Fibre Optical Distributed Sensing

STRONGMAR Winter School - Aberdeen 23 March 2017

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Outline of Presentation

- About CMR

- Project Examples:
  - Marin Monitoring
  - Optics
  - Decision Support

- Distributed Fibre Optical Sensing
  - ODIMS
  - Distributed Acoustic Sensing (DAS)
  - Distributed Sensing

OUR LEGACY

Our legacy can be traced back to 1930, as part of the Christian Michelsen Institute.

The institute was established to provide free and independent research, as a personal initiative from former prime minister Christian Michelsen.

OUR MISSION AND VALUES

Christian Michelsen Research creates value for society and customers through innovative and sustainable solutions

Trustworthy | Innovative | Committed | Competent

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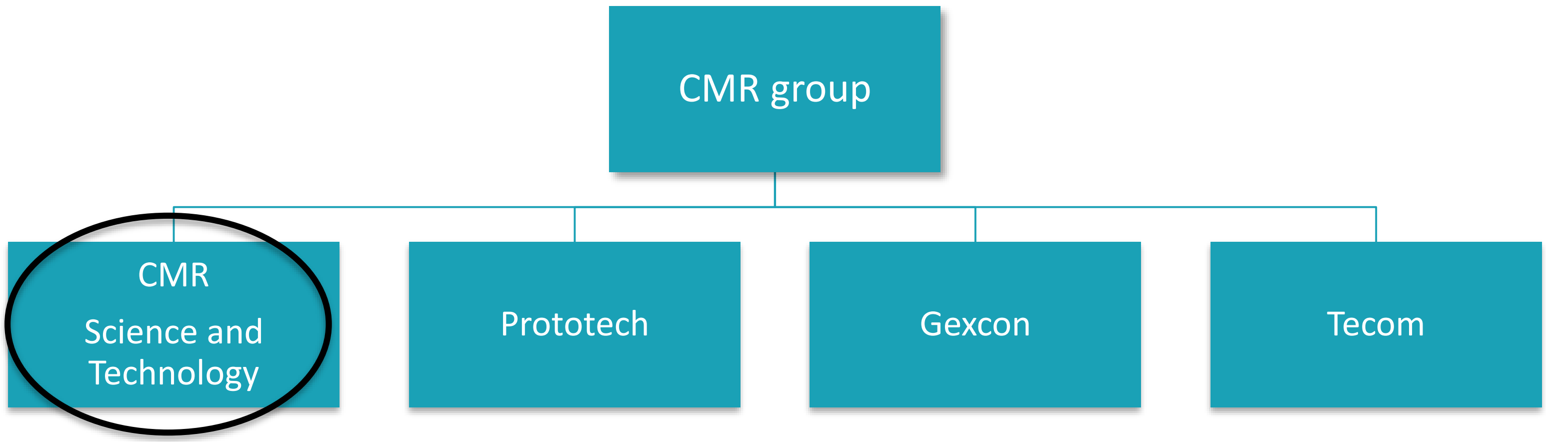
- Owner structure
  - University of Bergen (50%)
  - UNI Research AS (35%)
  - Statoil Technology Invest AS (5%)
  - Sparebanken Vest (5%)
  - CGG Services (NORWAY) AS (5%)

- Non profit
  - CMR is a non profit organization and all profit is invested into new research

