Tightly coupled electric field and photogrammetry measurements from a remotely operated vehicle for inspection of subsea infrastructure

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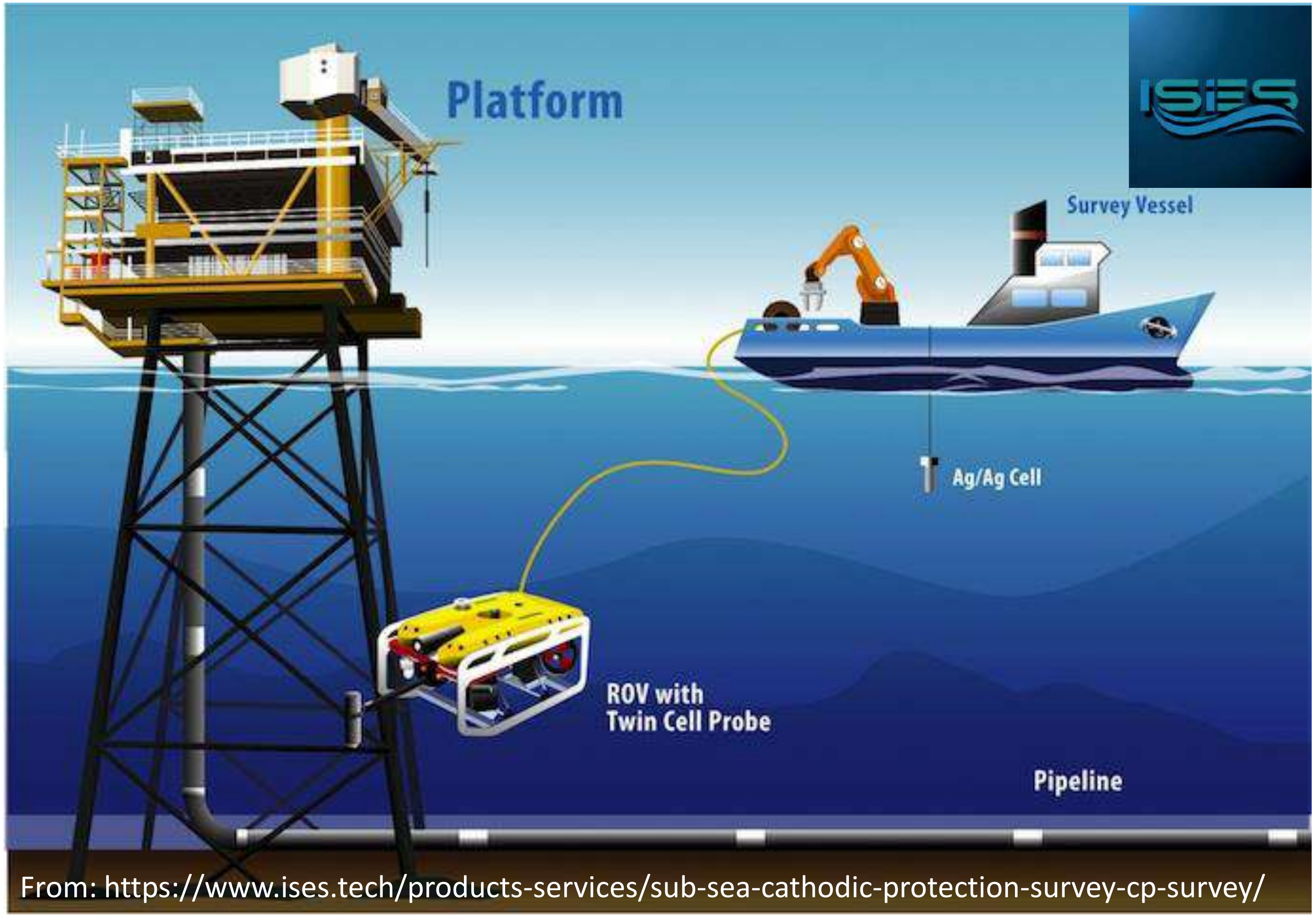
Photo Credit: ROV Team

Traditional Subsea Cathodic Protection (CP) Survey



may consist of :

1. Single component electric field measurement (Field Gradient).
2. Potential reading at Stab tip location.
3. Visual inspection from ROV Video feed.
4. Still photographs from ROV camera.

CP Surveys:

From https://www.ises.tech/wp-content/uploads/2018/12/ISES-CP-Survey-Data-Sheet-2018-FINAL.pdf

Allow the CP engineer to

1. Determine if corrosion is occurring.
2. Compute the remaining life on the anodes.
3. Make recommendations to correct any corrosion issues.

https://acteon.com/products-services/pipeline-cathodic-protection-cp-survey/#:~:text=Cathodic%20Protection%20(CP)%20surveys%20verify,life%20of%20the%20anode%20system

Typically decisions are based on

1. Sparse data coverage:
   - Potential readings only where contact is made with the structure using the CP probe.
   - Visual inspection only where ROV video or photographs are taken.
2. Design of the CP system.

Fast Digital Inspection (FDI)

Photo Credit: ROV Team

consists of :

1. Full 3D electric field components measured around the entire structure (along sensor paths on port and starboard side of ROV).
2. Potential (voltage) computed and draped onto the photogrammetry surface of the structure.
3. 3D Recon uses 3 vision cameras and an IMU to produce a high density 3D model.
4. Photogrammetry system also collects video and still photographs.

ROV iCP Components

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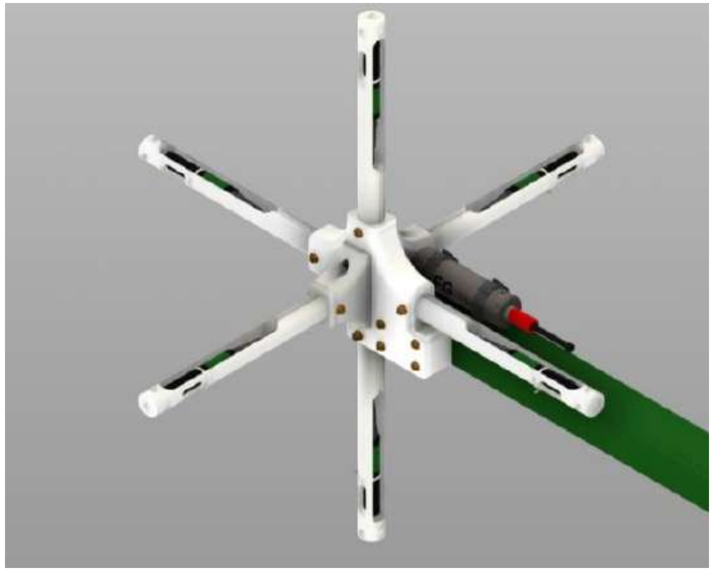
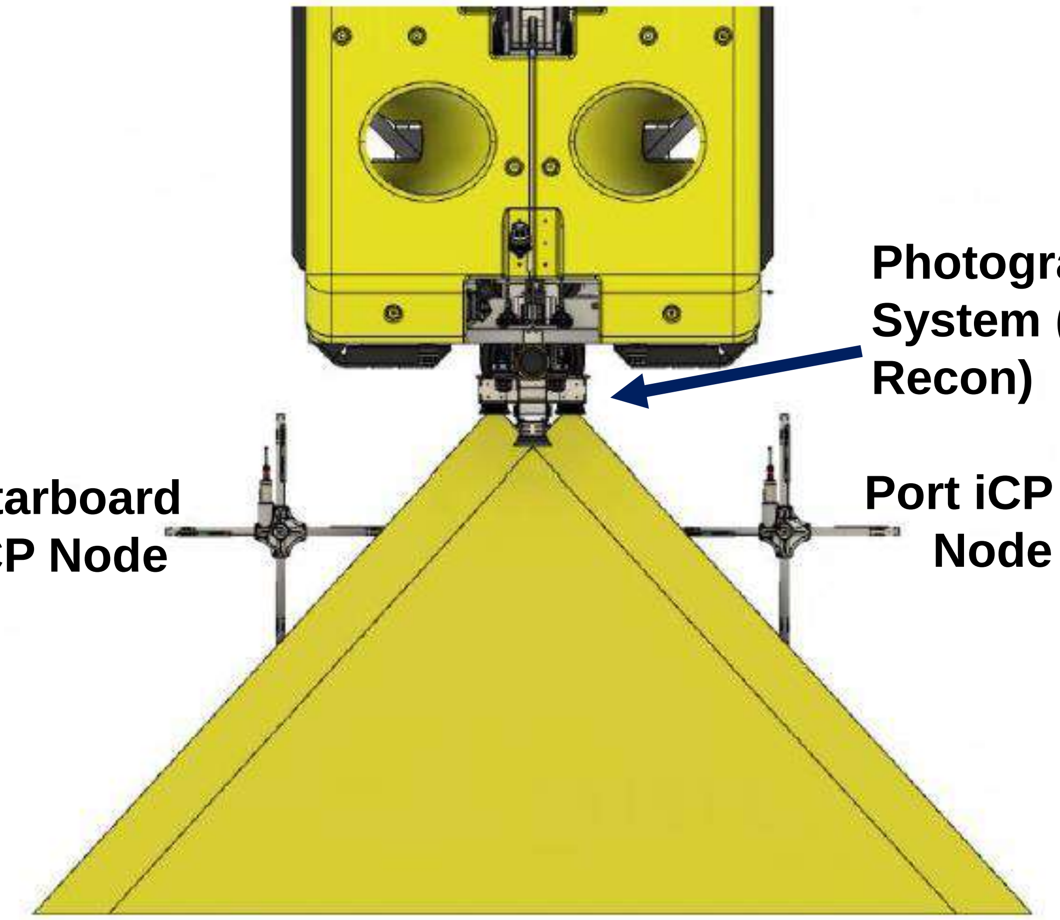
ROV iCP Node



