



Implementation of Unmanned Magnetometer Survey Technology for Munitions Response

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Poorly Accessible Sites

Gain Access to All Sites

Terrain & Site Challenges

- Surf zone / shallow water
- Salt Marshes
- Reefs / Obstacles
- Shorelines / Cliffs
- Steep/Mountain Terrain

Unmanned Aerial System (UAS)
Sensors Provide Safe Surveying



surf zone



marsh / wetland



reefs



sea cliffs

Outline of This Talk

1 Background

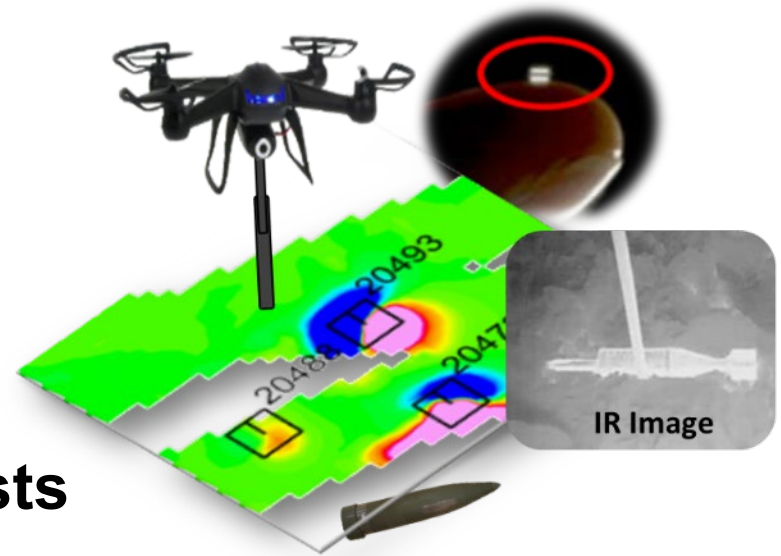
MAG Physics & Sensors
Unmanned System Use

2 UXO Missions

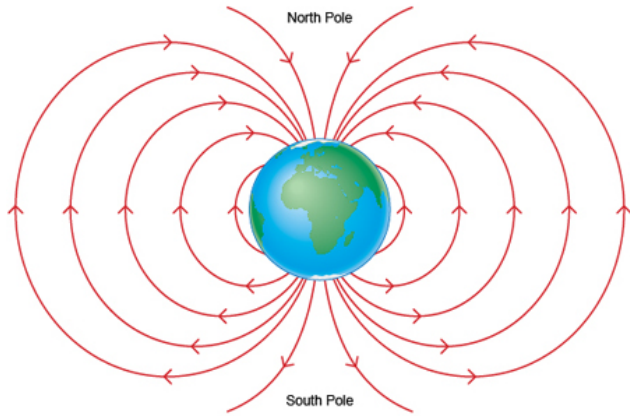
3 Flight Operations

4 Controlled & Live Site Tests

5 What's Next?

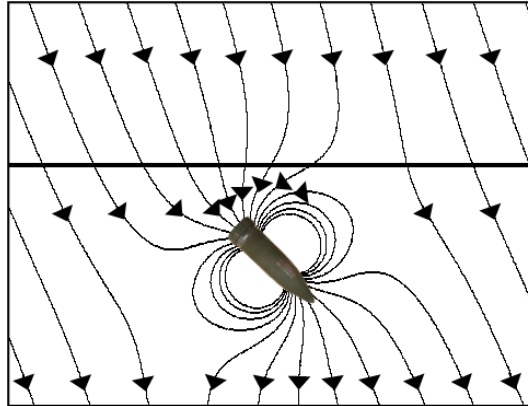


Magnetics For UXO: Physics

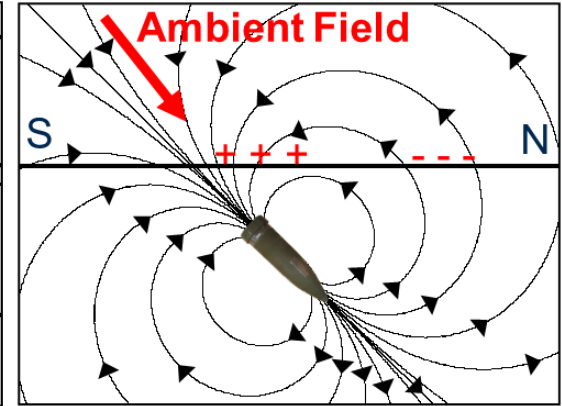


- Earth provides “transmitter”
- B_{Earth} locally uniform but directional
- Temporal variation generally slow

