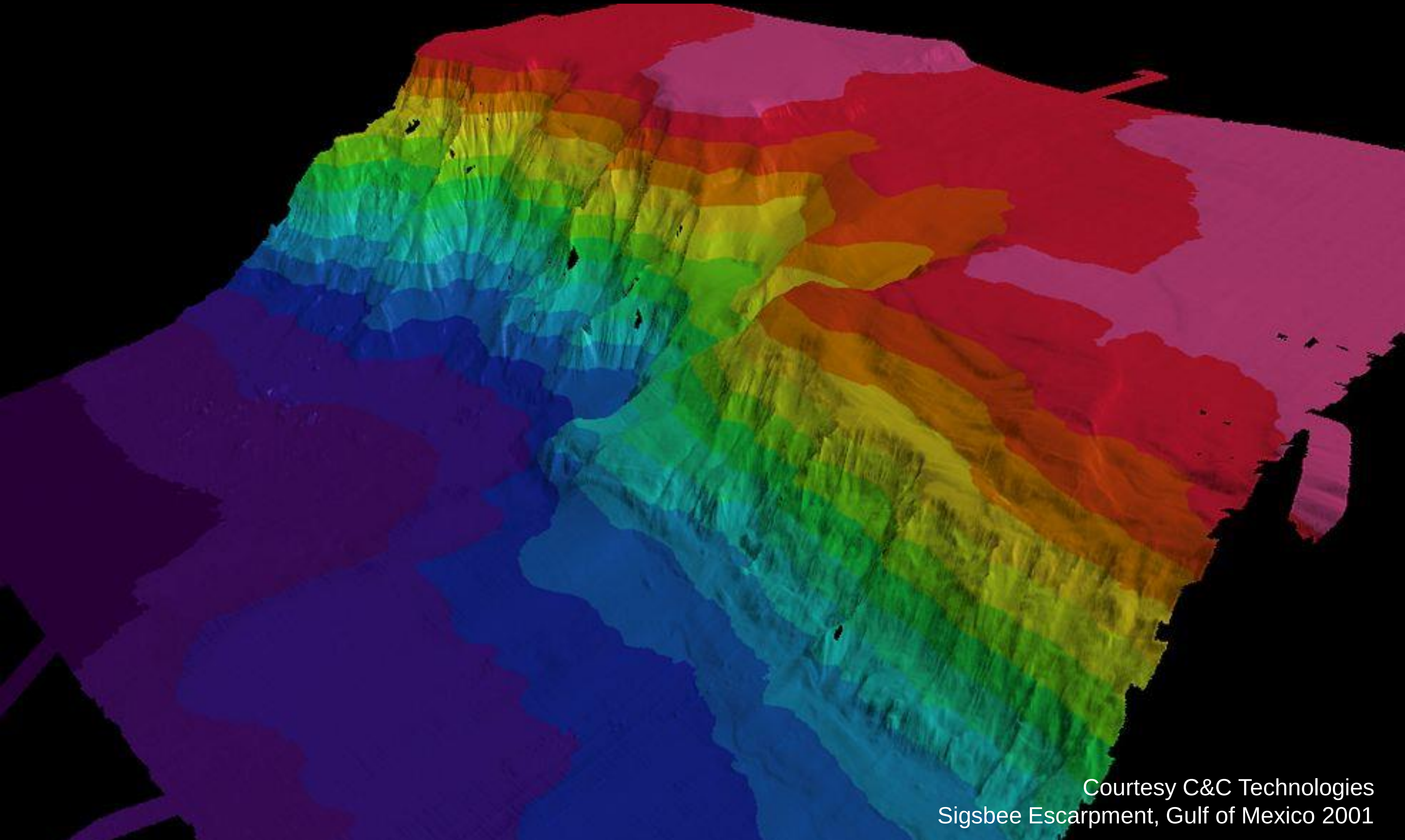
- **Survey Parameters:**
  - Altitude: 3 to 150 m
  - Speed: nominally 1.5 to 2 m/s (~3 to 4 kts)





