A case study from Middlesbrough, UK of the HyperMag system – a multiple three axis magnetic field sensor used for mapping cables, pipelines and UXO's.

Dr. Karen Weitemeyer, Dr. Brian Claus, Peter Kowalczyk,
Dr. Steve Bloomer, Brett Prairie, and Nathan Ehrenholz

April 21st 2023, Southampton, UK

Photo Credit: OFG Field Team

Features of the Hypermag System

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- Scalable magnetic sensor array in sets of **4 sensors per system**
- **Synchronous sampling** allows for **gradiometry** between sensors
- **3-vector sensors** provide directionality of magnetic fields for increased information over scalar sensors

- 4-6 pTrms/rthz
- Wide bandwidth (up to 1kHz)
- <4 W power consumption
- Ethernet Enabled

Applications and Deployment Platforms

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Applications

- UXO
- Mapping, Depth of Burial and Tracking of:
  - Pipelines
  - Fibre Optic Cables (with DC power for repeaters)
  - Export and Inter-array windfarm cables (AC/DC)
  - Utility Power Cables (AC/DC)
- Archaeology
- Geology
- Cable Fault Finding (when combined with electric field)
- Corrosion Inspection of Pipelines and Structures (OFG talk later this afternoon)

Potential Deployment Platforms:

- ROTV (Active Towfish)
- Towfish
- AUV
- ROV
- USV

Motivation for the Hypermag in Scanfish 'Strapdown' Configuration

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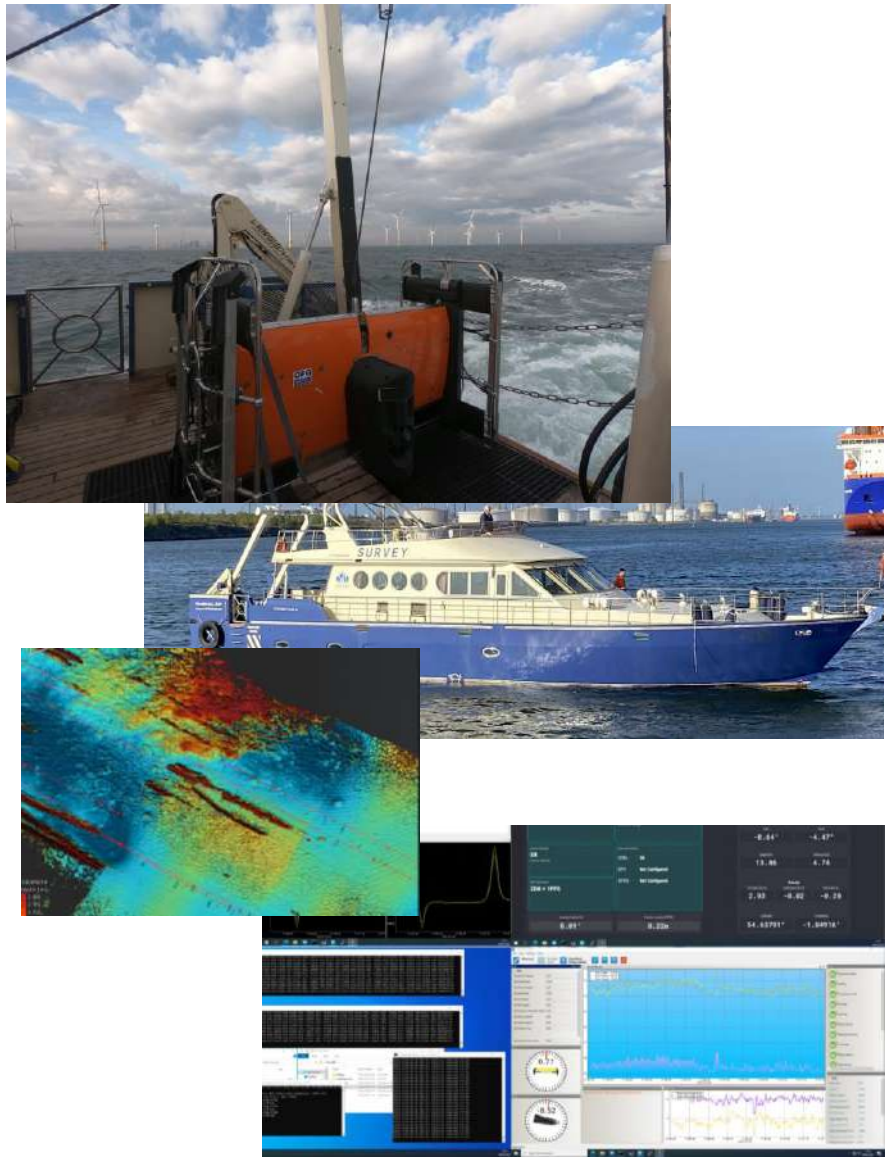
Why the Scanfish + Hypermag?

- **More efficient then ROVs** for UXO, cable and pipeline surveys:
  - Flies at ~**6 knots**
  - Can be deployed from much **smaller vessels** than ROVs
  - Has payload capacity for **high grade navigation** systems
  - Can be equipped with **complementary geophysical sensors** (e.g. multibeam, SSS, SBP)
  - 3D steer allows for development of **real-time cable and pipeline tracking** capabilities



Installation onto ScanFish Katria III

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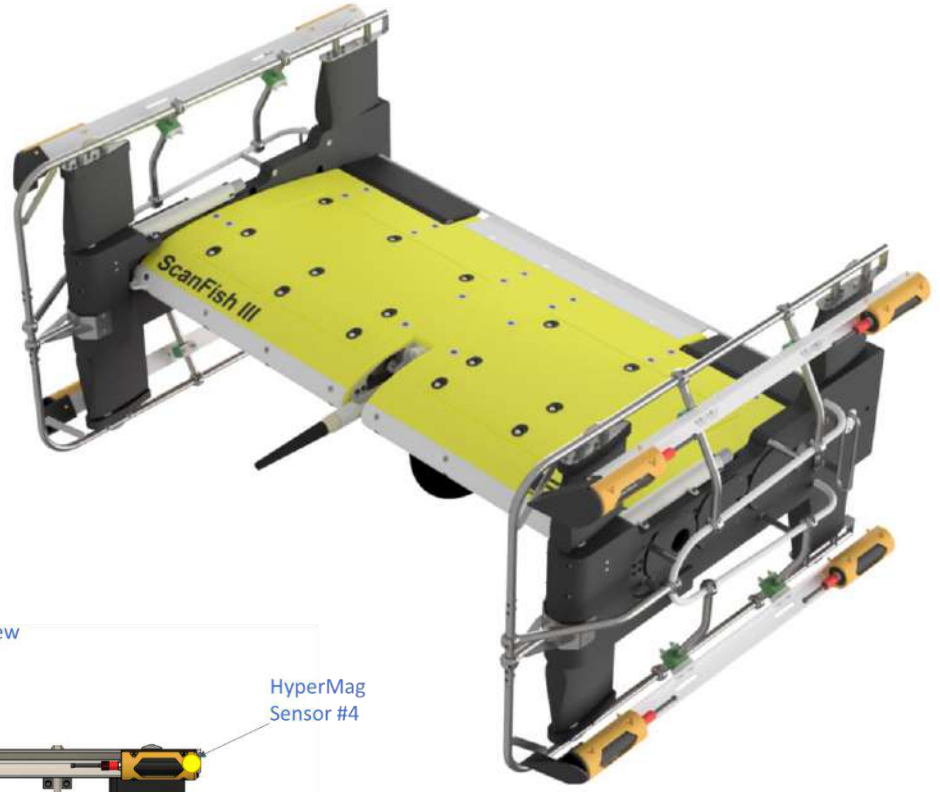
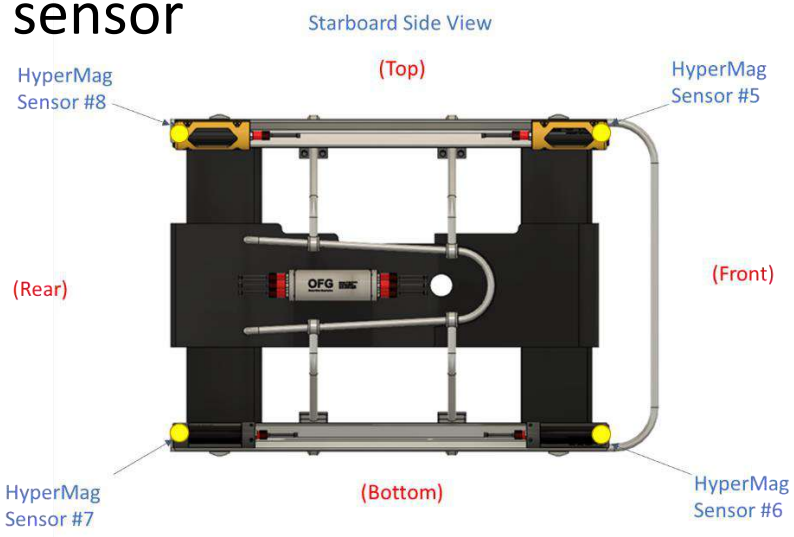
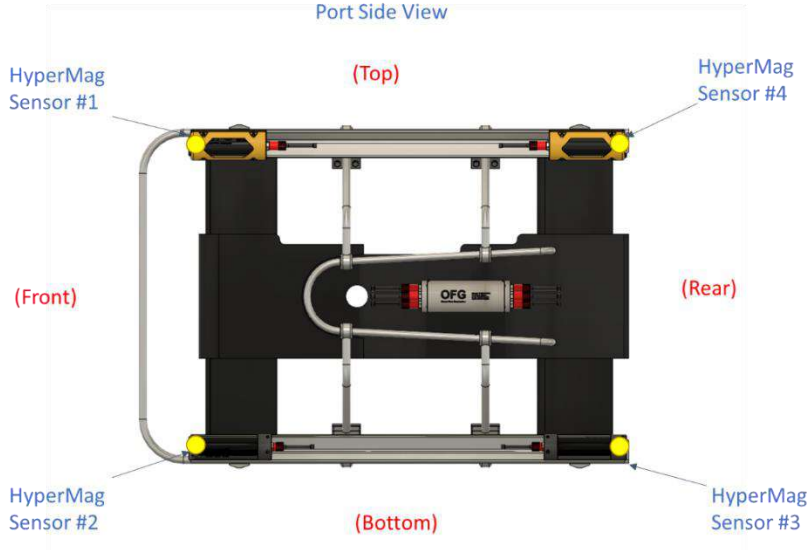
- Next generation of the patented OFG Self-Compensating Magnetometer (SCM) system
- Each Hypermag has **four 3-vector magnetometers**
- Self-compensation allows for a '**strapdown**' integration onto multi-sensor platform:
  - **SPRINT-Nav Mini** (FOG + DVL), Sonardyne Ranger USBL and transponders, Norbit MBES, altimeter, depth sensor







