Quantitative Depth of Burial State Monitoring of Offshore Power Cables using the Distributed Temperature Sensing Technique

Dr. Wissem Sfar Zaoui, AP Sensing

Dr. Jonathan Lux, AP Sensing

Dr. Thomas Hamm, AP Sensing

Tony Lucignano, Statnett

Ole Petter Hobberstad, Statnett

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Company Introduction

- Leading distributed optical sensing solution provider (DTS, DAS)
- Over 35 years of optical measurement expertise based on HP/Agilent heritage
- Approved manufacturer by UL, FM, VdS, IECEx, ATEX
- ISO 9001, 14001, 45001, and 27001 certified
- Experienced and certified project managers and engineers, 365 days support, proven training programs

1939

Hewlett-Packard (HP) started as a test and measurement company.

1959

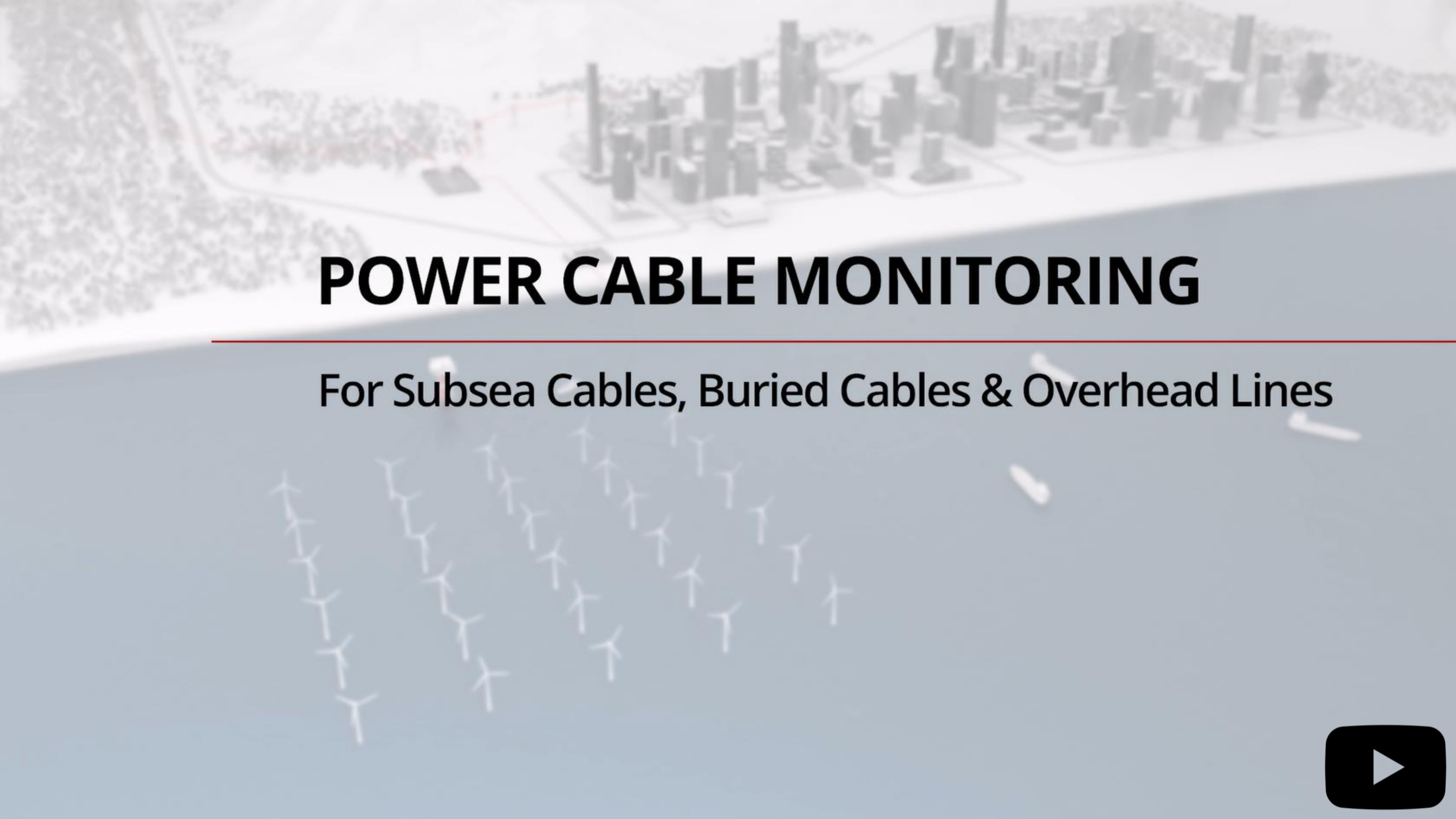
HP establishes its first production site outside of the US in Böblingen, Germany.

