Crawler-towed Sensor Technologies in Challenging Nearshore Sites

MR-201422

Greg Schultz
White River Technologies

Winter 2018 IPR

ESTCP

21 February 2018

MR-201422: Crawler-Towed UXO Technologies

White River Technologies, SeaView, & USACE FRF

Technology Focus

- *Nearshore environments are important and uniquely challenging for UXO operations, thus specialized mobility and sensing platforms are needed to address munitions remediation in beach, surf, and tidal areas*

Demonstration Sites

- *Primary site: Duck, North Carolina USACE Field Research Facility*
- *Demonstrations in surf zone (Atlantic) and intertidal areas (sound)*

Demonstration Objectives

- *Evaluate and quantify amphibious mobility platforms for towed digital geophysical operations under a variety of challenging conditions*

Project Progress and Results

- *Completed assessment of crawler platforms; configured and validated integrated crawler-towed sensor system & demonstrated at Duck surf and sound areas in 2016 & 2017.*

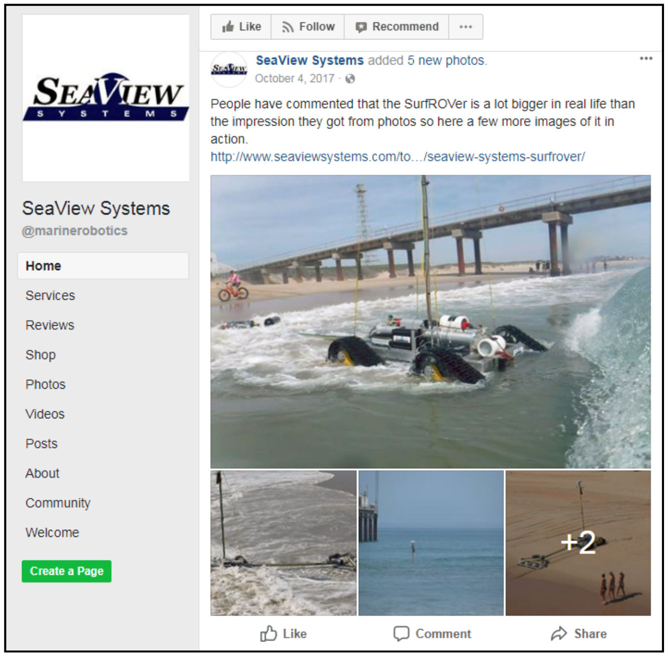
Implementation Outlook

- *System validated through three demonstrations for stable operations on rocky, muddy, and sandy substrates and varying hydrodynamics. Further improvements and testing should be conducted to optimize the system for largest operating envelope and full-scale operations.*

Social Media Content

Proposed Content

"Robotic Crawler-based UXO Detection System Testing: Scientists from the Army Corps of Engineers, White River Technologies, and SeaView Systems completed demonstrations of new amphibious underwater UXO detection system to help find and clear nearshore areas of military munitions."



Project Team

Dr. Greg Schultz (PI), White River Technologies
EMI sensing & UXO technology development

Dr. Jesse McNinch, USACE-ERDC Field Research Facility
Expert in nearshore surf zone and seabed geophysical processes

Dr. Brian Degnan & Chet Bassani, White River Technologies
Systems engineering, experienced with marine EM/Mag platforms

Joe Keranen, White River Technologies
Specialist in marine acoustics, EM, and Mag acquisition/processing

Dr. Tim Crandle and Ed Celkis, SeaView Systems
Experts in robotic crawler platforms and seafloor mapping systems

US Army Corps of Engineers®
Engineer Research and Development Center

WHITE RIVER TECHNOLOGIES

SEAVIEW SYSTEMS

Technical Objectives

Demo technologies aimed at filling gaps that limit DGM in challenging nearshore environments

1. **Assess mobility platforms for towed DGM ops at littoral sites**
2. **Demonstrate collection of high-quality EMI data from integrated system** (crawler + EMI array + navigation and positioning system)
3. **Evaluate survey modes, SOPs, and cost savings from tailored crawler-based DGM**
4. **Validate specialized field procedures and data analysis** (to reduce instability & noise in high energy shallow environments)

Combine Existing Technologies To Fill Capability Gap

Technical Progress

2015

Task 1. Amphibious Platform Assessment *(revised AoA Report)*

Task 2. Tow Platform Configuration *(modifications based on 2015 Lake Erie and Duck FRF tests)*

Task 3. FRF Engineering Tests

2016

Task 4. Configuration of Integrated System & Development of Mission CONOPS

- Verify integrated crawler+EM sensor sled → shakedown tests

Task 5. Develop Data Processing Flow

Task 6. Submit Demo Plan & Prepare Site

- Demo 1 Plan completed; site(s) installation completed

2017

- Demo 2 Plan completed; site installation completed

Task 7. Demonstration(s), Analysis, and Reporting

- Demo 1→ Nov 2016, Demo 2 → Jul 2017
- Analysis & Reporting: Demo 1 Report completed; **FR, C&P report**
- Transition services to MMR partners; assess regulatory reqt's

2016 Demo Lessons Learned

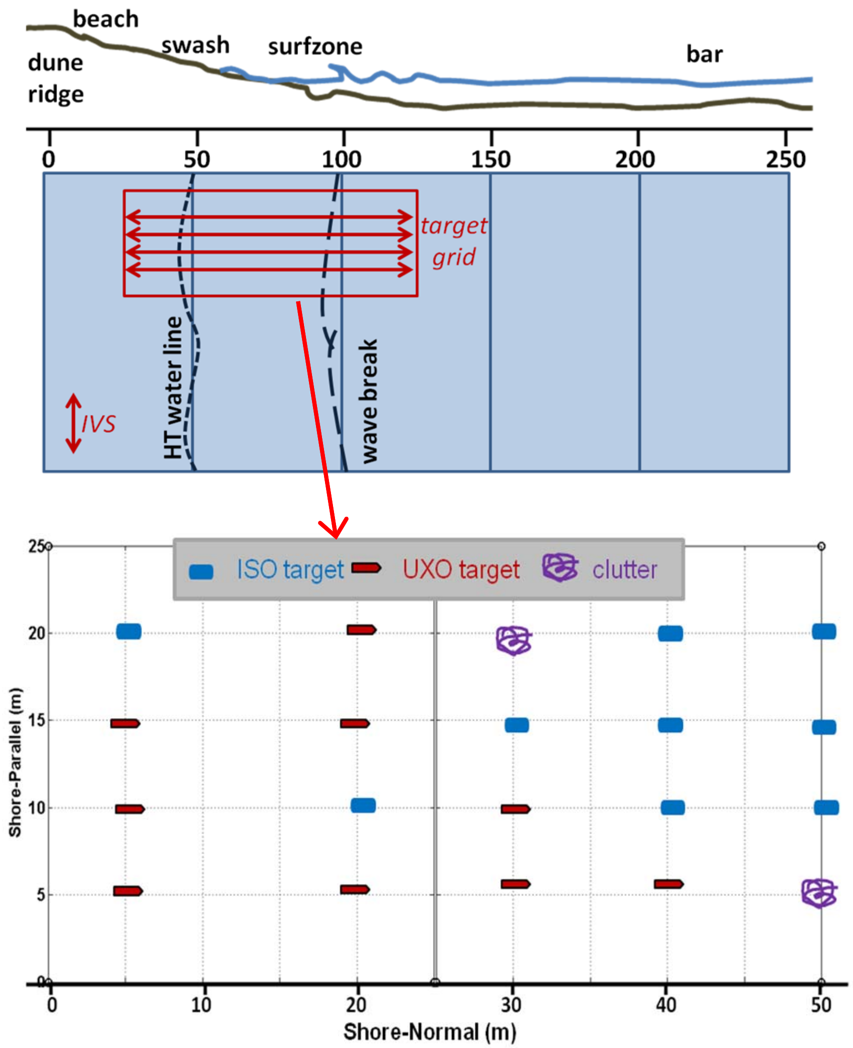
- **Wireless alternative to fiber-optic tether desired**
- **Crawler battery management improvements**
  - When both battery modules simultaneously faulted due to overvoltage/current, there is no auxiliary PS for restart
  - Need an additional auxiliary PS for reset or cross-module “smarts”
  - Improved battery charging needed for unattended charging without breaking any o-ring seals
- **Tow system heading and orientation information critical**
  - Incremental encoder at tow point provided nothing useful
  - Absolute encoder needed - to be fused with tow sled IMU data for accurate heading and orientation of the towed array
- **Motor noise pickup on EMI system transmitter**
  - EMI noise pickup on transmitter observed (especially when testing out of water – e.g., Blossom Point shakedowns)
  - Power supply filtering in parallel to isolated power supply for tow system (although ~50% of noise was directly coupled through the power supply junction box)

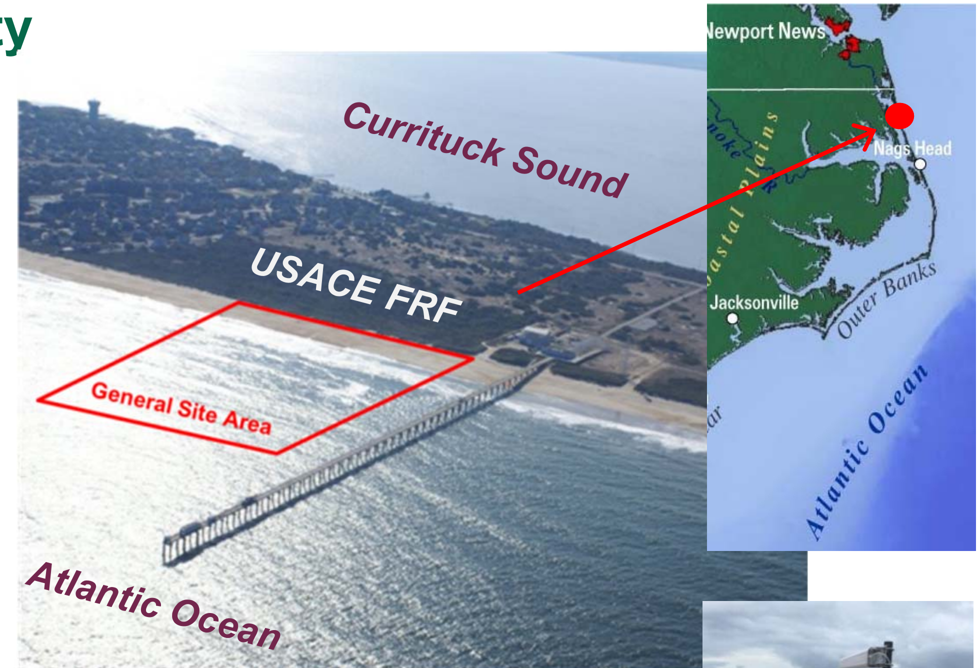
System Improvements & Test Prep

1. Wireless radio link in place of tether; ruggedized tether if needed
2. Absolute angle encoder at tow point implemented / validated
3. Complete optical isolation of EM array system; improved power supply unit
4. Shortened tow bar from 6.5 m to 4.7m
5. Added topside mission control and navigation user interface display

