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Mapping at Scale: Saildrone Surveyor and Kongsberg EM304 MkII Deep-Water Survey Operations, Performance, and Lessons Learned

29 September 2026

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- ☐ Overview
- ☐ Saildrone Surveyor
- ☐ Project Scope
- ☐ Operational Lessons Learned
- ☐ Processing Lessons Learned
- ☐ Results
- ☐ Contributors



AGENDA



- Saildrone began large-scale, uncrewed surface vehicle (USV) deep-water bathymetric surveys in the Caribbean and Pacific in August 2024.
- Long-endurance remote operations prompted advances in hardware, software, and workflows.
- Adapted sonar and real-time monitoring show that uncrewed platforms suit large-scale ocean mapping and meet International Hydrographic Organization *S-44 Standards for Hydrographic Surveys*



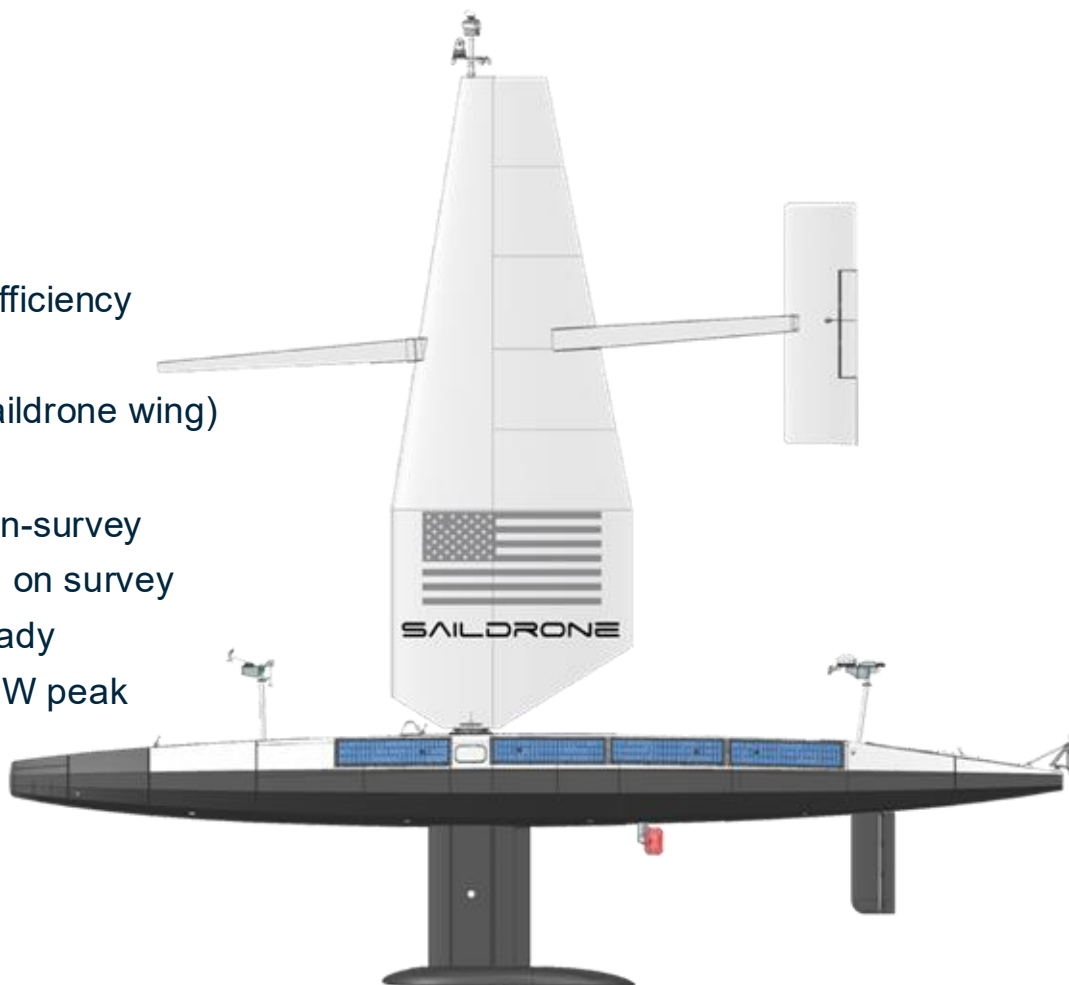
Overview

SAILDRONE SURVEYOR

World's largest and most advanced uncrewed surface vehicle for ocean mapping and exploration

SPECIFICATIONS

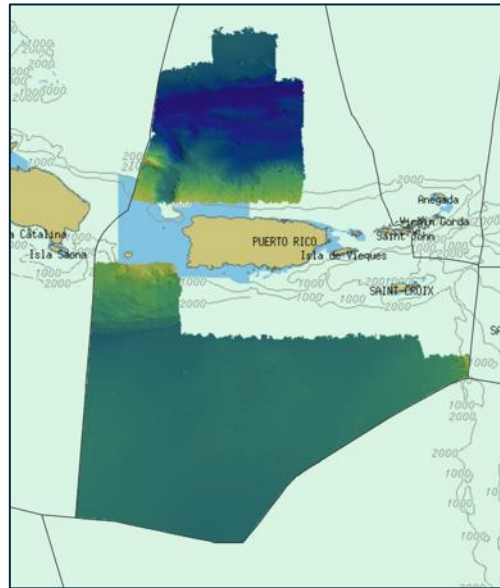
- ▶ Length: 20 m
- ▶ Wing height: 13 m
- ▶ Draft: 3 m
- ▶ Primary propulsion: 78 hp high-efficiency diesel
- ▶ Augmented propulsion: Wind (Saildrone wing)
- ▶ Mapping speed: 4-6 kts
- ▶ Endurance: 90+ days non-survey
30-45+ days on survey
- ▶ Payload power: 2,000 W steady state, 4,000 W peak



Variable	Sensor
Positioning	Applanix POS MV OceanMaster
Deep-water bathymetry	Kongsberg EM 304 MkII multibeam sonar
Shallow-water bathymetry	Kongsberg EM 2040 MkII multibeam sonar
Wind speed & direction	B&G WS730S
Barometric pressure	Yacht Devices YDBC-05N
Ocean currents	Teledyne Pinnacle 45 ADCP
Surface sound velocity profiler	Teledyne SVP 70 (fixed on bottom of gondola)
Sound velocity profiler & winch	AML-3 (cast depth: 450 m)
Satellite communications	Starlink, Iridium
Camera	FLIR M364C Pan-tilt-zoom camera
AIS transceiver	SRT Marine Cobalt, Class B

PROJECT SCOPE

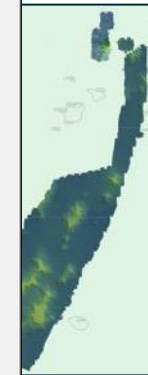
- Utilizing Saildrone Surveyor uncrewed surface vehicles equipped with Kongsberg EM304 MkII sonar systems, the team has mapped more than 450,000 km² of the continental shelf to depths greater than 8,000m.



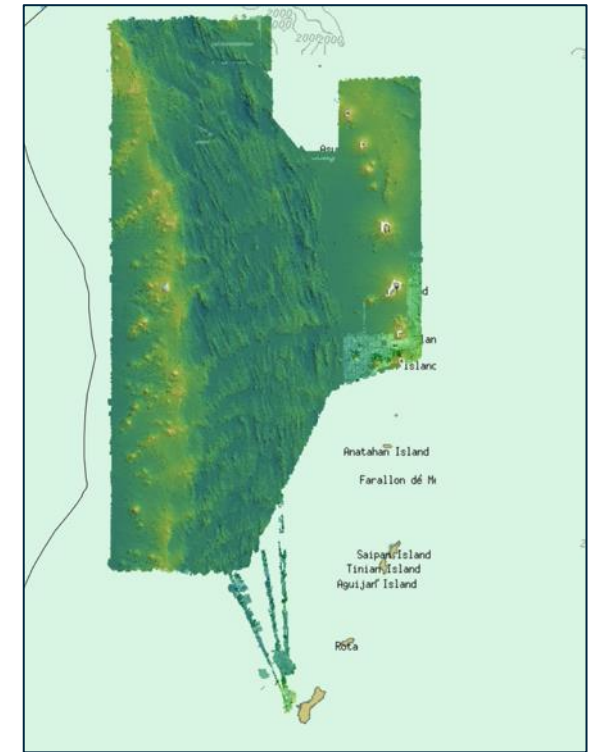
122,700 km²



- Surveyed area is roughly the size of Sweden**
- Accounts for 0.17% of remaining unsurveyed seafloor.**

