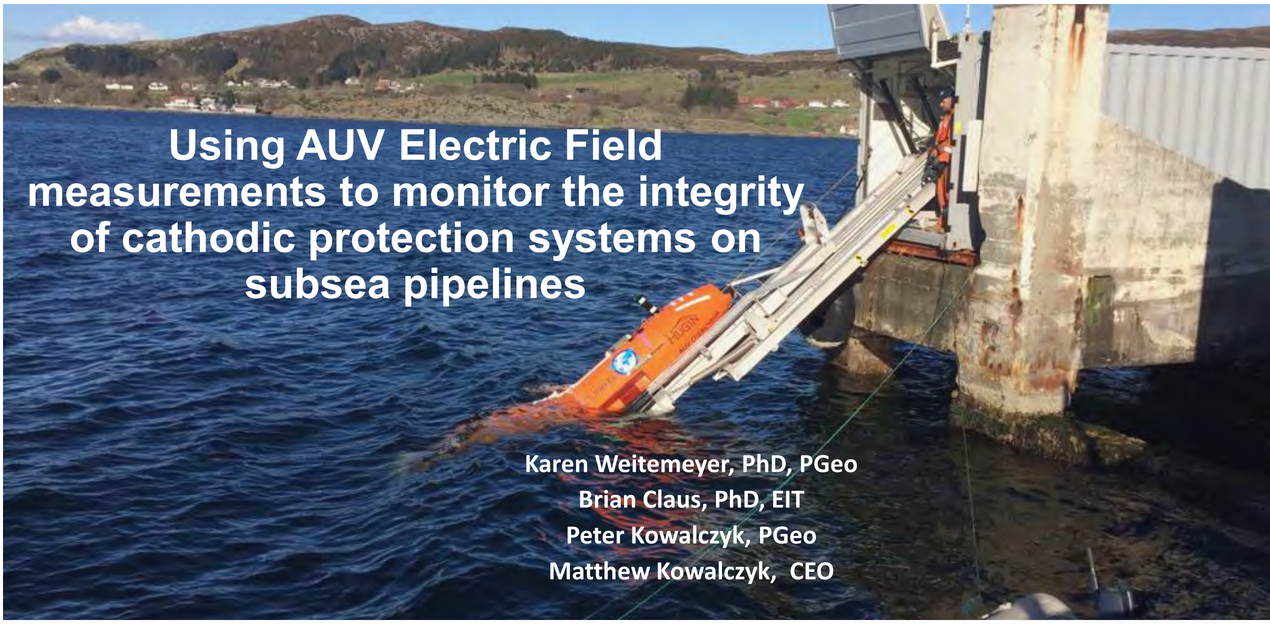

Using AUV Electric Field measurements to monitor the integrity of cathodic protection systems on subsea pipelines

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The BC Geophysical Society 2019 Fall Symposium
Geophysics Applications to Environmental, Civil and Mining Engineering Studies

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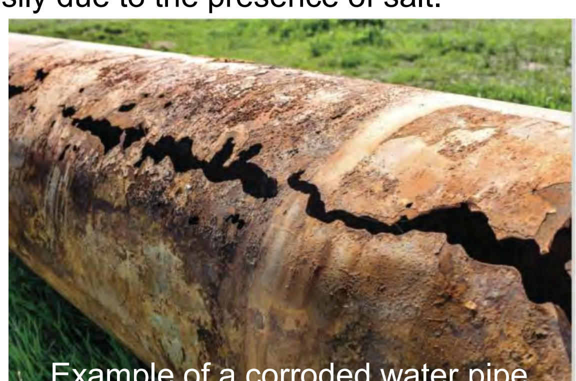
Corrosion

- A natural process that happens when a metal reacts with its environment. In this case rust, an iron oxide, is formed by the redox reaction of iron and oxygen in the presence of water. The iron structure weakens and disintegrates.
- In the presence of salt / seawater the rusting is accelerated because electrons can move more easily due to the presence of salt.

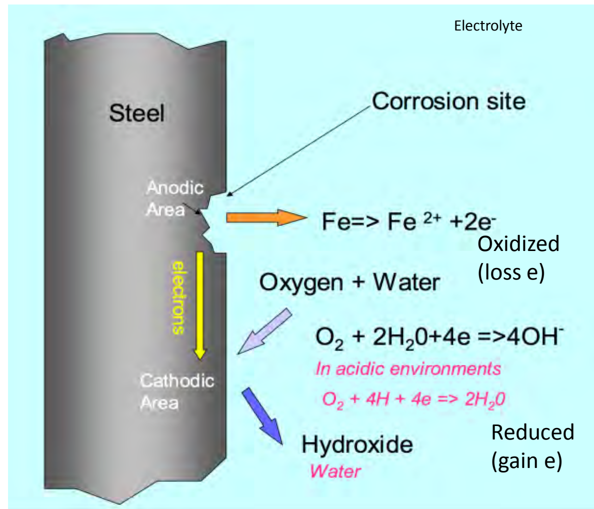


Example of a corroded water pipe

From https://kwikzip.com/using-spacers-to-mitigate-water-pipeline-corrosion/

Corrosion

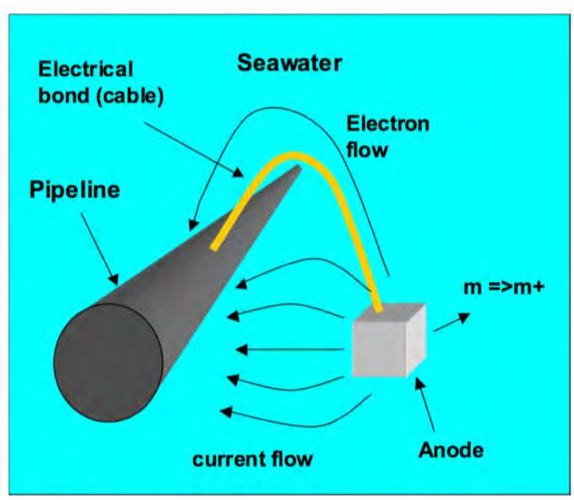
- Site for the reduction reaction to take place (cathode)
- Site of oxidation reaction to take place (anode)
- Electrical path – electrical continuity allows electrons to transfer from the corrosion site
- Ionic path – medium that allows the metallic ions to be transported



