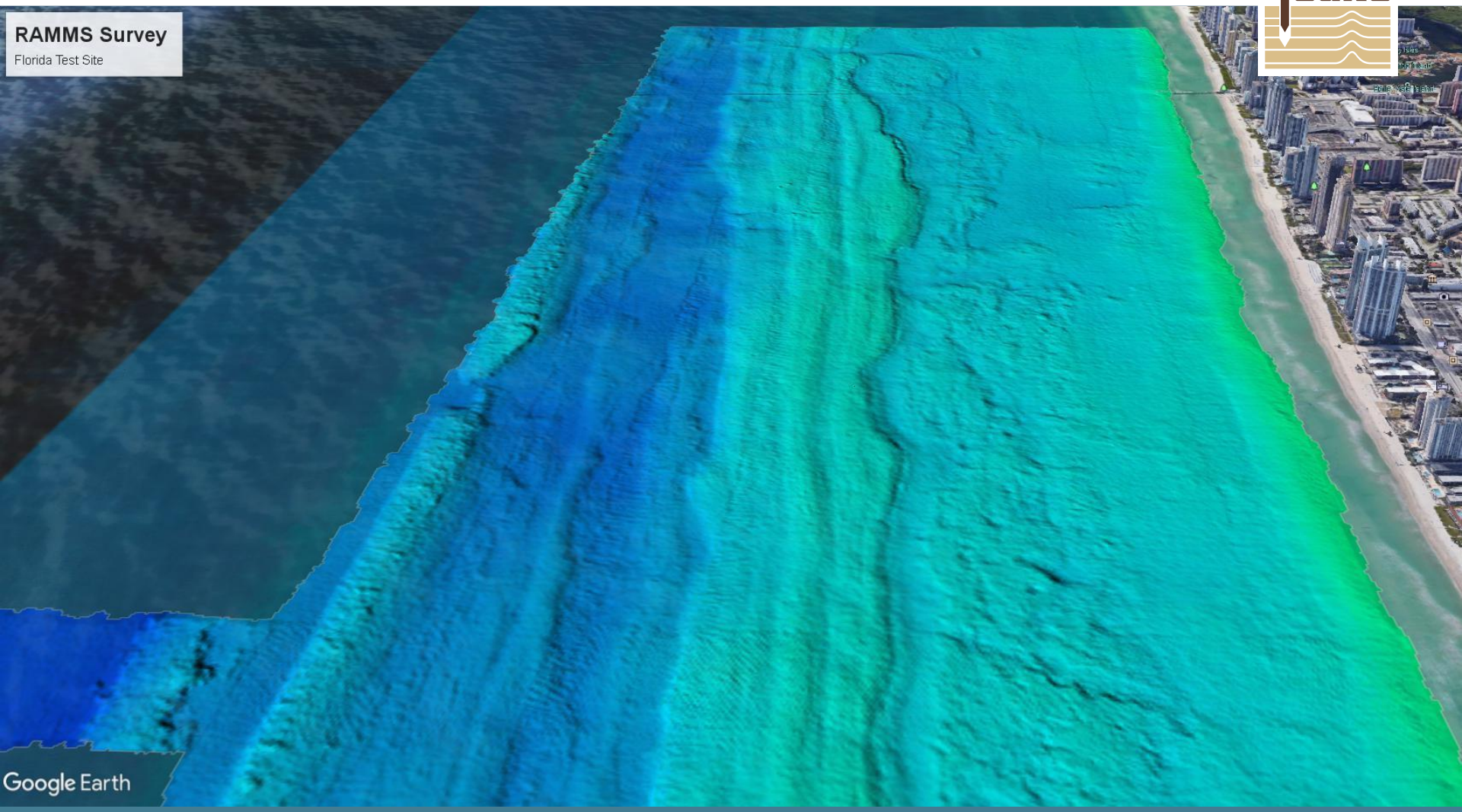
We are Fugro

proud to provide
geo-intelligence
and asset integrity
solutions to contribute
to a liveable world.

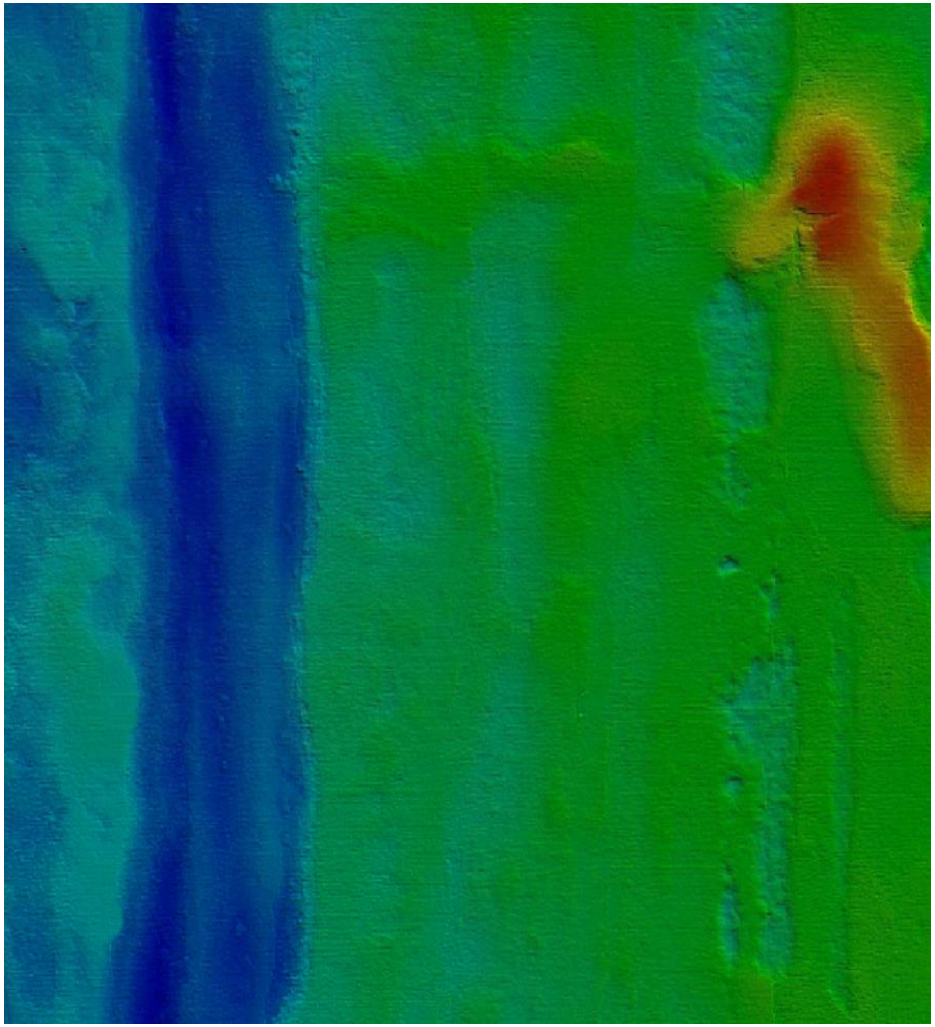


Introduction to Fugro RAMMS (Rapid Airborne Multibeam Mapping System)

A brand new concept in Airborne Lidar Bathymetry (ALB)

Introduction

- Challenges of Current Technology to meet Client Expectations
- Status quo vs Ideal solution
- What is RAMMS?
- Design Differentiation
- Key Performance Characteristics
- Key Performance Differentiators
- Operational and Economic Advantages



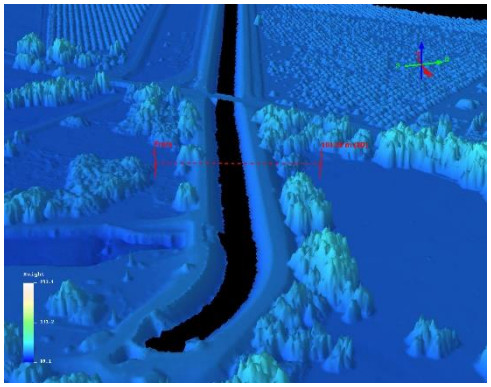
What Drove Change?

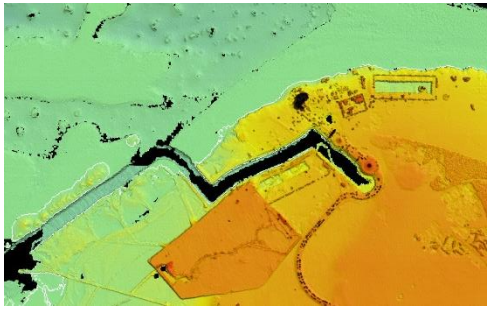
Client Feedback Past 3+ years Created a Need for Change

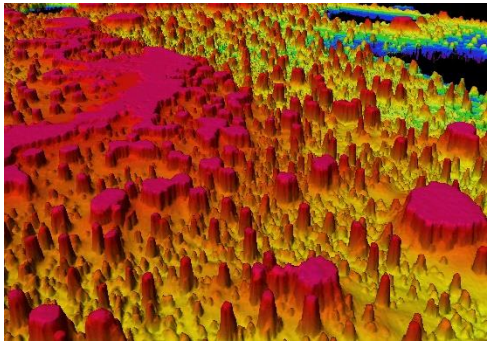
- US Army Corps of Engineers looking for comparative equivalent to CZMIL
- US NOAA looking for systems to provide data to support detailed coastal flood modeling but also for charting
- United Kingdom Government IHO 1B, but desiring IHO 1A (their definition: 9 soundings per 2m x 2m bin single pass)
- Canadian Government using ALB simply to reduce multibeam fieldwork time – and selecting based on lowest cost
- For engineering projects (e.g. ports & harbors), small projects are not cost effective to perform. Yet, these projects often require better water penetration than can be achieved with shallow-water systems

= None of these requirements

Challenges…







Challenges

- **No one system on the market could satisfy the demands of our key clients**
- Present airborne bathymetric solutions require a compromise between price, data density, and depth of penetration.
- Poor system reliability among most ALB sensors
- Turn-around time of deliverables not always suitable for our customer's needs.
- Ideal to use smaller aircraft and to reduce human footprint in the field.

