Lidar Bathymetry Overview
&
Process & Benefits Of A Multi-sensor Approach

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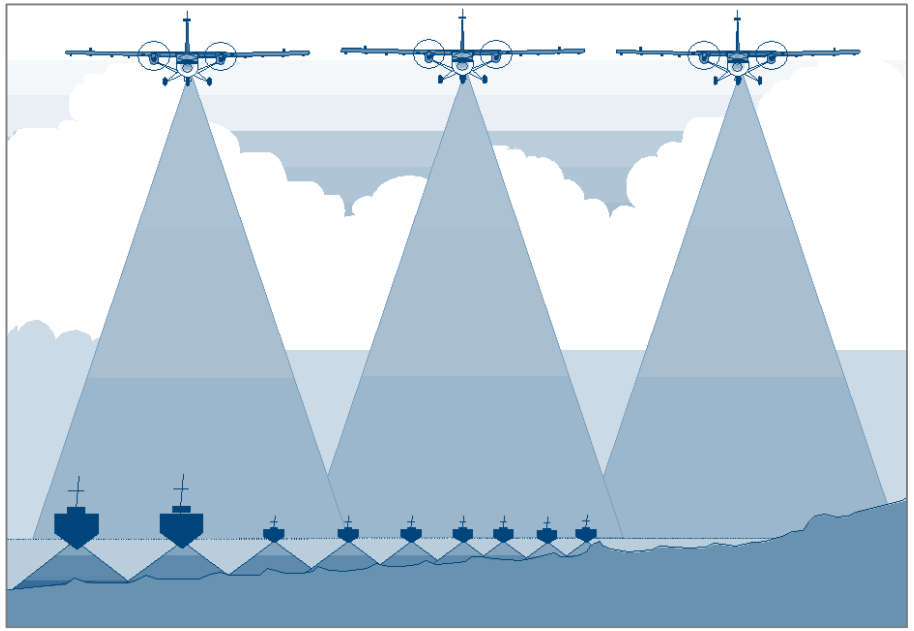
Operational Concepts for Bathymetric Lidar

- Consistent swath widths
- More efficient coverage in very shallow water (<5 – 15m)
- Eliminates safety concerns of boat operations in shallow uncharted water
- Can be combined with multibeam for optimal survey results, efficiency & safety

Sample Project >200km^2

- Very Shallow Depths (3m on average)
- Understand limitations

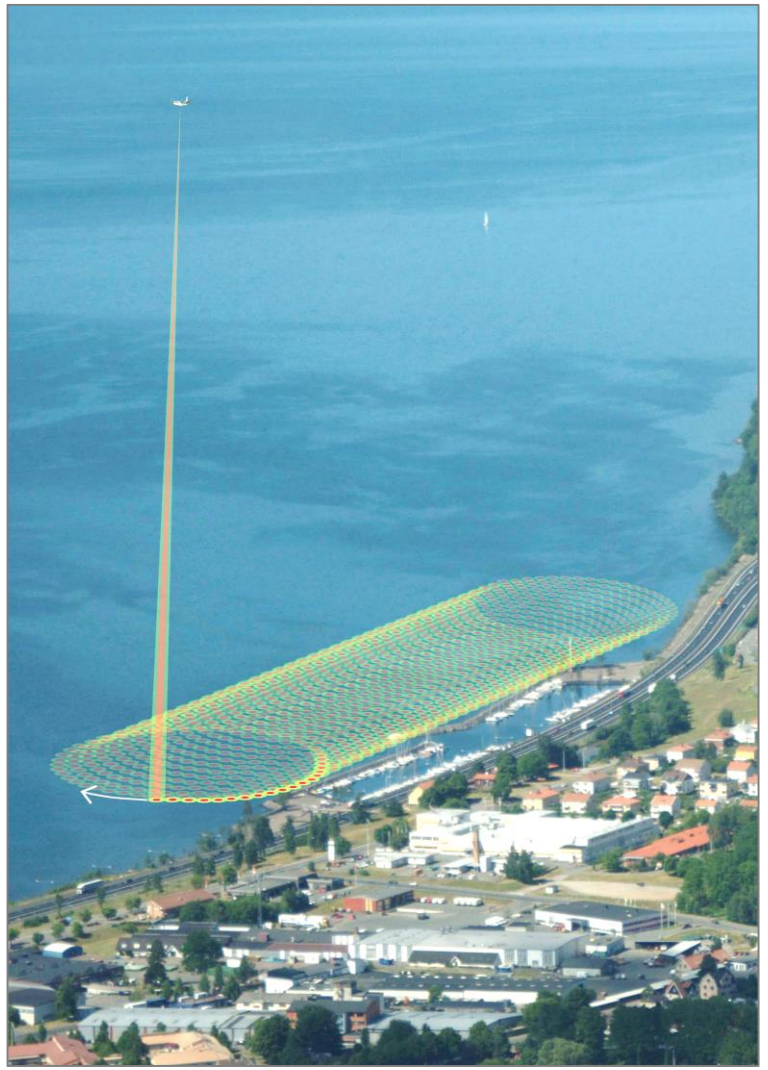


Technology	Time to Survey
Full Coverage Multibeam	1 year
100% Sidescan Sonar (with singlebeam or striped bathy)	60 days
Bathy Lidar	**2 days**

Bathymetric Lidar Theory

- Frequency Doubled ND:YAG Class IV Laser output **or** Independent Lasers:
  - Infrared (1064nm)
  - Visible Green (532nm)

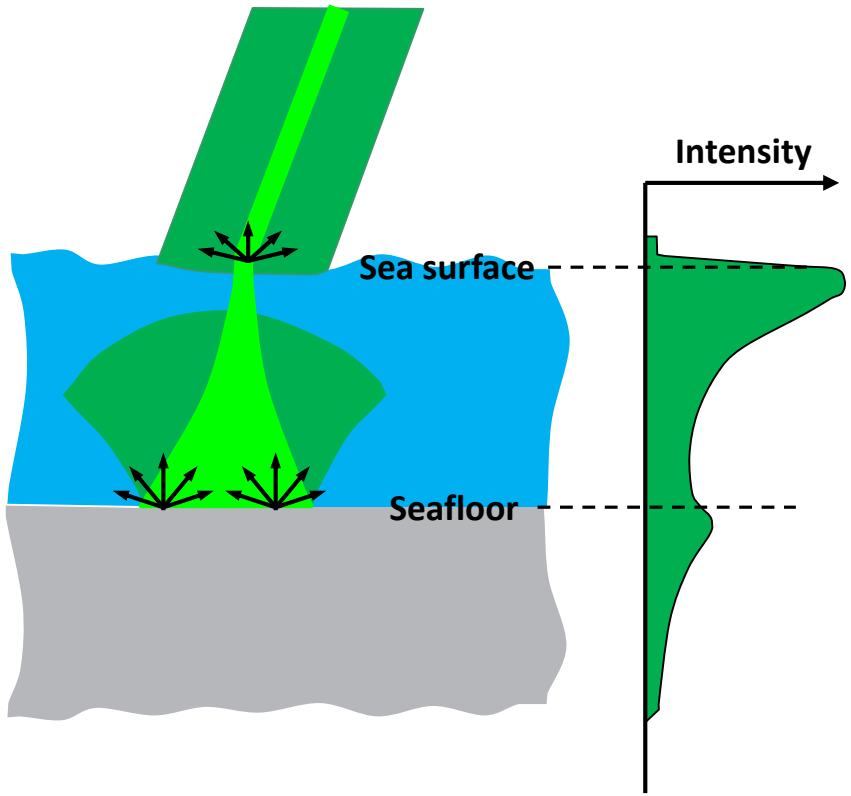
- Laser fires against a scanning mirror or circular palmer scanner to create a swath of points.



Bathymetric Lidar Theory

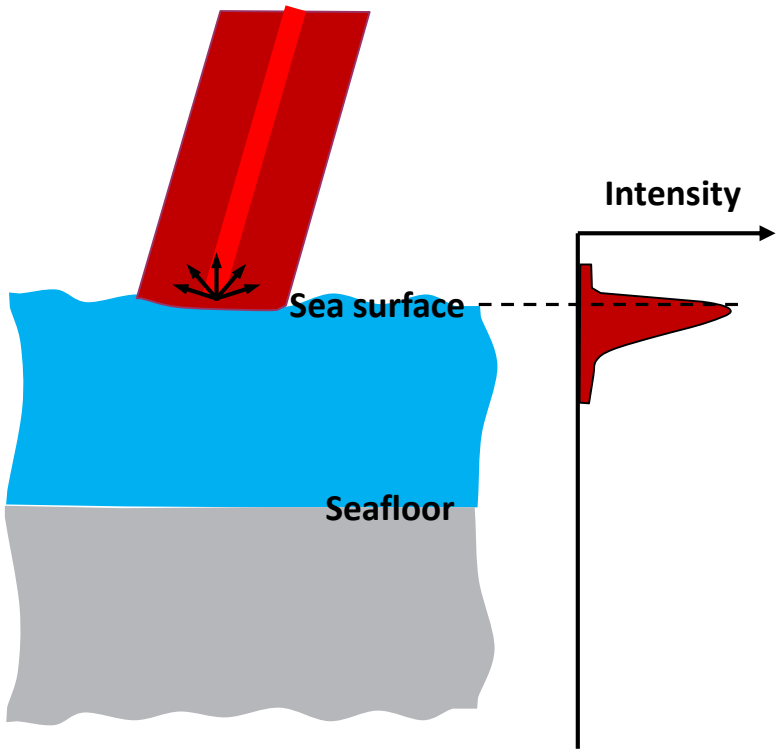
Green (532nm)