From ISES Theoretical Basis for data analysis system methodology and specifications

Cathodic Protection

- 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

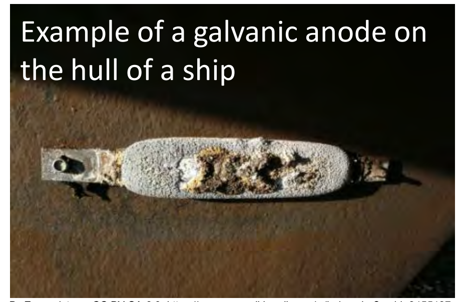
Sacrificial Anode

Zinc, an example of a sacrificial anode, prevents iron metal from "corroding".

Standard Reduction Potentials Table

Half-reaction Oxidant	⇌	Reductant	$E°$ (V)	Ref.
$Zn^{2+} + 2e^-$	⇌	Zn(s)	−0.7618	[7]
$Fe^{2+} + 2e^-$	⇌	Fe(s)	−0.44	[5]

https://en.wikipedia.org/wiki/Standard_electrode_potential_(data_page)



The standard reduction potential of zinc is about -0.76 volts.
The standard reduction potential of iron is about -0.44 volts.

The difference in reduction potential between zinc and iron results in faster zinc oxidization than iron.

https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Exemplars/Corrosion/Sacrificial_Anode

Prevent Corrosion (specific to carbon steel pipelines and sacrificial anodes)

- Subsea pipelines are normally protected from corrosion by an external coating and by cathodic protection using galvanic/ sacrificial anodes.

coating

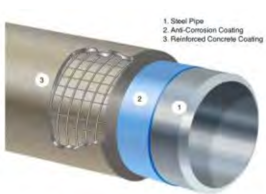


Figure 5: Hevicote™. Source: Bedero Shaw (2008)

From Shittu et al., AJER 2016

Bracelet Anodes

https://stoprust.com/products-and-services/bracelet-anodes/

- The specific design is dependent on the environment that the pipeline is located, subject to the temperature, salinity, water depth (in wave zone or deep water), other biologic, chemical (anaerobic), and physical factors etc…

Why do Cathodic Protection Inspection?

Check the CP system's operational integrity

Detect any corrosion problems and to adjust/retrofit before any major failure

Confirm integrity of the structure/pipeline & CP system

Collect data to reduce future inspection requirements

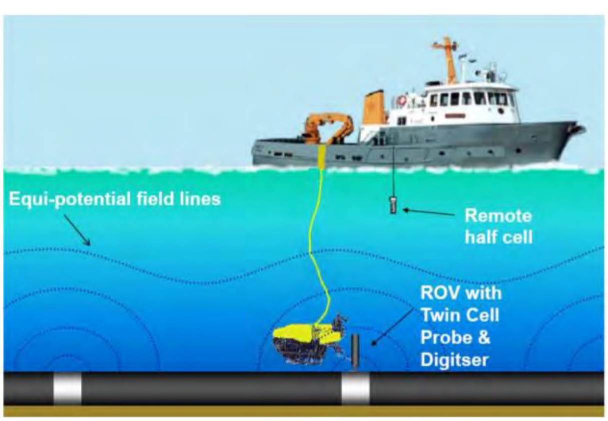
Adherence to Regulatory Authority Requirements

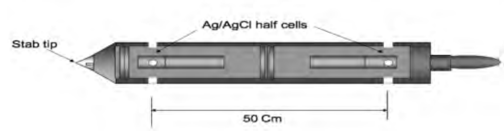
- Government Regulations
- DNV-RP-B401 *CATHODIC PROTECTION DESIGN JANUARY 2005 latest amendment April 2008*
- NORSOK STANDARD M-503 Edition 3, May 2007 *Cathodic protection*
- ISO 15589-2:2004 *Petroleum and natural gas industries -Cathodic protection of pipeline transportation systems – Part 2: Offshore pipelines**
- NAMAS ; *National Accreditation of Measurement and Sampling* (or Equivalent)

From ISES Theoretical Basis for data analysis system methodology and specifications

Twin cell Contact Probe and Electric Field (FG) Survey

- Typical Method used to inspect the CP system of a marine pipeline
- Typically surveyed with ROV for visual assessment and stabs



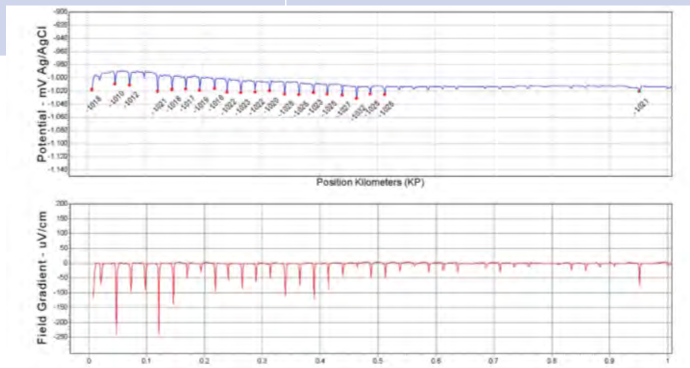


Example of twin half cell contact probe.