1999

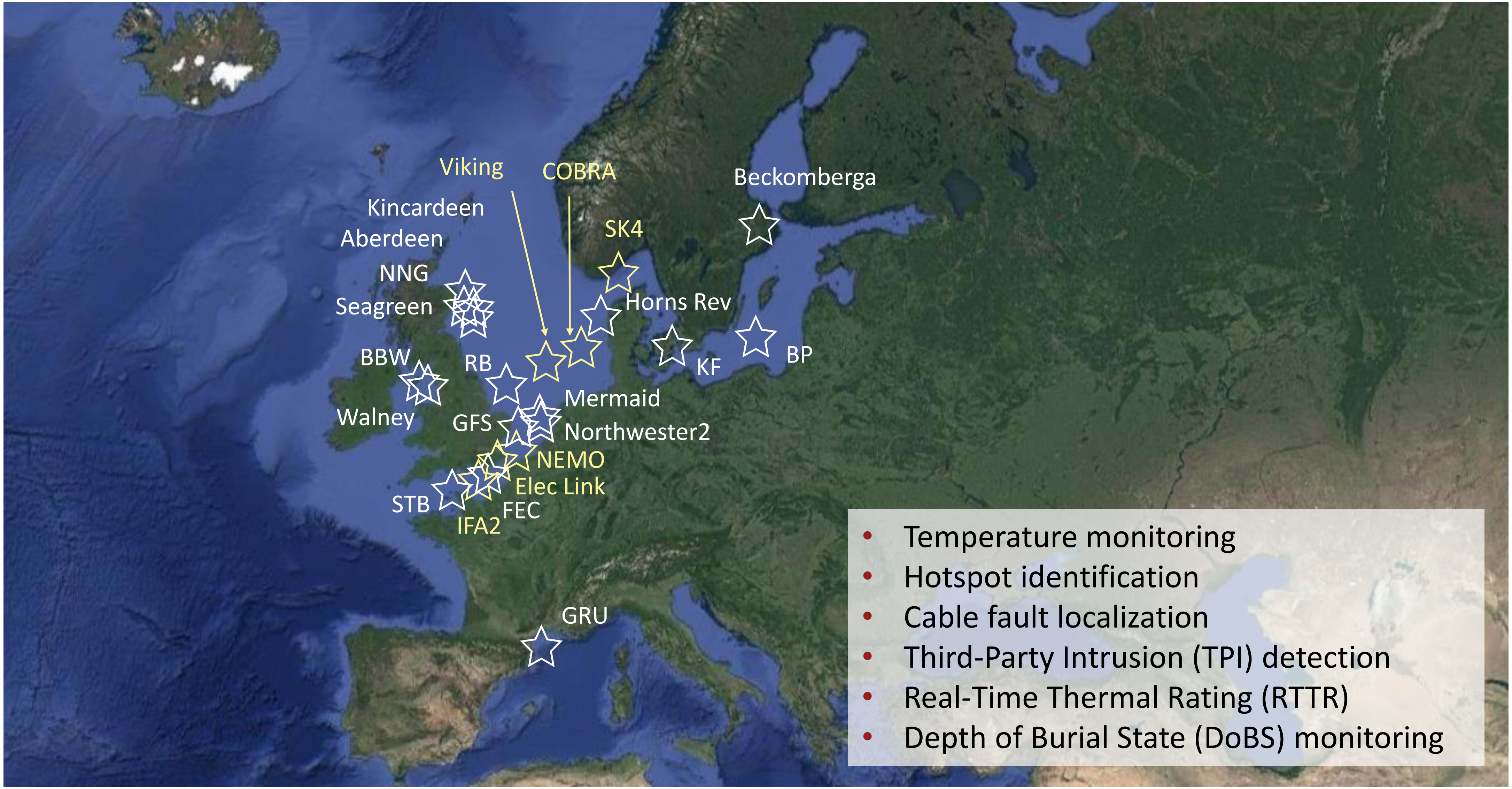
Measurement business from HP is spun off into Agilent Technologies.

2007

Fiber optic sensing business is spun off into AP Sensing.


POWER CABLE MONITORING
For Subsea Cables, Buried Cables & Overhead Lines

Examples of AP Sensing Offshore PCM Projects in Europe



- Temperature monitoring
- Hotspot identification
- Cable fault localization
- Third-Party Intrusion (TPI) detection
- Real-Time Thermal Rating (RTTR)
- Depth of Burial State (DoBS) monitoring

Risks of Offshore Power Cable Exposure

- There are policies in some countries that regulate the burial depth of power cable systems and therefore the maximum induced temperature increase at the seabed surface to avoid any negative impacts of cable warming on the marine environment "2K criterion" [1)]
- In the period between 2006 and 2015, 89% of submarine power cable faults with external cause were reported on **unburied** cables. Most failures were mainly due to **anchor** damage. The average mean outage time of the reported submarine cable failures was estimated to 105 days [2)]
- Based on the Distributed Temperature Sensing (DTS) technique, it is possible to determine the **depth of burial** of offshore power cables to locate exposed sections and make predictive maintenance plans

[1)] Bundesamt für Seeschifffahrt und Hydrographie, 2017, "Bundesfachplan Offshore für die deutsche ausschließliche Wirtschaftszone der Nordsee 2016/2017 und Umweltbericht"

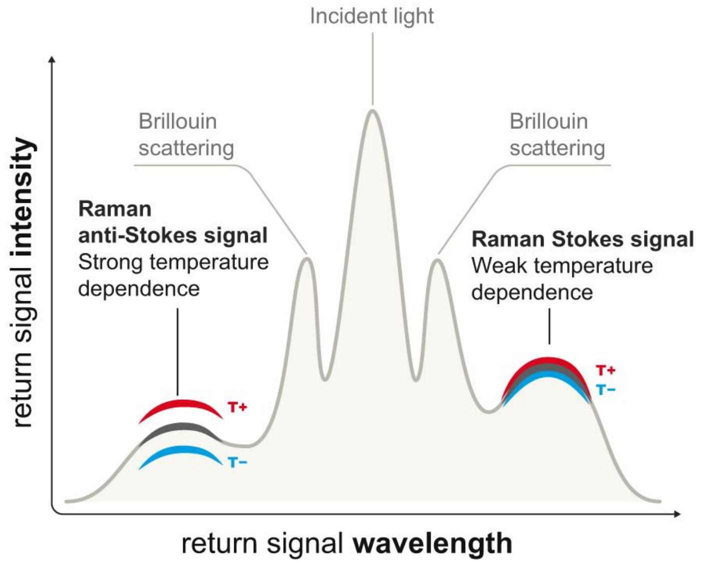
[2)] CIGRE WG B1.57, 2020, "Update of Service Experience of HV Underground and Submarine Cable Systems", Technical Brochure 815