Demonstration Site: Duck FRF Surfzone

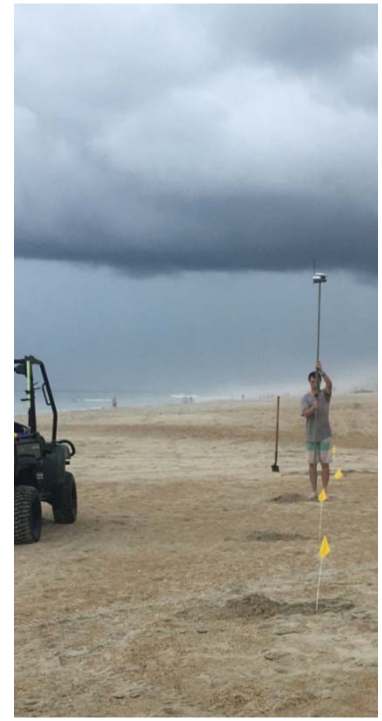
Duck, NC Field Research Facility

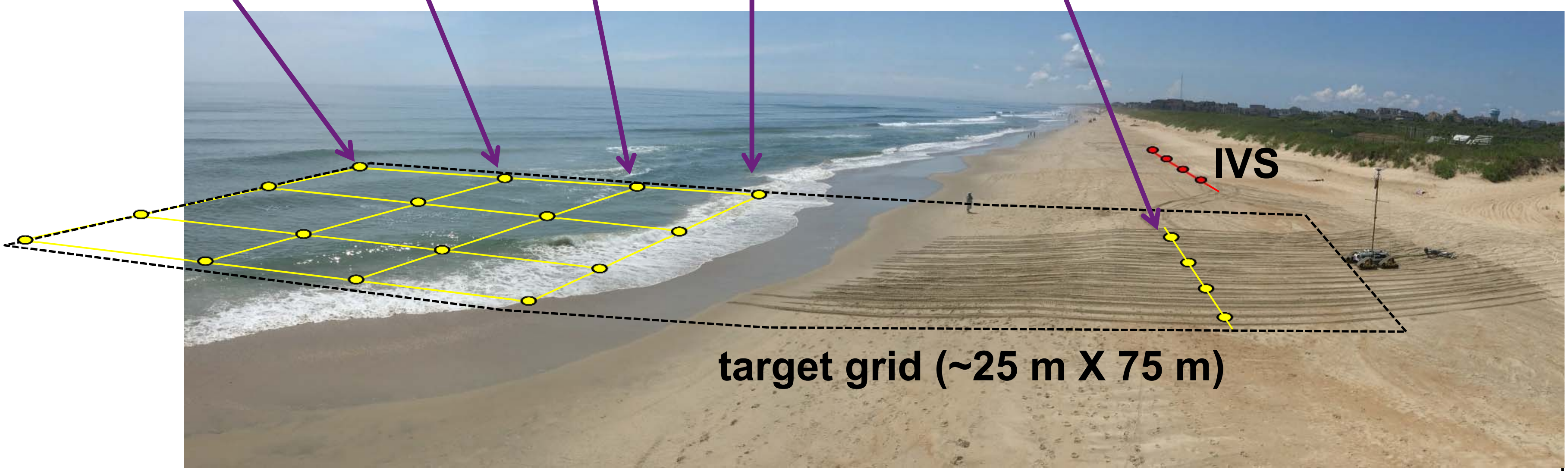




Site Preparation

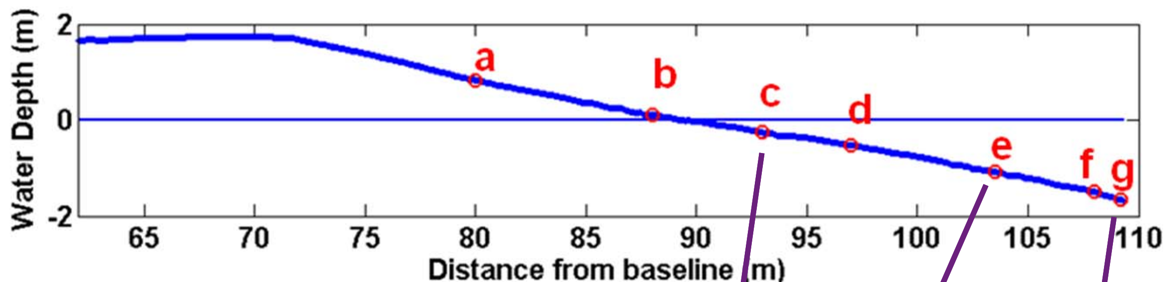
- 4 IVS targets
- 20 beach (4) & surf (16) targets

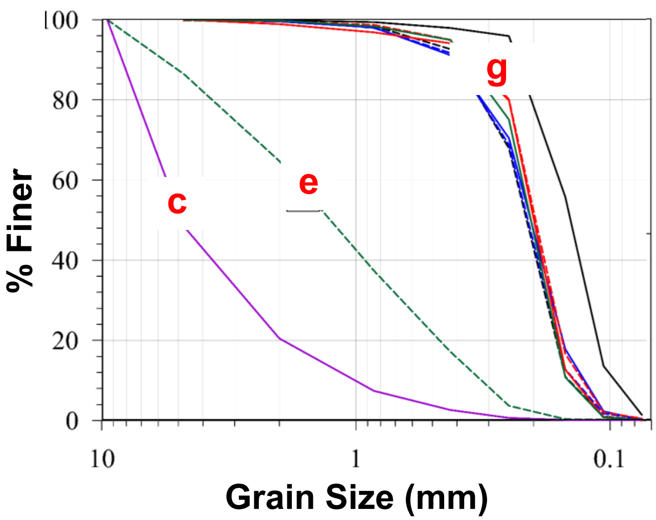




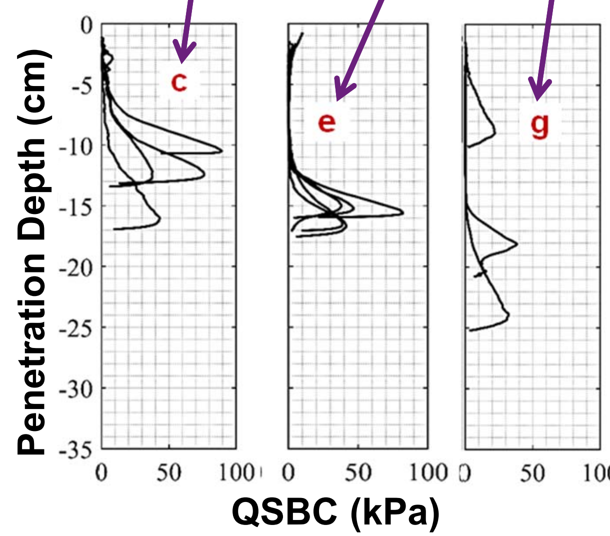
Site Preparation

Oceanographic and Geotechnical Properties Characterization





Station ID	Dist (m)	D_{50} (mm)	Cone Index
a	80	3.2	557
b	88	0.8	139
c	93	4.9	870
d	97	0.9	152
e	103	1.2	207
f	108	1.4	242
g	111	0.3	102



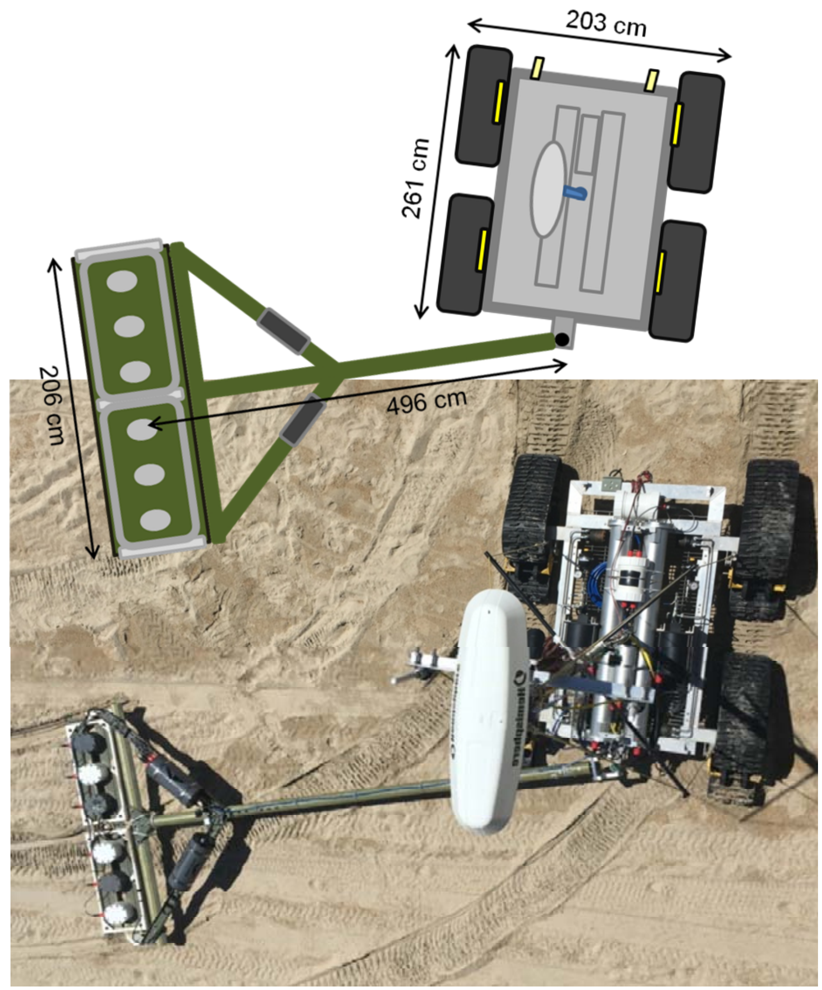
Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Quantitative Performance Objectives		
Surfzone Stability	• Orientation (R,P,Y) and translational (X,Y,Z) positional data: Crawler & Tow Sled • Water velocity, wave height	ΔR, ΔP: < ±6° , σR, σP < 3° ΔY < ±4° , σY < 2° ΔX < 20cm , σX < 15cm ΔY, ΔA < 10cm , σY < 15 cm
Area Coverage	• Position, time, orientation data from NAV system	100% coverage at Rate ≥ 0.2 hectare/hour (0.5 acre/hr)
On-shore/Off-shore Mobility	• Position, time, orientation data from NAV system	Advance Rate ≥ 0.3 m/s (1 kph; 0.58 knots; 0.53 acre/hr)
UXO Detection	• Signal received and noise estimated during anomaly interrogation • Positional reports from NAV system	SNR > 9 dB for all UXO ≥ 60mm
UXO Location Accuracy	• EM array data, NAV data • True target locations	ΔTN and ΔTE < 1.0 m σTN and σTE < 0.5 m
Classification	• Regions of Interest, Ground Truth • Ranked Anomaly list	Pclass > 0.75 50% clutter rejected

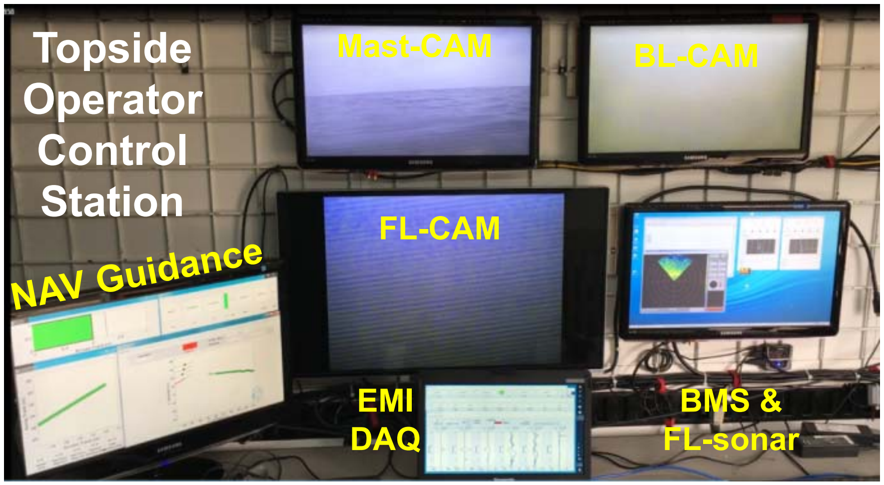
Integrated System Configuration

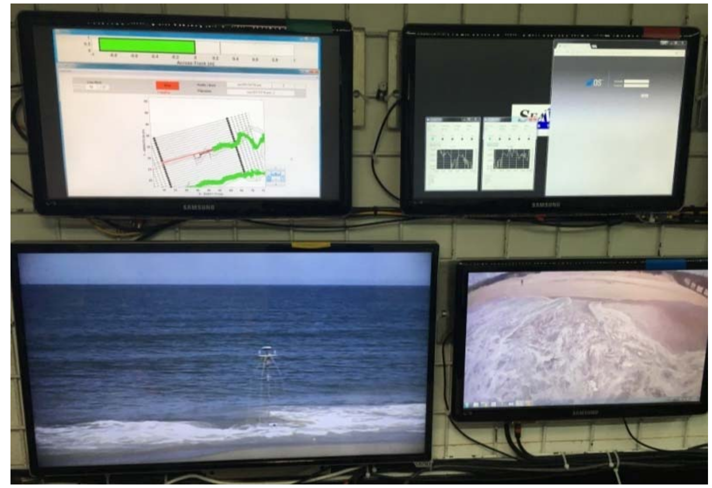
i) Crawler – ii) GPS/Mast – iii) Tow Sled – iv) EM Array – v) OCS

