CHC-NSC 2018
www.chc-nsc2018.ca
Victoria, B.C. March 26-29, 2018 | Victoria, C.B. 26 au 29 mars 2018
Land and Sea Shaping the World
Terre et Mer Façonnant le Monde

Examination of bathymetric data and SAS imagery collected through collaborative autonomous operations between a USV mothership and a deep water AUV equipped with a HISAS Synthetic Aperture Sonar and EM2040 Multibeam System

Alison Proctor
OCEAN FLOOR GEOPHYSICS

#chcnsc2018

The Challenge

Shell OCEAN DISCOVERY XPRIZE®

A $7 million global competition challenging teams to advance deep-sea technologies for autonomous, fast and high-resolution ocean exploration.

Create solutions that advance the autonomy, scale, speed, depths and resolution of ocean exploration
http://oceandiscovery.xprize.org

The key elements of the challenge (ROUND 1)

1. Create an autonomous solution to collect seafloor data in up to 2000m of water
   - People can be involved but they need to stay on the beach
2. All components used for data gathering must fit within a standard 40 ft shipping container
3. Produce a high-resolution bathymetric map of an area of 100 km^2
   - (5 m horizontal and 0.5 m vertical resolution)
4. Produce images of a specified object at a depth of 2000m
5. Image five archeological, biological or geological features
6. Data collection must be completed in 16 hours
7. **Deliver all Data Products to ArcGIS Online Portal within 48 hours of the end of the survey**

GEBCO-NF ALUMNI

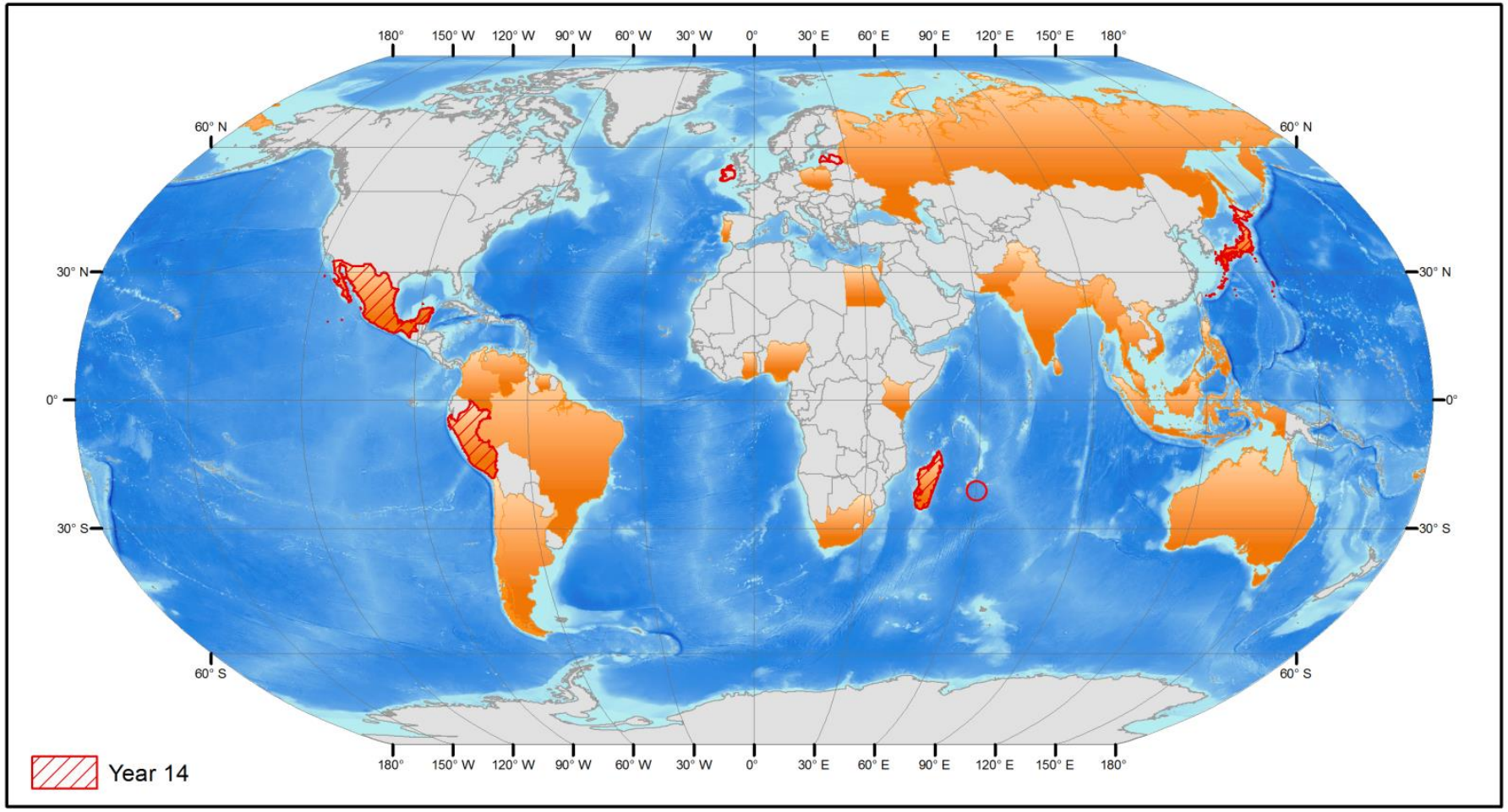
OFG Ocean Floor Geophysics

The GEBCO-NF Alumni Team

The Postgraduate Certificate in Ocean Bathymetry

Designed to train a new generation of scientists and hydrographers in ocean bathymetry

84 scholars from 37 coastal states over last 14 years



OFG Ocean Floor Geophysics

The GEBCO-NF Alumni Team

Team is comprised of people from 10 different coastal states & 8 years of the training program

GEBCO-NF Alumni:

E. Bazhenova, T. Martin, H. Minami, J. Roperez, A. Rosedee, I. Ryzhov, H. Sade, S. Seeboruth, M. Sumiyoshi, N. Tinmouth, R. Wigley, Y. Zarayskaya, K. Zwolak

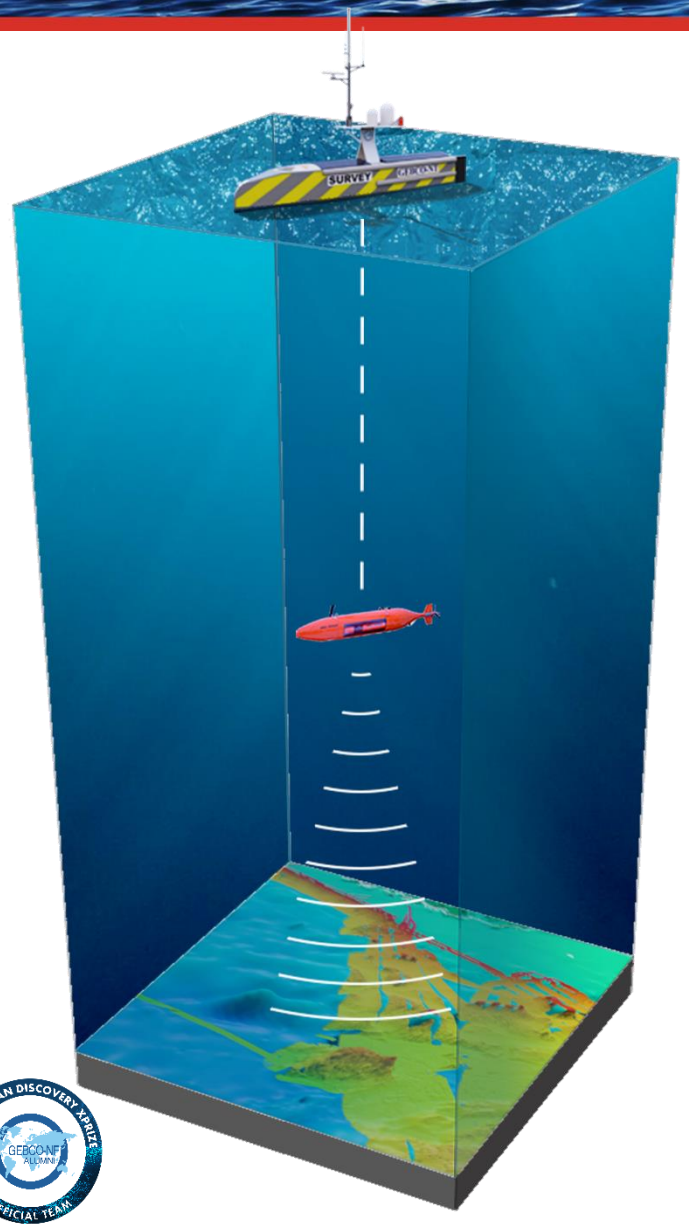
Industry Partners:

- Kongsberg Maritime
- ***Ocean Floor Geophysics***
- University of New Hampshire
- Hushcraft Ltd
- Teledyne CARIS
- OceanAero
- Earth Analytic
- ESRI

Advisors:

R. Anderson, R. Falconer, T. Kearns, B. Simpson

The GEBCO-NF Alumni Team Concept



Integrating existing technology with innovative new ideas

Hushcraft Limited USV SEA-KIT

- USV *Maxlimer* with KM HiPAP 351P-MGC
- Remote and Autonomous operations facilitated by Kongsberg Maritime K-MATE

Kongsberg Maritime HUGIN AUV

- OFG *Chercheur* AUV (rated to 3,000 m)

TELEDYNE CARIS esri

High quality seafloor bathymetry and imagery

- Fusion of EM2040 MBES, HISAS real aperture bathymetry, HISAS synthetic aperture side-scan imagery, and spot-focused synthetic aperture HISAS imagery and bathymetry

SHELL OCEAN DISCOVERY XPRIZE GEBCO-NF ALUMNI OFFICIAL TEAM

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Project Timeline

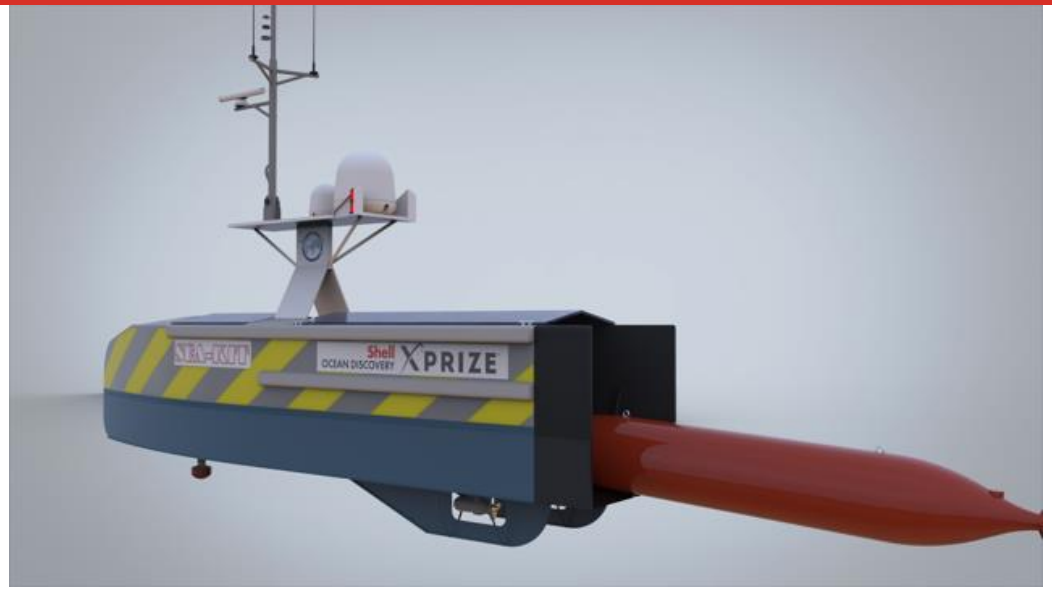
2016

Decision to register a XPRIZE team	June
First discussion with boat designer	Sept
meeting	5 Oct
meeting	3 Nov
Shell Ocean Discovery XPRIZE summit	11-14 Nov
Submission of technical documents	17 Dec
Through to Round 1	7 Feb
	27 Feb
Submission to Nippon Foundation	16 March
Round 1 funded by NF / SPF - $3.25M	22 March
meeting	**6 April ***
meeting	11-14 April
Metal cut for Boat Build	21 April
First installment of funds	22 April
meeting	26 April
meeting	15-16 May
K-MATE contract	2 June
SEA-KIT delivered	28 June
2nd installment of funds ($2,741,500)	30 June
Data Group: 2 week visit	24 July
AUV arrives in Norway	7 Aug
AUV tests with chase boat Storm	14 Aug
AUV & Data Team sea-trials in Norway	19 Aug
OFG contract signed	24 Aug
SEA-KIT christened USV Maxlimer	1 Sept
USV Maxlimer's first wet test	2 Sept
USV Maxlimer in Norway	14 Sept
USV Maxlimer K-Mate development & trials	**18 Sept ***
First USV– AUV trials: Testing HiPAP	27 Sept
First AUV retrieval	3 Oct
Start of final sea trials	3 Nov

