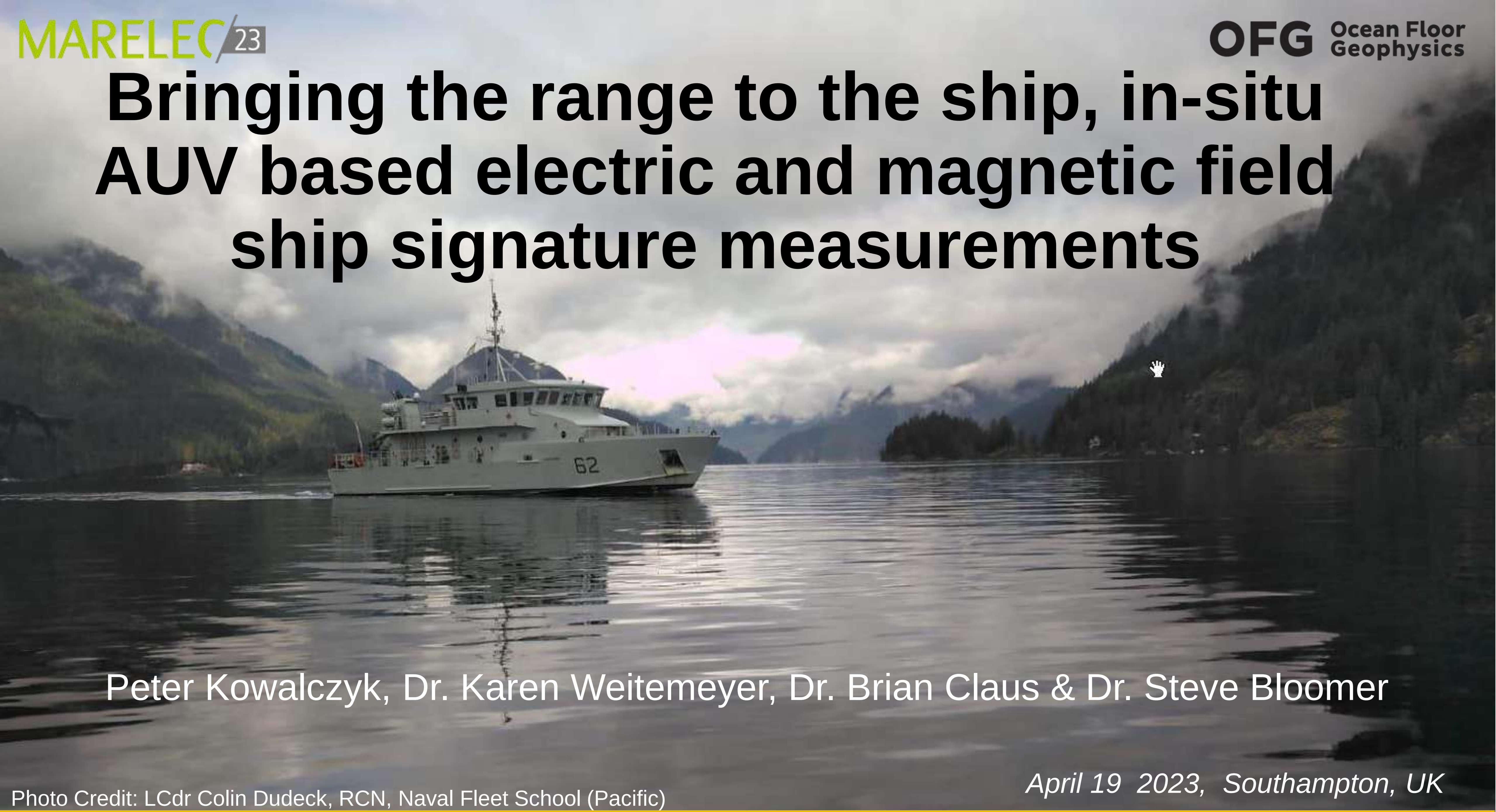
Bringing the range to the ship, in-situ AUV based electric and magnetic field ship signature measurements



Peter Kowalczyk, Dr. Karen Weitemeyer, Dr. Brian Claus & Dr. Steve Bloomer

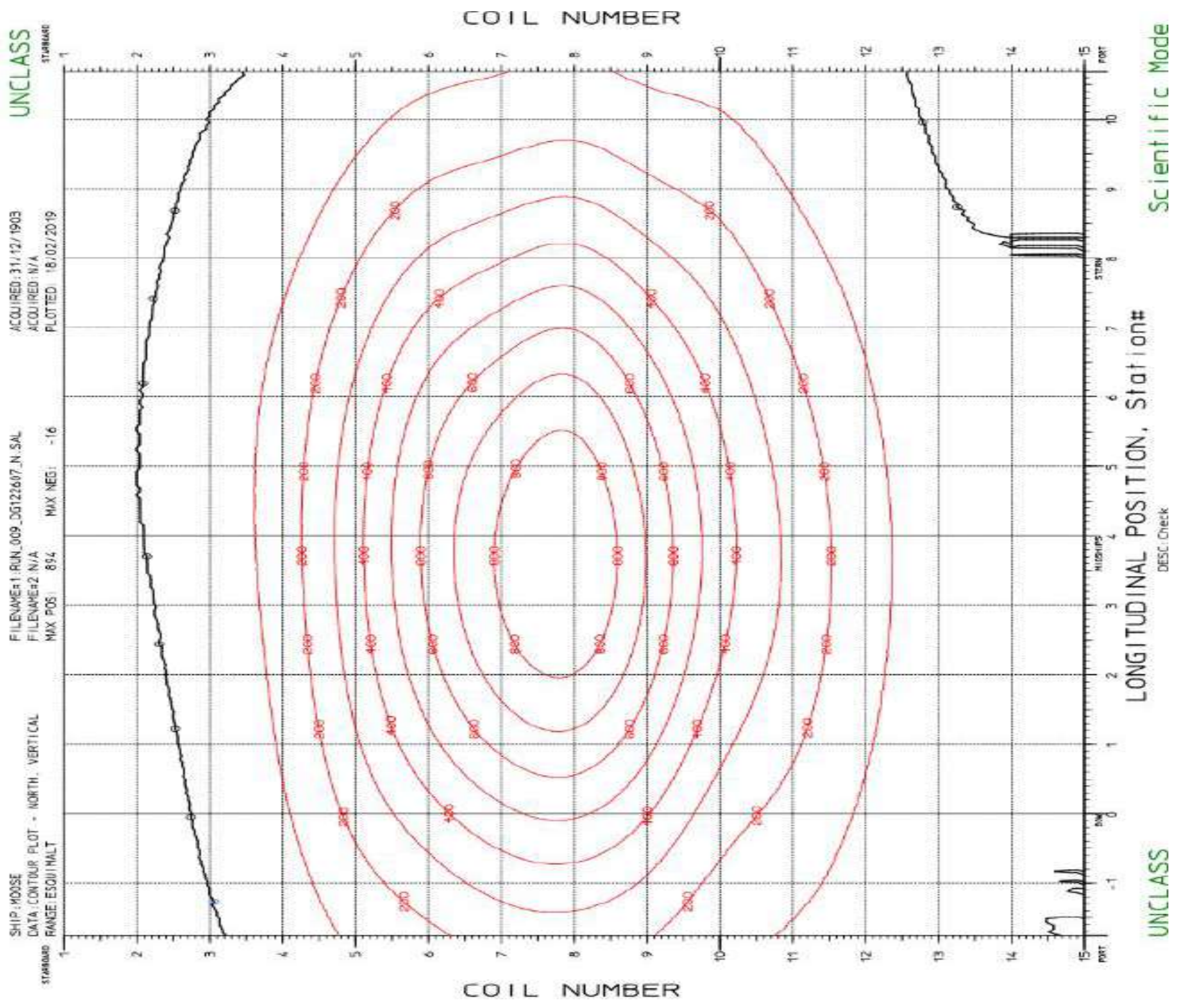
April 19 2023, Southampton, UK

Photo Credit: LCdr Colin Dudeck, RCN, Naval Fleet School (Pacific)