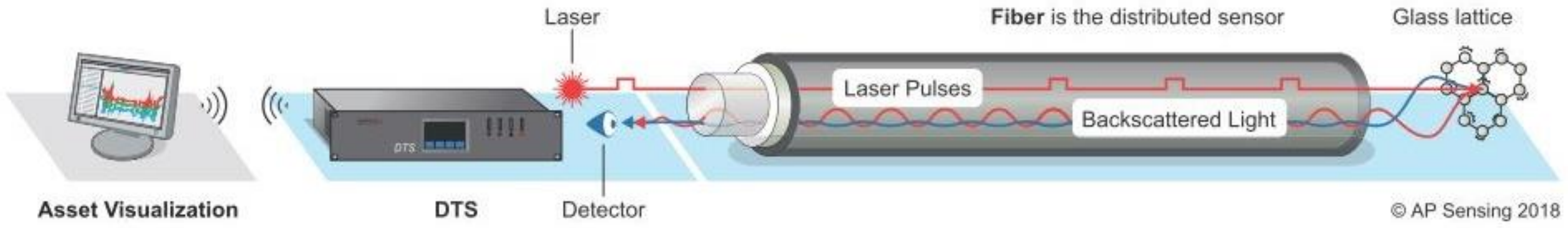
Distributed Temperature Sensing (DTS)

Measurement Principle

The Distributed Temperature Sensing (DTS) utilizes the **Raman effect** to measure the temperature. An optical **laser pulse** sent through the fiber results in some scattered light reflecting back to the transmitting end, where it is analyzed. The intensity of the Raman scattering is a measure of the **temperature** along the fiber.

The **position** of the temperature reading is determined by measuring the arrival timing of the returning light pulse similar to a radar echo.





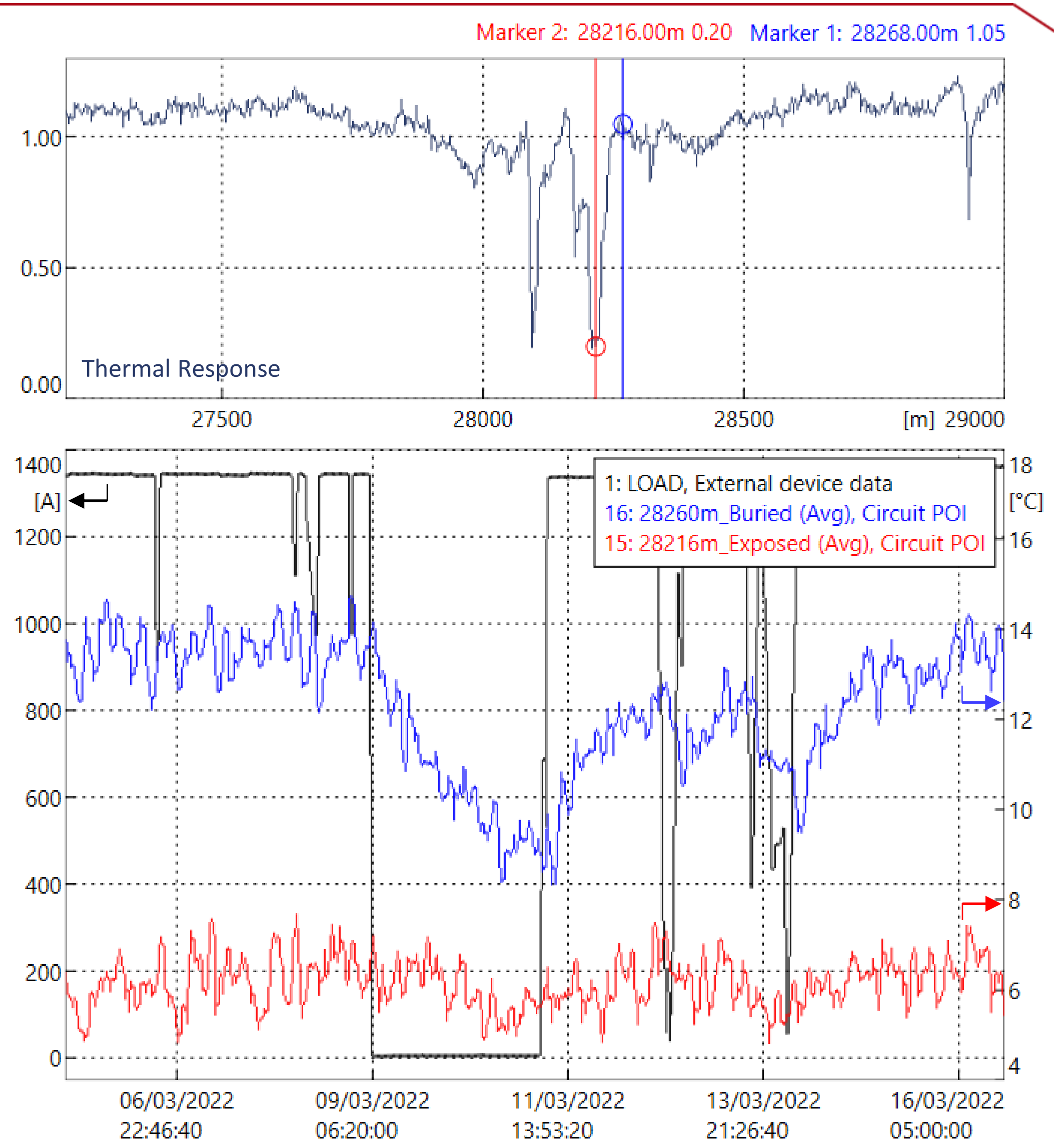
Depth of Burial State (DoBS)

