# Real-time Magnetic Anomaly Detection using Mobile Autonomous Platforms

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# MFAM
# Miniature Magnetometer

GEOMETRICS
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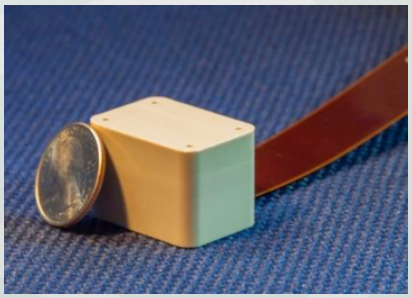
## Laser-pumped Total-field Cesium Optical Magnetometer

- Small size:
  15 $cm^3$ sensor and 200 $cm^3$ electronics
- High performance:
  ~ 1pT/√Hz noise, 1 KSps (GPS Sync), 400 Hz BW
- Low power operation: 2.5W / sensor nominal
- Dead Zone: Polar, ± 30°
- Light Weight:
  Each Sensor: 25g, Electronics Module: 190g
- Customizable interface for multi-sensor applications
- Designed for manufacturability
- Built-in inertial measurement sensors

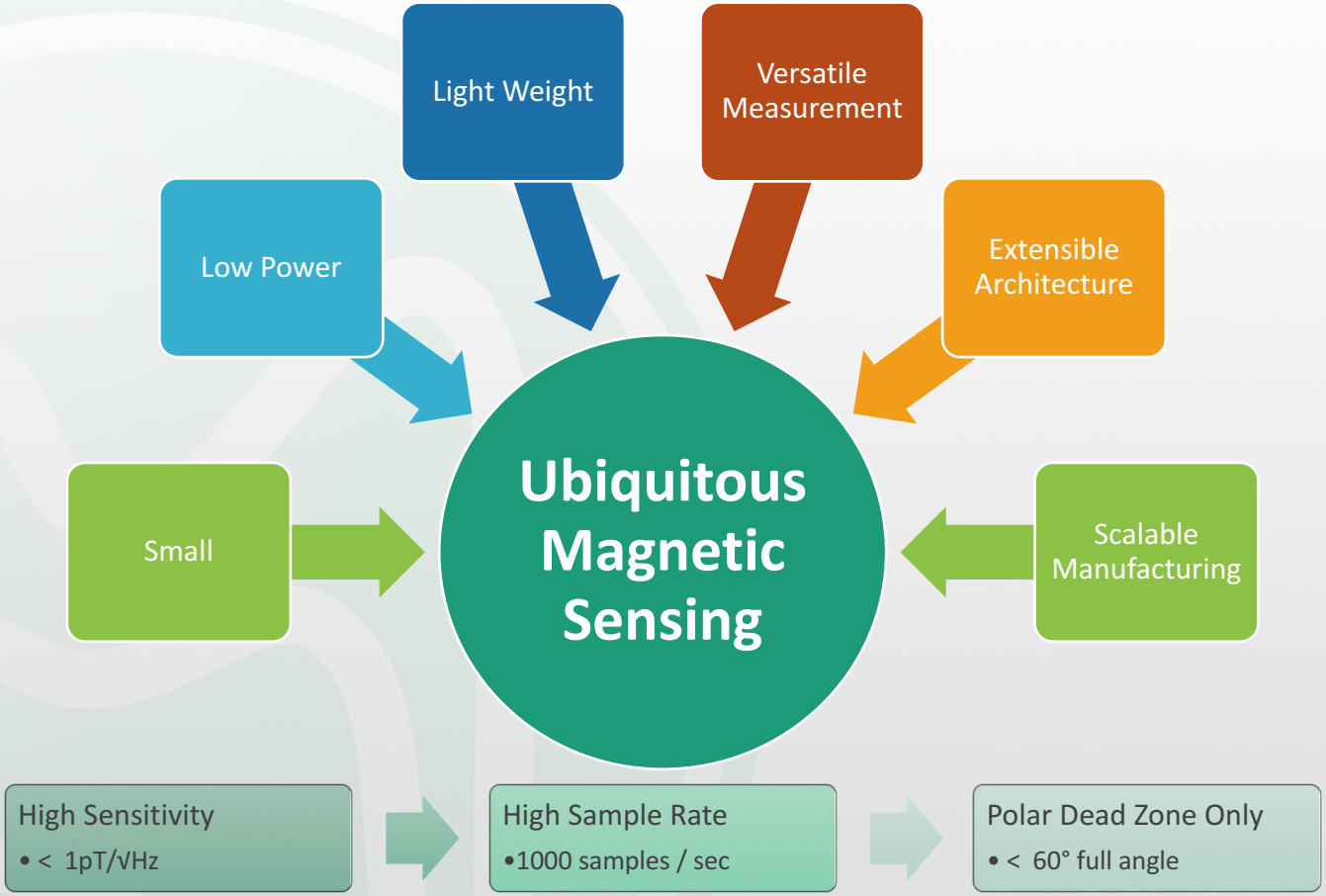
## Reconfigurable dual-sensor module for:

- Gradiometry
- Intrinsic heading error compensation
- Dead-zone free operation



* Strategic Environmental Research and Development Program (SERDP) Projects MM-1512 and MM-1568

# MFAM Characteristics



# UAS-deployed MFAM

- Drones established in Civil Engineering and Construction Industry, Mining, Agriculture, Security, Property Management, …
- AeroMAG: Only UAS-deployed sensor for sub-surface magnetics with high-precision