From ISES Theoretical Basis for data analysis system methodology and specifications

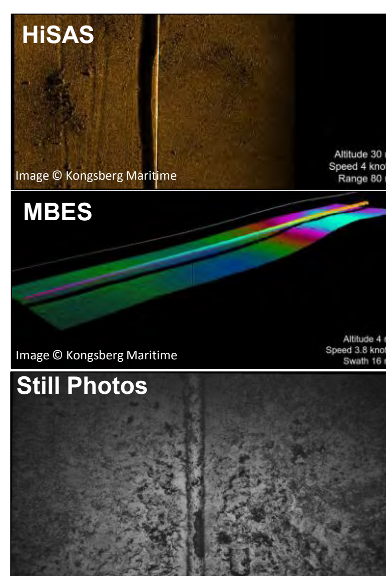
Motivation for the development of the OFG iCP inspection system

SYSTEM	MEASURES	CALCULATES	LIMITATIONS
ROV MOUNTED (TWIN CELL CP/FG SYSTEM)	• Contact Potential (CP) units: mV • Continuous CP/FG v KP. Industry terminology: Field Gradient (FG) Units: microvolts/cm • Sensitivity 1mV & 1µV/cm	• Anode current (mA} • Areas of current drain • Estimation of anode remaining life	• Slow survey speed ~0.5 knots • Regular calibrations contacts required • Probe orientation and distance can limit accuracy • Limited application on buried pipelines

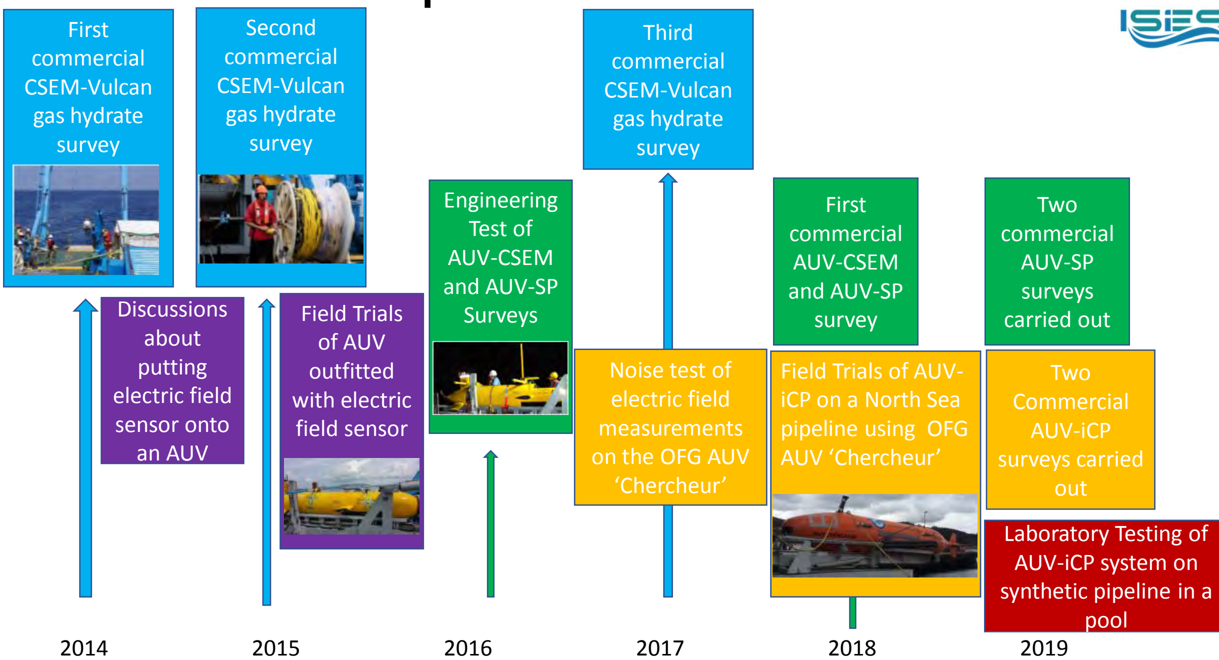


The AUV-iCP System Development

- Developed and deployed system on an AUV for mineral exploration
- OFG's AUV *Chercheur*, a 3000m HUGIN 1000,
  - Can perform pipe inspection and tracking using MBES, HiSAS, magnetometer (SCM), and photos
- Combine pipe tracking on *Chercheur* with **iCP** system