Total Magnetic Field



UXO (Anomalous Field)



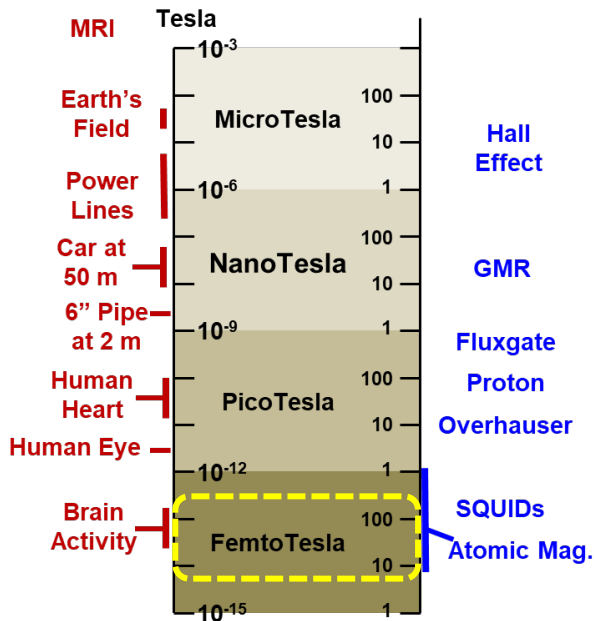
- Ambient field perturbed (flux concentrated)
- Anomalous field is projection of $B_{ambient}$ onto the effective dipole moment of object

At range $\gg D_{object}$ objects looks & acts like a dipole

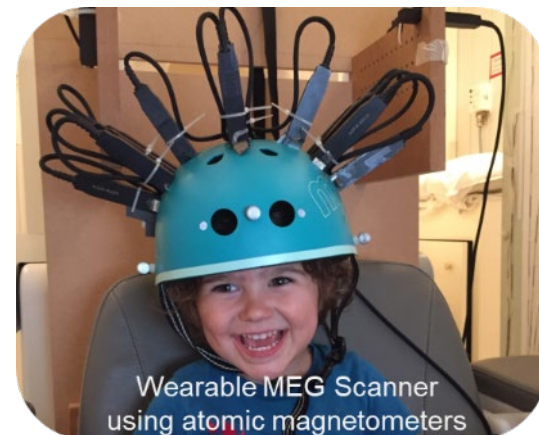
Modern Magnetometers

(What's a NanoTesla? What's quantum?)

- Survey magnetometers usually measure total field
- Most sensitive are atomic magnetometers or SQUIDS
- Sensor noise limited by:
 - Motion errors
 - Electronic noise
 - Slew rate / gradients
 - Thermal stability
 - Processing / control



adapted from Romalis et al.



Wearable MEG Scanner using atomic magnetometers
 Photo credit Rebecca Slater: from PhysicsWorld

Responsive to all sources of magnetic induction
Quantum Precession

$$\omega = \gamma B$$

Integrating Payloads on Platforms

Platform Noise

- Metal bits (ferrous)
- Actuation, circuitry

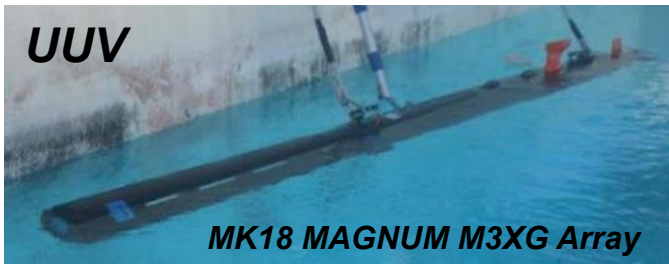
Motion Noise

- Moving through Earth's field
- "Compensation"

Environmental Noise

- Geology, clutter
- Geomagnetics (weather)