ORGANISATION



CMR Science and Technology

~60 employees

Measurement science
Computer science

Prototech

~ 40 employees

Mechanical design and production
Fuel cells

Gexcon

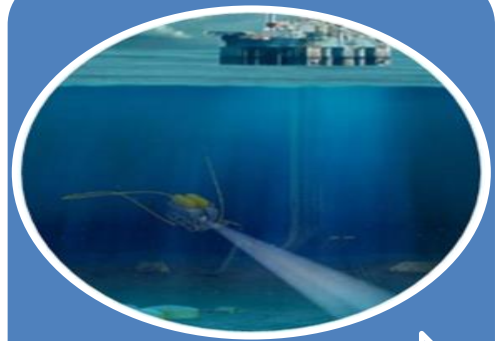
~ 100 employees

Safety and risk management
Advanced dispersion, explosion and fire modelling

Tecom

XSENS AS
Offshore Sensing AS
UPTIME CC AS
ZegPower AS
BioZEG AS
Seamless AS

CMR Science & Technology main market areas



Advisory services, training courses and testing, test centre

Renewable Energy

Offshore Wind

Geothermal Energy

CO_2 Storage

Energy Systems

Marine & Environment

Cost-effective sensors and observation platforms

Autonomous and power efficient systems

Distributed sensing

Data management and processing tools

Oil & Gas

Flow and flow assurance

Fluid characterization

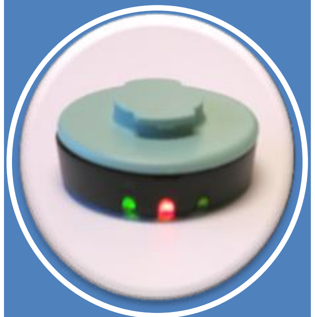
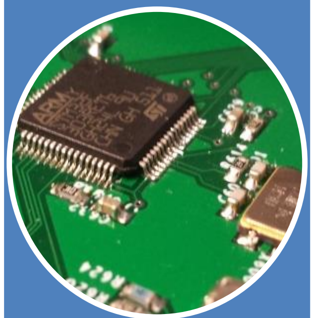
Courses and test facilities

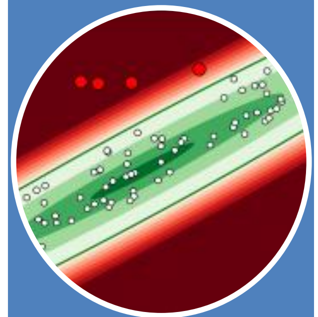
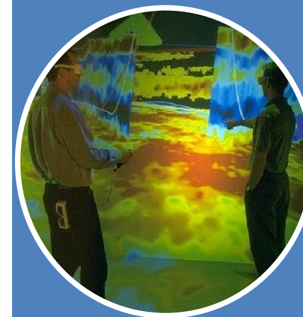
Subsea leak detection

Subsea pipeline inspection

Visualization tools

CMR Science & Technology competence areas

From sensing to decision

Properties

Temperature
Pressure
Wind
Fluid flow
Etc.

Sensing

Electromagnetics
Optics
Acoustics
Gamma

Processing

Filtering
Optimization
µProcessors
Electronics design
Embedded software

Communication

Mesh
Networking
Cloud
Wireless

Analysis

Analysis
Modelling
Big Data

Decision

Visualization
Automation
Decision support
Machine learning

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1930

Acoustic measurement methods
Radiosonde
Coastal navigation

1940

High-voltage equipment for treatment of cancer
Nera AS

1950

Harestua Solar Observatory
CERN atom collider
Nuclear reactors, Norway

1960

Andøya Rocket Range
Aanderaa Instruments AS
Modelling assignments

1970

Meteorological instrumentation and positioning systems
Computing centre for Hydro
Temperature system for Hansa
Improved pacemaker

1980

Process safety
Computer technology
Multiphase flow measurement
Fluenta AS and Prototech AS

1990

Fuel cells to Mjøllner
Space research
The torch, OL Lillehammer
GexCon AS

2000

Space flowerpots
FME and SFI centres
Zeg Power AS and CellPower AS

2010 –

Offshore Sensing AS
Greenstat AS
Michelsen Medical AS
MF Vågen (on hydrogen)
Sino-AkvaVis (China)

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CMR Optics Group

- Jon O. Hellevang (MSc, photonics)
- Peter Thomas (PhD, photonics)
- Erling Kolltveit (PhD, fibre optics)
- Benny Svardal (BSc, optics)
- Dag Roar Hjelme, Scientific Advisor 15% (Professor NTNU)