# MagArrow

Drone-deployable lightweight self-contained cesium magnetometer with data logger

Applications: Infrastructure, UXO Detection, Geology, Minerals, Archeology


## Features:

Weight: 1kg
Size: 1m length
Battery powered: 2 hours
Onboard GPS
WiFi Access Point
Browser and app interface

## Sensor Specs:

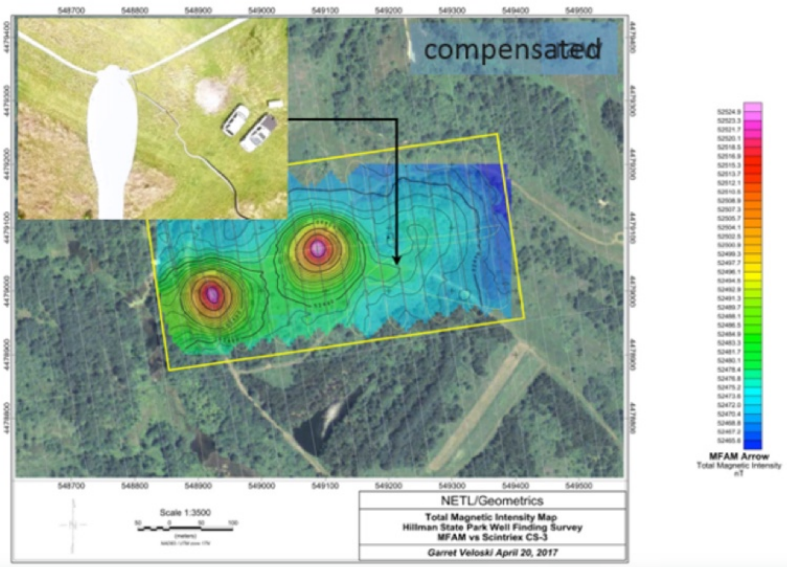
Heading Error: 10nT p-p
Sensitivity: ~ 10 pT/√Hz noise
Sample Rate: 1 KSps (GPS Sync)
Bandwidth: 400 Hz

# MagArrow Prototype Results

## MFAM Flight Testing

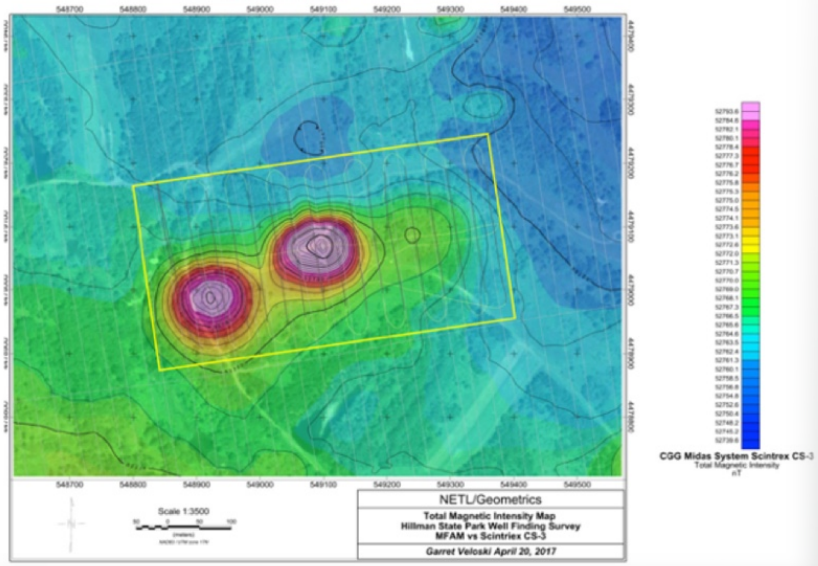
MFAM vs CGG Midas System Results – Hillman State Park buried wells