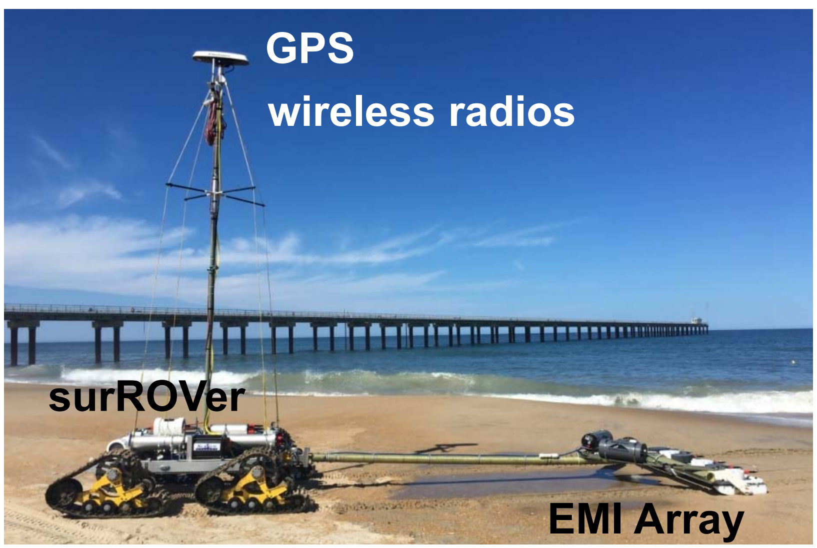
Feature	Specification
L x W x H	261cm X 203cm X 91cm
Operating Depth	300 msw
Weight (air)	670 kg (1477 lbs)
Weight (msw)	382 kg (841 lbs) est.
Battery Life	8-12 hours
Pull Force	500 kgf (1100 lbf)
Tracks	4 X Rubber Mattracks
Propulsion	Electric / hydraulic
Pressure	0.52 PSI (sw) / 3.5 kPa
Speed	1.5 m/s submerged
Sonar	Imagenex 881 scanning
Cameras	3 fixed RGB cameras
Tether	500m umbilical or Wireless Ethernet



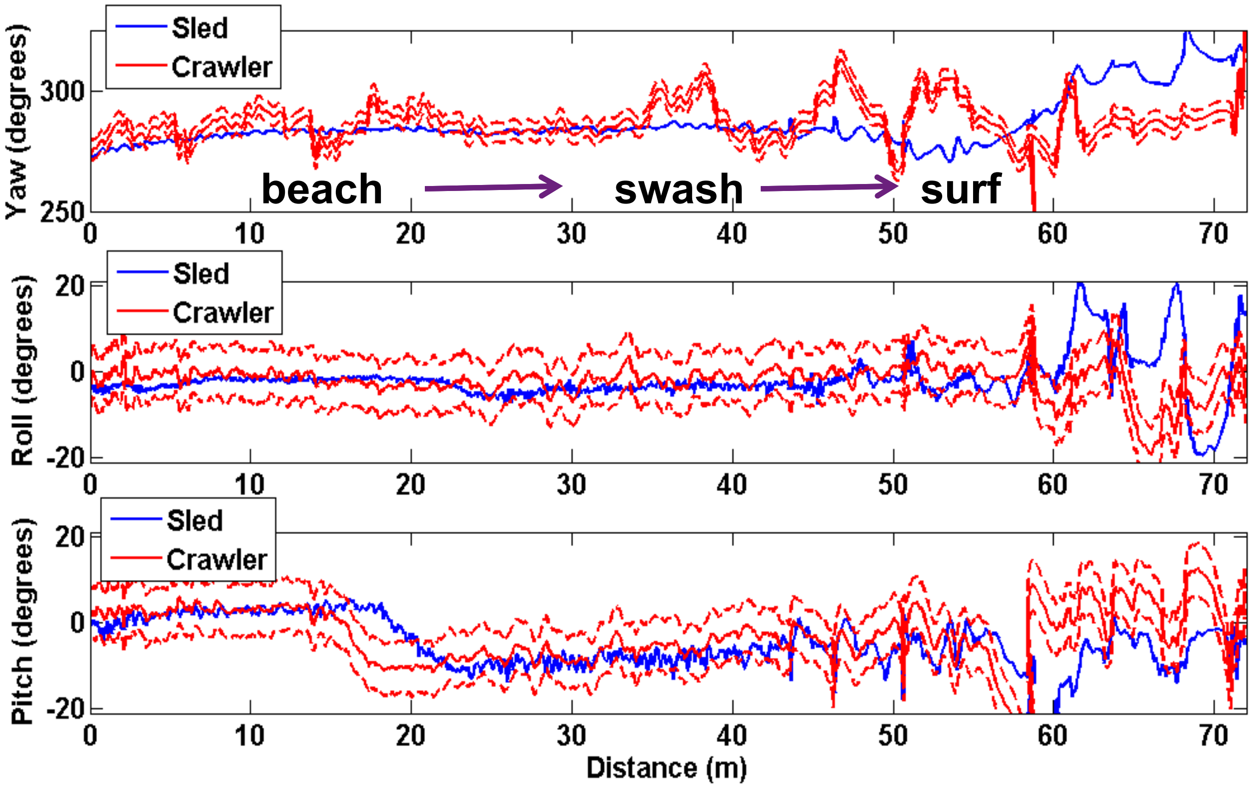
Topside Configuration

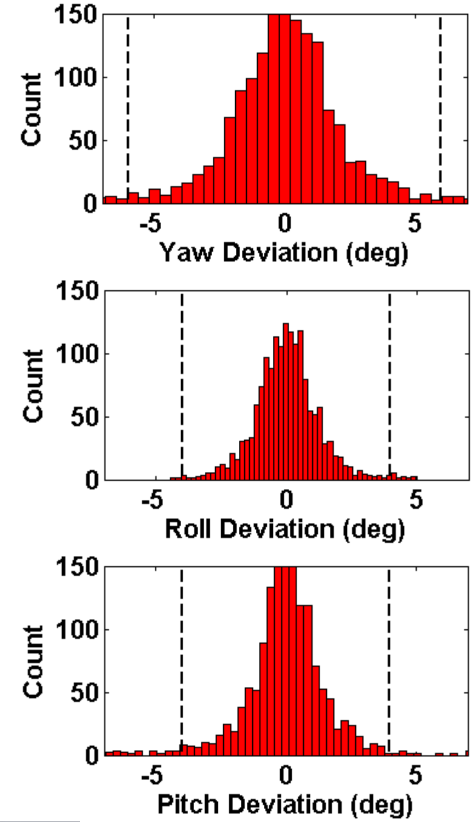


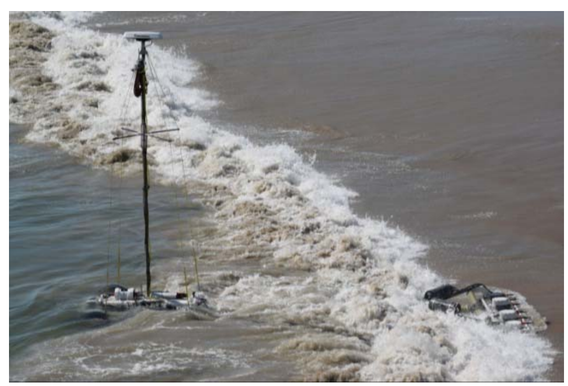




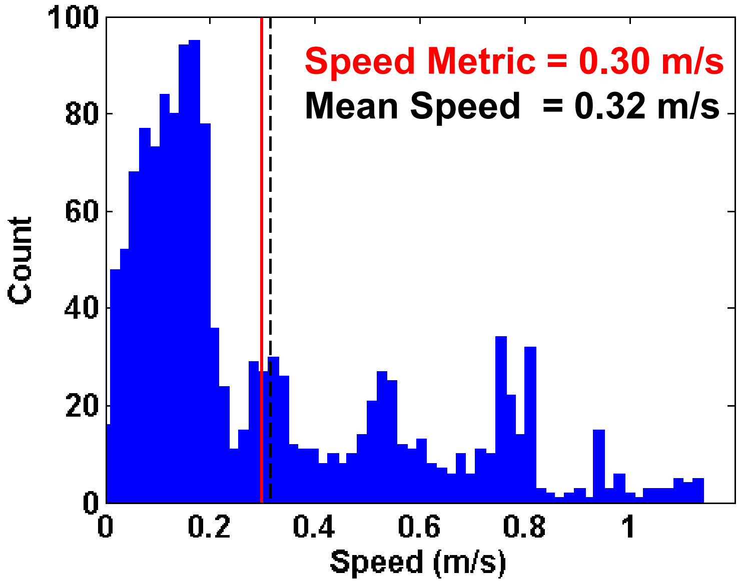
Roll, Pitch, Yaw Stability in Surf

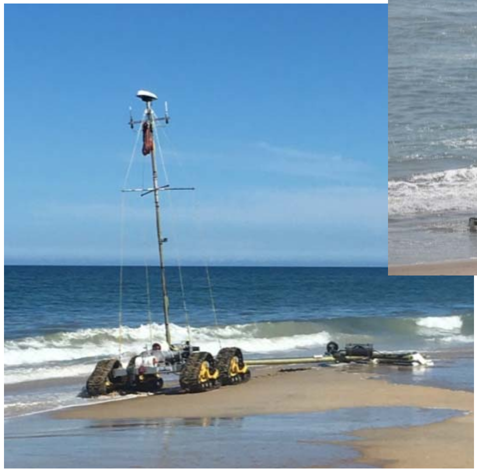






Coverage Efficiency





27 transects covering 1.77 line km

Mean Inst. Speed = 0.32 m/s (0.63 knots)