- Bård Henriksen (MSc, electronics)
- Stian Stavland (MSc, instrumentation)

Focus area

- Technologies:
  - Fibre Optics
  - Spectroscopy
  - Imaging and robust optics
- Applications:
  - Condition monitoring / distributed sensing
  - Water monitoring
  - Fluid and flow characterisation and measurement
  - 3D imaging, structural surveillance
- Marked:
  - Main focus on the energy sector
  - Marine, industry, transport and medical

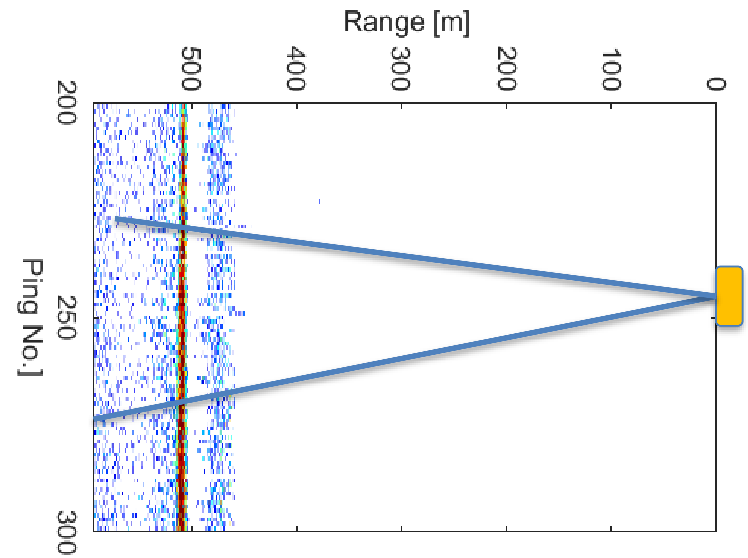
PROJECTS EXAMPLE
- MARIN MONITORING

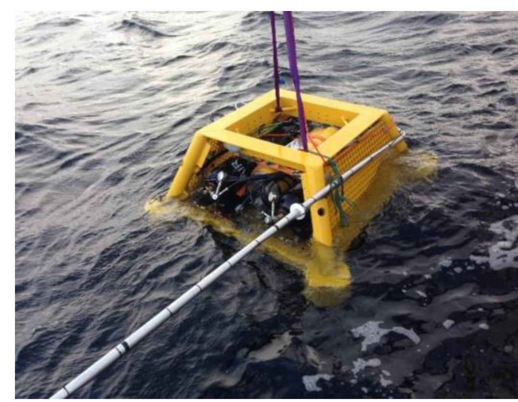
AALDOG – Active Acoustic

AALDOG – Active Acoustic Leak Detection of subsea Oil and Gas

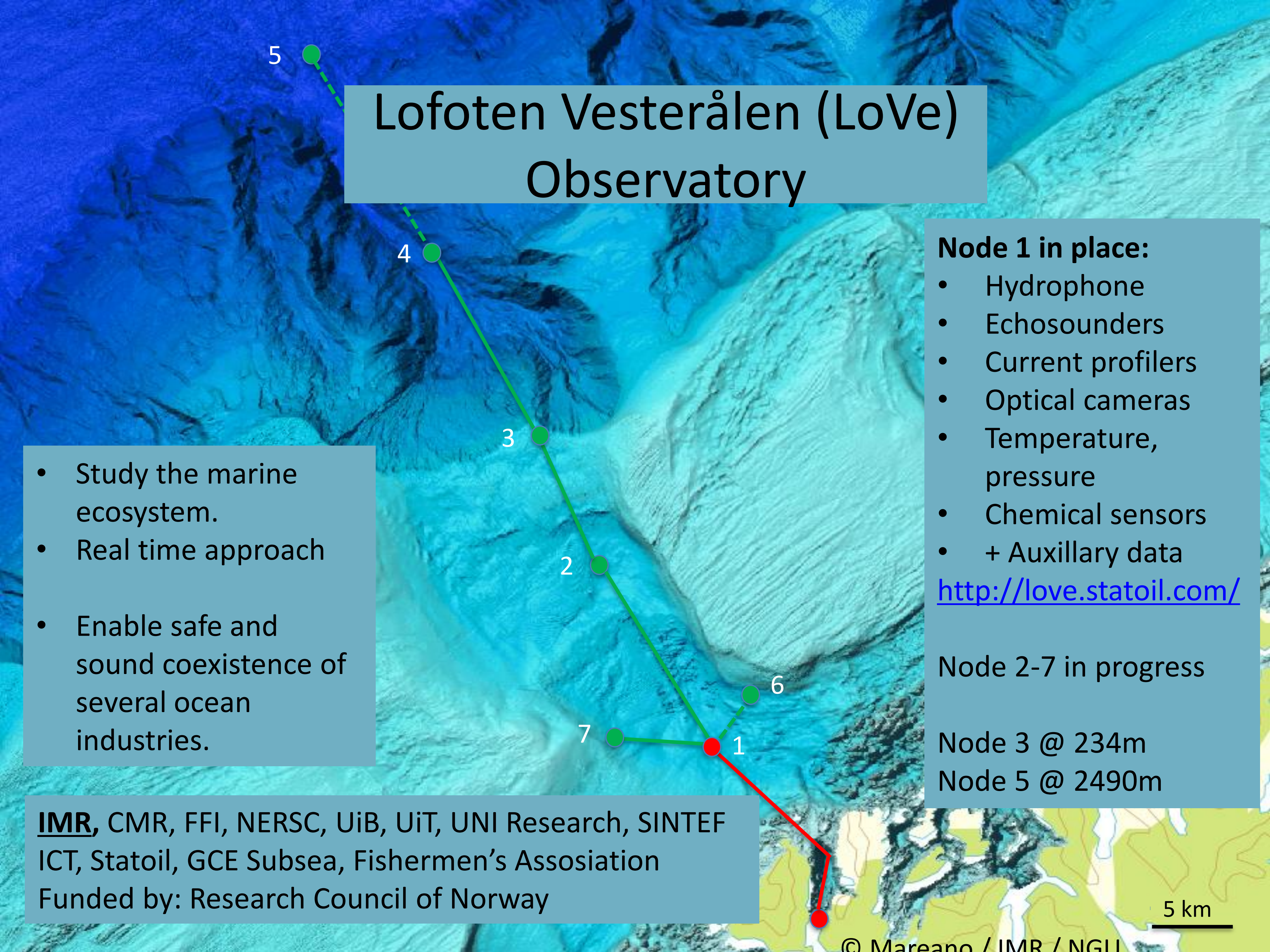
- **Goal:** Develop subsea technology for long range detection of oil and gas leakage
- **Partners: Metas**, CMR, IMR, UiB, Statoil, Kongsberg Maritime
- Funded by: DEMO 2000 / RFF Vest

CMR contribution: Acoustic propagation and scattering – simulations and measurements, measurement data analysis.





Lofoten Vesterålen (LoVe) Observatory



Node 1 in place:
- Hydrophone
- Echosounders
- Current profilers
- Optical cameras
- Temperature, pressure
- Chemical sensors
- + Auxillary data

http://love.statoil.com/

Node 2-7 in progress

Node 3 @ 234m
Node 5 @ 2490m

- Study the marine ecosystem.
- Real time approach

- Enable safe and sound coexistence of several ocean industries.