6 Ag/AgCl electrodes arrange in 3 dipoles (X, Y, Z) collocated with an OFG Hypermag sensor (3 axis Magnetometer)

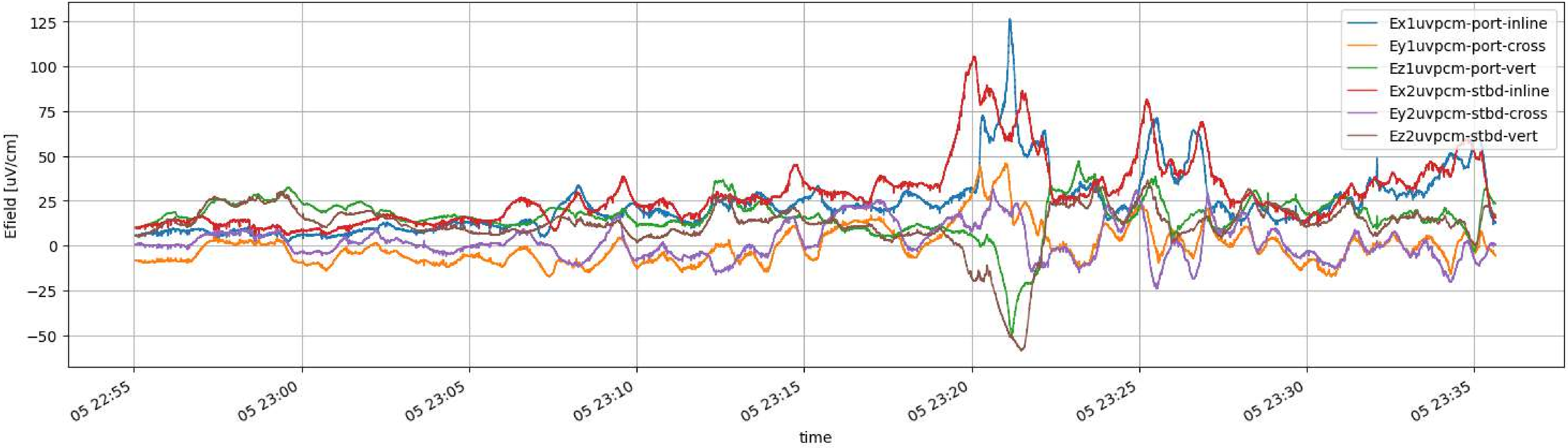
Measures 3 components of the electric and magnetic fields.

ROV iCP Top down View



Zupt 3D Recon Field of View

Example Electric Field Time Series



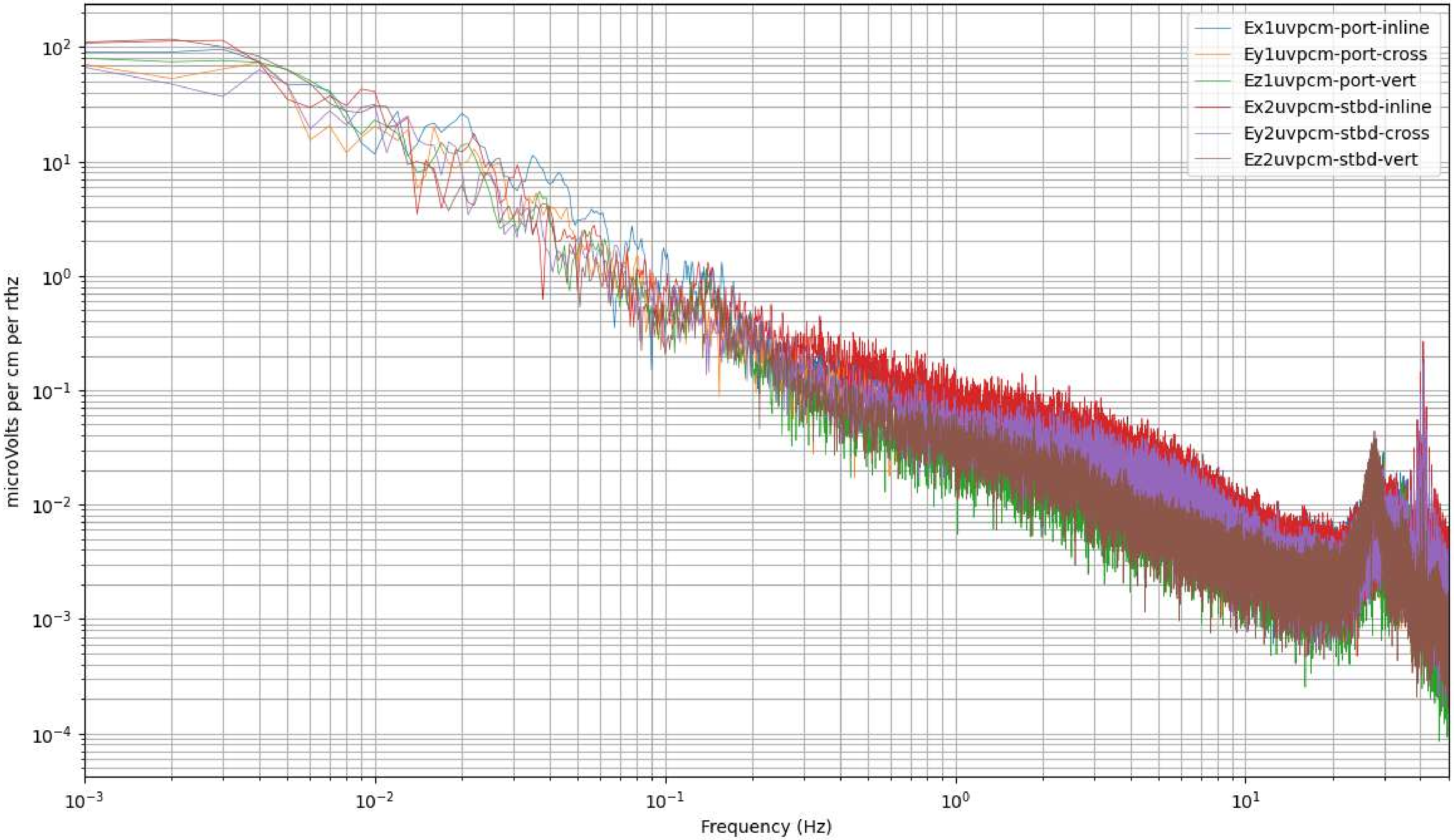
About 100 uV/cm signal from the structure
Noise is about 5 uV/cm
Good signal to noise ratio