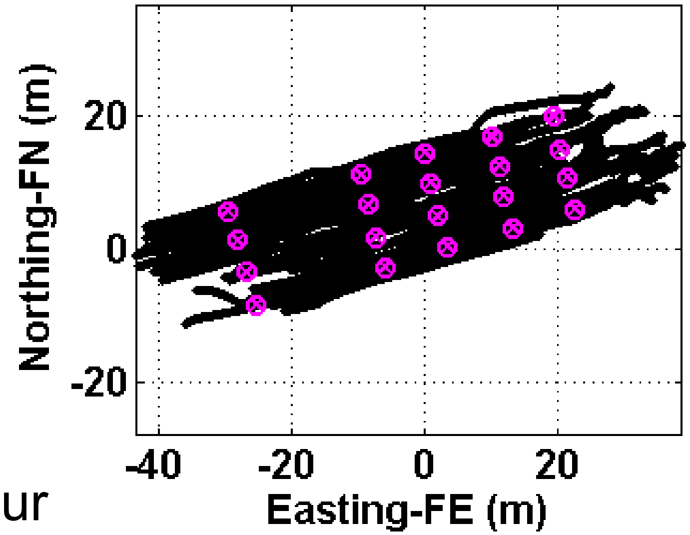
Est. Coverage Rate = 0.57 acres/hour

Mean GSD = 3.9 cm

Max GSD = 16.5 cm

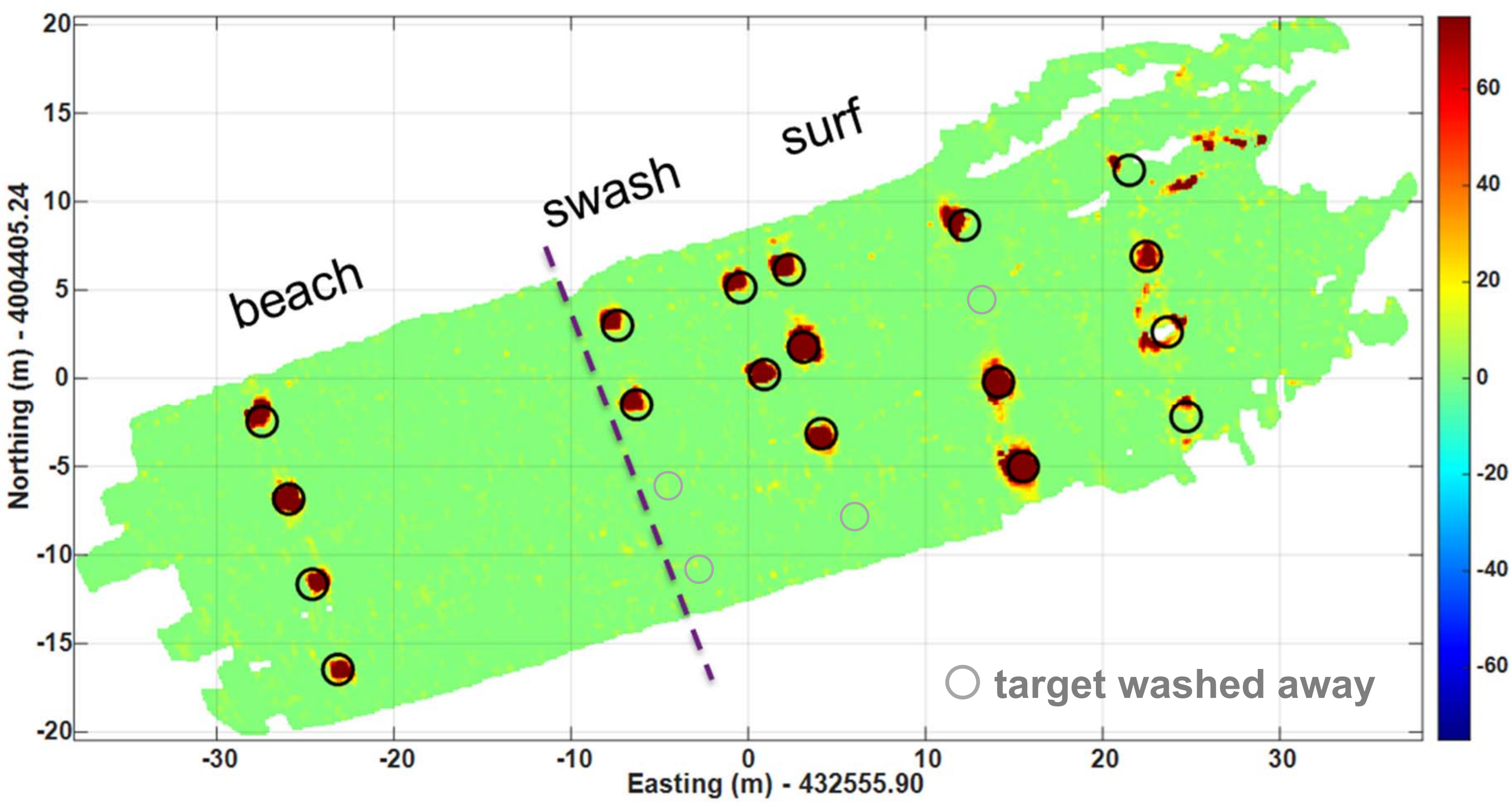
Total Duration = 1:43 hrs (0.88 acres)

Cumulative Coverage Rate = 0.52 acres/hour

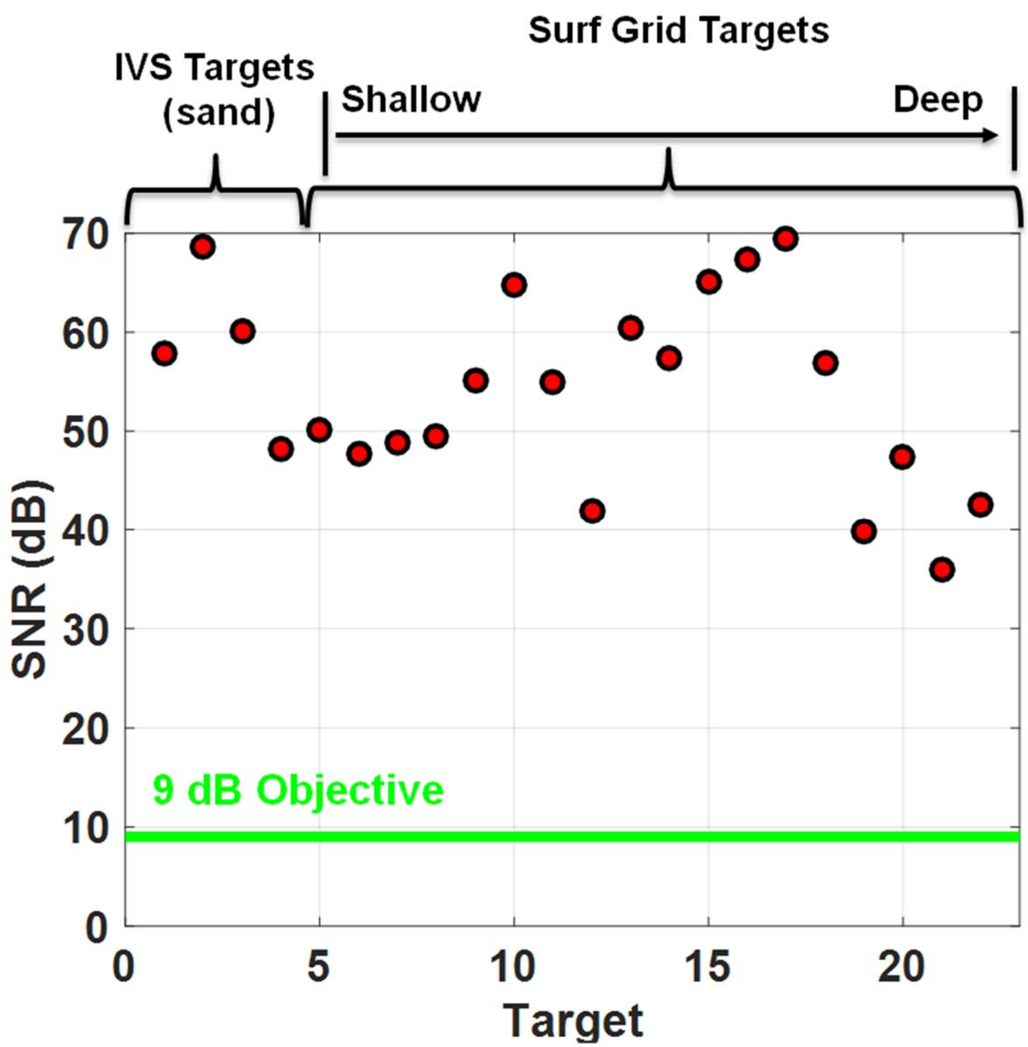


Detection Summary (Mapping)

- 100% coverage over foreshore region (beach → surf zone)
- Target detection adequate in all regions, but degraded in deep surf
- Increased array motion over deepest target row; SNR decreased
- Standard deviation of EM noise: beach (IVS) = 1.4 mV; surf = 1.1 mV



Target Detection Summary

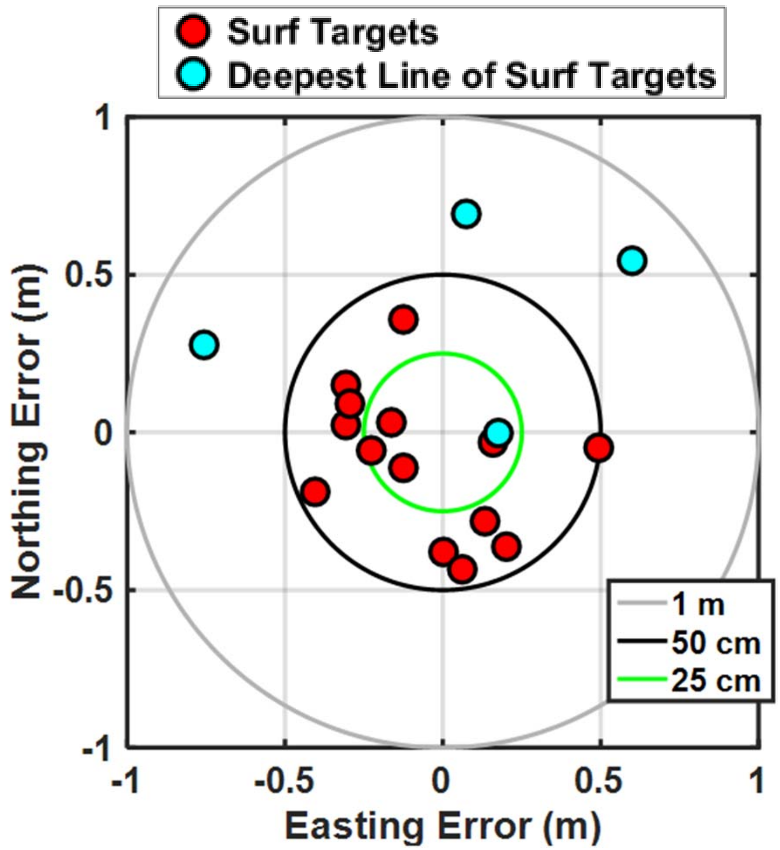


- All targets detected with SNR greater than 9 dB objective
- SNR reduction over deepest row of targets
- Standard Deviation of Noise
  - Beach (IVS) = 1.4 mV
  - Surf = 1.1 mV

Detection Localization

Summary of detection localization over 22 targets in sand and surf

- Location estimated using RTK-DGPS + heading with: i) encoder or ii) IMU
- All targets localized with 1.0 m, all but 3 (86%) within 50cm
- Deep surf targets (~2m deep) have greatest localization error



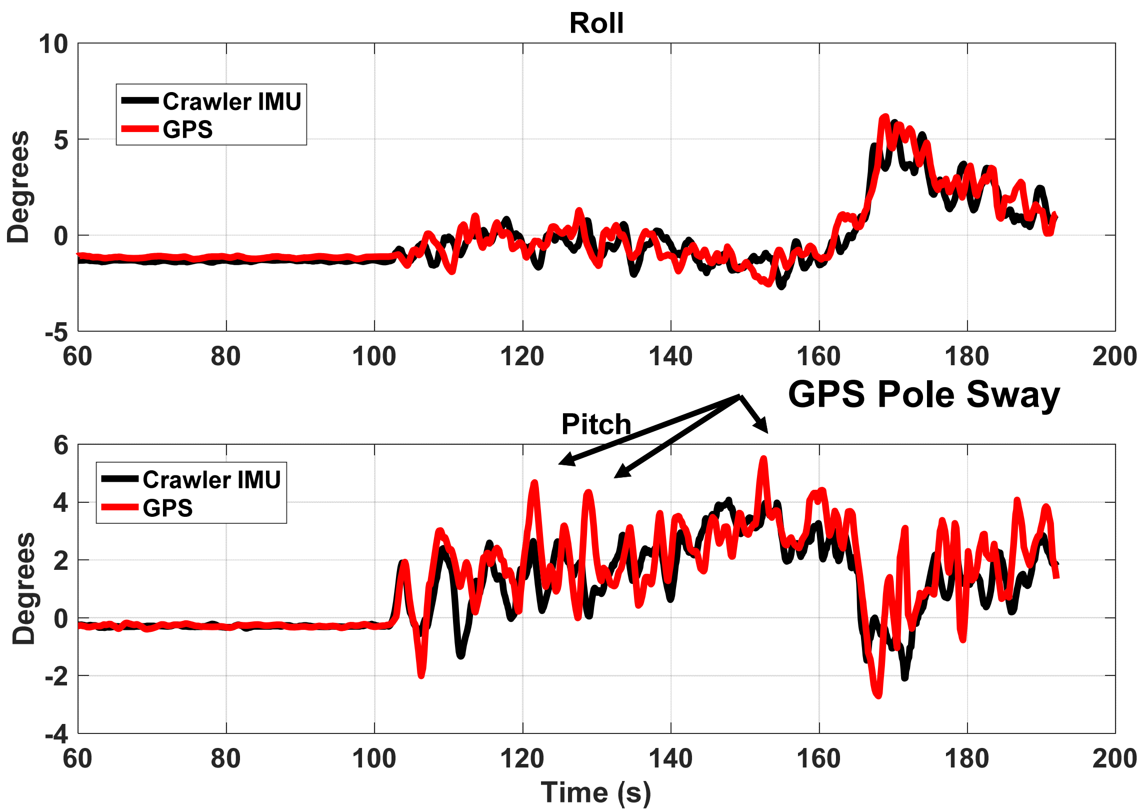
IVS Targets (sand)
$\Delta E = -0.06$ m, $\sigma E = 0.20$ m
$\Delta N = 0.01$ m, $\sigma N = 0.13$ m

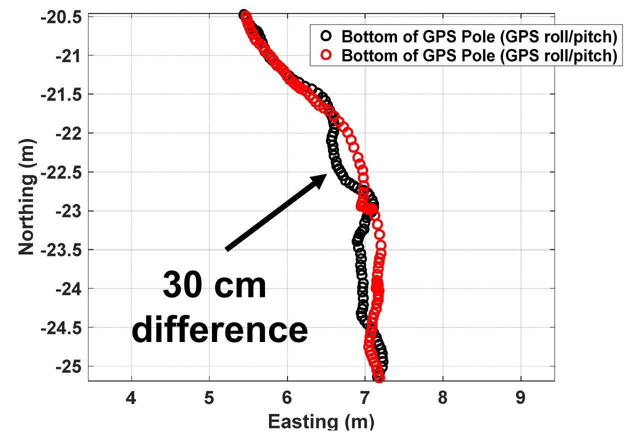
Grid Targets (surf)
i) Encoder-based:
$\Delta E = -0.04$ m, $\sigma E = 0.33$ m
$\Delta N = 0.02$ m, $\sigma N = 0.31$ m