Field Trial Location Middlesbrough, UK

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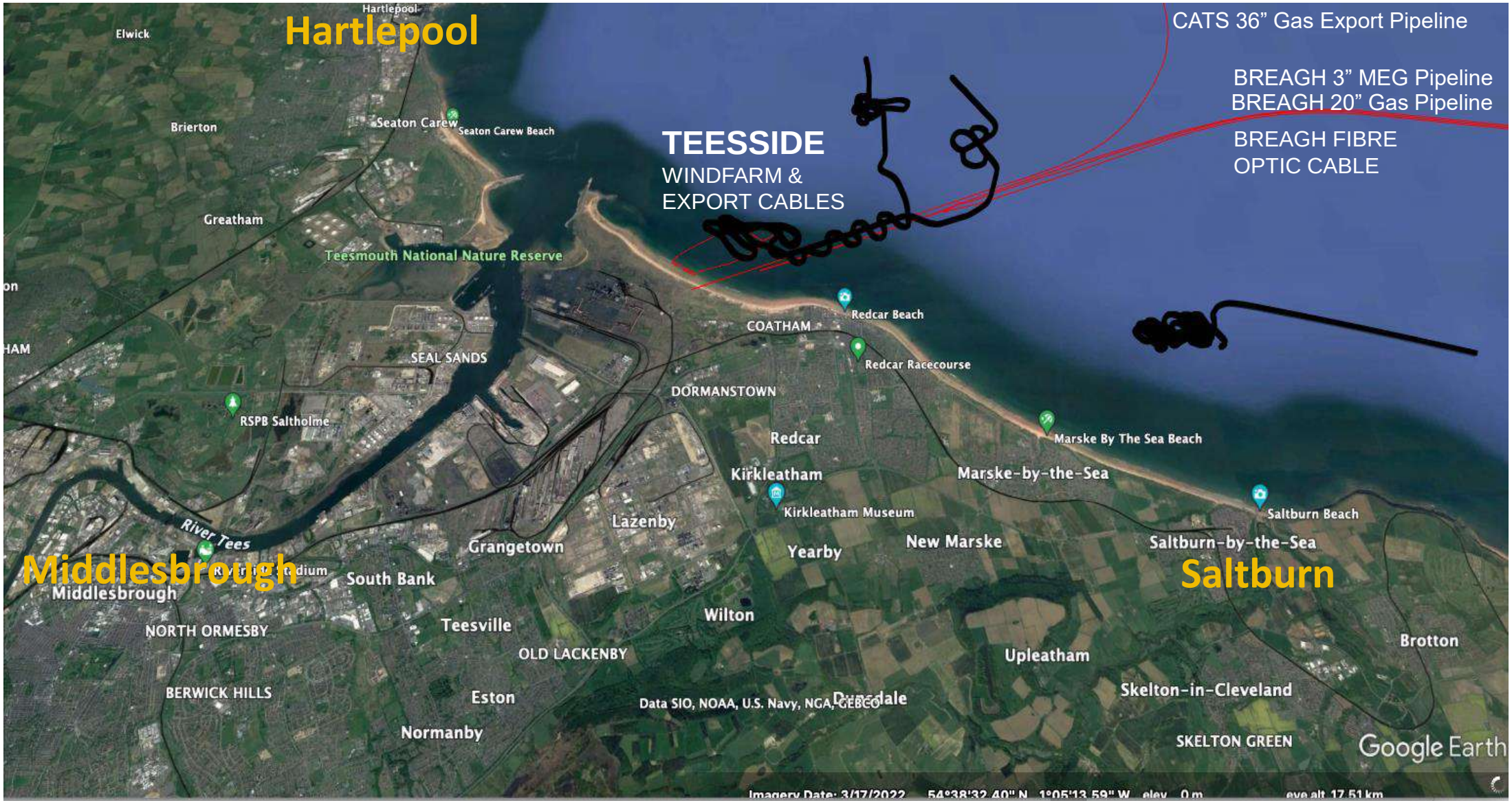

Field Trial Overview Map

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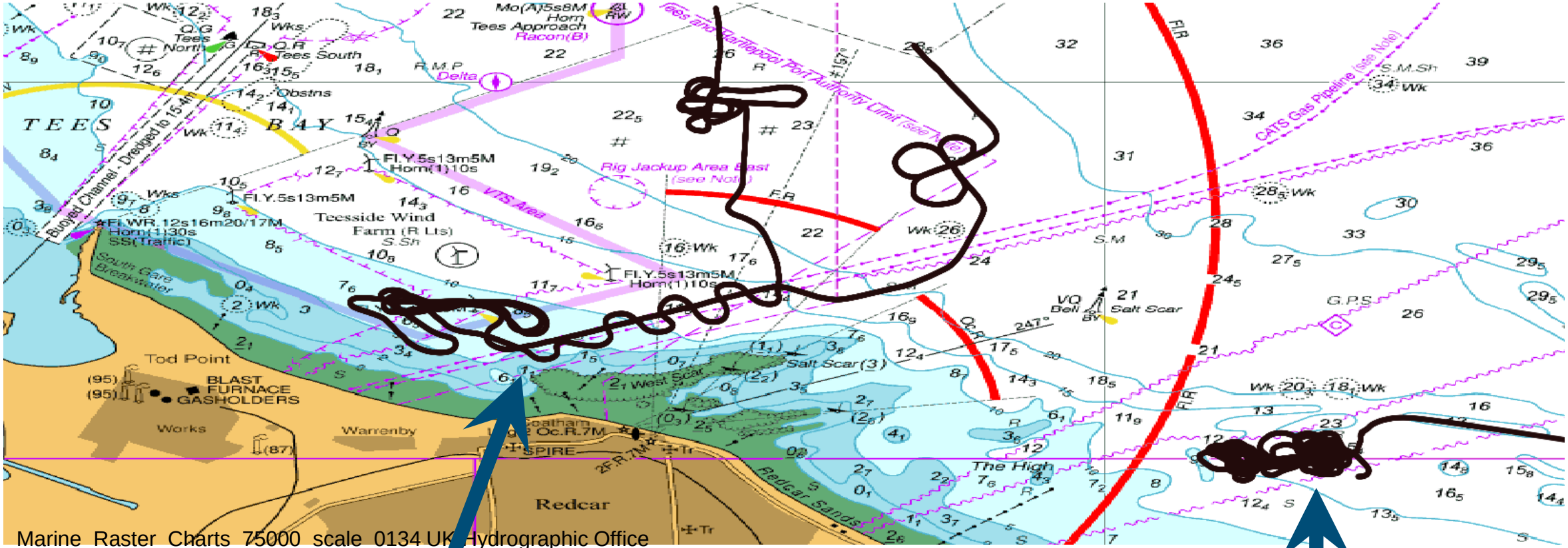

Day 1 (March 9, 2022): Calibrations, pipelines, telecom cables, Teesside interarray and export cables.
Talk focusses on Day 1 data and results.