sea surface, water column & seafloor



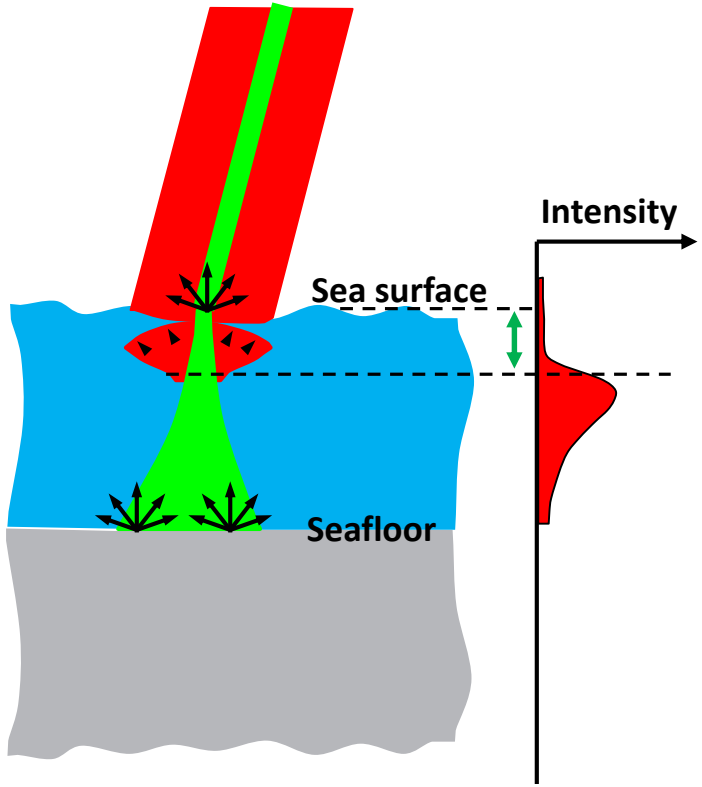
IR (1064nm)

sea surface

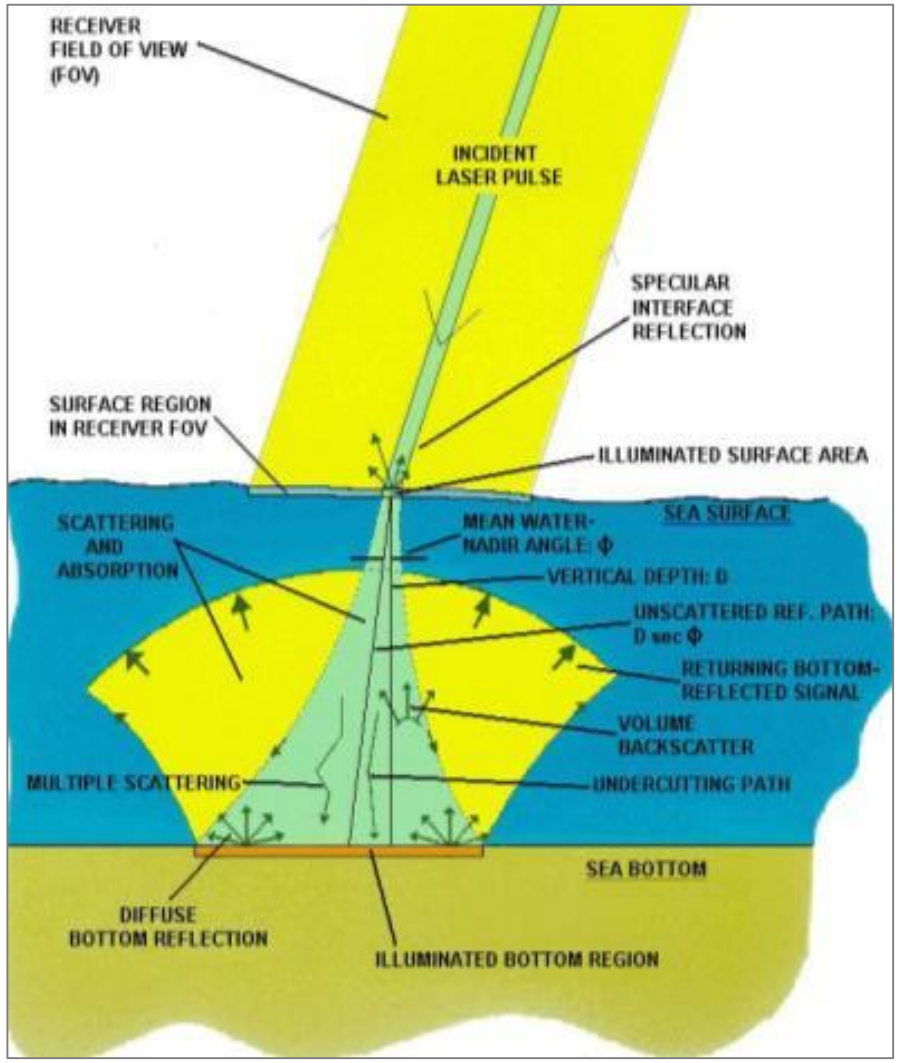


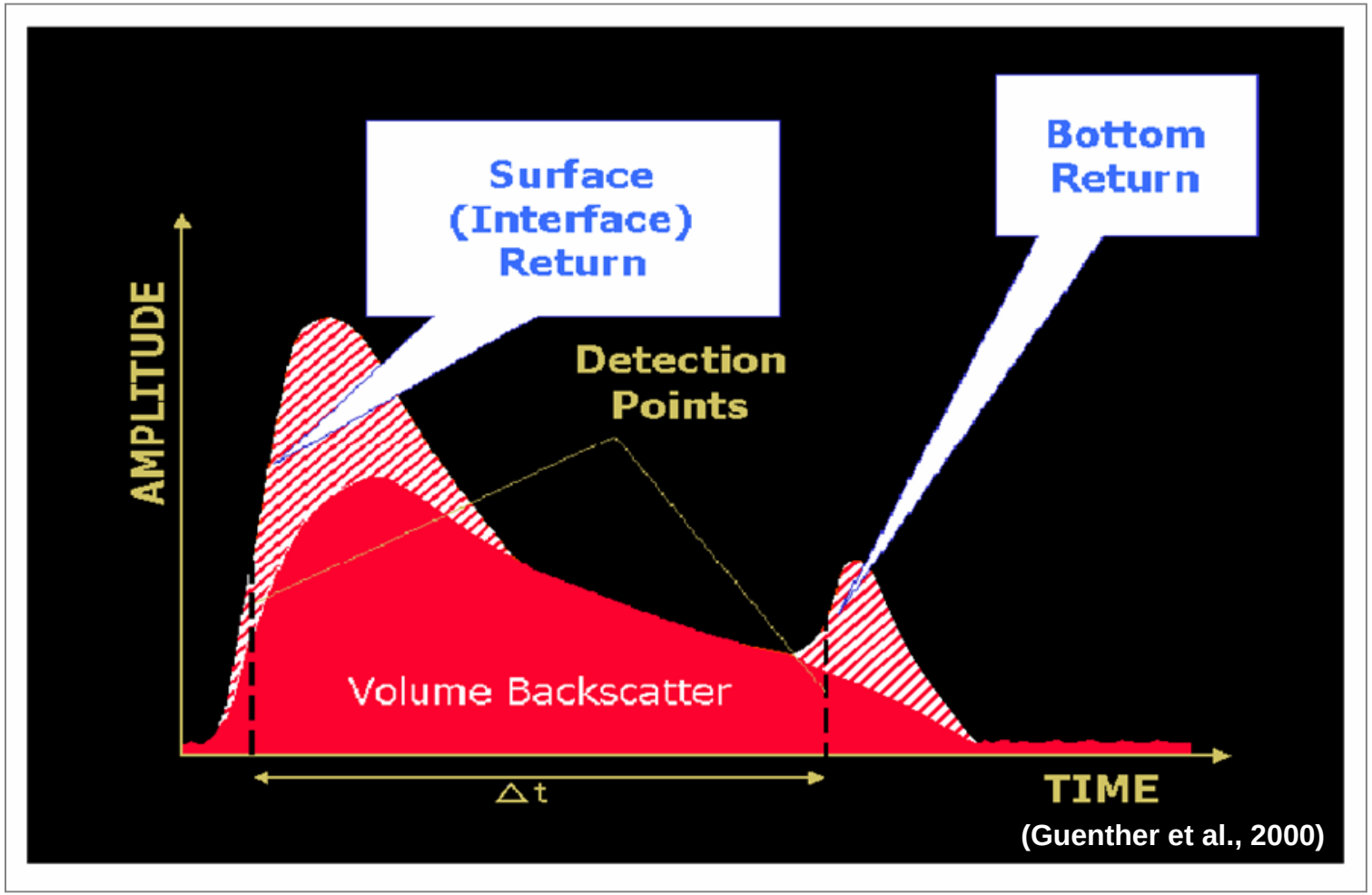
Raman Return (Red 640 to 670nm)

sea surface, upper water column



Conceptual Green Waveform





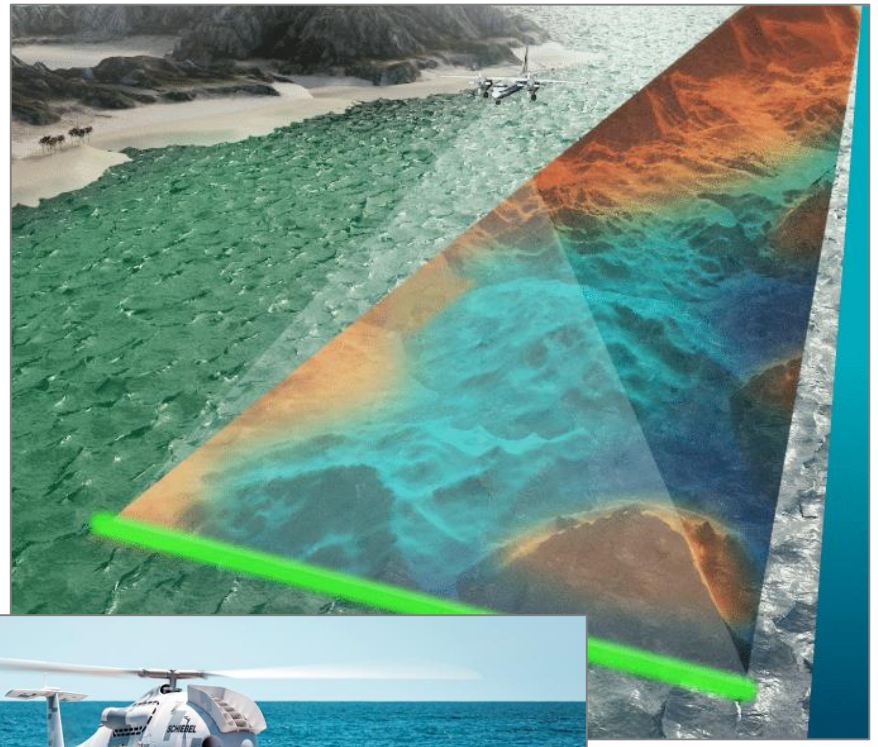
System Flavors

System Type	Size & Weight	System Characteristics	Depth Penetration	Data Density
Lower Power Laser	Smaller, Lighter	Smaller Footprint Size / Beam Divergence (~0.5 - 1m)	Less Depth Penetration	Denser Data
High Power System	Larger, Heavier	Larger Footprint Size / Beam Divergence ** (~2m)	Greater Depth Penetration	Less Dense Data
Modular System	Multiple Lasers – low and high power		Greater Depth Penetration	Denser data in shallow plus less dense data deeper