2017

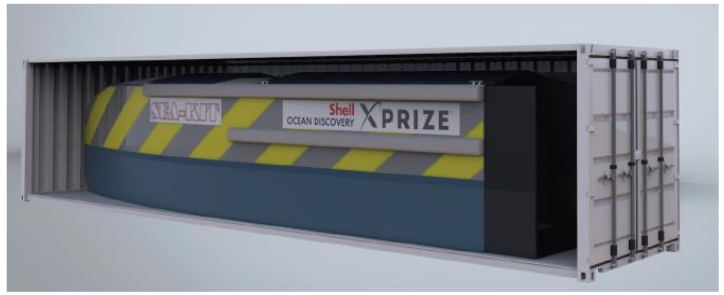
Technology readiness test	20 Nov

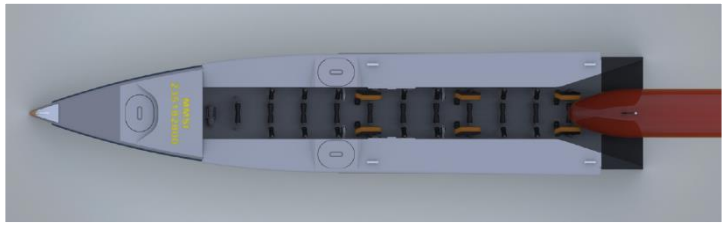
USV SEA-KIT: Uninhabited surface utility craft



HUSHCRAFT

- Designed as mother vessel for AUV
- Exclusion area safety vessel
- Border Safety / Patrol vessel
- Passive Acoustic Monitoring Platform
- Ocean Data Collection Platform
- Communications Repeater Station





- Fits in 40 ft container
- Rapid deployment
- USBL Acoustic positioning

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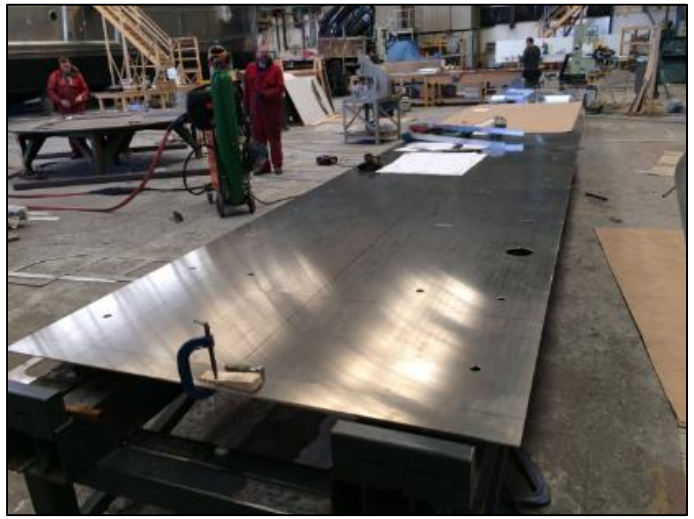
Build of the SEA-KIT USV *Maxlimer*

The start of construction with metal for the hull being cut - 21 April 2017



Delivery of completed hull 28 June 2017

ALUMINIUM MARINE CONSULTANTS

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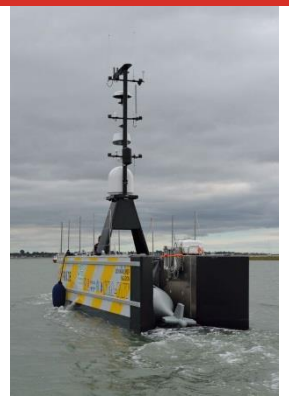
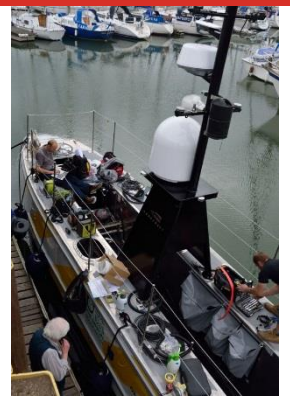
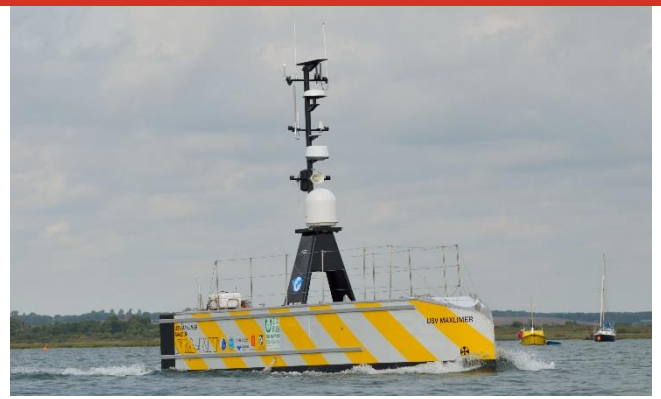
USV SEA-KIT *Maxlimer*


SEA-Kit Dimensions:	• Length: 11.75 m (38.55 ft) • Beam: 2.2 m (7.22 ft) • Transport Height: 2.0 m (6.56 ft) - Operational Height: 7 m (22.97 ft) • Weight: 12,300 kg
Fully redundant propulsion and communication systems	• Propulsion: 2 X 10 kW / 1200 rpm electric directional thrust motors • Communication: Wi-Fi, Radio, Satellite (Iridium and Inmarsat) and Kongsberg Maritime Broadband Radio (<45 km offshore) • CCTV: 2 interior and 6 fore and aft cameras, 1 night-vision camera
Two independent power supplies and power charge	• Fuel 2,000 l • Generator 2 X 18 kW 48 V DC • Main Batteries: 12 V – 12,000 Ah capacity • Auxiliary Batteries: 12 V - 400 Ah

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OFG HUGIN AUV "Chercheur" Specs

General	• Rating: 3,000 m • Length: 5.5 m • Weight in Air: 1,200 kg • Neutrally buoyant
Sensors	• SAS: Kongsberg Maritime HISAS 1032 • MBES: EM2040 200-400 kHz (0.7° x 0.7° beam width) • Sub-Bottom Profiler: EdgeTech DW 106
Navigation Sensors	• IMU: Honeywell HG9900 • Compass: Leica DMC • DVL: Teledyne RDI Workhorse Navigator 300 kHz • Altimeter: Kongsberg Mesotech 675 kHz down looking • Forward Looking Sonar: Imagenex MBES sonar • CTD: SAIV CTD • USBL: HiPAP Transponder • Depth Sensor: DigiQuartz 8CB4000 • GPS Receiver: Novatel
Power	• 3 batteries (24 kWh) • Endurance estimates: 37 hrs @ 3 kts & 27 hrs @ 4kts

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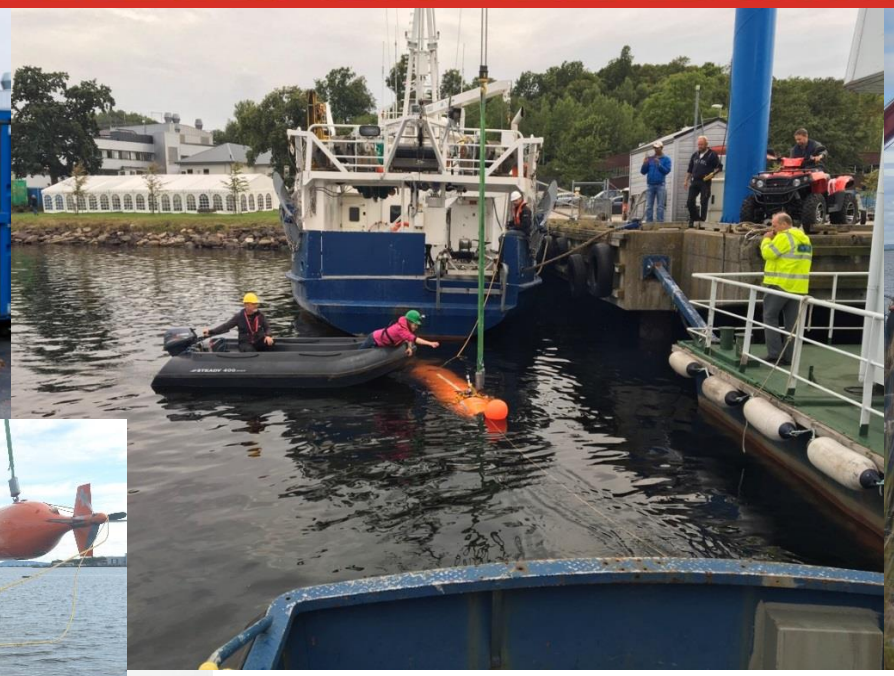
AUV sea-trials: max coverage and resolution



Data group and OFG operators acquired bathymetric and side-scan data, as well as sub-bottom profiles during 12 dives over 4 weeks.

- DVL calibrations
- Patch tests separately for EM2040 and HISAS 1032
- Testing different operational modes
- Data collection different altitudes and speeds

Developments by Data Team

Focus on Automated Data Flow

- Worked with Teledyne CARIS to understand:
  1. AUV work flow in processing HISAS data & EM2040 data
  2. Developed automated work flow based on CARIS processing tools
  3. Fine-tuned and further developed workflow during sea trials at Kongsberg Maritime
- CARIS output is imported into ArcGIS:
  1. Analysis of bathymetric data (contours, slope etc.)
  2. Publish image services in ArcGIS online
  3. Integrate collection of bathymetric data available from internet sources

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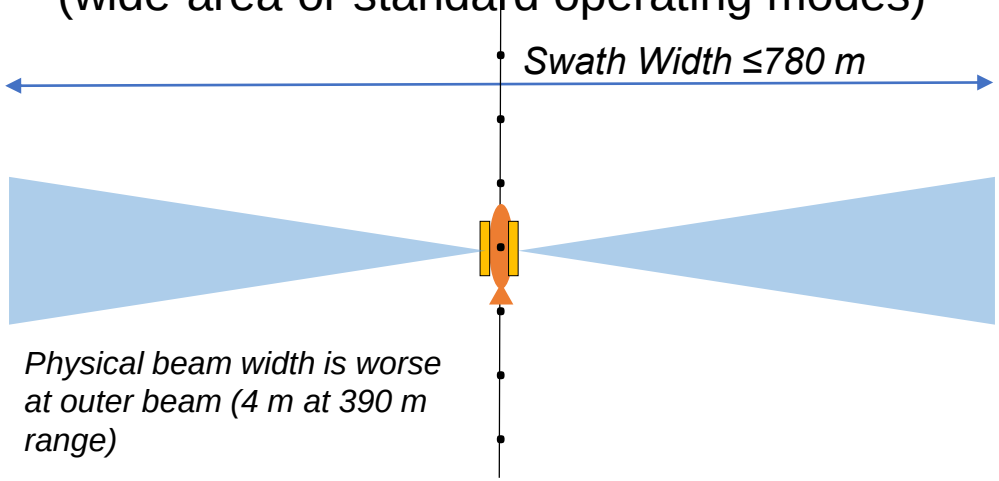
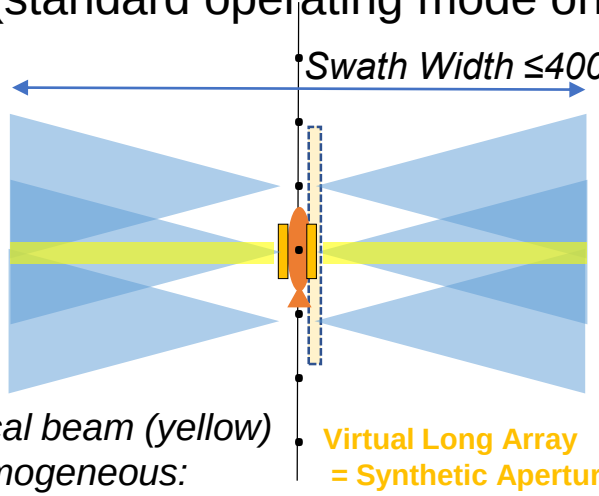
HISAS 1032 Data Types

Real-Aperture Method
(wide-area or standard operating modes)



Physical beam width is worse at outer beam (4 m at 390 m range)