IMR, CMR, FFI, NERSC, UiB, UiT, UNI Research, SINTEF ICT, Statoil, GCE Subsea, Fishermen's Assosiation

Funded by: Research Council of Norway

BRIDGES

- Bringing together Research and Industry for the Development of Glider Environmental Services
- ARMINES, ACSA-ALCEN ++

- Gliders for:
  - Ecosystem
  - Oil and gas
  - Deep sea mining
- Sensors: chemical, optical, acoustic
- 2015-2019

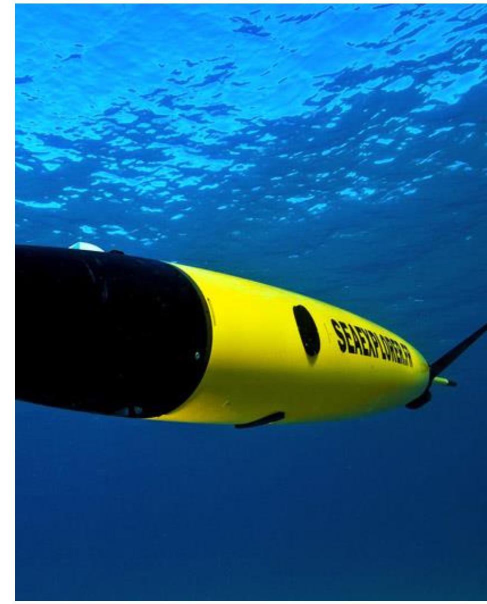


Illustration: ACSA

BRIDGES

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

HORIZON 2020

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GLIDER

DEMO 2000 project «GLIDER» (2017-2019)

Akvaplan Niva, NIVA, CMR, NTNU, UiT, NU, MET, industry partners, …

- Mapping environmental data using three unmanned autonomous vehicles
  - **Seaglider (KM), Sailbuoy (OS) and Waveglider (LR)**
- The vehicles will operate and collect data with a wide range of sensors
- In/near LoVe august 2017 (initial deployment), and for an extended period and area winter/spring 2018
  - Excact area and mission plans TBD

Illustrations: Kongsberg Maritime

Offshore Sensing

Liquid Robotics

Sailbuoy – Technical Data

Unmanned Surface Vehicle

- Length: 2m Width: 0.5 m
- Displacement: 56 kg
- Payload: 10 kg / 60 dm^3
- Average speed: 1-2 knots
- Tested navigable wind speed range: 4 – 30 m/s
- On-board autopilot and optional data logger
- Mission design length: 12 months
- Typical operational period: 1 - 3 months
- Global 2 way satellite communication