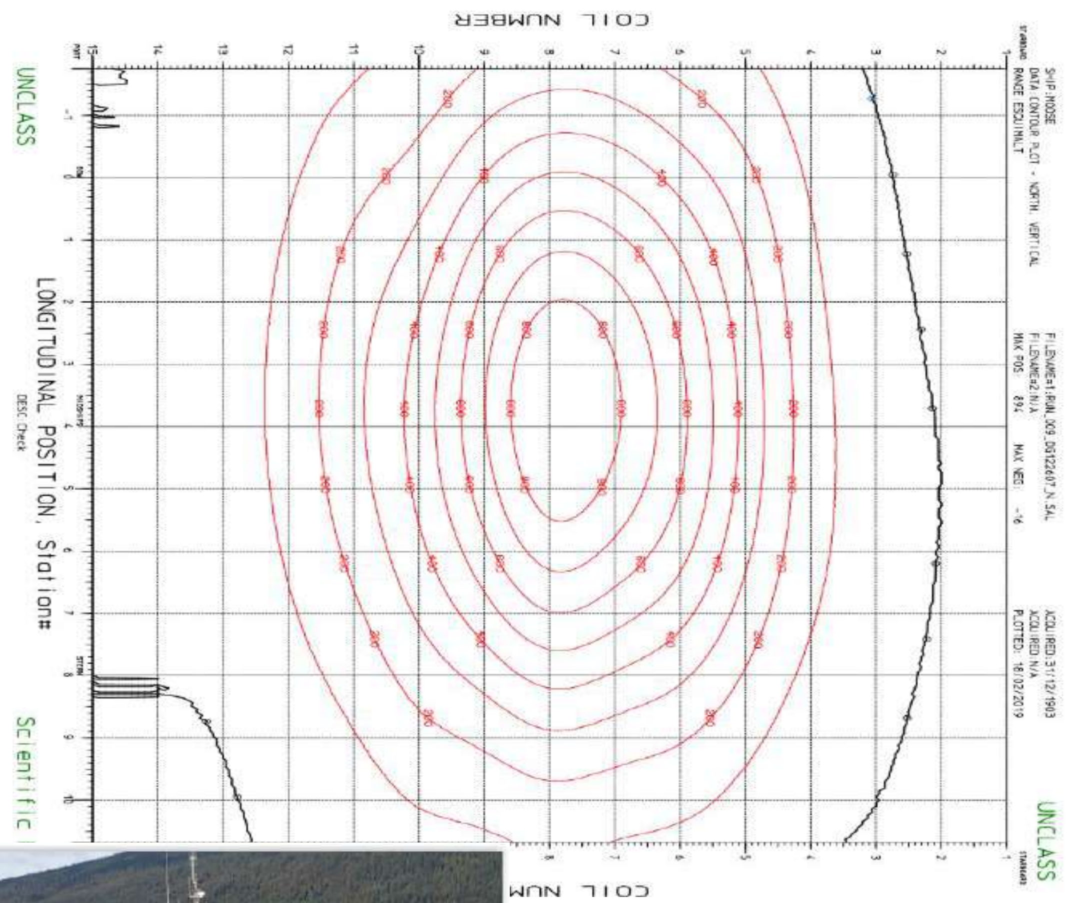
Fixed Range

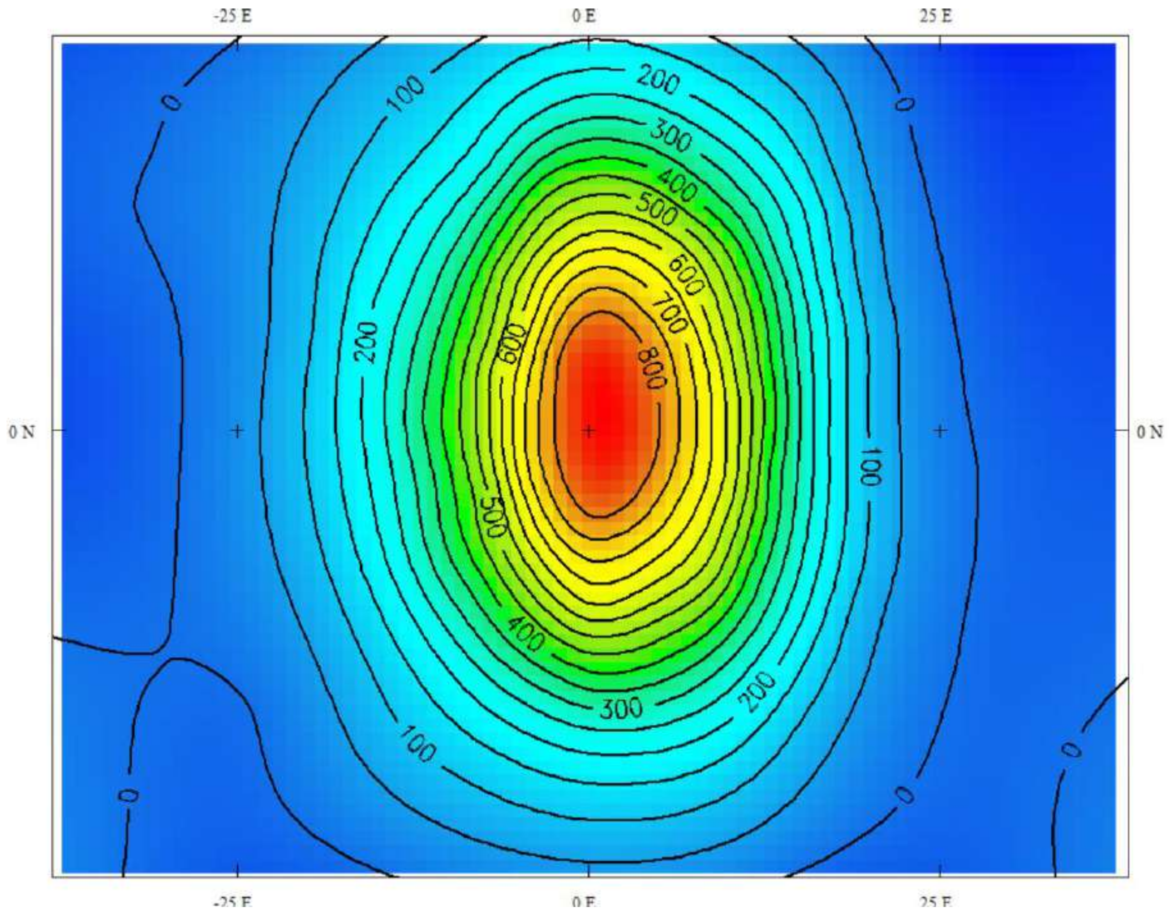
- Ship moves over a line of fixed sensors on the seafloor.
    - Usually coils – ballistic magnetometer, instead of moving coil into magnetic field, one moves the magnetic field past the coil.

- Like a photo finish camera – image built as ship moves over line of sensors, magnetic and electric.



Magnetic signature: PCT Moose at Esquimalt fixed range.





Our problem, to do this away from the range.

Why?
Reduce costs and improve reliability

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- Taking a ship to a fixed range requires scheduling, removes a ship from operations and costs considerable amounts of time and money.
- The ambient magnetic field direction and strength varies greatly as a function of location in the world. So a measurement made in a fixed range in Victoria, for example, will not represent the ship when it is in the Arctic ocean.
- The magnetization of a ship can change as a function of time – due to the stresses induced by the ship working in a sea.
- It is important to check that the deperming and degaussing systems are operating as intended by direct measurement of the ships magnetic signature.

How?
Use equivalent sources & sparse data

- Calculate equivalent source models for the vessel for both magnetic and electric fields after measuring the ship's fields with a sparse data set in the volume around the ship.
- Then calculate the field below the ship at the depth of the fixed range sensors to compare our estimate of the vessel's field with the field measured at the fixed range.
- We made a simple equivalent source model using a sparse set of measurements made around the ship. Where to measure the magnetic and electric fields was investigated first using theoretical models, then real data was acquired.

The forward theoretical magnetic model

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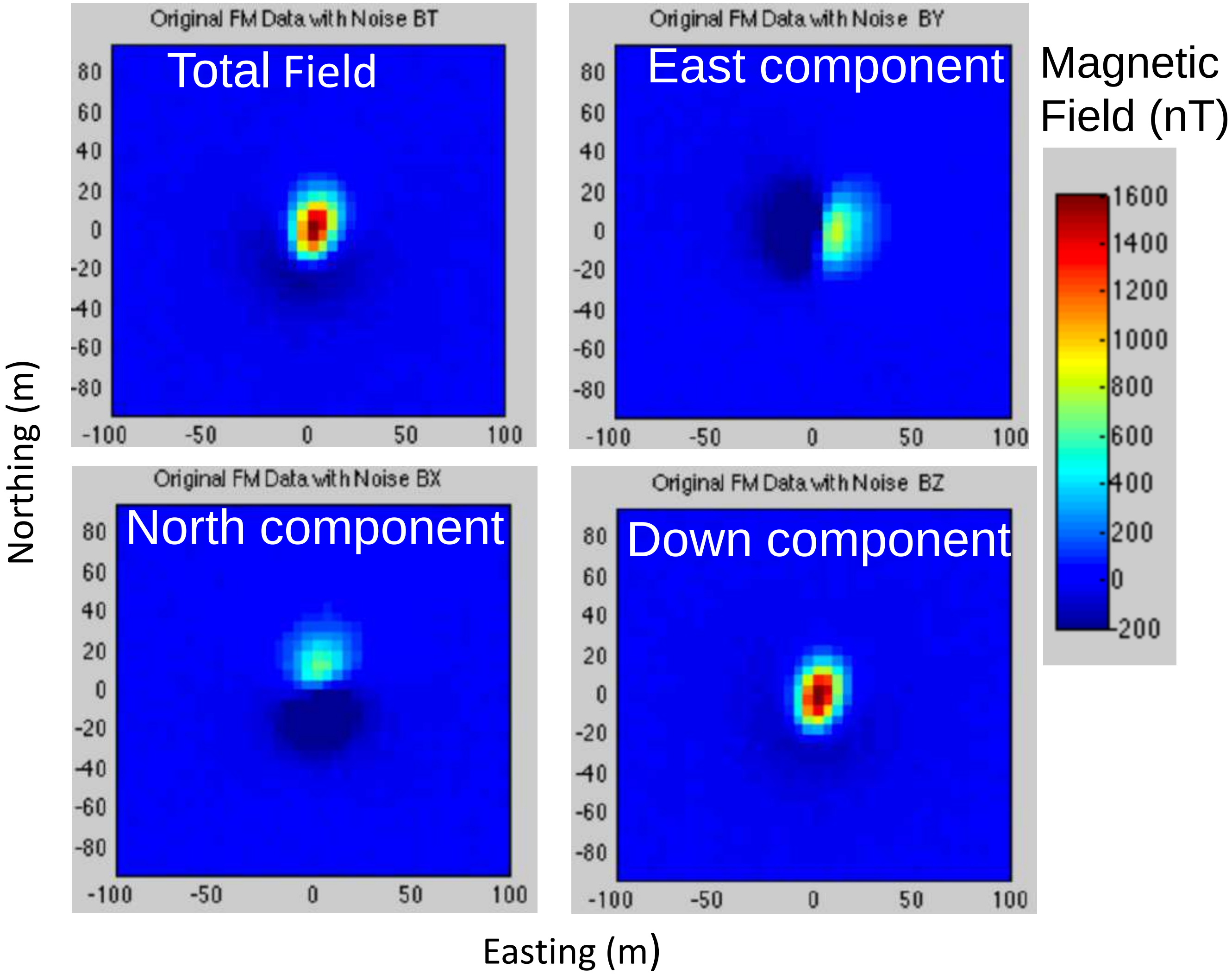
	Ellipse outer	Ellipse Inner
a	33/2	32.918/2
b	8.34/2	8.258/2
c	8.34/2	8.258/2