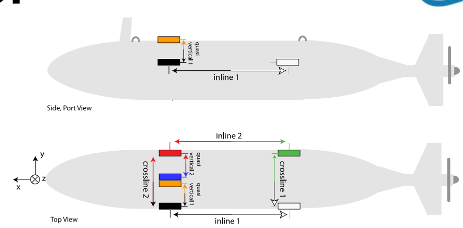


The AUV-iCP Development Time Line



Main components of AUV iCP

Autonomous Underwater Vehicle (AUV) fitted with



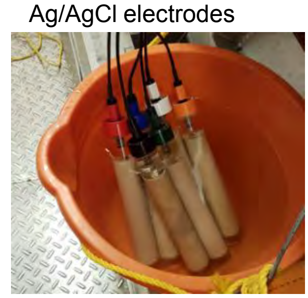
SCM – Self Compensating Magnetometer

3 channel magnetometer (X, Y ,Z)
19 Hz sample rate

iCP DAQ– integrated cathodic protection data acquisition unit

6 channel electric field sensor (redundant X, Y ,Z)
100 Hz sample rate

Ag/AgCl electrodes

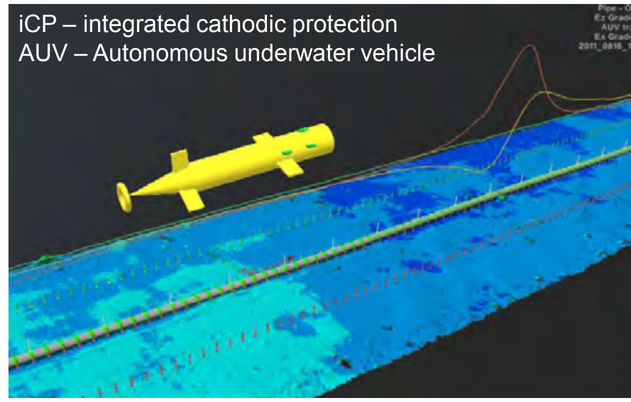


6 low impendence Ag/AgCl electrodes

The AUV-iCP System

iCP uses AUV pipe tracking combined with E-Field system concurrently to accurately locate E-field measurements relative to pipe.

- High speed (~3-4 knots)
- High sensitivity (~0.01uV/cm)
- Accurate positioning relative to the pipe
- Measurement of fields for buried and rock dumped pipe



The AUV-iCP System Inputs/Outputs

Precision Navigation
Real-time accuracy of ~2m with HiPAP USBL system

Pipe Tracking
Real-time tracking of pipe using HiSAS/MBES provides ~cm level positioning relative to pipe

Electric Field
Gradient measurements in 3-axes

Magnetic Field
Measurements in 3-axes

Seawater Conductivity

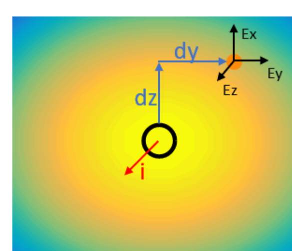
X/Y/Z

dx/dy/dz

Ex/Ey/Ez

Bx/By/Bz

Cathodic Current Estimation i
By combining these systems the currents flowing through the pipe can be estimated



AUV iCP Trials over a North Sea Pipeline

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ISES

OFG, ISES and DOF subsea conducted field trials of AUV iCP on an operational pipeline installed in the North Sea in 2018

AUV-iCP Electric Fields (FG) were measured on multiple survey runs in opposite directions.

ROV CP "stab" and FG survey performed as a reference survey

AUV Flown at altitude of 5m above pipeline at 3.3 knots (~6km/hr)

iCP data was collected with all usual AUV payloads running, to confirm no interference with MBES, HISAS, Camera, acoustic comms, USBL, magnetometer, DVL, FLS