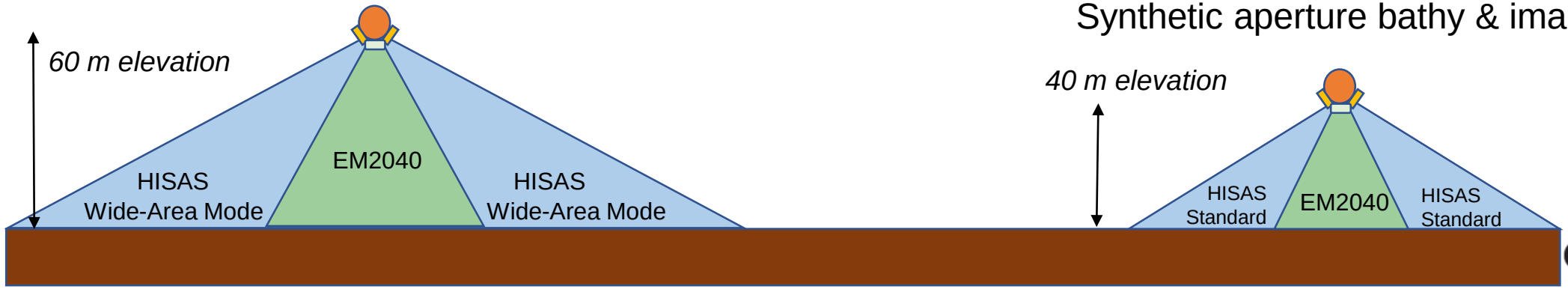
Synthetic-Aperture (SAS) Method
(standard operating mode only)



SAS Physical beam (yellow) width is homogeneous: ~4 cm resolution

Virtual Long Array = Synthetic Aperture Array

RAPID BATHY COLLECTION:
Wide-area operating mode
Real aperture bathy **only**



SEAFLOOR FEATURE DETECTION:
Standard operating mode
Real aperture bathy
Synthetic aperture bathy & imagery

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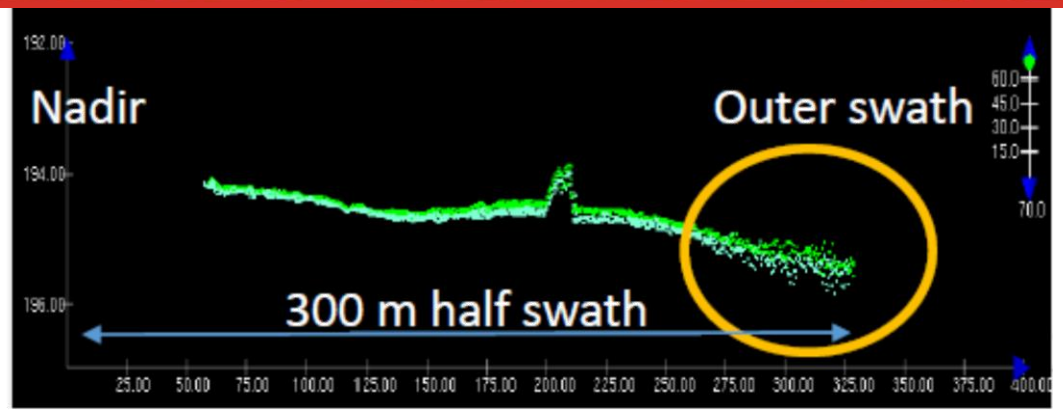
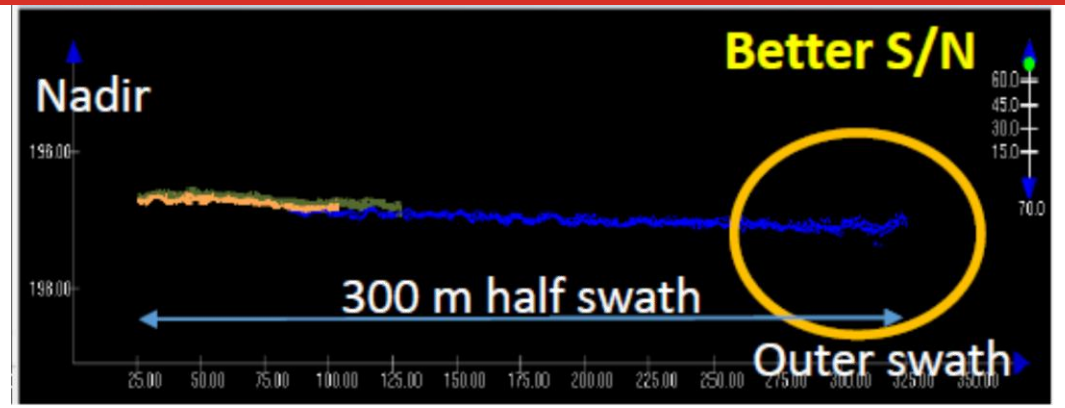
HISAS 1032 Data Types



Wide Area Mode @ 30 m AUV altitude



Wide Area Mode @ 60 m AUV altitude

Wide Area Operating Mode

- Time-triggered pings
- Swath width: ± 375 m (750 m)
- Side scan image: = ~ 1 - 2 m
- Bathymetry Resolution: = ~2 m
- Speed: = 4.3 knots (2.2 m/s)
- **Altitude 60 m**

Standard HISAS Mode

- Distance-triggered pings
- Swath width: ± 200 m
- Side scan image: ~ 4 cm
- HISAS Bathymetry Resolution: 1 m
- HISAS Spot Bathymetry Resolution: 10 cm
- Speed: 3.9 knots (2.0 m/s)

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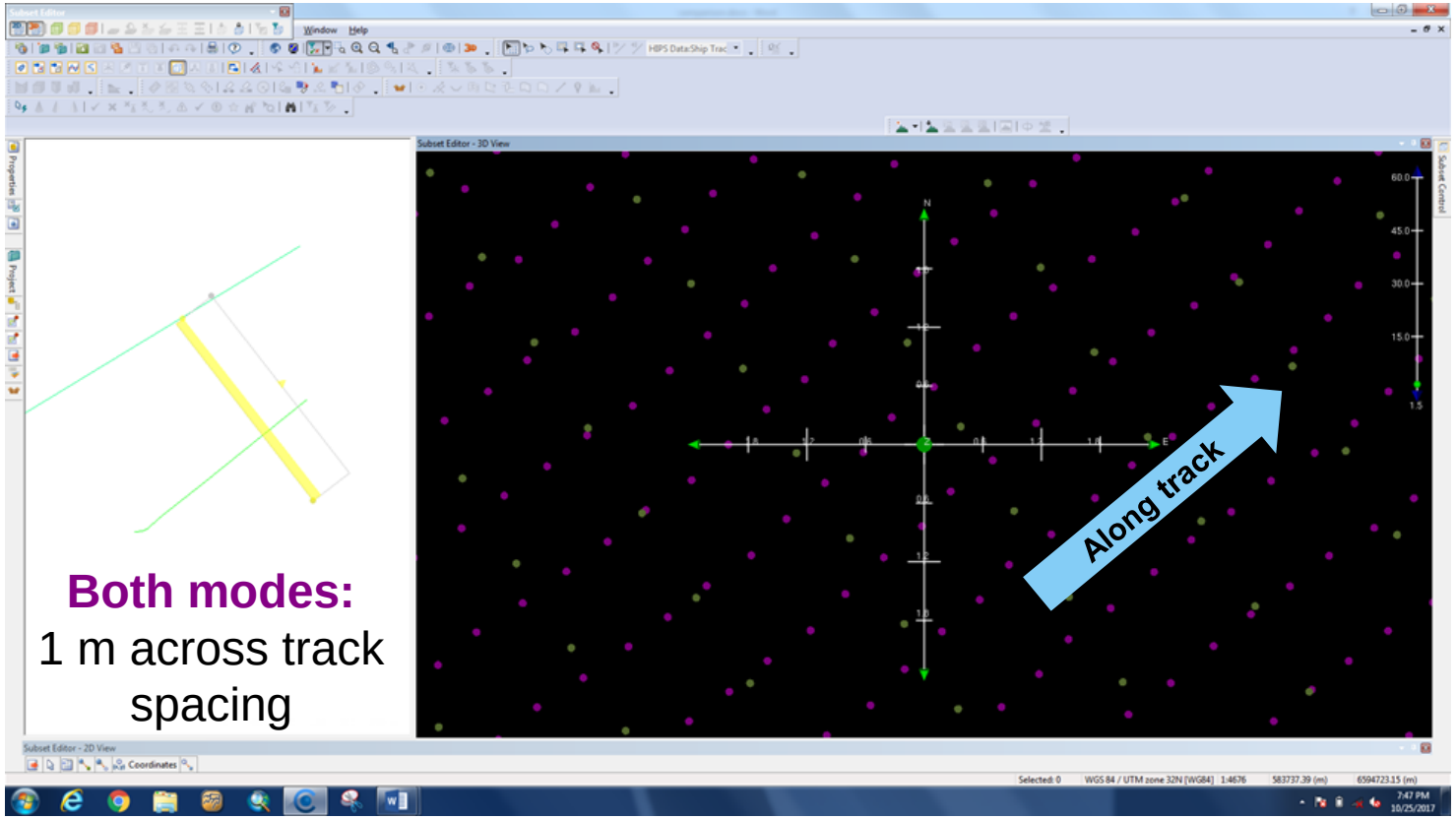
Statistics for Different operating modes

Standard operating mode
Data Density
0.5 m along track spacing

Wide-area operating mode
Data Density
~1.5 m along track spacing



Both modes:
1 m across track spacing

Coverage Estimates

- Standard operating mode: 2.7 km^2/hour
- Wide-area operating mode: 6.2 km^2/hour

This includes coverage of the nadir gap by the EM2040

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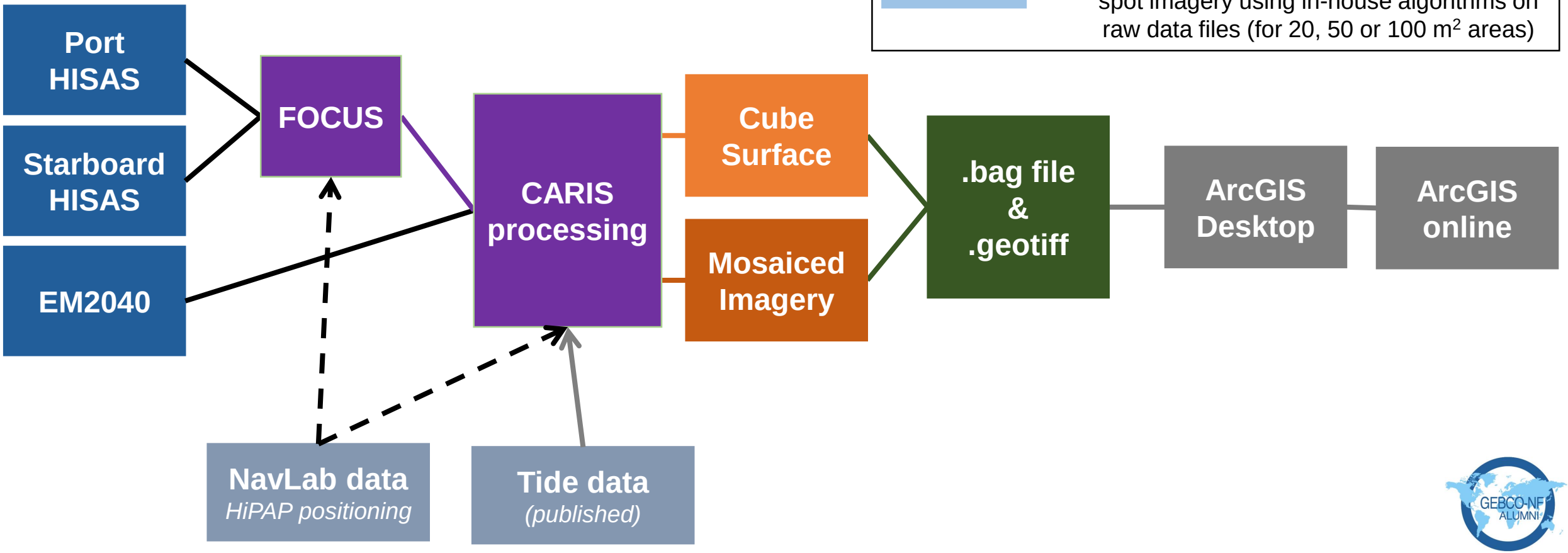
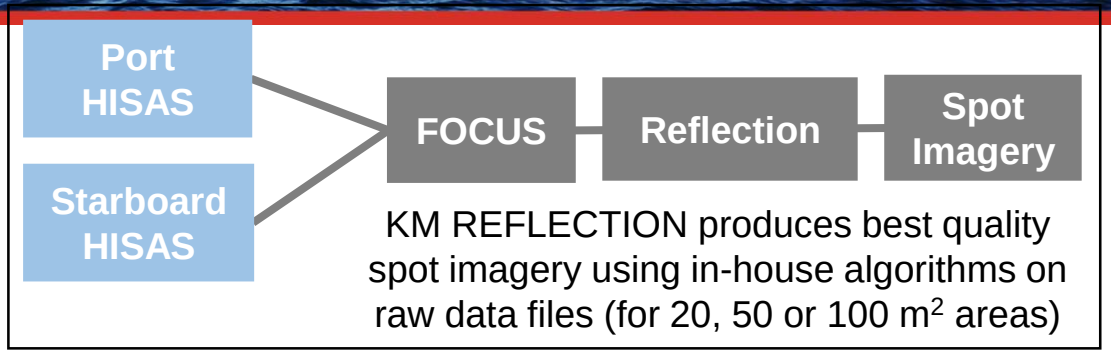
Simplified Data Work Flow