Result

- Surveys are either inadequate for program requirements or too expensive to win.
- Delivery of data takes too long for emergency response applications

Status quo vs Ideal solution

Status Quo

- Sacrifice point density for depth penetration
- Best deep-water systems require large aircraft and high operating costs
- Mechanical moving parts impacts reliability
- Data processing solutions are slow meaning emergency response is difficult

The Required Solution

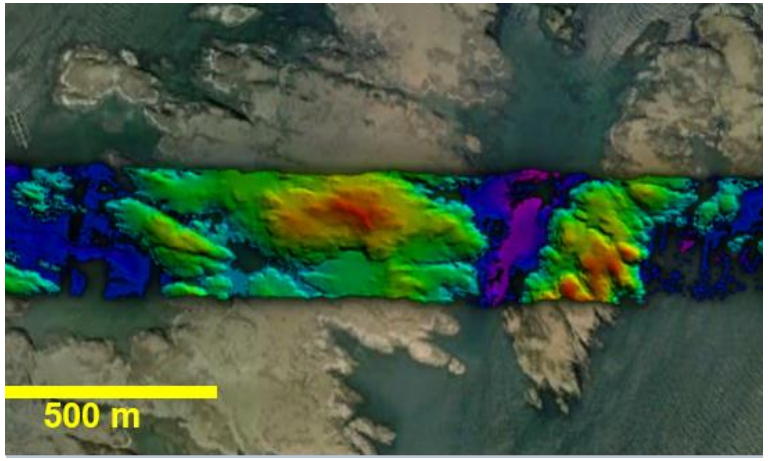
- **High density AND good penetration**
- Smaller aircraft – or even UAV deployment
- Solid-state & reliable
- Cloud computing and distribution
- Rapid data processing to provide interim deliverables for emergency response applications

RAMMS dramatically improves upon traditional airborne bathymetric surveying techniques

- Compact sensor designed for small aircraft and UAVs
- Streamlined data processing and delivery
- 3-Secchi depth penetration
- >25,000 range observations per second
- ~1:1 swath:altitude
- No moving parts
- Low-power consumption
- Smaller system footprint

RAMMS System Outline

- Advanced bathymetric Lidar developed in cooperation with Areté Associates.
- Airborne multibeam lidar via a push-broom laser scanner with beam forming at the ‘streak tube’ type receiver.
- Technology derived from 20 years and 3 generations of ISR&T ocean mine-detection sensors including delivery of 64 MIL-qualified blue/green lidar systems
- Fugro’s role has been to enhance the system to meet modern charting requirements



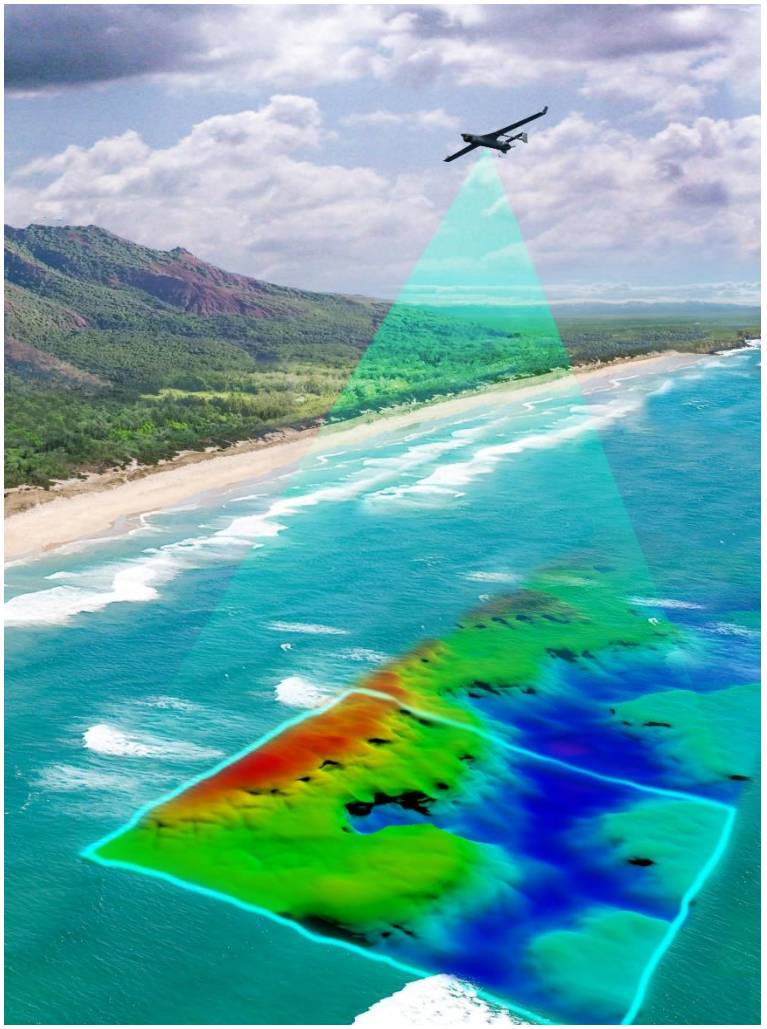
Data from UAV missions in Scotland

UAV mission line records

RAMMS: how it works

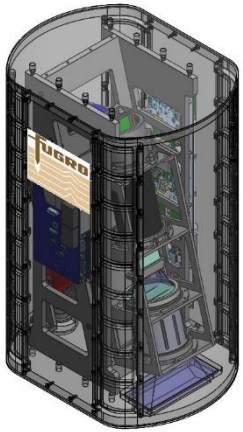
A new collection paradigm

- Compact and lightweight, the system is air-cooled and requires low power consumption
- With no mirrors or moving parts, the sensor projects pulses of diffused laser energy down to the water surface and through the water column, where the light is then reflected off the seabed
- As the light transmits, it spreads out laterally to the direction of flight, collecting data over a swath width that is approximately equal to the flight altitude
- When this ‘fan’ of energy returns to the receiver, it is digitized into individual but adjacent observations forming a uniform swath of bathymetry from the main waveform



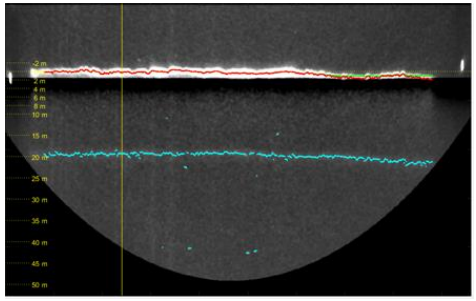
Key Differentiators

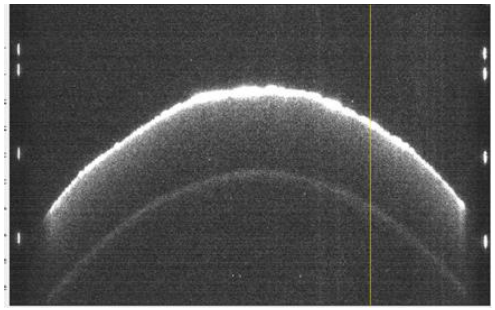
RAMMS	Current Deep Water ALB
3 Secchi depth-capable	3 Secchi depth-capable
~1:1 swath:flying altitude	0.7:1 swath:flying altitude
25,000 observations/second*	10,000 observations/second
1.6 points/m^2 @ 300m altitude @140 knots	0.49 points/m^2 @ 400m altitude @140 knots
Continuous cross-track acquisition	Individual observations
<10A current draw	>70A current draw
UAV-capable (now)	Non-UAV-capable
Large platform flexibility	Manned aircraft types only (usually turbo-prop)
Multibeam alignment with full swath, full water column	Single point waveform limited



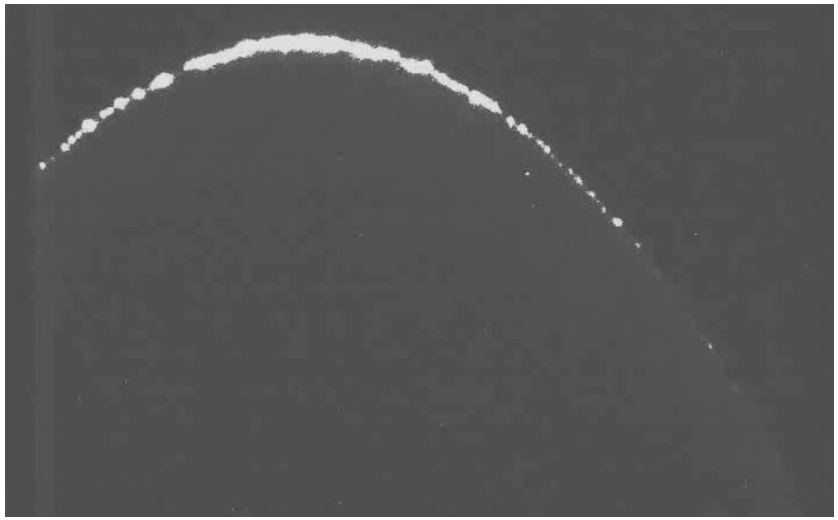
RAMMS primary sensor is 14kg (UAV or Camera Port)