Example forward calculation result



A forward model was run using a hollow ellipsoid to estimate the magnetic field from the ship.

Computed magnetic fields for the reference ellipsoid used to approximate a 210T vessel

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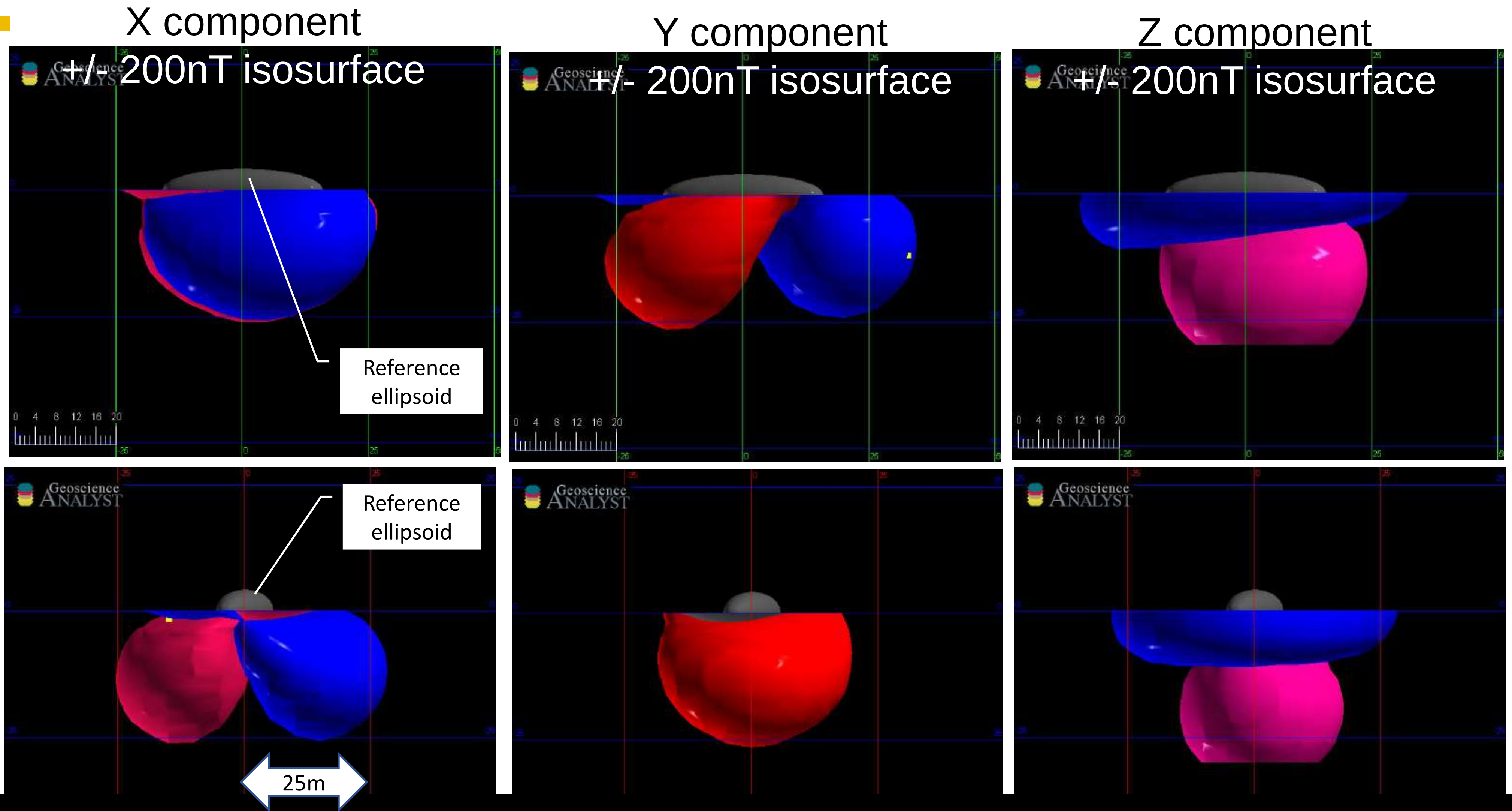

Traverses at ~16m depth and +/-16m (twice the beam) on either side, probe inside the 200nT shells, and pass close to the characteristic points of all 3 magnetic components

Percentage errors using equivalent source models

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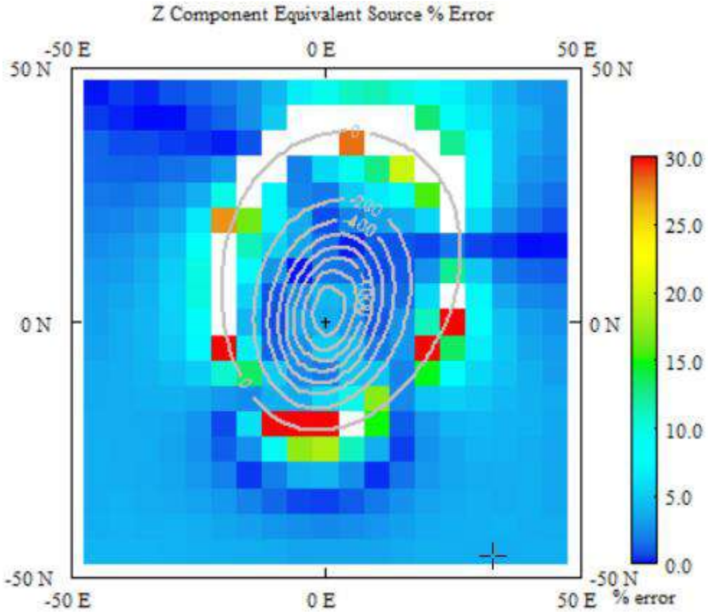

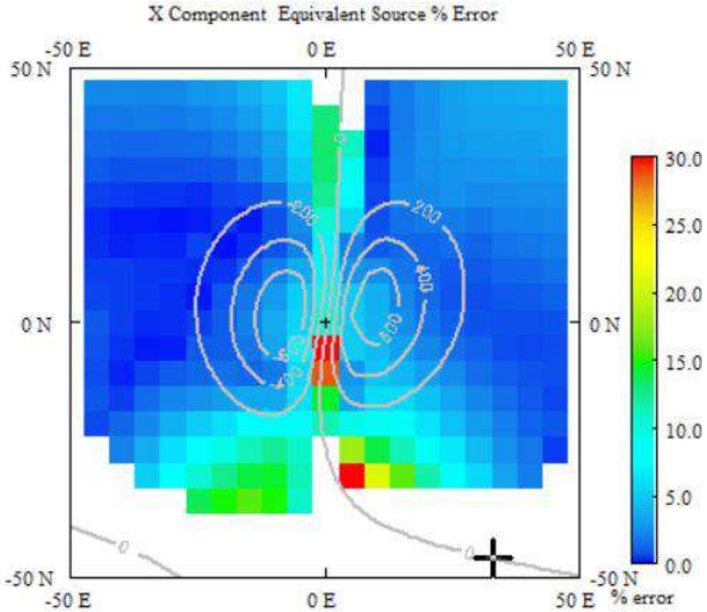

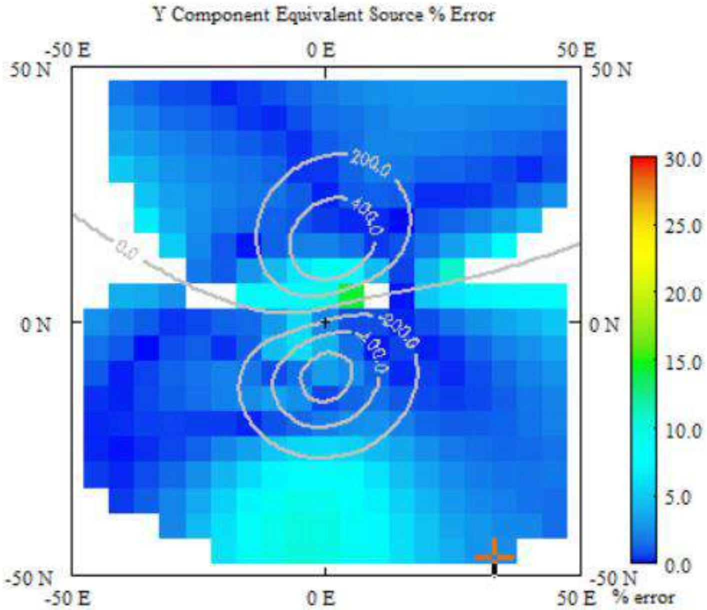

FOR A MODEL STUDY…
NOT A BAD RESULT!