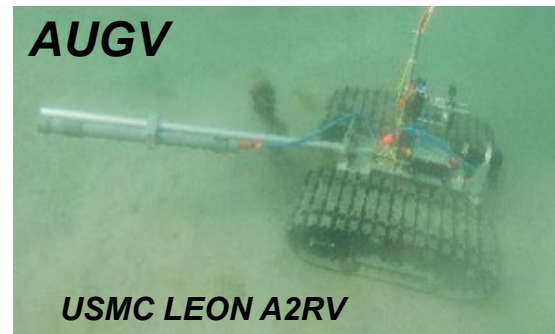
UUV



UAS



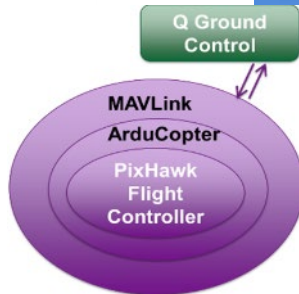
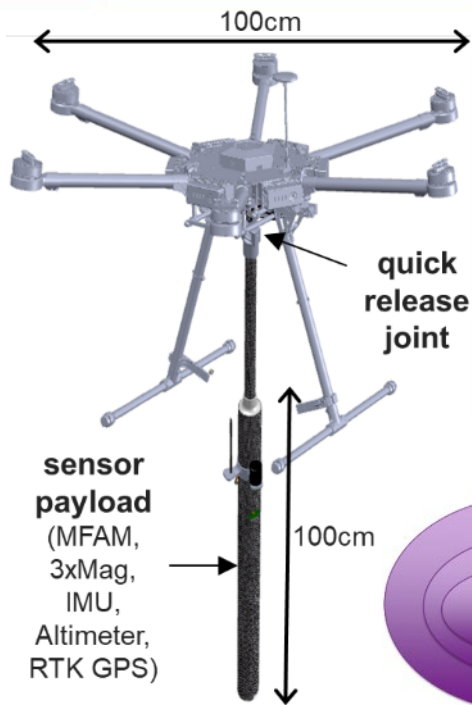
AUGV