Day 2 (March 10, 2022): Dummy UXO targets, abandoned cable

Map View Day 1:

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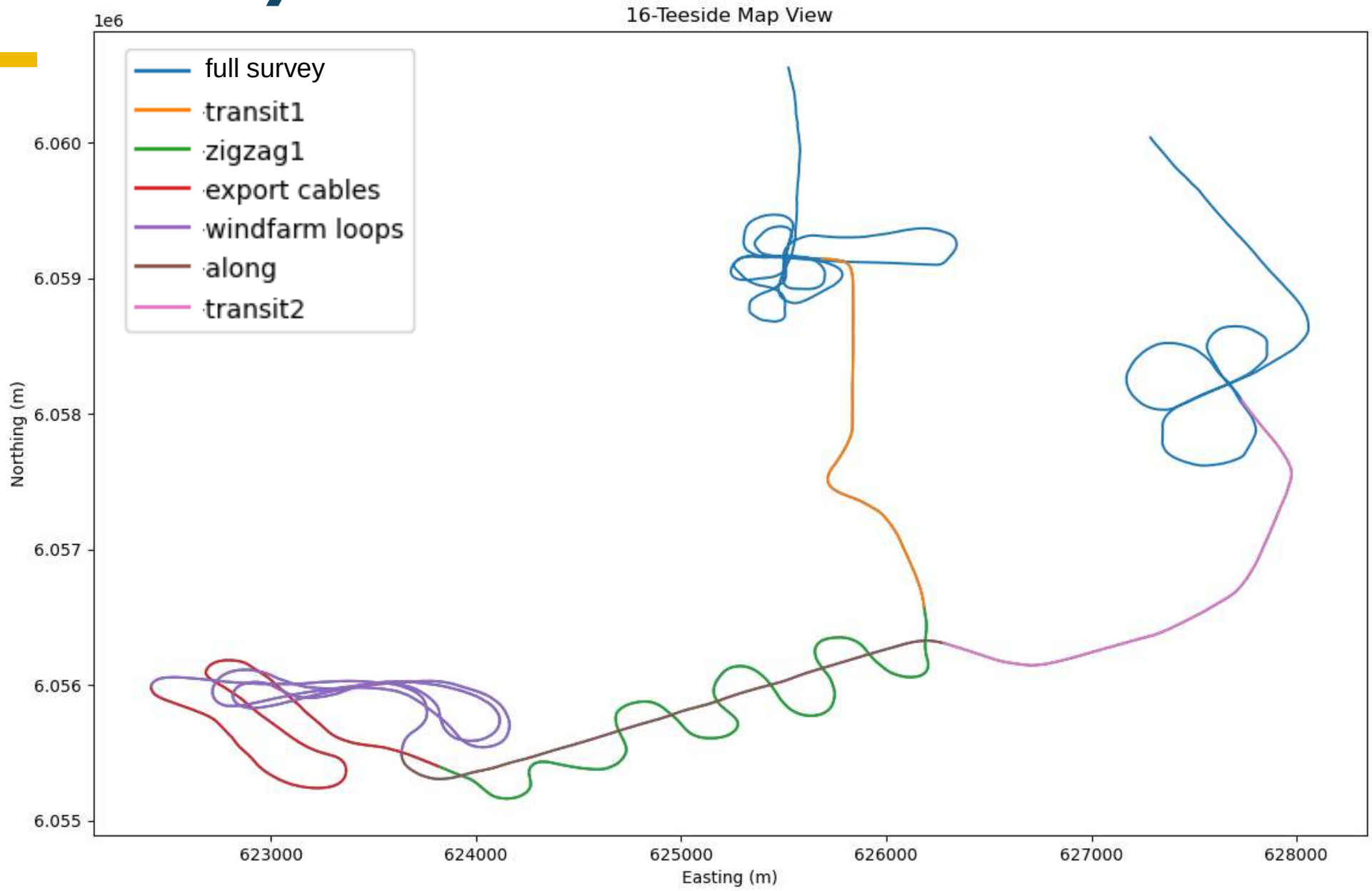

TMI Mag 1 Day 1:

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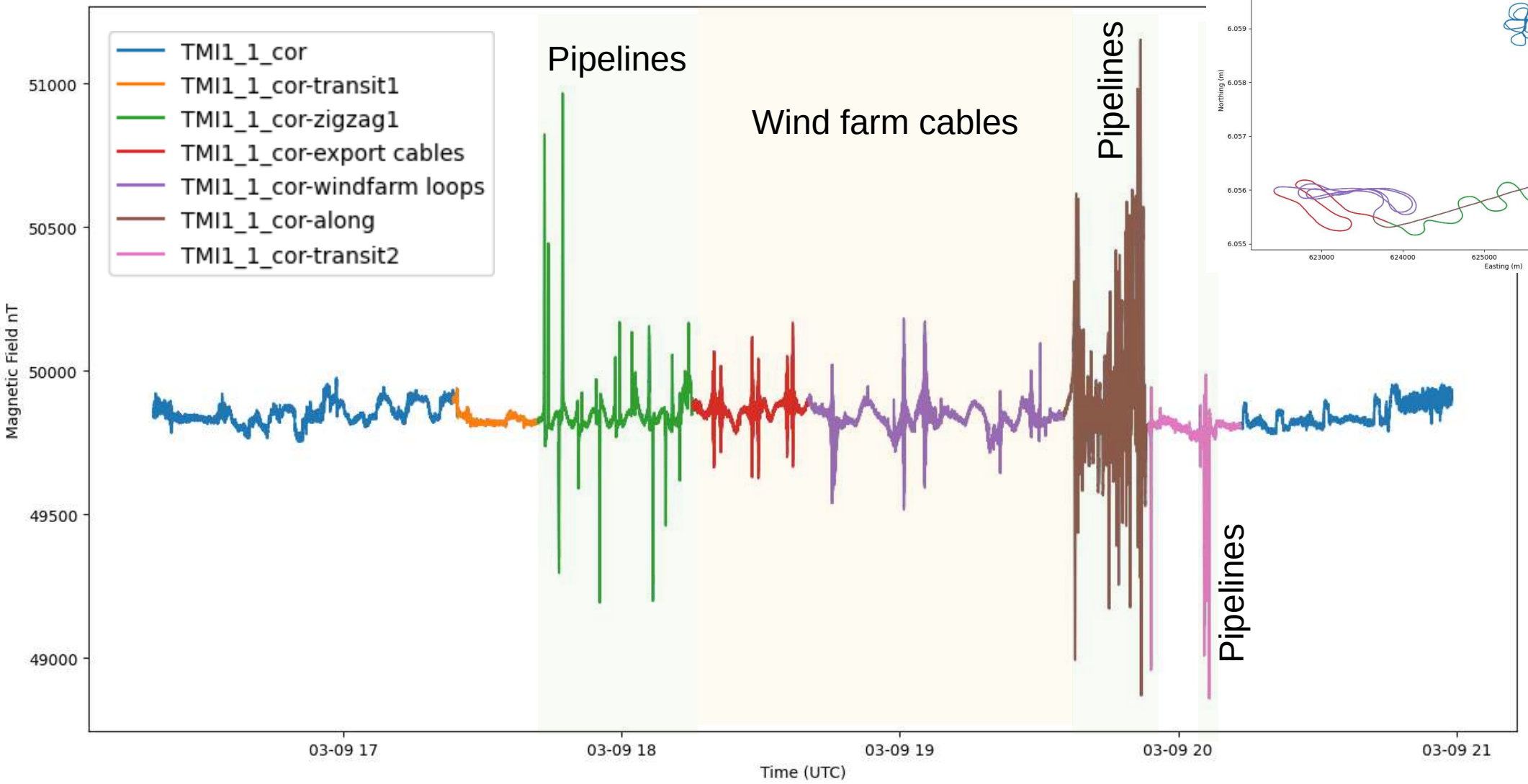