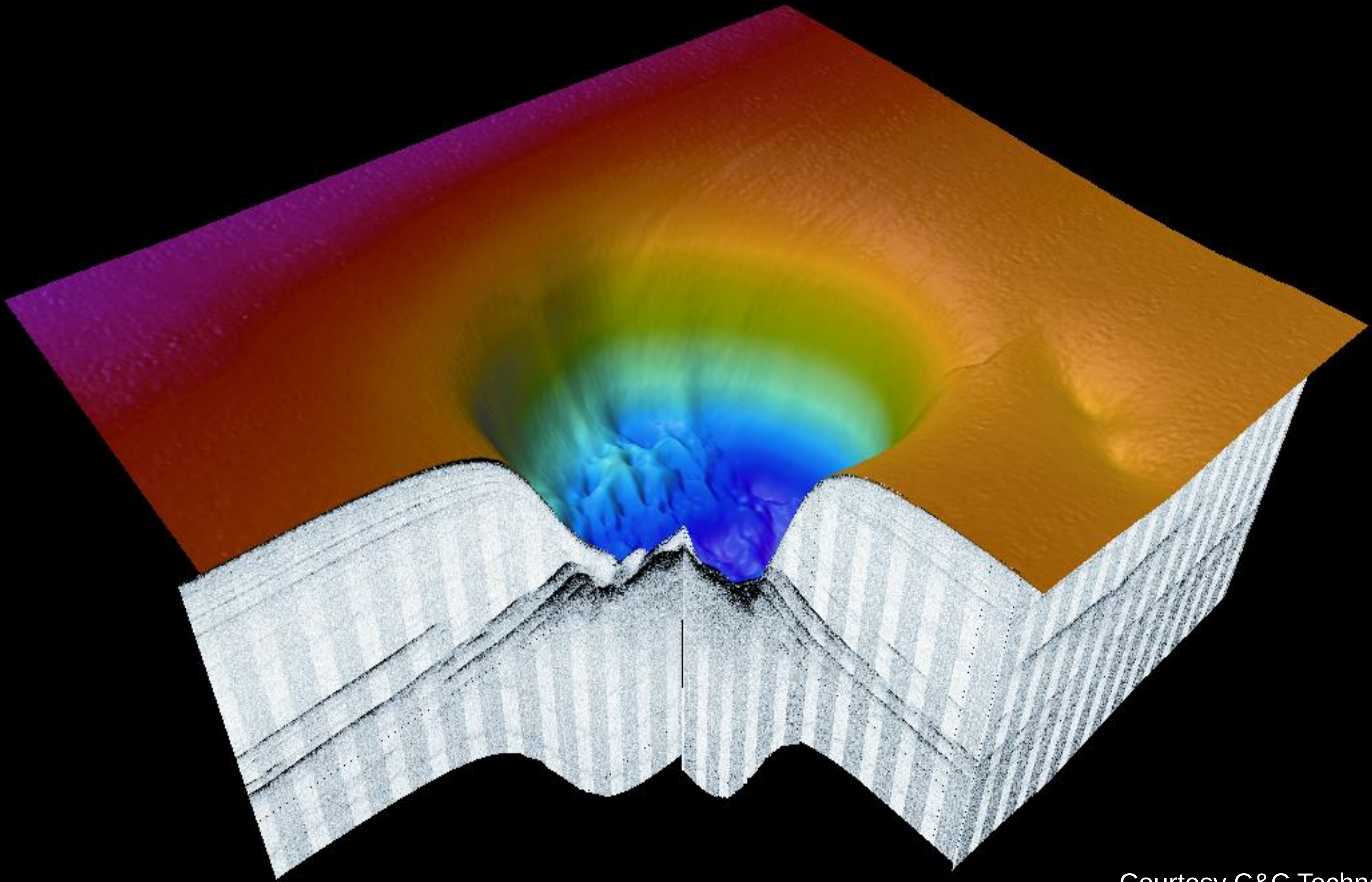
- Sensor combinations improve coverage rates
- All sensors can be used concurrently
  - HISAS/SSS
  - EM2040
  - SBP
  - Camera
  - Magnetometer/Environmental/Geochemical

Bathymetry



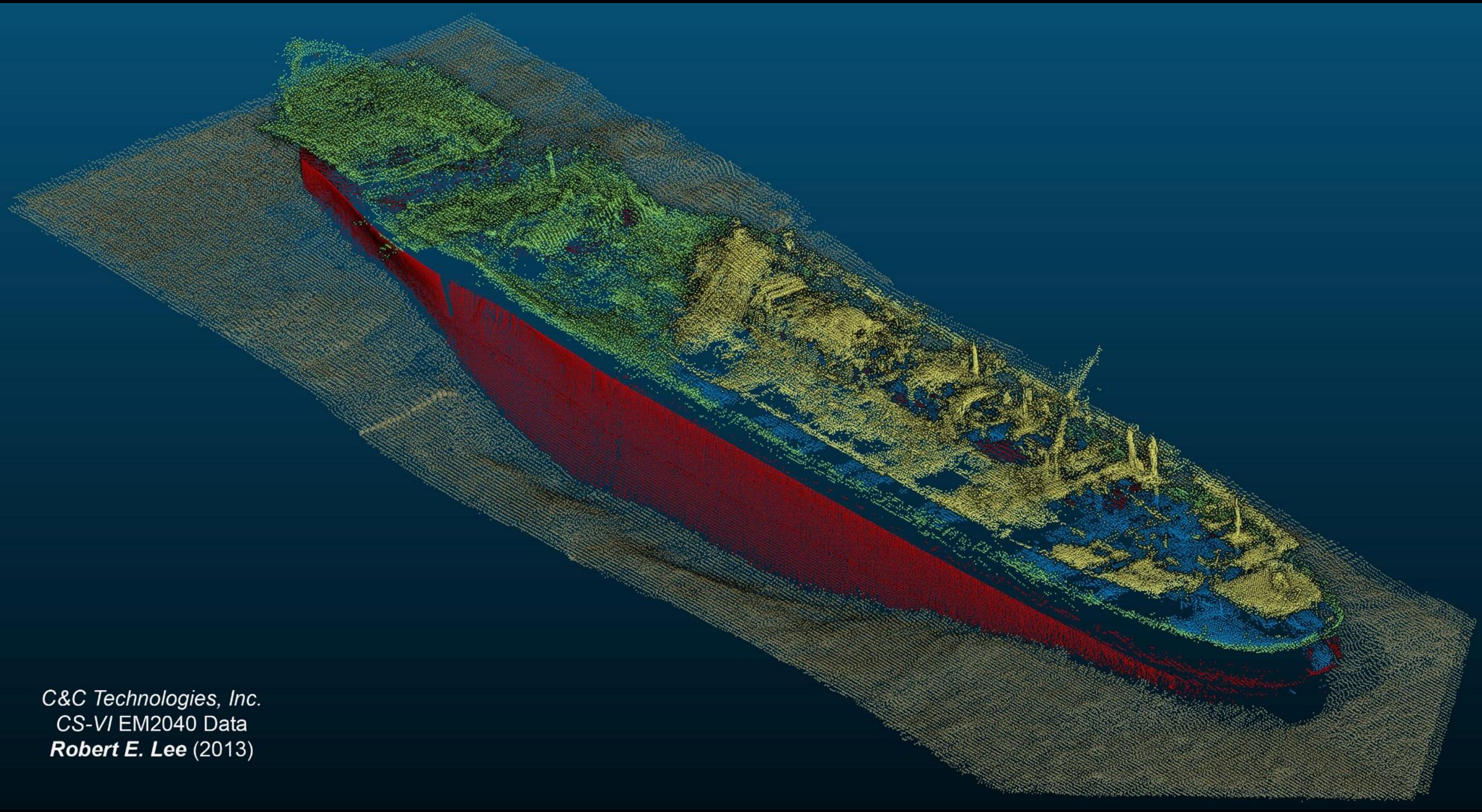
Courtesy C&C Technologies
Sigsbee Escarpment, Gulf of Mexico 2001