Kongsberg Proprietary software FOCUS takes raw HISAS data and produces .all & .xtf for input into CARIS





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Resolution of Collected Data

Sonar	Data	Resolution
EM2040	Bathymetry & Backscatter	<1 m
HISAS (Standard)	Bathymetry	1 m
HISAS (Standard)	Imagery	<10 cm
HISAS (Wide-area)	Bathymetry	2 m
HISAS (Wide-area)	Imagery	1 m
HISAS (Spot)	Spot bathymetry	2 cm
HISAS (Spot)	Spot Imagery	2 cm

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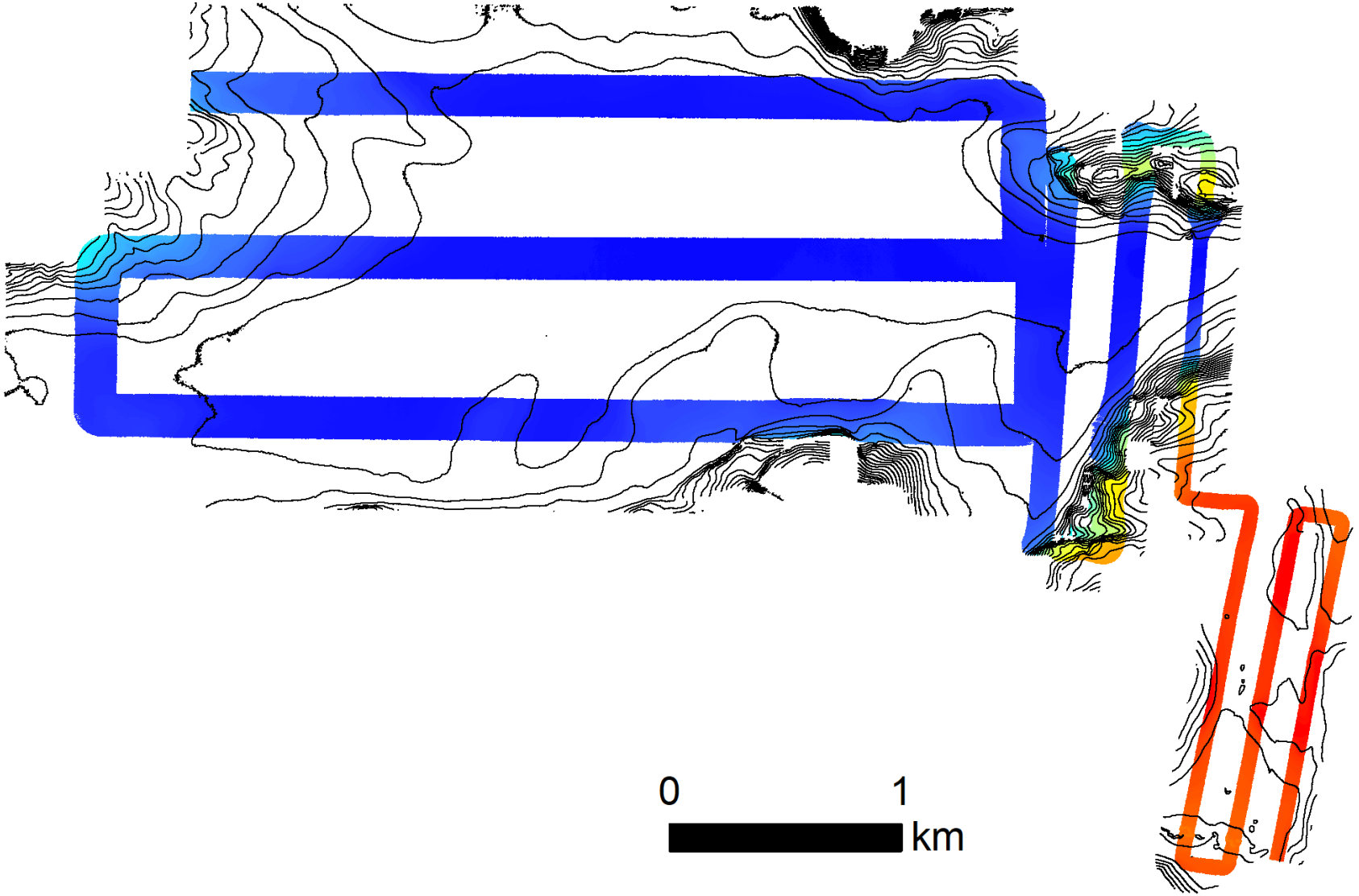
EM2040 Surface (1 m grid)



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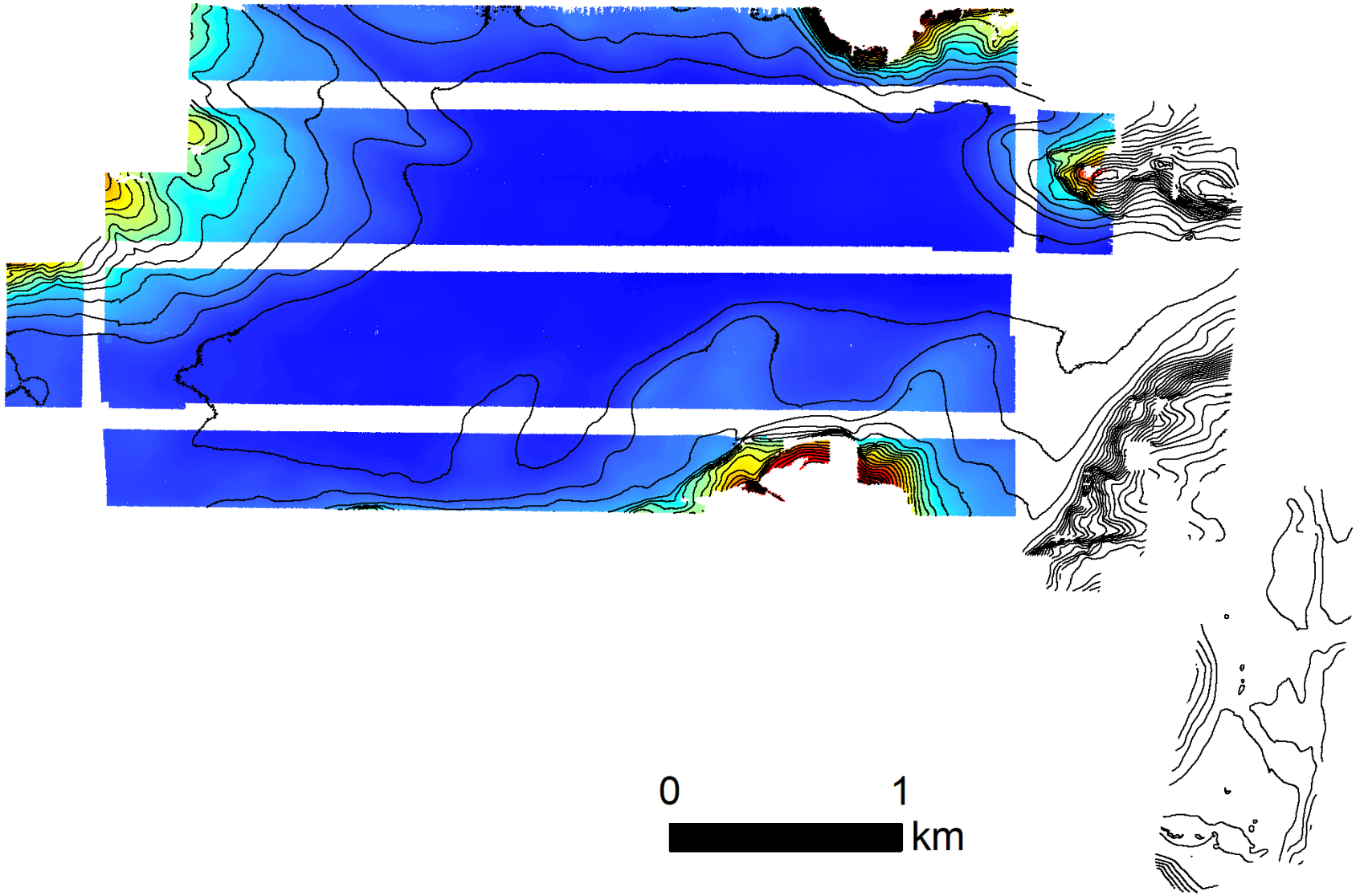
HISAS Wide Area Surface (2 m grid)



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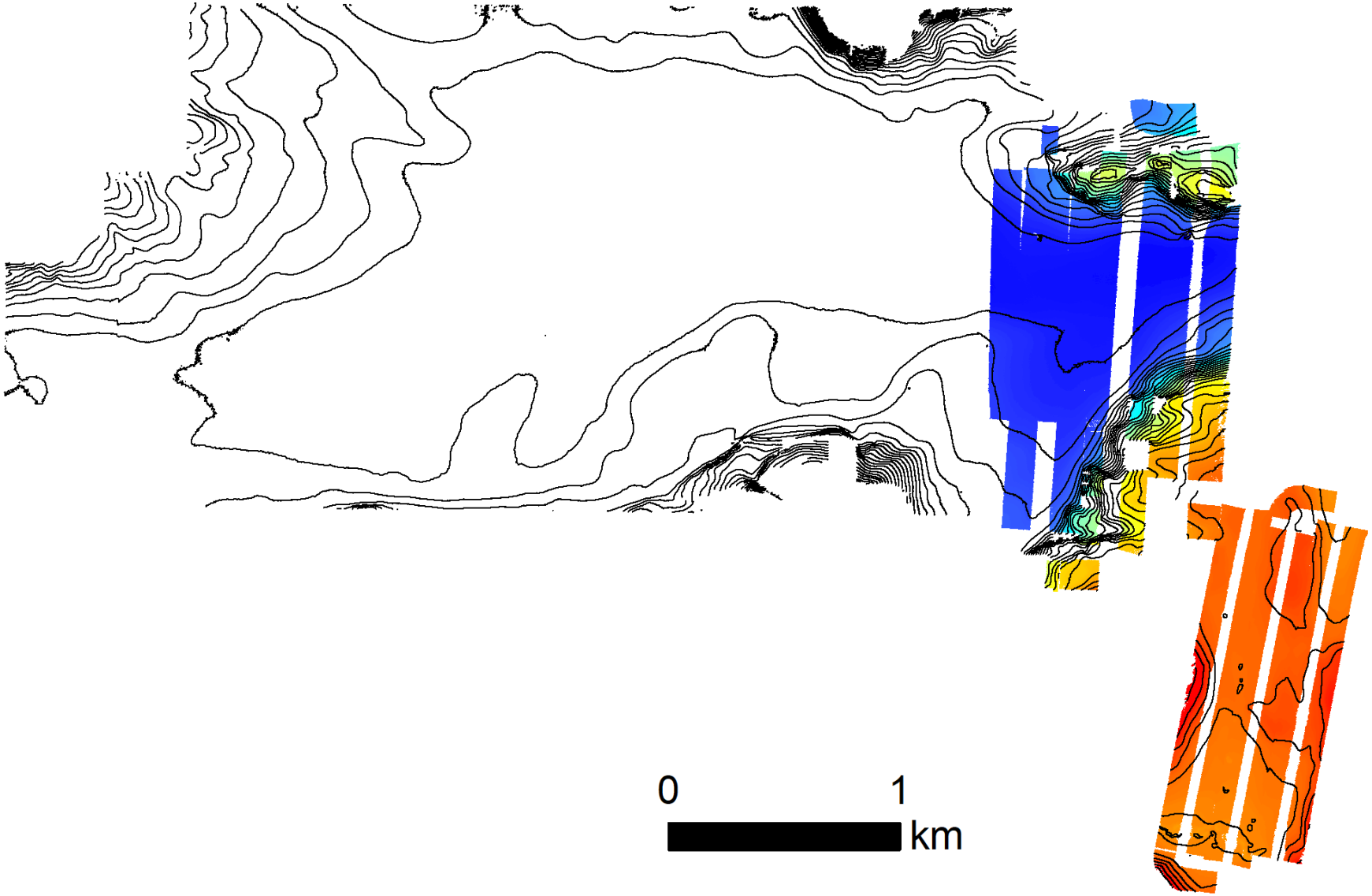
HISAS Standard Surface (1 m grid)