ROV

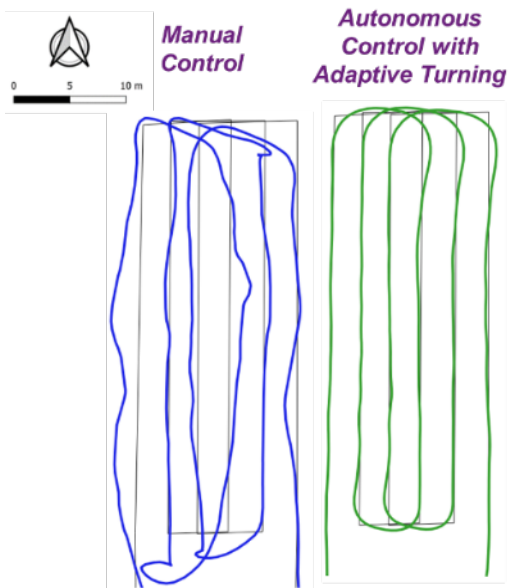


MAG on Drones

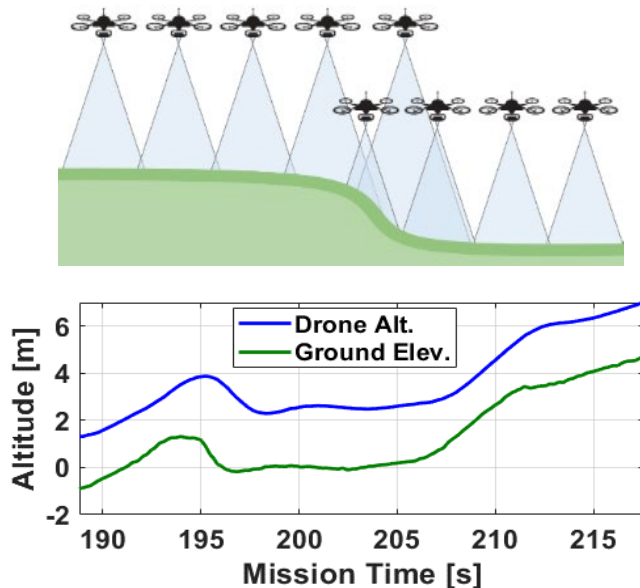


UXO Mission Plan: *Fly Low and Steady*

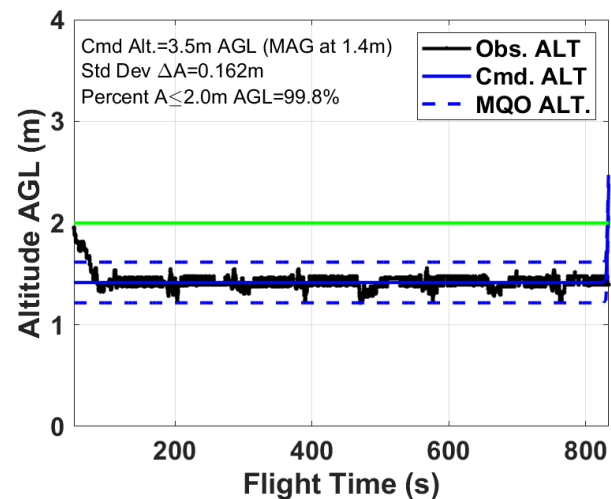
Auto Survey Control



Obstacle/Ground Avoidance



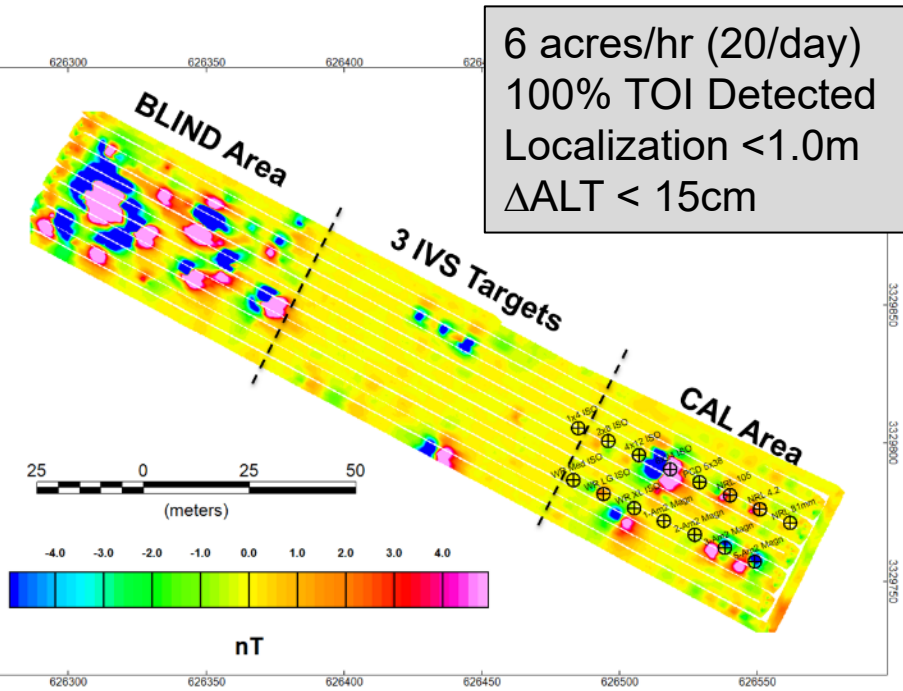
Terrain Following Altitude Control



Operations

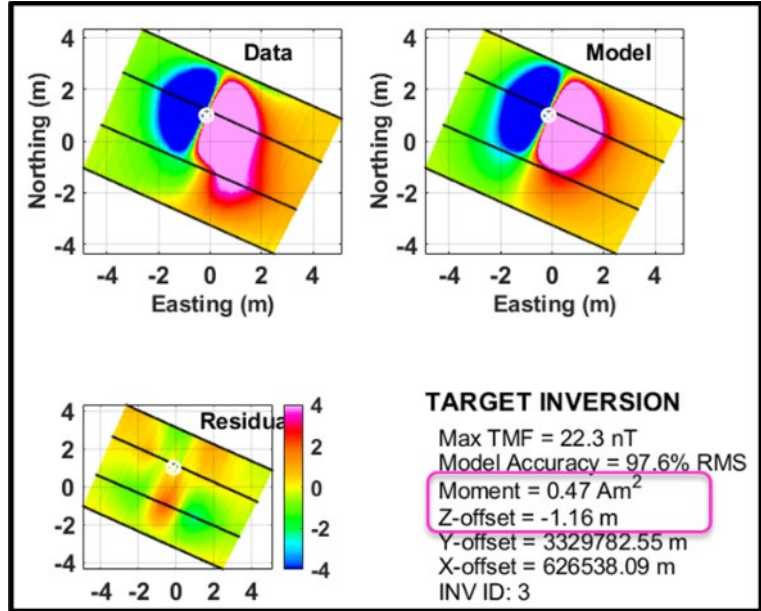


ESTCP Demonstrations: Florida Gulf Coast 2022



6 acres/hr (20/day)
100% TOI Detected
Localization <1.0m
 Δ ALT < 15cm