Working Principle

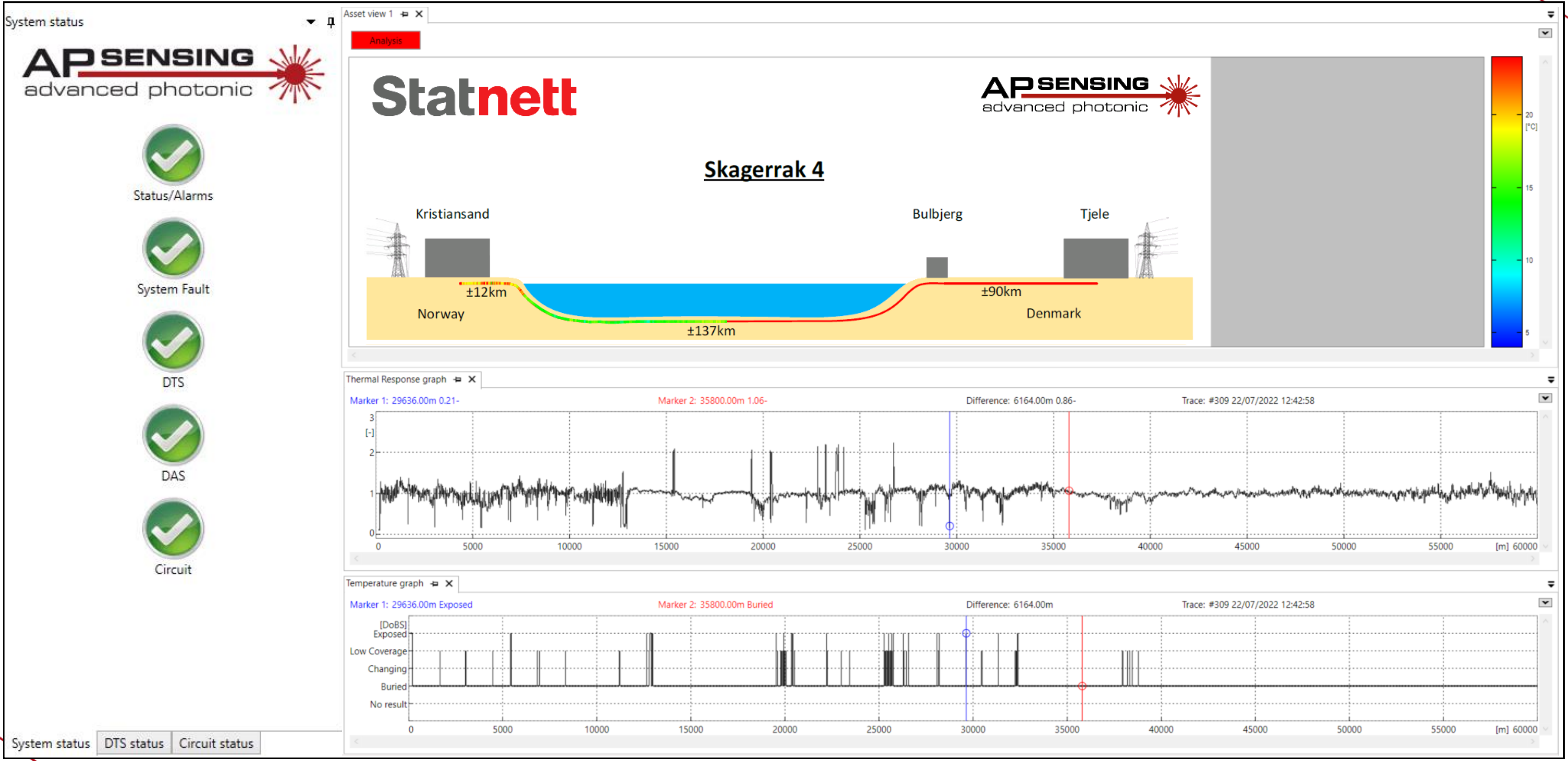
- The Depth of Burial State (DoBS) of the power cable is determined by calculating the local **load temperature-change correlation** function $C_i(\Delta t)$ (called thermal response)

$$C_i(\Delta t) = \sum_t^{T_{av}} I(t) \cdot \left(T_i(t + \Delta t) - T_i(t)\right)$$

- The closer the cable to the water, the faster the dissipated heat can be transported away, and hence the lower the temperature change measured by the fiber upon a load change
- Low correlation values indicate an unburied cable location
- The exposures are identified based solely on the power cable **load** $I(t)$ and the **DTS temperature traces** $T(t)$