MFAM Arrow



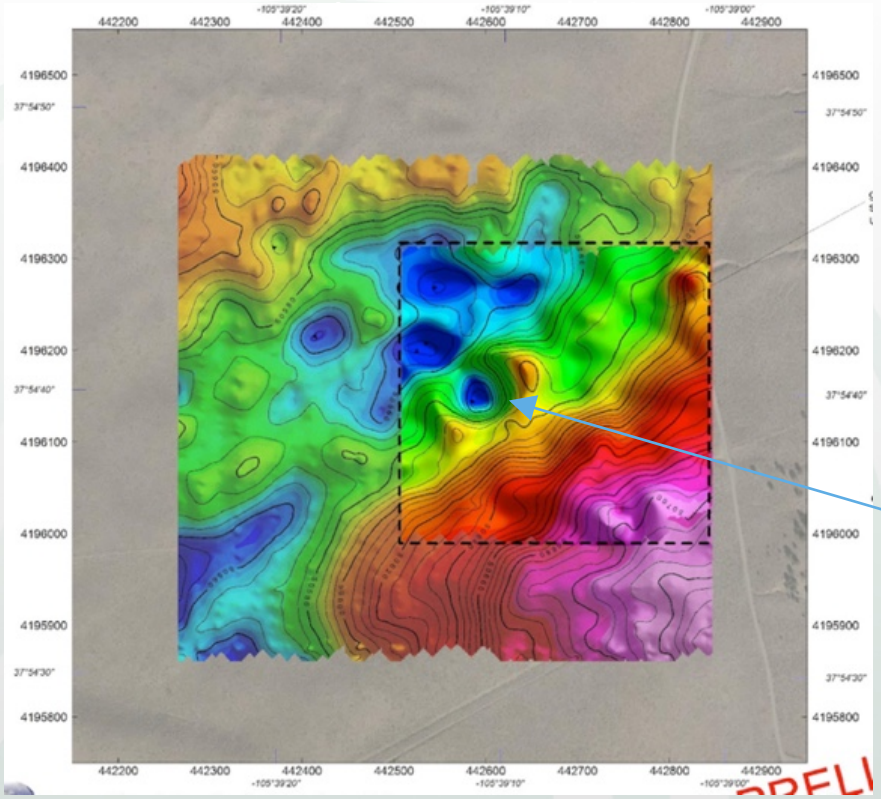

Drone-deployed Survey

CGG Midas System
(Scintrex, CS-3)




Helicopter Survey

# MagArrow Prototype Results

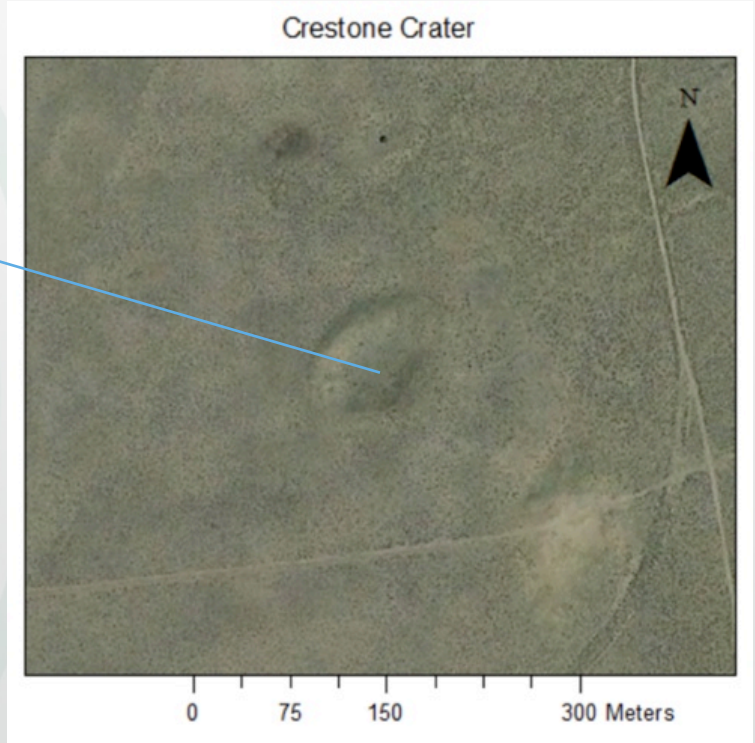



Inset Dotted Image: Ground Survey
5nT Contour Spacing

**International Geophysical Services, LLC**

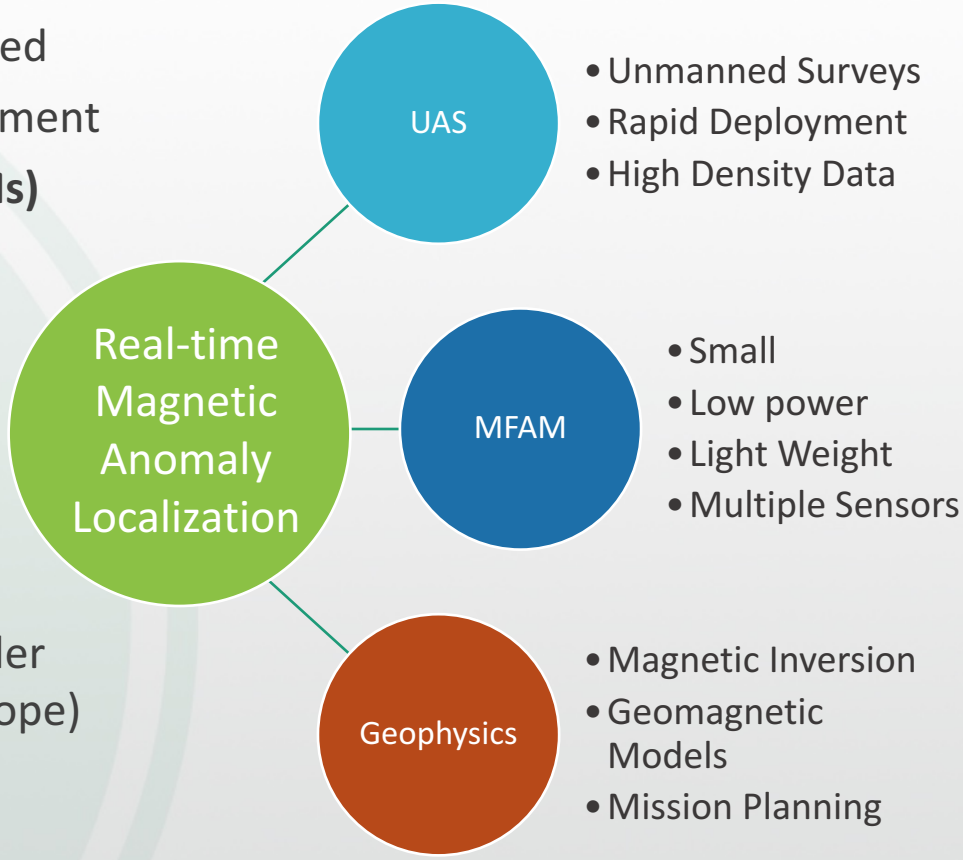
Crestone Crater Survey

https://www.instagonline.com/media/Bev6FQ6ABHX



# Multi-Sensor UAS MFAM

1. **Unmanned Aerial Systems**
   → UAS surveying technology established
   → See construction, property management
2. **Miniaturized Magnetometers (MFAMs)**
   → Established commercial units
3. **MagArrow System**
   → successfully integrates MFAMs