Optech CZMIL Nova: complete package weighs 287kg



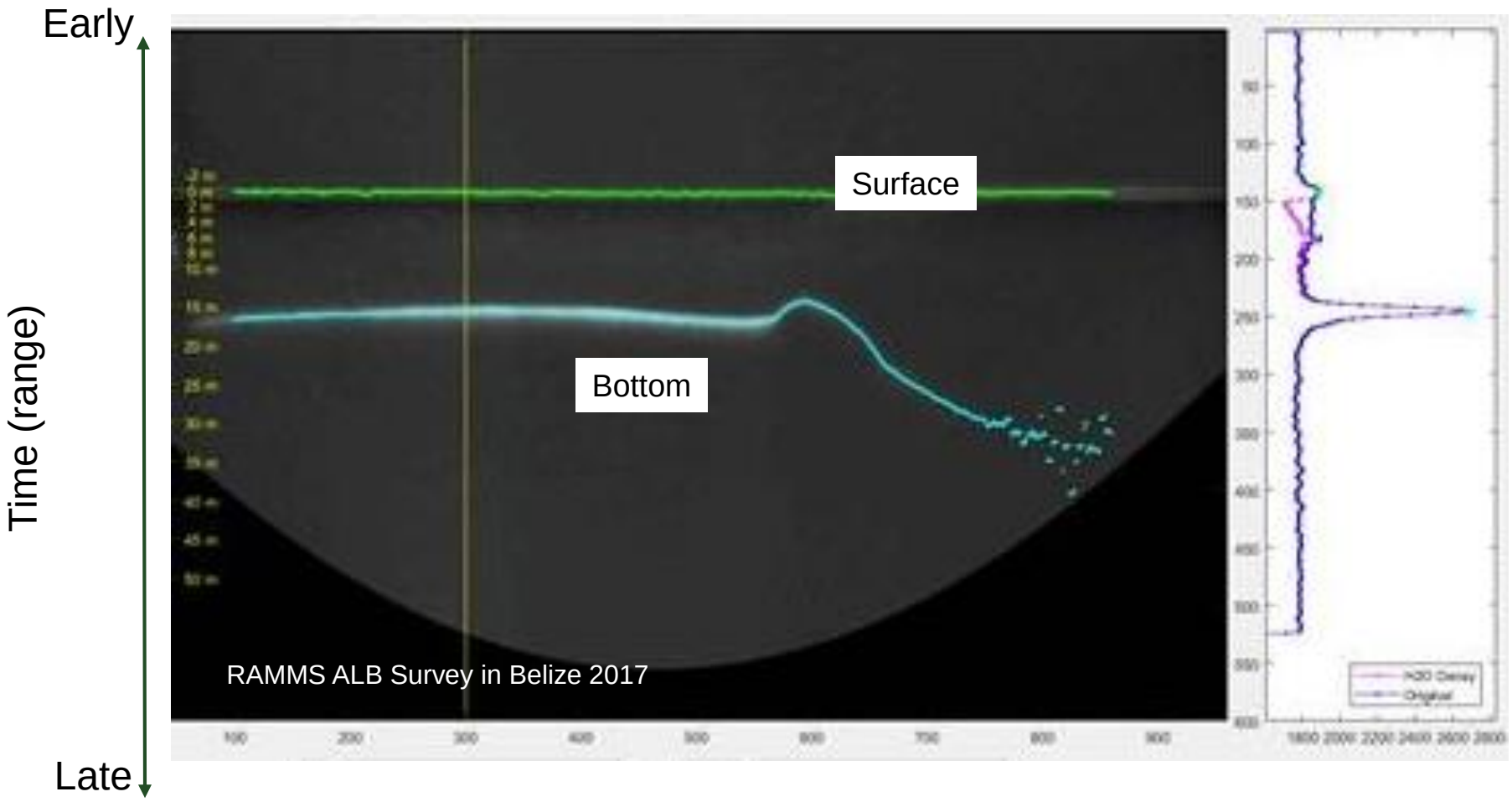


Key Performance Characteristics

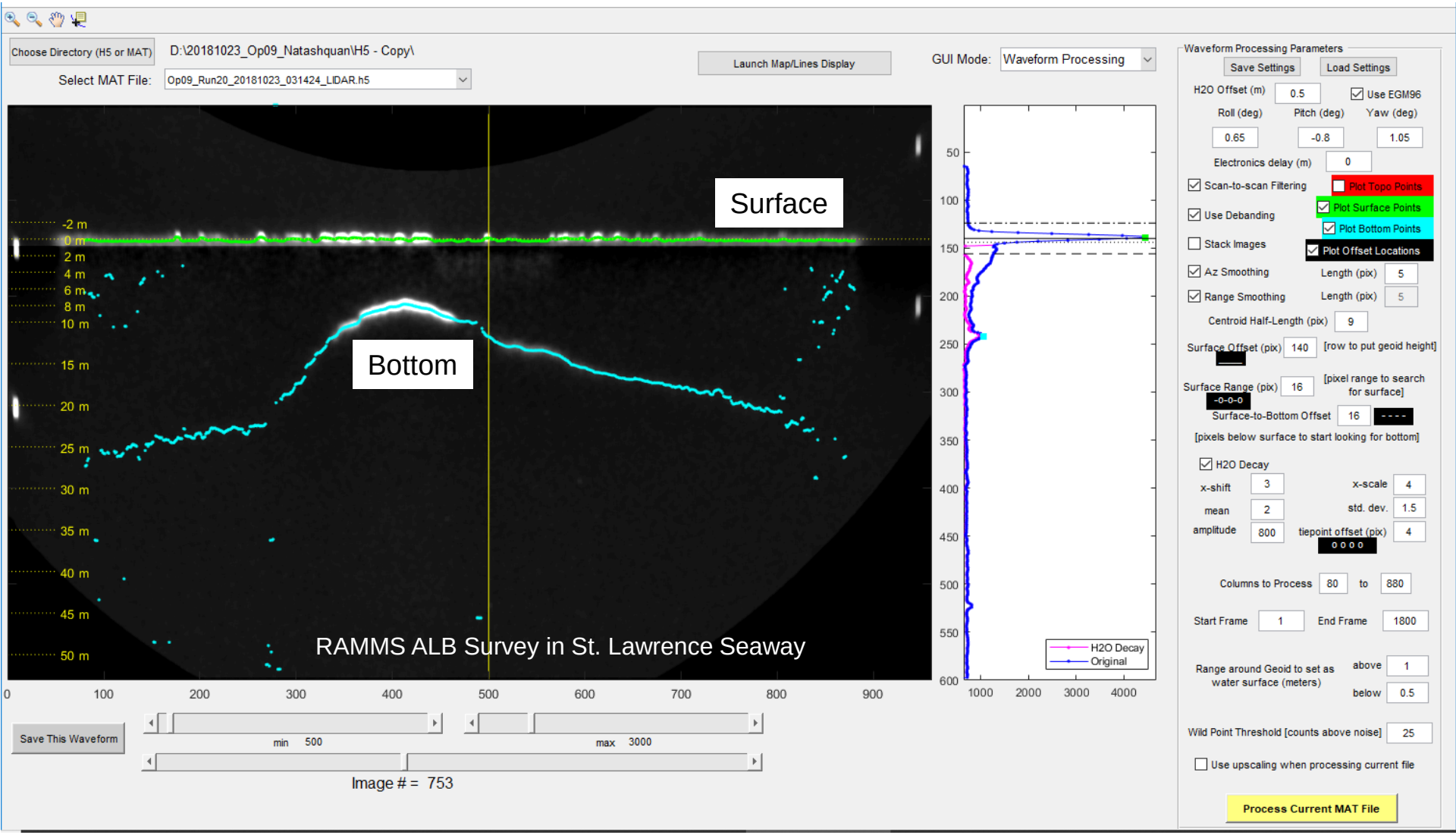


- RAMMS has no moving parts:
  - Solid-state electronics creates more ruggedized, low-maintenance design
  - Greatly minimized mobilization and check calibration procedures
  - Increased reliability
- Swath width ~ equal to flight altitude
- Nominal operational altitude (and therefore swath) is 300~350m
- Improved eye-safety limitations
- Ability to observe and process water column data
- Back-2-Base® technology = next-day QC at the home office