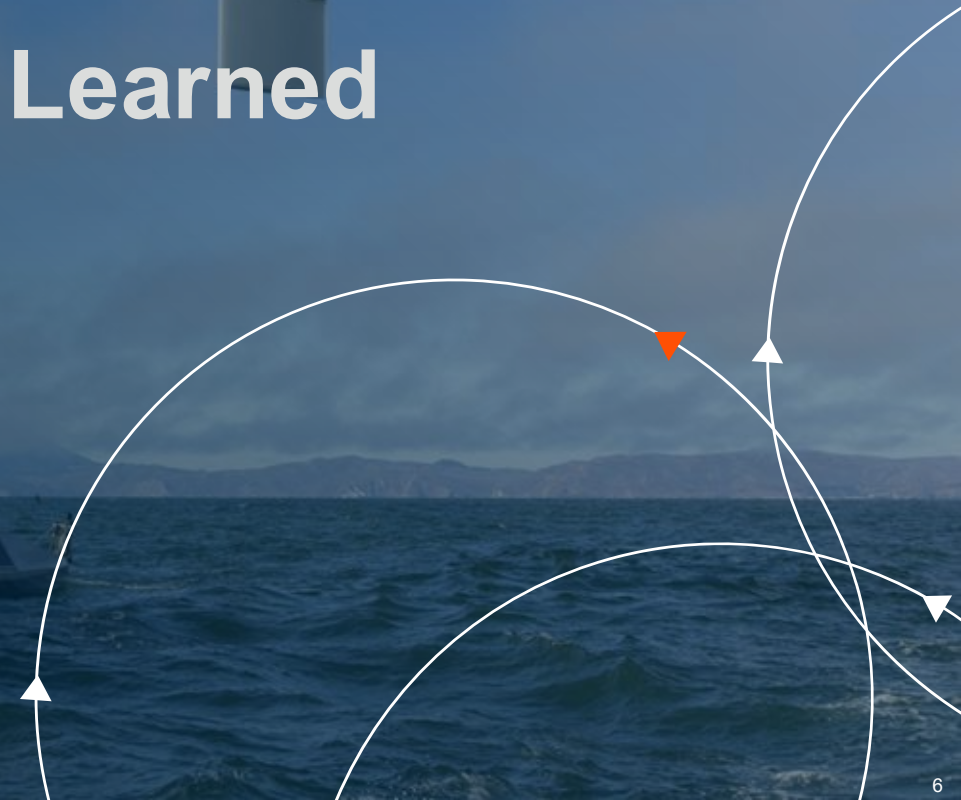


km²



191,500 km²

Operational Lessons Learned



Kongsberg EM304 DC Conversion

USV HARDWARE OPTIMIZATION

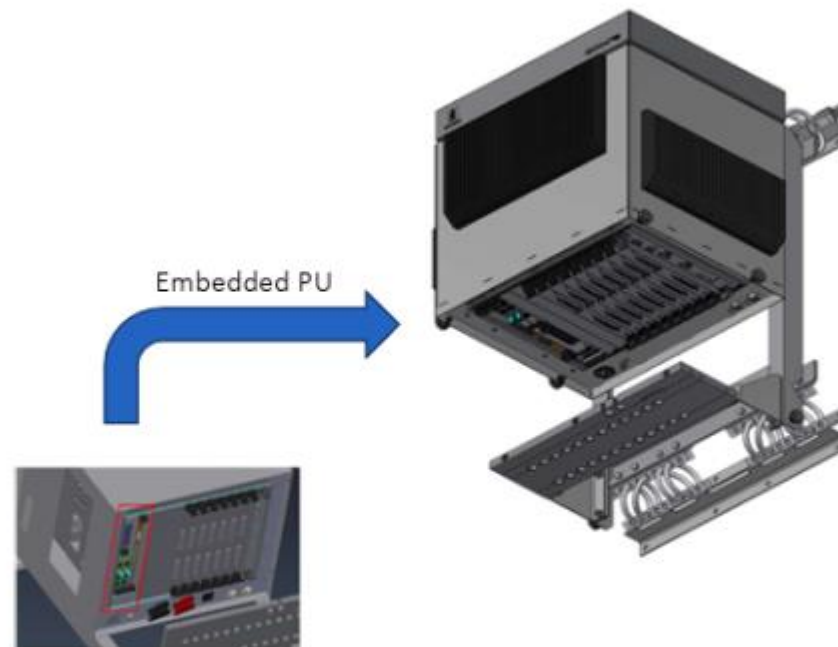
⚠ CHALLENGE

The legacy Kongsberg EM304 uses an **AC electrical architecture** split across three separate components (TX, RX, and PU). This creates severe inefficiencies and complex grounding issues on USVs

✅ SOLUTION & KEY IMPROVEMENTS

Kongsberg developed the **DC-E system** (EM124 DC-E & EM304MKII DC-E) tailored specifically for USV platforms:

- ✓ **Native DC Power:** Eliminates AC-DC inverters, significantly cutting electrical noise and power consumption.
- ✓ **Embedded Processing Unit:** Integrated directly into the TXU to save physical space, cabling, and installation complexity.
- ✓ **Form Factor Parity:** TXU and RXU maintain standard unit dimensions for seamless integration.
- ✓ **Zero Transducer Changes:** Fully compatible with existing transducer hardware without modifications.



Embedded Processing Unit (PU) integration into the TXU enclosure

SVP Sargassum Clogging Mitigation

USV OPERATIONAL OPTIMIZATION

⚠ CHALLENGE

Operating in the Caribbean during peak **sargassum weed season** caused frequent clogging of the Sound Velocity Profiler (SVP). As an uncrewed platform, lack of onboard personnel necessitated full vehicle recovery to clear blockages.

✅ SOLUTION & ACTION ITEMS

Multi-layered operational and hardware solutions implemented to maintain continuous survey capability:

- ✓ **PTZ Camera Visual Inspection:** Pilots assess sargassum density via Pan-Tilt-Zoom camera prior to initiating each SVP cast.
- ✓ **Daylight Cast Scheduling:** Shifted SVP deployments exclusively to daylight hours to ensure visual clearance.
- ✓ **"The Salad Chopper" Mechanism:** Modified the SVP bazooka with a cutting device that slices and disposes of weed using the force of the cast.
- ✓ **Glider Array Comparison:** Deployed gliders alongside USV to compare traditional SVP profiles with glider sound velocity data.



Saildrone SIS Wizard Utility

⚠ KEY SIS ISSUES ADDRESSED

Operating standard SIS natively presented operational friction for hydrographers managing complex survey campaigns:

- ✗ **Filename Linetypes:** Inability to directly append linetypes to SIS output filenames.
- ✗ **Job Configuration:** Cumbersome manual setup for new survey jobs in GUI/JSON.
- ✗ **Config Recovery:** Absence of historical sounderinfo.json backups for troubleshooting.

🔧 SIS WIZARD SOLUTION & CAPABILITIES

Saildrone developed the **SIS Wizard** utility (built in Python with AI assistance) to assist hydrographers:

- ✓ **Dynamic Linetype Appending:** Modifies vessel identifier string via GUI to append linetype tags automatically (e.g., SD-3000-0020_XL or SD-3000-0020_CAL).
- ✓ **Automatic Backups & Instant Undo:** Automatically creates timestamped JSON backups prior to edits with a single-click "Undo" to restore prior states.
- ✓ **Intuitive Job Creation:** Simple GUI interface for creating new survey jobs with pre-configured settings and path defaults.
- ✓ **AI-Assisted Development:** Developed rapidly in Python utilizing AI programming tools to solve hydrographer pain points.

HYDROGRAPHIC WORKFLOW TOOLING



Linetype Control Interface (Primary Acq, Crossline, CAL, TEST)



New Survey Job Setup & Parameter Configuration

SIS 5.14 Software Transition

⚠ CHALLENGE

Upgrading from legacy SIS 5.11 to SIS 5.14 was stalled by strict hardware enforcement:

- ✗ **Hardware Lock-In:** Early SIS 5.14 builds strictly favored physical Kongsberg Hydrographic Workstation (HWS) hardware.
- ✗ **Virtualization Bottleneck:** Enterprise USV virtualization standards prohibited direct physical server installs.

✅ SOLUTION & UNLOCKED CAPABILITIES

Successfully resolved VM compatibility barriers to transition to SIS 5.14, unlocking major operational advances:

- ✓ **Full VM Deployment:** Executed SIS 5.14 on Virtual Machines, fully breaking reliance on physical HWS units.
- ✓ **Remote Survey Integration:** Full remote capability breaking dependency on local vessel UIs.
- ✓ **Optimized UI & 3D Graphics Engine:** Supports massive high-density point clouds with minimal CPU/GPU overhead.
- ✓ **Expanded K-Controller Features:** Unlocks multi-frequency pinging, water column phase logging, and advanced detection algorithms.
- ✓ **Enhanced Data Synchronization:** Improved handling for delayed heave, RTK positioning, and SSP integration.

ACQUISITION SOFTWARE UPGRADE

PHYSICAL HARDWARE ELIMINATED



Migrated to Virtual Machine (VM) Architecture

Replaced standalone Kongsberg HWS hardware box with VM deployment

KMALL Ellipsoidal vs. Orthometric Workflows

KMALL PROCESSING & REFERENCING

⚠ CHALLENGE / SOFTWARE DISCREPANCY

Workflow mismatch between Saildrone (using **CARIS HIPS&SIPS**) and client post-processors (using **Qimera**) regarding KMALL height datagram interpretation:

- ❗ **GGA vs GGK Discrepancy:** When POS/MV outputs GGA, the KMALL #SPO Ellipsoidal Height record actually stores *Orthometric Height*.
- 📦 **Software Parsing Difference:** CARIS uses high-frequency #SKM binary data for ellipsoid referencing, whereas Qimera relies on #SPO—causing vertical offsets if set to GGA.

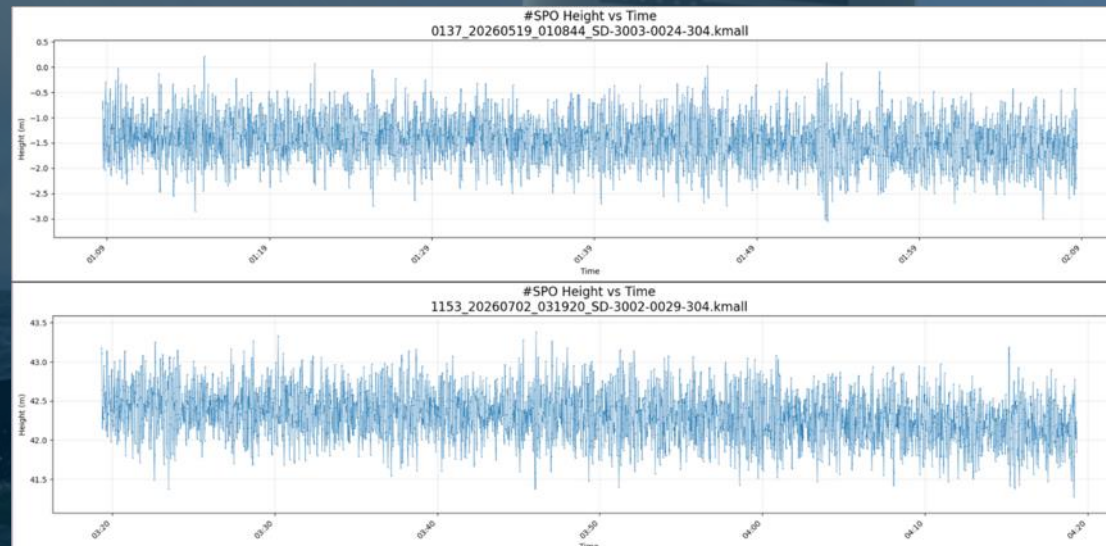
✅ SOLUTION & BEST PRACTICE

Configuring system parameters to guarantee seamless multi-platform post-processing:

- ✓ **Mandate GGK Output:** Configure POS/MV to output GGK NMEA strings, ensuring the #SPO record accurately stores true Ellipsoidal Height per specification.
- ✓ **Geoid-Spheroid Separation Model:** If orthometric height is required for specific deliverables, compute it using geoid separation models in post-processing.
- ✓ **Standardized NMEA Settings:** Prevents vertical reference discrepancies regardless of whether data is processed in CARIS or Qimera.