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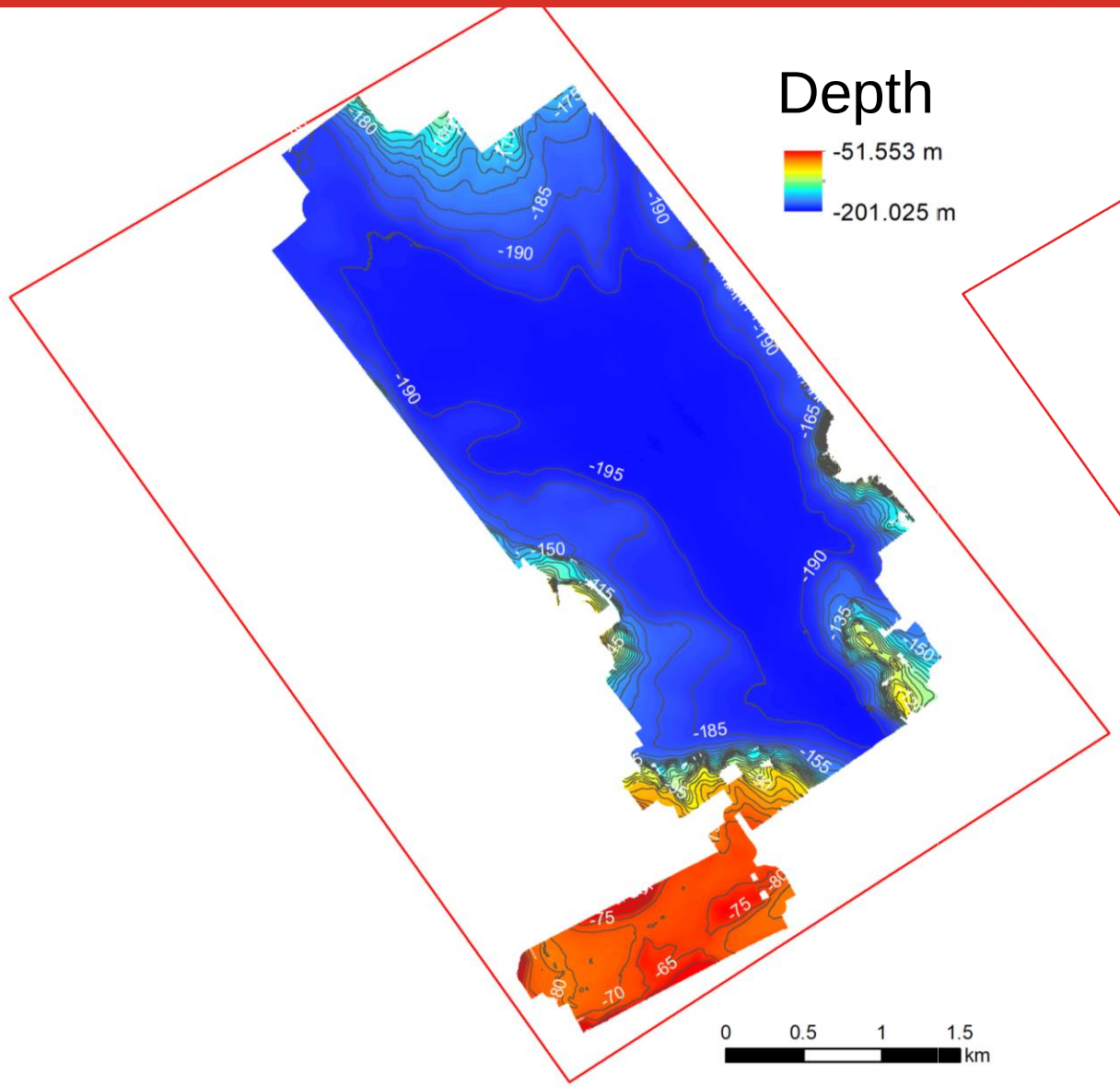
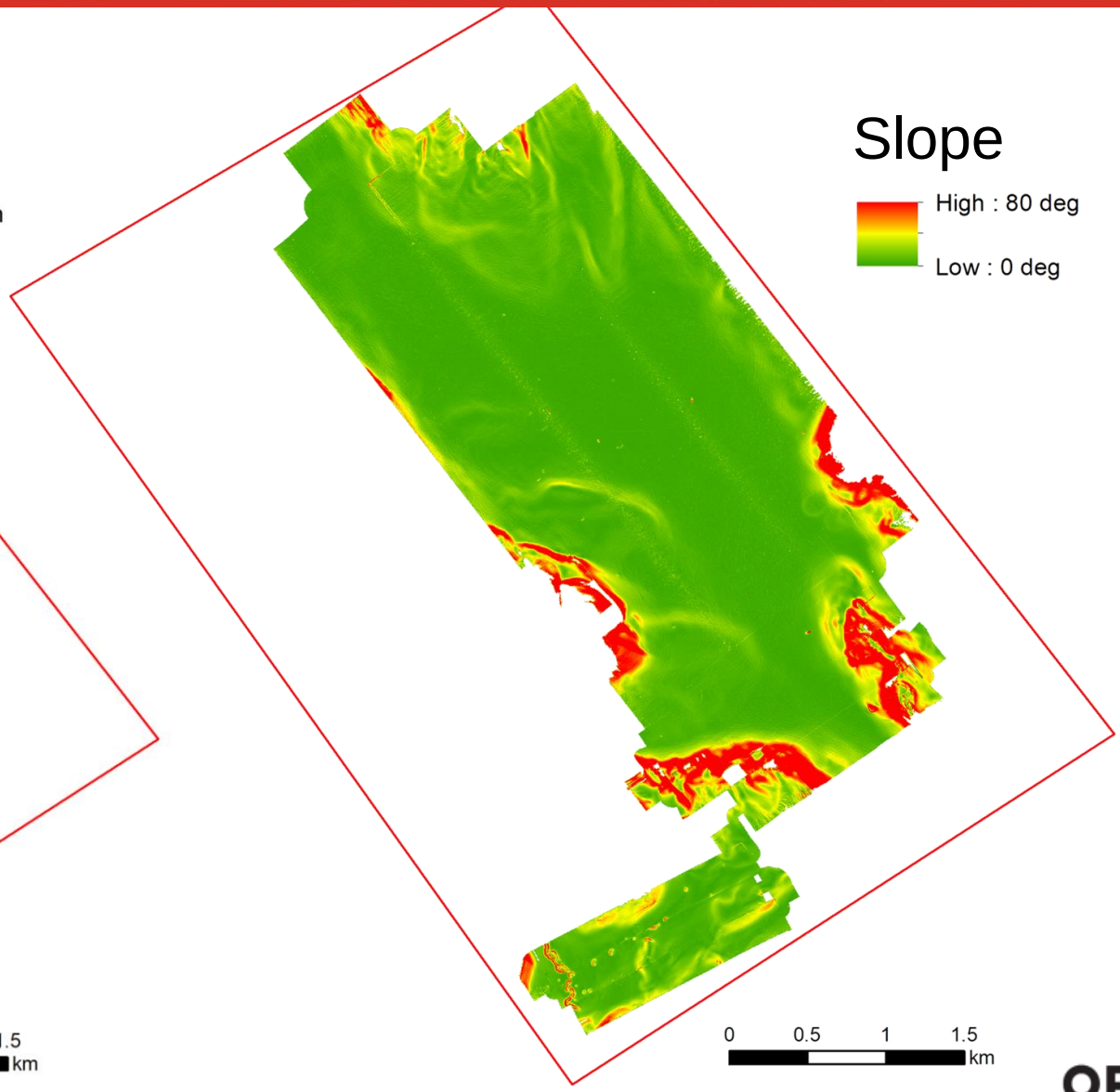
Final Bathymetric Surface (2 m grid)





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Backscatter EM2040 (50 cm grid)