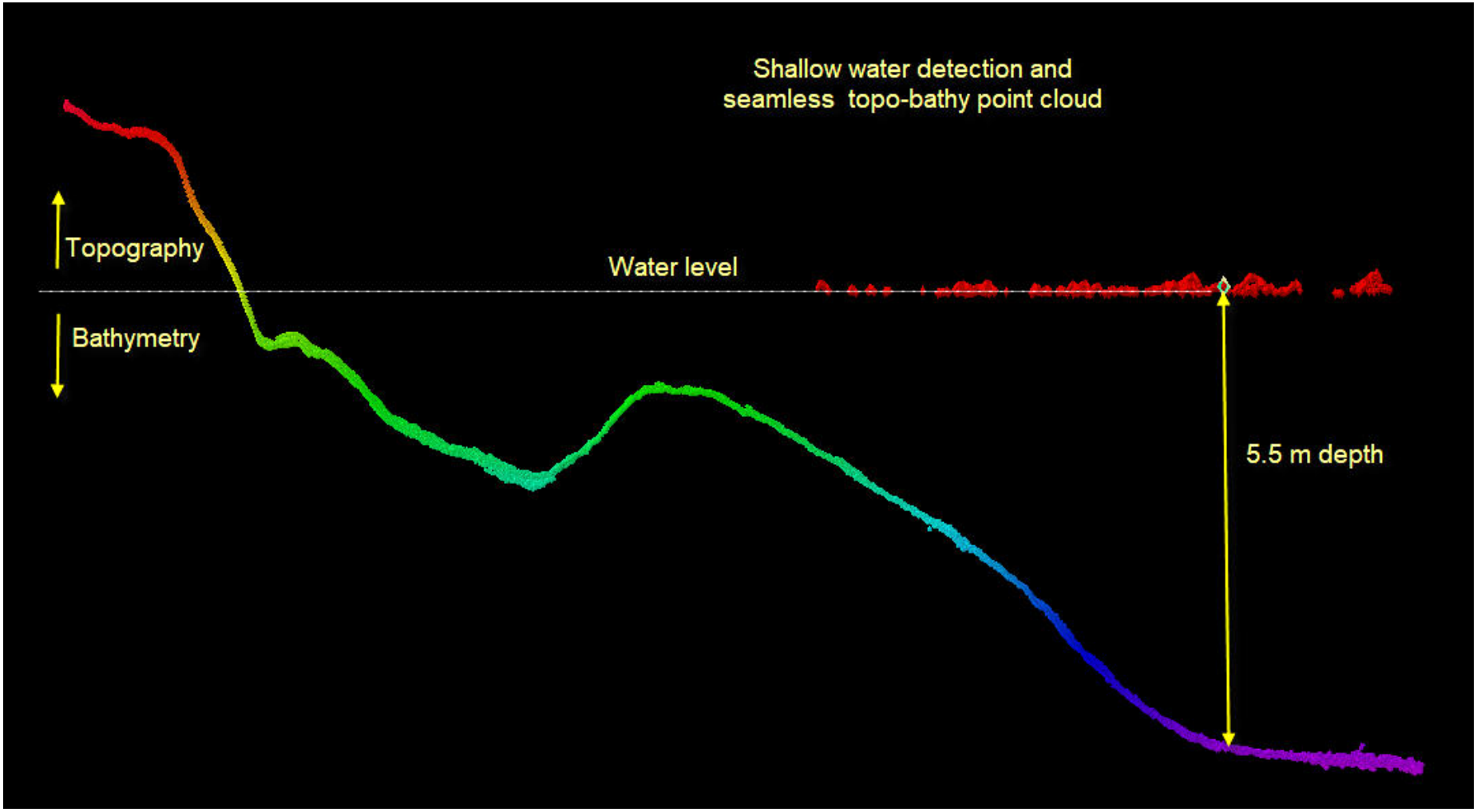
Raw Laser Waveform Conversion



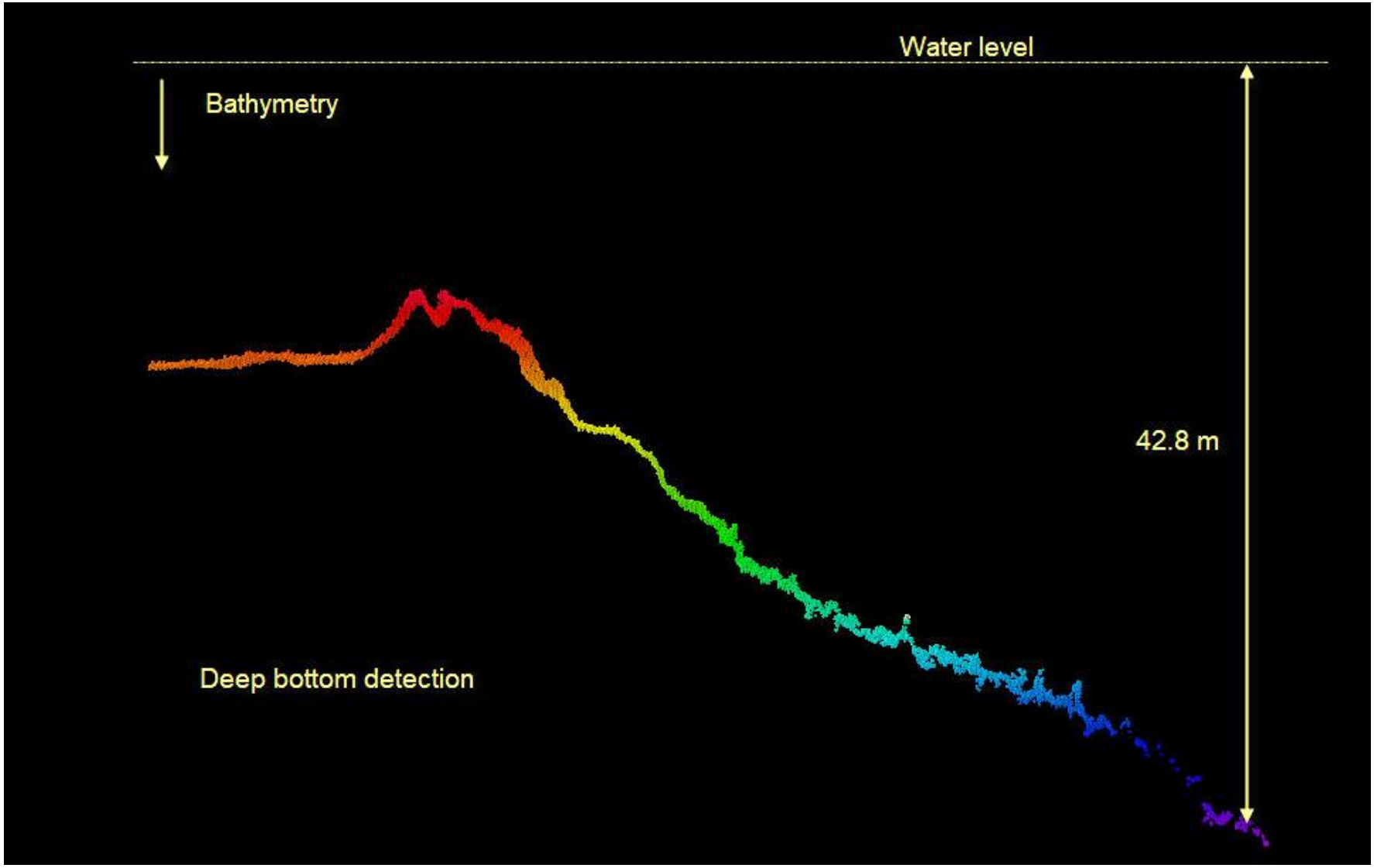
Processing GUI Development – Improving Performance



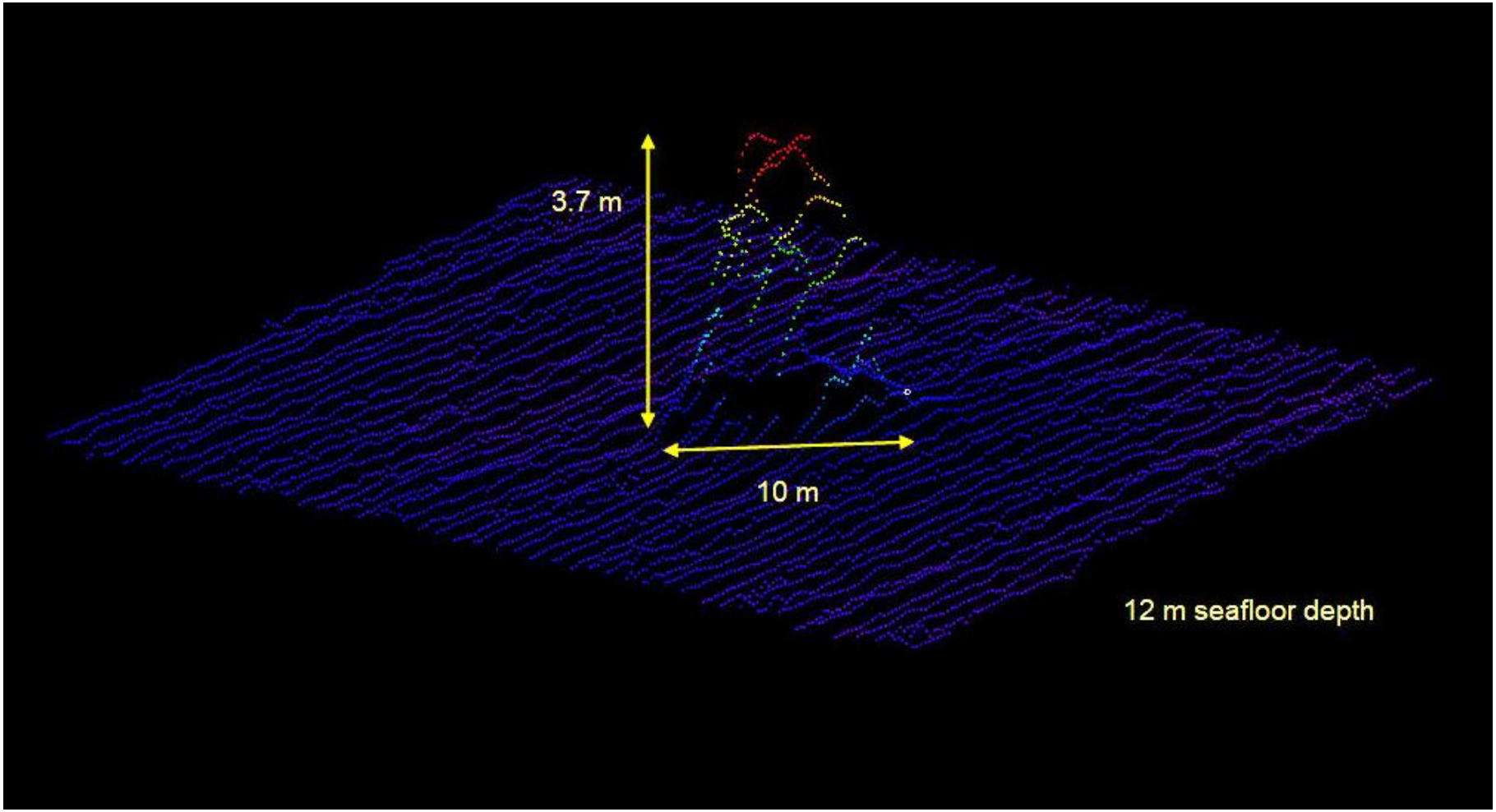
Bottom Detection - Shallow



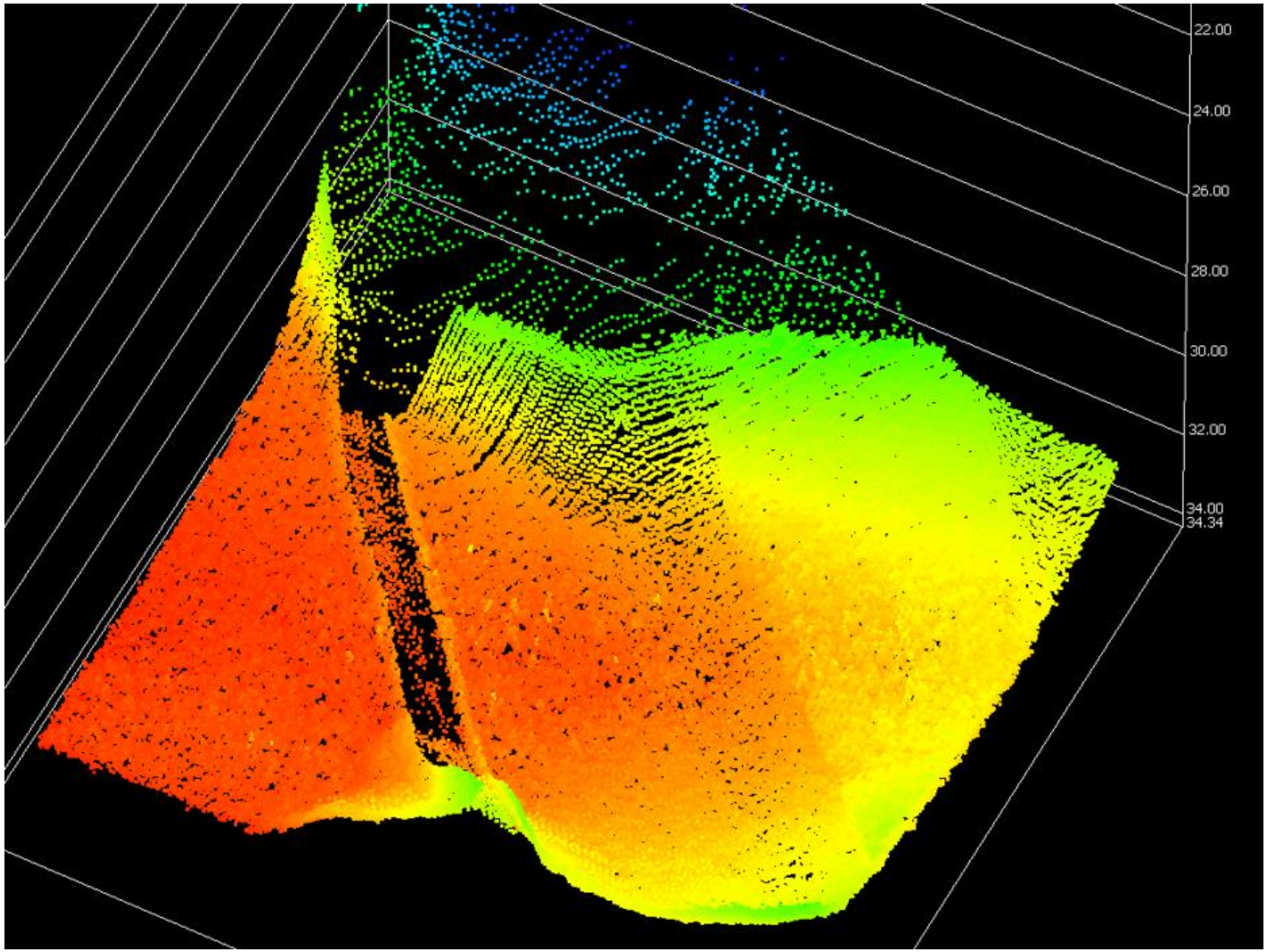
Bottom Detection - Deep



Feature Detection



Coverage (cf. SHOALS)