Avg ht = -1.5m

Avg ht = 42.5m



POS/MV Navigation & Trajectory Optimization

POS/MV TRAJECTORY OPTIMIZATION

⚠ CHALLENGE

Post-processing navigation data revealed critical quality defects: **excessive IMU data gaps** (up to 20/day requiring POSPAC file splitting) and **unexplained altitude jumps** forcing data discarding.

✅ ROOT CAUSE ANALYSIS & DUAL SOLUTIONS

Investigation confirmed these were independent issues with distinct root causes and solutions:

🔧 1. IMU Data Gaps (Network Resource Contention)

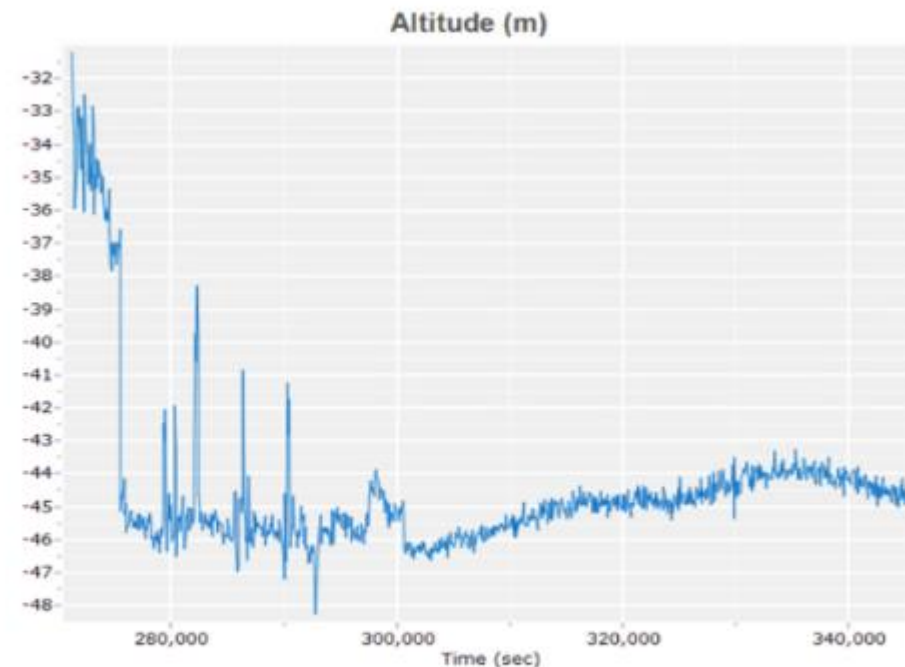
Cause: Network logging running on the same VM as MBES acquisition software.

Solution: Migrated MV POSView to execute on an isolated, dedicated Virtual Machine.

📈 2. Altitude Record Jumps (IMU Roll & Correction Error)

Cause: IMU misalignment during heavy vessel rolls & unapplied DGNSS corrections.

Solution: Upgraded POS/MV firmware for roll recovery & transitioned to Trimble RTX.



Real-time POS/MV altitude trajectory jump (-32m to -48m artifact)

Swath Overlap Analysis & Verification

⚠ CHALLENGE

Lack of standard or consistent tools to verify strict client **swath overlap requirements** in real-time and post-processing. While the SIS depth grid visualizes overall coverage, it lacks explicit overlap metrics between adjacent survey lines.

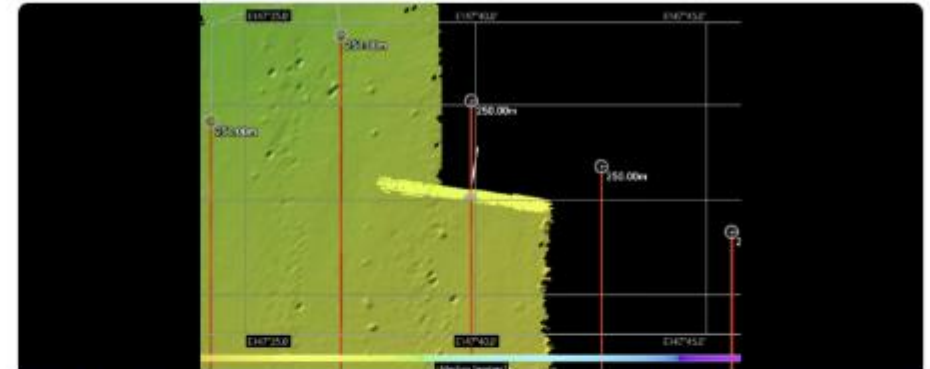
✅ SOLUTION & RECOMMENDATIONS

Multi-stage software enhancements implemented to enable track-line overlap analysis:

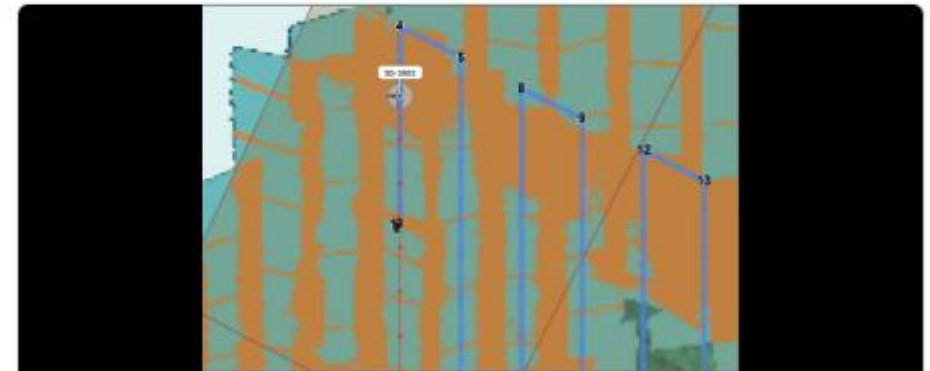
- ✓ **Saildrone Overlap Analysis Tool:** Integrated MB-System into Mission Portal to display track-lines, routes, and explicit overlap visual layers for pilot review.
- ✓ **Software Vendor Engagement:** Collaborated with leading processing SW vendors to drive native swath overlap calculation and comparison toolsets.
- ✓ **Vendor Recommendation:** Advise Kongsberg to integrate native, real-time swath overlap visualization directly into future SIS software builds.

★ **Approach Attribution:** This approach was identified by Paul Johnson, Center for Coastal and Ocean Mapping.

USV OPERATIONAL OPTIMIZATION



SIS Real-Time Depth Grid (Displays coverage, lacks overlap analysis)



Saildrone Mission Portal MB-System Overlap Layer

SIS Penetration Filter Swath Optimization

OPERATIONAL OPTIMIZATION & TRAINING

💡 OPERATIONAL DISCOVERY

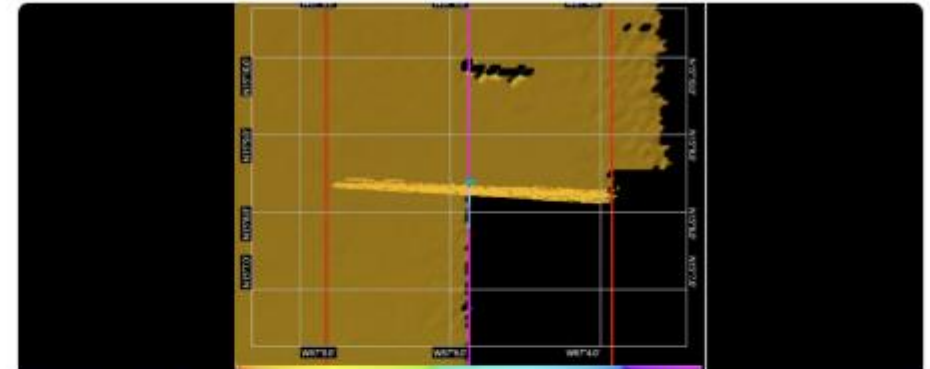
During 1:1 acquisition training with **Seirios Solutions SMEs**, watchstanders evaluated the **SIS Penetration Filter** and uncovered an unannounced operational benefit:

- 📊 **Kongsberg Doc Variance:** Documentation states the filter only affects central beams, but field testing proved a massive impact on outer swath width.
- 🔄 **Immediate Impact:** Toggling the filter from "Off" to "Weak" instantly extended swath coverage by hundreds up to 2,800+ meters.