3 Dipole model vs. reference model at 16m depth

- Reference model is calculated using the theoretical response from a hollow ellipsoidal body.
- The equivalent source model is three 1m magnetic spheres fitted by inversion from sparse data.
- The % error shown is the final difference between the equivalent source calculation and the reference model, where the reference model's absolute value is greater than 10 nT.
- Contours displayed are the reference field drawn at 200 nT intervals.

Data acquisition and analysis:
A vessel and an AUV

- This is primarily a navigation and data acquisition problem.
  - Ship’s position needs to be controlled and measured.
  - Sensors’ position needs to be controlled and measured.
  - All data needs to be levelled and backgrounds removed.

- OFG elected to use an AUV to carry the sensors as the necessary workflows of sensor navigation, orientation, and data acquisition were already well understood by OFG and a suitable DND owned AUV was available from Cellula Robotics, a partner company to OFG. Not necessary to build any hardware.

Field and Remote Support Locations

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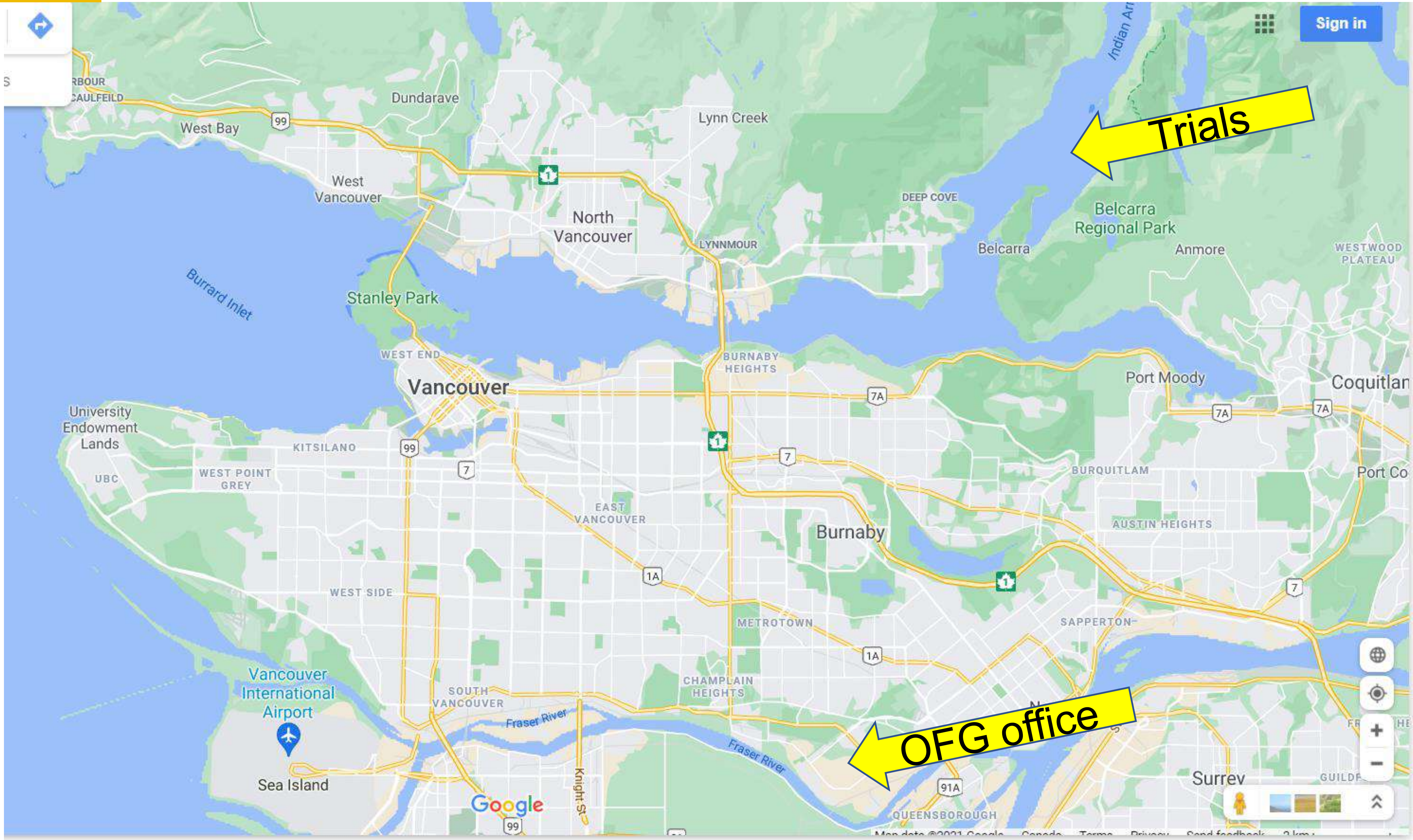

Bedwell Bay
Site of Trials

A vessel and an AUV

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- Orca Class vessel provided by RCN.
- Two OFG persons quarantined, then stayed on board to coordinate ship and AUV.
- OFG had one person on AUV support vessel.
- Rest of team on remote link in OFG office.

OFG Sensors on Solas-LR AUV.

- Magnetometers (internal)
- Electric field / iCP sensors (external, yellow arrows)
- Hydrophone (internal)

Survey Operations: rinse & repeat February, 2021

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- Feb 16 - background survey
- Feb 17 - Day 1 of Trials
- Feb 18 - Day 2 of Trials – Windy
- Feb 19 - Day 3 of Trials
- Weekend
- Feb 22 - Day 4 of Trials
- Feb 23 - Day 5 of Trials
- Feb 24 - Day 6 (1/2 day) Quicklook