** Necessary to make higher power systems eye safe

Arete PILLS: Pushbroom Imaging Lidar for Littoral Surveillance
Fugro RAMMS: Rapid Airborne Multibeam Mapping System

- Pulsed laser fan beam and a streak tube imaging lidar (STIL) receiver
- For each laser pulse, maps out an image of objects within the fan beam



- Solid state system
- Low SWaP
  - Low Size, Weight and Power
  - UAV Deployable
    - Recent test in Pensacola, FL
      - U.S. Navy's Office of Naval Research (ONR)
      - Schiebel CAMCOPTER S-100

(Schiebel, 2021)

- 27,000 range observations per second
- 3x Secchi depth penetration

Rapid Airborne Multibeam Mapping System

OnePass Topo | Bathy | Ortho-Imagery

IHO Order-1 Compliant
DeepChannel, 3x Secchi Pen.
> 2Pts./m2
290m Swath
3x Global Systems Active

Reduced form-factor offers minimized Carbon-Footprint in operations (& allows UAS deployment)

Fugro

Bathy Lidar: Future

Woolpert's Maritime Research Lab through contracts with government and industry clients is working to:

- Increase efficiency and productivity
- Implement off the shelf technology to:
  - Model surface topography
  - Improve geometry
  - Increased spatial resolution
- Real-time Total Propagated Uncertainty (TPU)

Operational Considerations: Depth ‘v’ Water Clarity

- Depth penetration depends on:
  - Water Clarity / Turbidity
    - Seasonal
    - Daily (tides/currents)
  - Seafloor reflectance
    - Bed type
    - Vegetation

Expected Depth of Penetration
Low Power: 1 to 2 x Secchi Depth
High Power: 3 to 4 x Secchi Depth

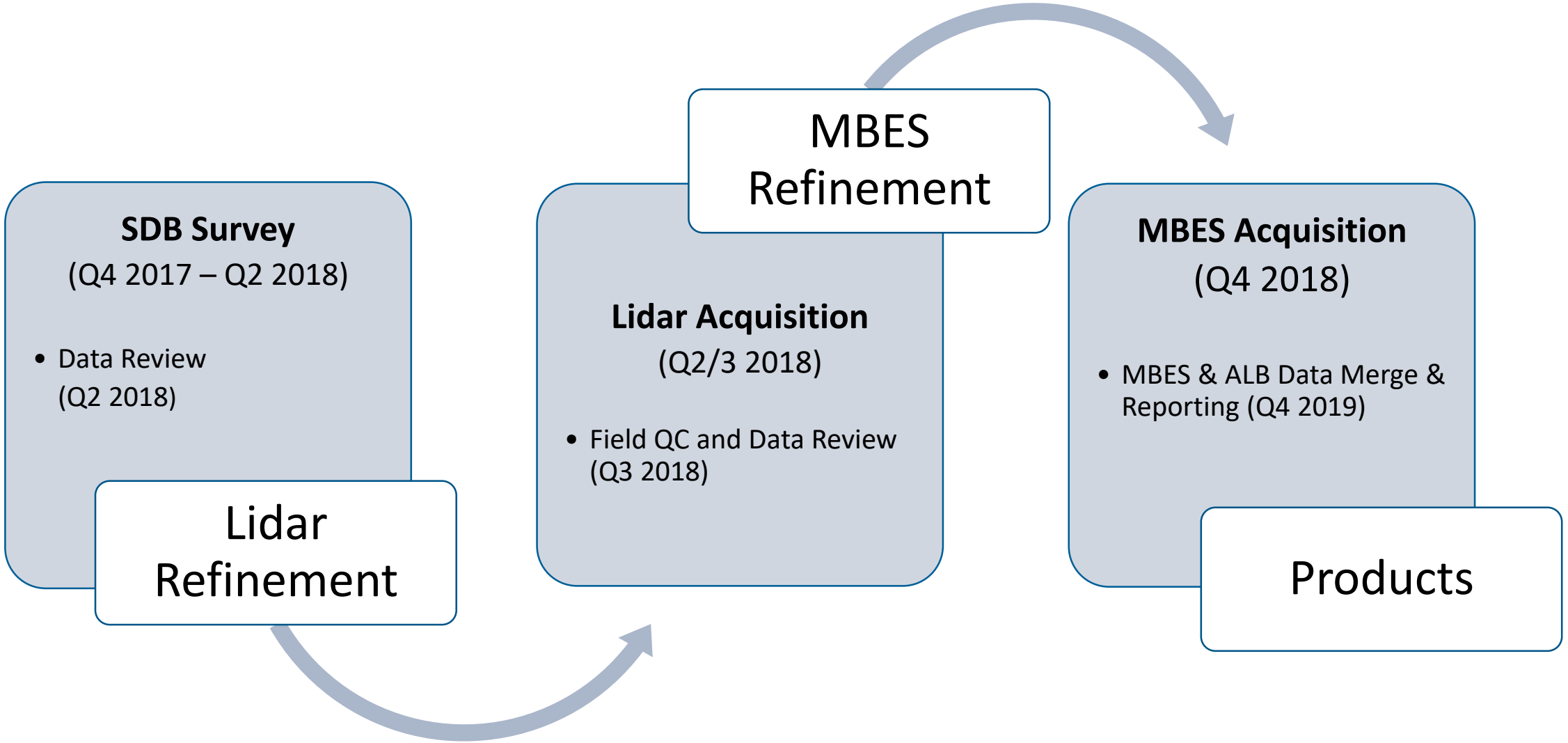
Secchi Disk

- Additional Considerations
  - Weather
    - Temperature, Rain, Cloud Ceiling, Sea State
  - Flight Logistics
    - Air Traffic/ Restricted Airspace / Flight Permits
  - Positioning Plan
    - GNSS (Singlebase, SmartBASE, PPP)
    - Tides (gauge installation?)

Process & Benefits of a Multi-Sensor Approach

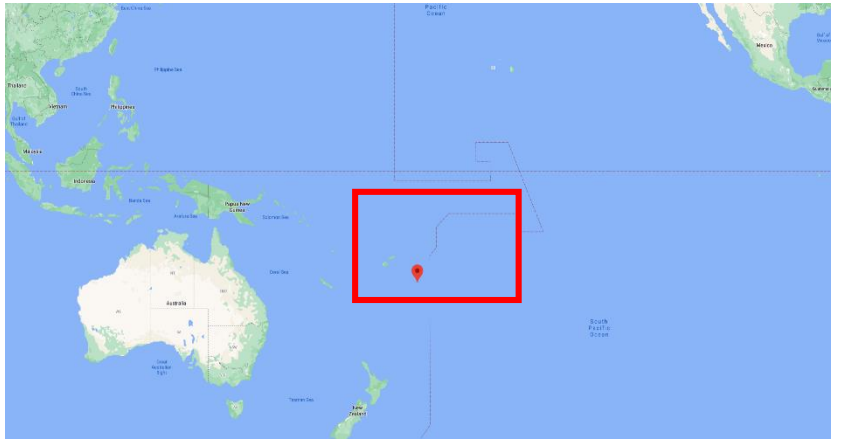
SDB, Lidar and MBES

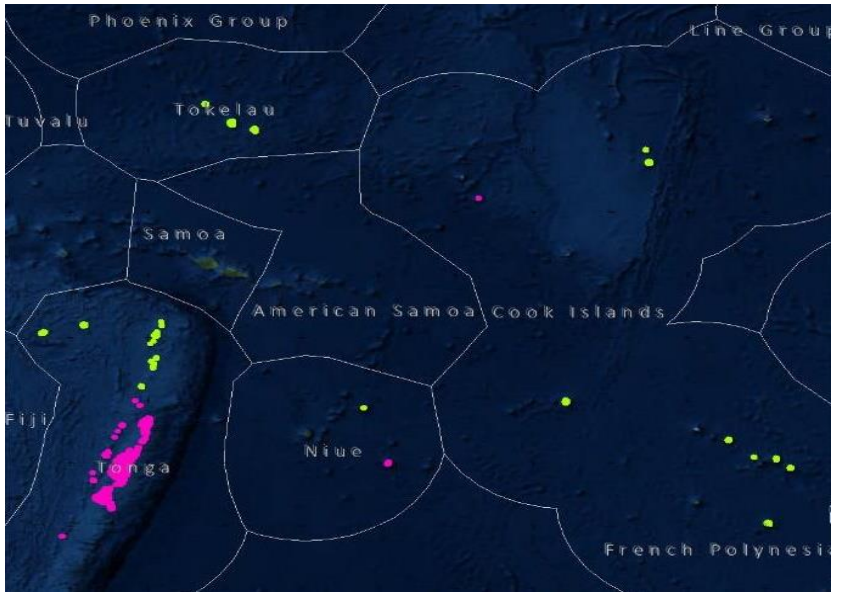
Project Management Overview



Phase 1: Satellite Derived Bathymetry (SDB)

- Review > 350,000 sq.. km using 15m resolution imagery
- 52 Areas of Interest identified
- Over 6,000 sq.. km of SDB using 2m resolution imagery