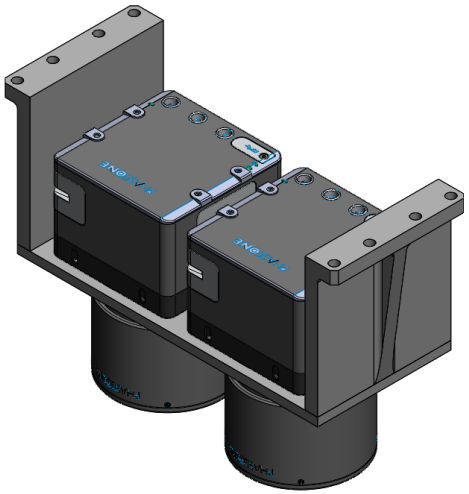


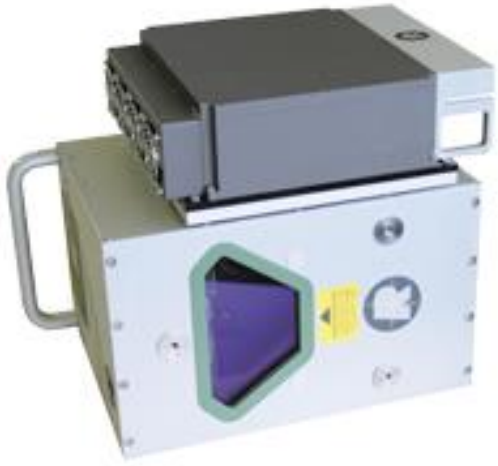
Sensor Bundling For Broader Applications

RAMMS solution can easily be complemented with:

- High-Density Topo/bathy Lidar Sensors
- RGB or Multispectral Phase One Camera
- Hyperspectral Camera (note there are limitations)

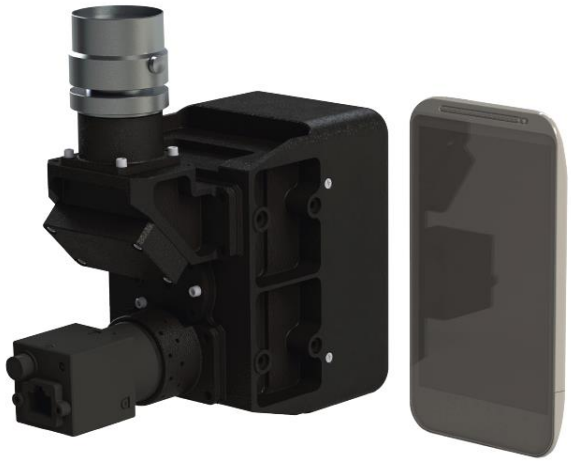
Phase One Compact 4-band Multispectral Camera





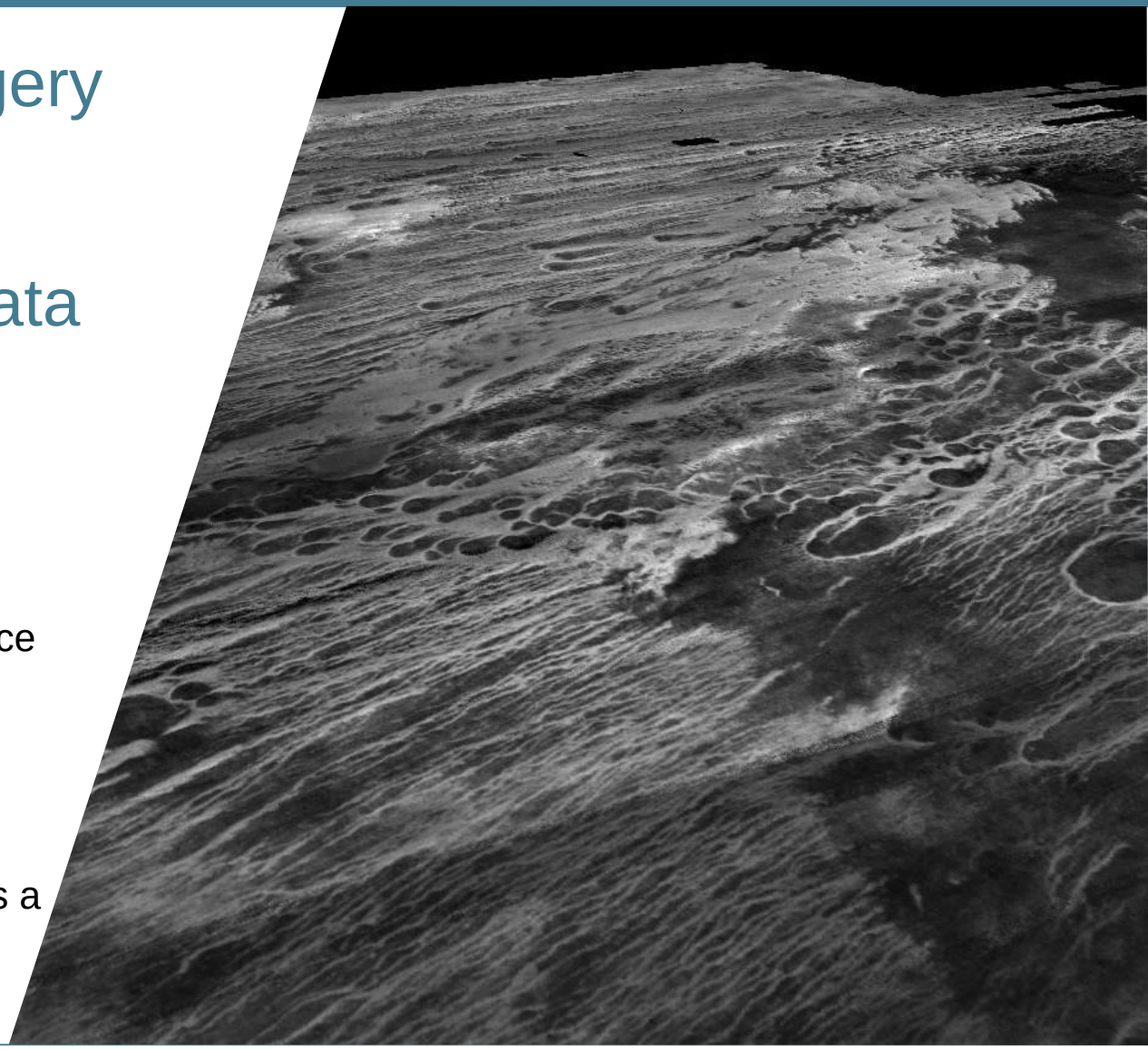
Riegl System can be co-mounted for HD topo/bathy

ITRES MicroCASI's small size can compliment RAMMS (see compared to mobile phone)



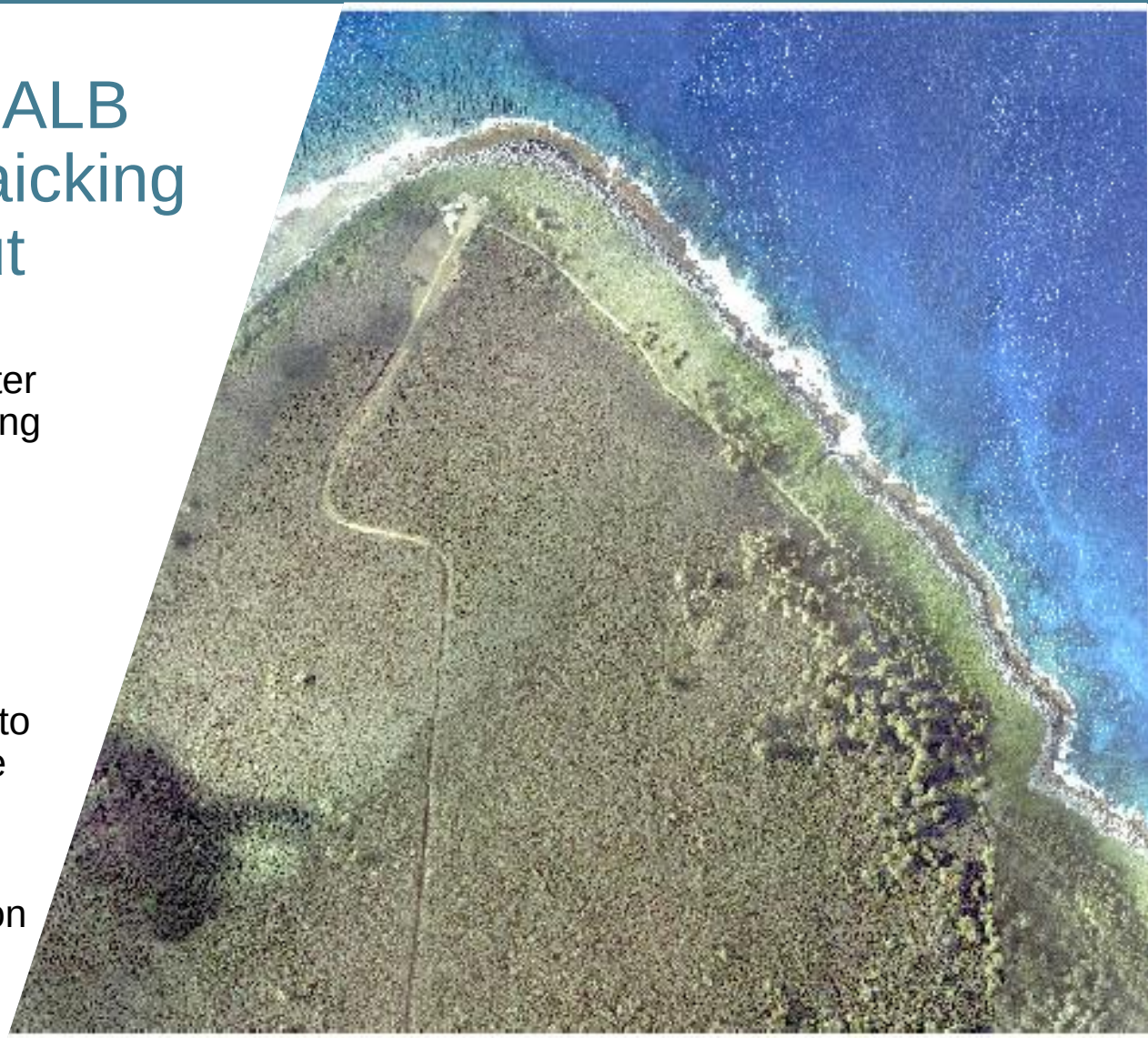
Reflectance imagery can be extracted from the full-waveform metadata

- Ideal for determining substrate distribution of the sea/lake/riverbed
- Further classification for habitat mapping possible through modelling reflectance ratios
- Co-terminus with x,y,z data allowing easy draping over DEM
- Added feature of RAMMS is a water column processing algorithm for improved mid-water target detection