Diurnal Magnetic Variation

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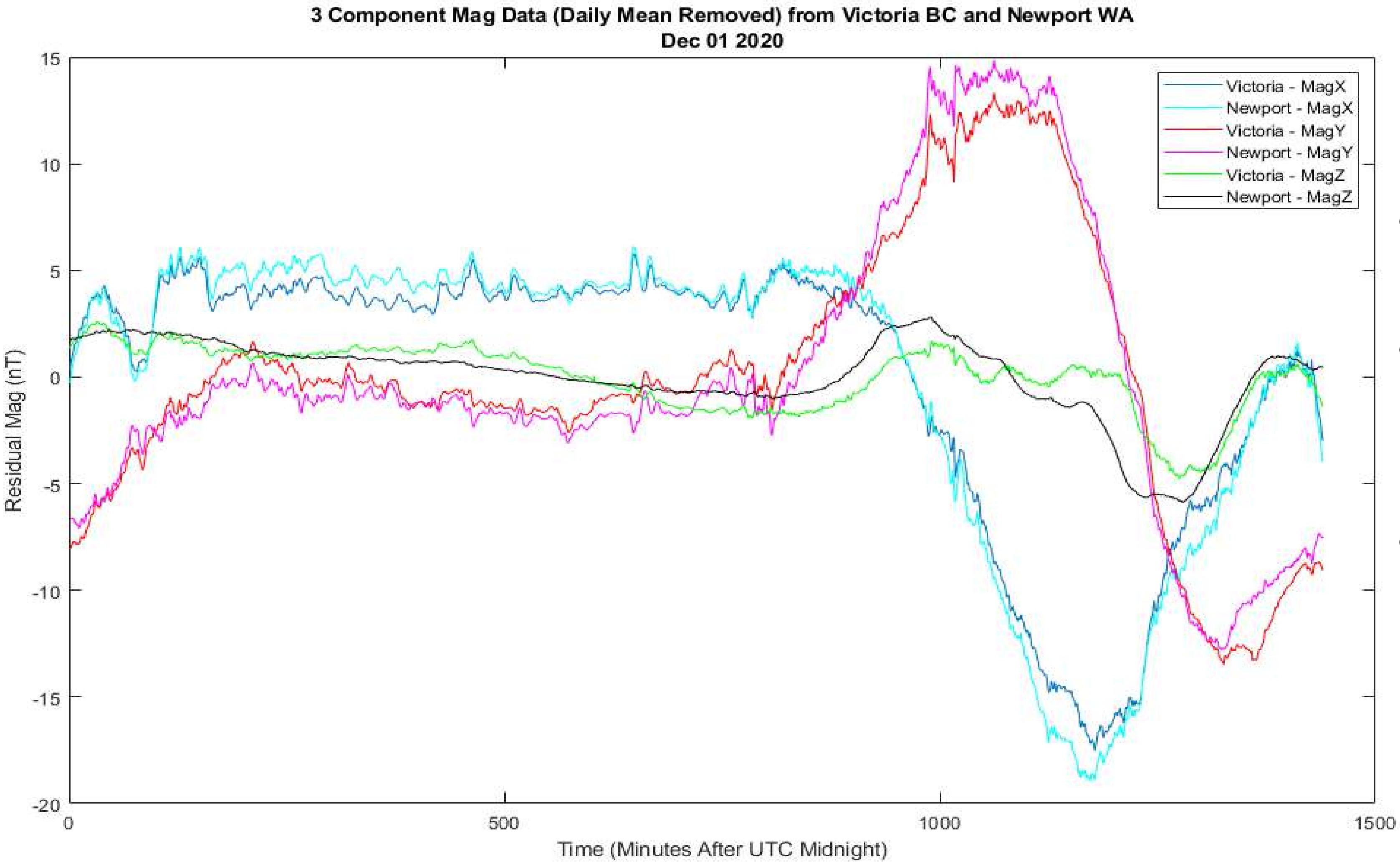
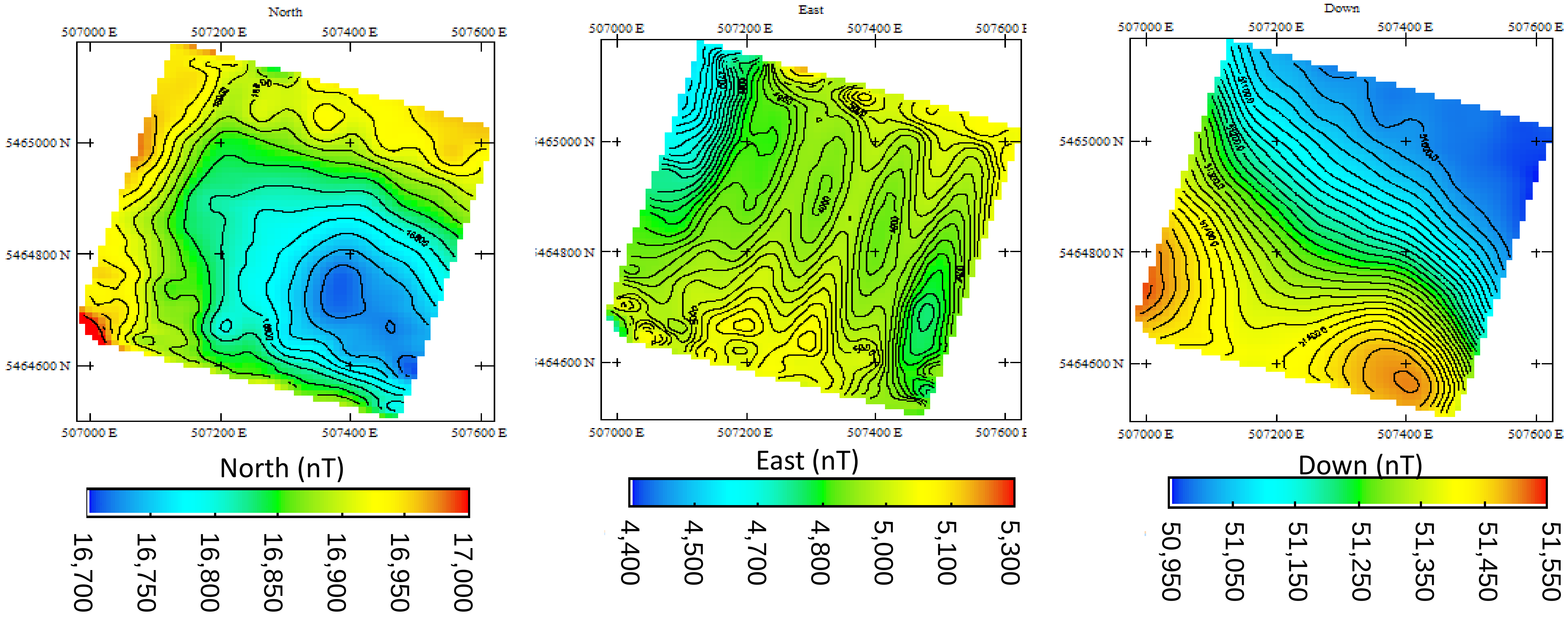
Comparison of XYZ magnetic fields from Victoria, BC and Newport, WA magnetic observatories for Dec 1, 2020.



Day 1

- Magnetic Background Survey
- Diurnal corrections made using Victoria geomagnetic observatory
- Data referenced to IGRF at Victoria

Day 1, Magnetic background grids established



Maps of diurnally corrected North (left), East (centre) and Down (right) magnetic fields from the background survey collected on 2021-02-16.

To acquire data, the ship passes the AUV

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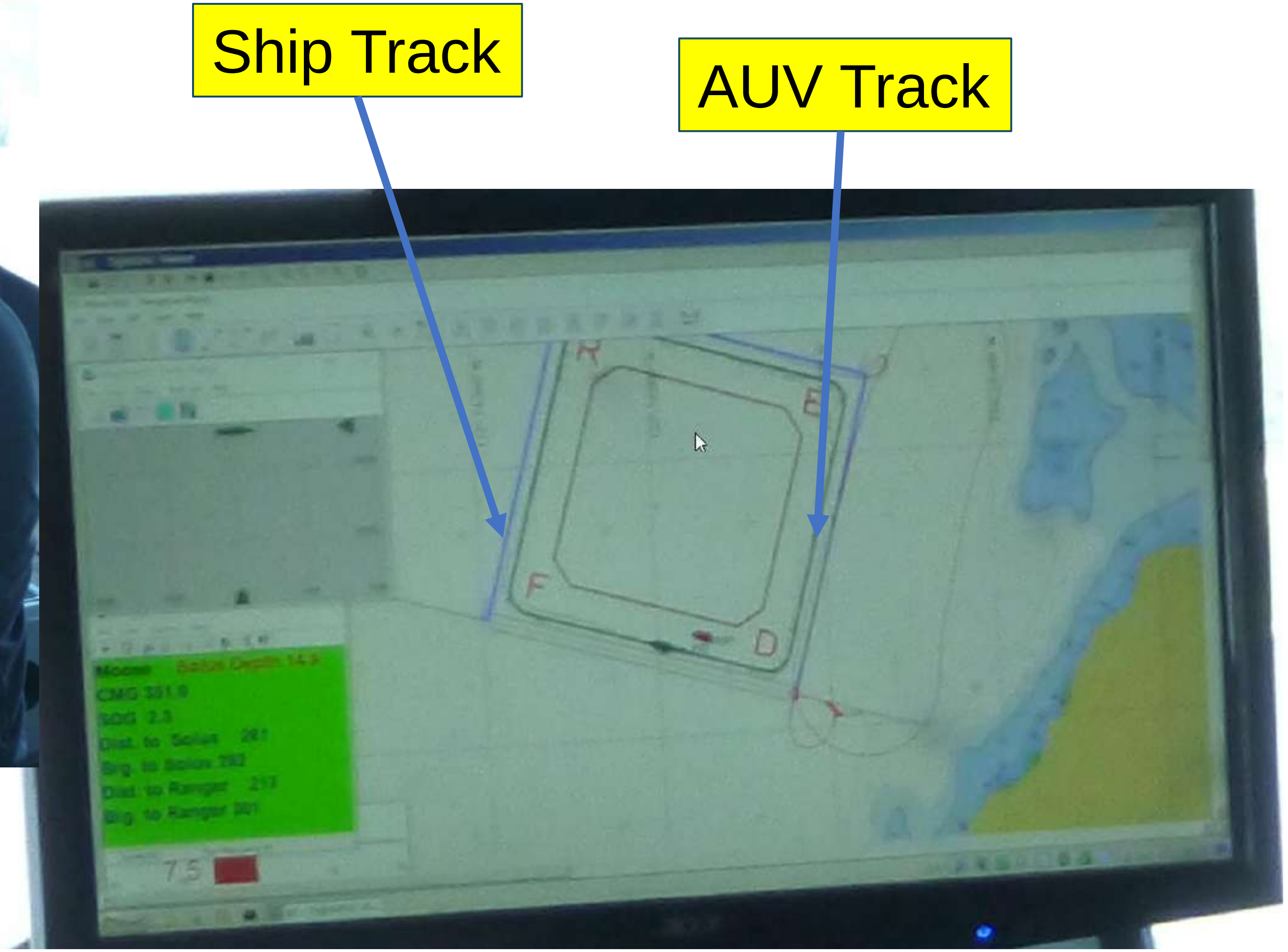

Analysis done in frame of reference of the ship.