Example Electric Field Spectra

41 minutes of data

Higher frequency noise peaks from ROV

Noise ~0.1 uV/cm per root Hz at 1 Hz



Example Electric Field Vector Plot

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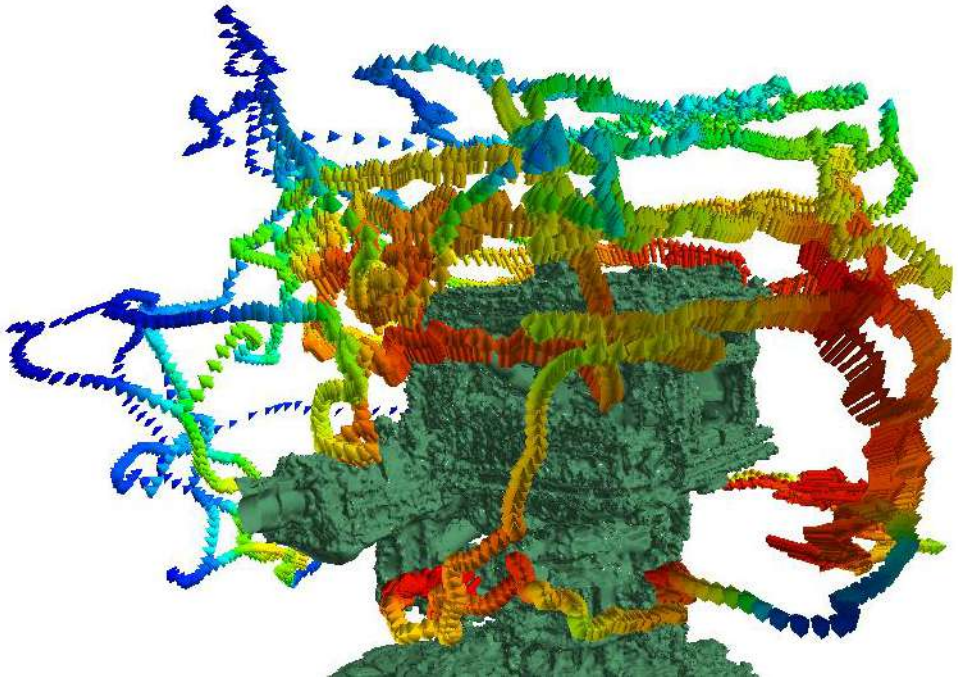
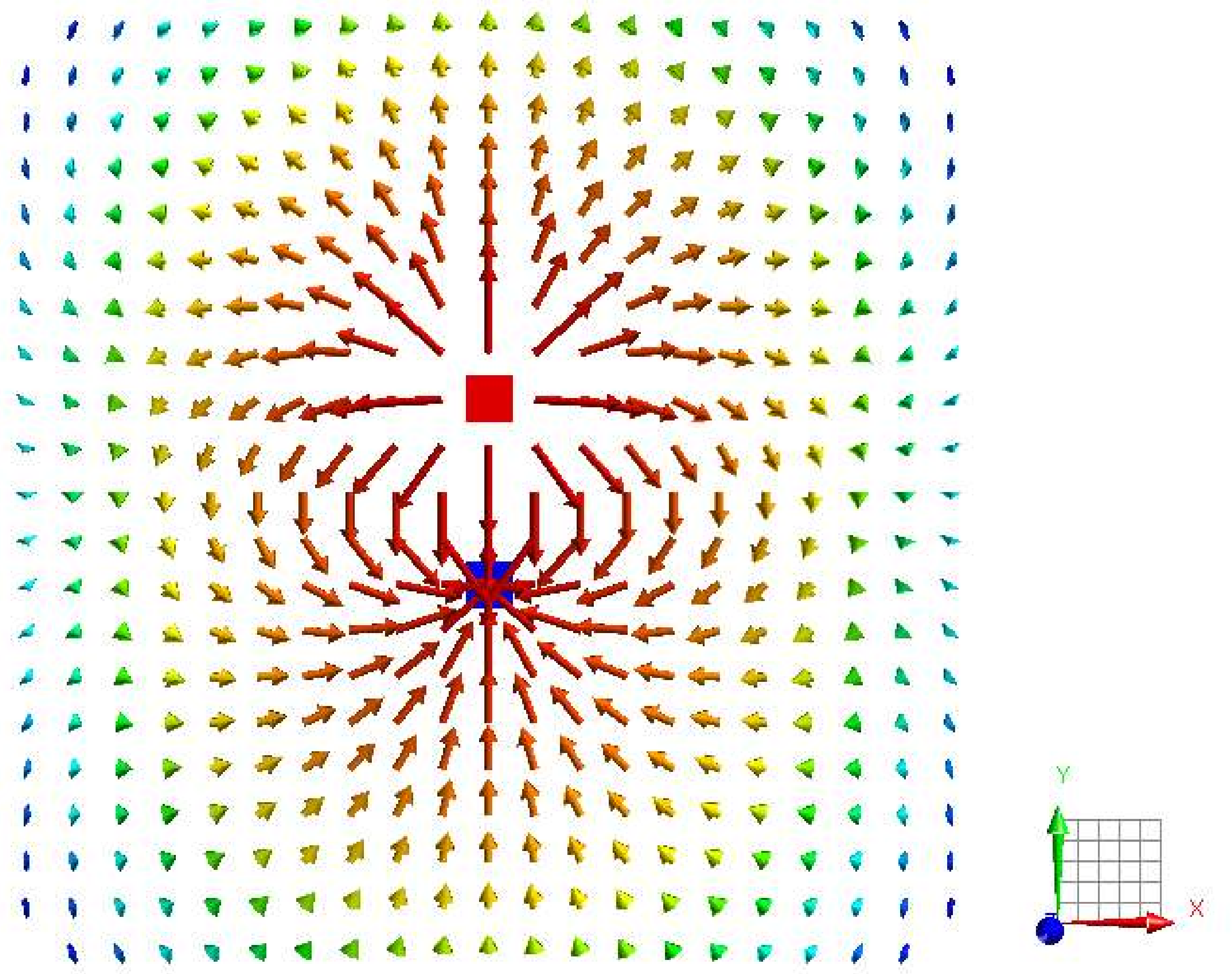
- Surface from 3D Recon sparse point cloud of structure is shown.
- Measured electric fields along the node path.
- The electric fields are directed primarily away from the structure suggesting it is primarily a source and protected.
- The stab measurements also suggest this structure is well protected.



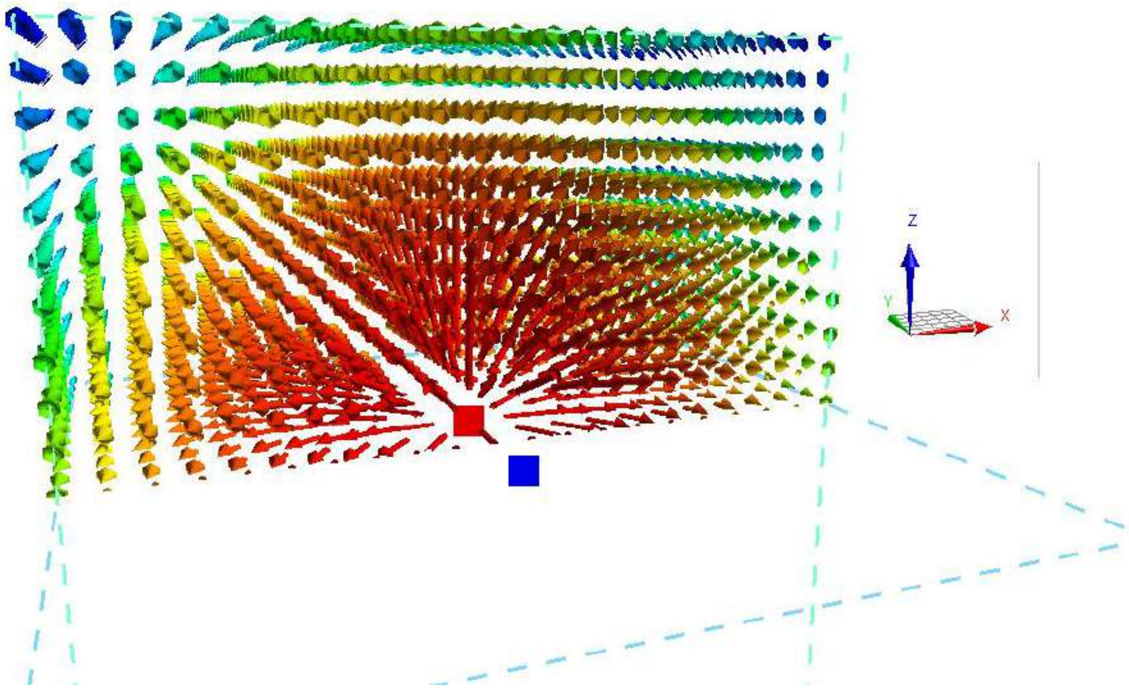
2D Simulated Electric Fields

- Source (red square) 100 mA
- Sink (blue square) -100 mA
- Electric fields are directed away from positive sources and towards negative sources.

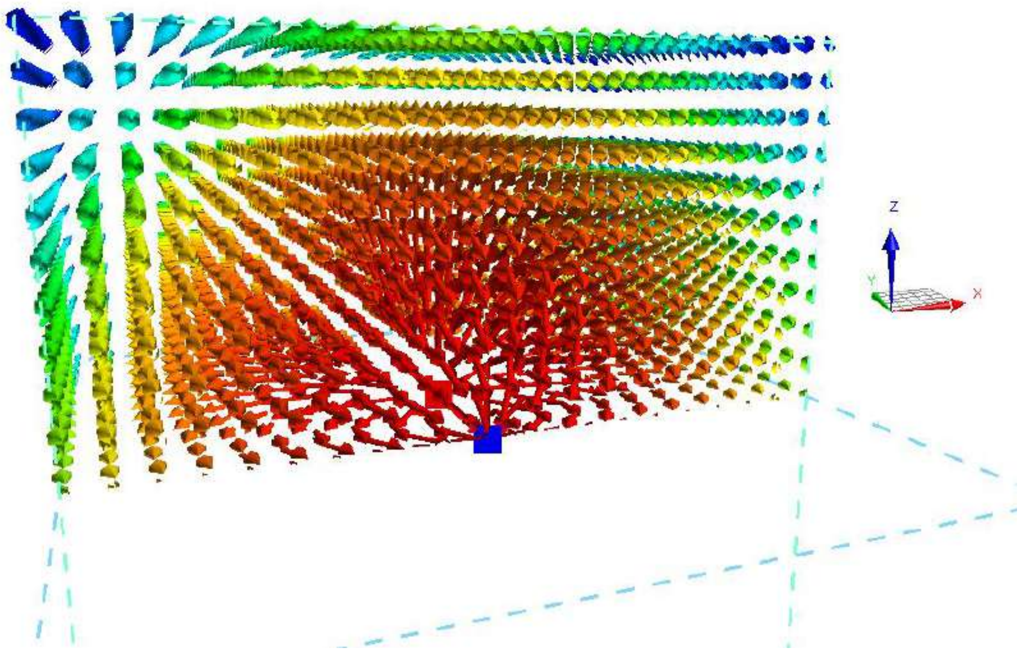


3D Simulated Electric Fields

- Source (red square) 100 mA
- Electric fields are directed away from positive sources