http://www.sailbuoy.no/

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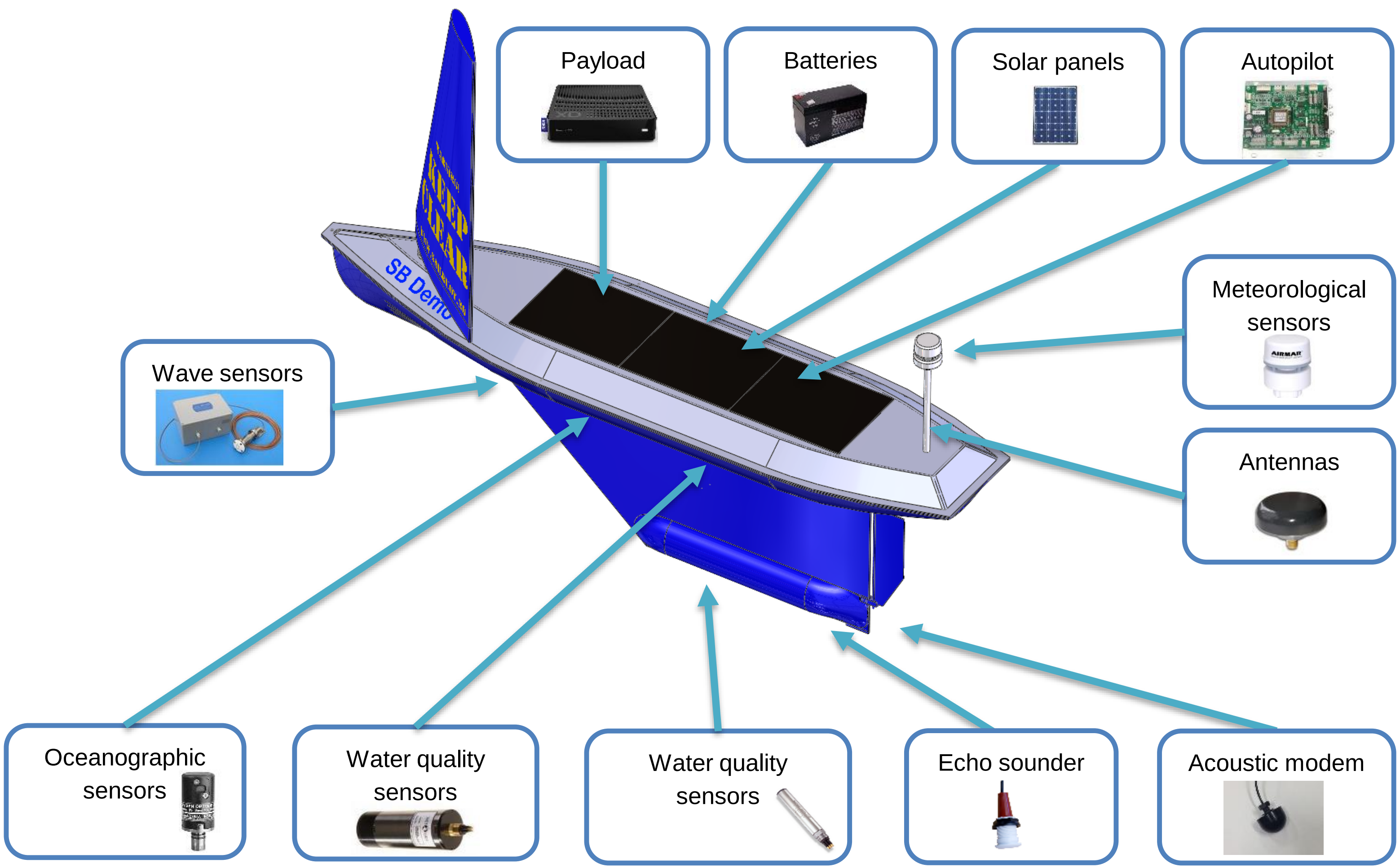
Sailbouy - Sensors and Payload