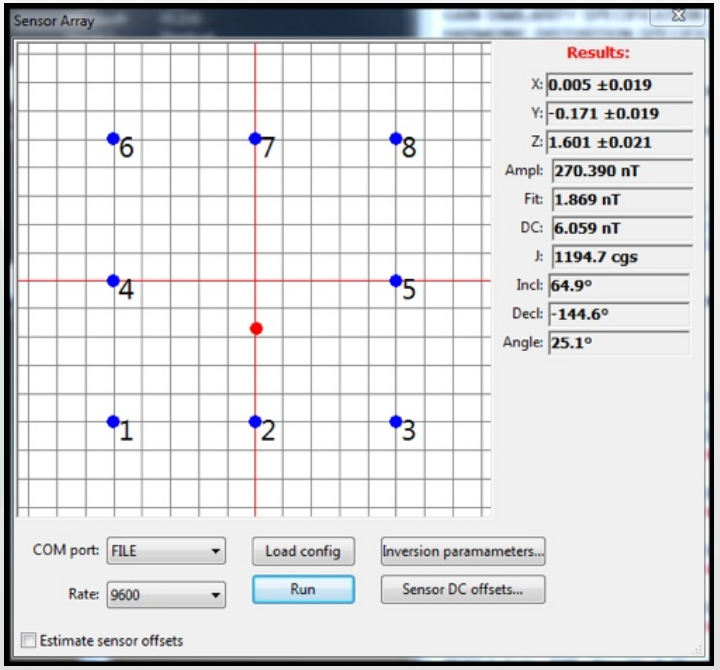

**NEXT:**

- Bring drone magnetic surveying to wider application set (larger operating envelope)
  - ***Real time anomaly processing***
  - ***Gradient array configurations***
  - ***End-to-end pre- & post-mission software***

# Multi-Sensor Array

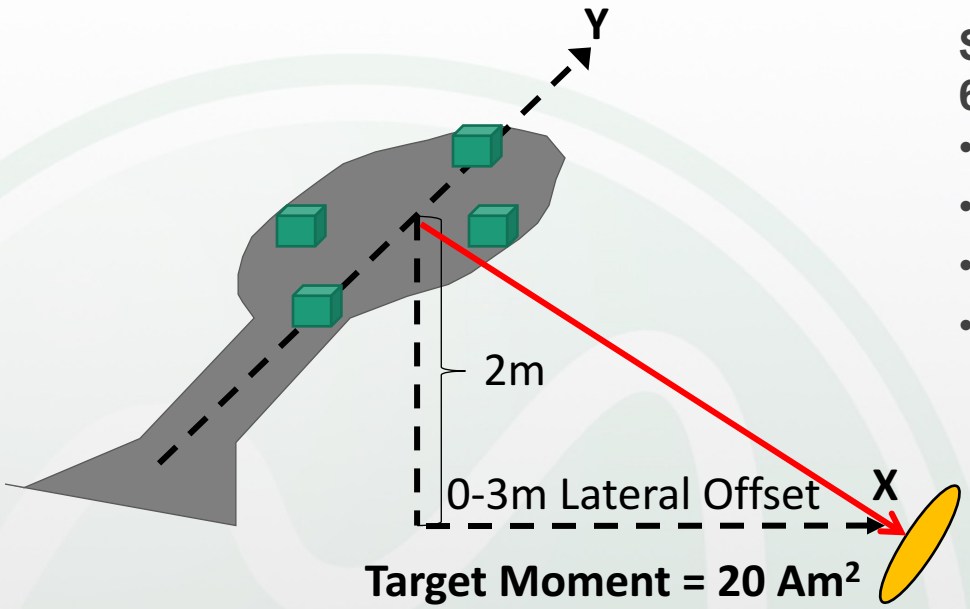
- Calculates position, magnitude and orientation of magnetic dipole in ***Real Time***

- Runs dipole-fitting inversion in less than 10 ms
- Tested with simulated and actual data sets




* Strategic Environmental Research and Development Program (SERDP) Projects MR-2104

# MagArrow Inversion: Gradient Configuration Simulations

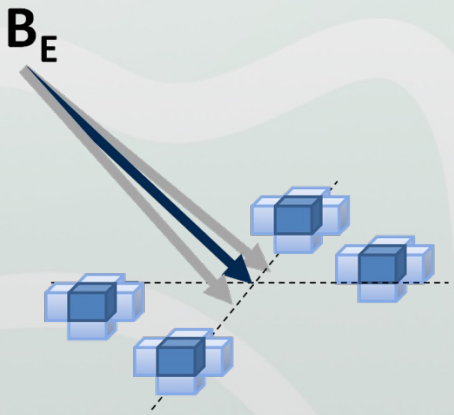



**Six Gradient Configurations Compared**
**684 simulations for each configuration:**

- $B_{EARTH}$ inclination: 0 to 90°
- Heading: 0 to 90°
- Target moment: x, y, z directed
- Target lateral offset: 0 to 3m