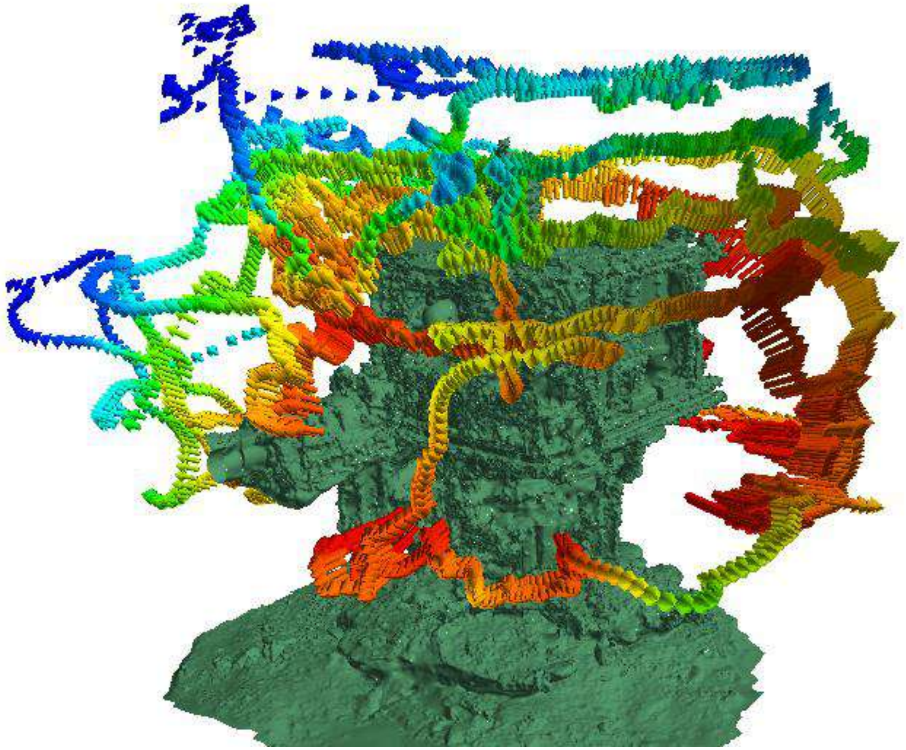


- Sink (blue square) -100 mA
- Electric fields are directed towards negative sources.



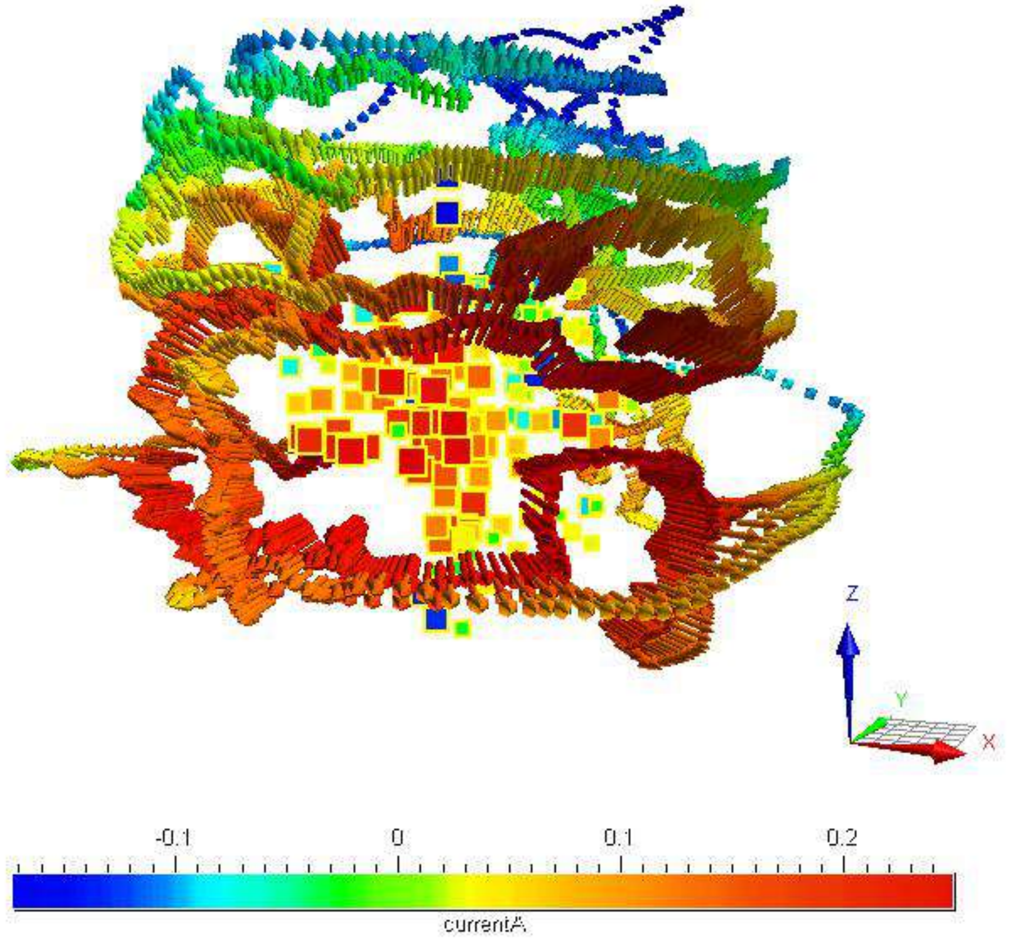
Geodetic Modelling (ENU)

- The modelled geodetic electric fields at the measurement locations.
- Modelled electric fields also oriented out of the structure



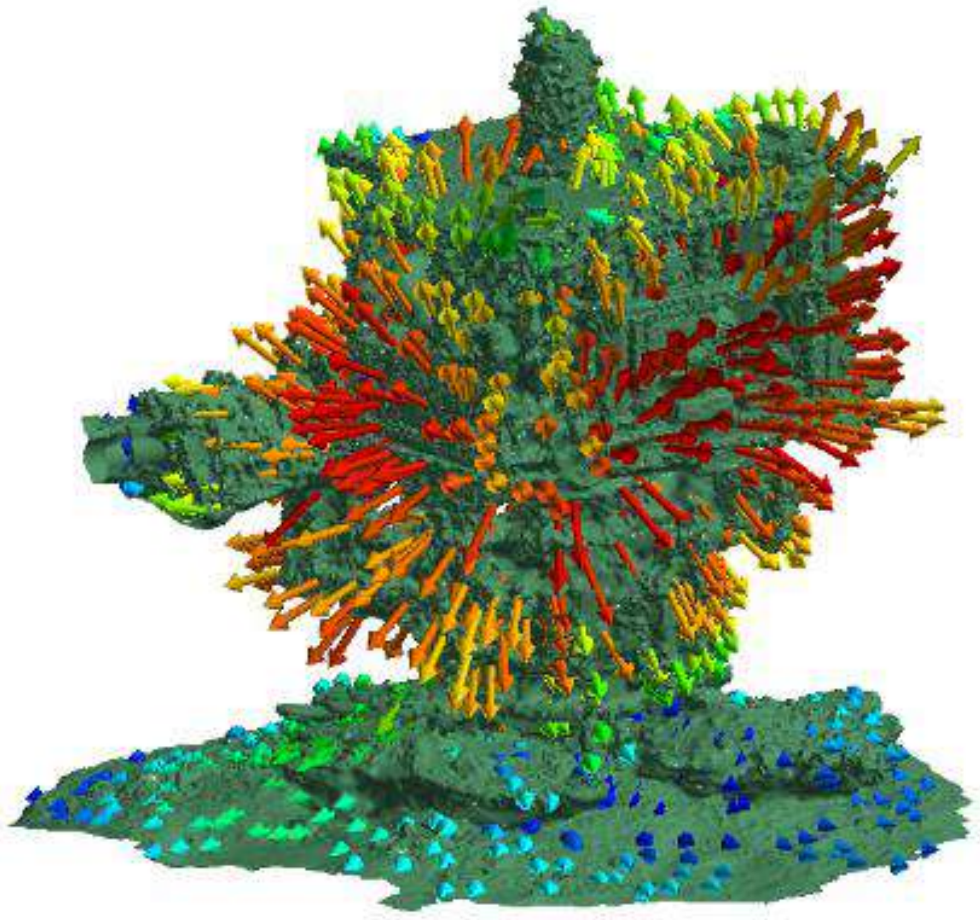
Equivalent Source Modelling

- Point sources are fixed within the 3D Recon surface and the current is allowed to vary.
- The modelled geodetic electric fields are shown at the measurement locations.
- Modelled electric fields are directed away from the predominately positive current sources (red squares) in the model.