Bathymetry and Sub-Bottom Imagery



Courtesy C&C Technologies
Nigeria 2002

Bathymetry

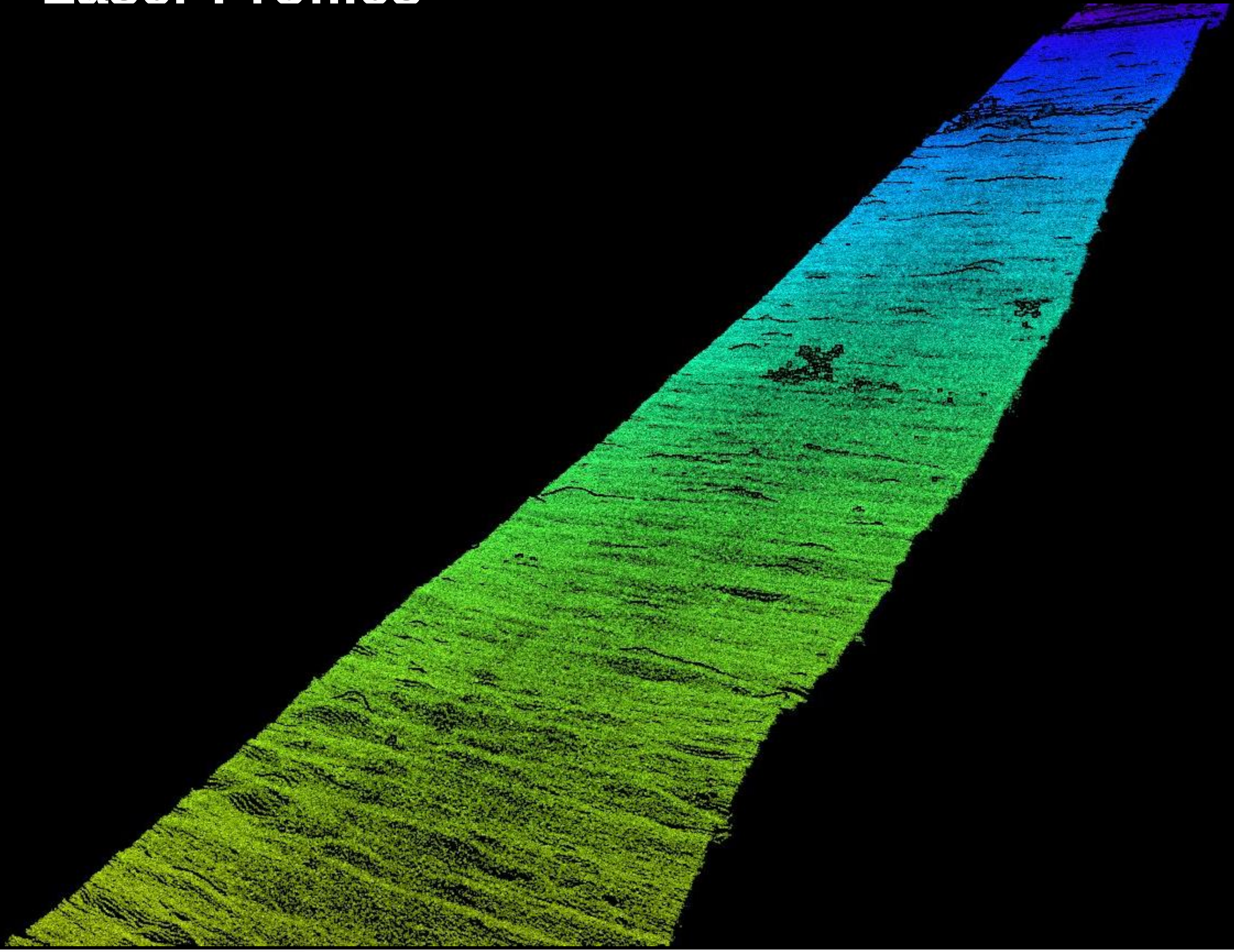


Courtesy C&C Technologies
Robert E Lee, Gulf of Mexico 2013

Seabed Imagery

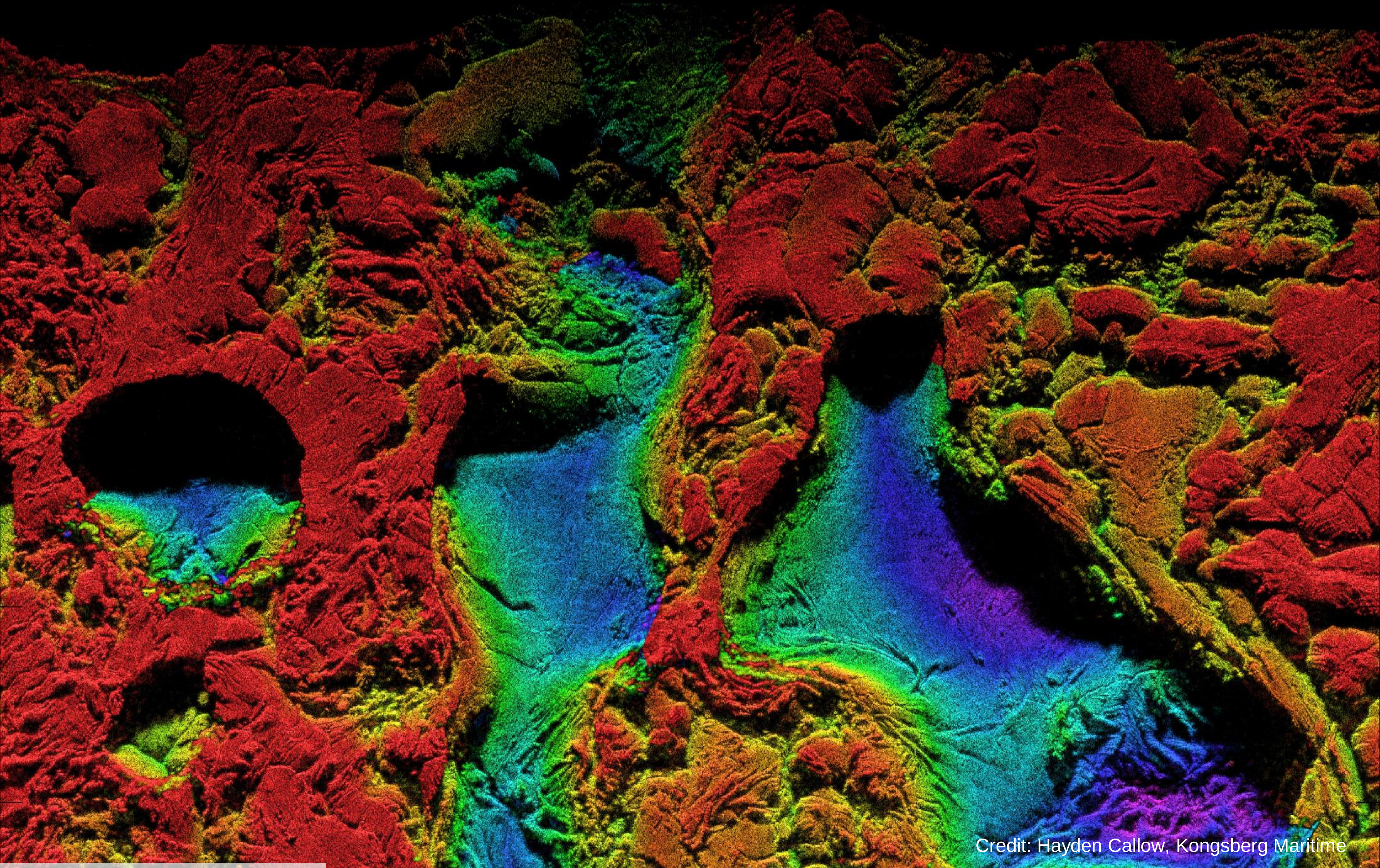
Altitude 5 m
Speed 2 m/s

Laser Profiles



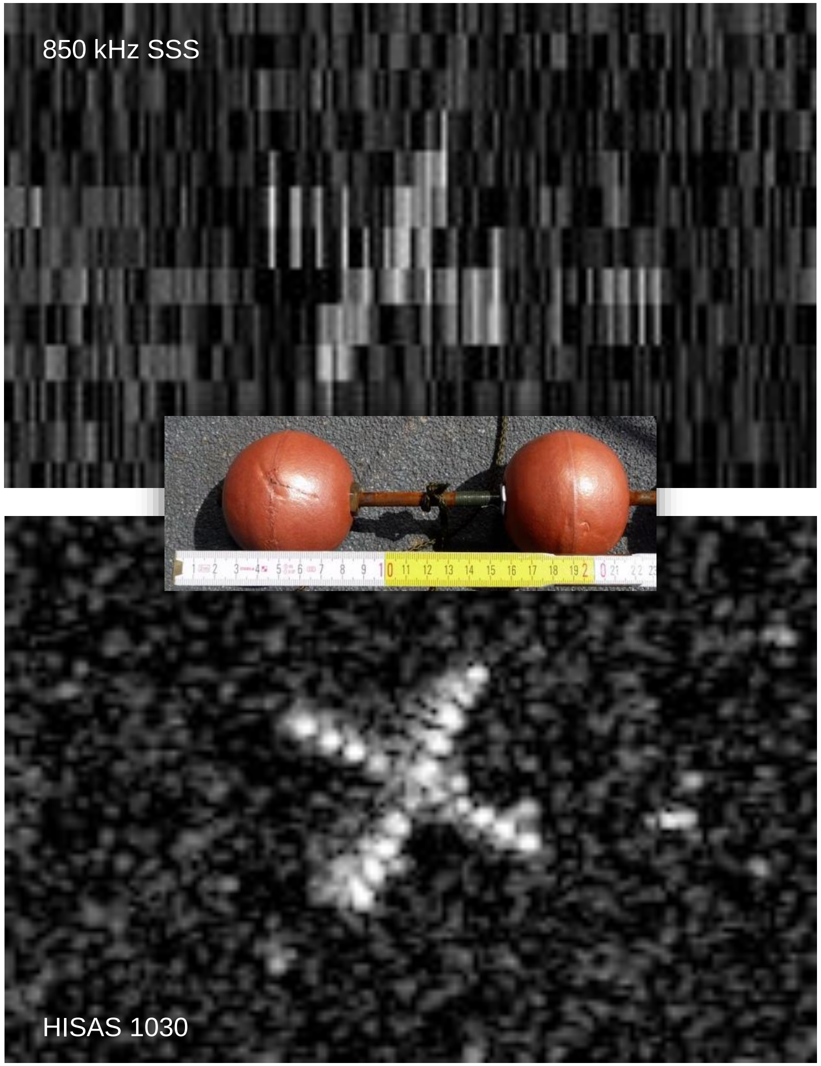
HISAS

KONGSBERG