**Error added to model:**

- $B_{EARTH}$ inclination error: $\sigma_{std} = \pm 5°$
- Sensor position error: $\sigma_{std} = \pm 1$cm
- Error added to produce synthetic data



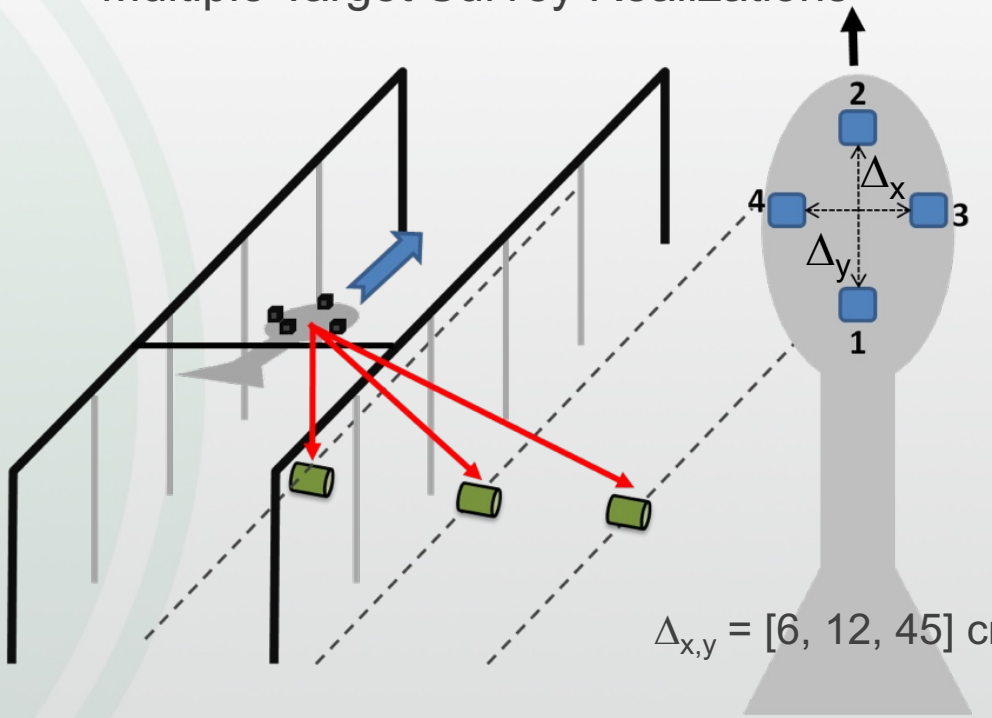

- Assessed Magnetic Moment and Target Localization Error
- Inverted Moment and Position of Target
  - **Within 2% error for Moment**
  - **Within 10% error for Position**

# MagArrow MFAM Gradient Testing

10m transect on UAV Test Gantry

**Controlled Tests: AUV Target Overpasses**

- Assess Varying Configurations
- Using WRT Motorized Gantry
- Gradient Array → 4 MFAM Sensors
- Multiple Target Survey Realizations




$\Delta_{x,y}$ = [6, 12, 45] cm

# MagArrow MFAM Gradient Validation

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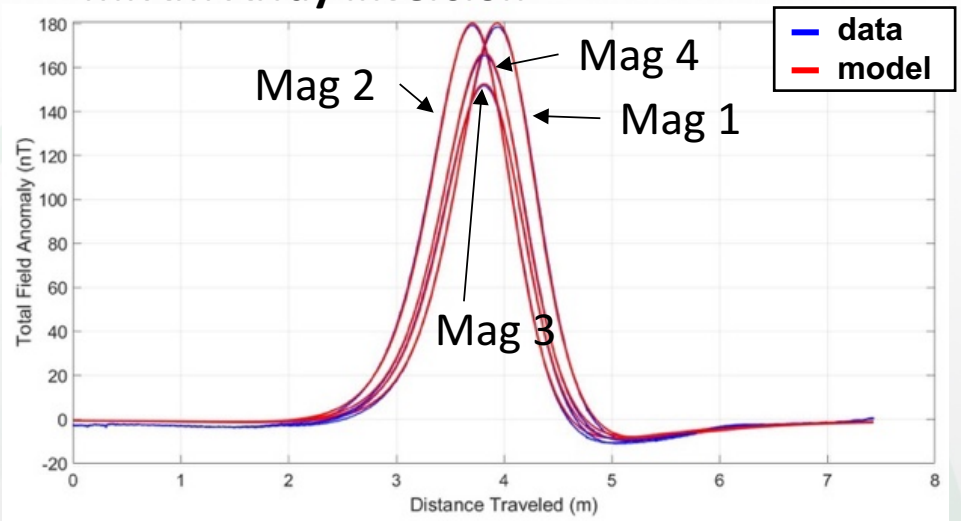
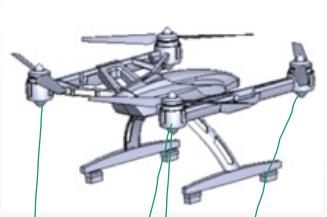
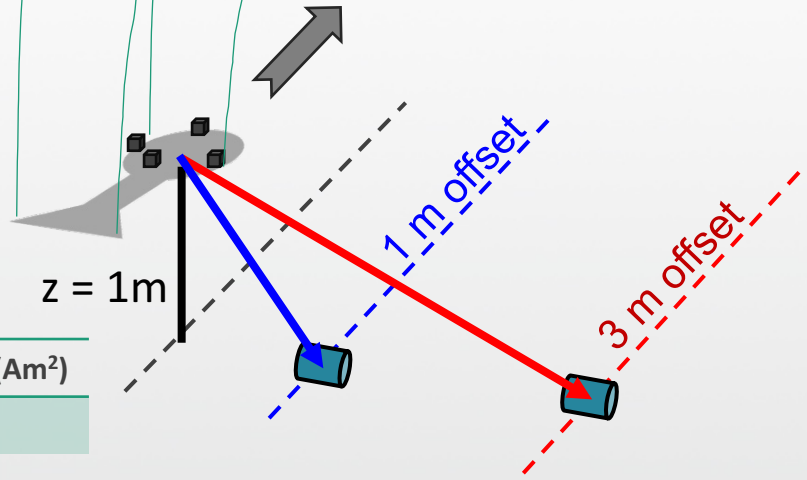
## MFAM Array Inversion