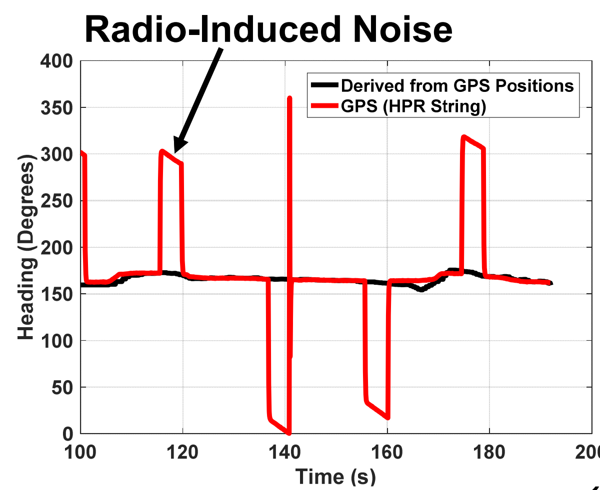
ii) IMU-based:
$\Delta E = -0.17$ m, $\sigma E = 0.45$ m
$\Delta N = 0.34$ m, $\sigma N = 0.42$ m

Detection Localization

i) GPS position + either crawler IMU or GPS roll, pitch, and yaw → location of crawler center
ii) Dual-antenna GPS heading → layback to tow hitch point
iii) Encoder or sled IMU yaw → array receiver locations rel. to GPS measurement point



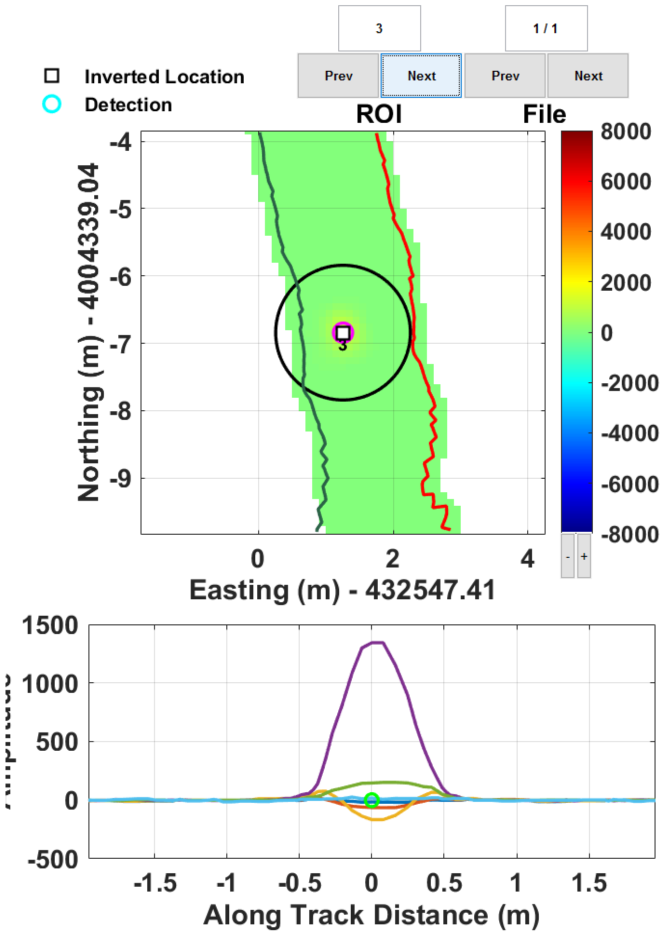


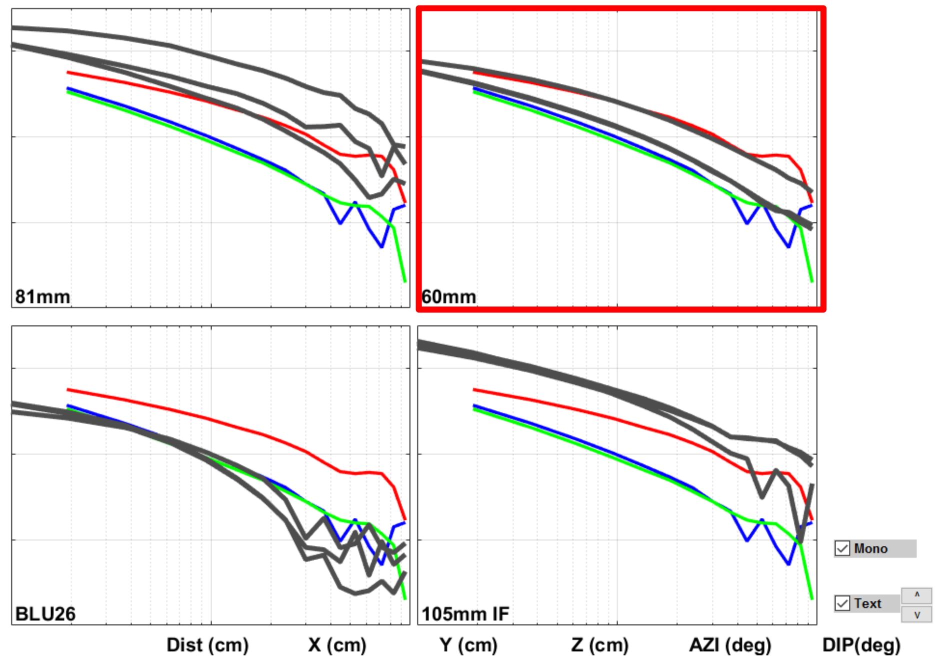


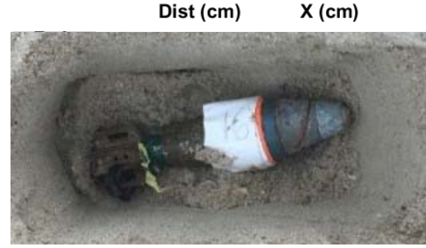
- Crawler IMU does not capture movement of GPS pole
- GPS yaw affected by noise from data radio

Classification Assessment

60mm: 25 cm bgs in beach





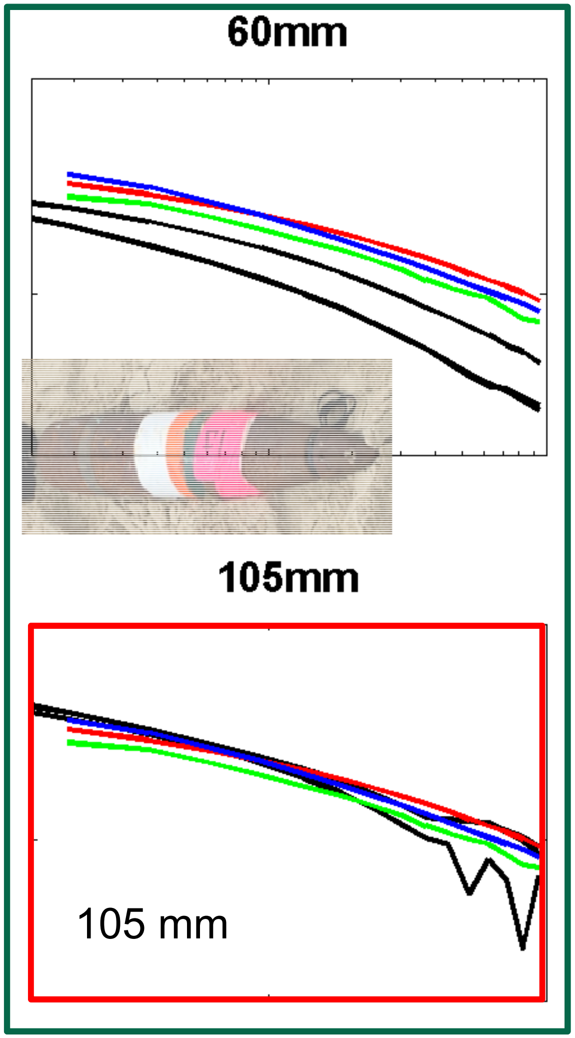


good 60mm library fit

Classification Assessment

Emplaced Surf Targets

TOI # 10



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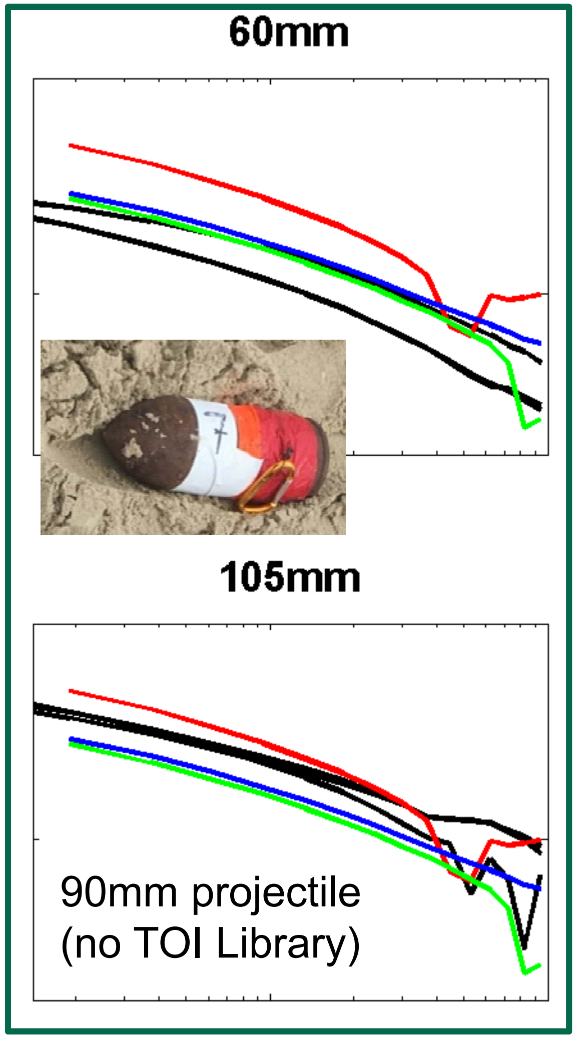

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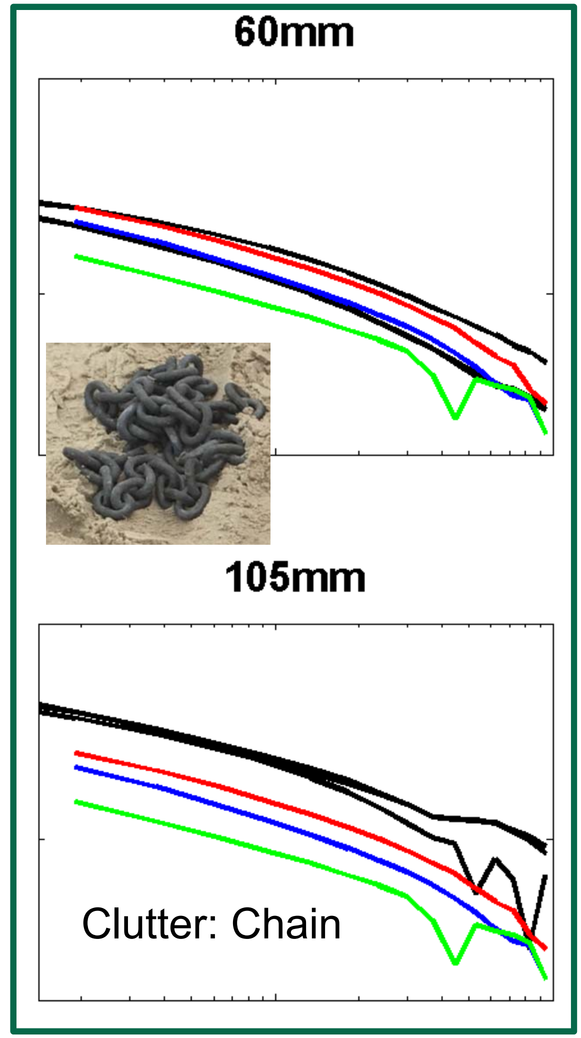