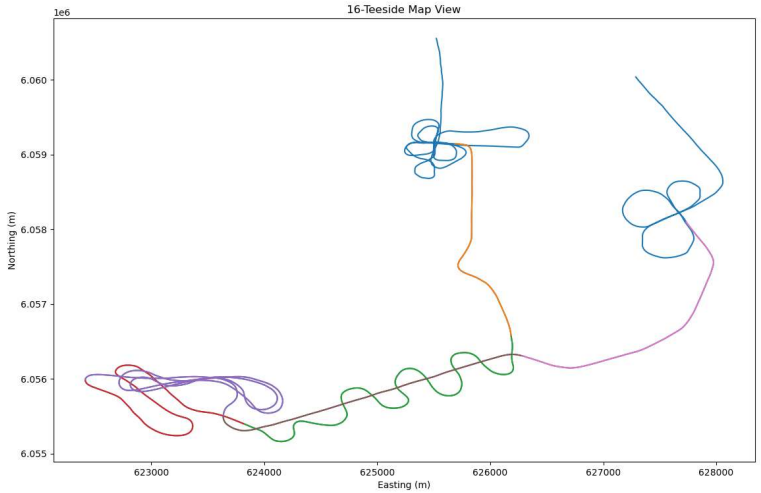

Spectrogram Compensated TMI Mag 1

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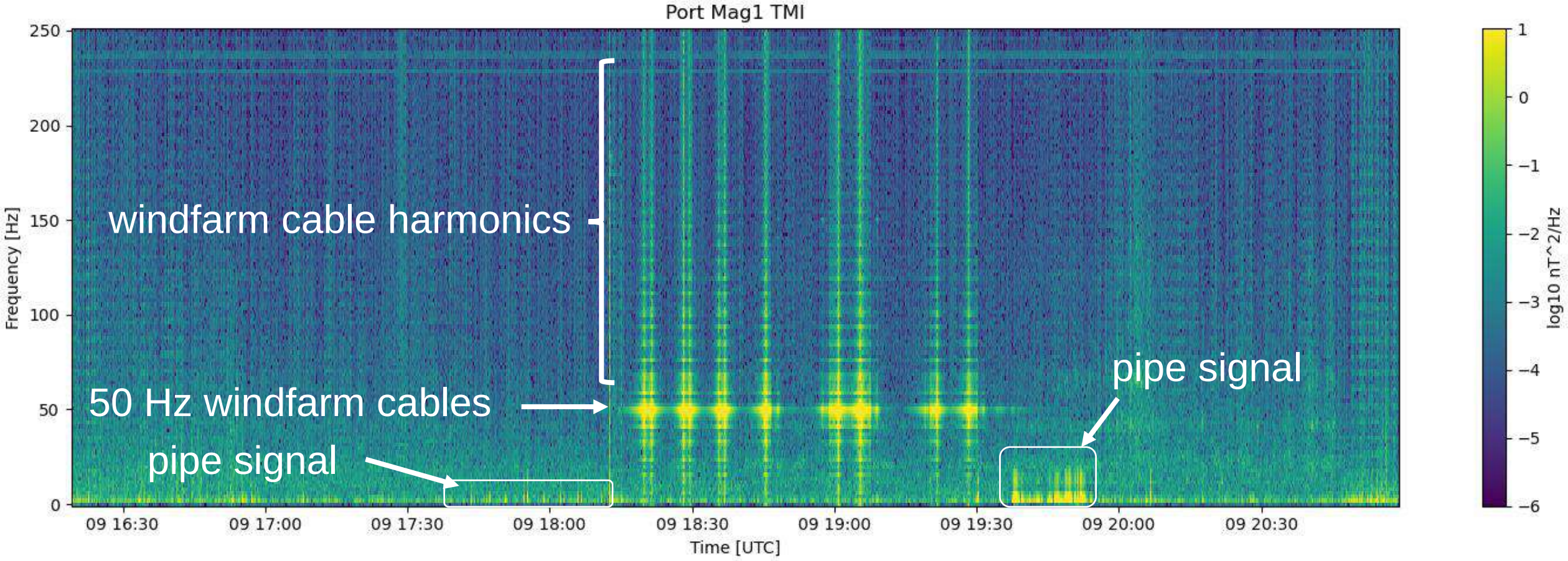
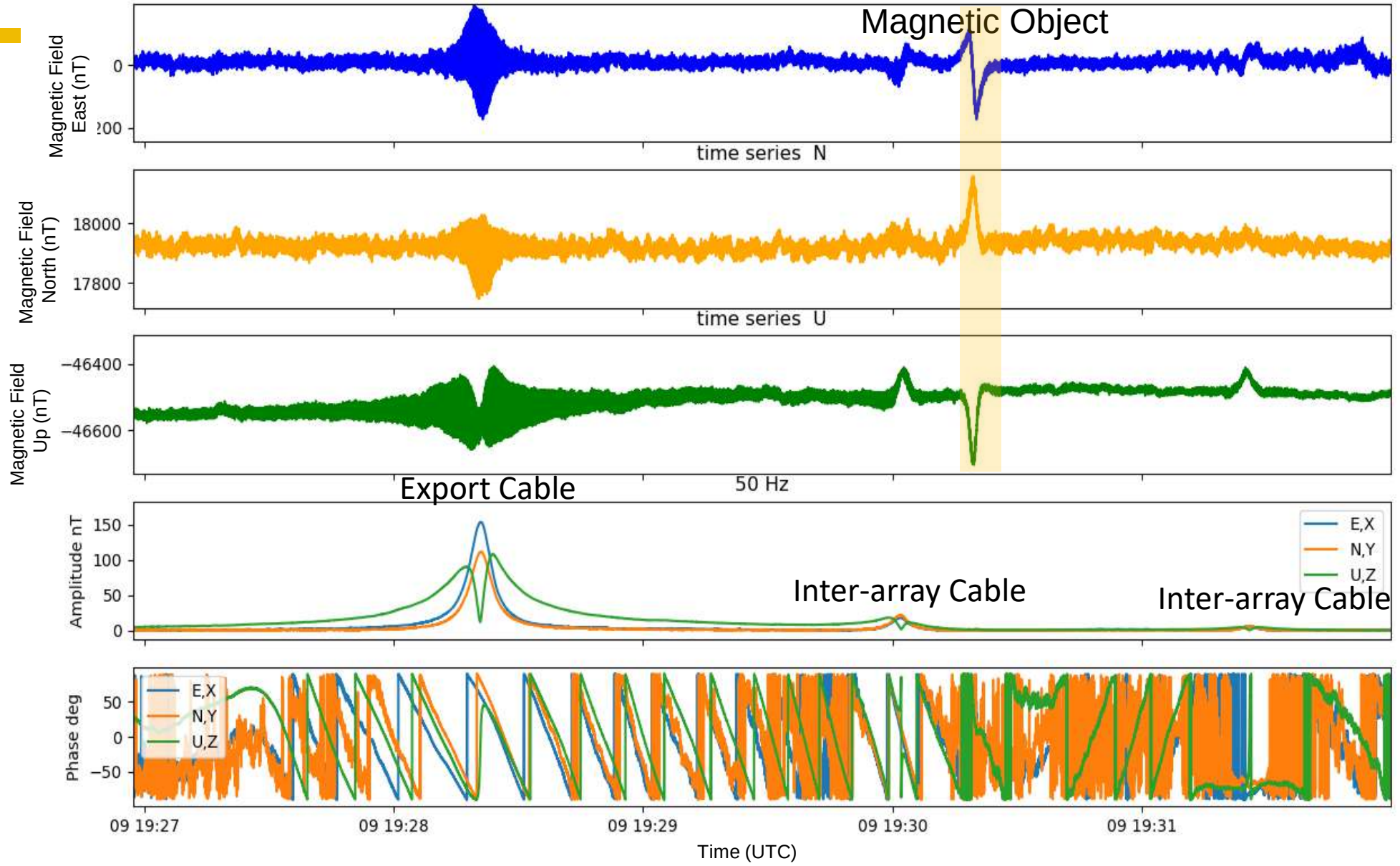


Fourier transform at 50 Hz, 3 cable crossings



Method A - Biot-Savart Law to compute Depth of Burial (DoB)

$$B = \frac{\mu_0 I}{2\pi r}$$

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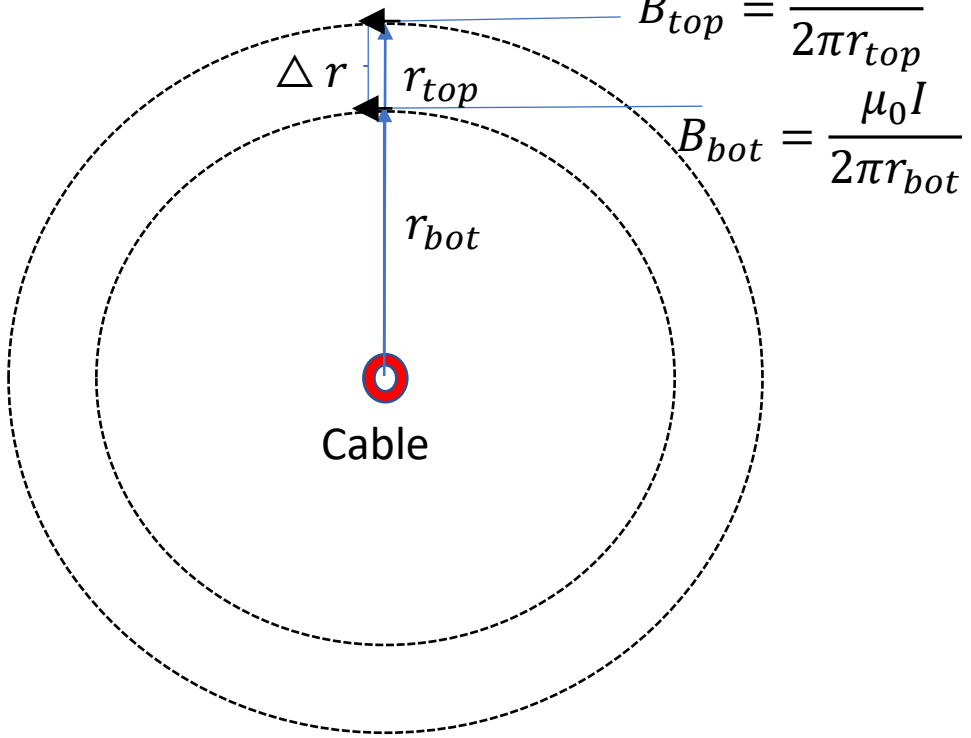
Assume both magnetometers observed the same current in the wire

$$\triangle r = r_{top} - r_{bot}$$

$$\frac{B_{top} 2\pi r_{top}}{\mu_0} = \frac{B_{bot} 2\pi r_{bot}}{\mu_0} \quad , \quad r_{bot} = \frac{B_{top}\Delta r}{(B_{bot} - B_{top})}$$

$$DoB = r_{bot} - Altitude_{bot}$$



Repeat for all four vertical magnetometer pairs

Assumes the cable has been crossed.