105mm ($M_{est} = 0.56 \text{ Am}^2$, $M_{inv} = 0.47 \text{ Am}^2$)



ESTCP Live Site Demonstration: Maine Bombing Range

- 700-Acre State Park Mid-Coast ME
- FUDS naval air training site
- Active from 1940-1973
- 46 UAS-MAG Sorties
- 30-Acres Covered
- 41 QC Seeds

1998 TCRA (5" warheads)



Surf

Beach

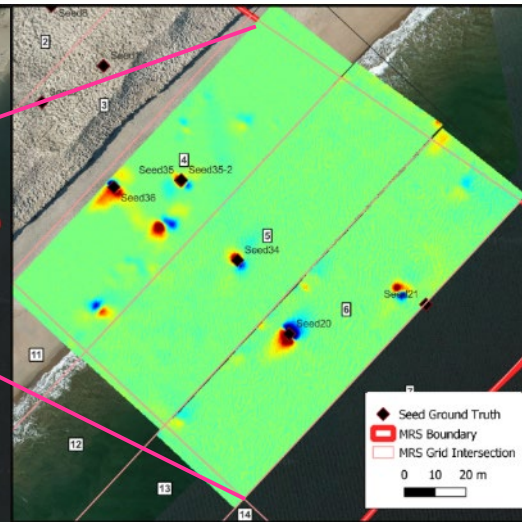
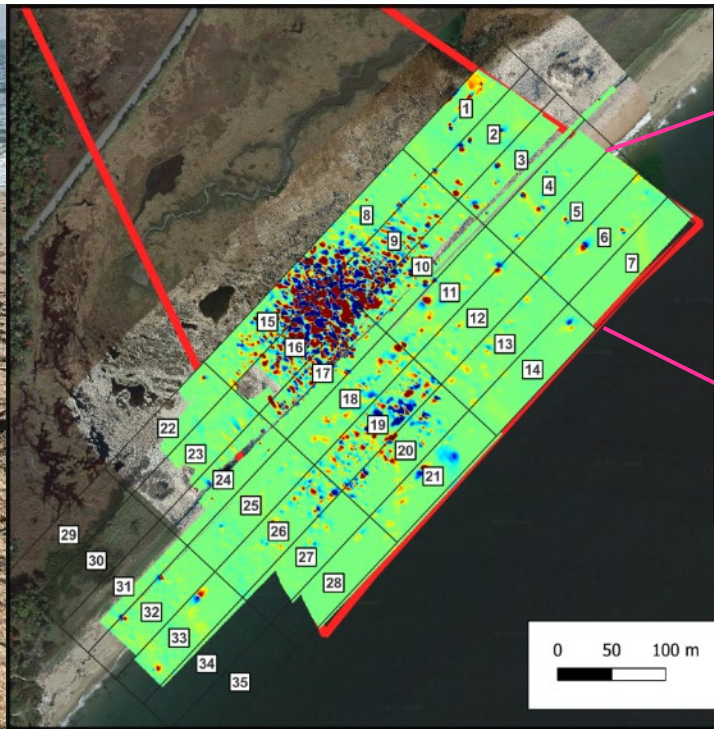
Dunes

Marsh

flight team →



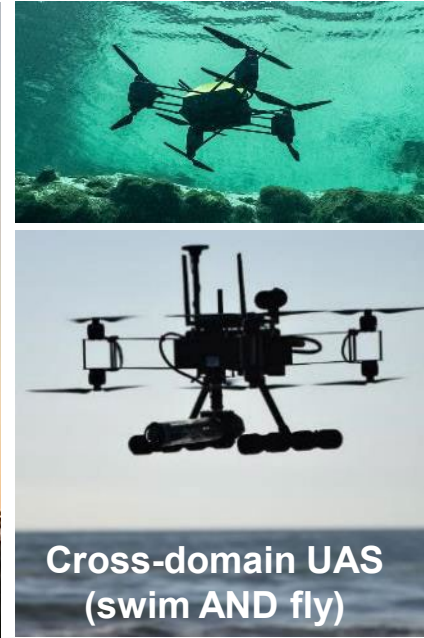
ESTCP Live Site Demonstration : Maine Bombing Range



What's Next?