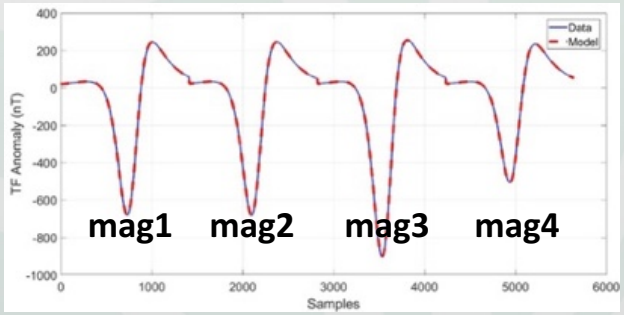
Location Error < 5cm

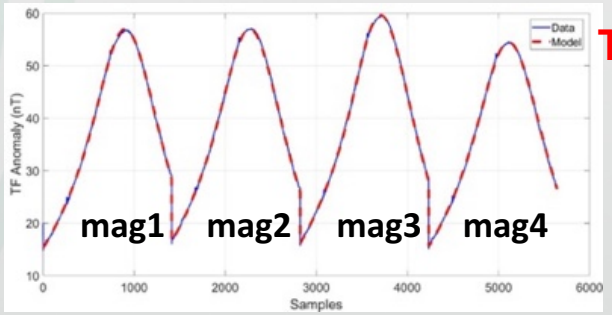
Moment Error < 1%




| | Across Track (m) | Across Track (m) | Depth (m) | Moment ($Am^2$) |
|---|---|---|---|---|
| Estimated | -0.02 | 4.01 | -0.86 | 0.61 |
| Measured | 0.00 | 4.04 | -0.87 | 0.61 |