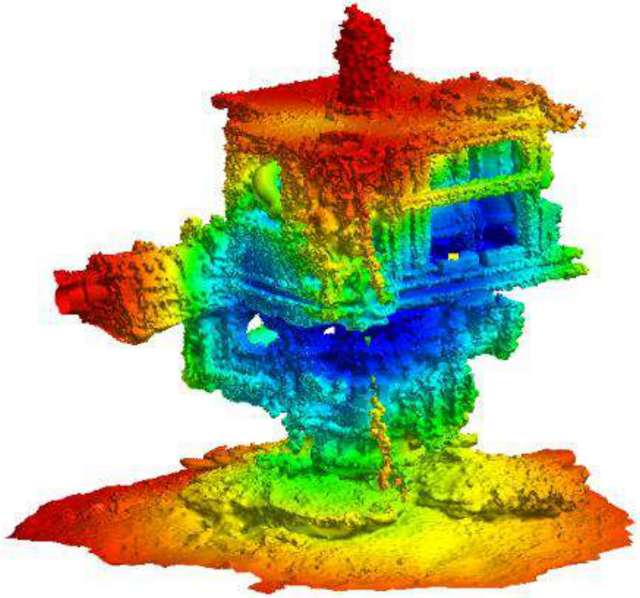


Geodetic Modelling (ENU)

- The modelled geodetic electric fields on the surface.



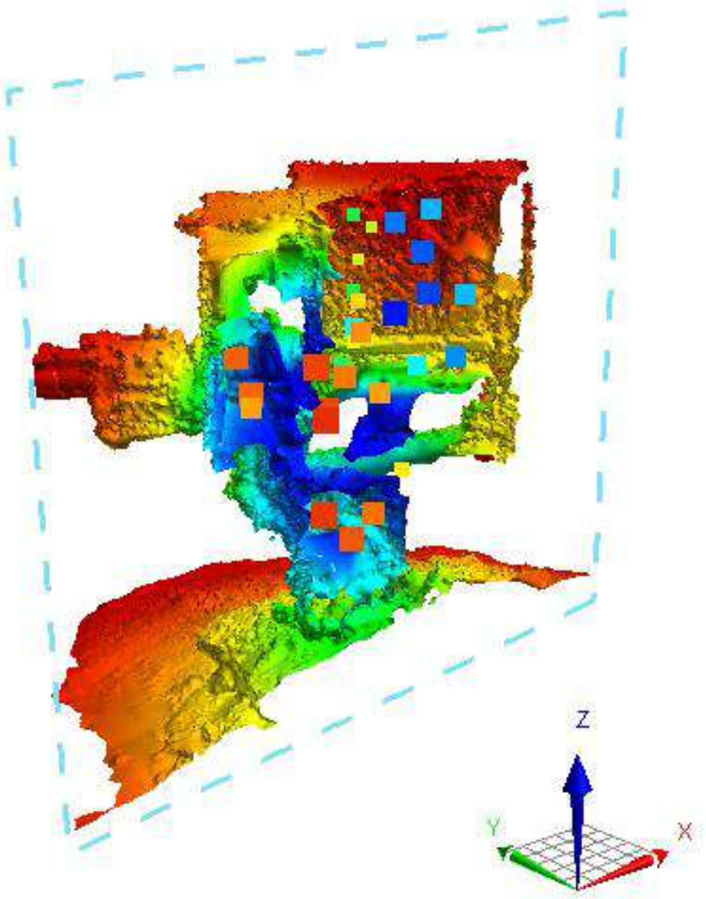
Drape Potential



- The potential estimated on the surface is largely more negative (blue) around positive point sources (red squares) and more positive (red) around negative point sources (blue squares).

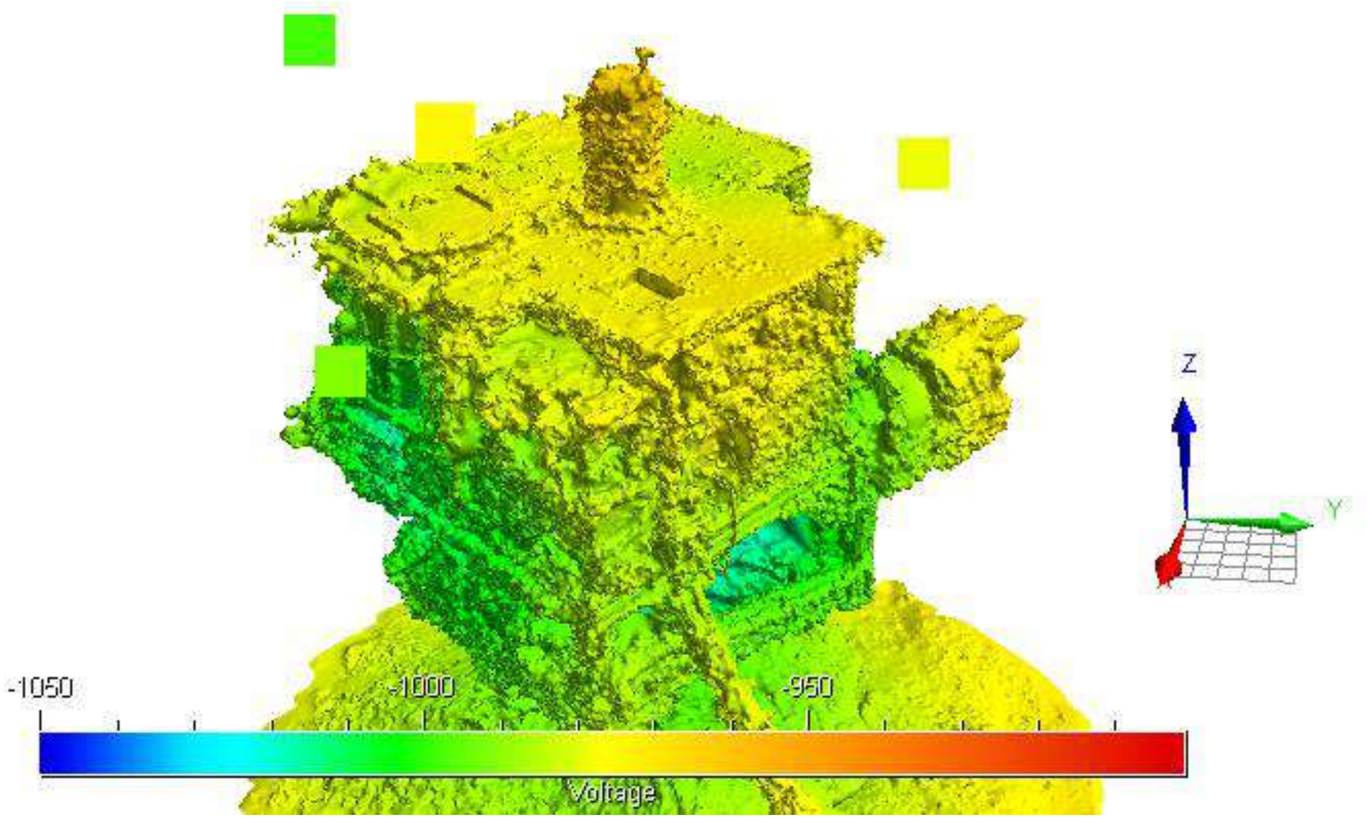
- This matches the expectation that anodes are positive current sources and will draw the potential down to their nominal potential of -1050mV (chemistry dependent).

- Negative current sources are sinks and will have more positive potentials



Biased Potential

- The potential of the top stab is matched to the roof potential drape
- The exact stab locations are not recorded but are approximated using the ROV positions at the time of the measurement from the overlay.

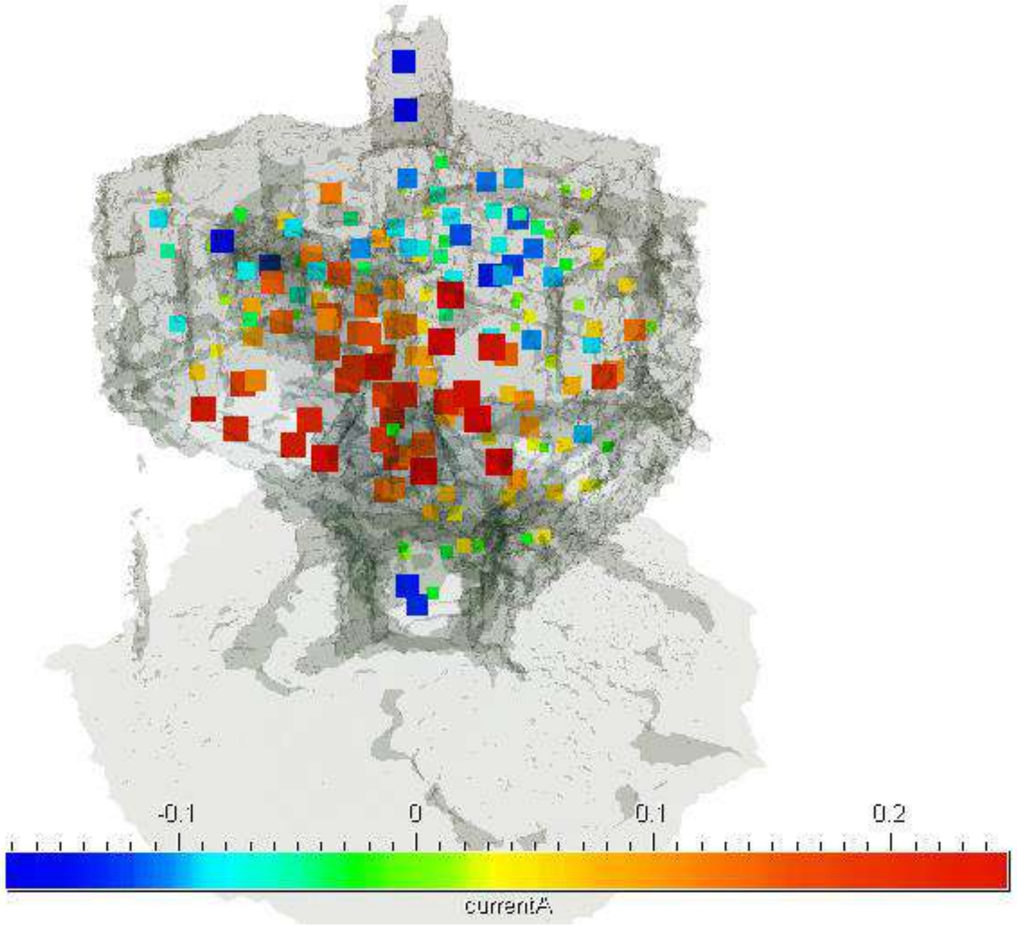


Currents

- Sum of current sources and sinks:
- Sum of sinks: -4.25189885 [A]
- Sum of sources: 11.40915040 [A]
- Total sum: 7.15725155 [A]

- The modelled current sources and sinks act in aggregate to best match the measured electric fields.