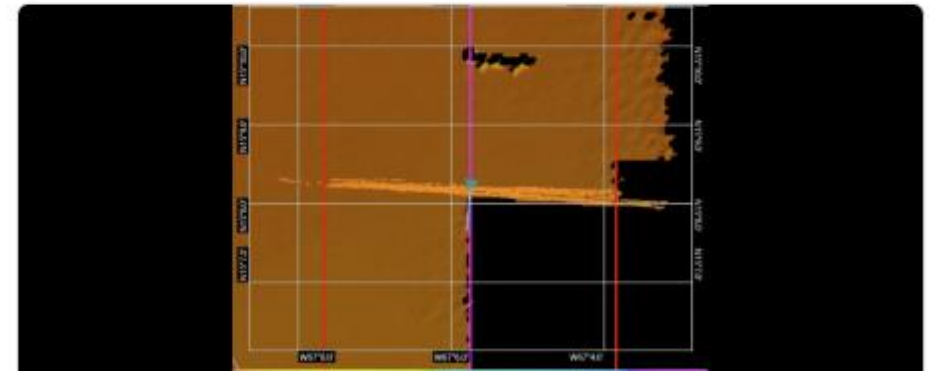
📈 OPERATIONAL IMPACT & KEY FINDINGS

Key findings and best practices established across USV platforms:

- ✓ **Extended "Deeper" Mode Operating Window:** Significantly delayed needing to switch to "Very Deep" mode, maintaining higher resolution and wider coverage.
- ✓ **Cross-Platform Verification:** Confirmed on all Saildrone vehicles, and verified independently on non-Saildrone EM304 MKII installations.
- ✓ **Watchstander Vigilance Required:** Watchstanders must monitor for edge-case artifacts (sector break spikes, noise amplification, nadir tracking on steep slopes).



Penetration Filter Turned OFF (Outer swath narrows significantly)



Penetration Filter Turned ON (Swath coverage expands up to 2.8 km)

Processing at Scale: Observations and Lessons Learned

Lindsay Gee & Erin Heffron
Ocean Mapping Services, LLC
info@oceanmappingservices.com

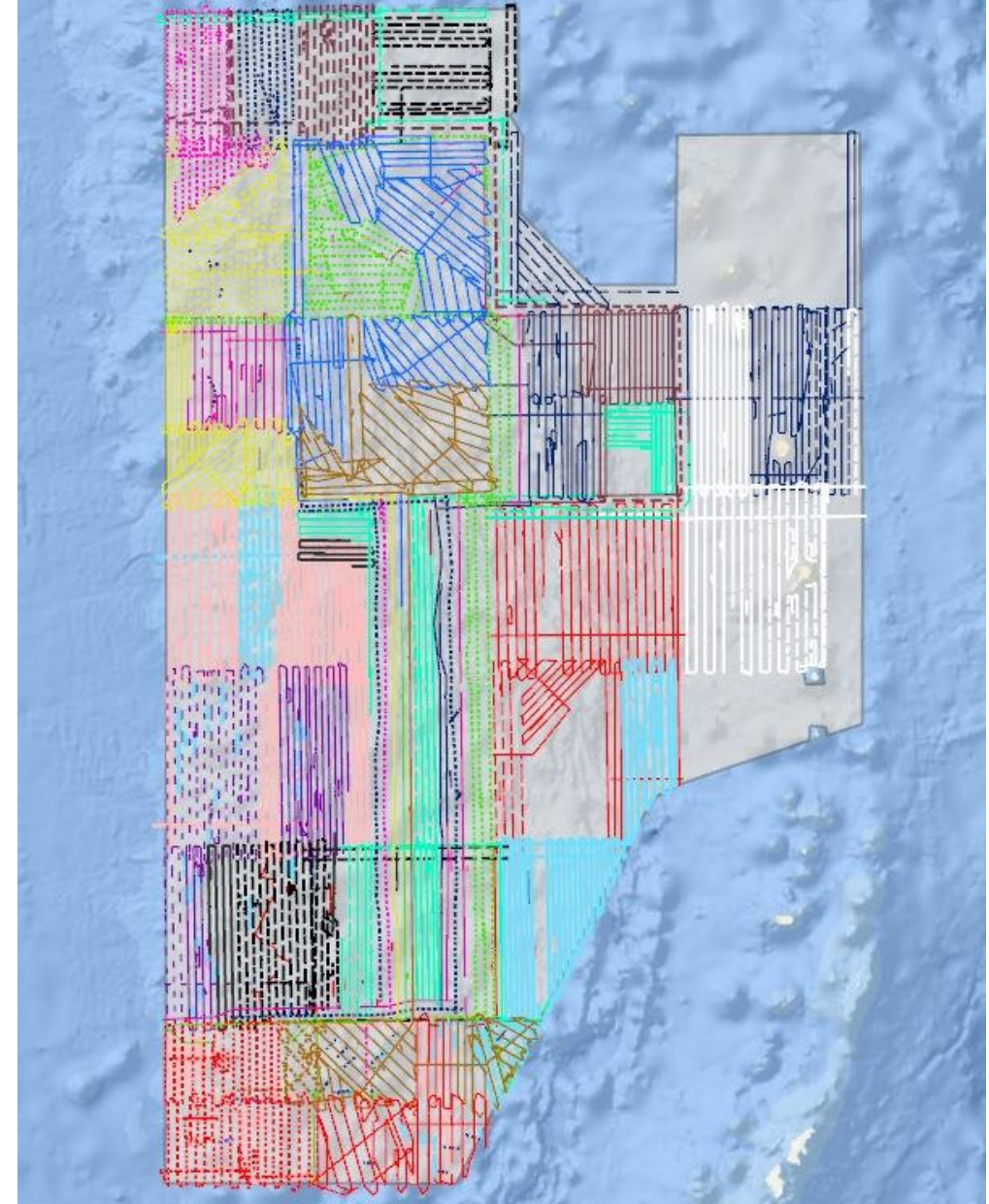
A Multi-Year, Distributed Survey Changed the Processing Challenge

Why this project was different:

- Multi-year acquisition by multiple Saildrone Surveyors across a large, evolving footprint
- Frequent deliveries covering multiple, often incomplete sub-areas
- Shore-side processors were not directly involved in acquisition
- Redundant data management – Saildrone/OMS

What this required:

- Adapt geospatial data management & processing workflows across vehicles, deliveries, and sub-areas
- Balance of operational efficiency vs. processing and QC progress
- Consistent products and archives designed for long-term reuse