OFG AUV iCP tests results over North Sea

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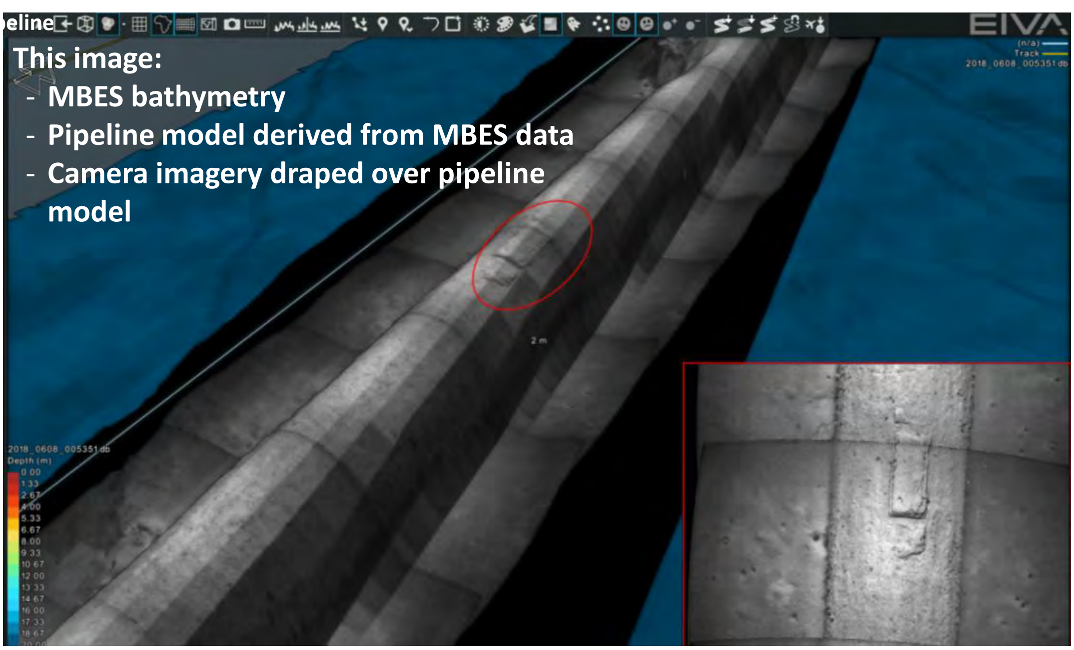
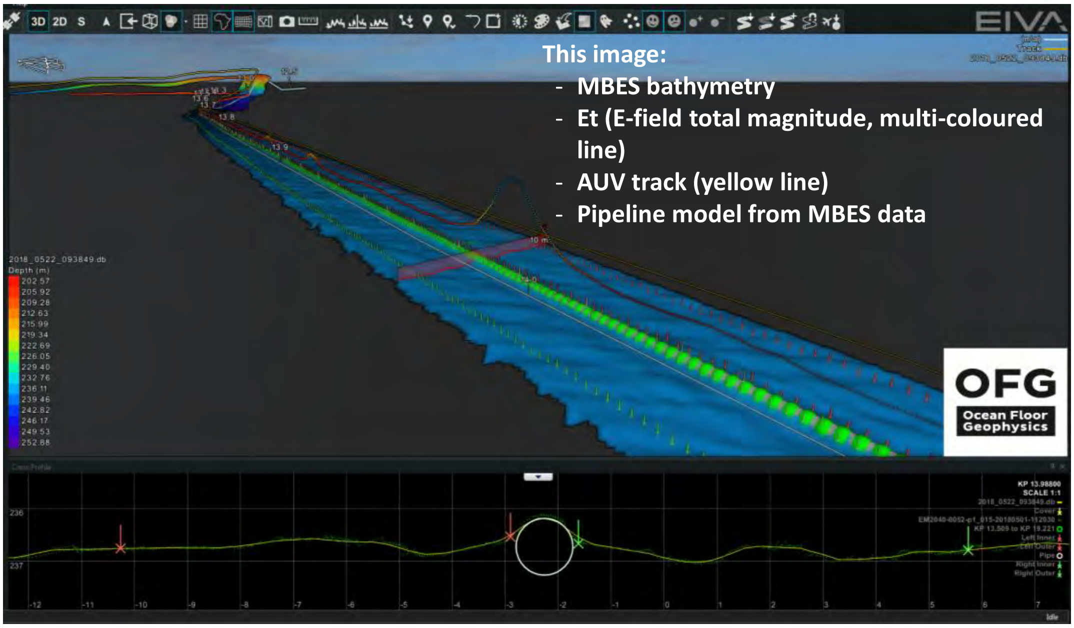
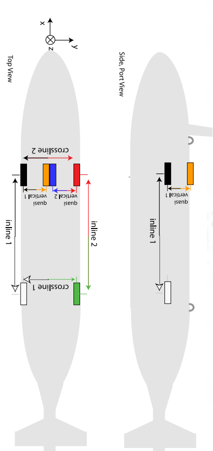
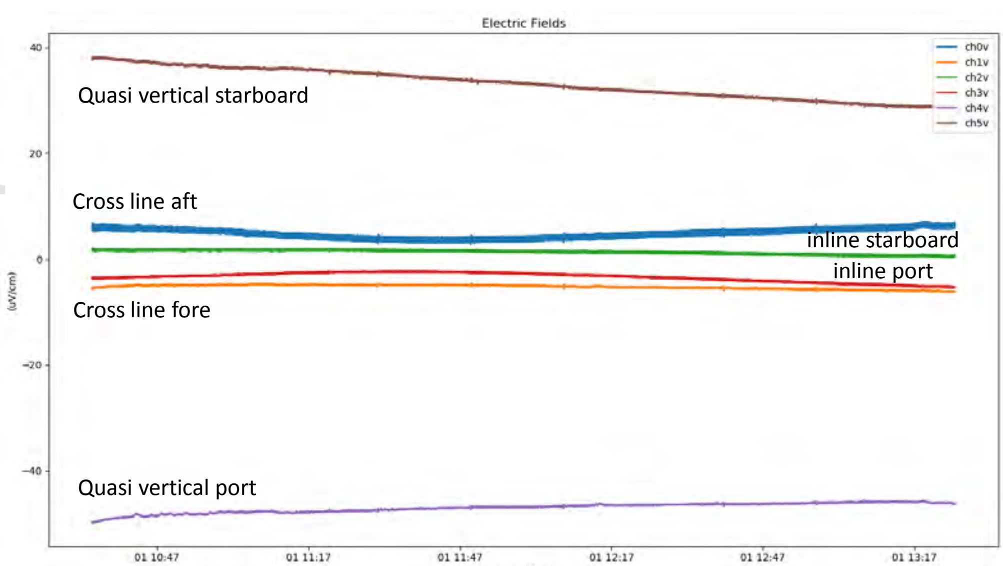