- Thus, the total sum is considered to be closest to the actual anode activity on the structure.



Comparison to Stabs

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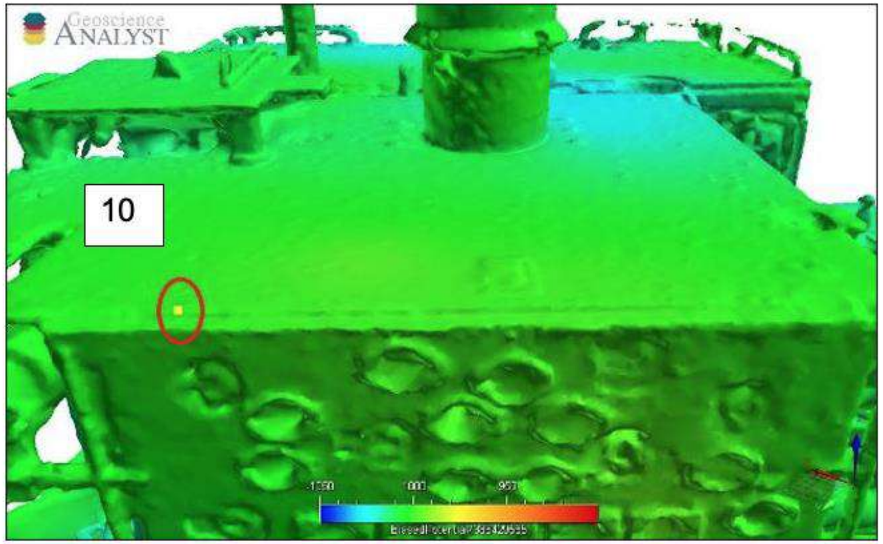
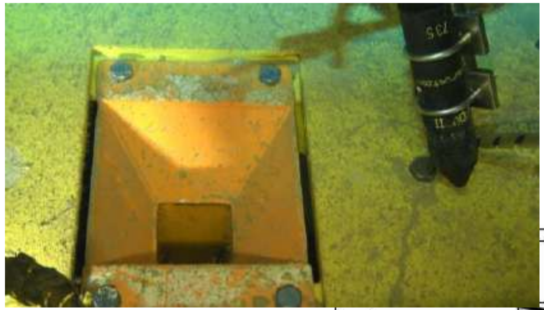
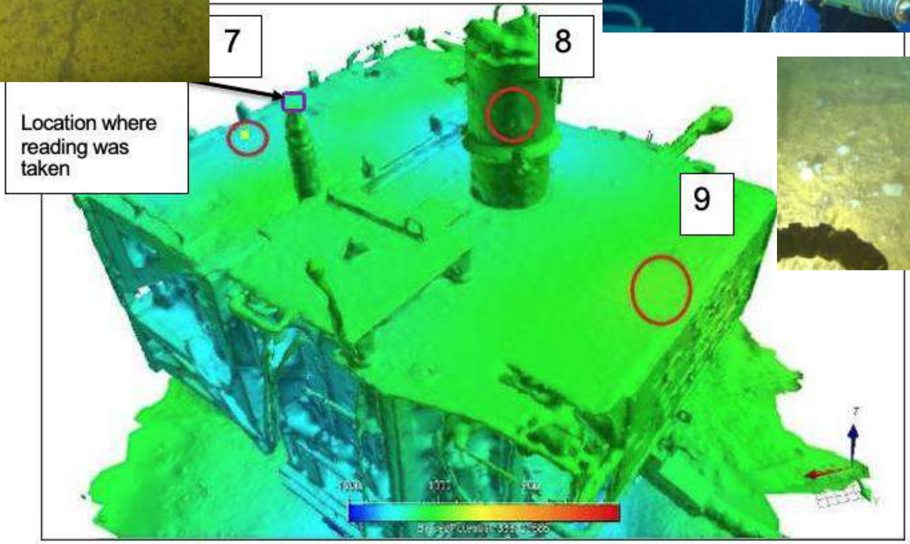
- During a later scope 30 sites were stabbed for comparison to the modelled results, twice at each location
- The model values and the stabs at the same location had a
  - **mean difference of 4.34mV**
  - **standard deviation of 6.78mV**
- This suggests our levelling by the roof stab had some bias remaining due to the mean difference
- A portion of the structures were isolated from the rest which showed elevated differences as this breaks our modelling assumptions

Comparison to Stabs

LOCATION OF TASK	CP READING 1 (mV)	CP READING 2 (mV)	3D Model Biased Potential (mV)	Difference (mV)
Choke roof (7)	-1007	-1007	-1018	-11.00
Tree cap (8)	-1066	-1066	-1007	59.00
Tree roof (9)	-1009	-1009	-1000	9.00

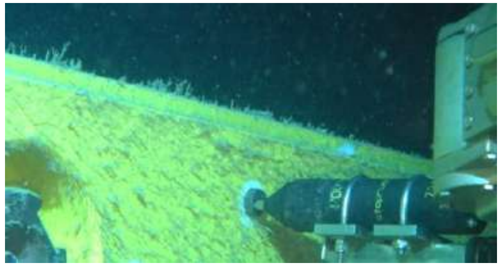


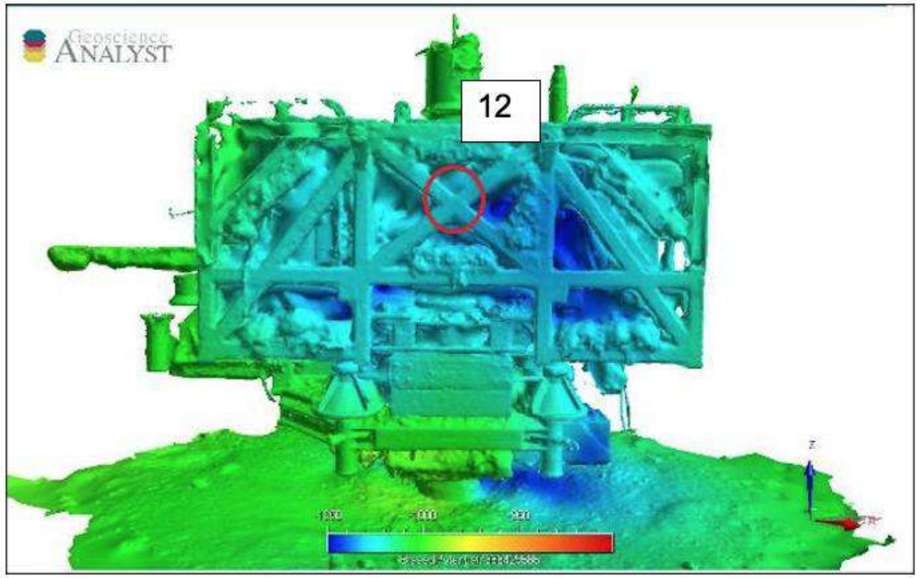


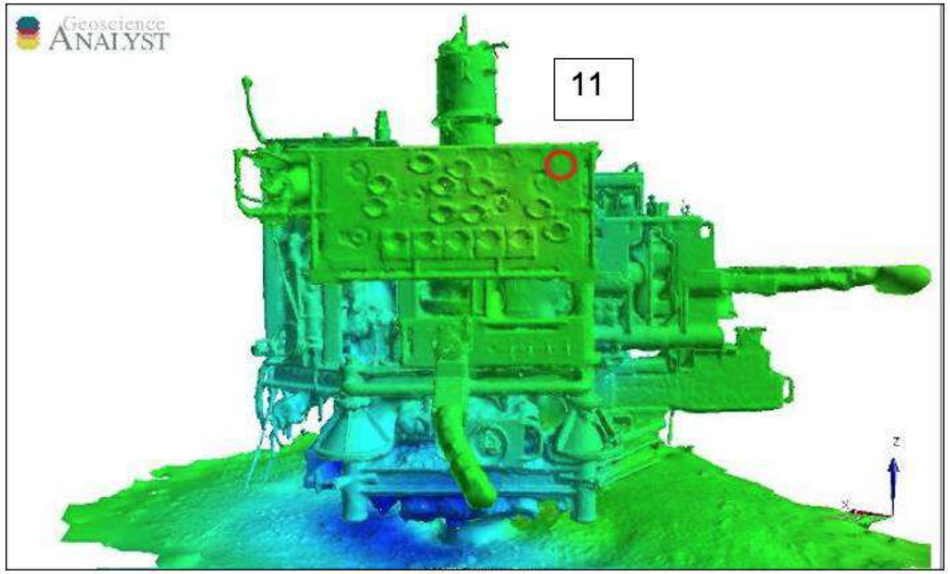


Comparison to Stabs

LOCATION OF TASK	CP READING 1 (mV)	CP READING 2 (mV)	3D Model Biased Potential (mV)	Difference (mV)
Above AWV1 (11)	-1005	-1005	-1001	4.00
Centre X (12)	-1037	-1035	-1030	6.00







Conclusions

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- Fast digital inspection allows for a 3D representation of a structures electric fields.