Sailbuoy – Application Example

NERSC: Ice edge north/west of Svalbard

Ice waves vs. ocean waves

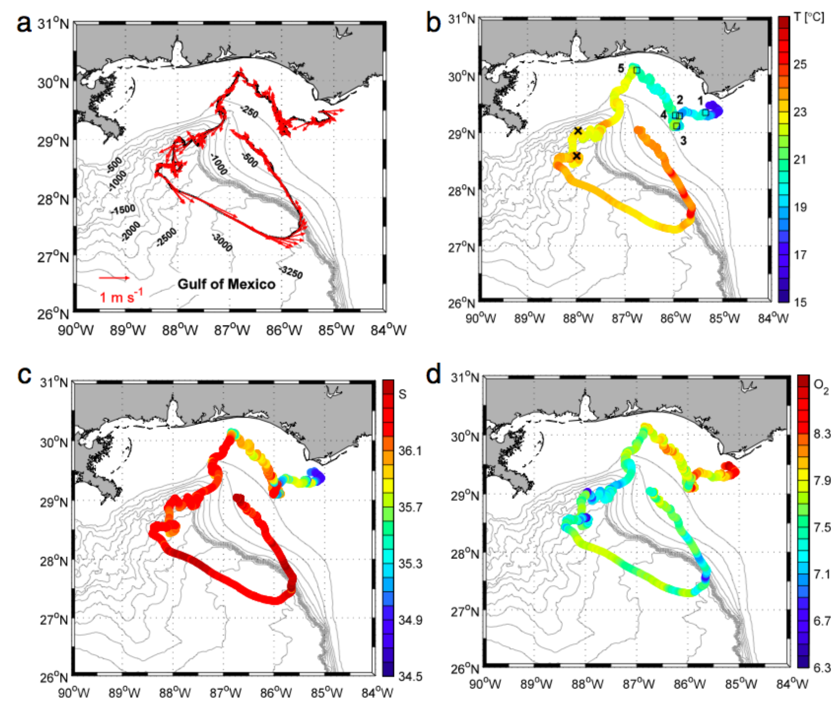
MET Norway

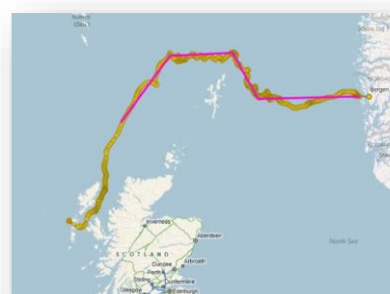
Wave measurements for improving of forecast models

NORCOWE Fino1 Campaign

Deep-C and MET Norway, Gulf of Mexico

Surface temperature, salinity and oxygen





Sailbuoy – Video demonstration

- https://www.youtube.com/watch?v=wMbAxejIDAM
- Video gallery: http://www.sailbuoy.no/gallery

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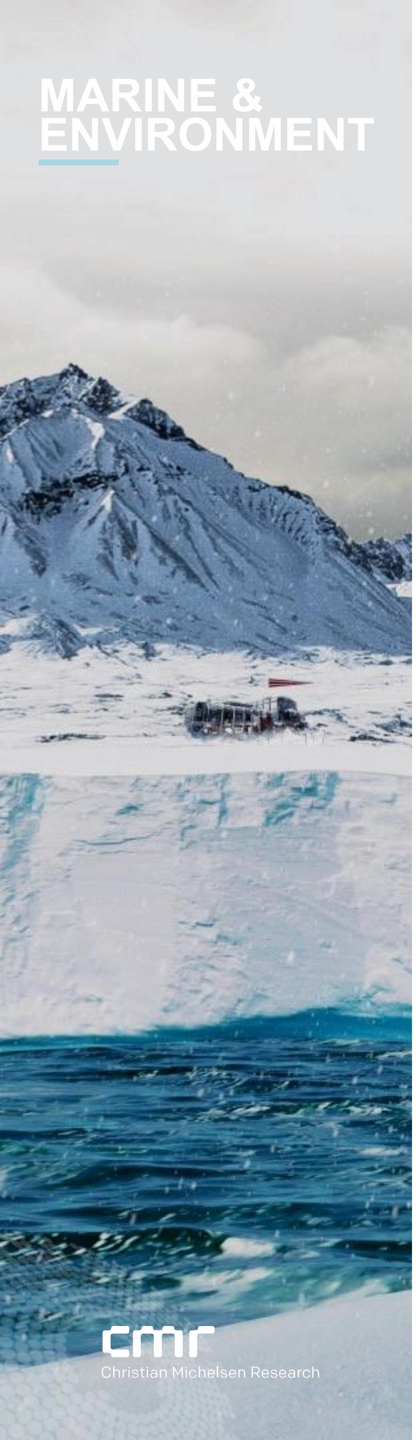
PROJECTS EXAMPLE
- OPTICS



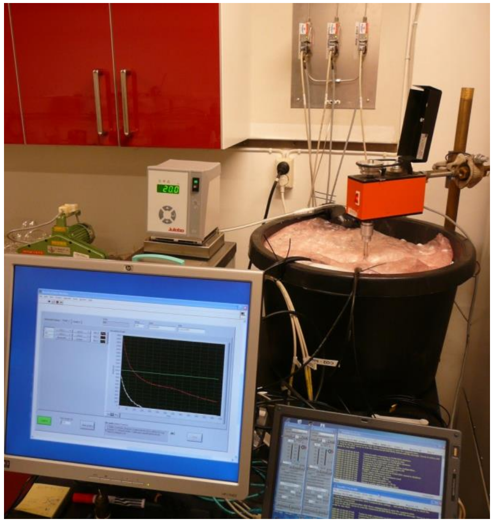
Optical sensors for measuring dissolved CO_2