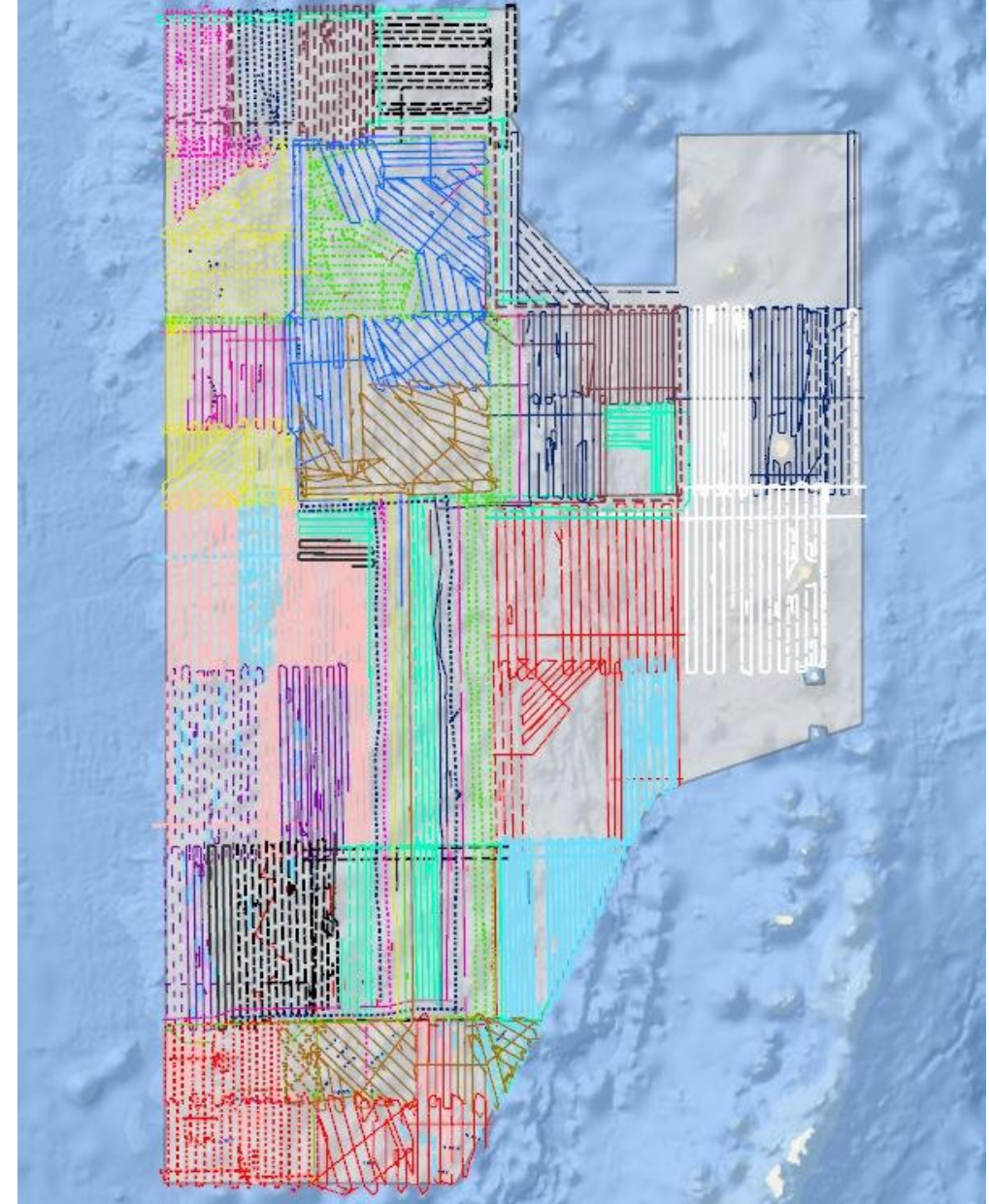


Multiple Vehicles and Deliveries Created a Growing Project Footprint

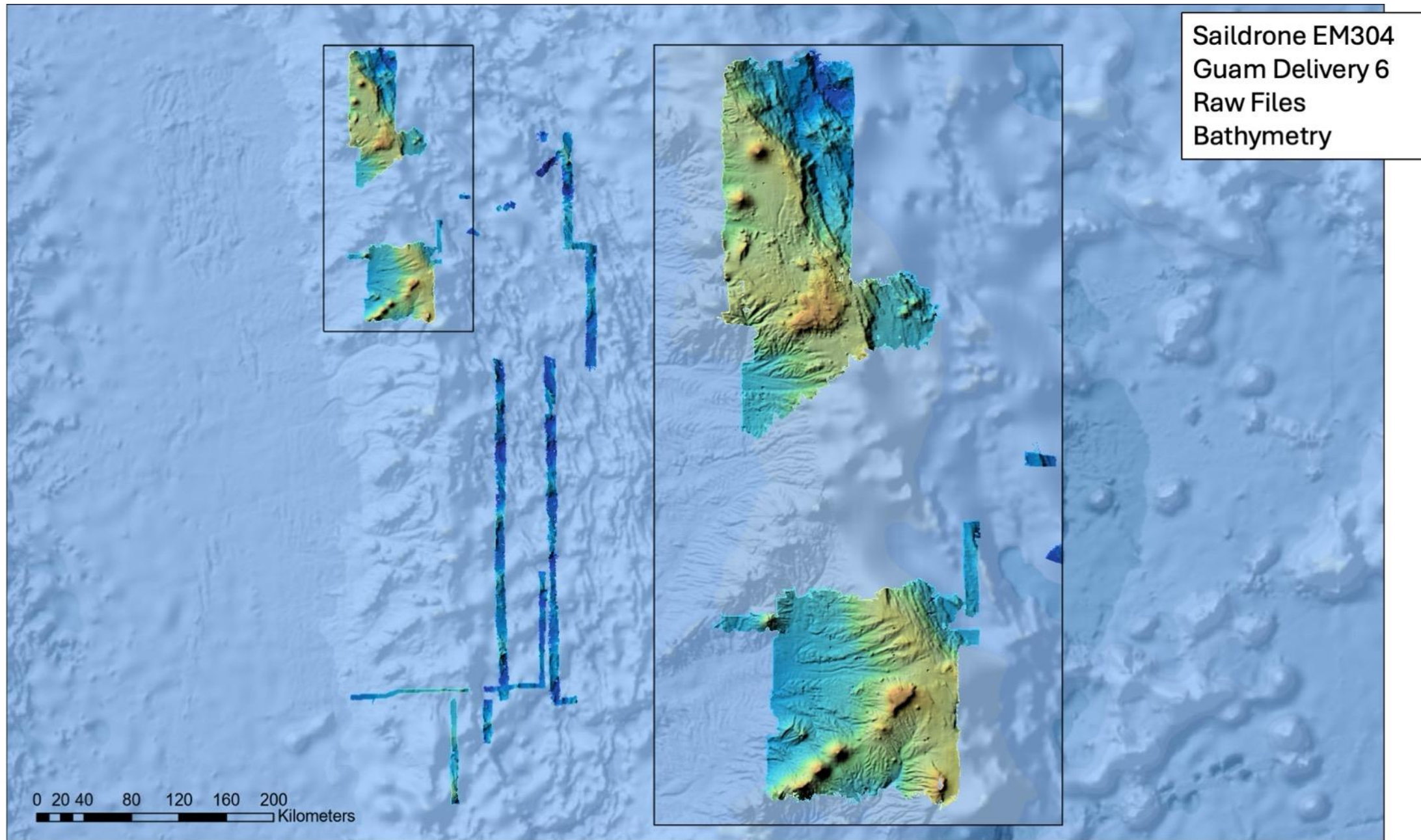
0 25 50 100 150 200 Kilometers

Geospatial Management Became the Backbone of Processing

- Mission portal and automated line logs preserved operational context.
- Geospatial management tracked lines by vehicle, delivery, sub-area, and processing status.
- Qimera, ArcGIS, KMALL-derived line and area shapefiles, and scripts connected processing, tracking, and reporting.
- QPS edits allowed corrections to transfer between projects.
- The workflow adapted and remained usable even as the project structure and processing methods evolved



Standardized Reviews Made Progress, Gaps, and Priorities Visible



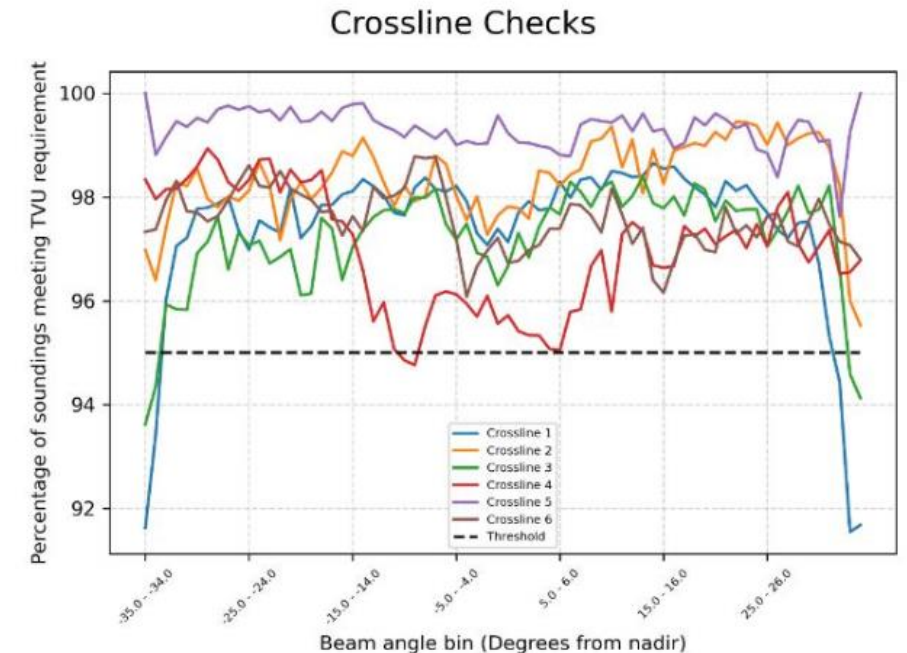
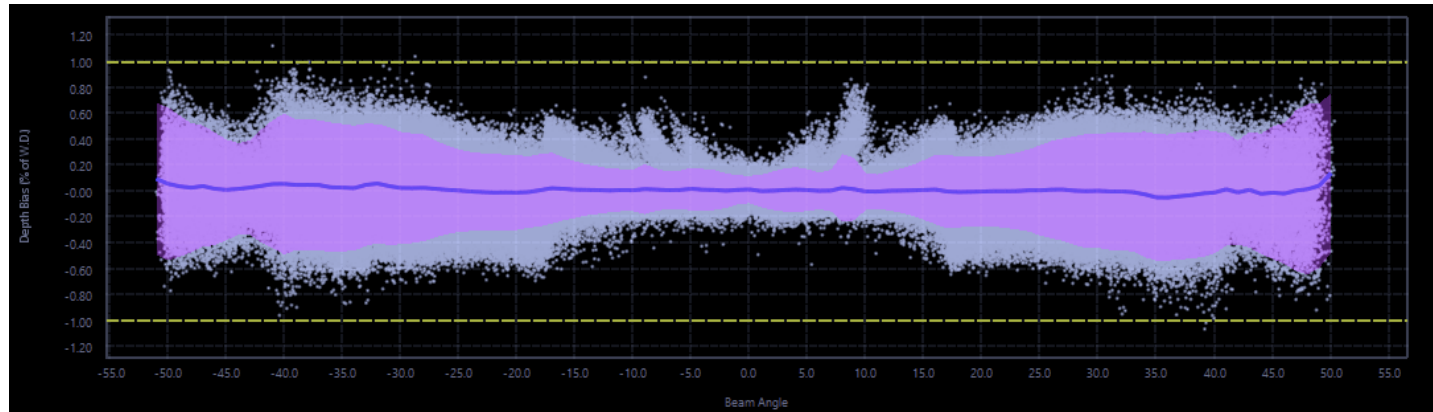
Independent Workflows Strengthened QC - Required Coordination

Challenges:

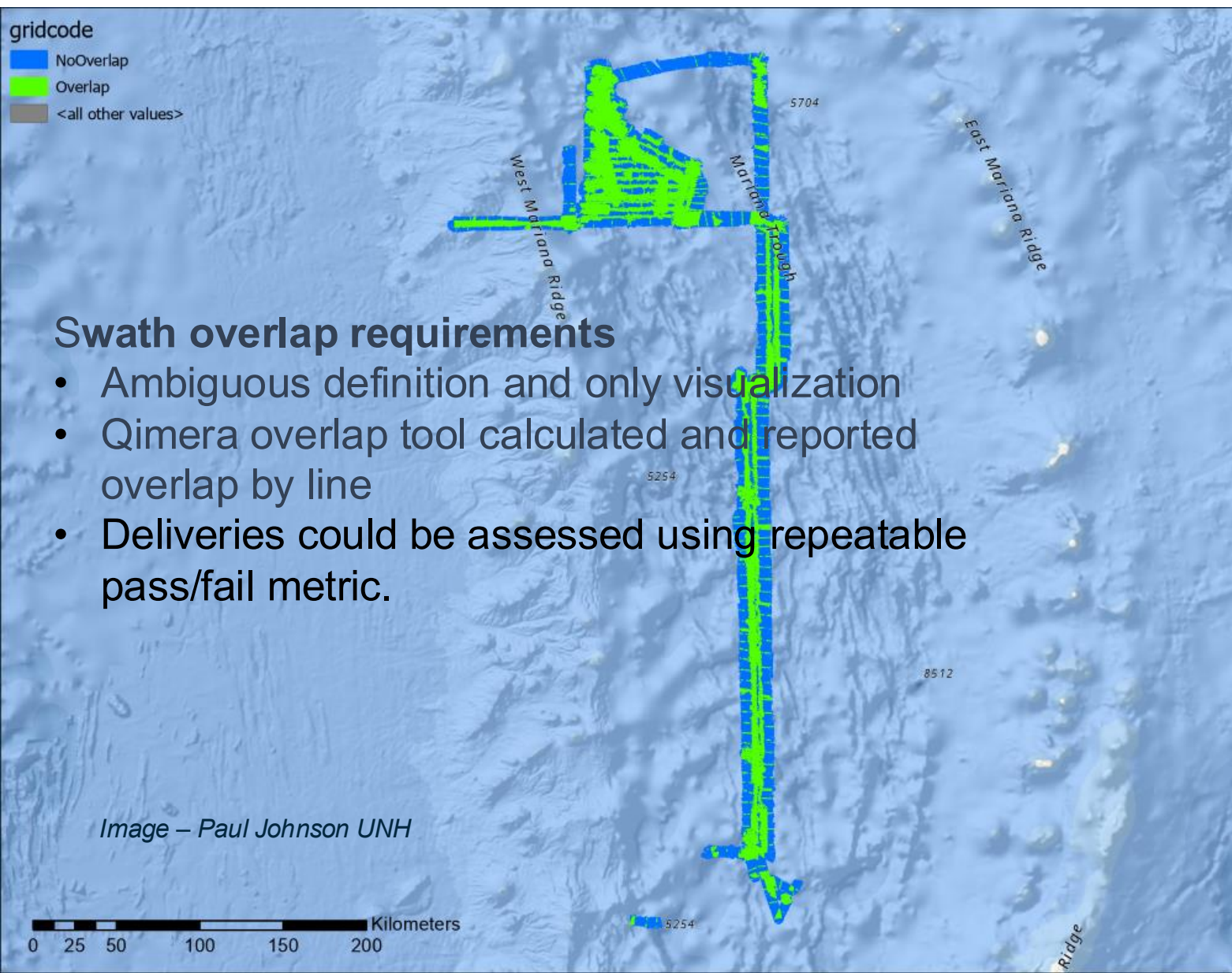
- Saildrone deliveries to meet requirements, progressively assessed with incomplete sub-areas
- OMS assessing deliveries, sub-areas and project requirements and complete processing
- Complicated by deliveries “stretched” over startup period and out of sync with issues