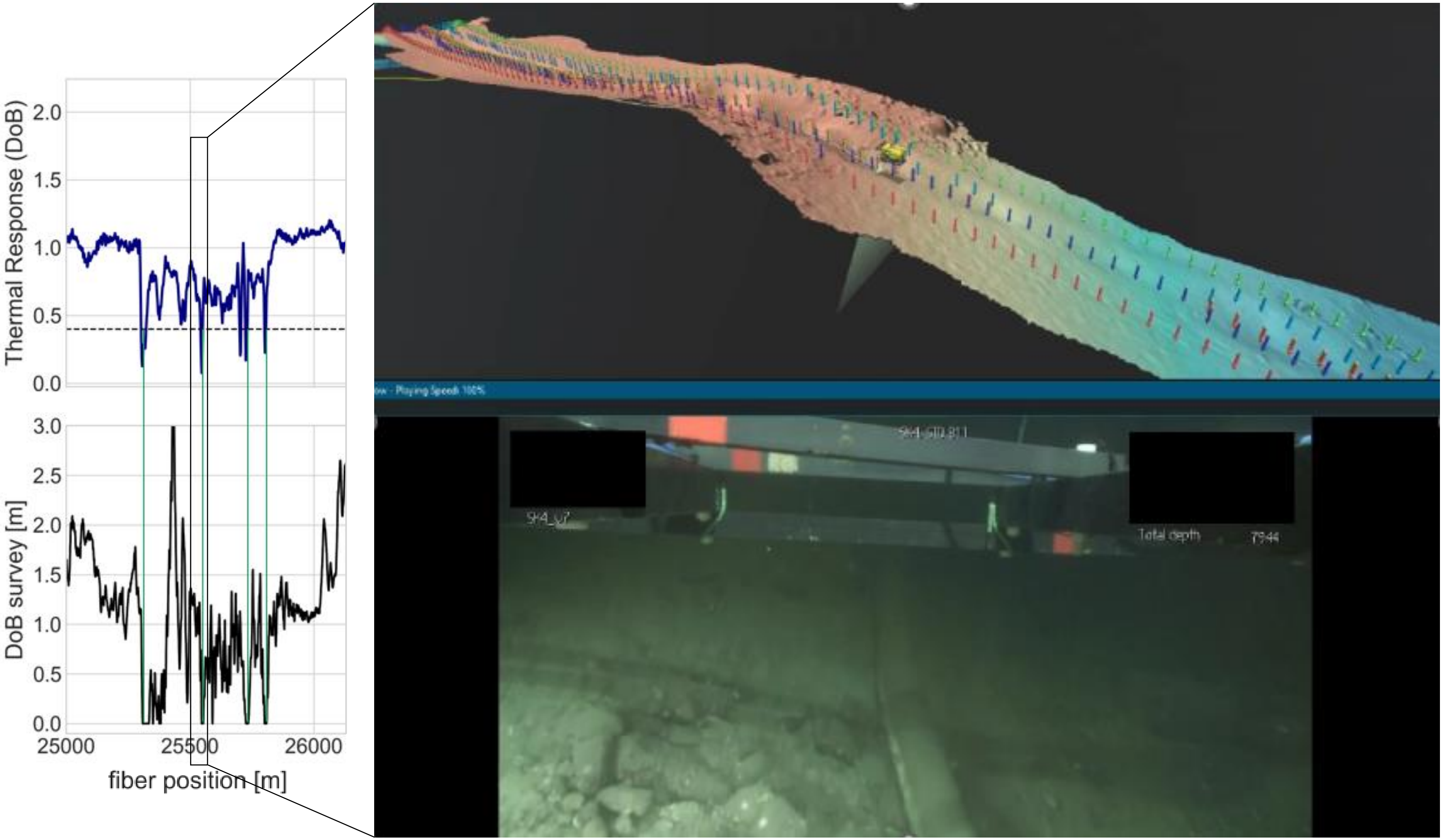
Depth of Burial State (DoBS)



Leading the Way with Passion.

New Approach – Quantitative Depth of Burial State (qDoBS)

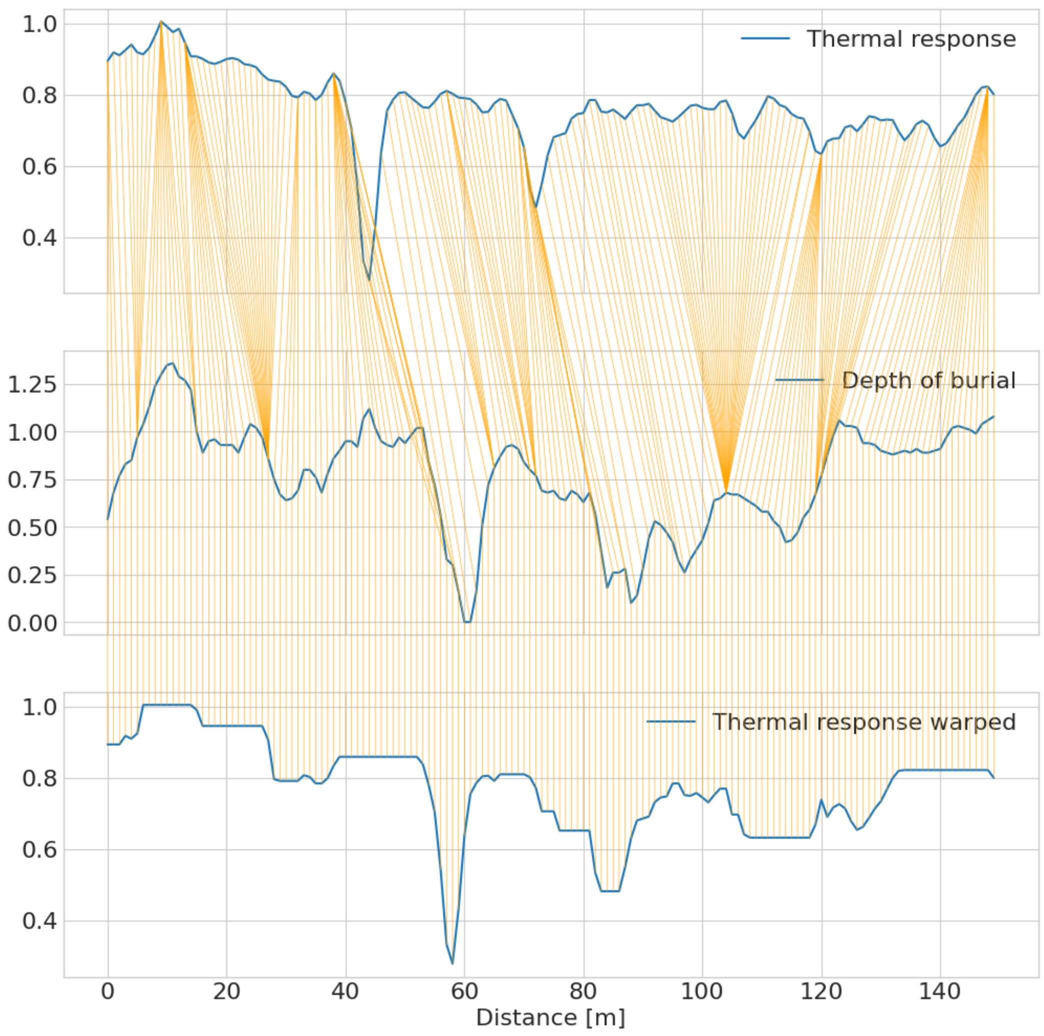
- **Question: How to convert real-time thermal response data into actual burial depth values?**
- Solution: Correlate the thermal response to ROV data at a time t_0 and predict/calculate the burial depth at any time t