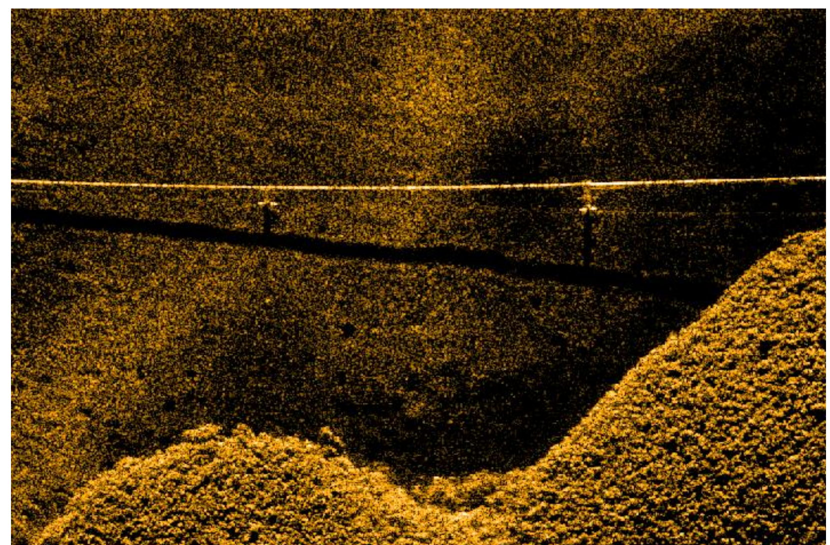


Credit: Hayden Callow, Kongsberg Maritime

Synthetic Aperture Sonar: HISAS 1032



- Synthesizes longer receive aperture
- Along track resolution is independent of range
- Up to ~300 m either side
- Includes bathymetry
- Requires very accurate installation with position and orientation of array known within a small fraction of the wavelength