**Target Lateral Range = 1m**



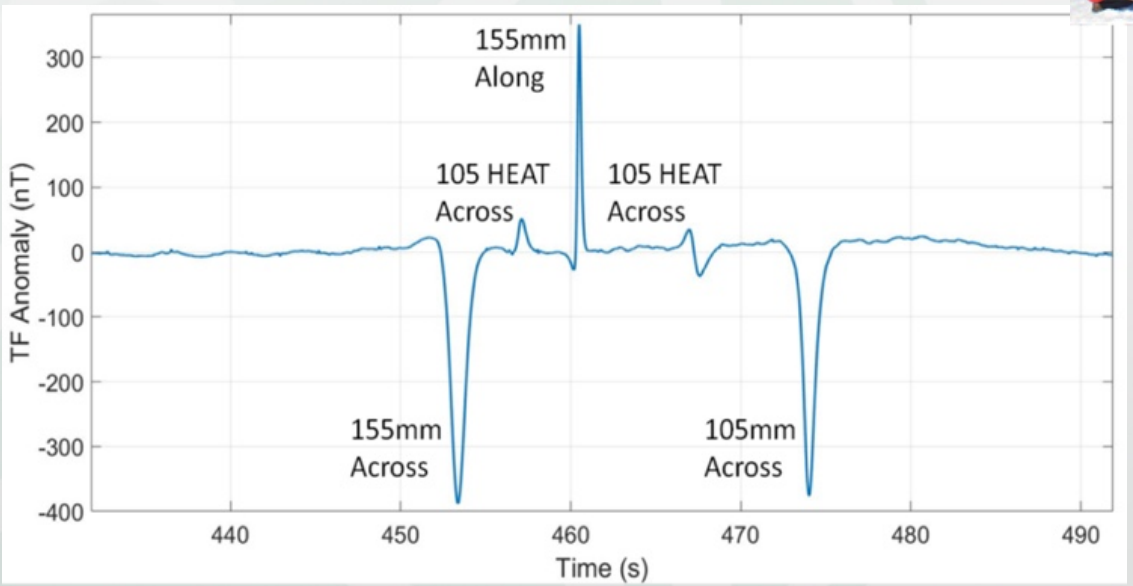




**Target Lateral Range = 3m**

# WRT UXO Flight Tests

**IVS Strip Flight Sortie:**

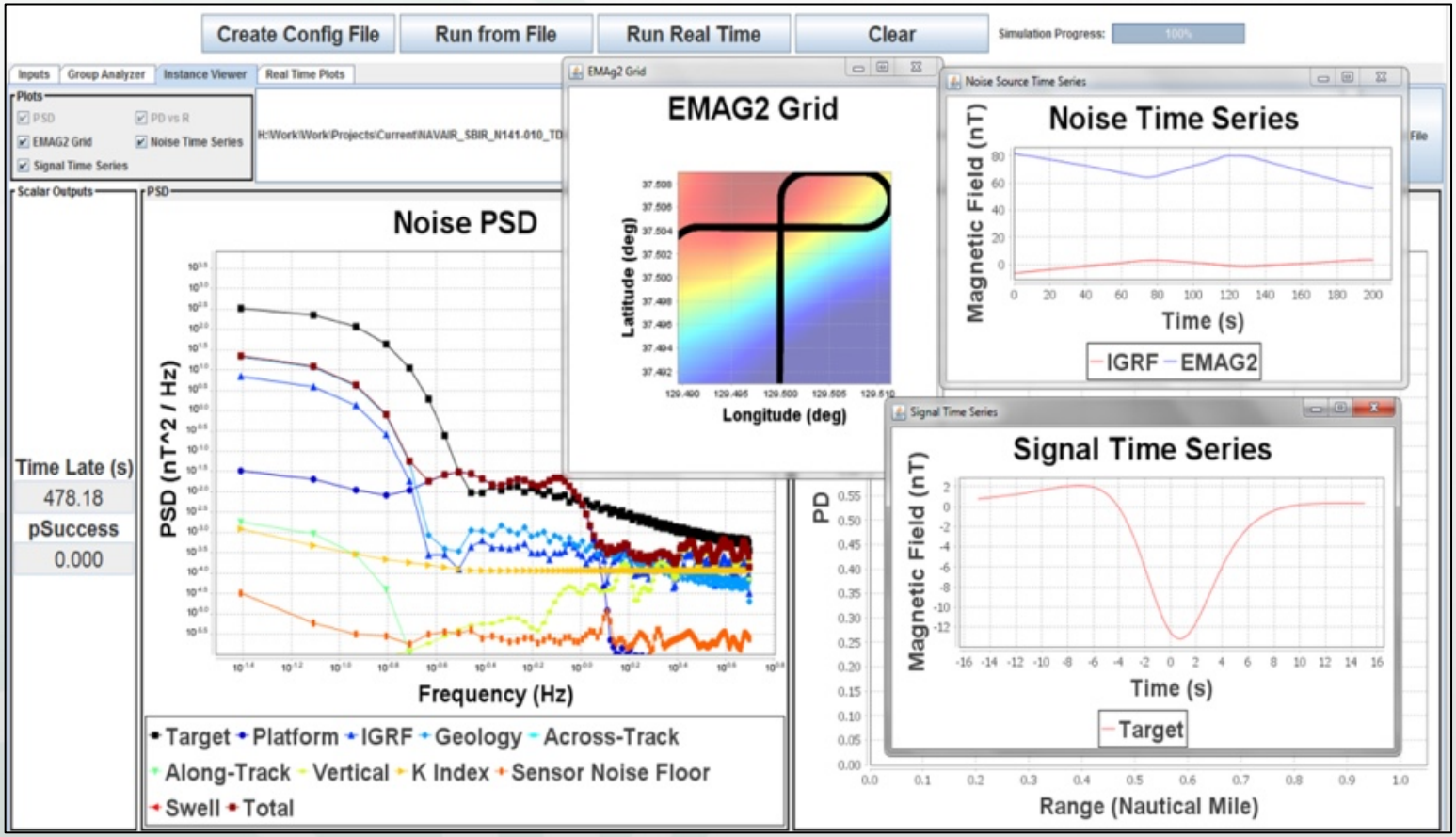
- UAVA Eagle XF Drone Integration in New Hampshire (..brrrrr...)
- ~5 m altitude
- 5 UXO Targets