Benefits:

- Saildrone production processing plus independent OMS review and processing
- Different software and workflows provided a second line of QC and verification, before processing
- Input parameters, analysis, and reporting had to remain closely coordinated



Swath-Overlap Checks Moved from Visual Review to Measurable Verification



Swath overlap requirements

- Ambiguous definition and only visualization
- Qimera overlap tool calculated and reported overlap by line
- Deliveries could be assessed using repeatable pass/fail metric.

```
# Qimera Line Overlap Report
# Generated by Qimera
# Date: Fri Aug 21 17:13:58 2026
#
# Each line in the report corresponds to one QPD file.
# A grid cell is considered to be overlapped if it has a coverage value of 2 or greater.
# The overlap threshold is the percentage of cells in the QPD polygon that must be overlapped for the QPD
to be considered as passing.
# A QPD is considered to have passed if the percentage of overlapped cells in the QPD polygon is greater
than or equal to the specified overlap threshold.
```

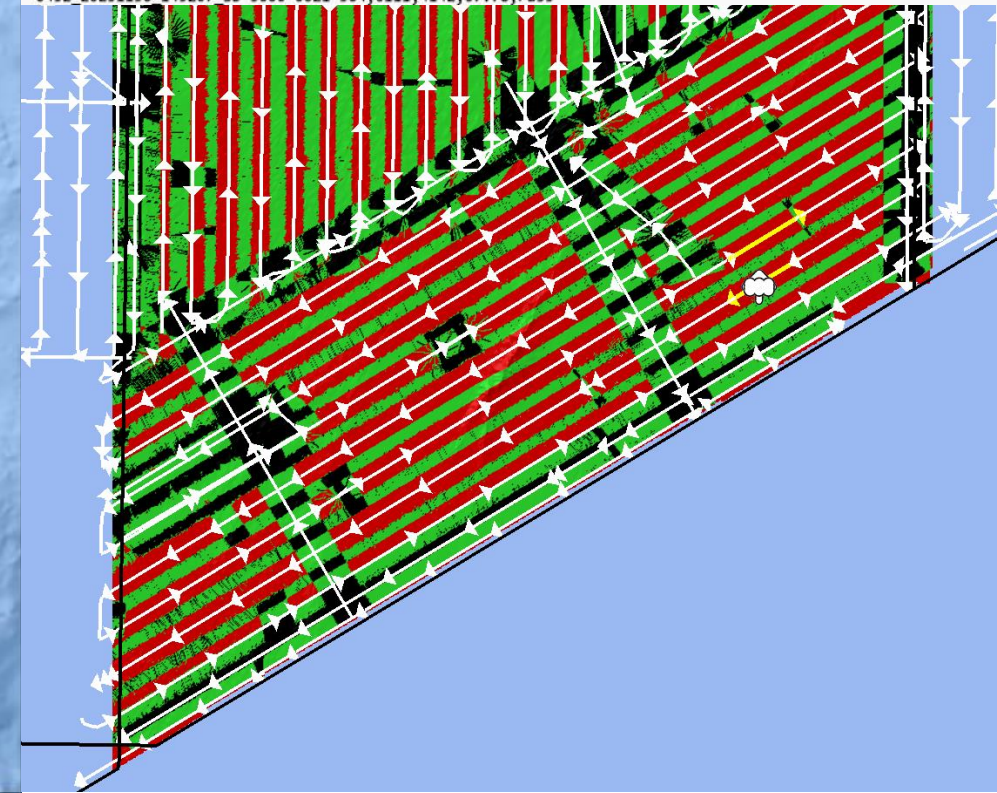
Specified Overlap Threshold: 40

```
Grid File: F:\Qimera-closeout-products\Closeout_Q2.8-plus\PR-A2-closeout\GridData\PR-B4-closeout-128
\PR-B4-closeout-128.dyngrid
Total QPDs Analyzed: 411
QPDs Passing: 368
```

The columns are:

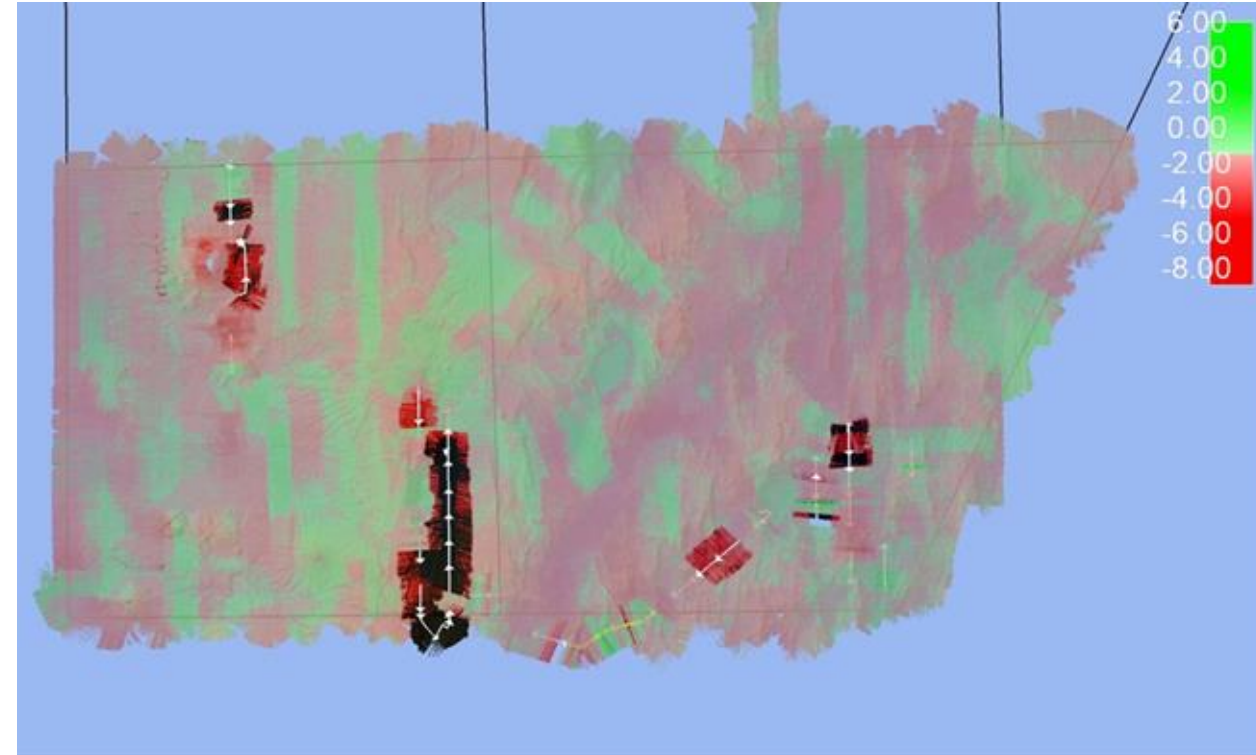
QPD filename, # of grid cells within QPD polygon, # of cells in polygon with coverage ≥ 2 , % with coverage ≥ 2 , Result (Pass/Fail)

```
0441_20251130_033742_SD-3000-0021-304,4527,1725,38.10,Fail
0442_20251130_043742_SD-3000-0021-304,3642,3072,84.35,Pass
0443_20251130_053742_SD-3000-0021-304,5229,3677,70.32,Pass
0444_20251130_063742_SD-3000-0021-304,3883,3025,77.90,Pass
0445_20251130_073742_SD-3000-0021-304,5350,2943,55.01,Pass
0446_20251130_083742_SD-3000-0021-304,613,526,85.81,Pass
0447_20251130_095001_SD-3000-0021-304,5862,3599,61.40,Pass
0448_20251130_105001_SD-3000-0021-304,4669,4570,97.88,Pass
0449_20251130_115207_SD-3000-0021-304,6117,5748,93.97,Pass
0450_20251130_125207_SD-3000-0021-304,6721,6032,89.75,Pass
0451_20251130_135207_SD-3000-0021-304,8322,5124,61.57,Pass
0452_20251130_145207_SD-3000-0021-304,6111,4142,67.78,Pass
```