HISAS in Mining Applications

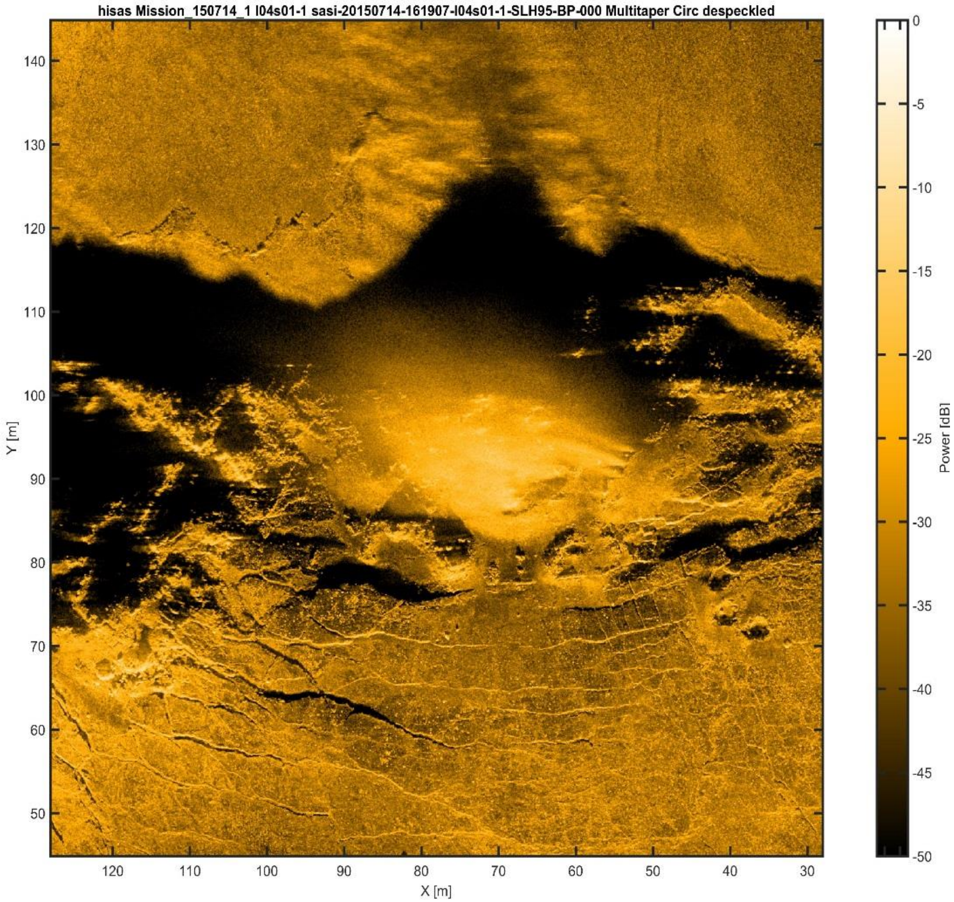


Image center Latitude 71° 17.8978' N, Longitude 05° 42.2541' W, Depth 538.0 m. Altitude 30.6 m. Time 16:19:07