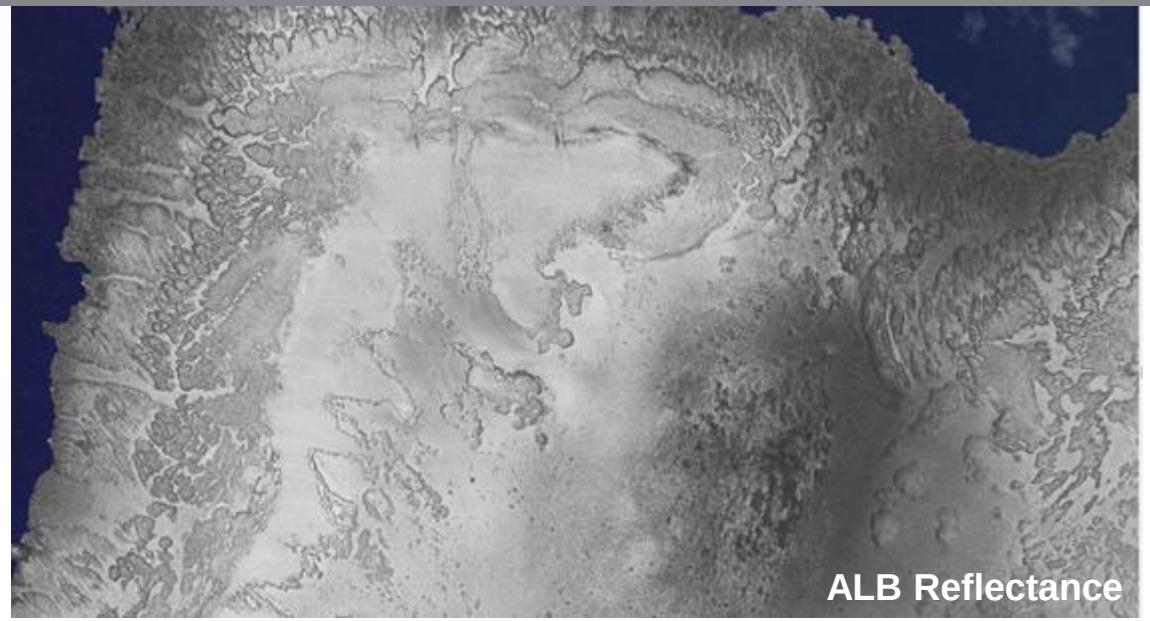


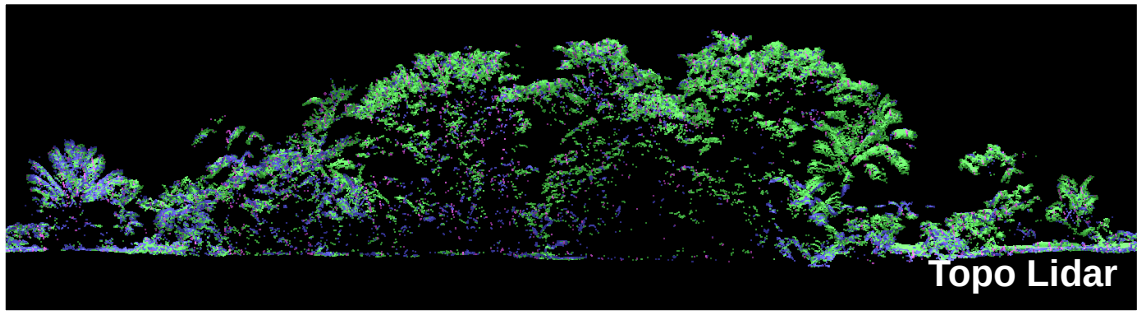


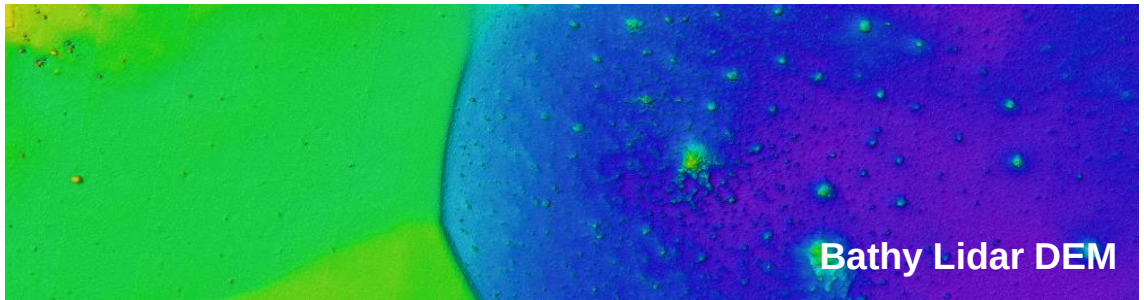
Charting products containing SDB data from this project have already been published

Phase 2: Topo-Bathymetric Lidar

- Chiroptera 4X
  - 400kHz Topo
  - 140kHz bathy
  - 80MP RCD30 RGBN Camera
- 635 sq. km of topo-bathy lidar data
  - 7395 flight line km
  - 9% reflights, 200% Coverage
- Hydrographic Object Detection to 20m
- Max Depth = 47m







Phase 3: Multibeam Echosounder (MBES)

- 32m Survey Vessel & 8m USV (iXBlue DriX)
  - Identical Survey Suites
  - 200kHz Kongsberg EM2040C MBES
- 590 sq. km of MBES data
  - 7450 survey line km (4022 nautical miles)
- 20m to 400m depths

Lidar Survey Refinement: Area Removal

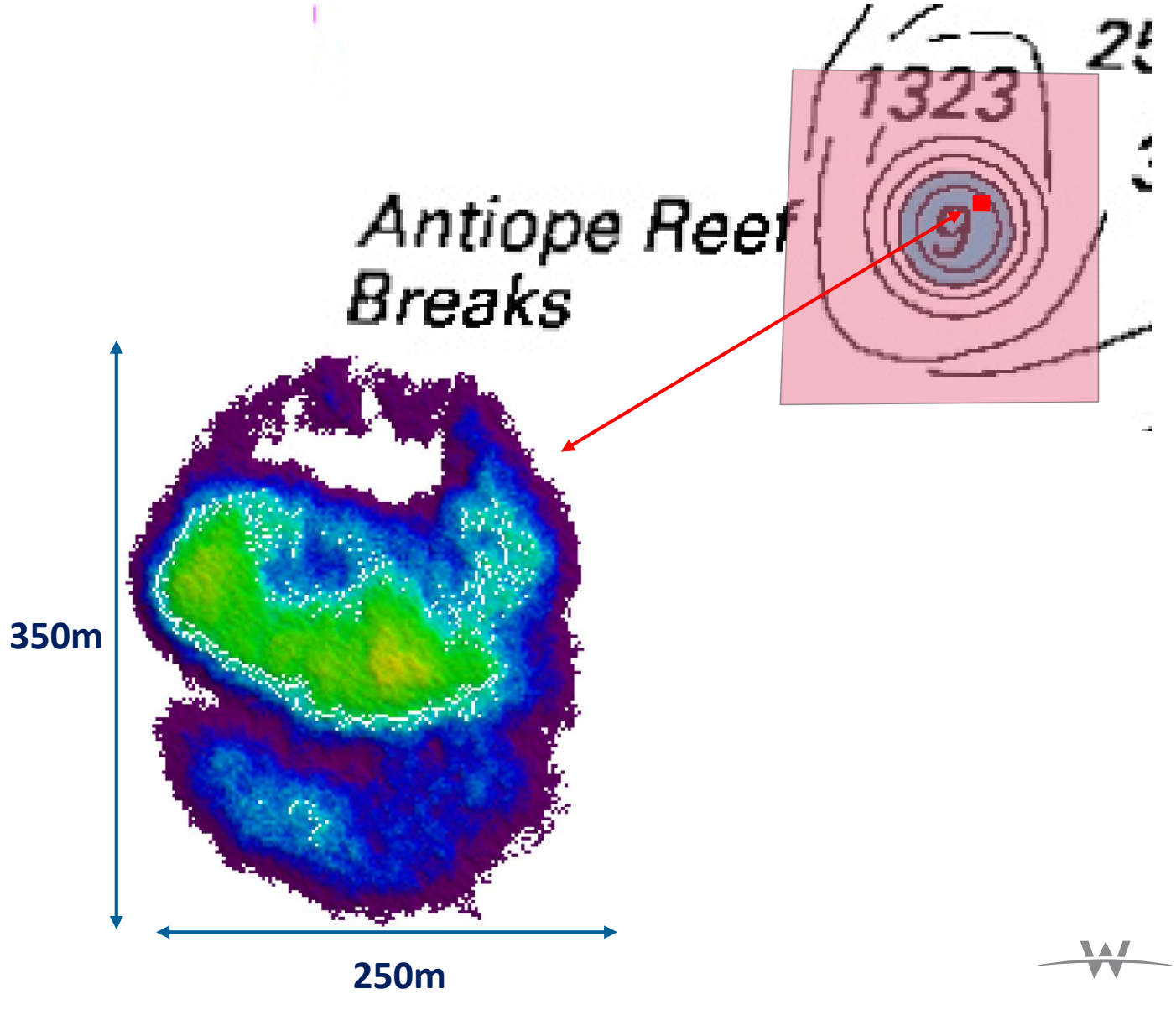
Prior to any Project Phases

- Antiope Reef targeted for lidar
- 180km from Niue (aircraft base)
- Appeared as large area on chart

Lidar Survey Refinement: Area Removal

After SDB Review

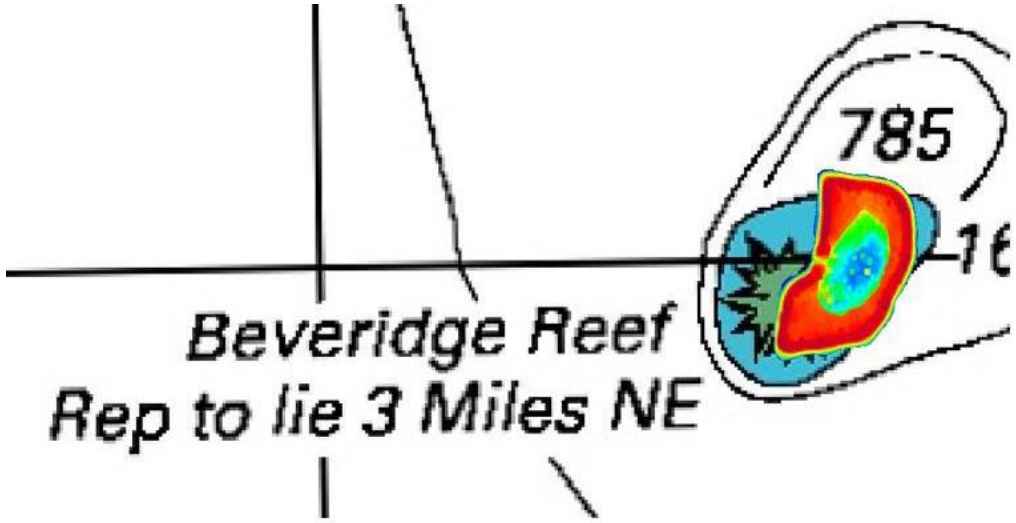
- Small Area 250m x 350m
- Not significant for Navigation
- Lidar not acquired