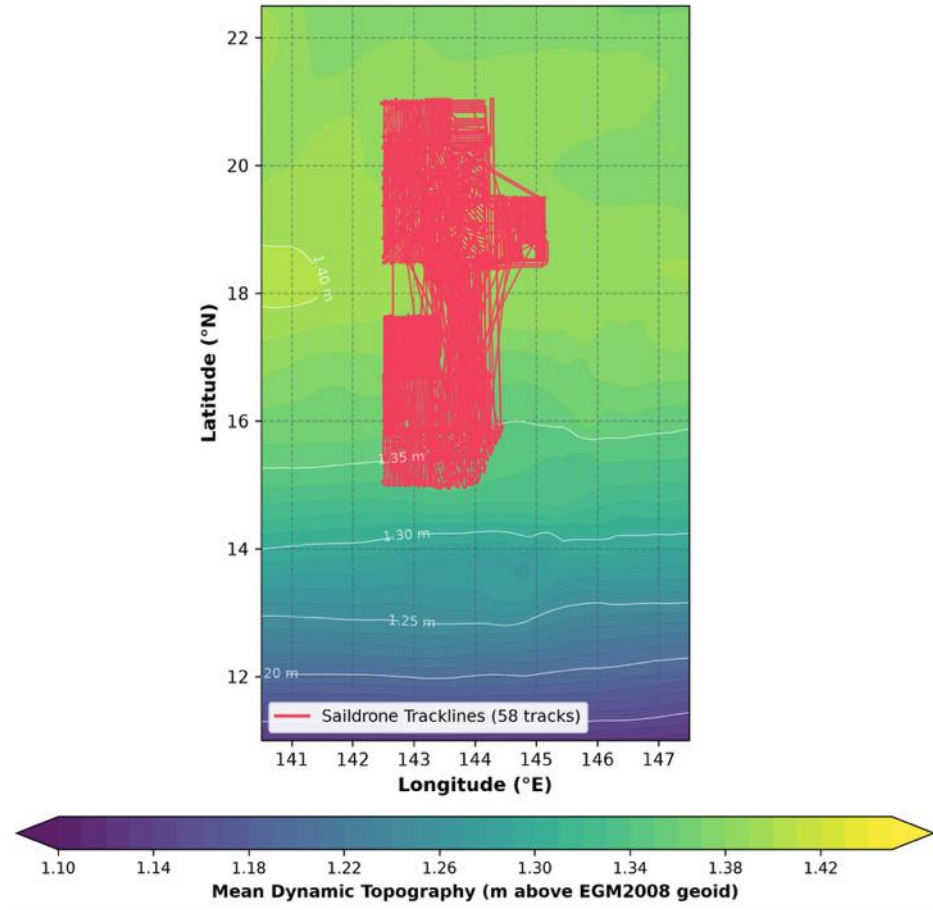
Navigation Issues Required a Consistent Vertical-Reference Strategy

- Persistent POS/MV height issues produced gaps and residual vertical jumps when POS and SBET data were combined.
- Established process to quickly identify issues
- Deep-water research products to be processed to the instantaneous waterline to improve consistency and limit unnecessary data loss.
- Ongoing assessment to quantify uncertainty associated with the IWL, dynamic ocean topography, and ocean tides to meet requirements



Water Level Vertical-Reference Strategy

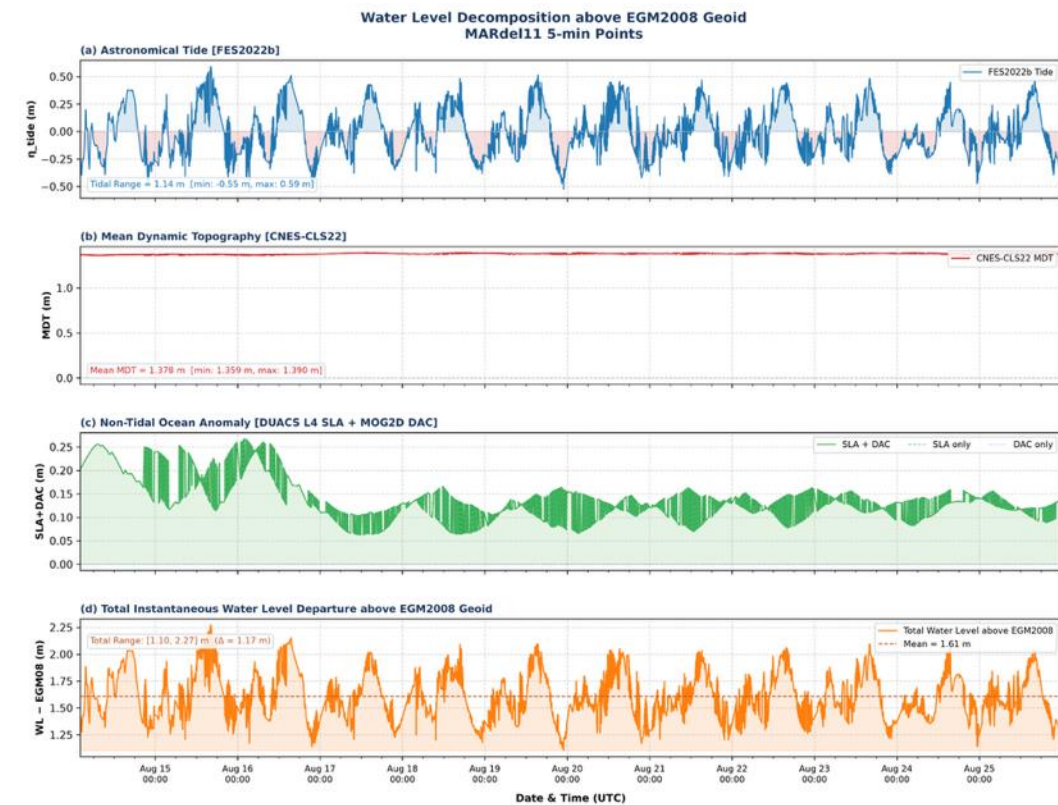
The Marianas Survey Block — Saildrone Trajectories & CNES-CLS22 MDT Mean Dynamic Topography (+1.20 to +1.45 m above EGM2008)



Analysis & Images – Ian Church OMG UNB

Region / Dataset	Tracks	Points	EGM08 Geoid (m)	FES2022 Tide Range (m)	CNES-CLS22 MDT (m)	DUACS SLA (m)	Total WL above EGM08 (m)
Marianas Block	25	258,852	+46.41 to +54.97 (mean +51.56)	-0.88 to +0.98 (range 1.86 m)	+1.21 to +1.45 (mean +1.37)	+0.04 to +0.22 (mean +0.14)	+1.07 to +2.28 (mean +1.45)
Puerto Rico Block	7	65,825	-69.84 to -36.55 (mean -45.00)	-1.07 to +1.55 (range 2.62 m)	+0.58 to +0.74 (mean +0.67)	+0.08 to +0.22 (mean +0.15)	+0.15 to +2.47 (mean +1.06)

Extracted physical component ranges across Saildrone survey track lines.



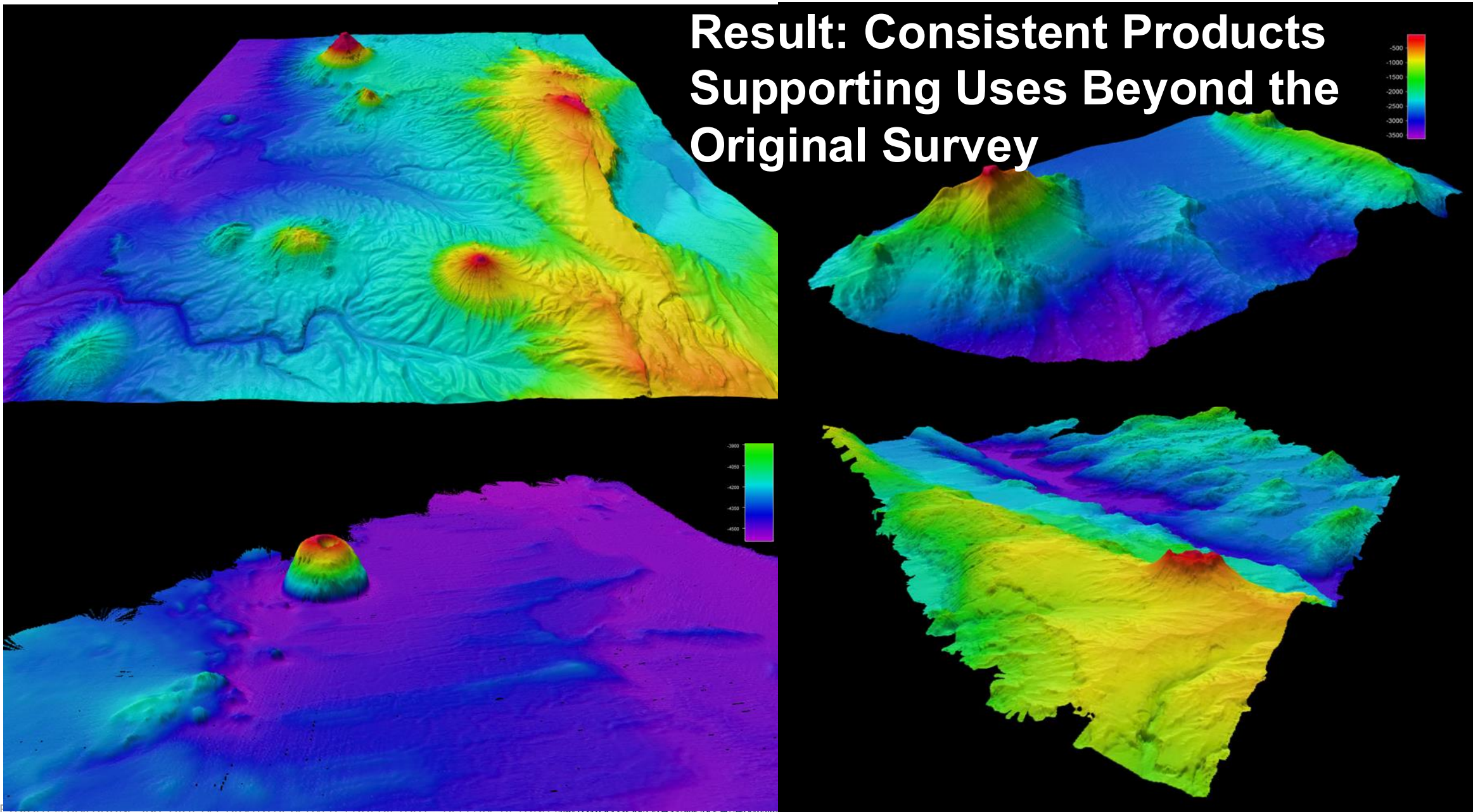
Lessons for Future Long-Duration Saildrone Surveys