Grid dx = 2.0 cm, dy = 2.0 cm, Theoretical dx = 3.7 cm, dy = 2.4 cm, Look dir -0.4°, Q-factor 38.4, pings 404-704

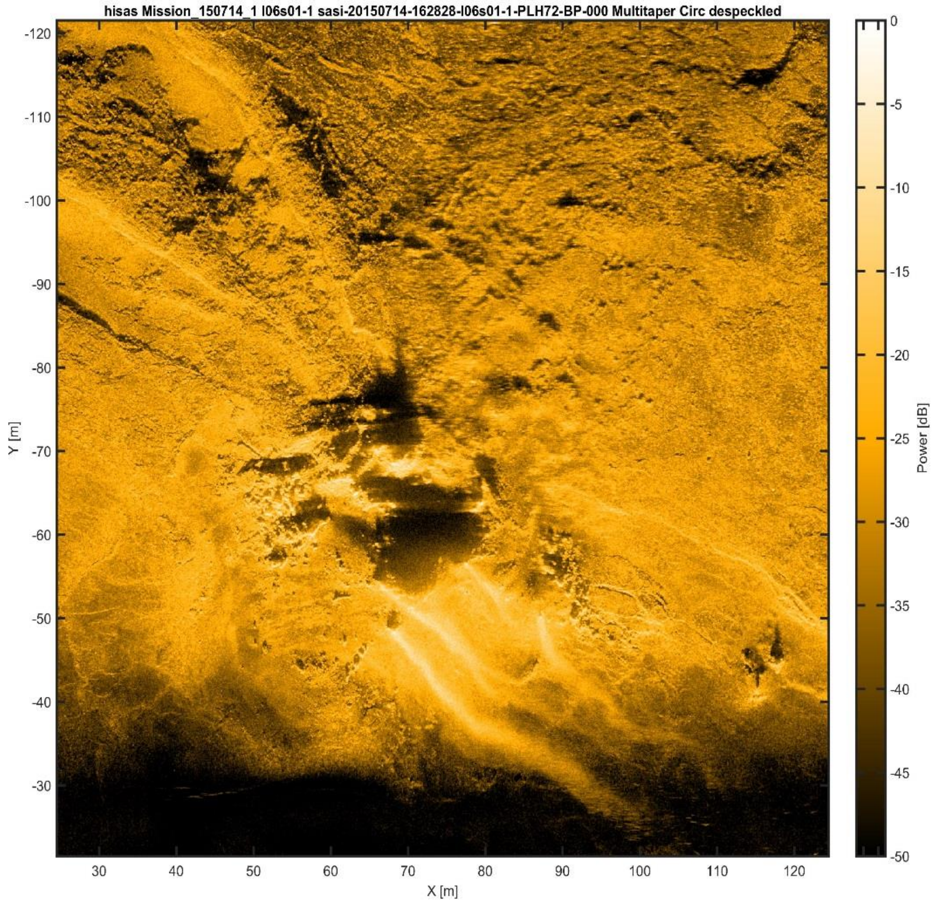
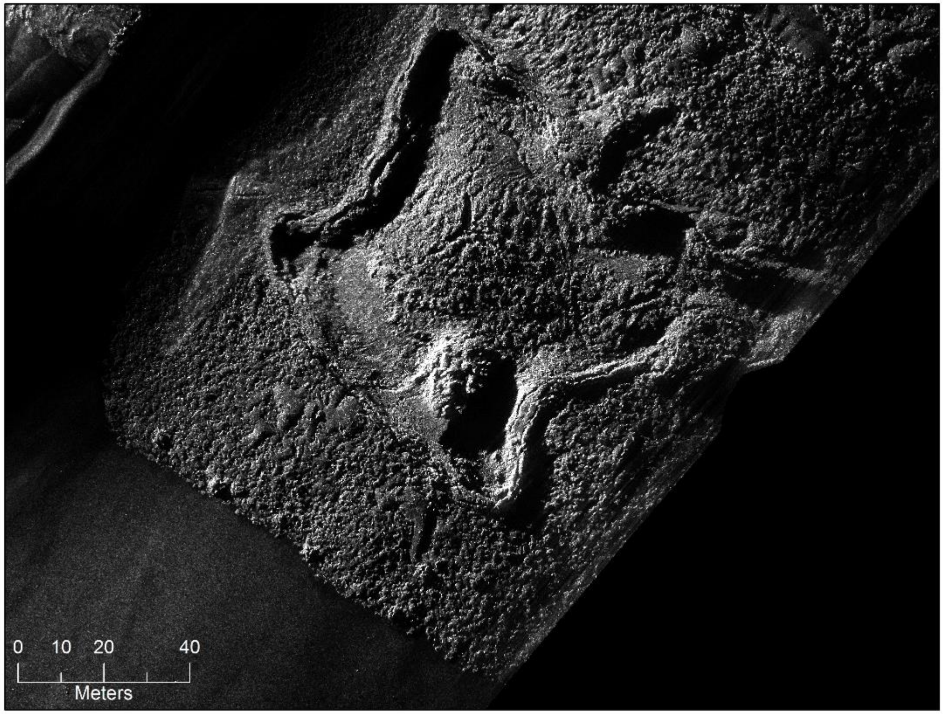