Emerging Advanced Capabilities:

- Implemented Real-time On-board Processing (adaptive compensation)
- Demo'd SWARM Flight with 4x UAS
- Demo'd new cross-domain UAS-MAG system
- New Payloads & Features



Synopsis / Transition

- **Flight tested over nearshore (surf, marsh) at 6 Different Sites**
- **ESTCP Controlled & Live Site Demonstrations (FL & ME)**
- **Mobilized & Successfully Flown in 3 OCONUS Tests**
- **Achieves Wide Area Survey (RI/FS) Objectives (“nature & extent”)**
- **Multiple Flight-ready MAGPi MAD Units Available**
- **Turn-Key Part107 Service Ready-To-Fly Kit (UAS+Pilot+Sensor)’s**
- **Transitioned to DOD COTS-Waivered Airframe (BH-E900 & Alta-X)**

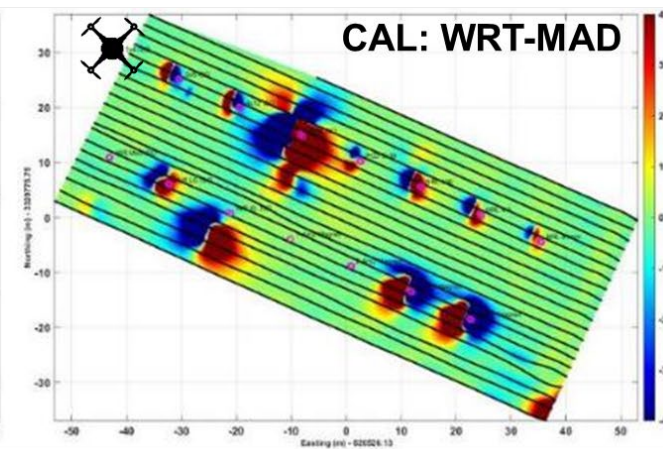
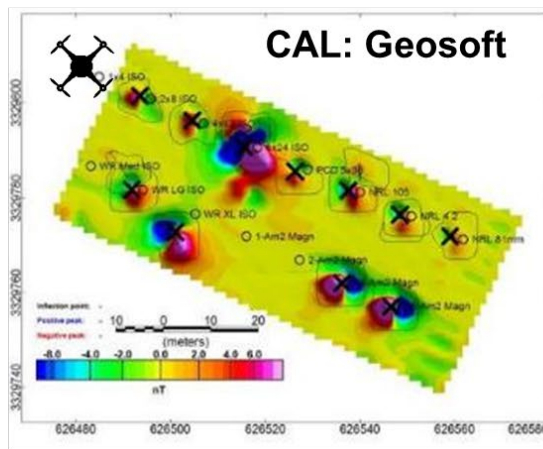
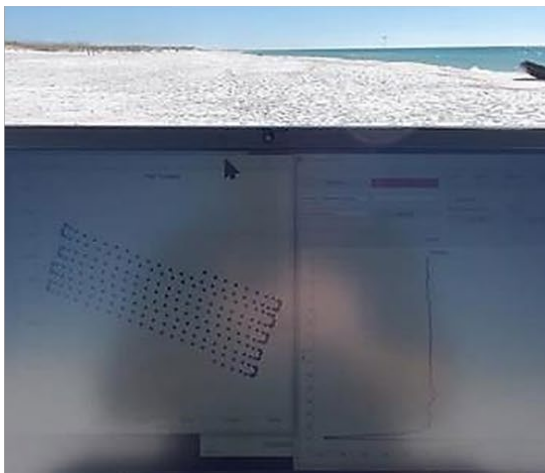
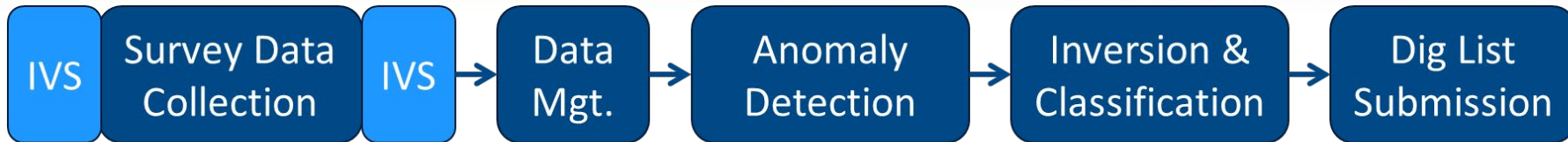
Acknowledgements