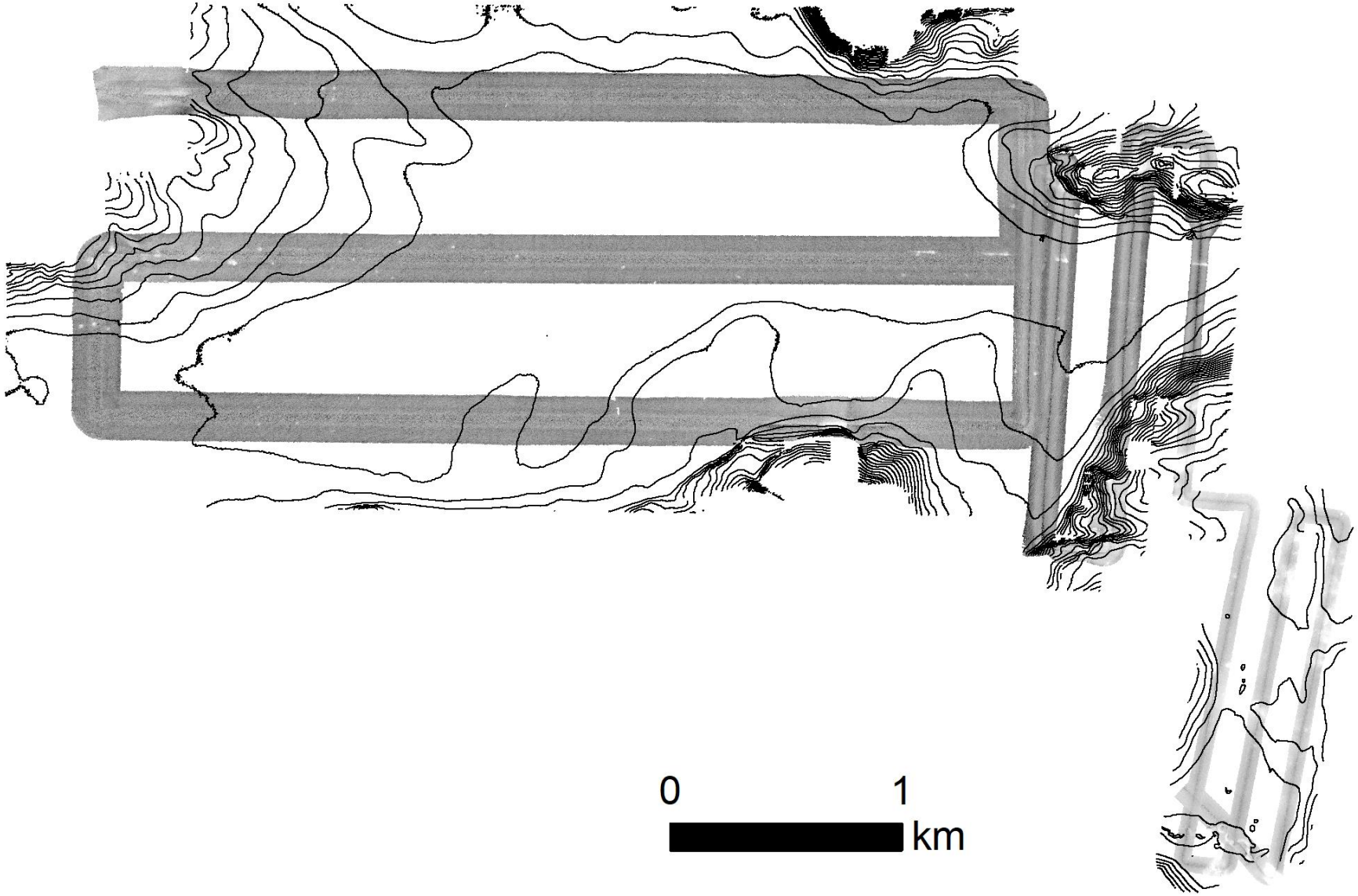

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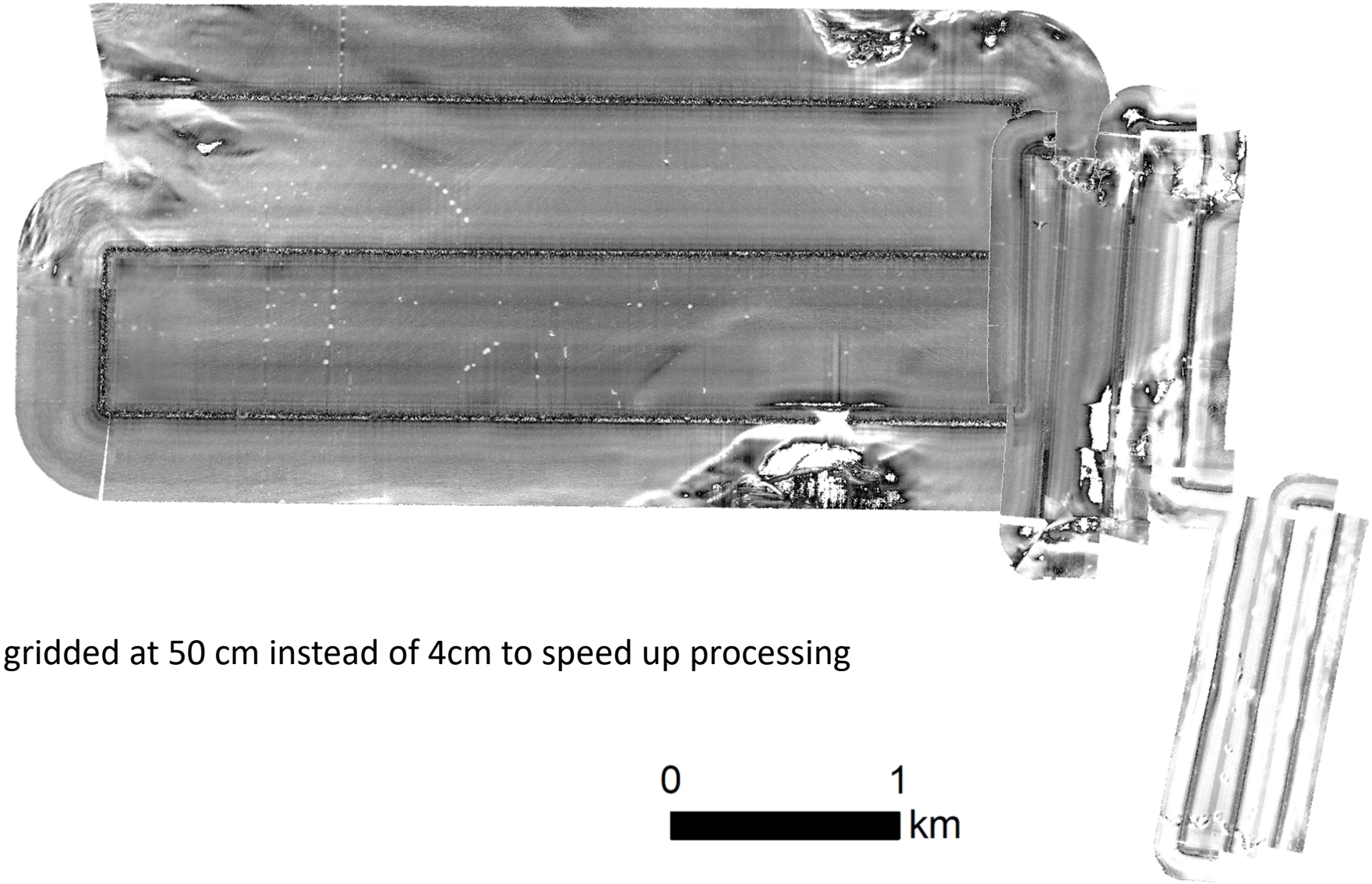
Image: SSS WA (1 m) + SSS STD (50 cm)



** SAS Imagery gridded at 50 cm instead of 4cm to speed up processing

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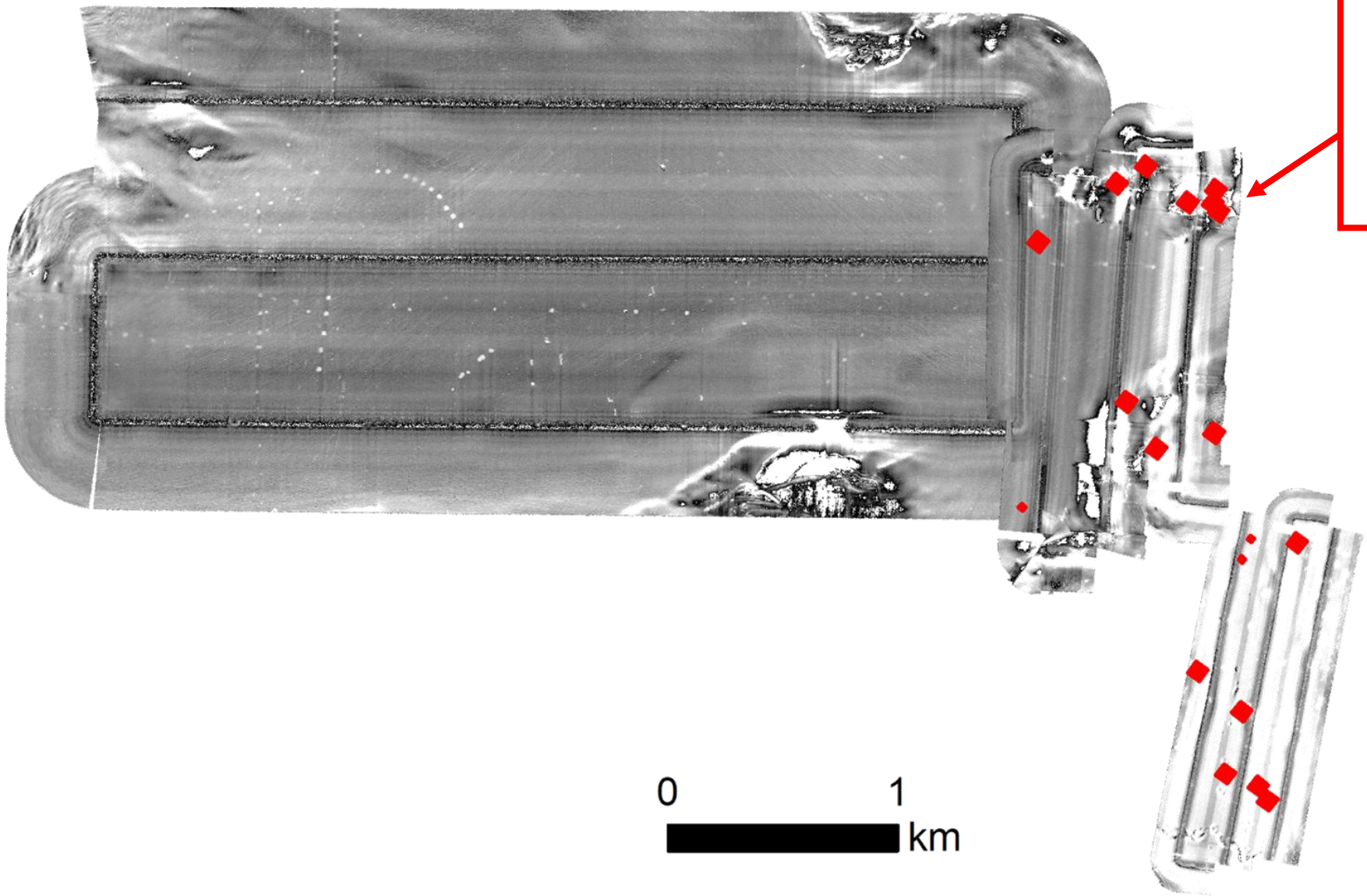
Footprints for SAS Spot Imagery



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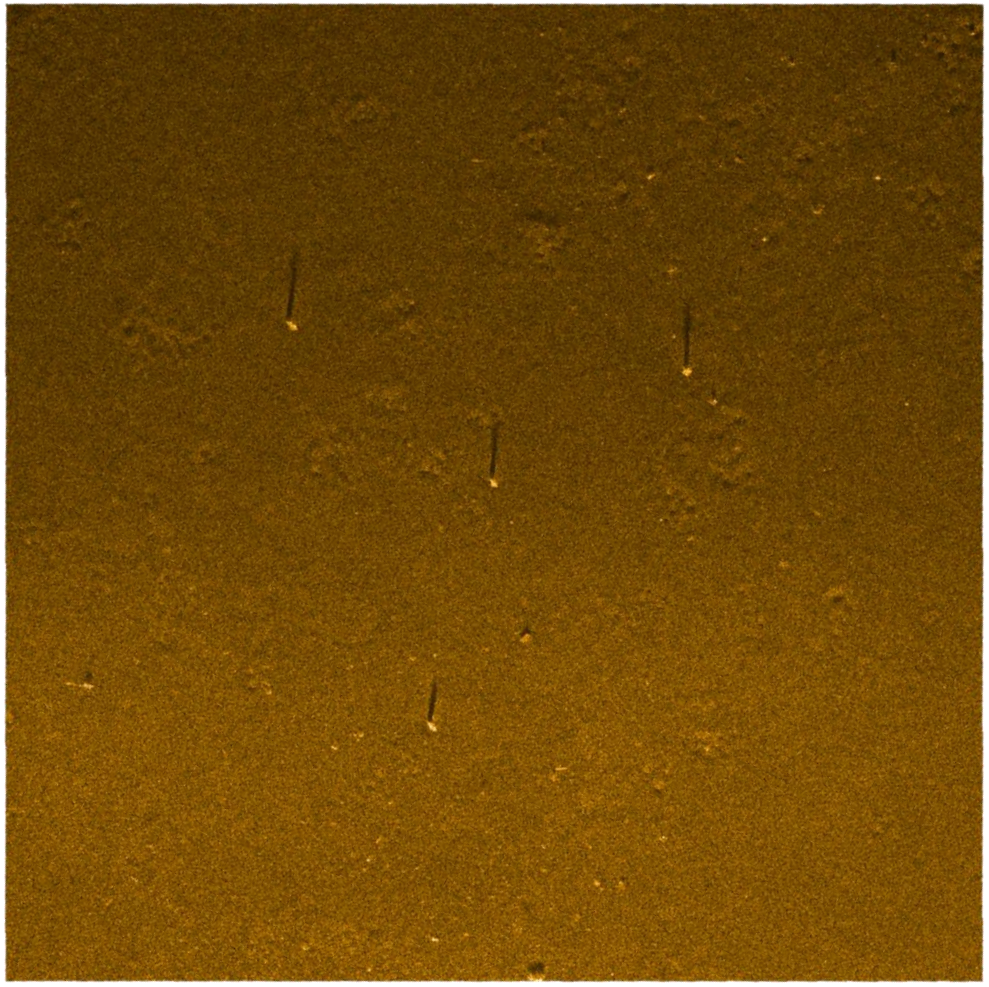
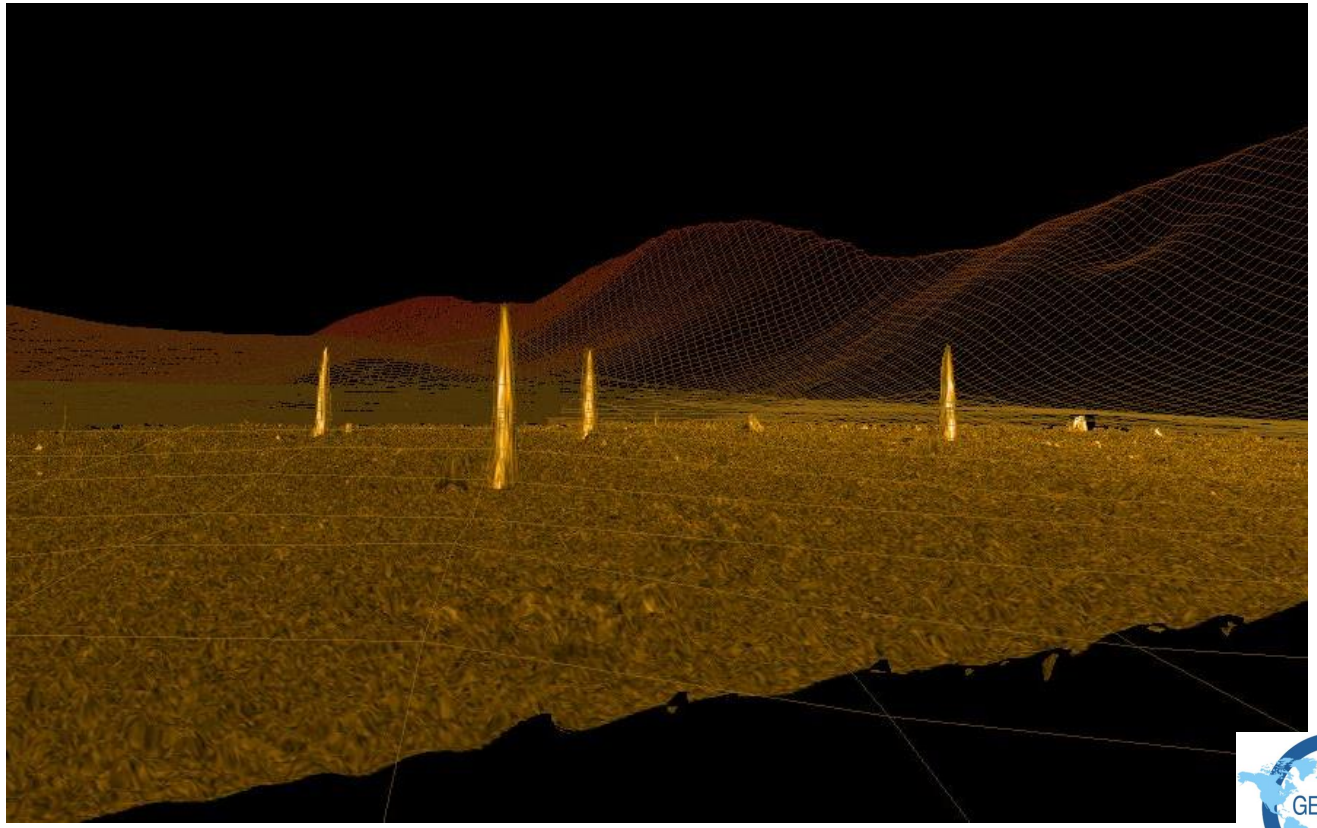
SAS Spot Imagery