2022.02.22: Results from one day

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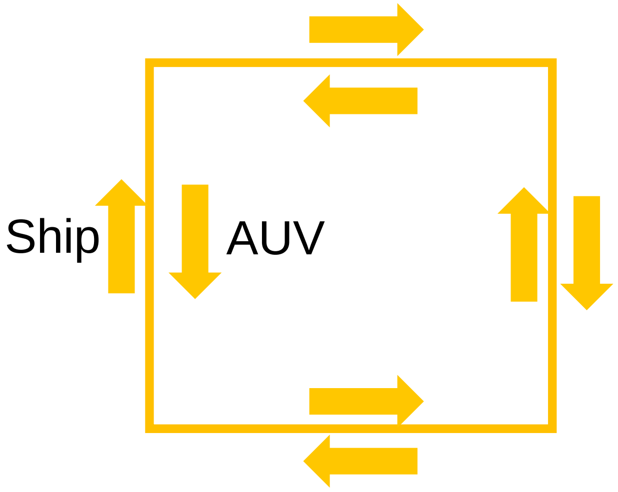
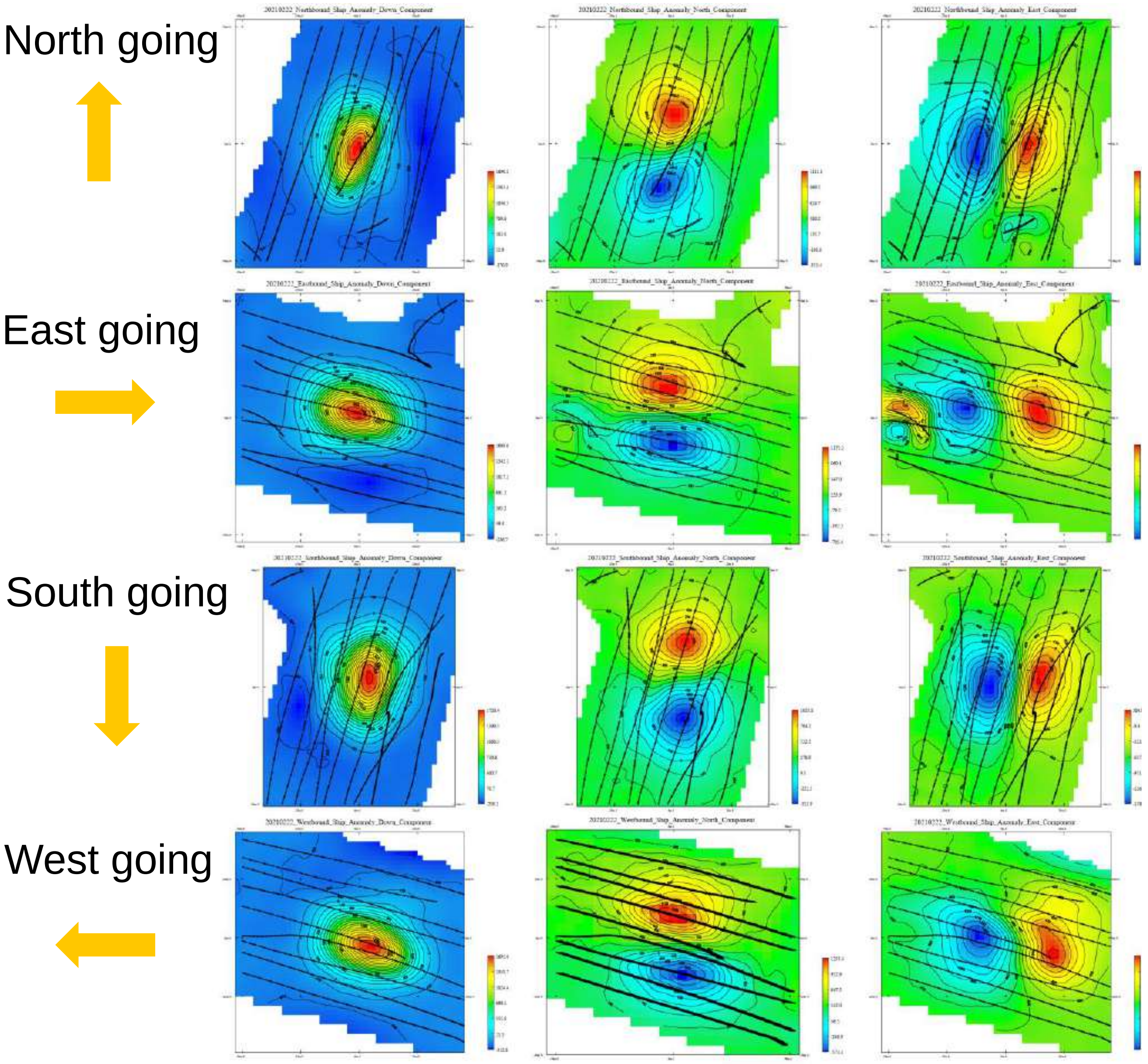


Going around the box and meeting the AUV, we were able to measure ship signatures for the vessel travelling in each cardinal direction.

It is possible to calculate the hard and soft magnetization of the ship from this set of measurements.



Magnetic Fields: measured and predicted

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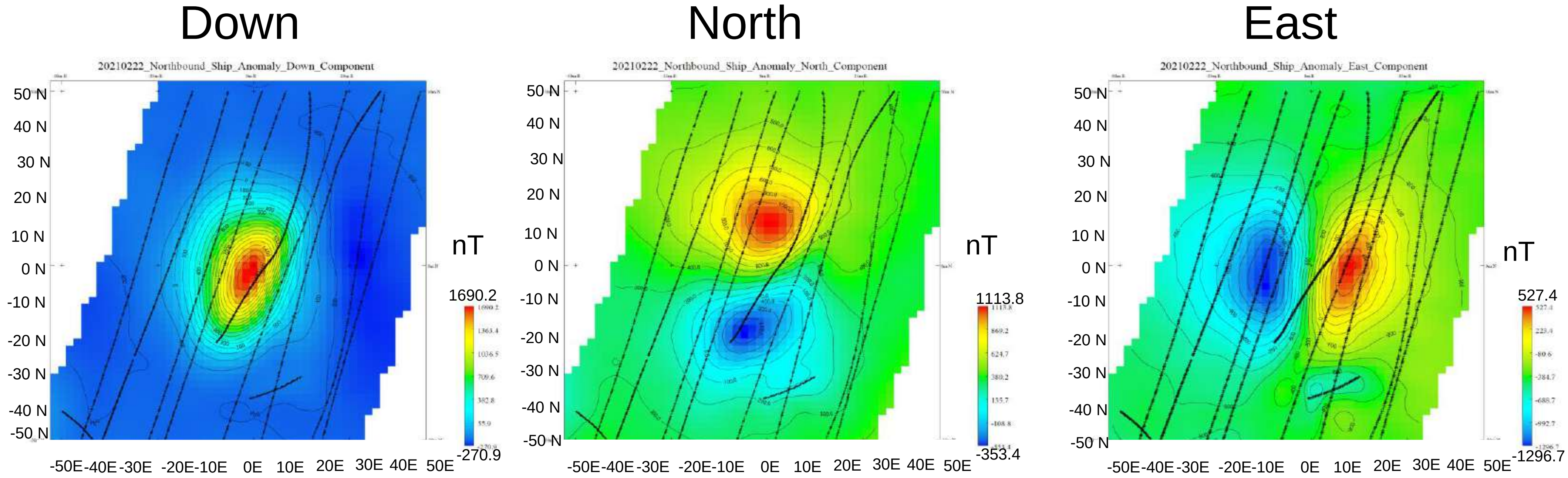
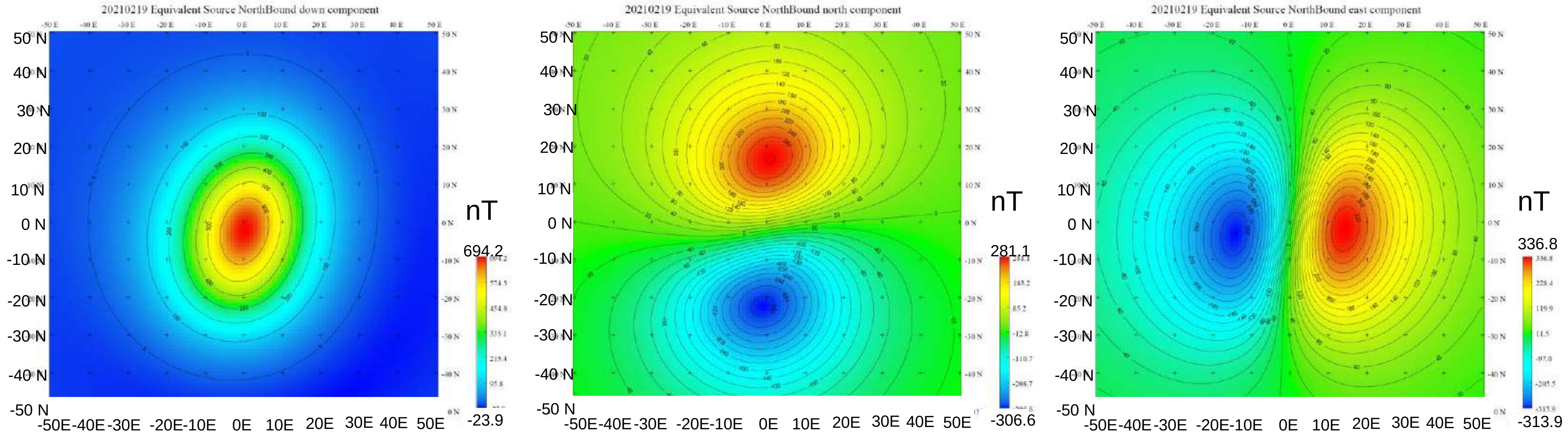
Measured