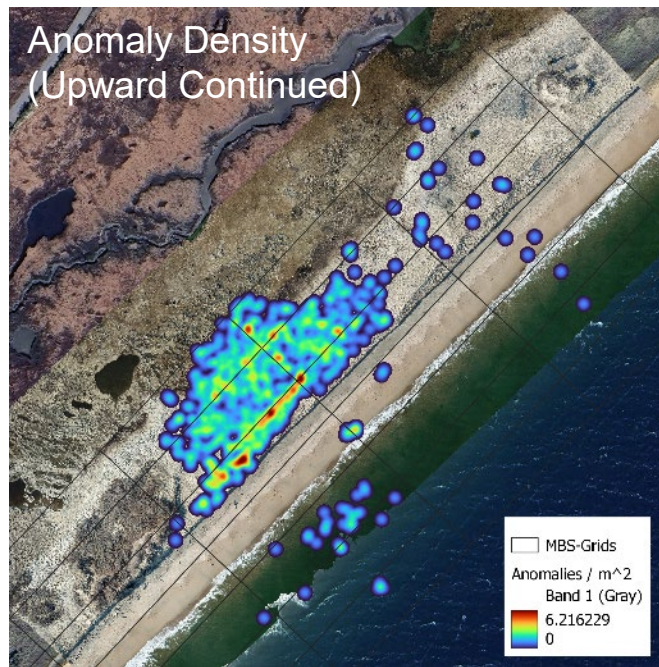
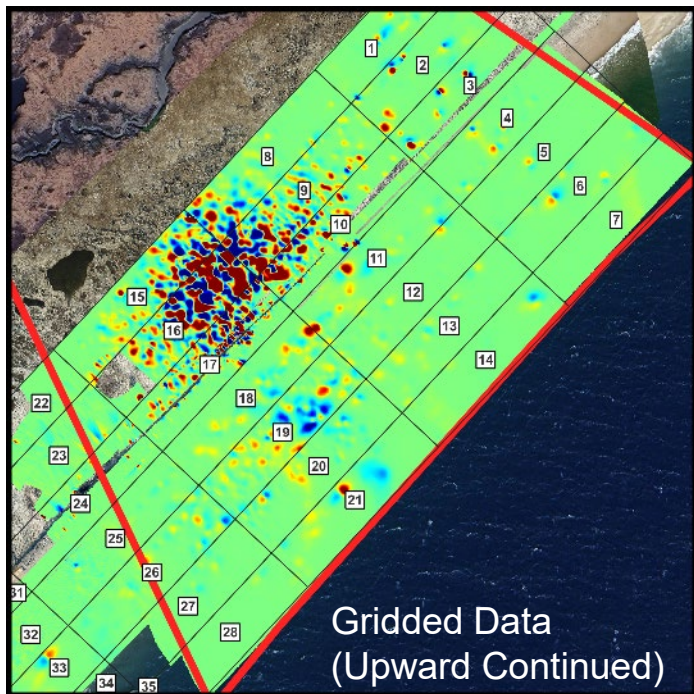
- Reid State Park & Maine DEP
- NSWC-PCD & NRL-Stennis
- UW MR Advisory Group
- WRT Flight Team:
 - Mike Gunnels*
 - Martin Helmke*
 - Andrew Masters*
 - DB Bhowmick*

ADDITIONAL SLIDES

UAS-MAG Workflow



MBA Density



MBA: Operation Snow Beach 1972