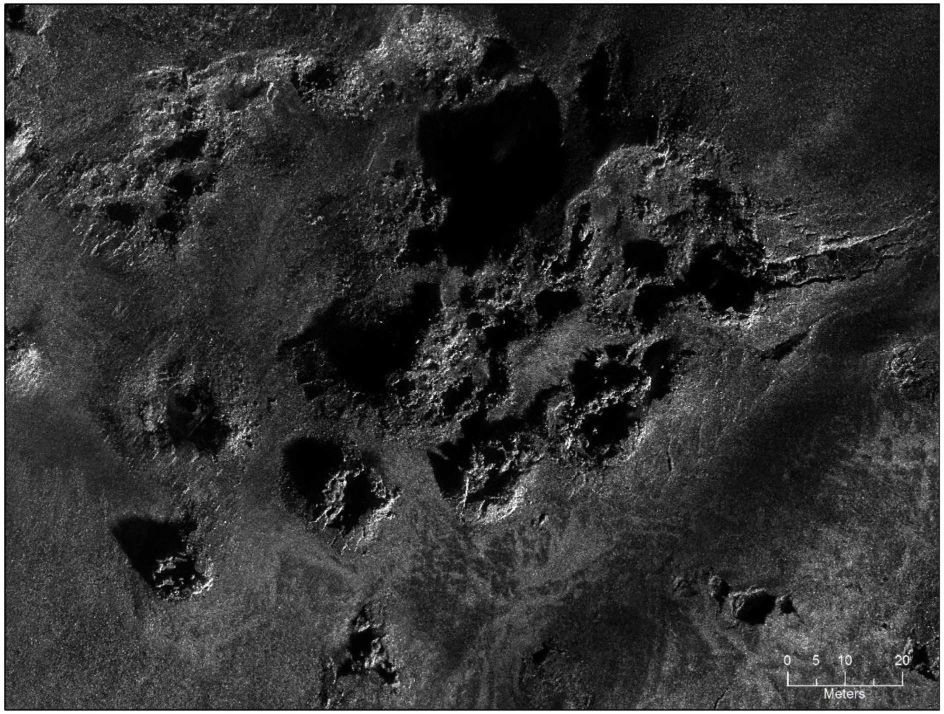
Image center Latitude 71° 17.8991' N, Longitude 05° 41.6262' W, Depth 560.5 m. Altitude 30.7 m. Time 16:28:28
Grid dx = 2.0 cm, dy = 2.0 cm, Theoretical dx = 3.7 cm, dy = 2.4 cm, Look dir -0.3°, Q-factor 30.2, pings 366-652