RGB imagery for ALB QC/QA and mosaicking is a regular output

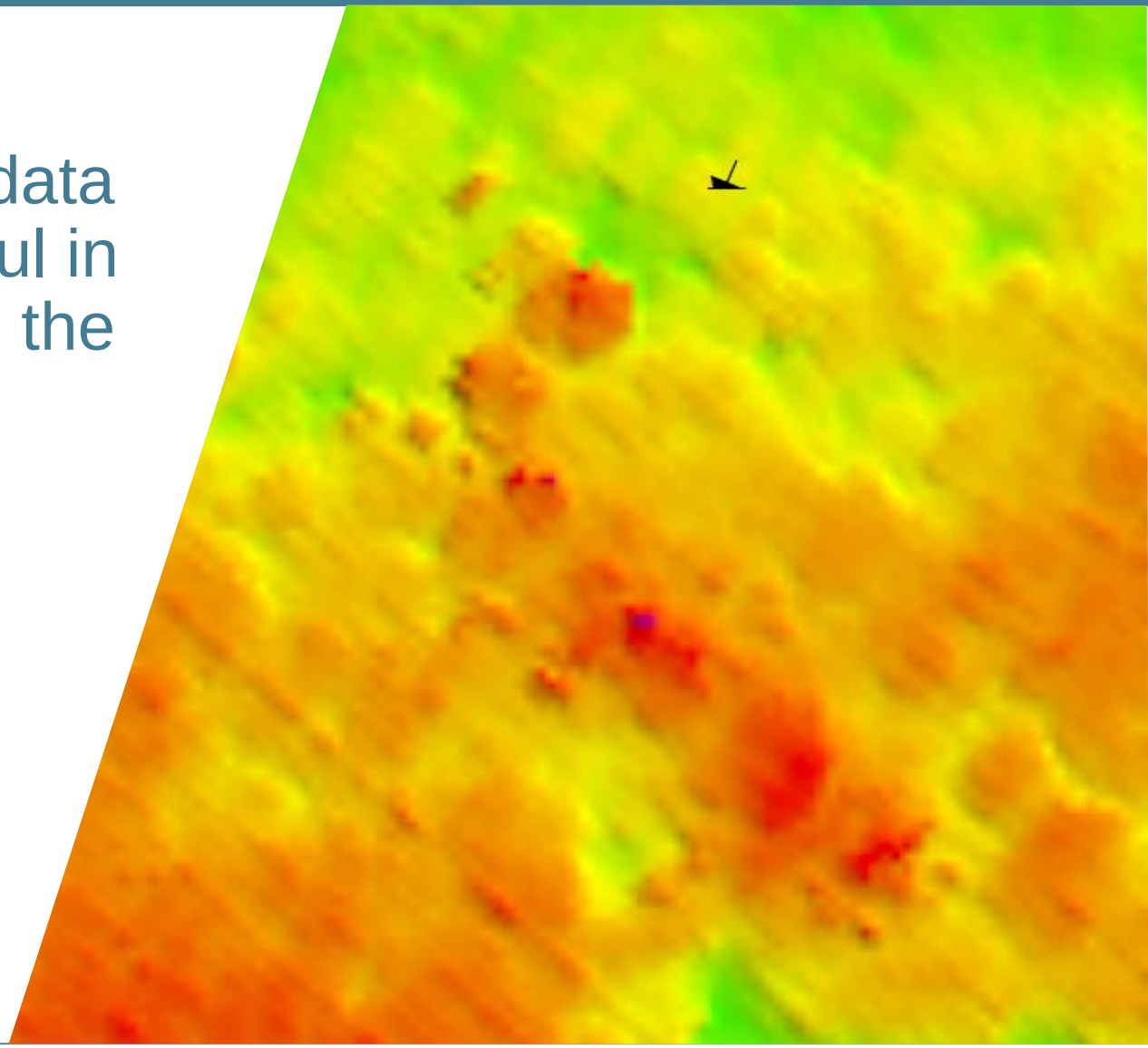
- Imagery FOV typically greater than ALB swath, guaranteeing good overlap
- Hi-res imagery allows independent checks and analysis of ALB data where observable
- Imagery can be mosaicked to create additional deliverable
- New camera combinations provides a multispectral (R,G,B,NIR) imagery solution



Additional Standard Outputs: Visual Imagery and DEM

In optically clear waters the RGB data is extremely useful in adding context to the DEM

- Good georectification from the outset is essential to ensure the datasets line up precisely
- Considerable detail enhancement is possible over the selected bin resolution of the ALB surface



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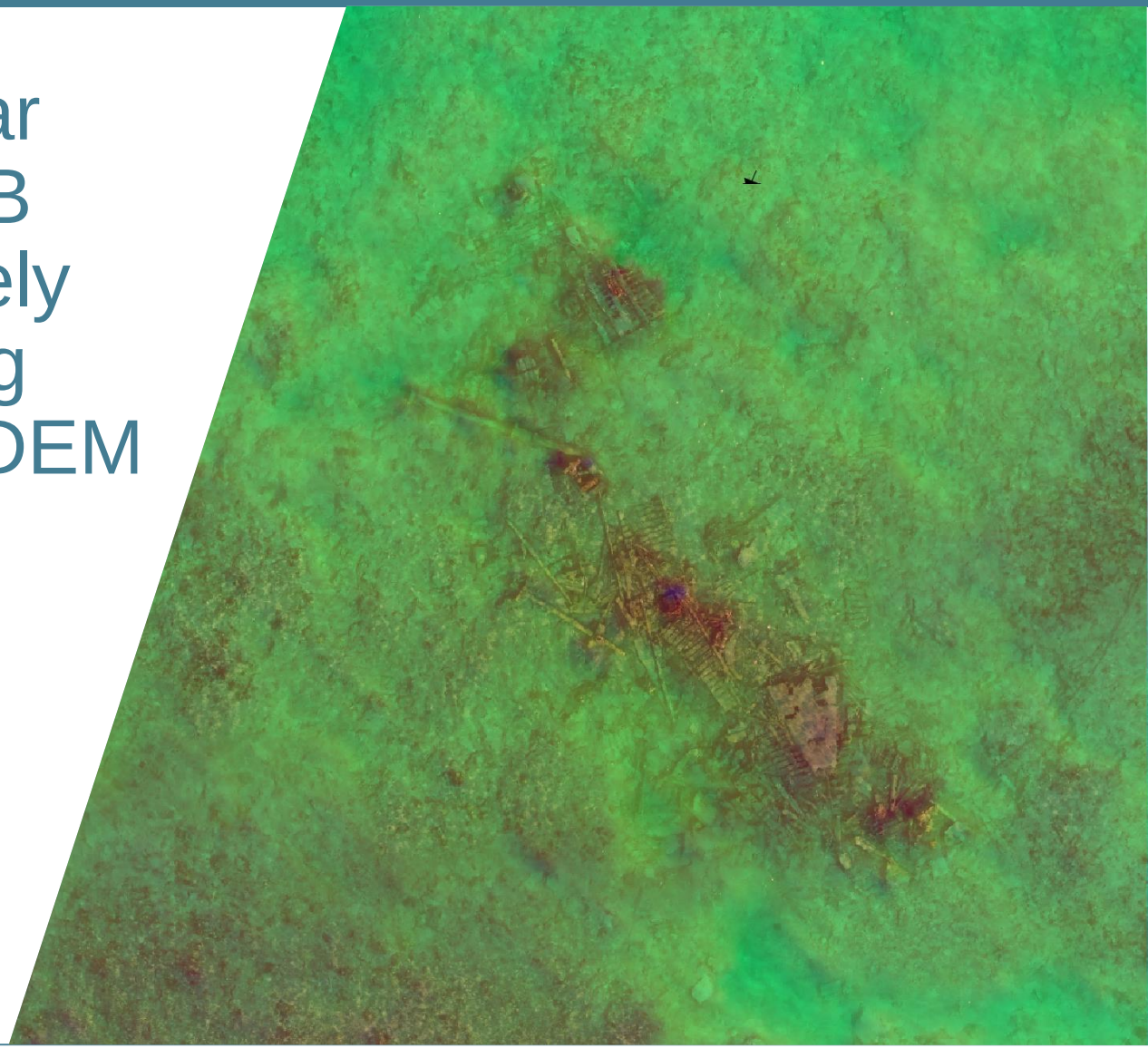
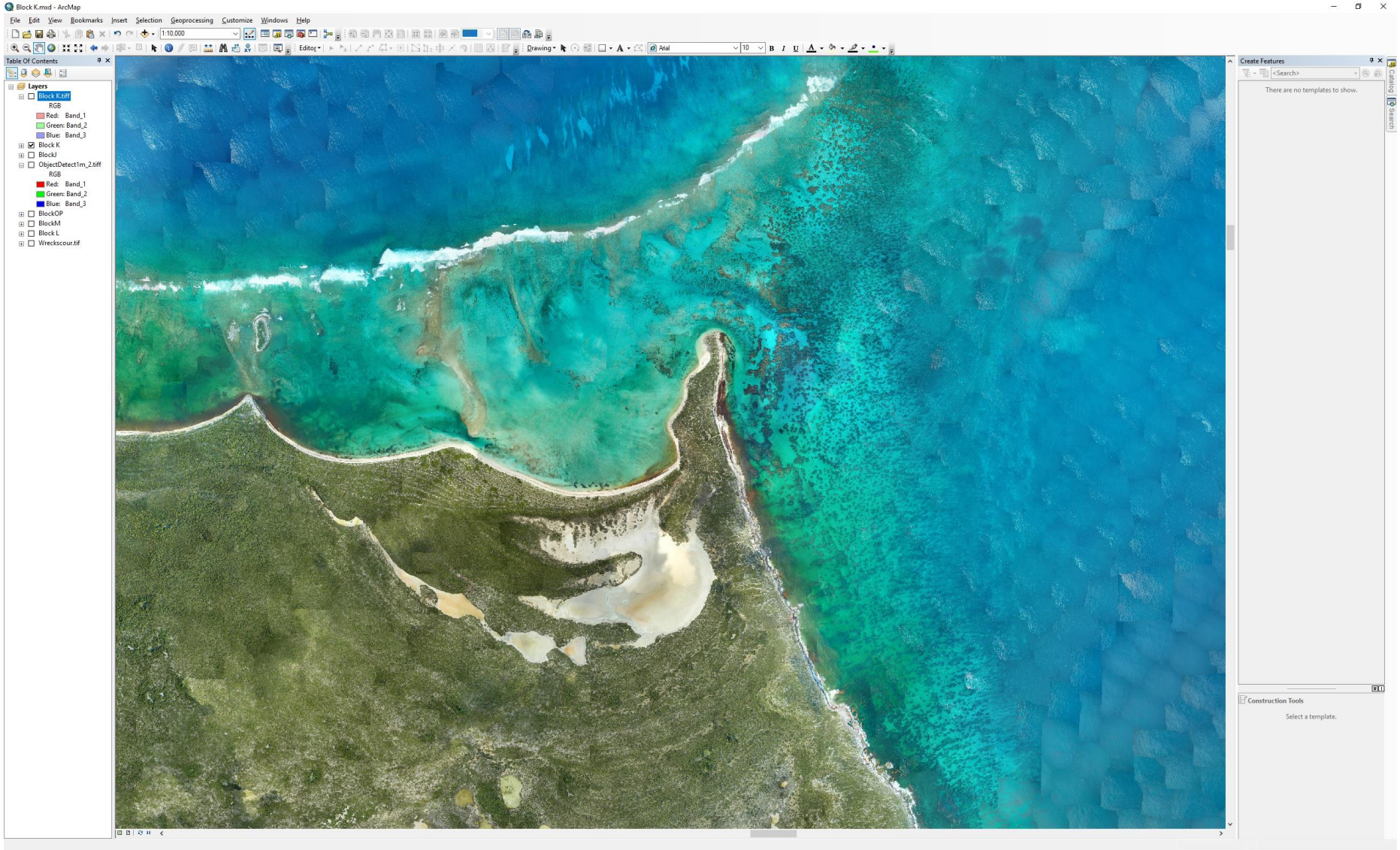