OFG AUV iCP tests results over North Sea pipeline

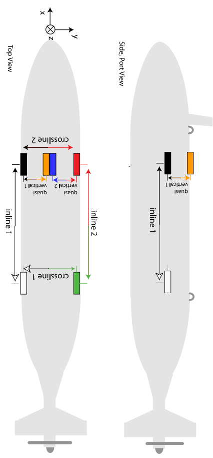


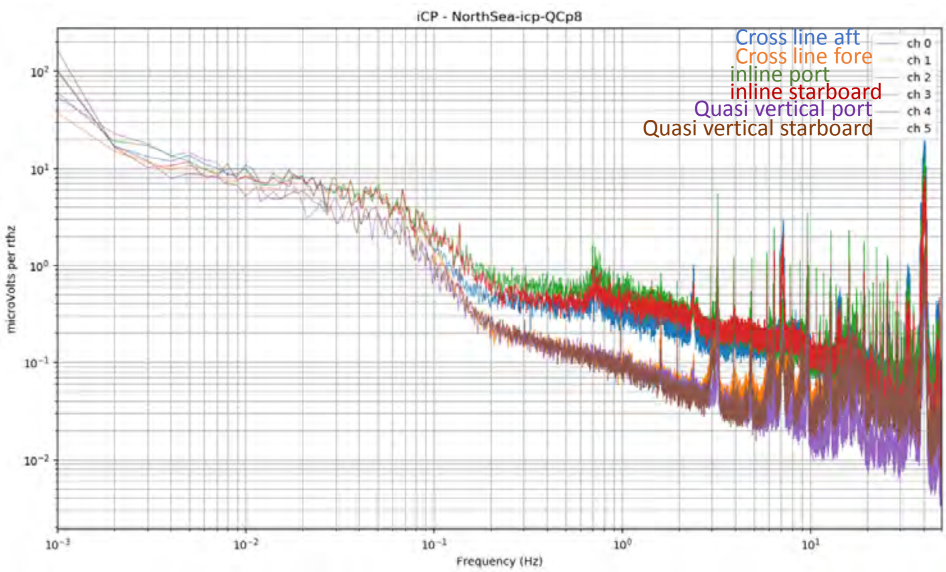
Time Series





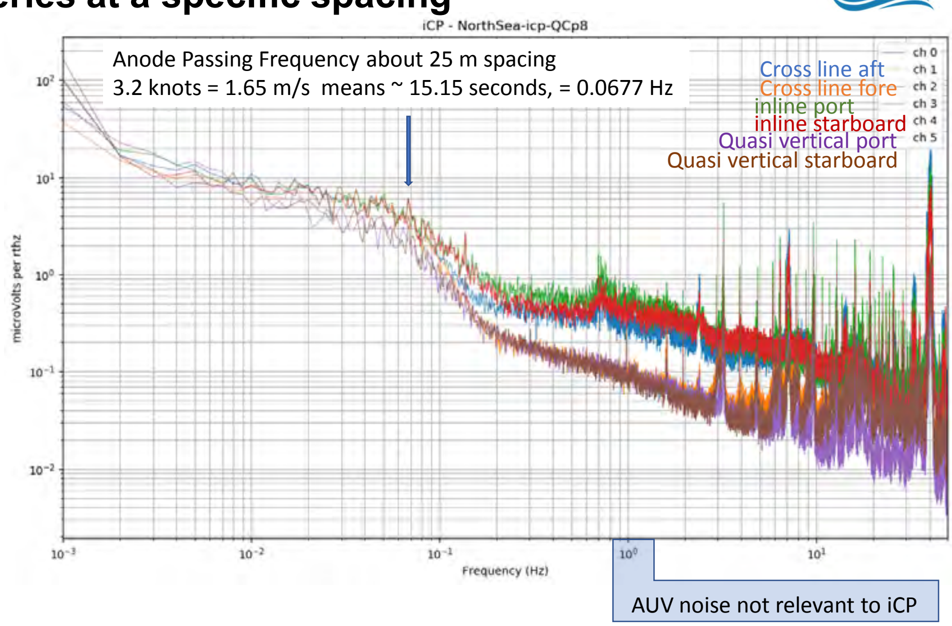
Spectra





Spectra – can predict anode spacing with a long enough time series at a specific spacing

Frequency (Hz)	Anode Spacing (m)
0.0165	100
0.033	50
0.066	**25**
0.1320	12.5



Example of Filtered Time Series Ey

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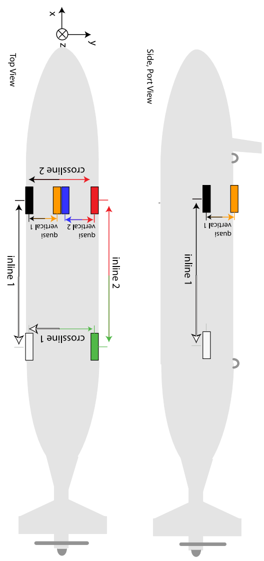