Data acquired Feb. 22, 2021 measured at a 16 m depth

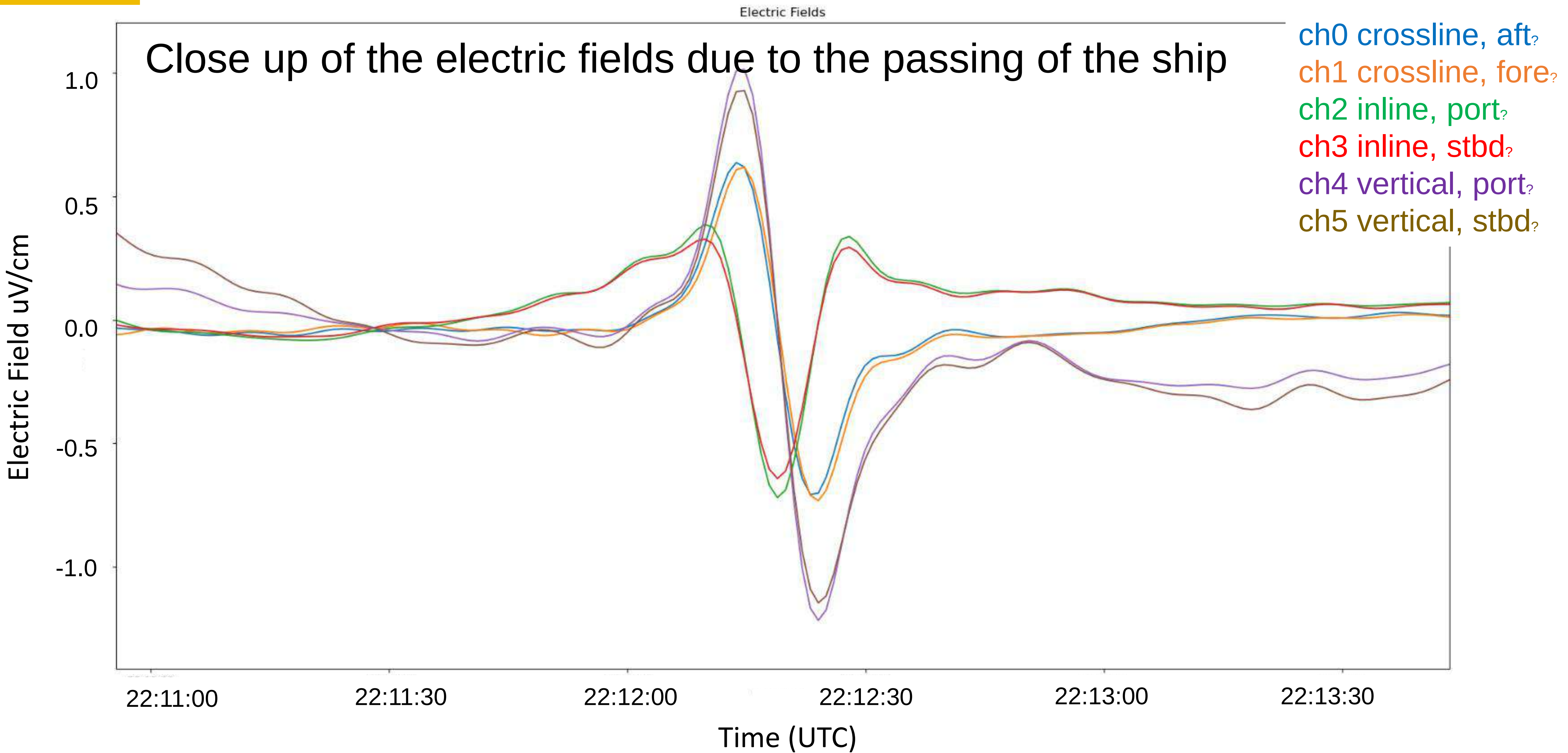


Predicted

Predicted by equivalent source at a 24m depth



Electric fields measured from the AUV observes the ship signature



Electric Fields: measured and predicted

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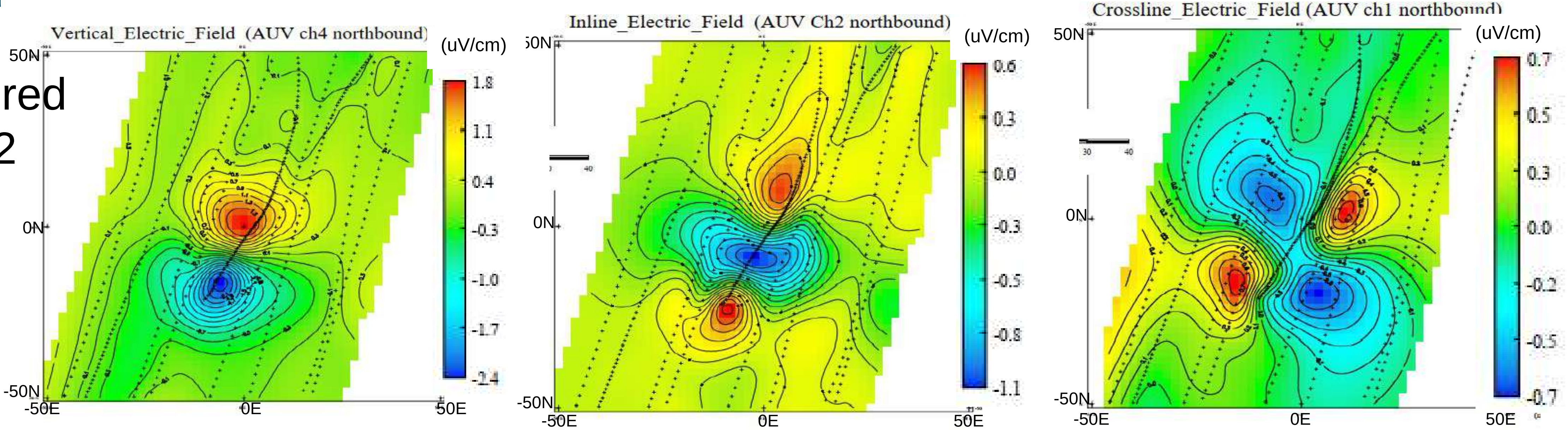
Measured