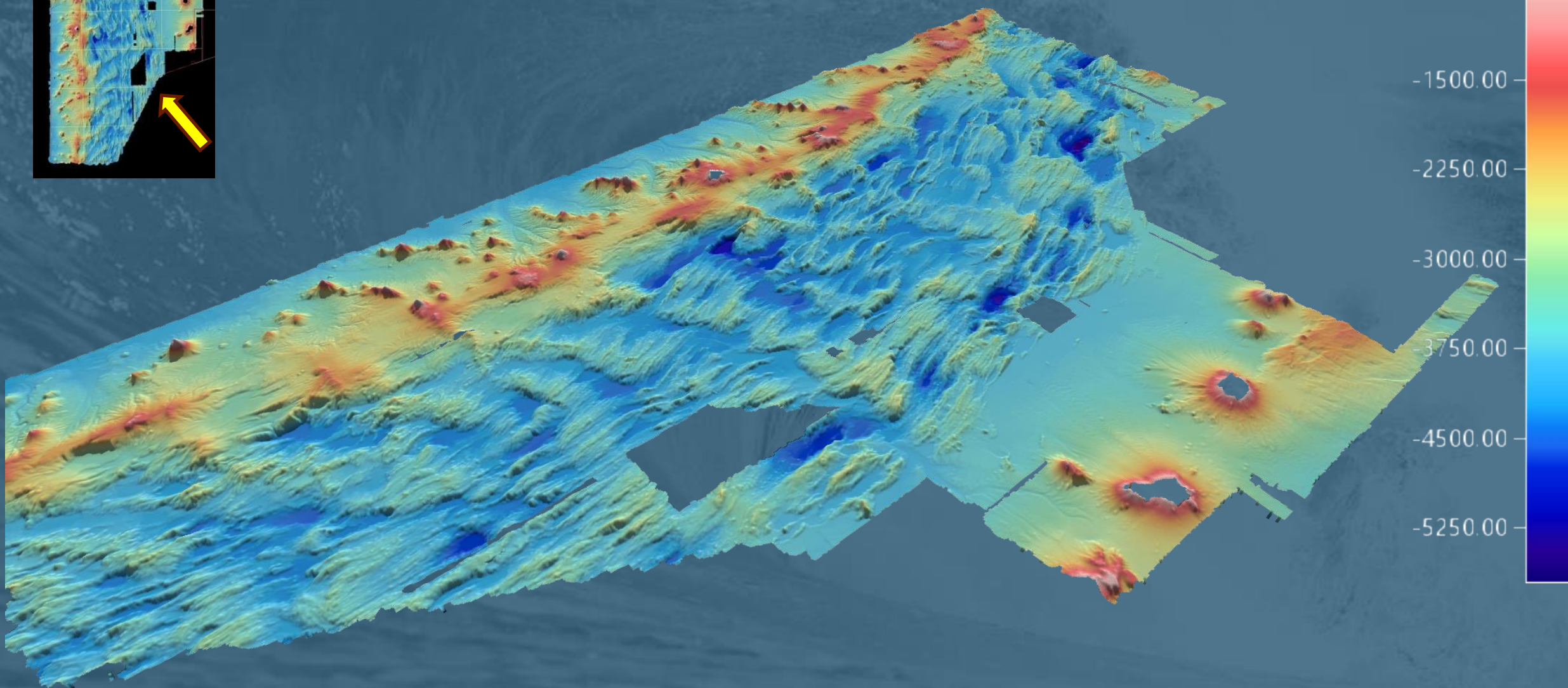
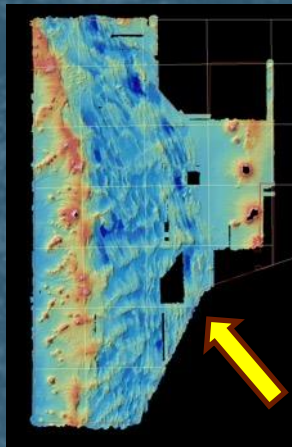
- Close collaboration with the acquisition team is essential with independent remote processing.
- Mission portals and automated line logs benefit both crewed and uncrewed surveys.
- Long-duration projects require standardized data management, QC, and delivery reviews.
- Oceanographic models support—but do not eliminate—the need for adequate SVP observations. Ongoing glider data analysis to assess suitability to support mapping.
- Approaches for processing and archiving should support reuse of data: for charting, SB2023-GEBCO, research, sampling, and submersible and ROV operations.

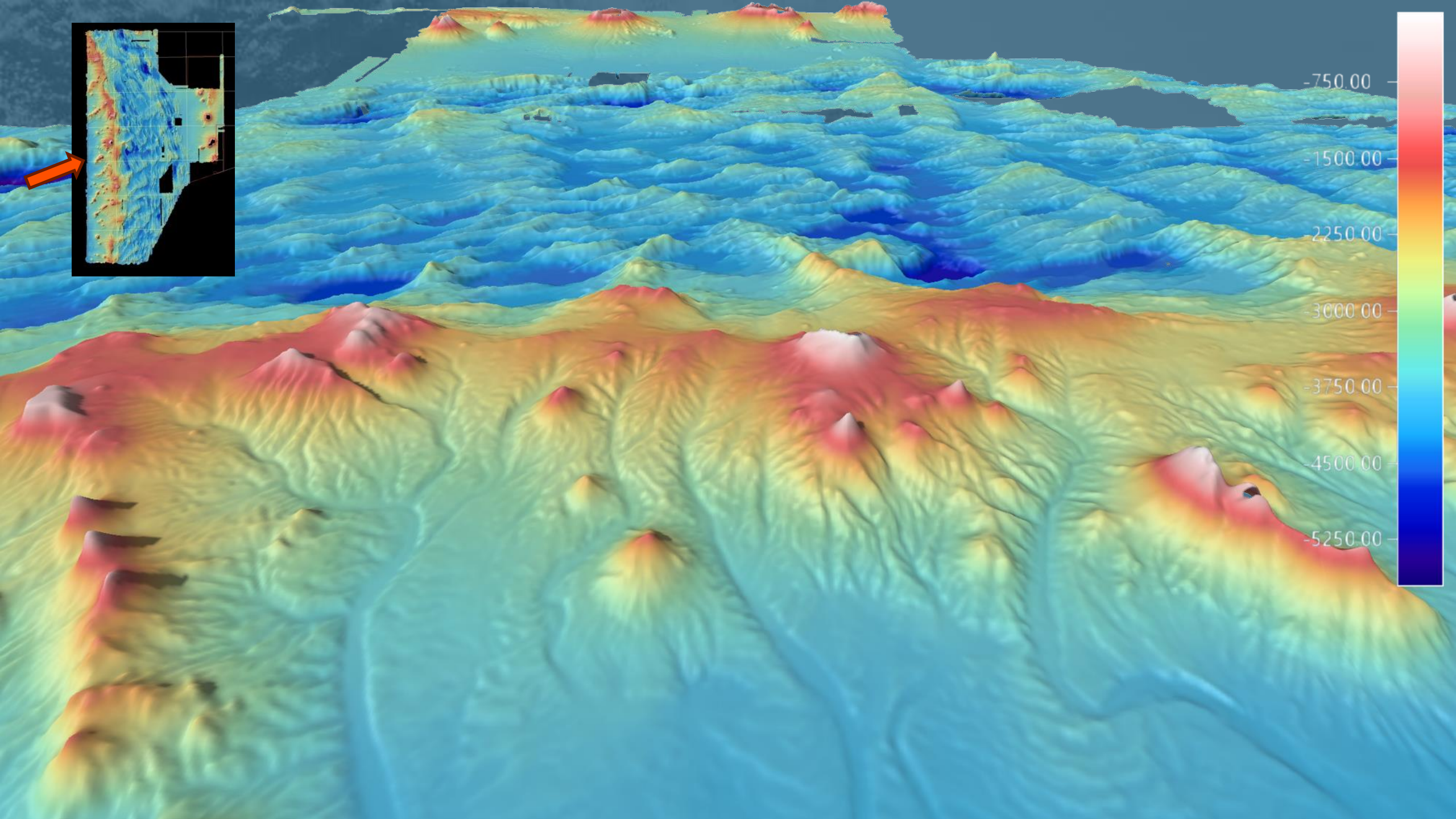
Community contributions and future work

- Updates to hardware/software from project: SIS, POS, AML, Qimera, MAC tools, HIPs.
- Extensive data set for further analysis, with extinction trials, backscatter calibration, glider for supplementing SVP observations and modelst, analysis of vertical-referencing uncertainty
- Deep-water survey standards and guidelines - extrapolating of IHO nautical charting standards not always appropriate, adapt for both data use and modern sensors and systems. *Pre-FEMME workshop*

Result: Consistent Products Supporting Uses Beyond the Original Survey









Conclusion & Discussion

CONTRIBUTORS

Joseph Harris, Office of Naval Research

Timothy McGeehan, Office of Naval Research/Marine Acoustics, Inc

Erin Heffron, Ocean Mapping Services

Daniel Boone, Saildrone

Bert Wyness, Saildrone

Tiziana Munene, Saildrone

Paul Johnson, Center for Coastal and Ocean Mapping University of New Hampshire

Ian Church, Ocean Mapping Group, University of New Brunswick