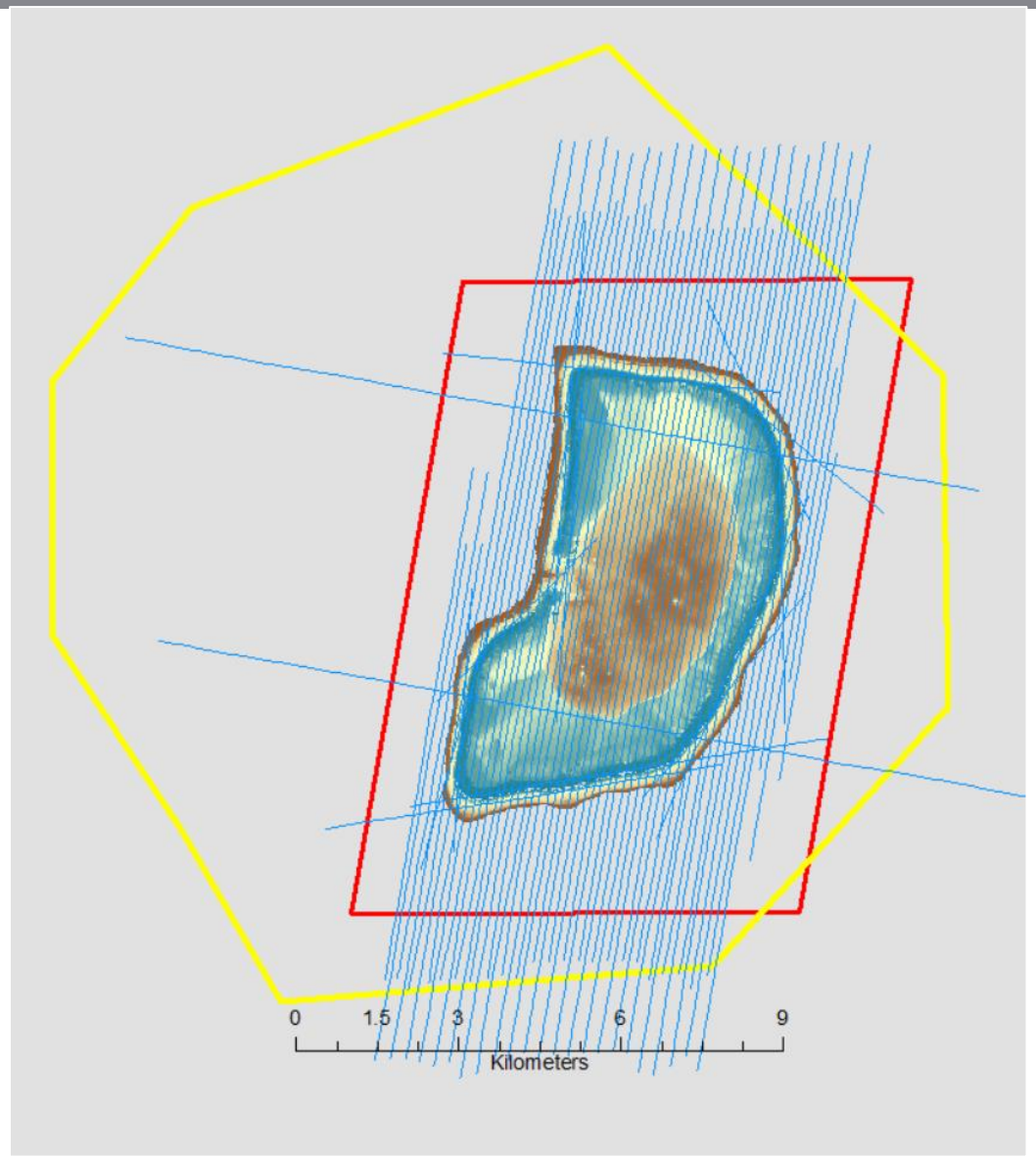


Lidar Survey Area Refinement: Area Reduction

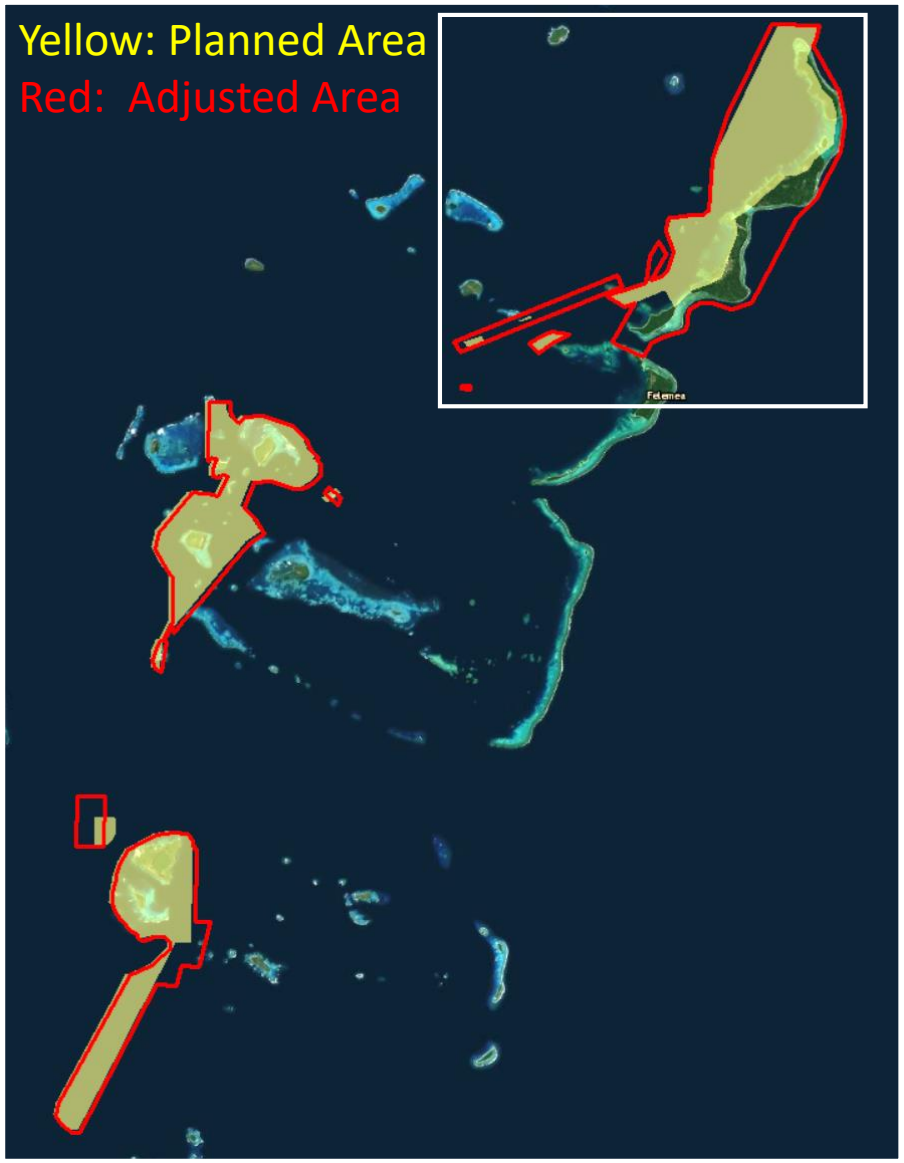
Beveridge Reef

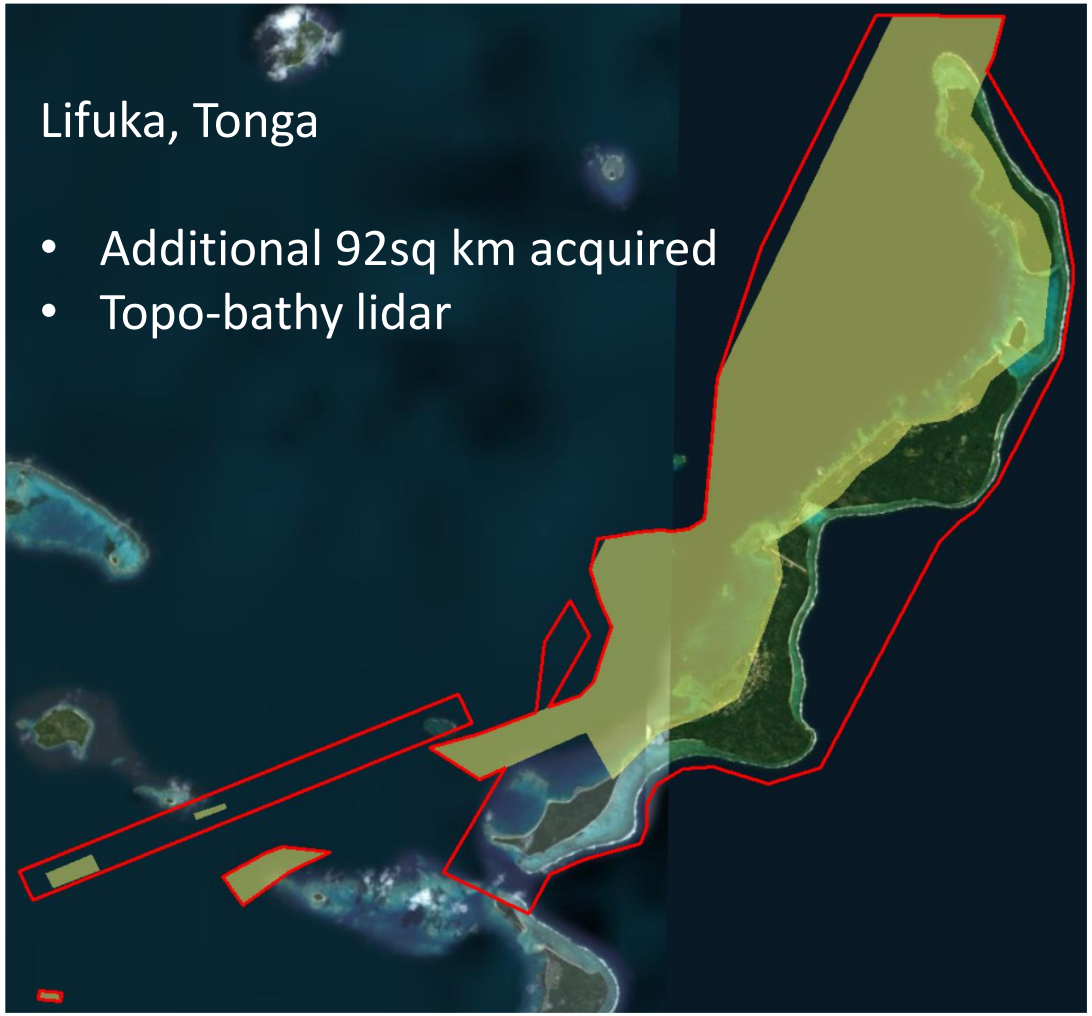
- SDB and Lidar Surveys
- Reef provides a safe haven for small vessels
- Allow technology comparison
- Add charting confidence