Assumes the vertical minimum defines the crossing point (Null)

Total magnetic field time series @ 50Hz

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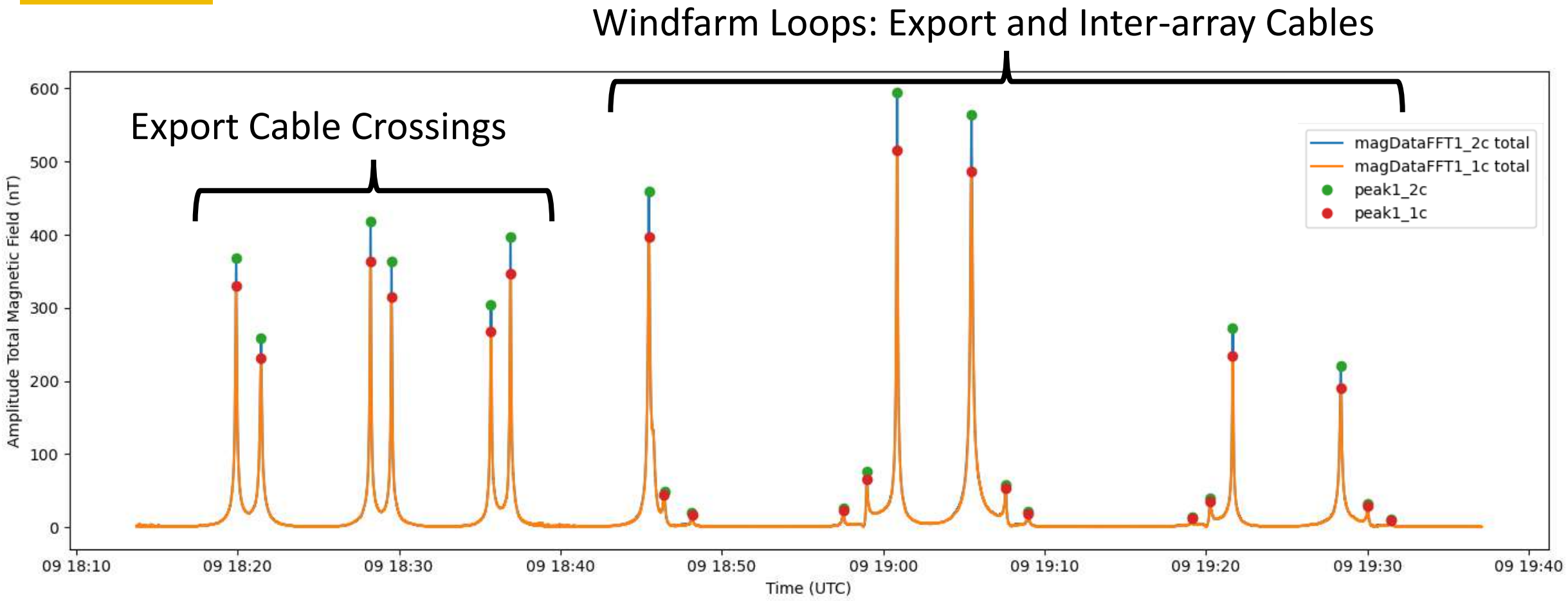

Example of the Total Magnetic Field Amplitudes and the peak picks for the Forward Port Top and Bottom Pair – these picks are used to determine Depth of Burial

Depth of Burial, Export Cables

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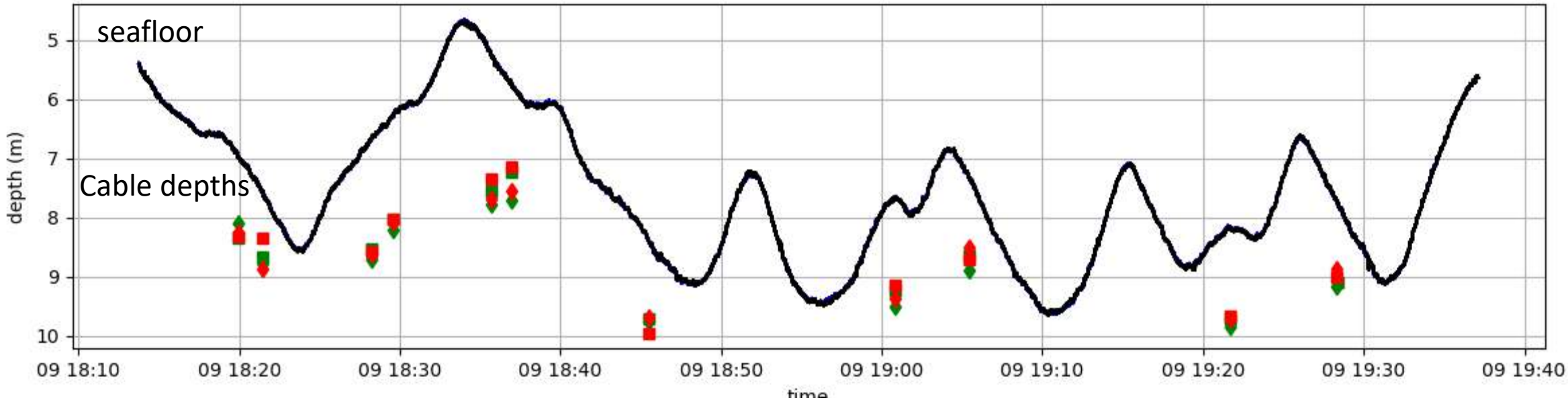
Seafloor from ADMIRALTY bathymetry

Cable depths
- **Port: Fore diamond, Aft square**
- **Stbd: Fore diamond, Aft square**



Extracted bathymetry, along the sensor path, from:
- 2018 HI1543 Sunderland to Redcar 2m SDTP
- 2017 HI1491A Whitby to Redcar Nearshore 1m CUBE
- 2016 HI1491 Whitby to Redcar drying-41m 1m CUBE

https://www.admiralty.co.uk

Depth of Burial, Export Cables

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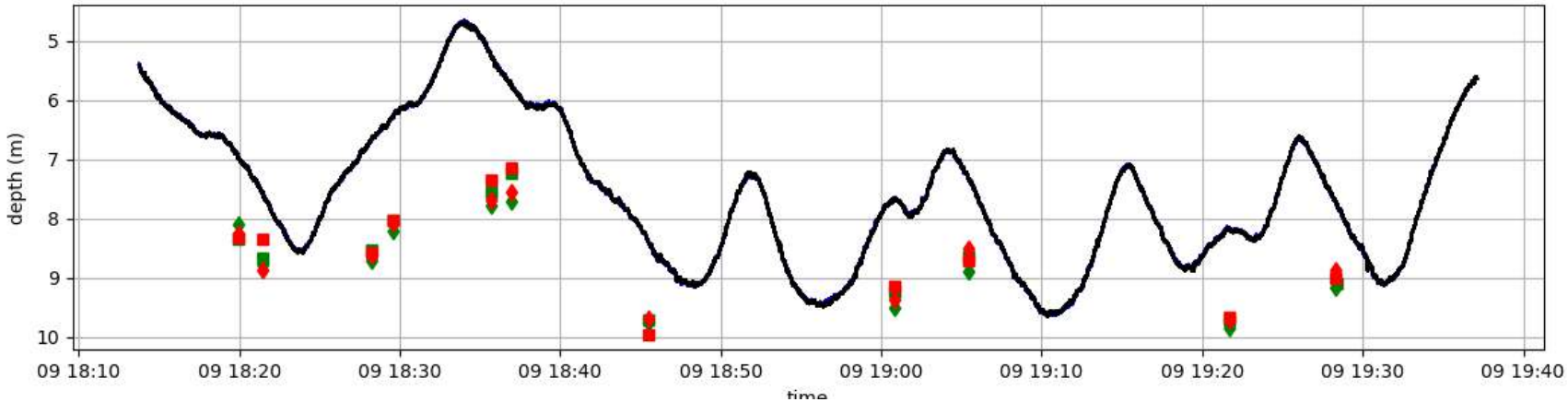
Crossing No.	Mean DoB (m)	Std DoB (m)
1	1.29	0.11
2	1.11	0.23
3	1.94	0.08
4	1.80	0.08
5	2.32	0.19
6	1.69	0.27
7	1.39	0.12
8	1.65	0.17
9	1.35	0.17
10	1.56	0.09
11	1.28	0.12

Seafloor from ADMIRALTY bathymetry

Cable depths
- **Port: Fore diamond, Aft square**
- **Stbd: Fore diamond, Aft square**



Std between the four DoB estimates are <27 cm, mean of Std = 15 cm. Mean DoB estimates are between 1.11 to 2.32 m for all export cable crossings

Extracted bathymetry, along the sensor path, from:
- 2018 HI1543 Sunderland to Redcar 2m SDTP
- 2017 HI1491A Whitby to Redcar Nearshore 1m CUBE
- 2016 HI1491 Whitby to Redcar drying-41m 1m CUBE

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Export Cable: Crossing picks and Depth of Burial Estimates