Cost Assessment

Biggest drivers are mobilization & daily on-site costs

Cost Element	Data to be Tracked
Support equipment lease rates	Integrated “wet lease” rates preferred • SurfROVer system: $7,440/day • Flex-EMI array: $2,100/day
Mobilization and demobilization	800 mile mob (NH to Duck, NC) • $15,500 mob / $7,500 demob (actual demob >$98K)
Site preparation	1 day x 2 tech (IVS, Seed Targets): $2,550
Instrument setup & calibration costs	Unit: Daily IVS report • $750 / day
Survey costs	Unit: $ cost / day • Estimated 0.5 acre/hour; 2.5-3 acre/day (4 pers) • $9,840 / day
Detection/classification data processing costs	Unit: $ per hectare as function of anomaly density Data Requirements: • Time required • Fixed costs and Personnel required

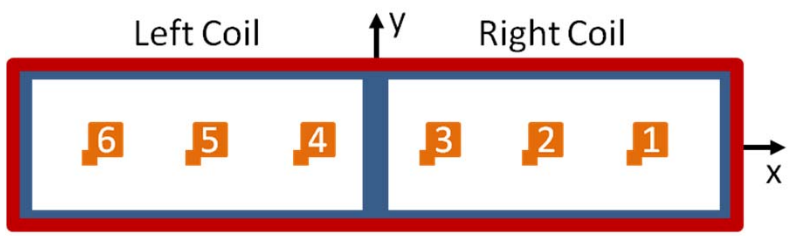
Potential Improvements: Crawler

1. Mast improvements: rigid spreaders, rigid stays, wireless antennae modifications
2. Scanning sonar / obstacle avoidance
3. Autonomous mission survey mode
4. Disentanglement guards

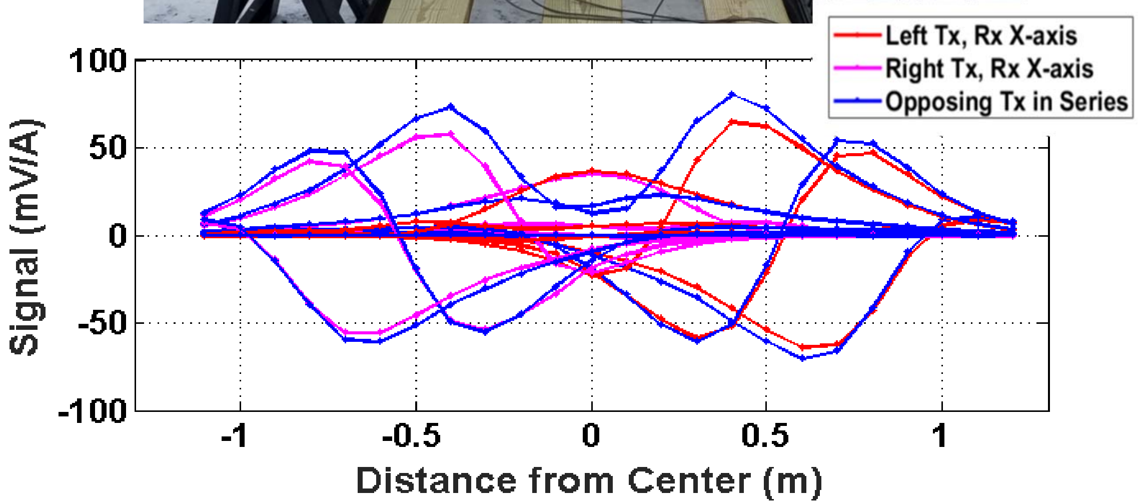
"rope brake [break?]"

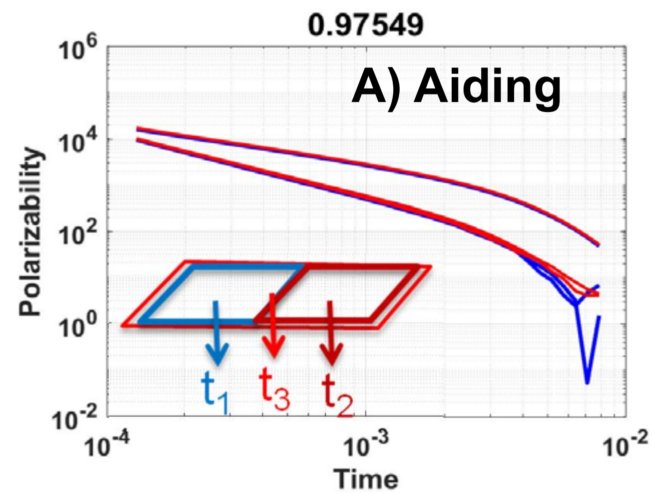
EM Array Improvements

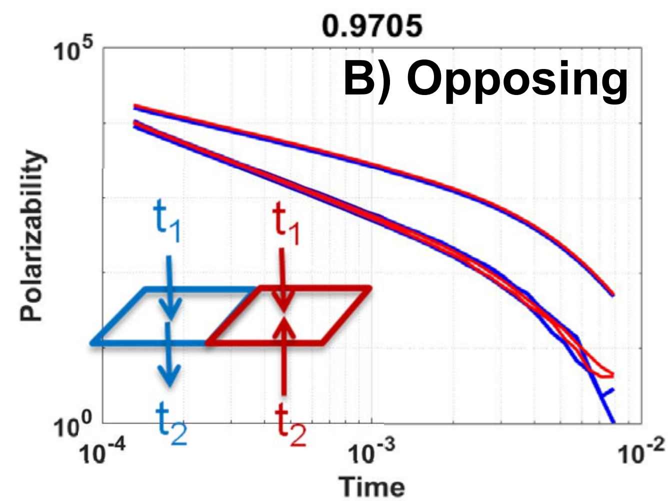
Rx-X: A) 3 Aiding Tx (Left, Right, All) & B) 2 Opposing Tx Configurations



Outer 2m Coil, L&R 1m Coils, 3x Receivers

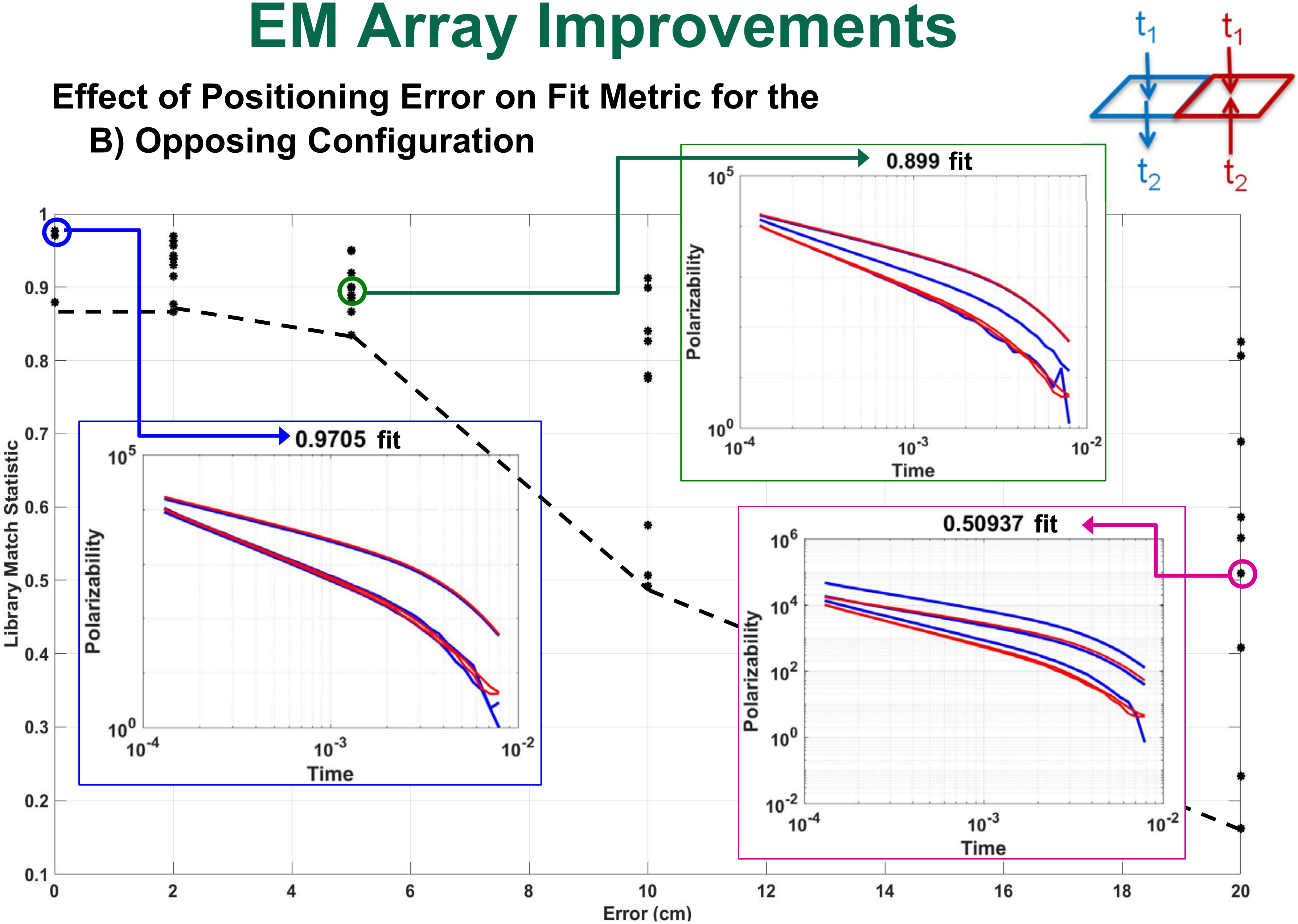






EM Array Improvements

Effect of Positioning Error on Fit Metric for the B) Opposing Configuration



Synthesis

- Implemented improvements at 2017 FRF Demo
  - Ruggedized tether coupling and wireless option (<6 msw)
  - Battery management and power filtering/isolation
  - Navigation guidance system tightly integrated w/ EM array GUI
  - Demonstration at FRF surf zone site
- Overall performance against metrics is promising
  - Mobility and stability in very rough surf proved effective
  - Tow system, navigation, and operator control successful
  - Towed array heading and orientation sensing modifications needed
  - Target detection in surf and sound environments successful – classification requires multiple overlapping passes
- Further improvements
  - array integrated positioning control and analysis
  - aiding/opposing 2D illumination upgrade

Technology Transition

1. ***<u>Information Dissemination & Outreach</u>***
   - **(upcoming) SAGEEP 2018:** presentation on Underwater UXO Technologies – Mar 2018
   - **NAOC Annual Meeting:** poster on Underwater UXO Technologies – Dec 2017
   - **AGU 2017**: "*Munitions in Underwater Environments*" session presentation – Dec 2017
   - **SERDP/ESTCP Webinar**: "*Nearshore UXO Arrays from Unmanned Platforms*" – Nov 2017
   - **Offshore Energy & Storage**: "*SurfROVer: ROV for Littoral Zone Survey Work*" – July 2017
   - **IEEE-Oceans 2017 paper**: "*Littoral* Applications of 3DEM from ROVs & AUVs" – June 2017
   - **Sea Technology article** "*Vehicle Design for the Littoral Zone*" – May 2017