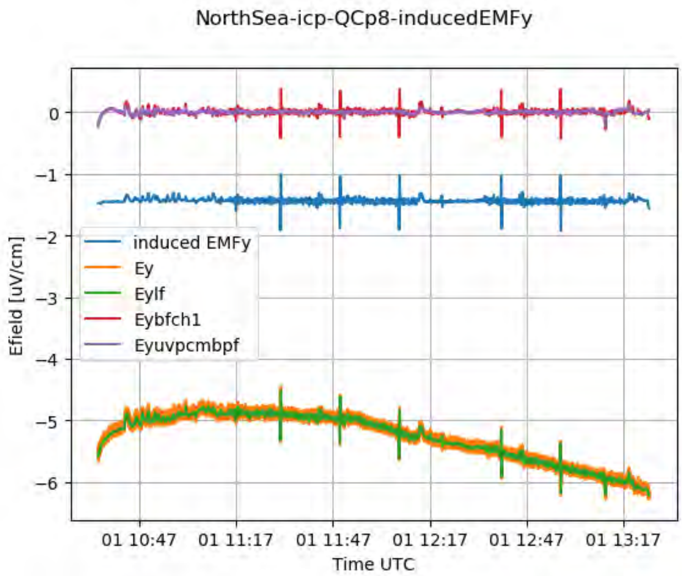

Plotted against pipe KP

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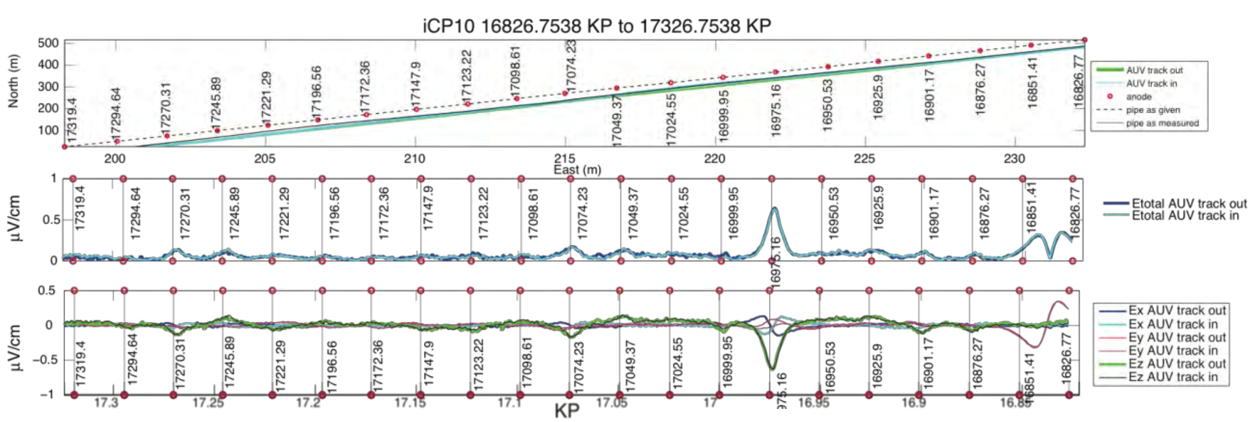
Example of a ~ 500 m section of pipe



AUV Repeatability

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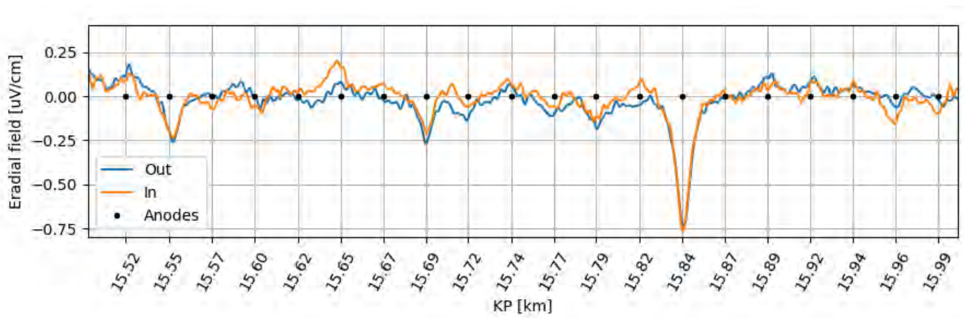
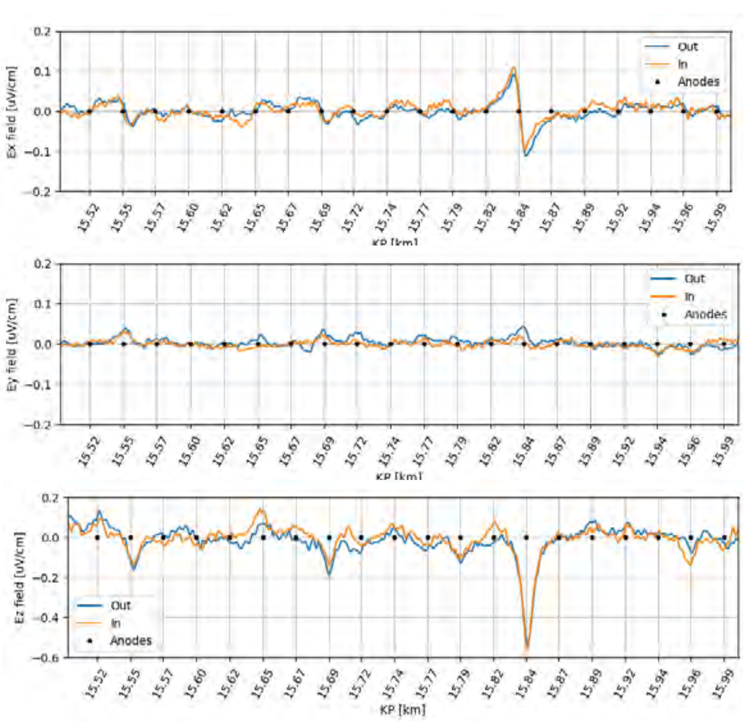
- **OFG AUV iCP Accuracy ~ 0.01 µV/cm**
- Standard ROV twin cell CP/FG system +- 1 µV/cm
- Rotating sensor +- 0.1 µV/cm (as per publicly available information)



Measured data showing 2 survey runs in opposite directions along the pipeline



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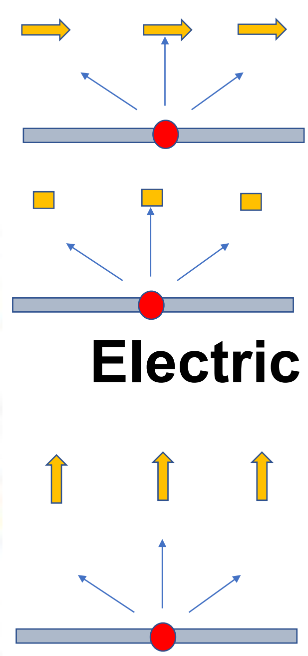


Electric Fields

Compute Anode Current

-**OFG AUV iCP** → Calculate anode currents → compute mass and energy remaining and **predict anode end-of-life much earlier**