Lidar Survey Area Refinement: Area Adjustment/Addition





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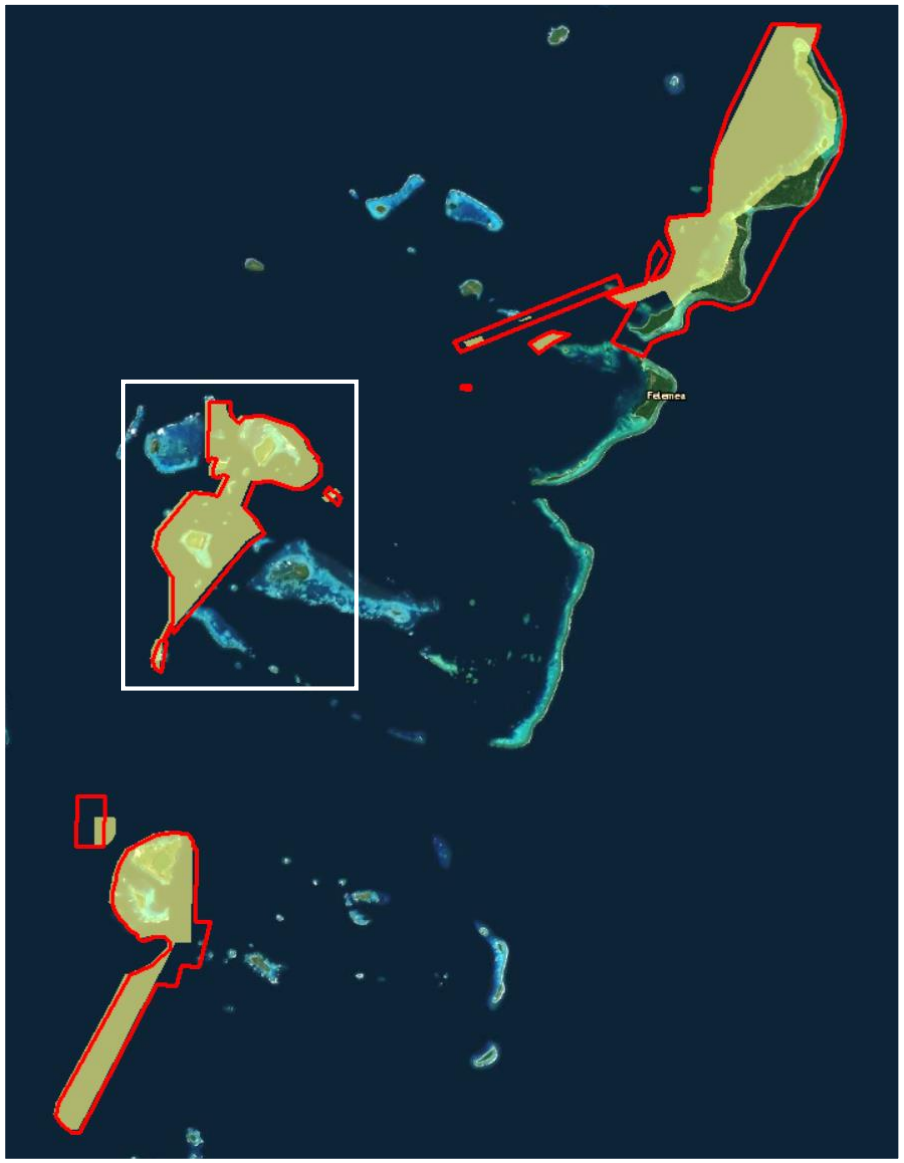
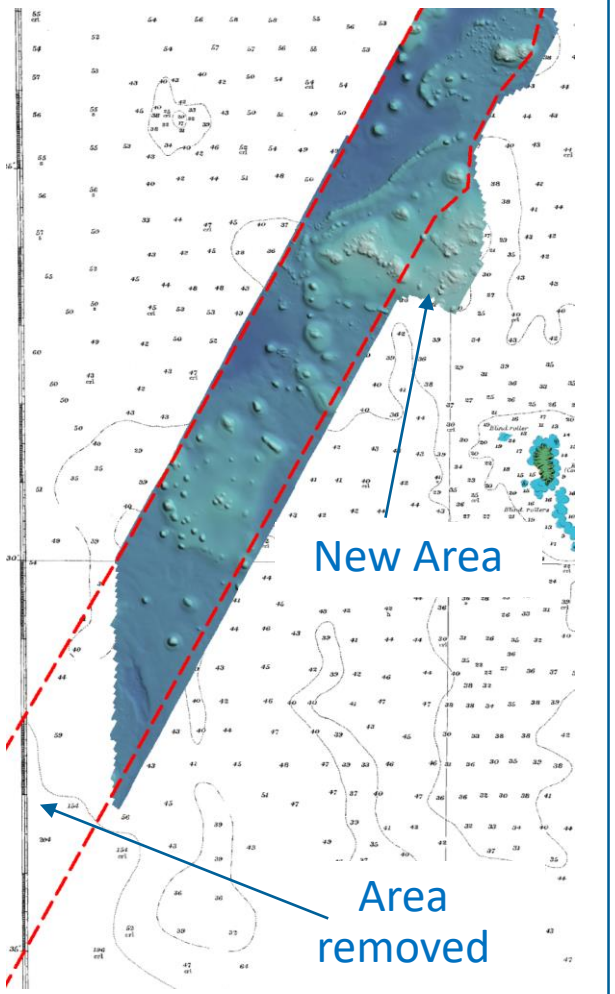
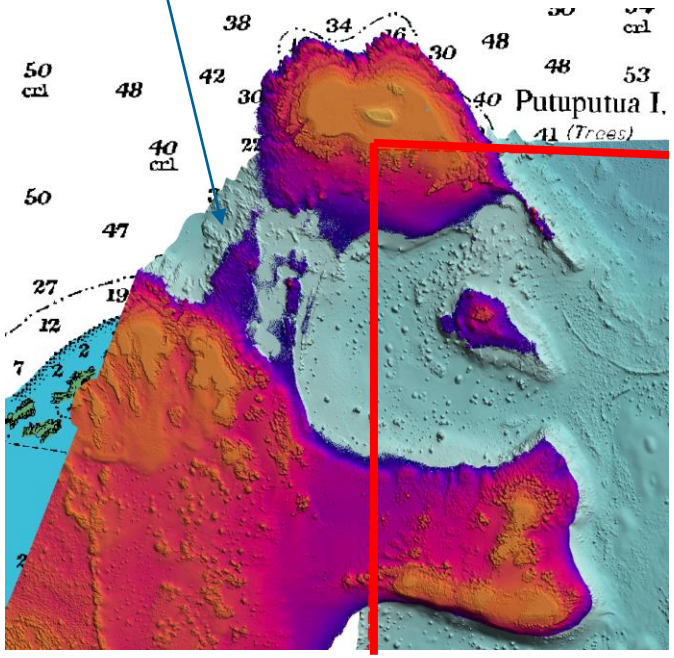
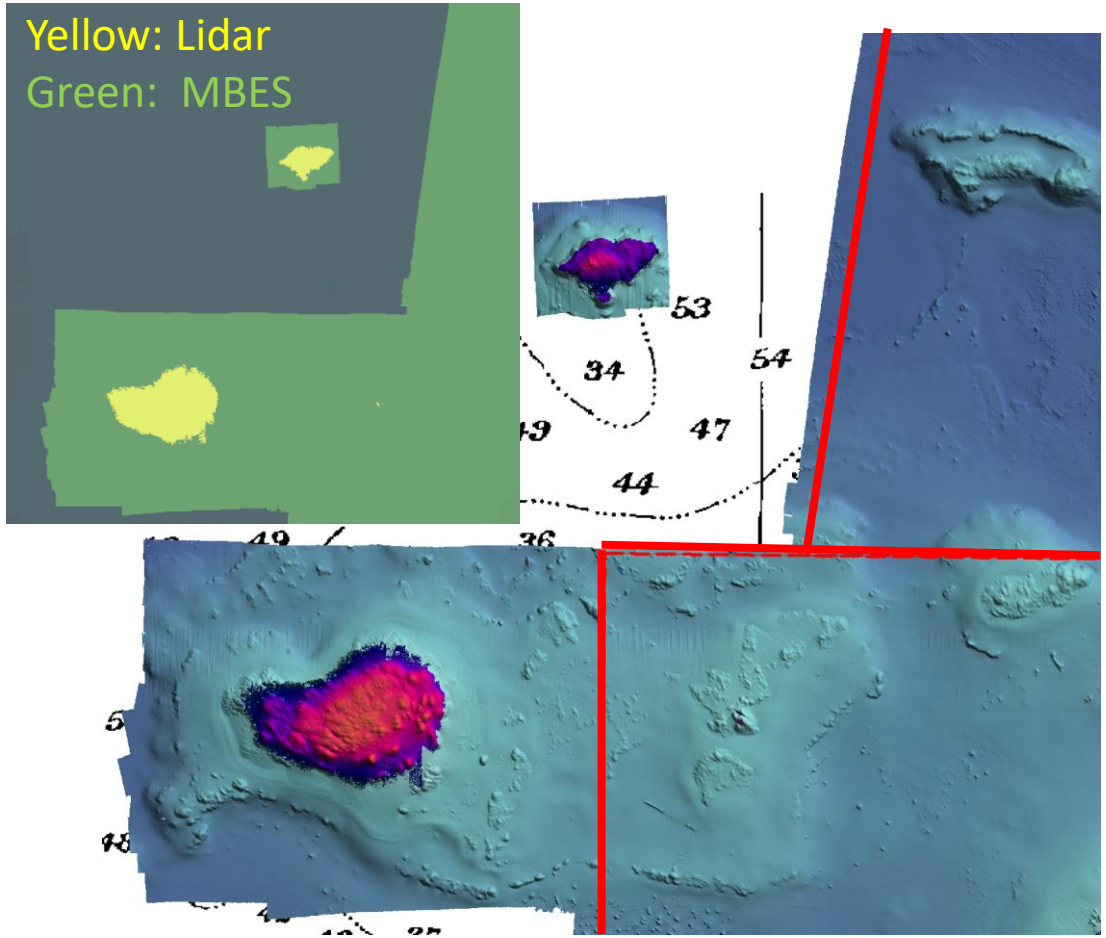