<u>2. Direct Transition to Production Geophysical Services</u>

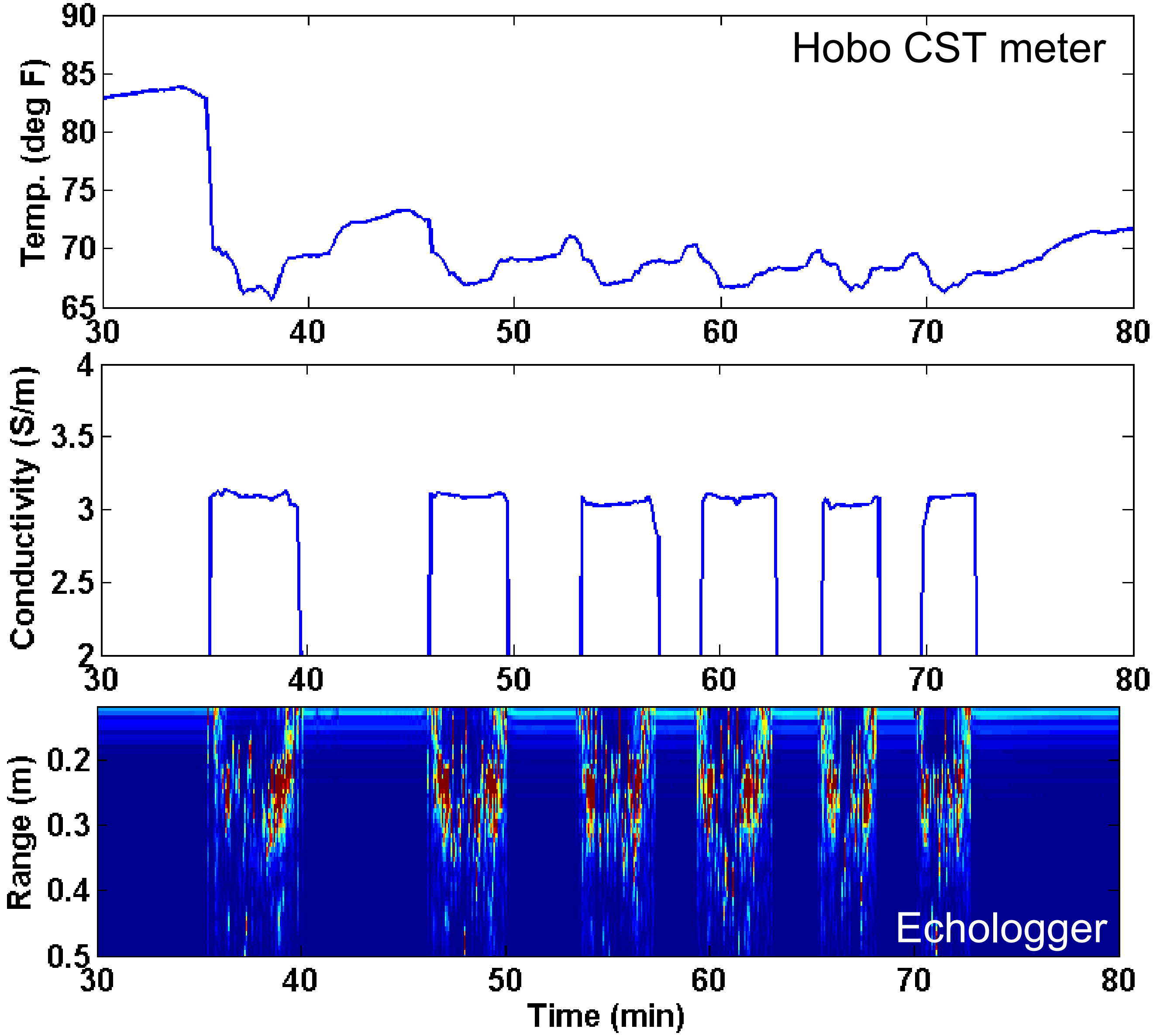
- Service firms stated application needs for amphibious DGM survey system for shoreline and nearshore MMR work → direct technology transition
- Cost structure for "wet" lease & service business model price structure established
- *e.g.*, RFP request: Makua, Oahu site TCRA; RFP request: FZT, Fla. site RI/FS

<u>3. Next Step: Scaled Pilot Study & SOP Development</u>

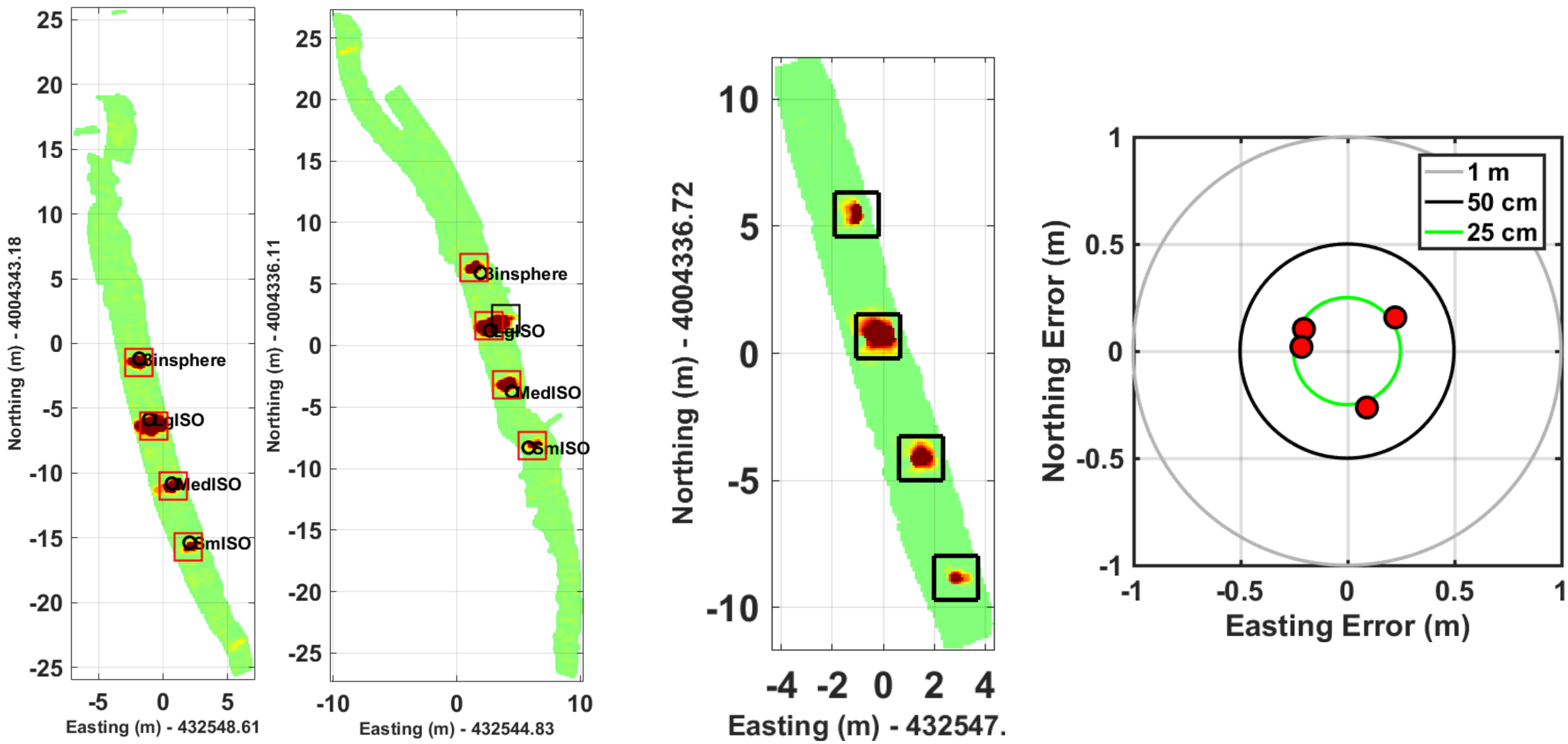
- Navy interest in demonstration pilot study at live site (VNTR)
- Regulatory constraints for bottom contact?