- Areas of current sink and source can be identified with vector representation of the electric fields.

- 3D photogrammetry allows for the electric potential to be draped onto the structure surface.

Acknowledgements

OFG Ocean Floor Geophysics

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ROV Team, Survey Team, Inspection Team, Captain and Crew

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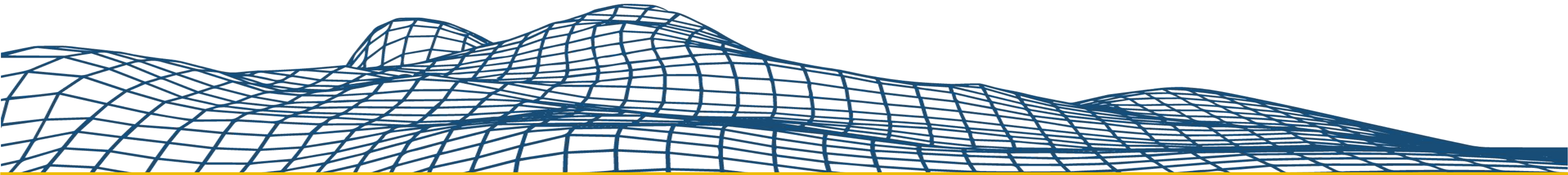
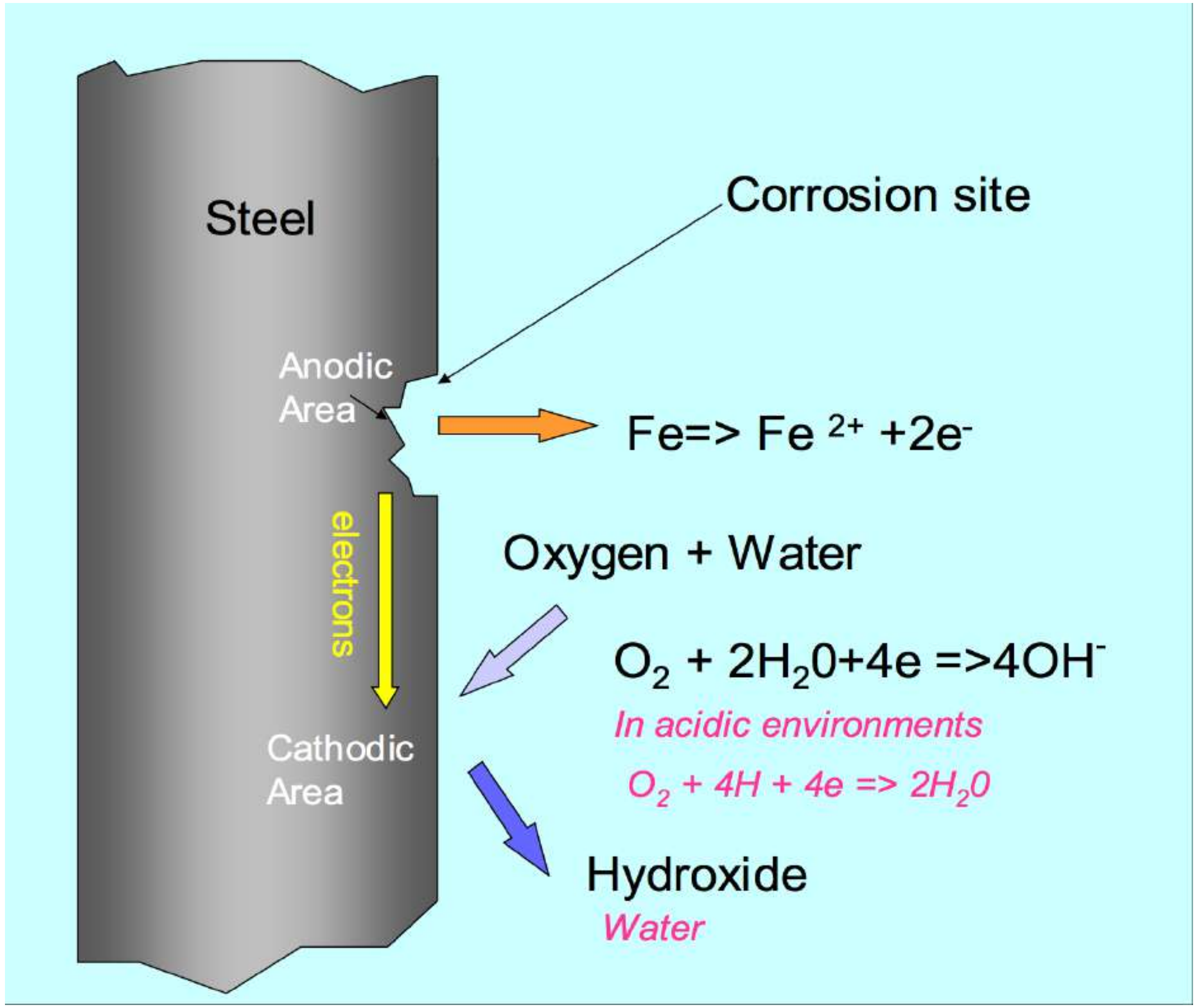


Corrosion

- Site for the reduction reaction to take place (cathode)
- Site of oxidation reaction to take place (anode)
- Electrical path – electrical continuity allows electrons to transfer from the corrosion site
- Ionic path – medium that allows the metallic ions to be transported



From ISES Theoretical Basis for data analysis system methodology and specifications