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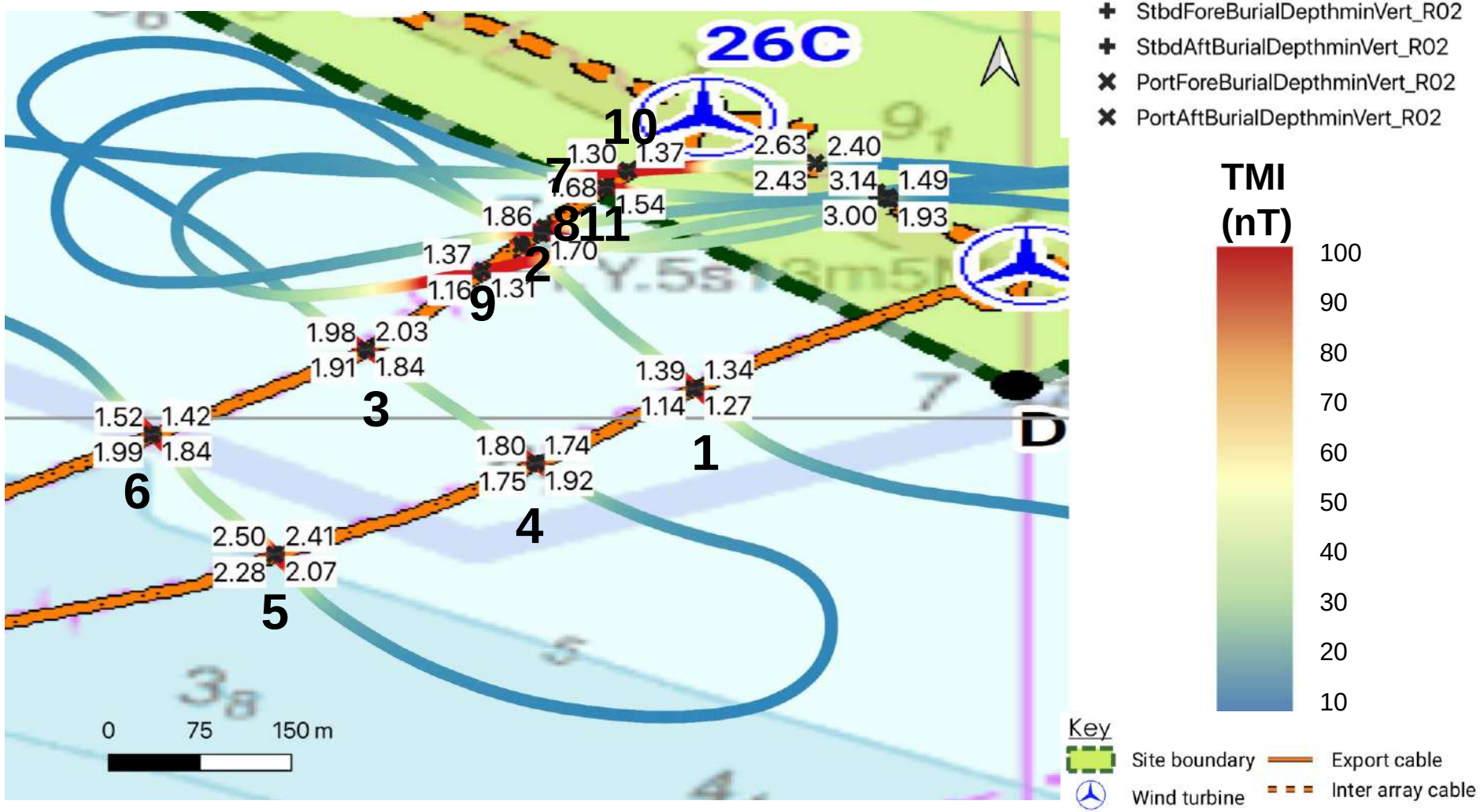
- Export cable crossings numbered in chronological order 1-11
- Depth of burial estimates for each of the four magnetometer pairs



From Chart-23-Teesside-2021.pdf
Kingfisher Windfarm charts
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Method B-Vector Depth of Burial Concept

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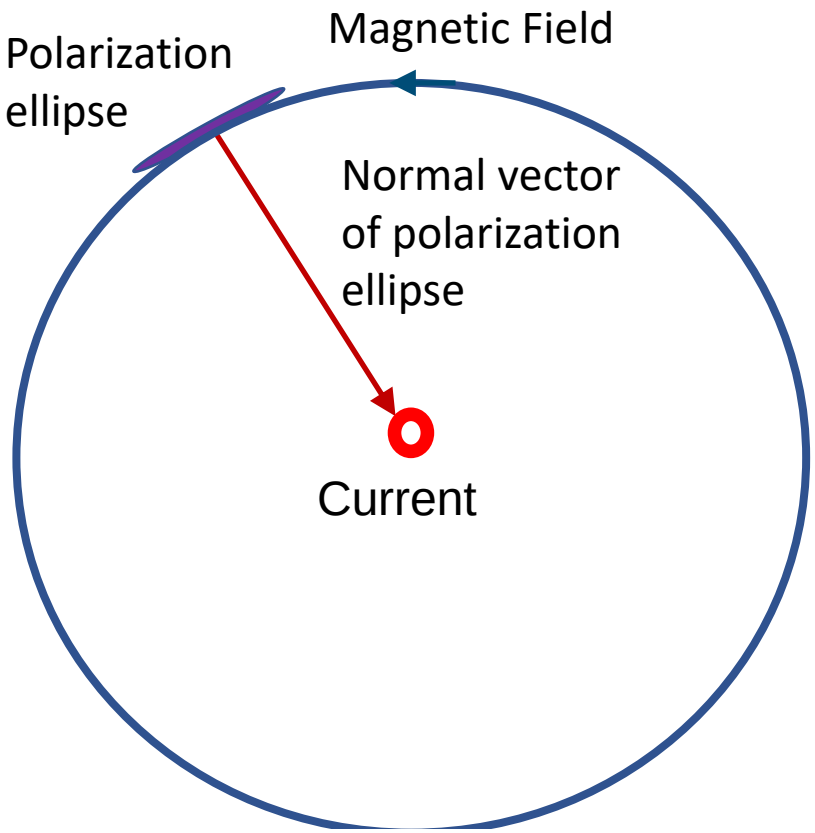

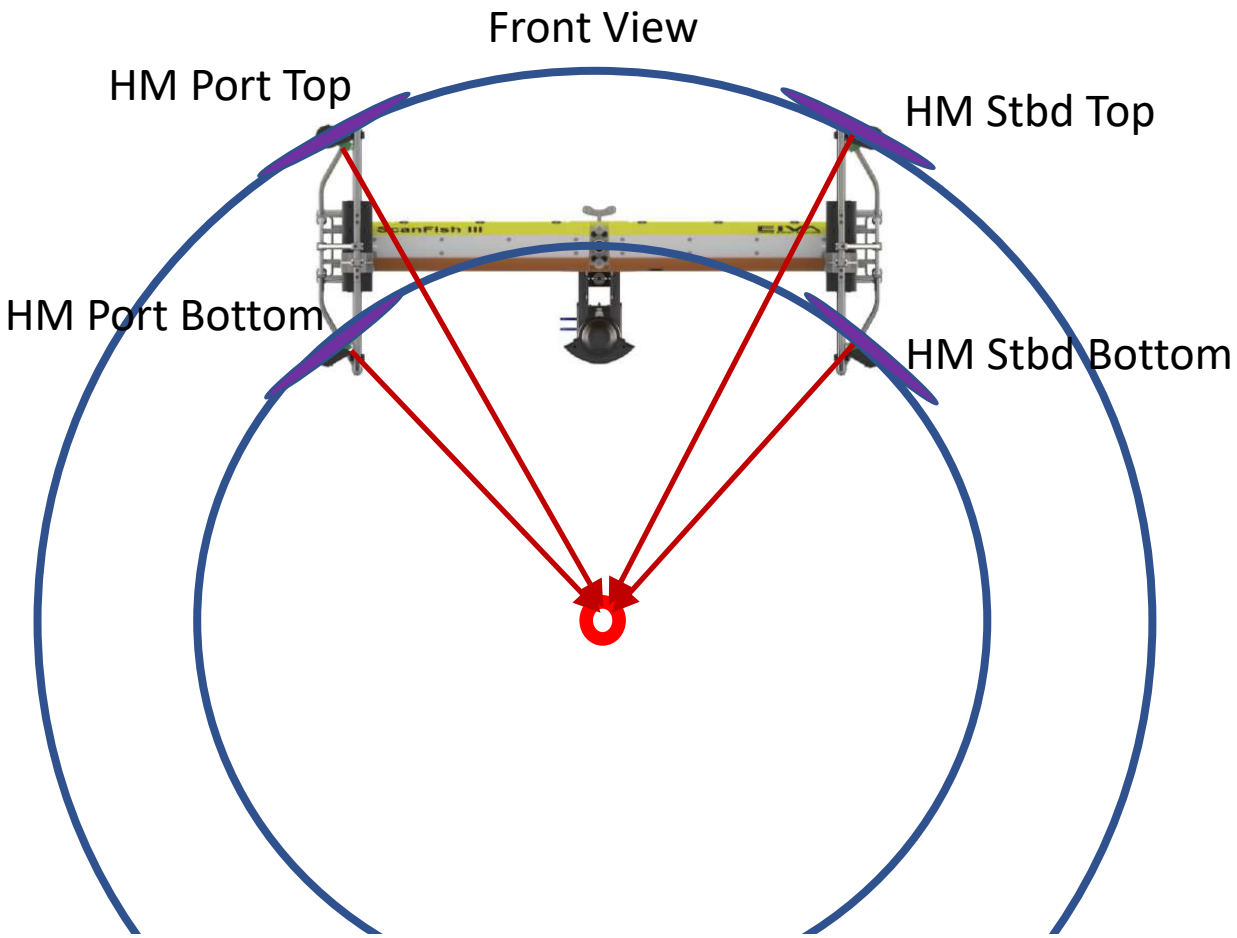

- Normal vectors of polarization ellipse plane point to the cable (See Panjandeh et al., 2012 and Carozzi et al., 2000 for concept and full derivation)
- Eight 3-axis magnetometers normal vectors will intersect at the cable location