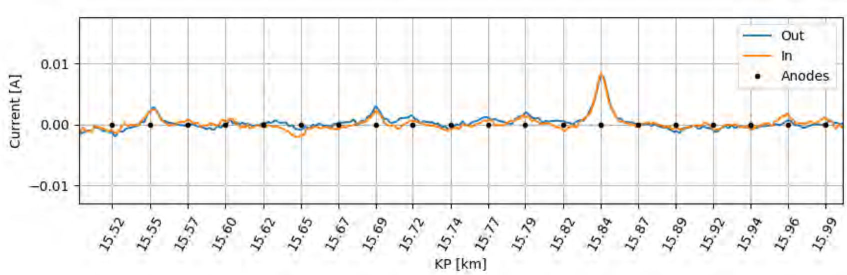
$$i = -4\pi r^2 \sigma E_{iCP}$$

E_{iCP} iCP Electric Field

r Distance between AUV and pipe

σ Conductivity of seawater

i current

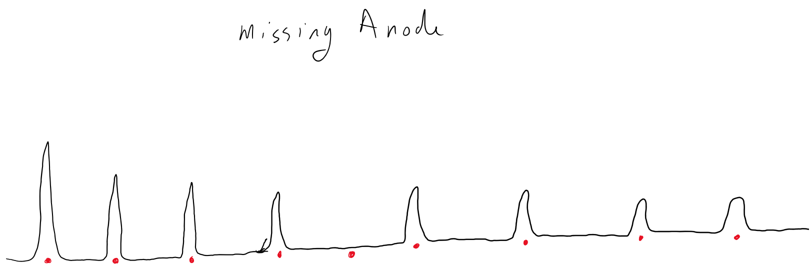


Can also compute anode wastage, and potential – not discussed here

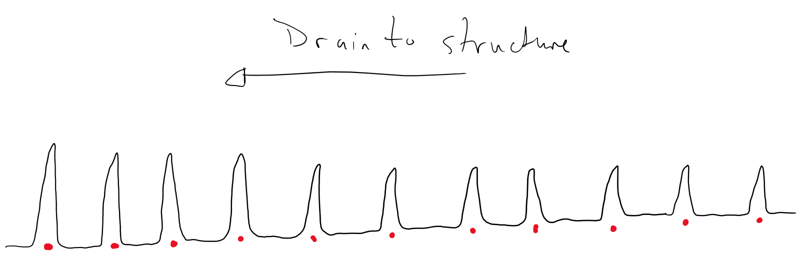
Sketches of Different AUV-iCP Observations

- Based on commercial survey in spring 2019
- Observe missing anodes
- Current drain to structures
- Short pipe response
- Missing anode
- Well protected long pipe

Missing anode

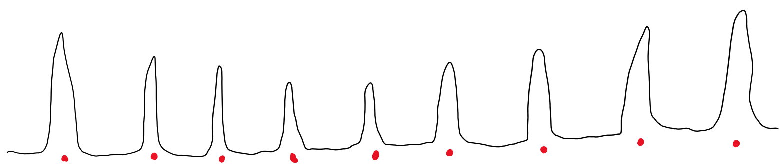


Current drain to structure



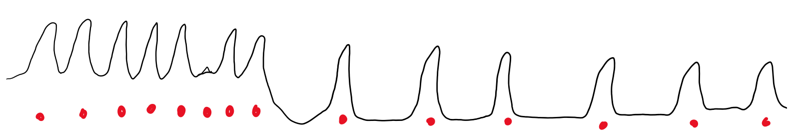
Typical short pipe response

Typical short pipe response with everything nominal

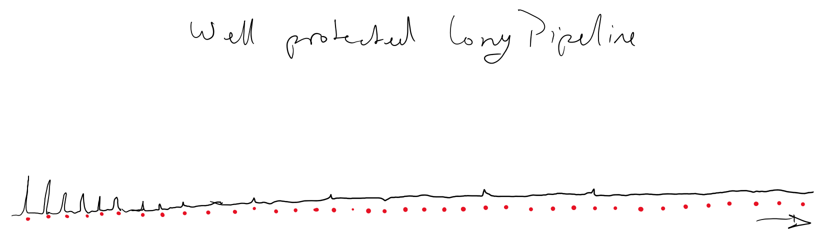


Missing Anode, close together

Missing Anode, close together



Well protected long pipeline



Low electric field strength, low anode output current

OFG AUV iCP Usage Scenarios in a Pipeline Integrity Management Strategy

Scenario One **- Maintenance CP survey**

To **determine** if the pipeline cathodic protection system is performing as designed in terms of **protection levels** and **anode performance** and **anode life**.

Scenario Two **- Intervention CP survey**

The iCP system can be used to undertake a **rapid assessment** of the condition of the pipeline **after the event** has occurred to provide accurate information

Scenario Three **- Post lay baseline/tie-in CP survey**

The **OFG AUV iCP** system can be used to undertake ***high speed visual*** and **field gradient** measurements.

Conclusions

The passive, **non-contact OFG AUV iCP** system allows **fast, accurate CP surveys** to be conducted:

1. **Real-time pipe tracking and inspection** using MBES, HISAS, magnetometer and photos.
2. **Accurately detect and quantify Field Gradient (FG)** along a pipeline route **at significantly higher speeds than an ROV survey.**
3. **Detect & quantify pipeline electrical fields to an unprecedented level** (variations of ~0.01µV/cm) from which currents (anodes and also damaged areas) can be calculated.
4. Signal accuracy was not reduced by either vertical or horizontal standoff distances between the AUV and the pipeline.
5. **Gather multiple data sets from other sensors simultaneously** without degrading the received signals due to system's operations noise.
6. **The system can add significant value in efficiency and cost savings when used as part of an integrated pipeline inspection management strategy.** Instead of an ROV stab measurement at every anode this can be reduced to a handful of selected key point contacts along the entire pipeline route.