# MUSE:
## MAD UAV Software Environment

→ ***Predicting Mission Success***

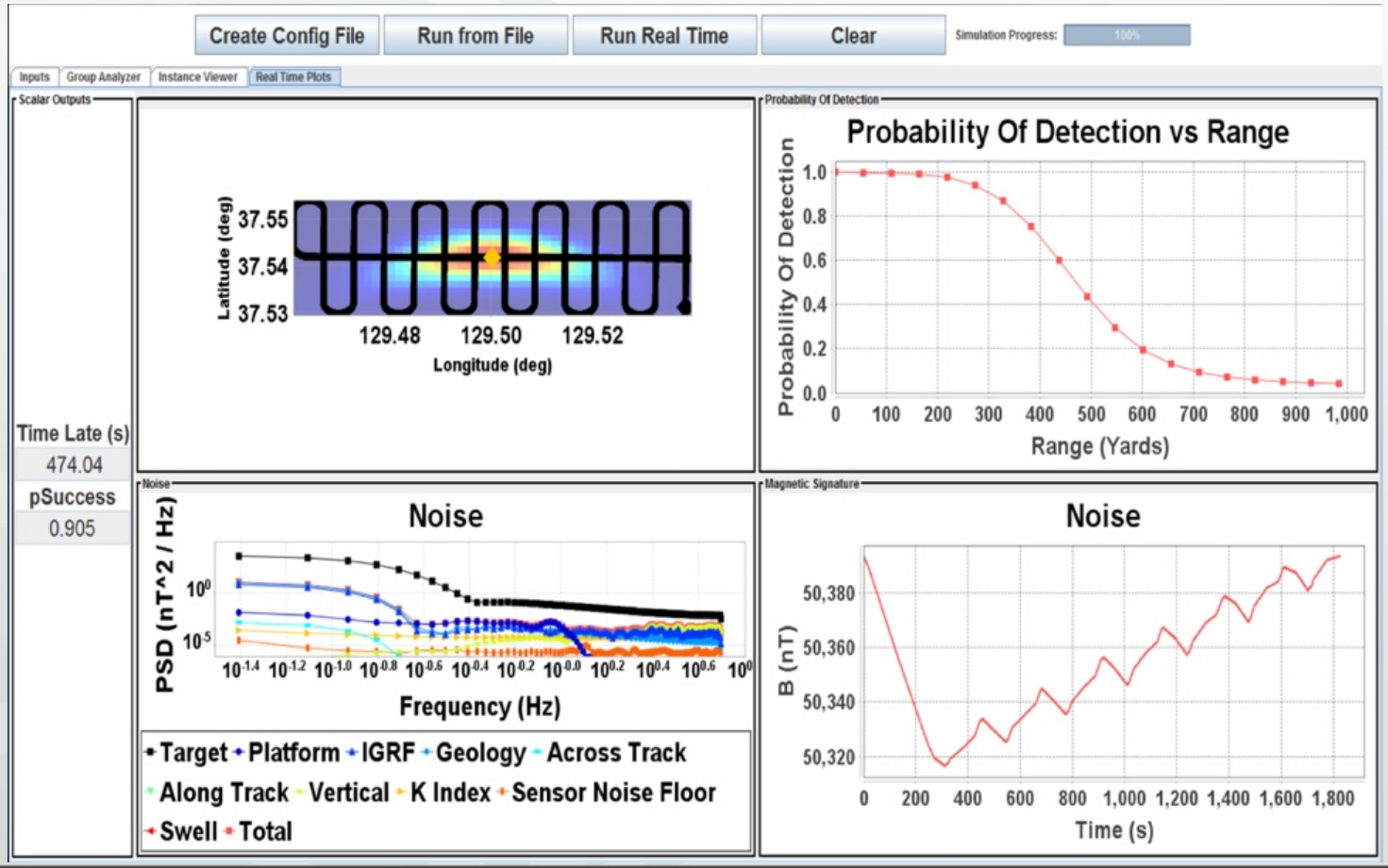
- Predicts Noise and Target Signature for Evaluating Detection Range, SNR, Mission Success, Coverage Rate, etc. performance metrics



# MUSE:
## MAD UAV Software Environment

→ ***Maximizing mission success through feasibility assessment***

- Incorporates custom airframe noise + environmental noise from geology, geoatmospheric, motion, etc. (anywhere in the world)



# Summary

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## *MagArrow Workflow*

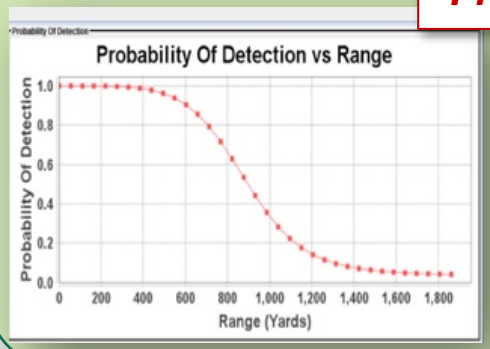
**Pre-Mission Planning**
- predict success
- assess feasibility
- design operations

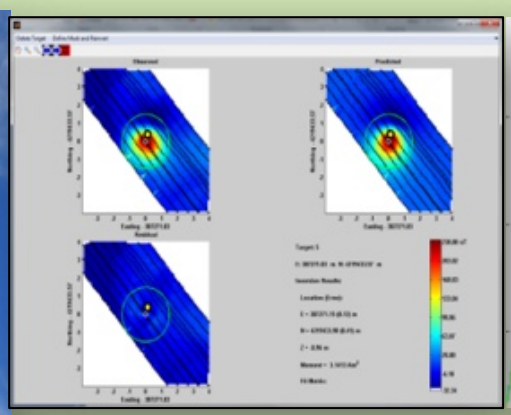
***Mission Profile***

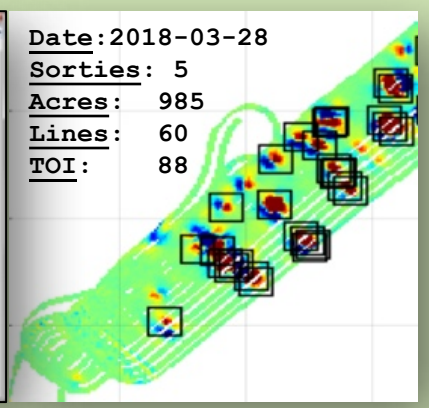
**Execute MagArrow Surveys**

**Real-time & Post-Mission Processing**

**Data Products Generation**






- ***MagArrow UAS Technology Established for Drone MAG Surveying***
- ***Improved Production*/Cost-Efficiency** for Wide Set of Applications
- ***Advancing Field-Ability*** → i) Pre-Mission Planning Software (MUSE), ii) Real-time Processing, & iii) Gradient Array Target Localization