Geoscience Analyst (GA) Visualization

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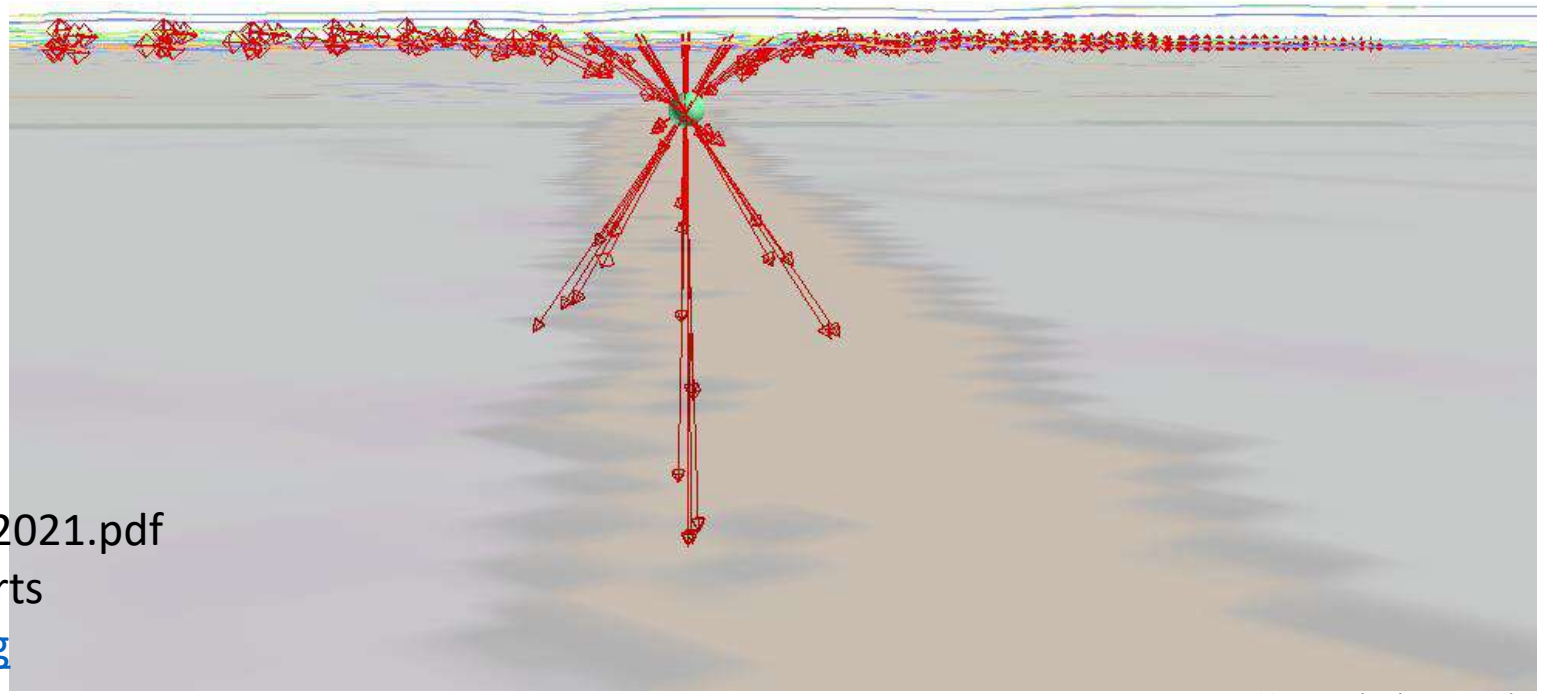
- Example of intersection for Crossing 13
- Intersection of 8 normal vectors
- Biot-Savart Law DoB method is shown as the green ball and is coincident with the intersection of 8 normal vectors



R00 processing (now at R02)

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GA Exports Cables

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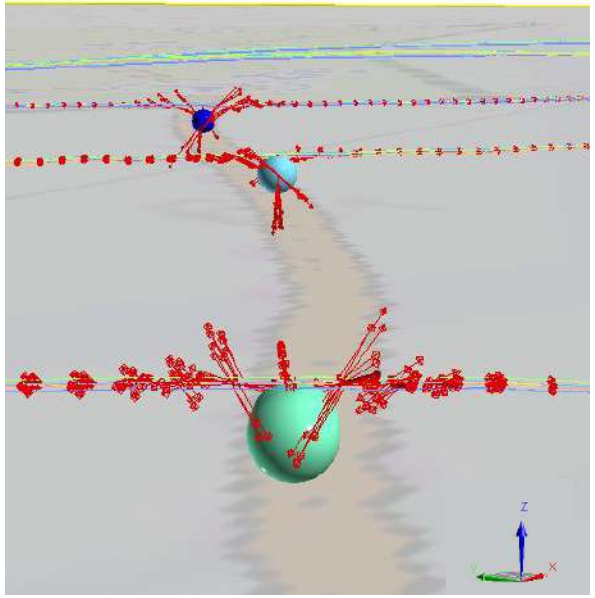
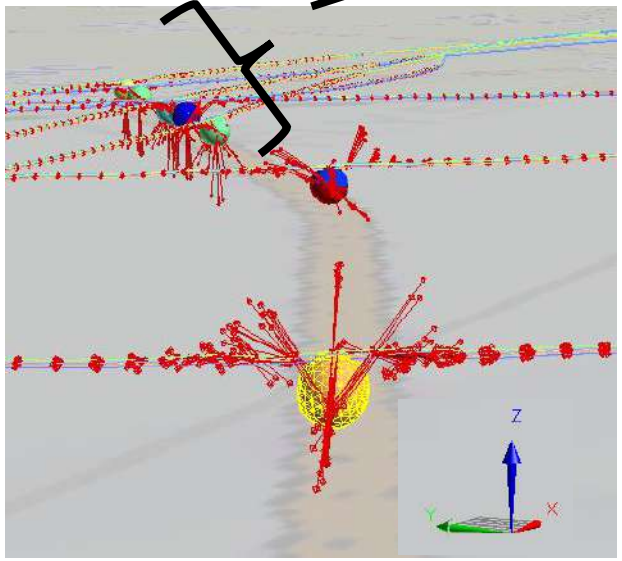
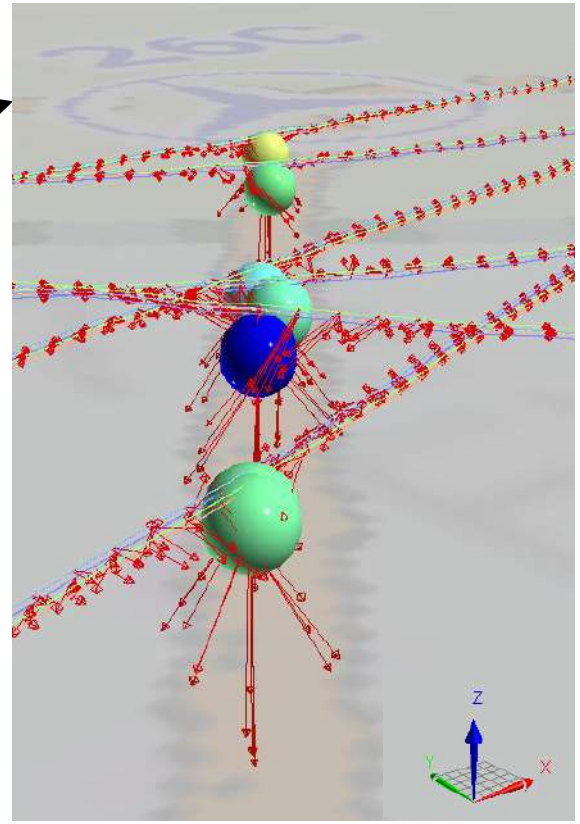
South Export Cable
Looking to sea



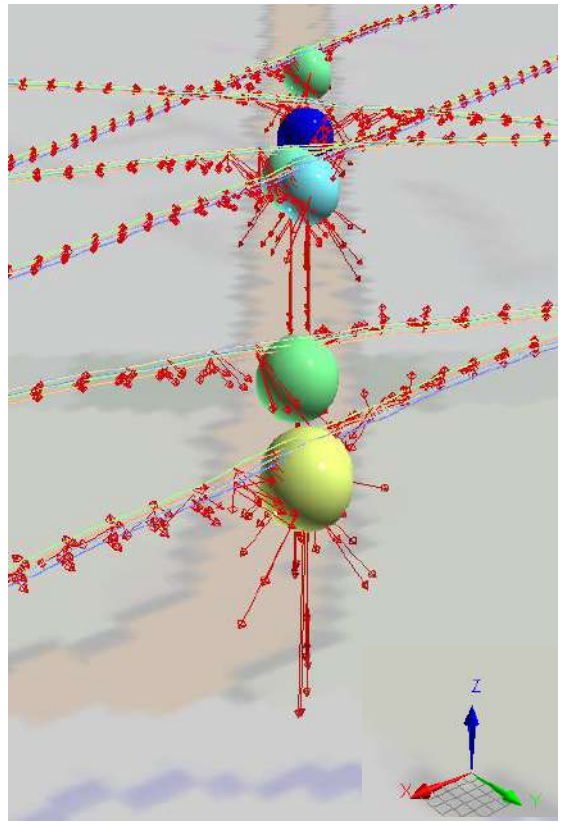
North Export Cable
Looking to sea



North Export Cable
Jog North
Looking to sea



North Export Cable
Jog North
Looking to shore



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Field Trial Teesside Pipelines