Multibeam Survey Area Refinement

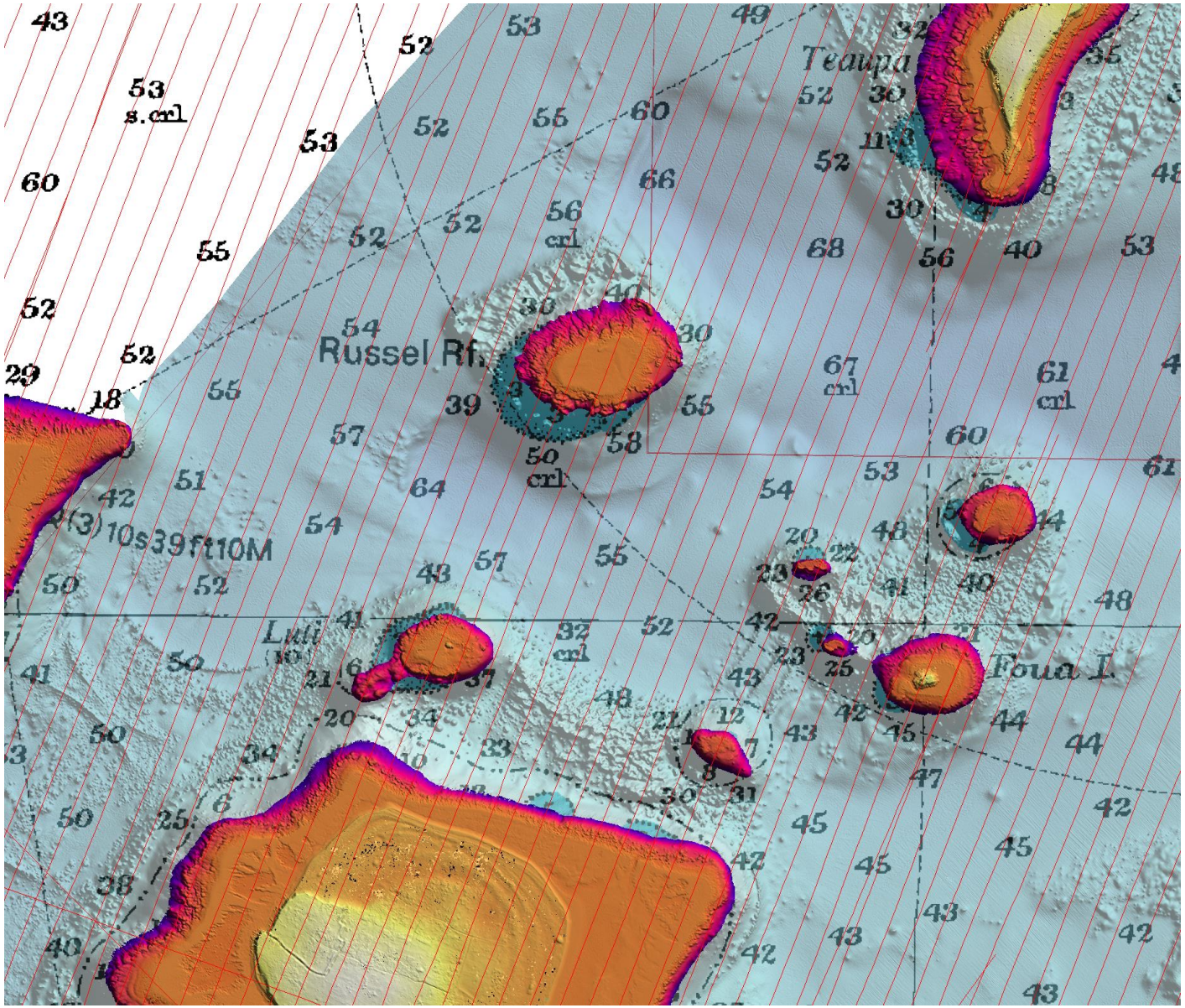


New area with significant shoals blocking channel





Multibeam Risk Management & Efficiency



Lidar coverage used during MBES acquisition:

- Confidence for 24/7 MBES ops
- Efficiency around reefs

Multibeam Risk Management & Efficiency

Lidar coverage in shallow complex seabed **significantly reduced risk to the multibeam vessel survey team.**

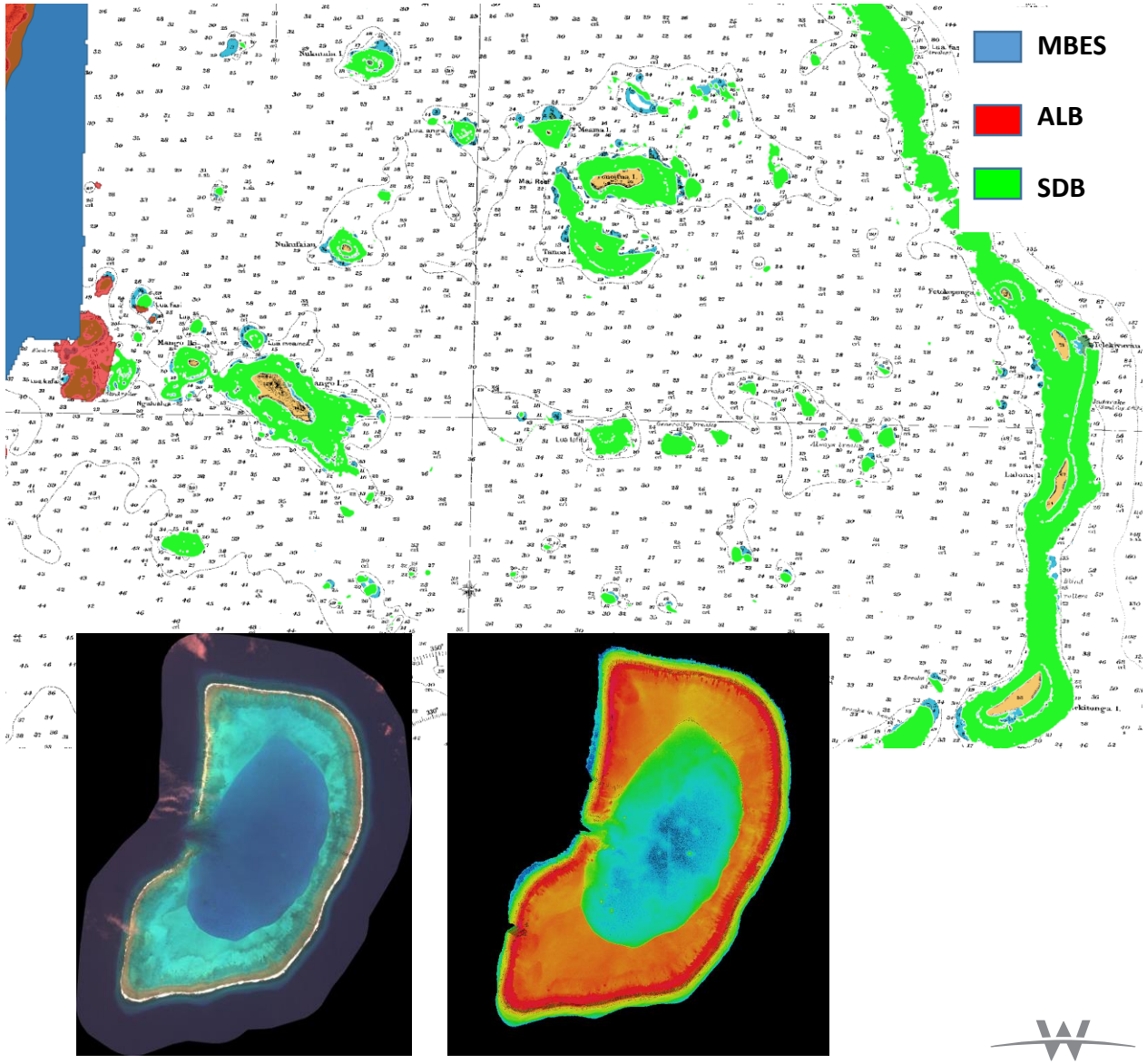
MBES work in this environment is:

- high risk, high consequences
- extremely time consuming
- costly

Elevation Model Colored by RCD30 Imagery

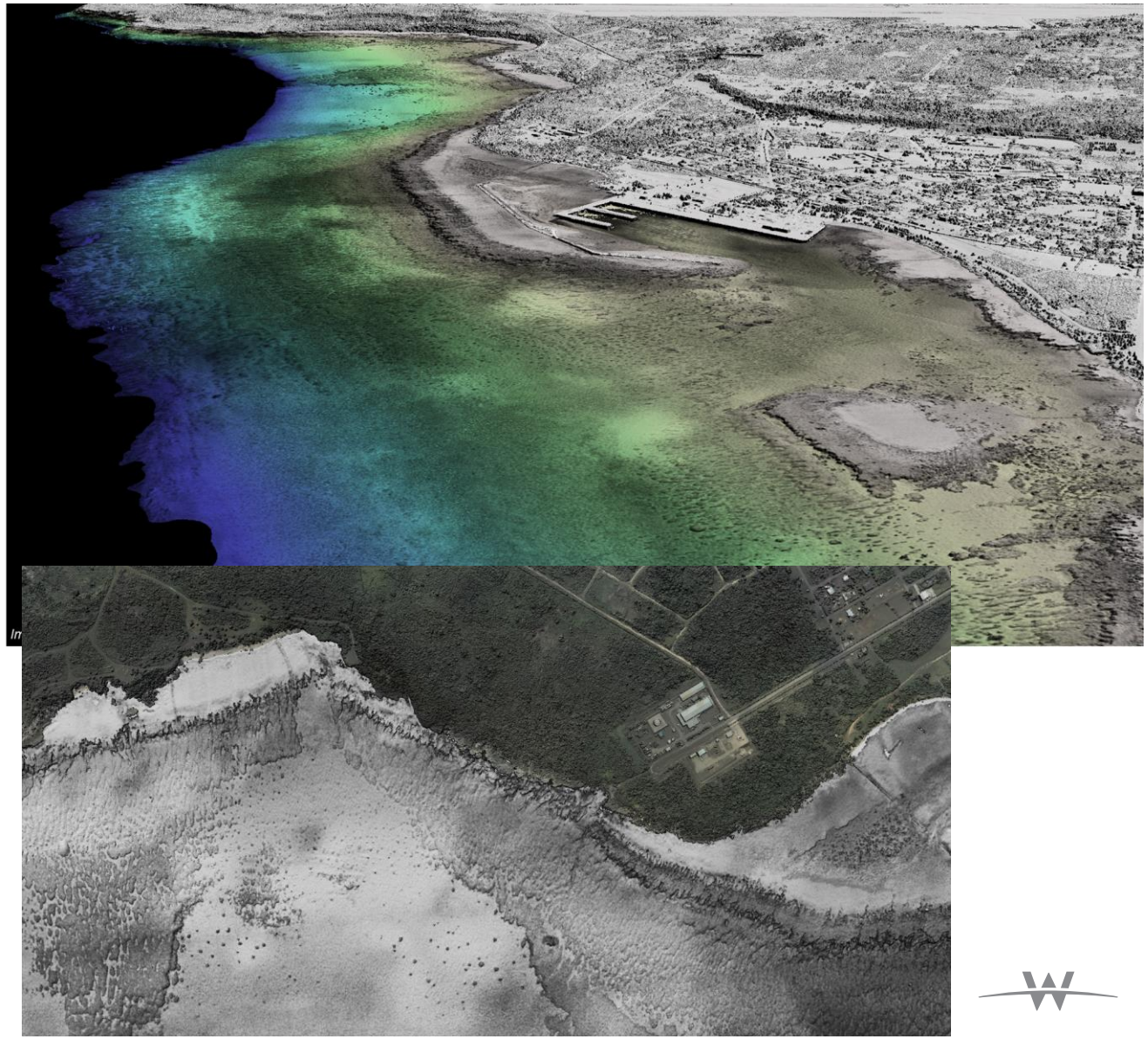
Benefits of a Multi-Sensor Approach: SDB