RGB Imagery and Single-Pass RAMMS Comparison



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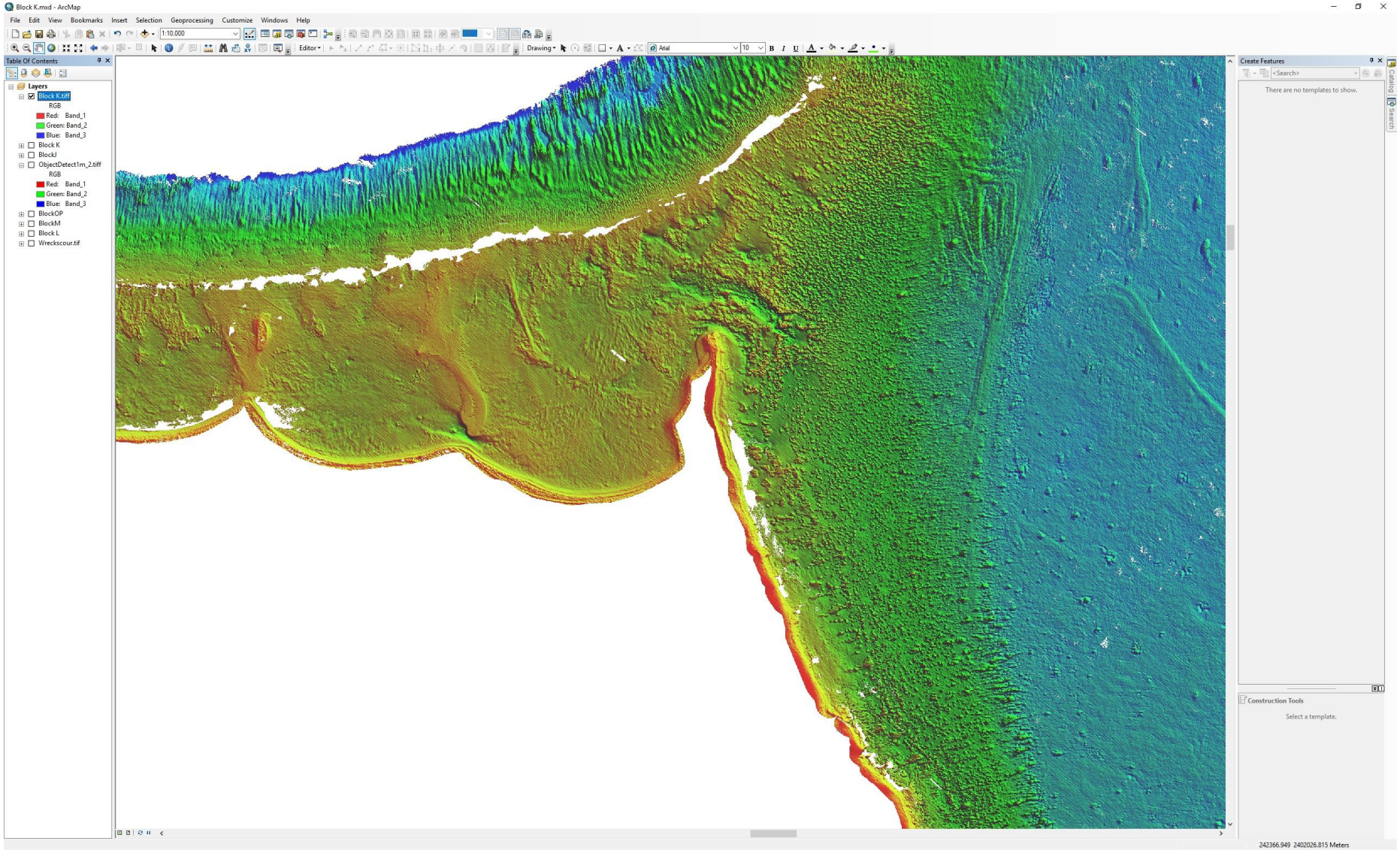

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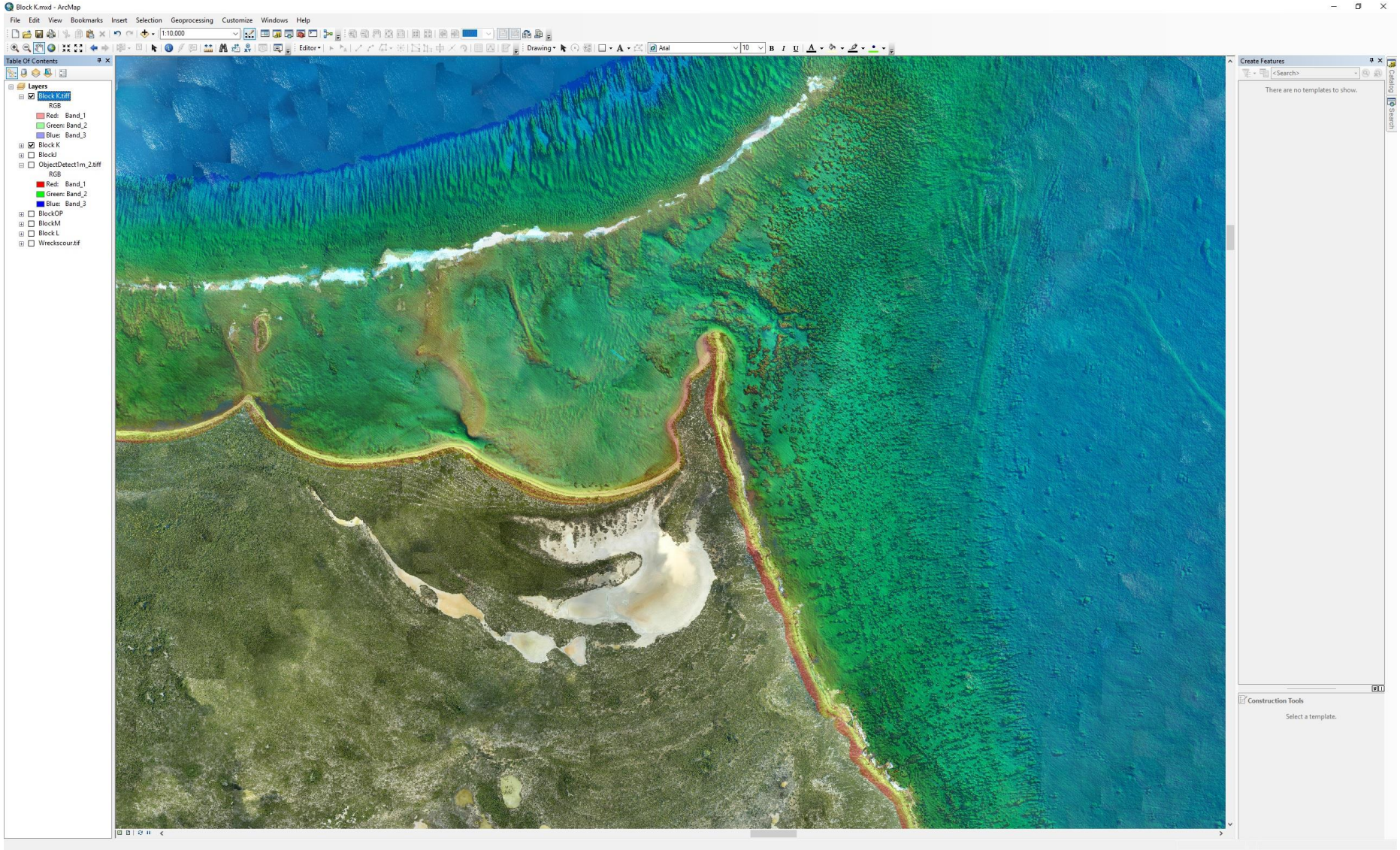


Economic Impacts of a New Solution

Economic impact

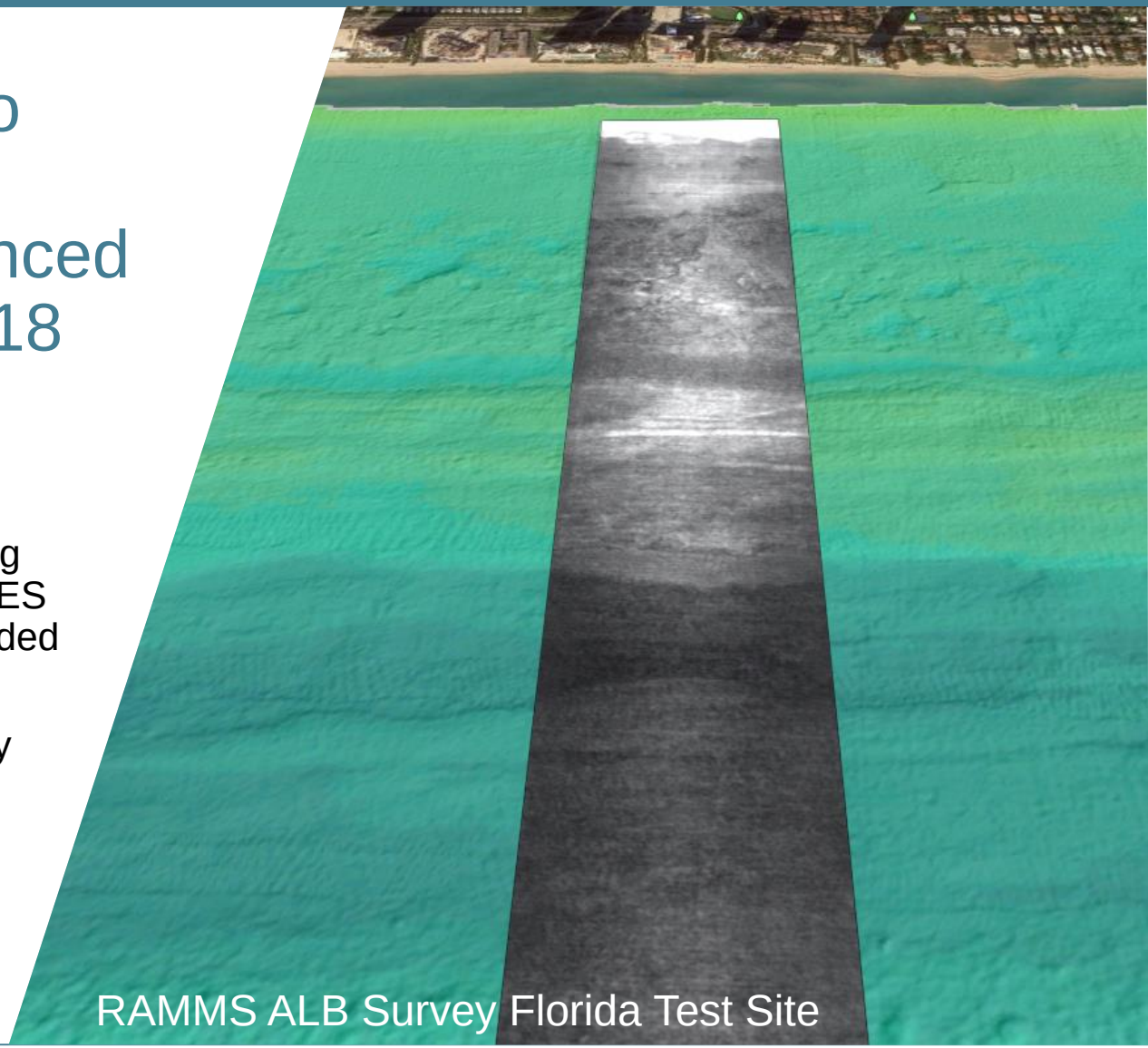
- Smaller aircraft &/or longer endurance
- Reduction of manpower for fieldwork
- Reduction of system down-time
- Increased collection efficiency
- Improved data quality