EXTRA SLIDES

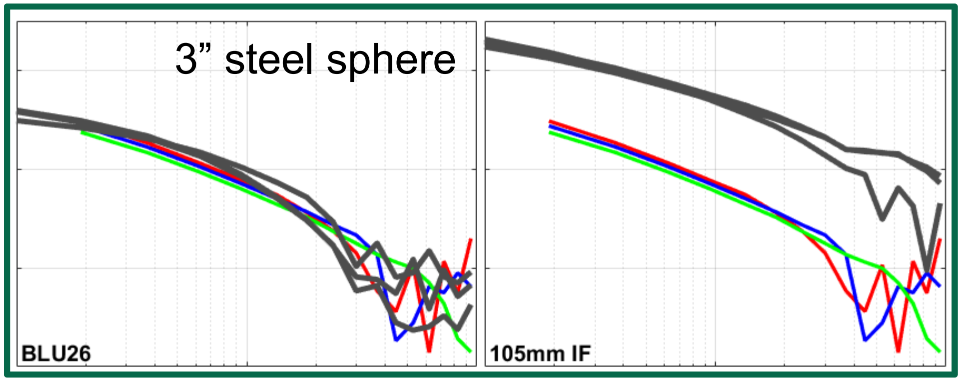
Temp, Salinity, and Bottom Reflection

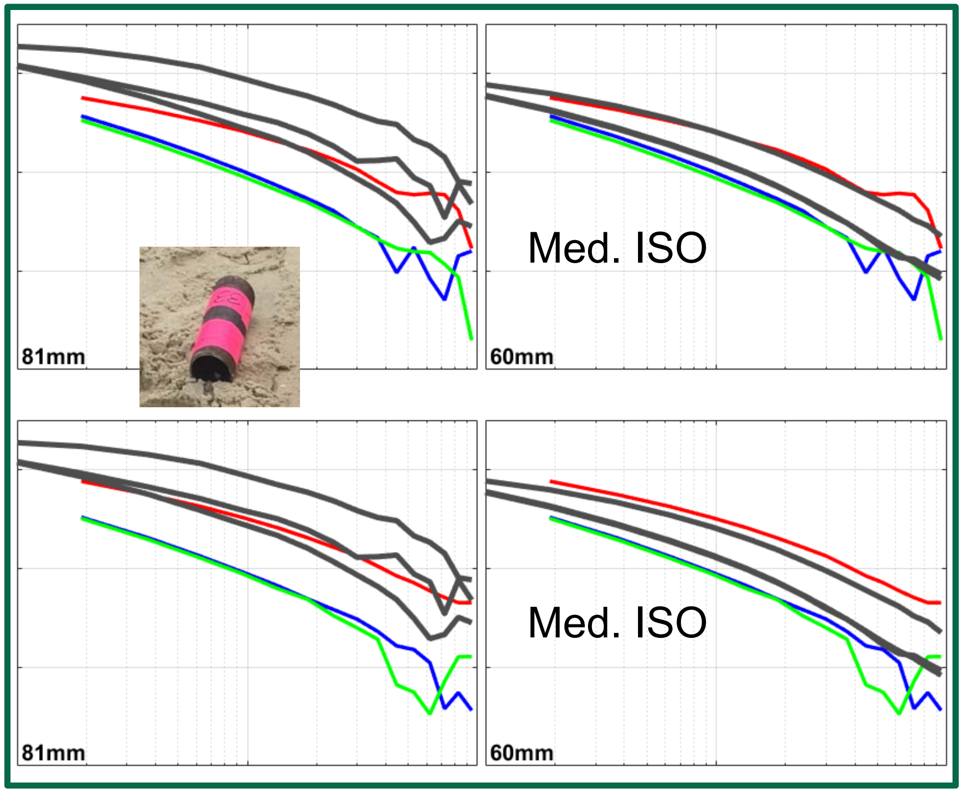


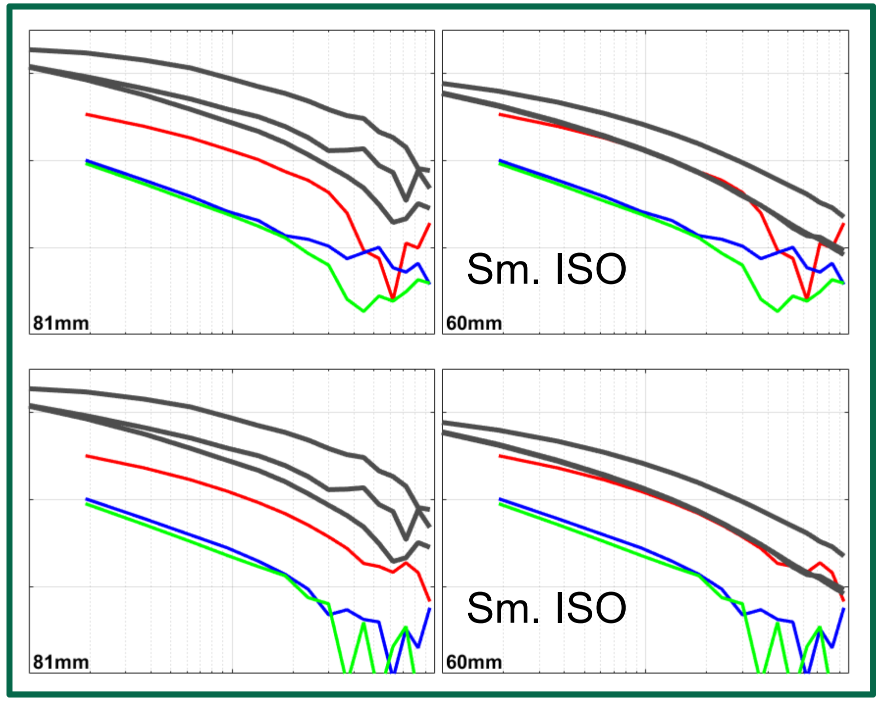
IVS Validation / QC



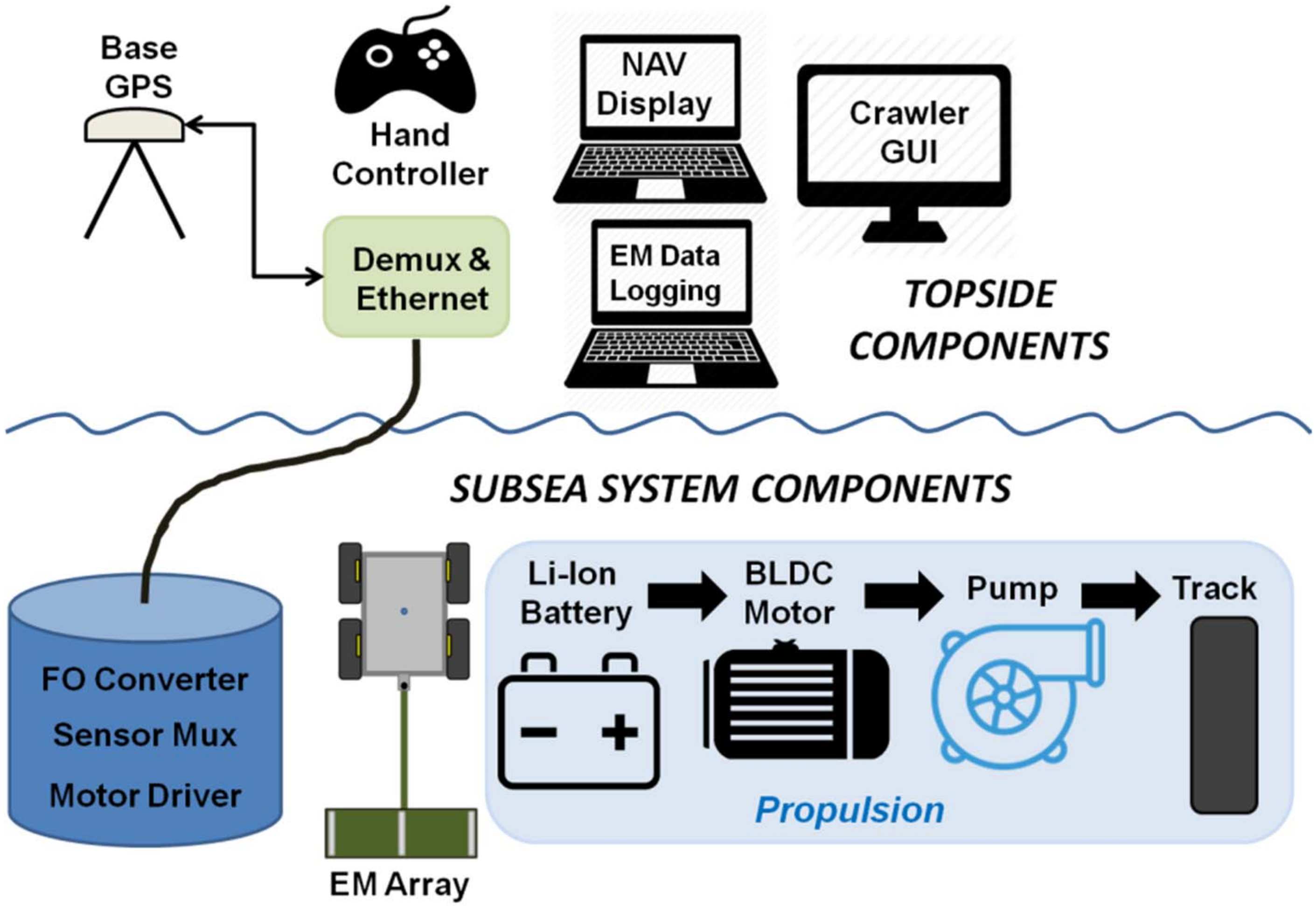
Classification Assessment



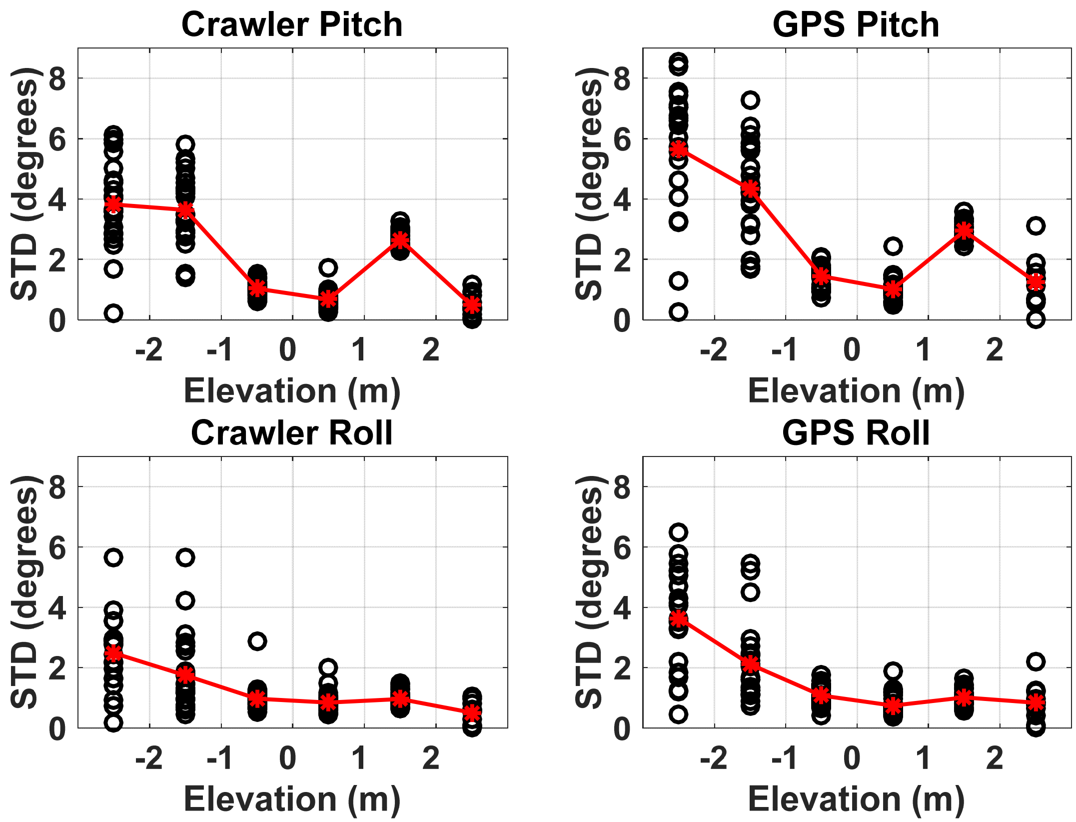




System Block Diagram



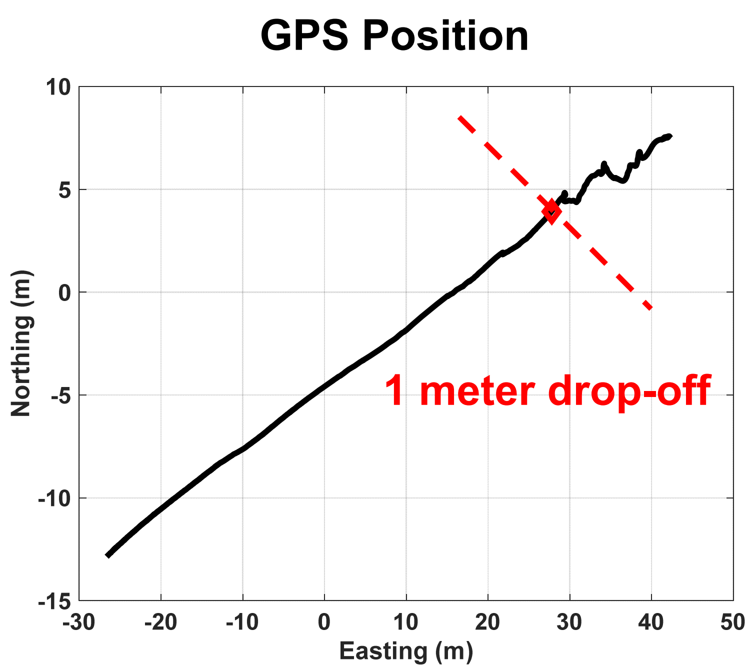
Variability of Roll / Pitch versus Elevation

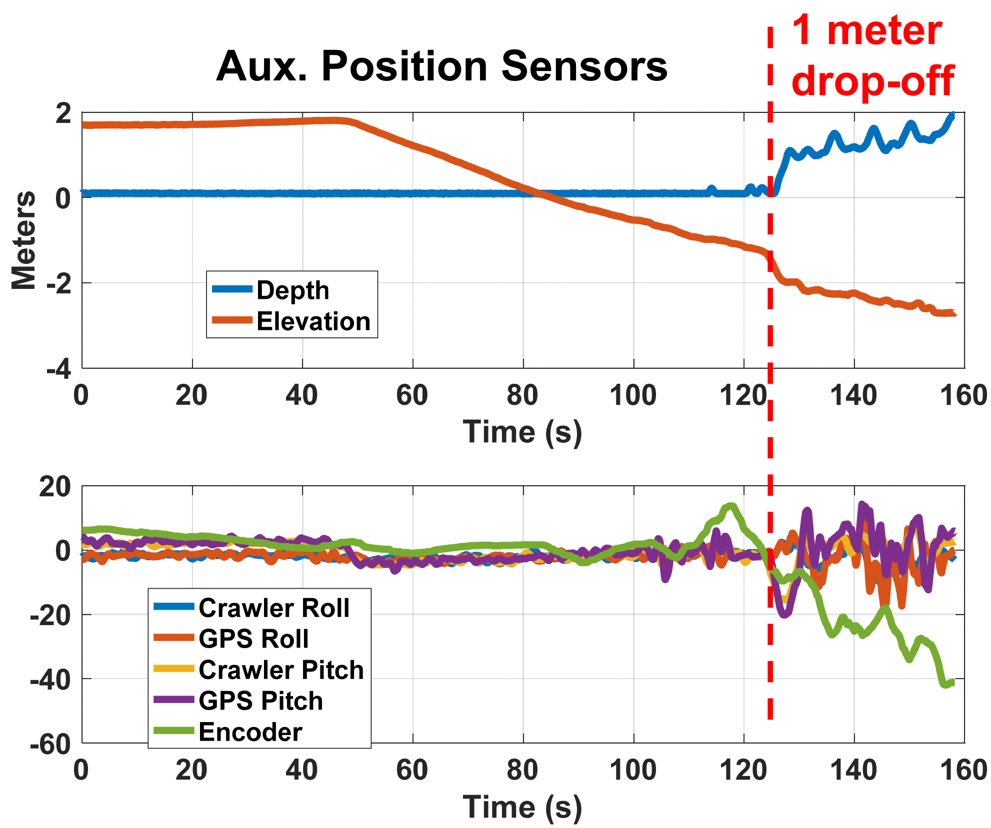


- Data shown are from transects perpendicular to shore
- Increase in roll / pitch variability as water depth increases (elevation decreases)
- GPS roll / pitch more variable than crawler roll / pitch
- Roll / pitch variability minimum over sand smoothed by waves (-1 to 1 m)

Deep Target Localization

- Decrease in localization accuracy for deepest line of targets
- Elevation / Depth sensors reveal sudden (1m) drop in elevation prior to last target line
- Following sudden drop all localization sensors show large increase in variability
  - GPS roll / pitch, Crawler roll / pitch, GPS location, GPS-derived heading, Encoder
- Likely crawler no longer following a straight path (left/right tracks not gripping equally)





Performance Objectives

Performance Objective	Data Requirements	Success Criteria
Qualitative Performance Objectives		
Ease of Use	• **Field notes with time stamps** • **Operator observations** • **USACE observations**	**Ease of use compared to alternative marine surveying procedures**
Launch and Recovery	• **Time to launch and recover** • **Observational notes**	**Time to launch, time to recover, mean down time nonprohibitive**