SAS Spot Imagery: ~ 2 cm



3D drape (6x vertical exaggeration)
Height = 0.5 m
Diameter = 0.2 m



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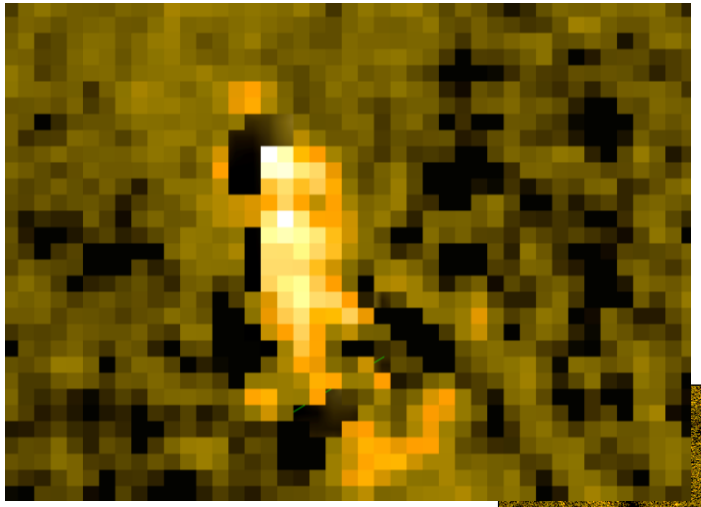
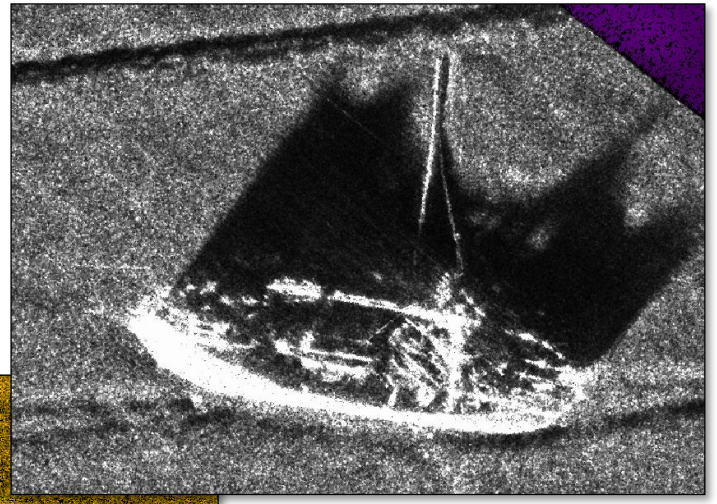
SAS Spot Imagery Resolution Comparison



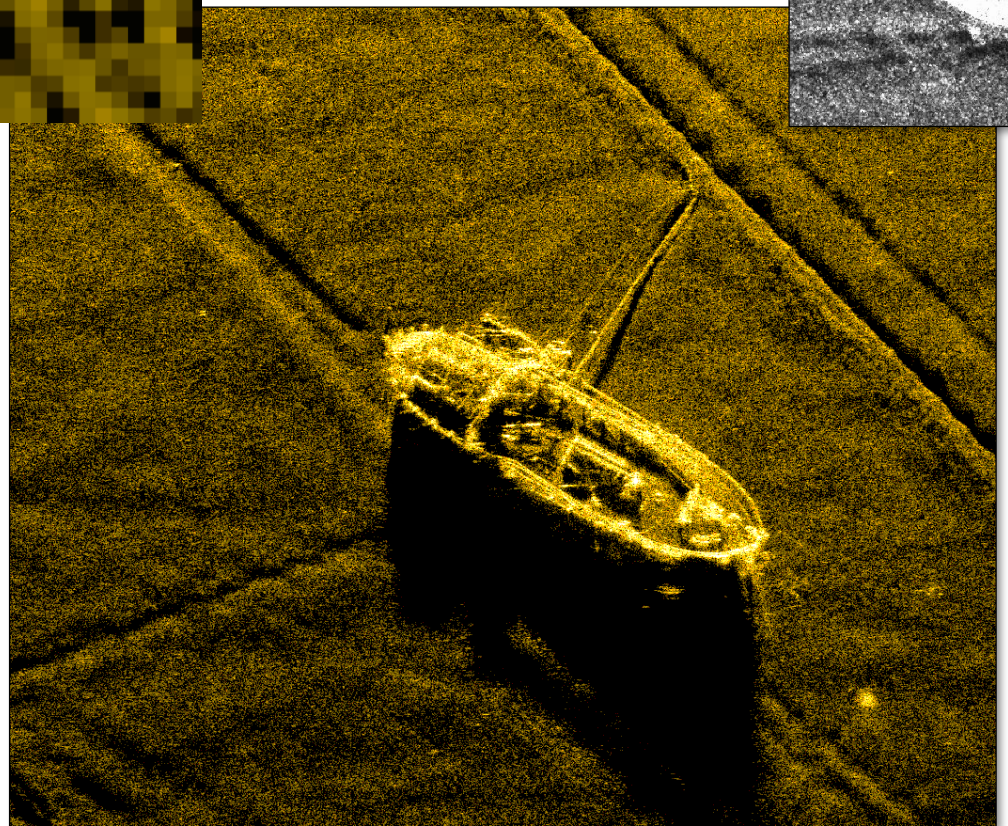
EM2040 backscatter

~1 m



SAS Imagery

~5 cm



SAS Spot Imagery

~2 cm

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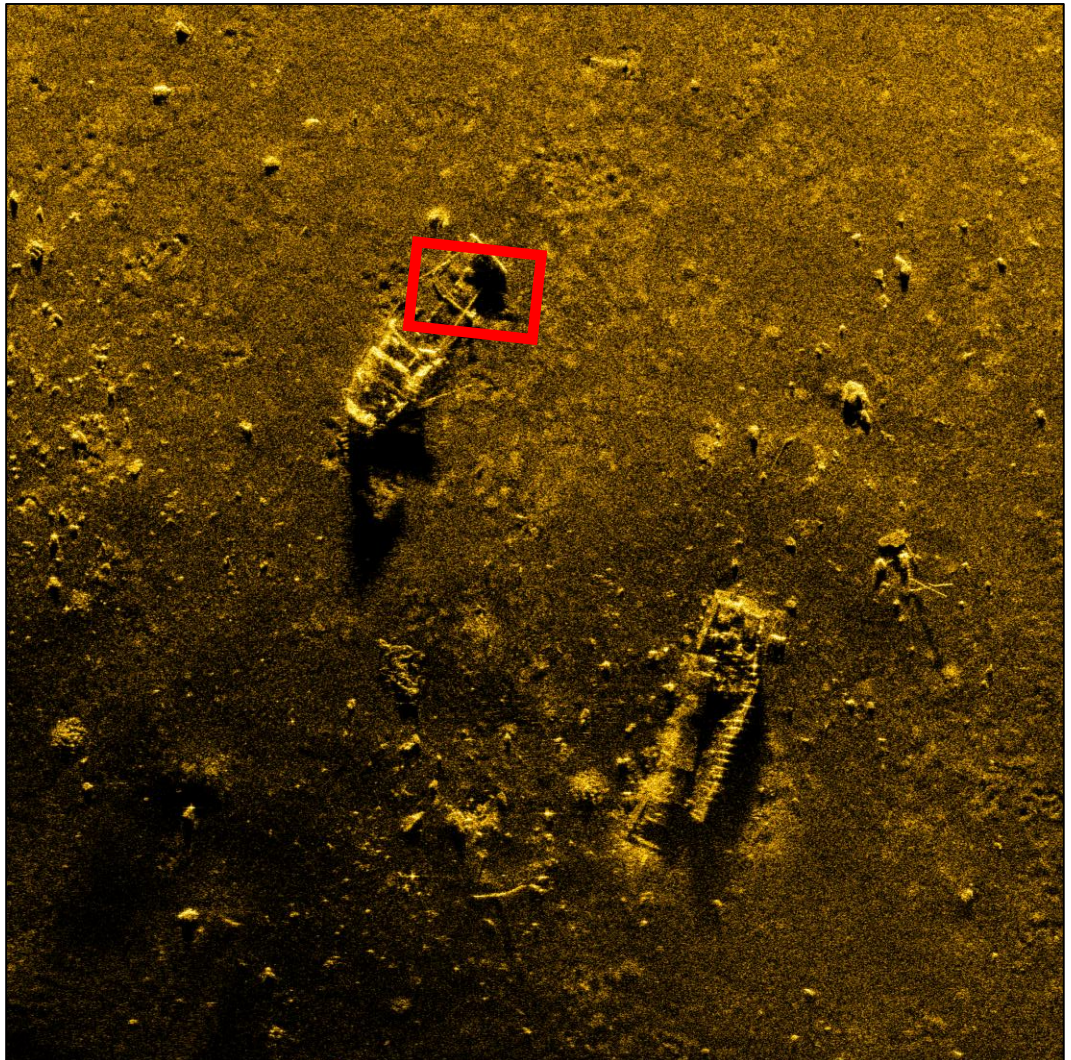
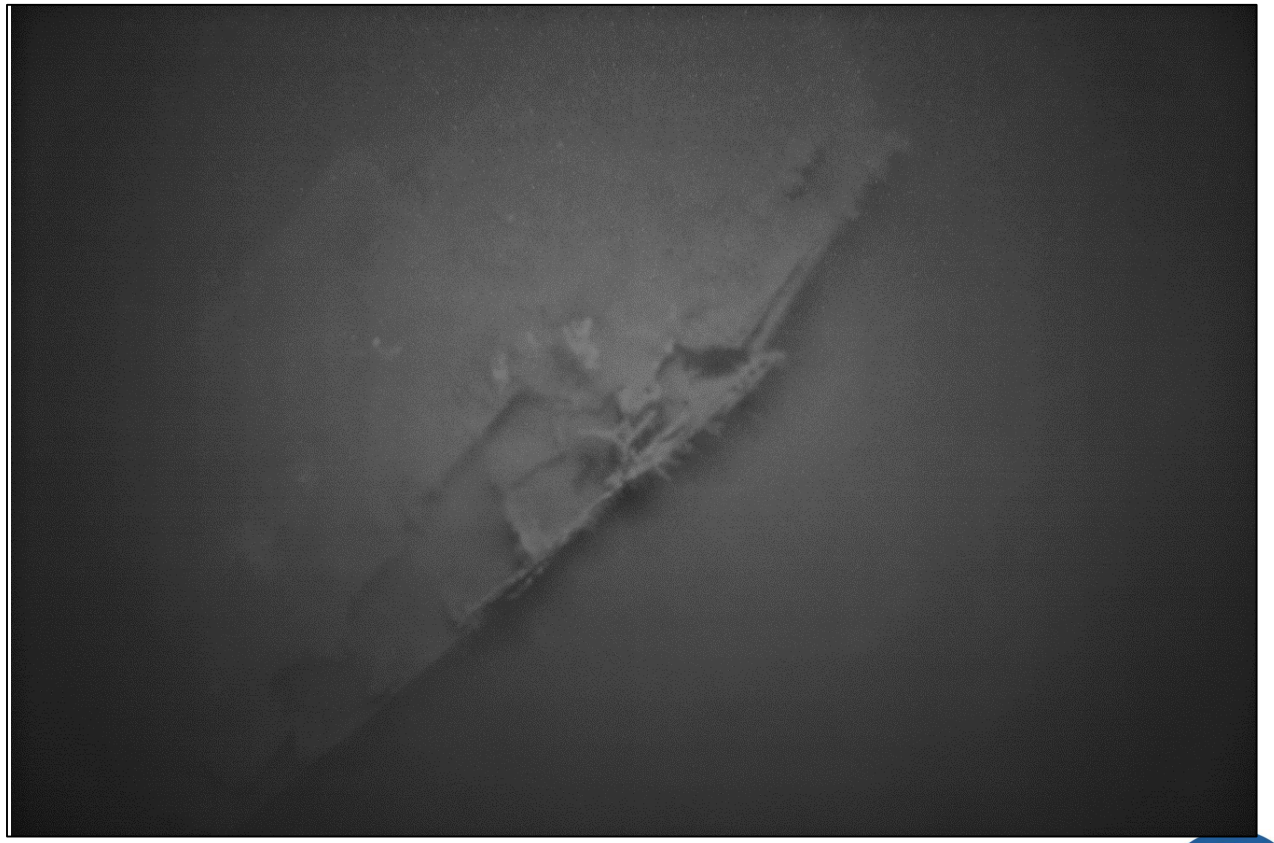
SAS Spot Imagery- Camera Comparison