- Vastly more efficient coverage
- More economical (comparatively)
- Plan & prioritize future surveys based on real modern data
- Effective at detecting shoals
- Excellent choice for very remote locations
- Very low risk, high safety factor
  - No boots on the ground



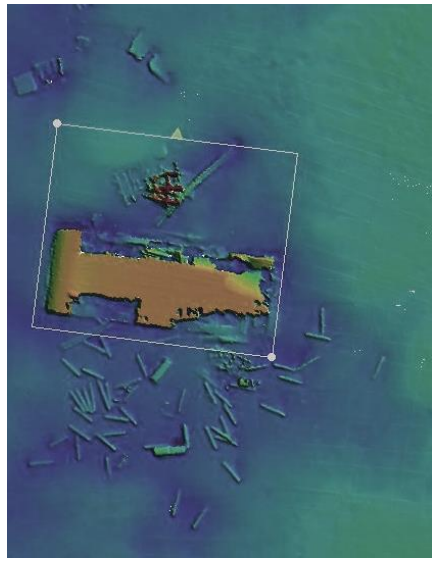
Benefits of a Multi-Sensor Approach: Topo-Bathy Lidar

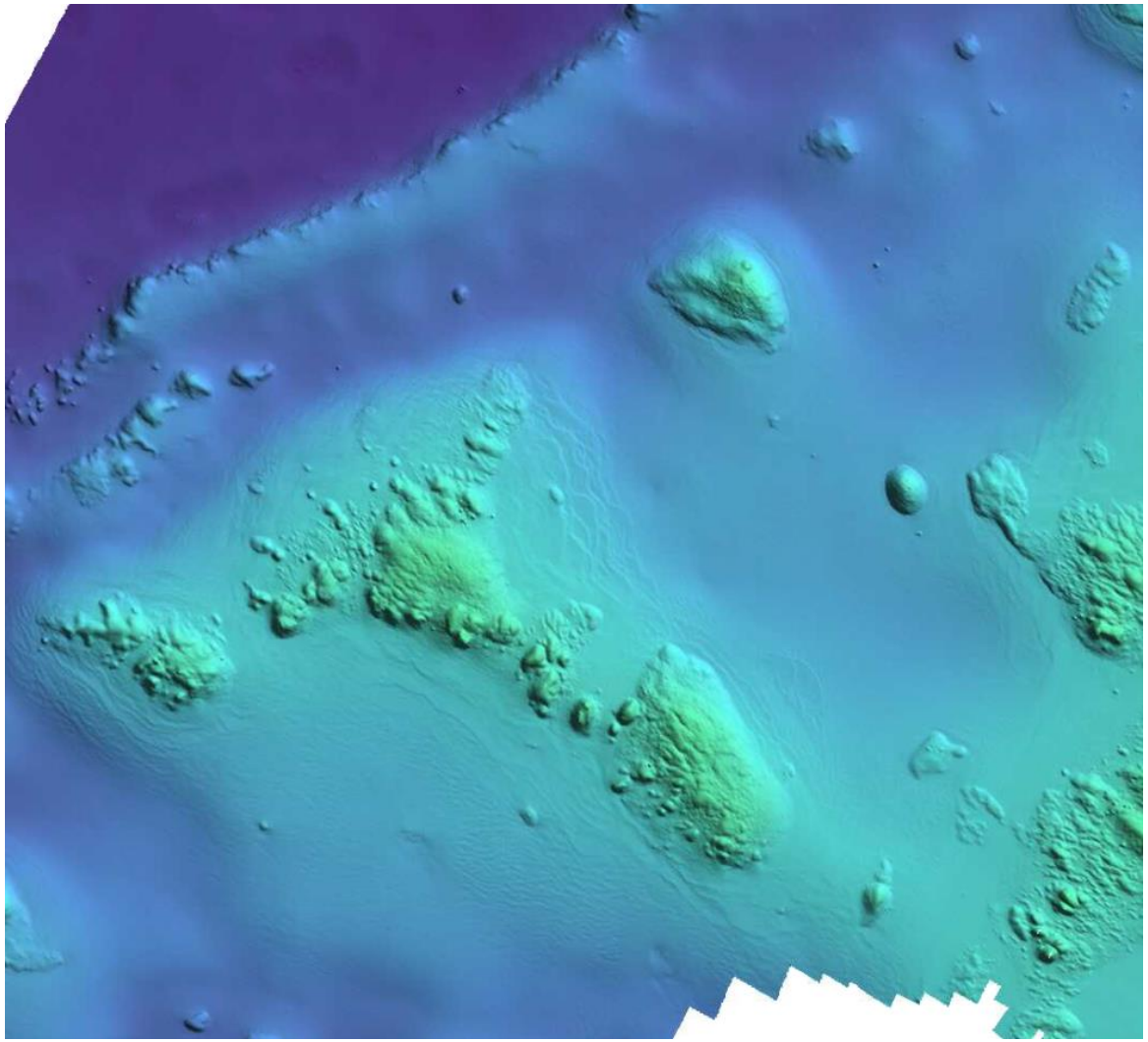
- More efficient coverage
- More economical than vessel-based surveys
- Increase safety and efficiency of vessel-based surveys
- Increased resolution versus SDB
- Excellent choice for remote locations
- Multi-Use Dataset: Topo, Bathy, Imagery, Reflectance for Habitat, Land Cover Analysis, etc…



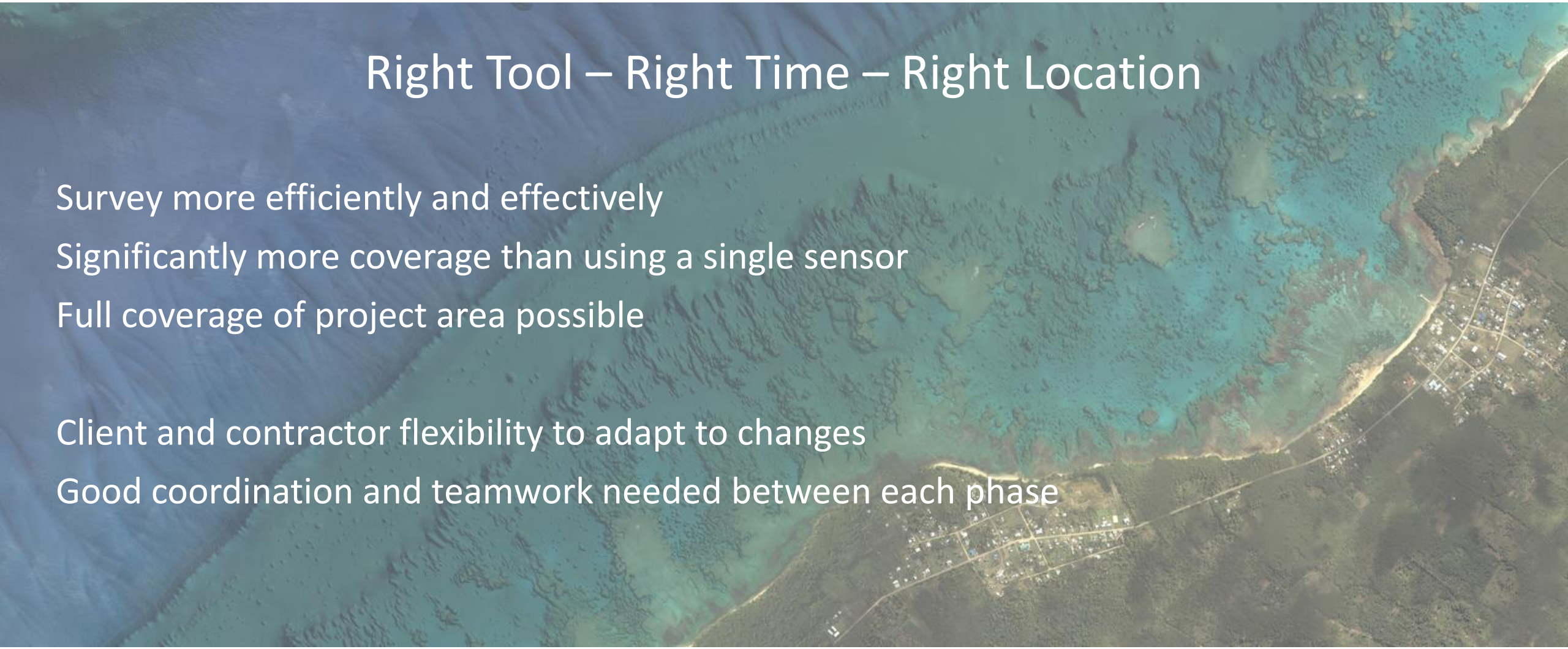
Benefits of a Multi-Sensor Approach: MBES

- Higher resolution over other technology
- Higher accuracy achievable (dependent on systems, users, location, etc..)
- Multi-Use Dataset: Bathy, Backscatter for Geology and Habitat, etc…
- Full depth ranges possible
- USV technology is an effective and efficient force multiplier.





Multi-Sensor Approach Summary



Right Tool – Right Time – Right Location

Survey more efficiently and effectively

Significantly more coverage than using a single sensor

Full coverage of project area possible

Client and contractor flexibility to adapt to changes

Good coordination and teamwork needed between each phase

Thank You

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