Down

North

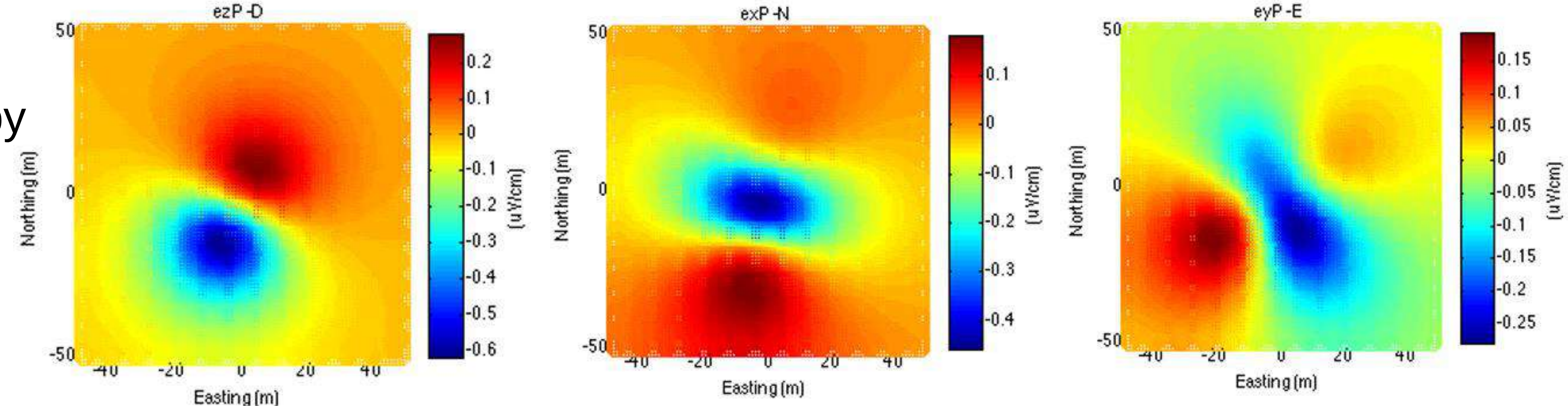
East

Data acquired 2021-02-22 at a 16 m depth



Predicted

Predicted by equivalent source at a 24m depth



Ship acoustic signature measured from AUV

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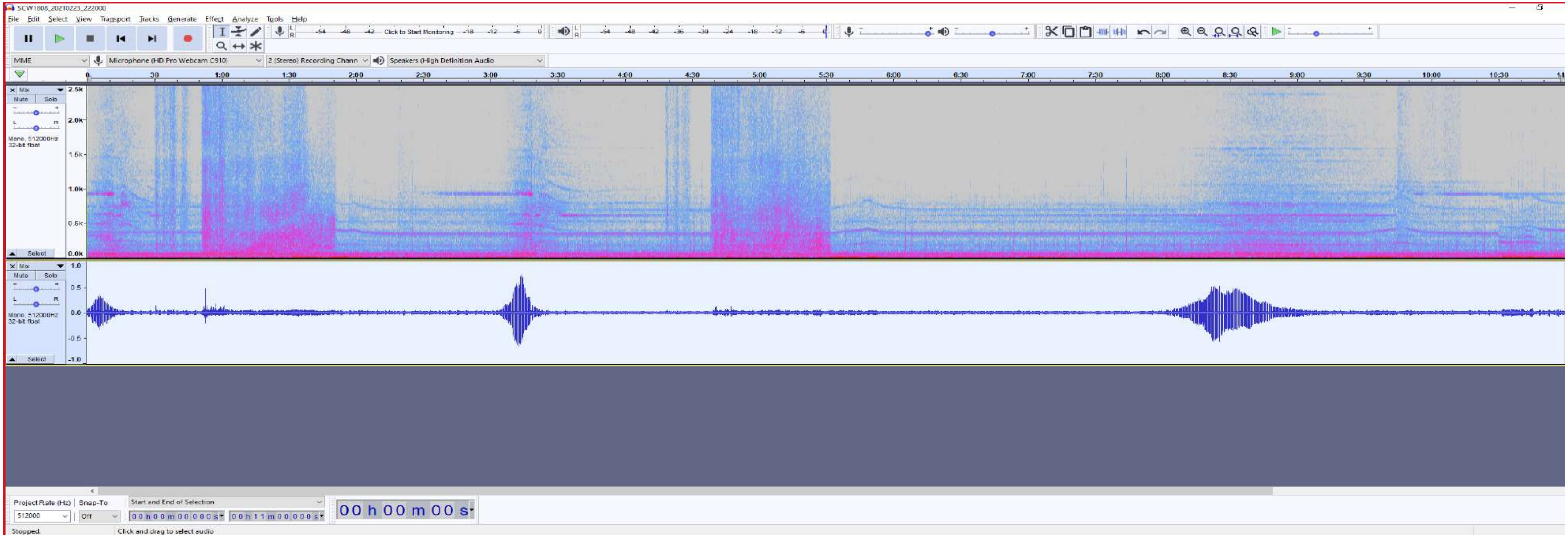
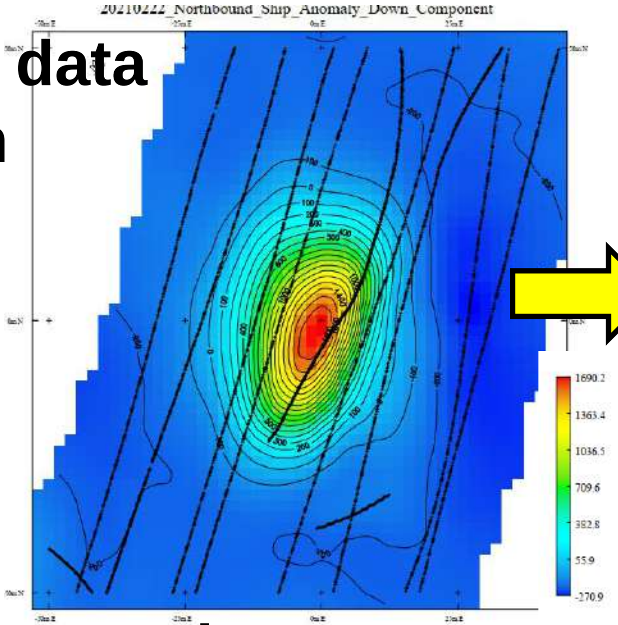


Spectrogram with audio timeseries below for the hydrophone data from 2220-2230Z 2021-20-23

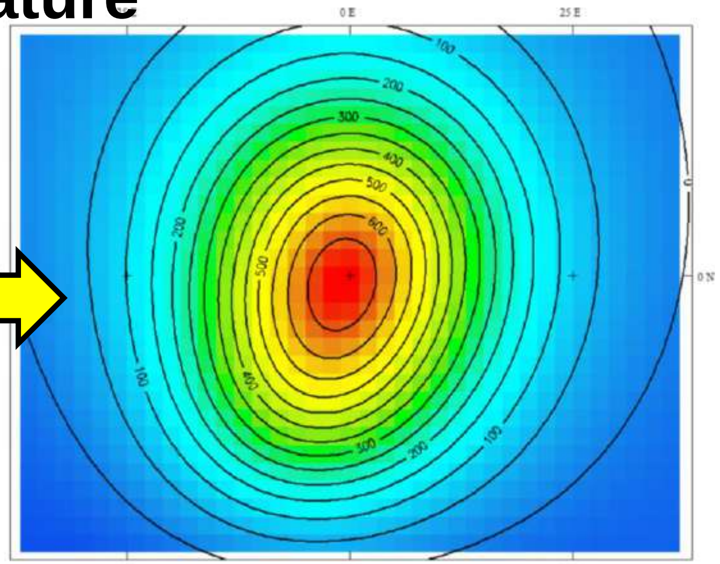
Magnetic fields estimated using the equivalent source model & measured at a fixed range

Sparse AUV data ~ 16m depth

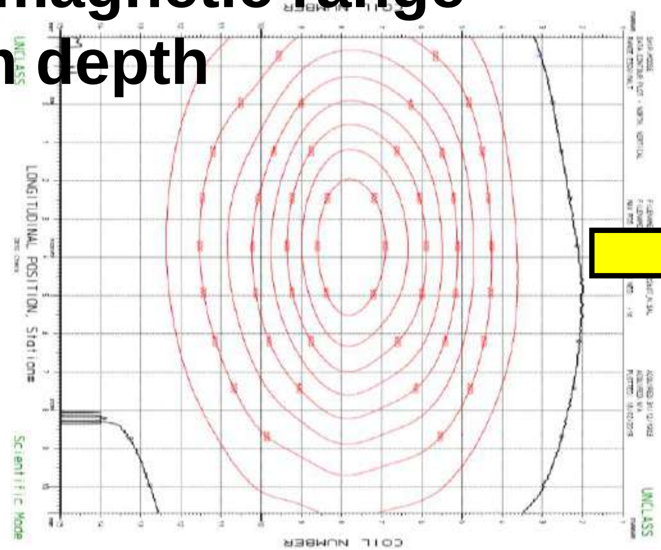


Equivalent source model used to calculate anomaly below ship at 24.3m depth to compare with measured range data

Predicted signature at 24.3m depth

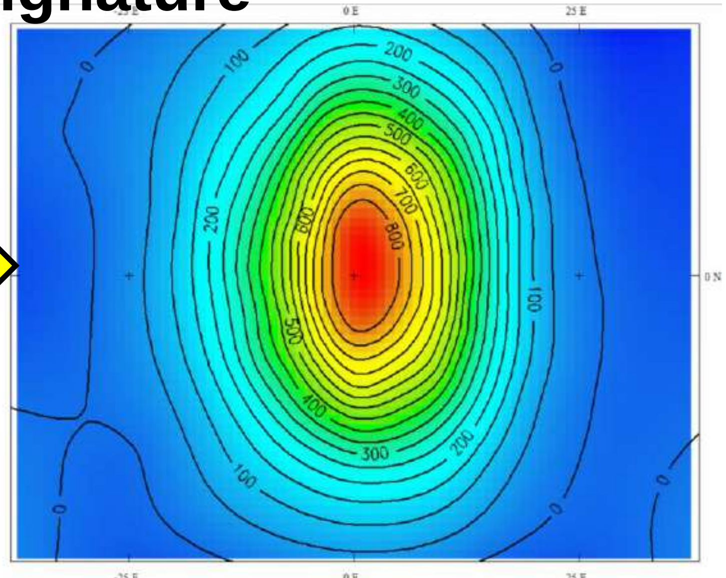


Esquimalt magnetic range data 24.3 m depth



Magnetic range data digitized to compare with predicted downward magnetic component data

Measured signature at Range



Summary

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- Using a sparse data set collected with an AUV a ship signature can be collected anywhere in the world.
- The use of an equivalent source transform allows an estimate of the magnetic or electric signature to be computed wherever desired below the ship.
- An acoustic signature can be collected at the same time.
- This process will be much less expensive than taking a ship to a fixed range.

Summary, cont’d

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- There were a lot of moving parts in this demonstration. A fit to purpose system with the necessary data systems, navigation and mobility is necessary to use this with a larger ship. Future work!

- The equivalent source formulation we used was not optimal, but “good enough” to demonstrate that the concept of collecting a sparse data set around a vessel and then predicting the magnetic and electric fields around it is a viable concept. Making an excellent equivalent source model was not our brief. DRDC has better models.

- It worked – in a short timeline, in the middle of a pandemic.

Acknowledgements

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Captain and Crew of the PCT Moose – ship operations
DND provided the AUV, which was designed by Cellula Robotics Ltd.
Cellula Robotics: AUV Operations
Tony Wass, Alexey Popov, Tim Kier (**OFG** operations)

OFG would like to acknowledge that the funding received and the support from the RCN was made available rapidly and in a way that allowed this project to proceed effectively even while the constraints of the COVID-19 pandemic were in full force.

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