Alden Denny et al, The Use of Synthetic Aperture Sonar to Survey Seafloor Massive Sulfide Deposits
Journal of Ocean Technology , Vol 10 number 1 2015

- Courtesy of Alden Denny (ade003@uib.no)
- University in Bergen (UiB) Centre for Geobiology and Norwegian Defence Research Establshment (FFI)

HISAS in Mining Applications





Images from a shallow vent feild in the Norwegian Greenland Sea

- Courtesy of Alden Denny (ade003@uib.no)
- University in Bergen (UiB) Centre for Geology and FFI

Magnetometer

- Mounted inside the HUGIN AUV
  - Between the nose and main body, away from magnetic sources
  - Small sensor: length = 259 mm, diameter = 51 mm, 1.53 kg in air
  - Low power: 5-12 VDC @ 50 mA
  - Rated to 6000 m
- Data is logged and timestamped on the Removable NAS drive
- Compensation Algorithm running in real-time on Payload Processor
  - Removes vehicle induced noise
- In the future the data could be used for in-mission adaptive control
  - e.g. modified to be a gradiometer for tracking along subsurface anomalies

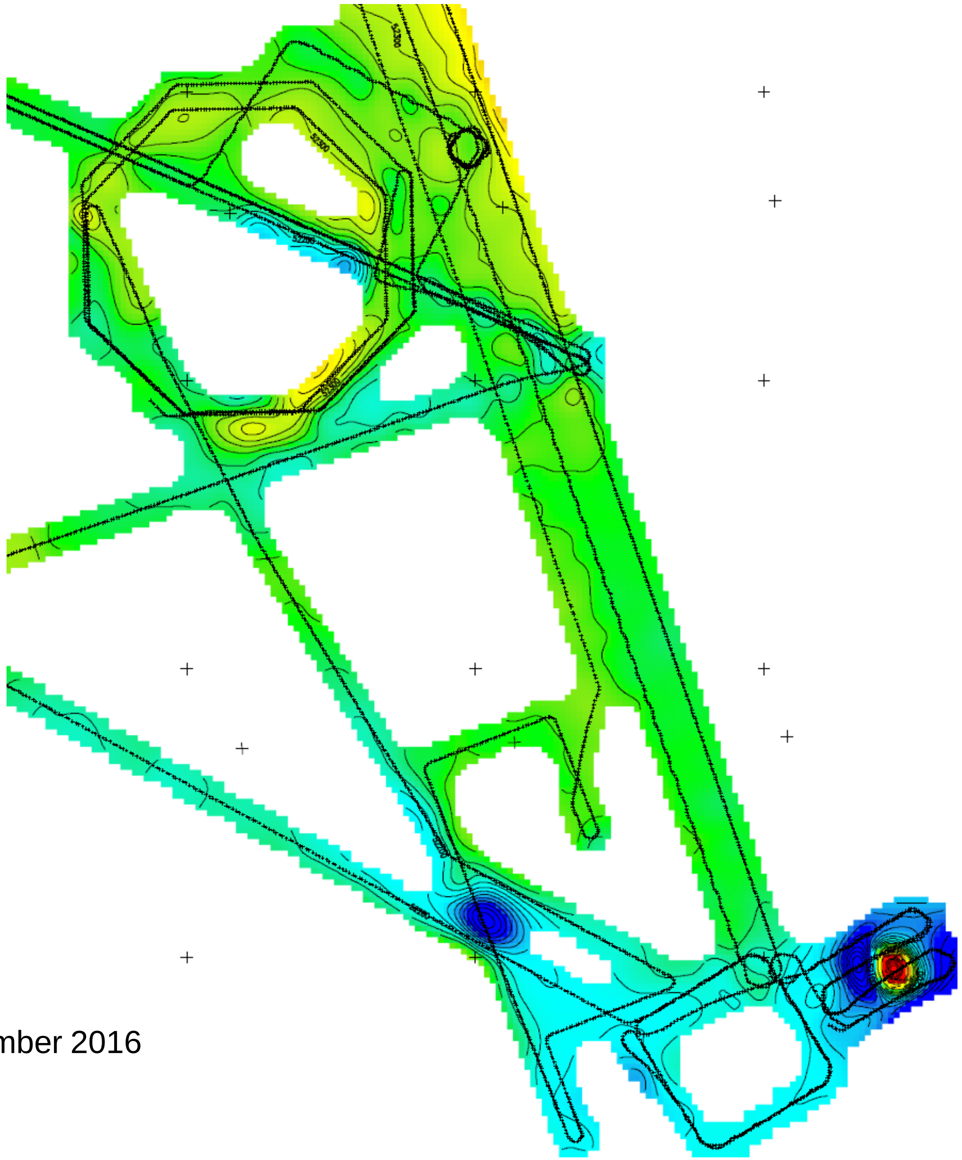


Image collected on KM R&D HUGIN in Oslofjord September 2016

- Vehicle altitude: 40 m
- Speed: 3.5 Knots

What's Next?

KONGSBERG

Eelume
SUBSEA INTERVENTION

KONGSBERG

Kongsberg Maritime

Autonomous Underwater Vehicles

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Director Sales Marine Robotics
Email: Richard.mills@km.Kongsberg.com

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