New Approach – Quantitative Depth of Burial State (qDoBS)

Step 1:

- Align ROV depth-of-burial data and thermal response measurements using Dynamic Time Warping (DTW)
- DTW is an algorithm for aligning two similar series of varying speeds
- Use DoB and warped thermal response measurements to compute a correlation function between both traces



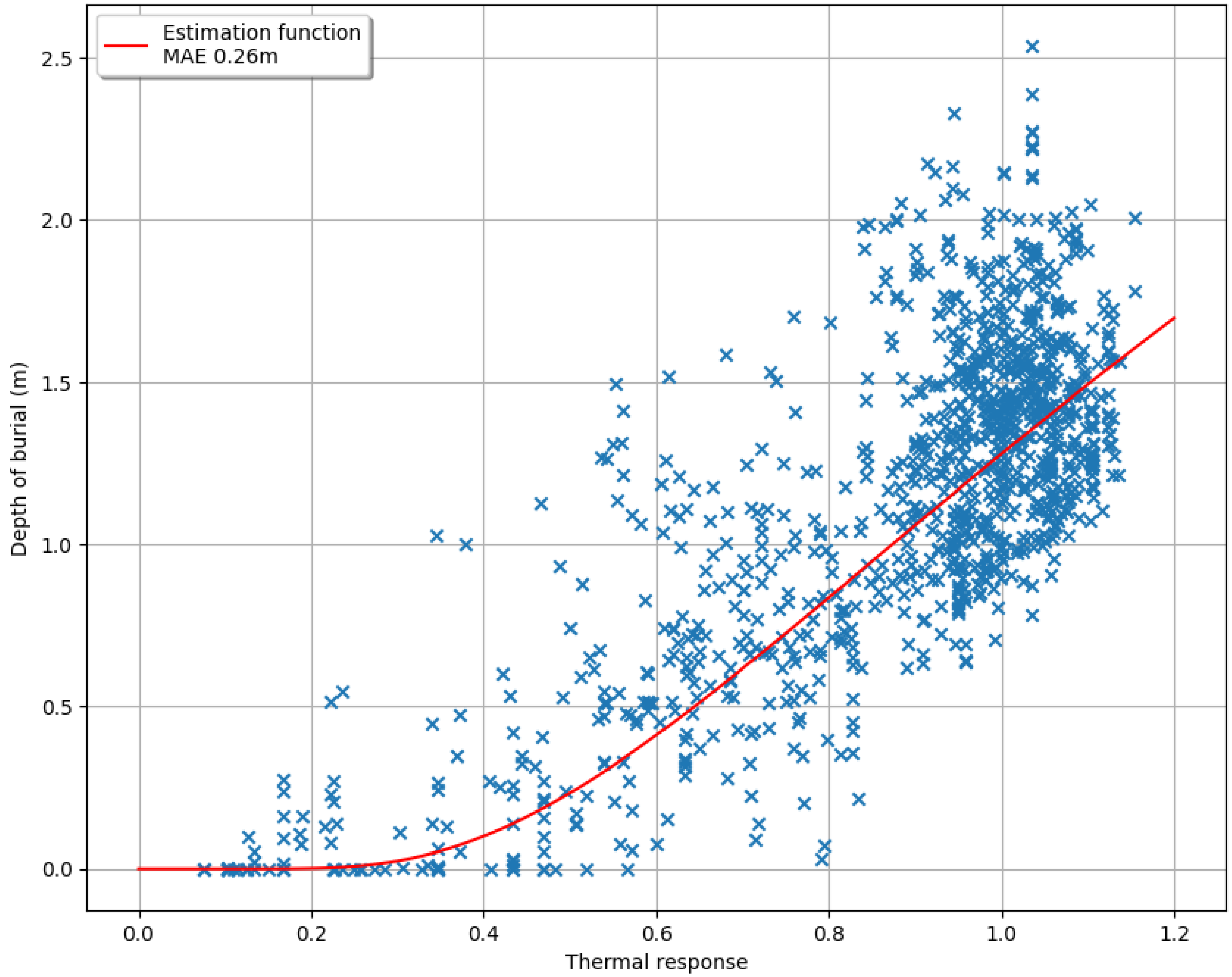
New Approach – Quantitative Depth of Burial State (qDoBS)

Step 2:

- Plot the initial depth-of-burial vs. warped thermal response values
- Correlate the data using exponential least squares fitting
- The correlation function (red line) has the form:

$$y = a\, e^{-\frac{b}{x}}$$

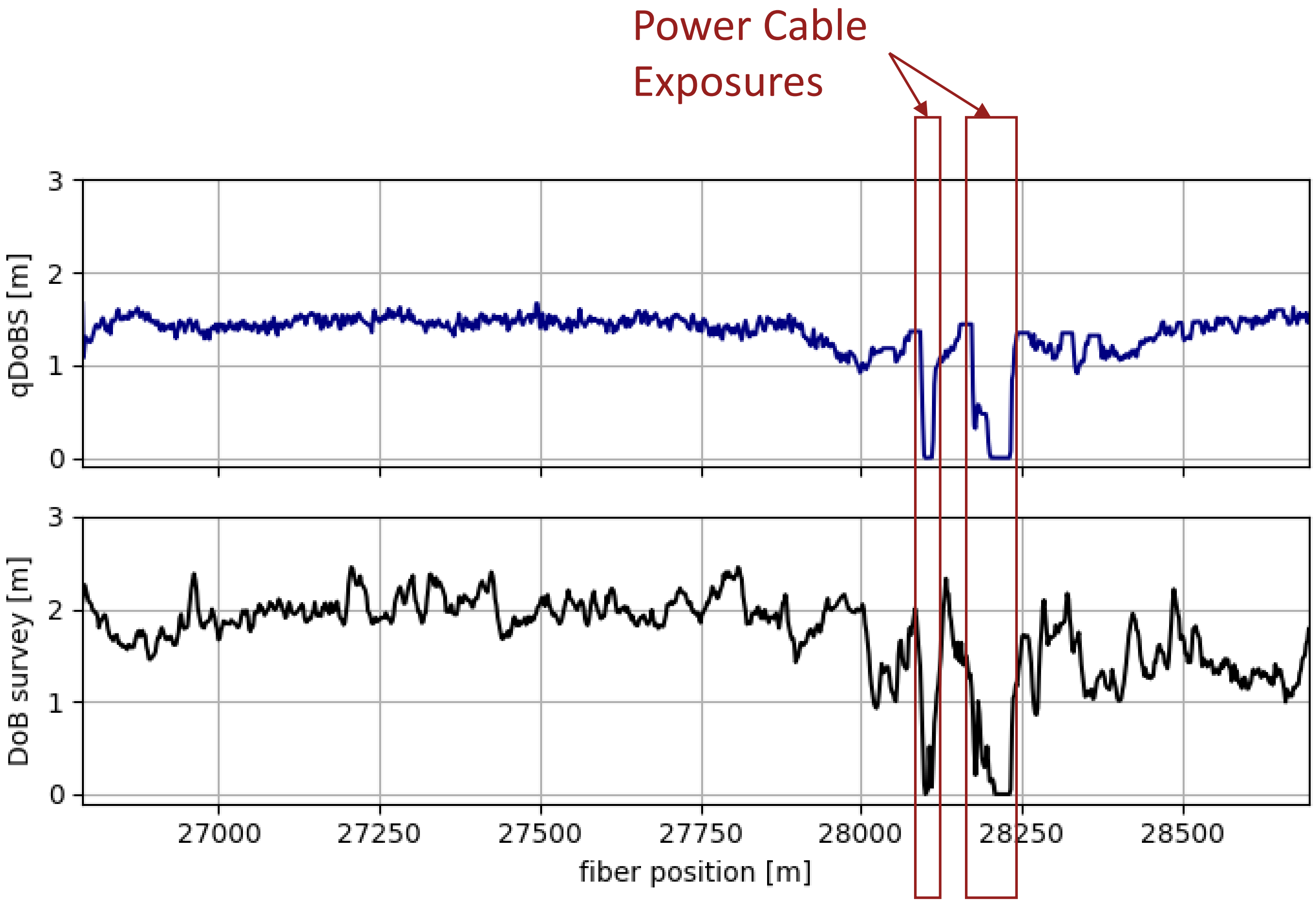
- Using the red correlation function for predicting the burial depth based on the thermal response leads to a Mean Absolute Error (MAE) of 26 cm along the surveyed fiber section



New Approach – Quantitative Depth of Burial State (qDoBS)

Step 3:

- Calculate the estimated depth-of-burial in real time based only on the actual temperature traces and load data
- This plot shows a comparison between measured and estimated depth-of-burial
- This new approach predicts confidently most of the exposed sections
- The estimation saturates for high burial depths

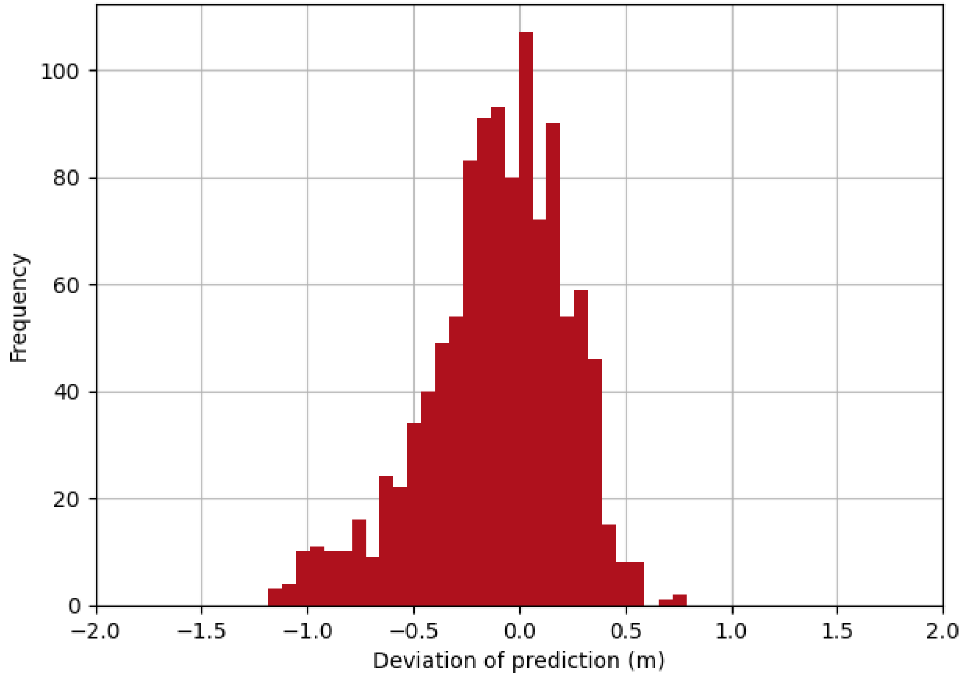


New Approach – Quantitative Depth of Burial State (qDoBS)