Cathodic Protection

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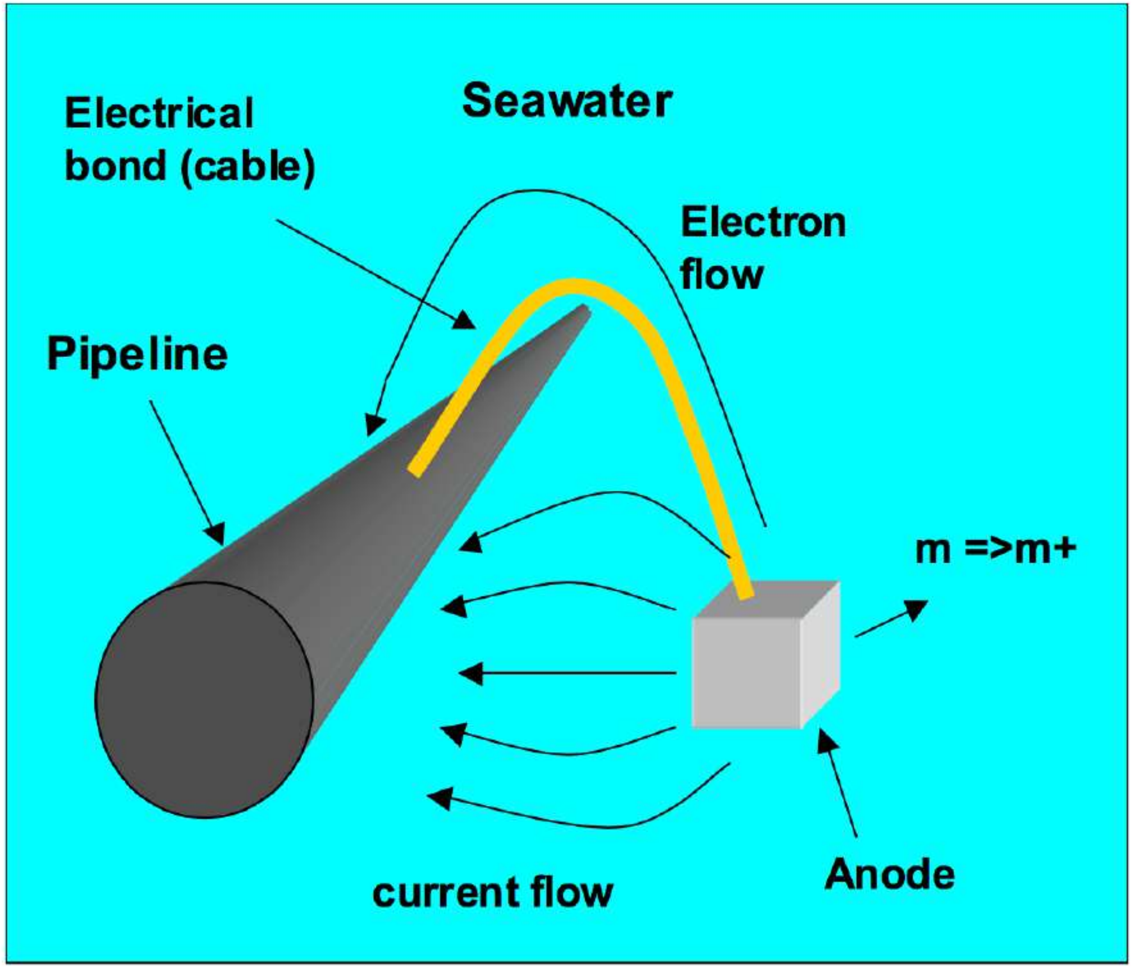
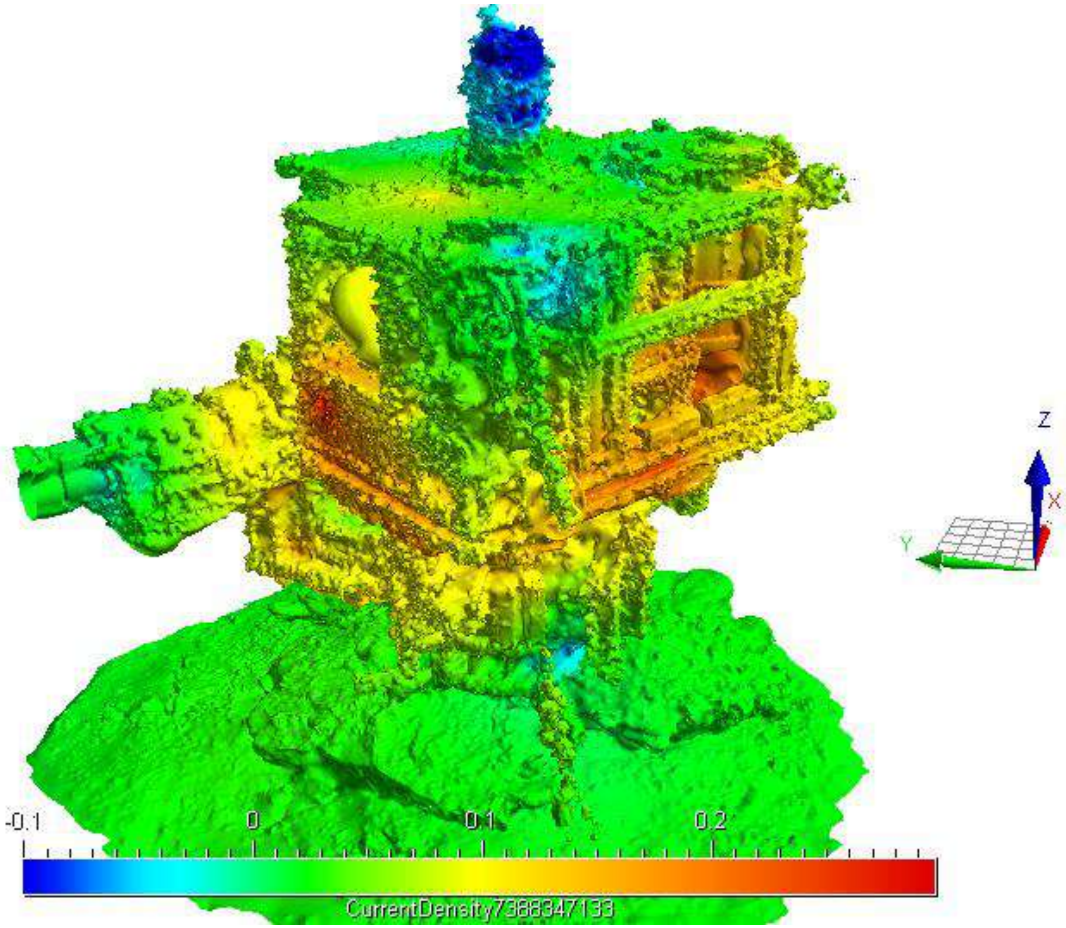
- A technique used to control corrosion of a metal surface by making it a cathode in an electrochemical cell.
- Typically the metal to be protected is connected electrically to a more easily corroded ‘sacrificial metal’ that acts as the anode.
- The sacrificial metal corrodes instead of the metal.



From ISES Theoretical Basis for data analysis system methodology and specifications

Current Density

- Current density is the product of conductivity and electric field.
- The current density can be draped onto the structure’s surface.
- Current is sourced primarily around the midbody (where anodes are located).
- Currents sink into the cap and the well.



Benefits of FDI

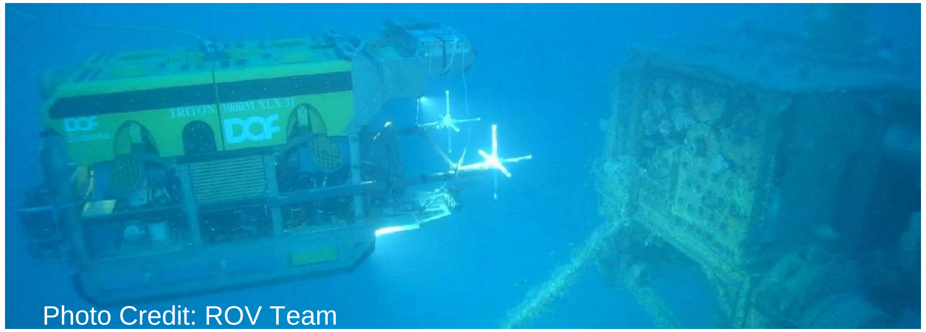
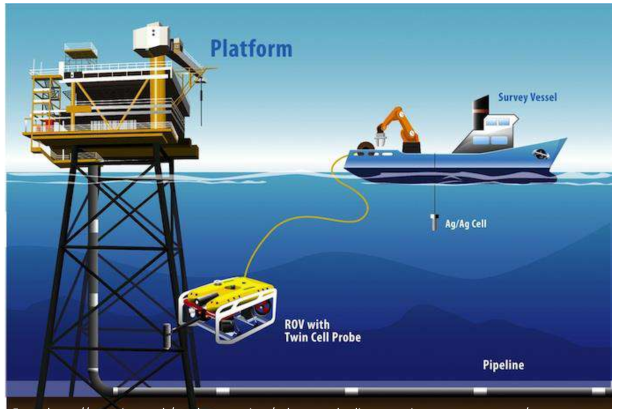


Photo Credit: ROV Team

More data results in more informed decision making



From: https://www.ises.tech/products-services/sub-sea-cathodic-protection-survey-cp-survey/

1. Obtain full 3D electric field reading and the vector components around the structure
2. Obtain Potential on the photogrammetry surface (not just at a single point)
3. Obtain current density on the photogrammetry surface
4. The overall current output of the structure is computed.
5. 3D Recon model allows one to observed the overall structure at once rather than in segmented parts of still photos and videos. Saves time in viewing many videos/photos.
6. CP engineer may view 3D model and potential in same media allowing for both visual inspection and potential field surface comparisons.
7. CP engineer may use 3D model to drill down to the higher resolution images

Drawbacks of FDI

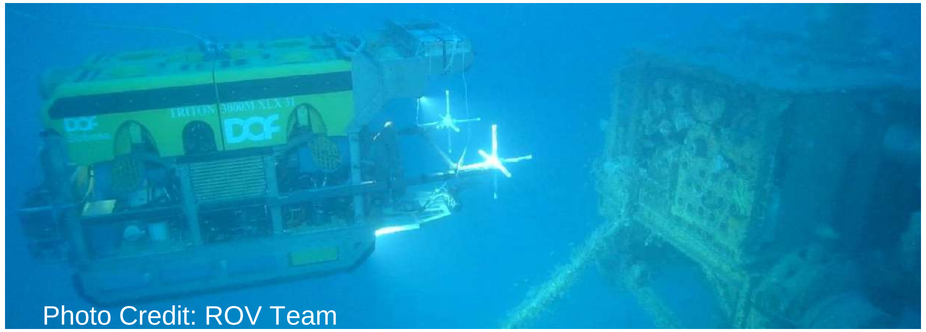
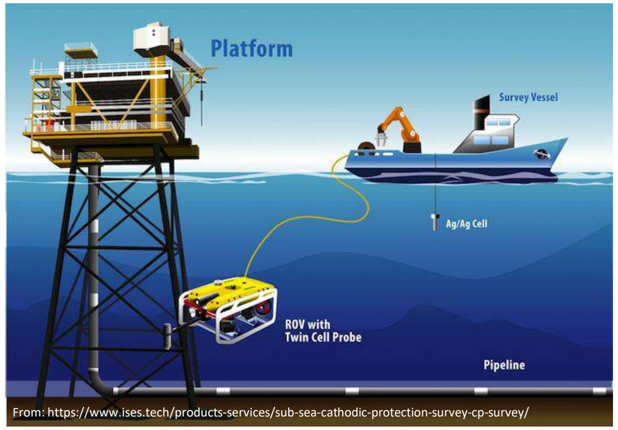


Photo Credit: ROV Team



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1. Relative Potential readings require an anchor point to get to a biased potential reading. Maybe obtained from previous Stabs on the structure.
2. Modelling assumes a whole space and seafloor reflection coefficients.
3. The Surface of the structure (from 3D Recon photogrammetry) and equivalent point sources maybe too close together and create anomalous features.