Result = More & better quality mapping data for your investment

RAMMS began to provide Fugro's clients with advanced capabilities in 2018

The phased launch included:

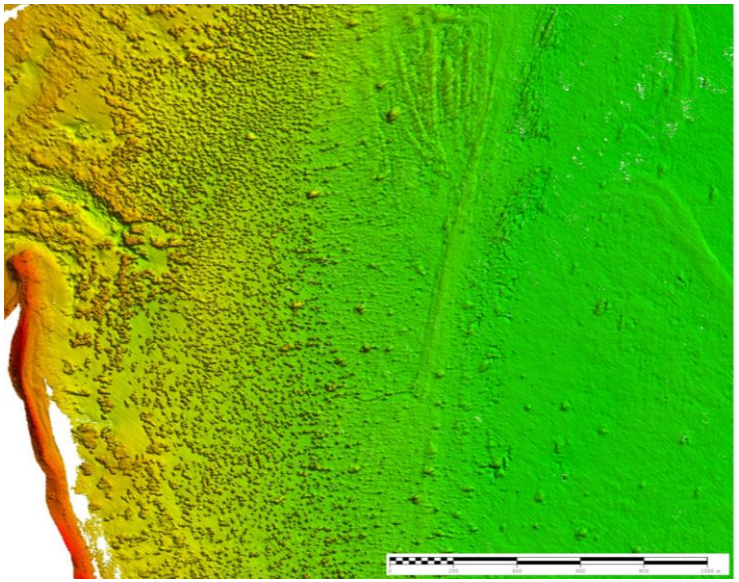
- Key-client briefings
- Initial projects demonstrating capability (in support of MBES operations which also provided good comparison)
- Full-scale, worldwide survey operations for a growing stakeholder group (so far Americas region focus)

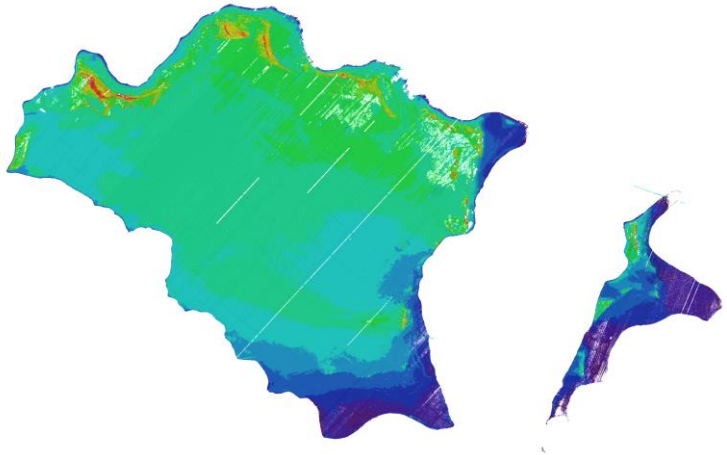


RAMMS ALB Survey Florida Test Site

RAMMS – Field Proven

- First Project: Belize 2017
- To date: 17,000 km^2 on 5 hydrographic charting projects;
  - Belize (2017) – 200 km^2 (first operational use)
  - Turks and Caicos (2018) – 7,400 km^2
  - Belize (2018) – 2,600 km^2
  - Quebec Canada (2018) – 2,000 km^2
  - Nova Scotia Canada (2018) – 5,000 km^2
- Currently at 1,000 hours without breakdown
- Achieving UKHO requirement for 2 pts per 2m bin to 40m (actual results 6 - 12 pts per 2m bin to 40m)
- Presently preparing bathy and reflectance products in LAS 1.4
- Integrated Phase One camera with RGB imagery to 3cm GSD (NIR channel also available)





	Nov 2016 Grenada	Oct 2018 Belize
Field Staff	11 staff	2 staff
Sensor	2 X Shoal	RAMMS
Data Density	<2pts/bin	6 - 12pts/bin
Aircraft costs/day	$15k/Day	$7k/Day
Size	2,566 km^2	2,575 km^2

Summary

- RAMMS delivers full 3-Secchi performance from a system comparable to the lightest topo-bathy systems available today
- It utilizes a completely revolutionary multibeam pushbroom laser swath design to deliver a superior number of obs/sec and therefore data density compared to contemporary systems
- Low-power, solid state design paired with Commercial Off-The-Shelf processing workflows and Fugro Back-2-Base™ utility drastically simplifies field and office operations
- RAMMS is now

Additional Topics:

Autonomous and Remote Hydrographic Surveying Technologies

Fugro Autonomous Surveyor 900 Class 9-meter USV

USV = Unmanned Surface Vessel

Fugro's New "**Autonomous Surveyor 900**" Class

This is the first fit-for-purpose 9-metre unmanned surface vessels (USVs).

The initial USVs that will be delivered are designed for medium to large scale hydrographic survey projects and are expected to increase acquisition efficiencies, optimize data quality, reduce offshore staff exposure and reduce environmental impact.

- Designed in partnership with L3 Technologies
- Sea trials are commencing later this month (April)

Fugro Autonomous Surveyor 900 Class 9-meter USV

Features

Wave piercing hull design - improved sea keeping, a stable configuration for high quality data acquisition

Gondola mounted sensors - best possible hydrographic data acquisition, low acoustic interference = improved data quality.

Robust hull design: with fenders on critical places - reducing downtime risk resulting due to damaged hull

Maximised situational awareness: 360 degree camera (including infrared), radar and weather station

Vessel control software with autonomous obstacle avoidance: capability, radar repeater

Robust and simple L&R: both from single point as well as via A-frame.

Benefits

- Improved safety (HSSE) / reduce offshore staff exposure
- Faster data collection (force multiplier)
- More efficient solution / operations
- More sustainable operations / reduce carbon footprint / fuel consumption is fraction of regular survey vessel

Fugro Autonomous Surveyor 900 Class 9-meter USV

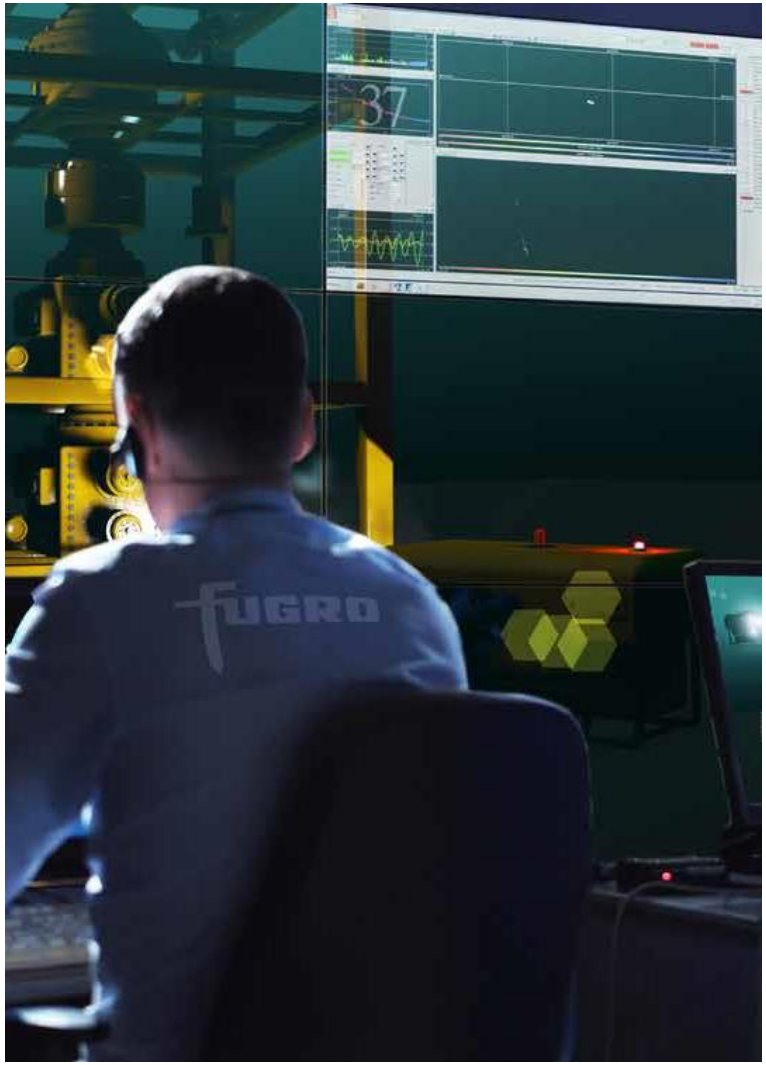
Fugro Autonomous Surveyor 900 Class 9-meter USV

Remote Operations Center: Inspection & Survey

OARS® (Office Assisted Remote Services) provides centralised command centres throughout the world with direct access to offshore survey projects. The system allows for optimisation of survey crew size, client engagement and access to Fugro's subject matter experts around the world.

These Remote inspection Services are offered with staff working 24/7 with operational centers in two locations now with two more being established.

The services can be employed to manage a variety of sensors and services for a variety of vessels.



Thank You for your time

Todd Mitchell
Fugro
tmitchell@fugro.com

Don Ventura
Fugro
dventura@fugro.com

Manfred Stender
Fugro
m.stender@fugro.com