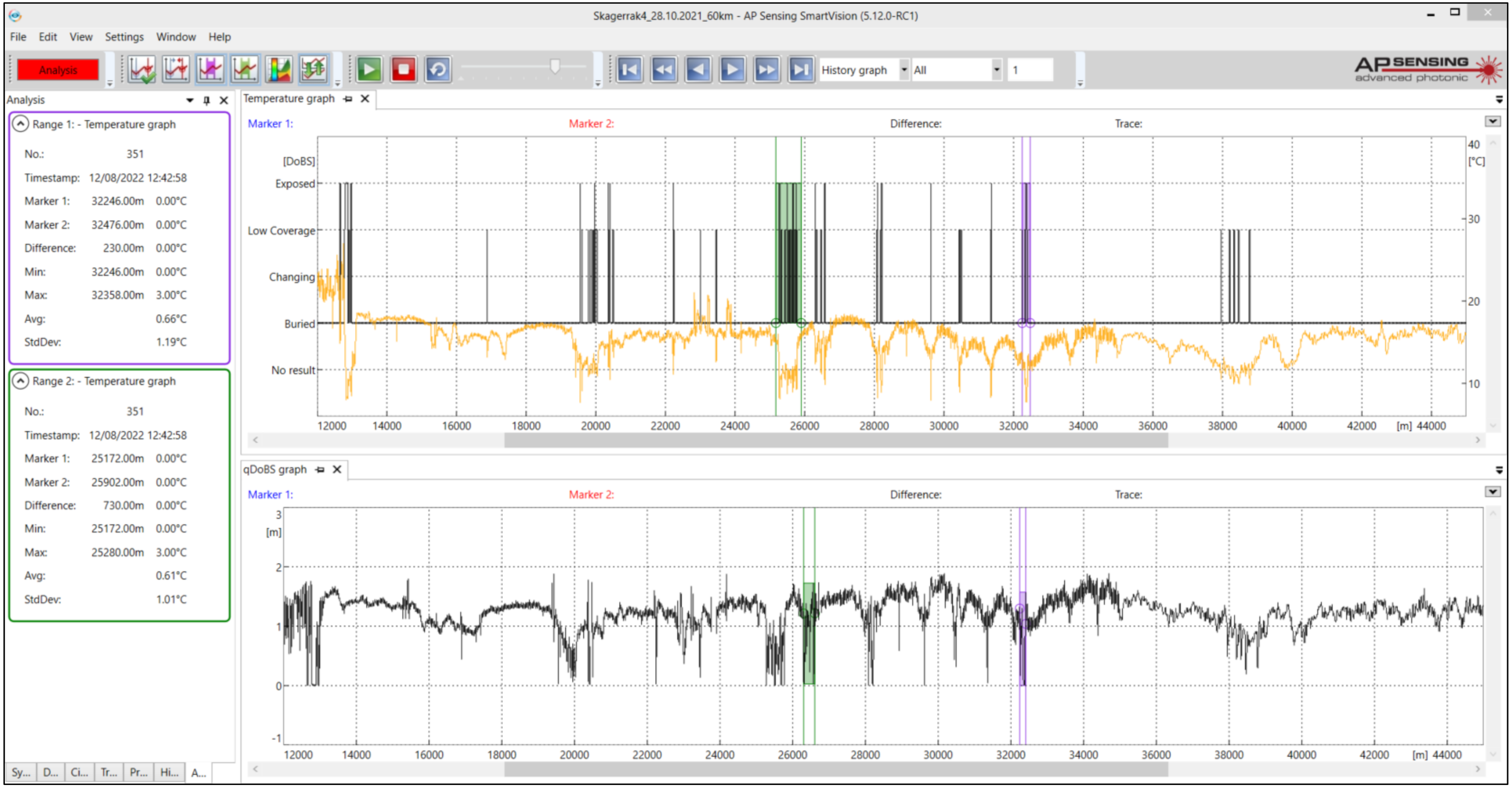
Burial Depth	Vertical Accuracy
0 m – 0.5 m	15 cm
0.5 m – 1 m	24 cm
>1 m	30 cm

Deviation	Probability
1 m	0.99
0.5 m	0.87
0.25 m	0.59
0.1 m	0.25

- The new qDoBS approach shows comparable results to other methods based on thermal modeling, however with much less complexity
- The qDoBS technique does not require any precise knowledge of the ambient conditions and thermal models of the seabed and the power cable
- This method reduces the commissioning effort, avoids any uncertainties caused by measurement deviations, and is applicable to retrofits, where soil sample data is not available



New Approach – Quantitative Depth of Burial State (qDoBS)



Summary

- The DTS/DAS technologies offer a variety of different functionalities for the offshore power cable market, such as:
  - Temperature monitoring and hotspot identification
  - Cable fault localization
  - Third-Party Intrusion detection
  - Real-Time Thermal Rating
  - Depth of Burial State monitoring
- Based on initial DoB data, e.g. from an ROV survey, in addition to the actual cable load and DTS traces, the qDoBS technique provides subsequently a real-time insight into the burial depth at any time, without the need for thermal modeling or knowledge of the seabed parameters
- The new qDoBS engine enriches the sensing portfolio for better monitoring of offshore power cables, identification of exposed sections, and calculation of power cable burial depths in centimeters
- The qDoBS contributes to better predictive maintenance and risk reduction of offshore power cable faults

Thank you!

Dr. Wissem Sfar Zaoui

wissem.sfarzaoui@apsensing.com

+49 7031 309 6655

Dr. Wissem Sfar Zaoui

Passion for Plants.