SAS Spot Imagery
50 m x 50 m @ ~2 cm resolution



Camera image
5 m x 3.3 m @ 0.37 cm resolution



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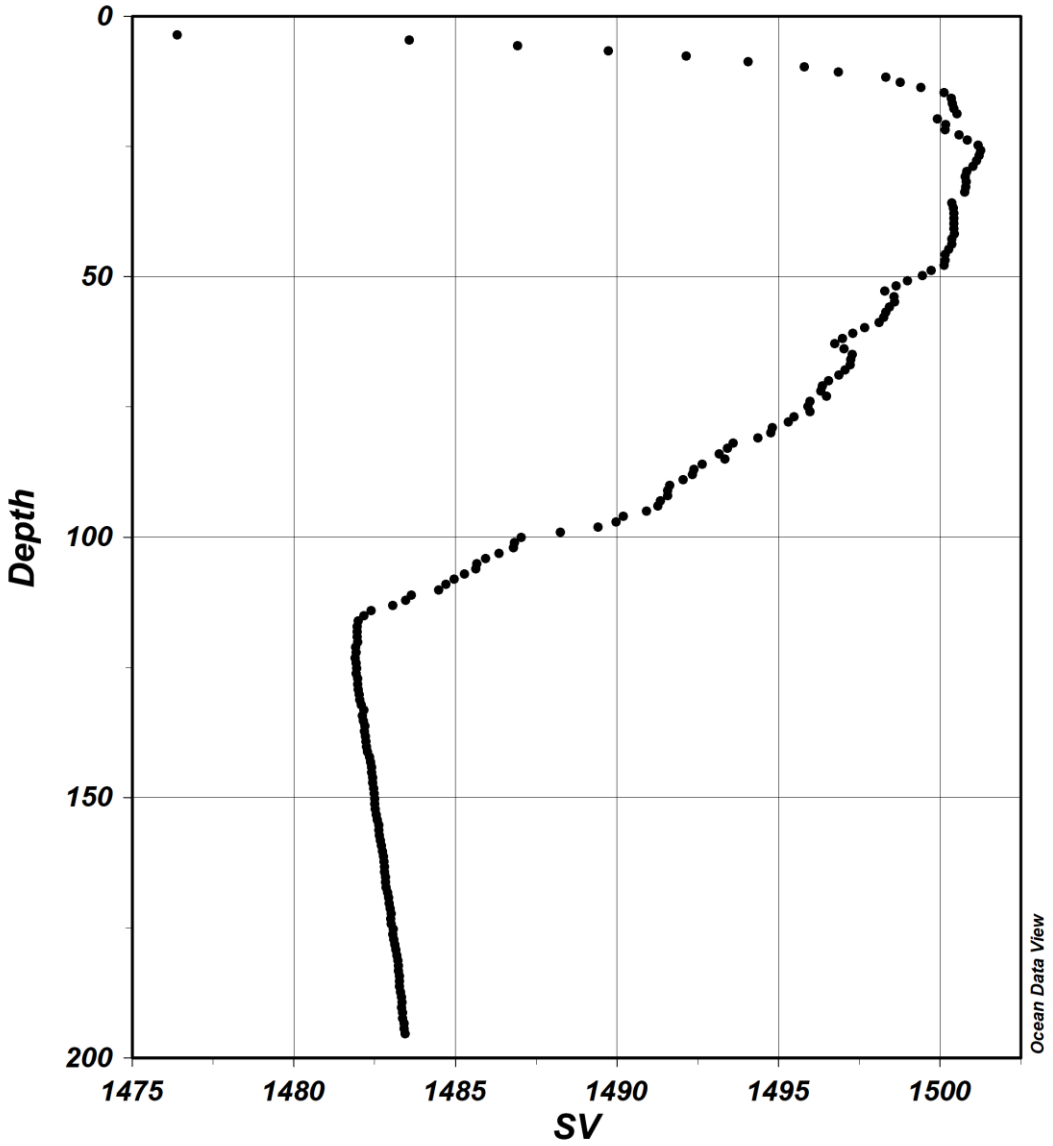
Still To Work on: Sound Velocity Corrections



- HISAS is using an Internally Generated Adaptive Sound Velocity Profile
- Not possible to apply a different SV profile during the HISAS data post-processing
- This is an issue in shallow areas (halocline, fresh-water inflow), especially for the outer beams
- Mission Planning around SV casts is **KEY**

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OFG Ocean Floor Geophysics

Acknowledgements

This work was done in partnership with the Nippon Foundation and would not have been possible without the support of the Sasakawa Peace Foundation.

THE NIPPON FOUNDATION

Promoting international exchange, international cooperation, international understanding.

THE SASAKAWA PEACE FOUNDATION

The team would also like to thank the 55 individuals from 13 countries who all dedicated themselves to ensuring the success of this project.

GEBCO-NF ALUMNI

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OFG Company History

- **OFG was formed in 2007 to develop and deploy advanced sensors for use in seafloor mineral exploration and has served clients worldwide**
- **Business lines: (a) deep water AUV operations and technical support, and (b) development of new marine geophysical systems (primarily EM and magnetic)**

2007: First commercial mapping of SMS deposit by OFG patented EM system

2008: Agreement with Canadian Microgravity for AUV borne gravity surveys, ROV borne EM Mark II and magnetometers deployed in commercial survey

2009: EM Mark III and magnetometers deployed in commercial SMS survey

2010 – Present:
- Continued commercial ROV borne survey and exploration services
- Operations support, geophysics and hydrography services

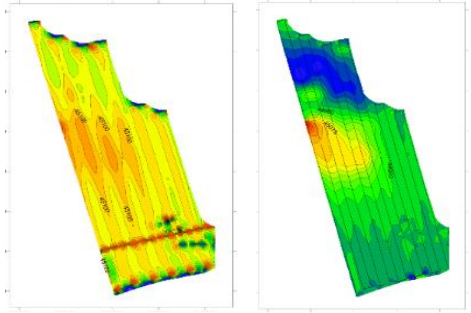
2012 – Present:
- AUV Operations
- Geophysical, geochemical and hydrography services.

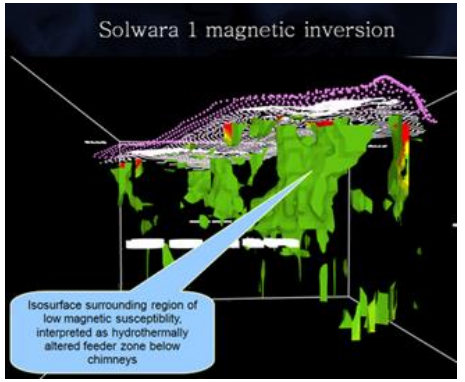
2014 – Present:
- Vulcan CSEM towed array
- 3D Vertical Cable Seismic (VCS)
- Towed Array Marine Induced Polarization System
- Improved AUV Magnetics

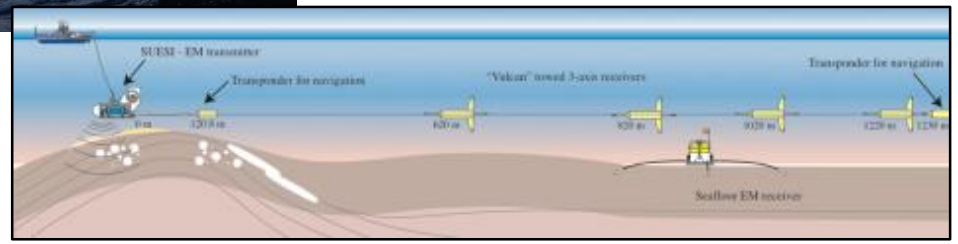
2015 – Present:
- AUV with Synthetic Aperture Sonar and pipeline inspection technology
- Release of OFG Self-Compensating Magnetometer for AUVs
- AUV CSEM
- Production and sale of low impedance Ag/AgCl marine electrodes

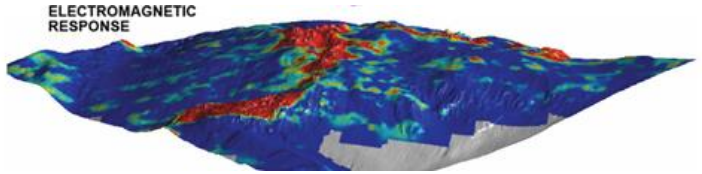
OFG Capabilities Overview

- Deep water **AUV** operations and data acquisition **for infrastructure inspection** and **survey**
- **EM and Magnetic 2D and 3D Inversions**, **Forward Modelling**, Integration and Visualization of subsea data
- **Magnetic** surveys (3 axis or total field) and 3D inversion post processing (ROV/AUV borne)
    - Patents pending on Self Compensating Magnetometer (SCM) for AUV deployment
- **CSEM** seafloor receivers, towed array and AUV deployed resistivity mapping and inversion post processing
- Electromagnetic mapping of SMS deposits with the **OFG EM Mark III**



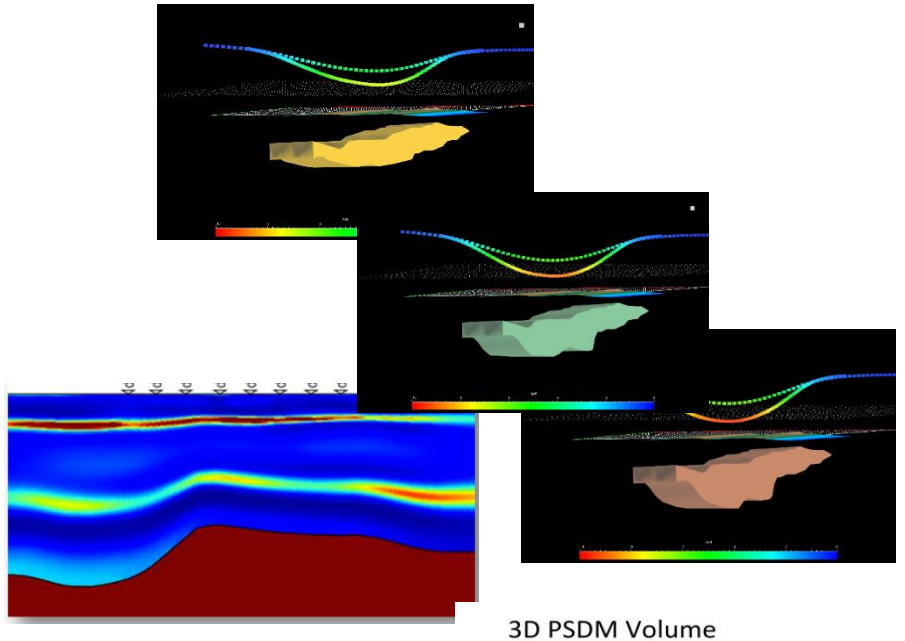


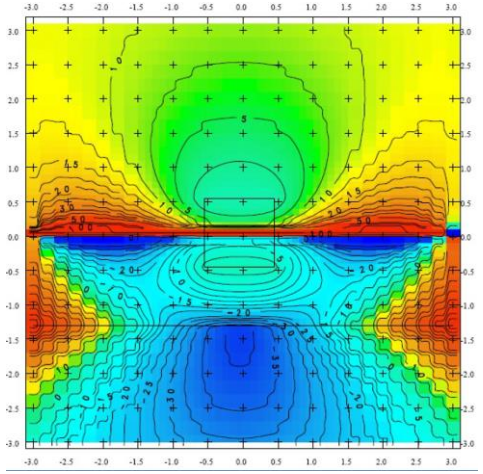




OFG Capabilities Overview

- **Geo-chemical** prospecting and mapping surveys: UV fluorimeters, turbidity, dissolved gases, pH, eH-ORP (ROV/AUV borne)
- Marine Induced Polarization System (**MIPS**) towed array
- **Gravity** and inversion post processing (ROV/AUV borne)
- Vertical Cable Seismic (**VCS**) mapping and 2D and 3D processing





3D PSDM Volume