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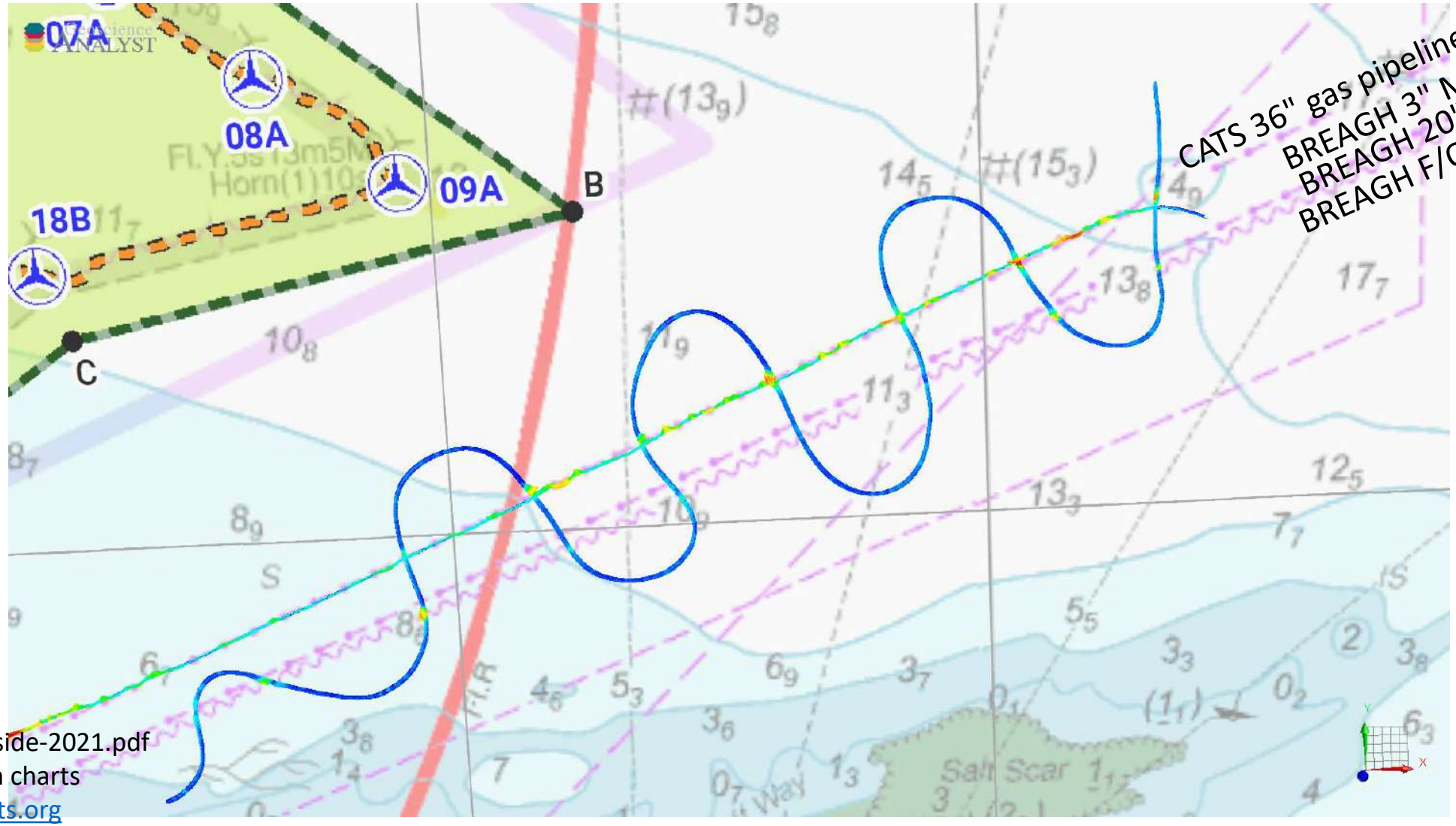

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Magnetic Vector Field Response over a Pipeline

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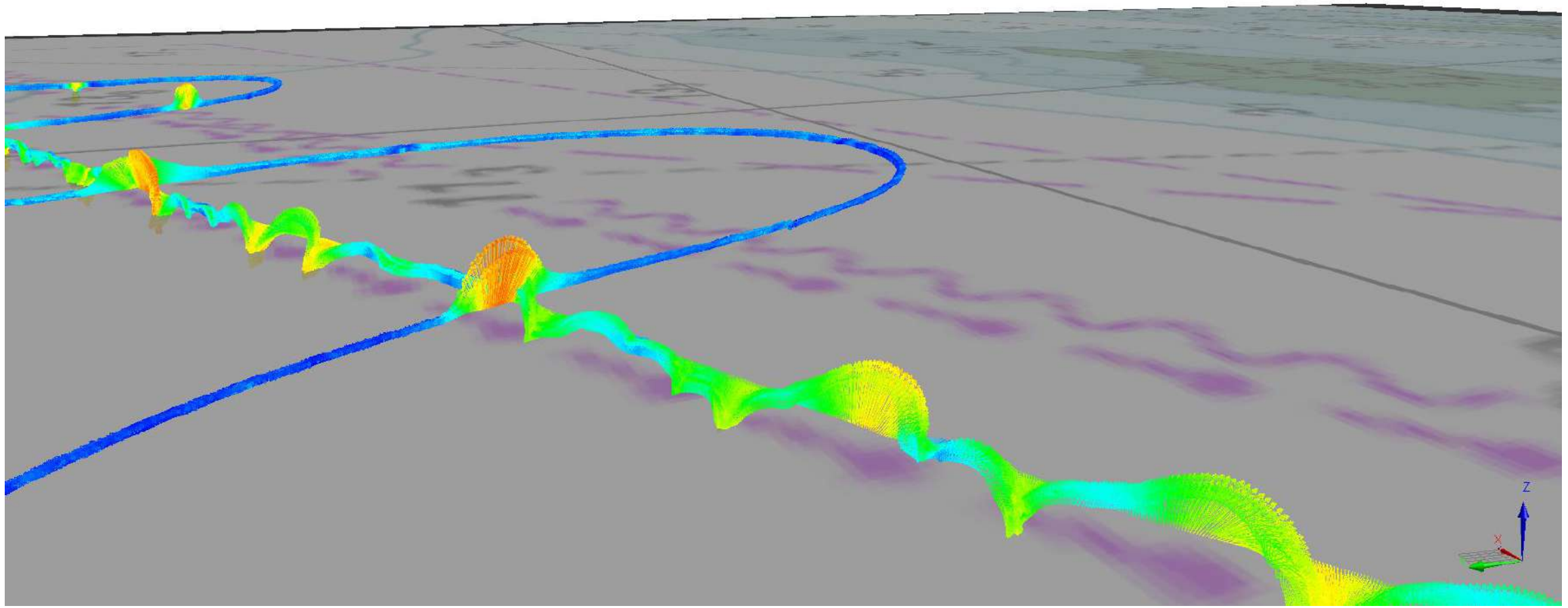

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Conclusions

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1. There are several **advantages of the strapdown Hypermag on the Scanfish**:
   - Eliminates the need for trailing magnetometers, allowing for **easier equipment handling**.
   - Enables calculation of **vector components** of the magnetic fields.
   - **Reduces navigation errors that propagate** into the magnetic data processing.
   - Allows for **co-registered data products** with other sensors, e.g. multibeam

2. The **wide bandwidth** allows for both static and 50Hz/60Hz fields to be separated and interpreted independently

3. Vectors of the magnetic field from each of the **eight magnetometers** allows for the location of the buried magnetic object to be determined.

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Alan Cameron (**Unique Group**)

Chris Jakeman (**Marshall Jakeman Marine**)

Captain and Crew of the Marshall Art

NRC Industrial Research Assistance Program

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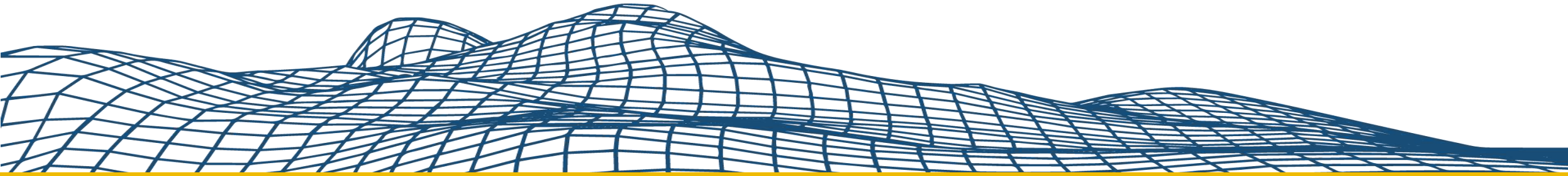

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