Need for detecting CO_2 leakages from geological storage, monitoring ocean acidification and aquaculture applications

- Standard procedures is laboratory analysis of water samples – time consuming and no online monitoring
- Commercially available sensors bulky expensive and consume a lot of power

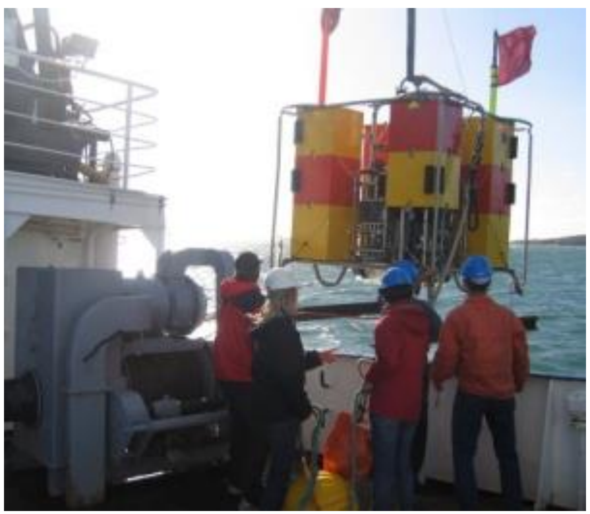
Optical CO2 sensors – Project timeline

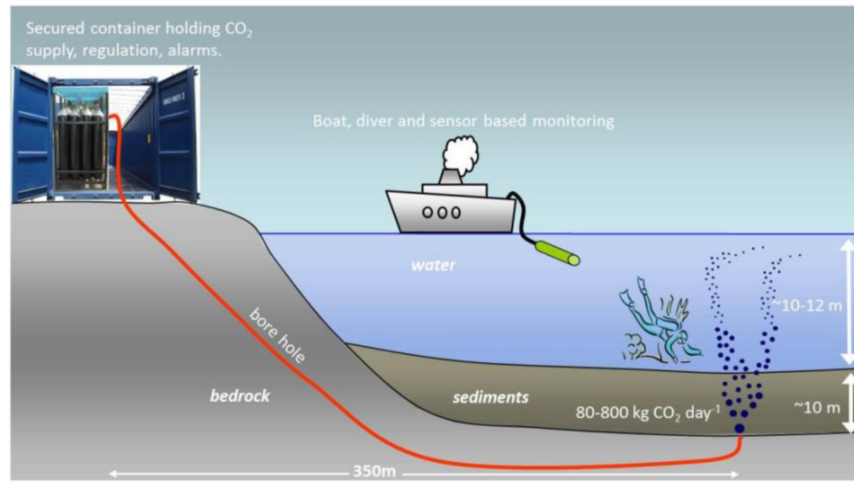
- 2009: First fluorescence lifetime prototype, development of calibration setup
- 2010-2013: numerous field trials and gradual improvement of performance
- 2014: Available to buy from Aanderaa data Instruments (AADI)

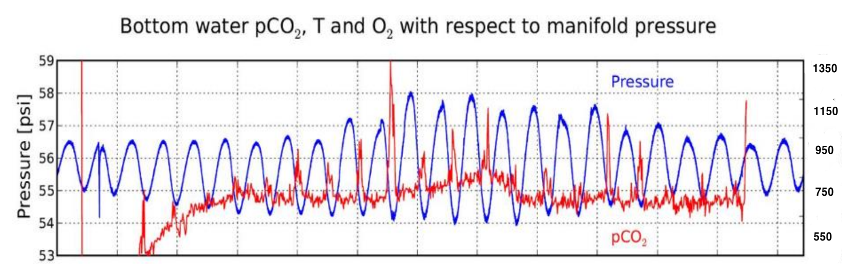


Optical CO2 sensor - Performance

- Sensitivity between 100-5000 µatm
- ~ 1min response time
- Stable over several months

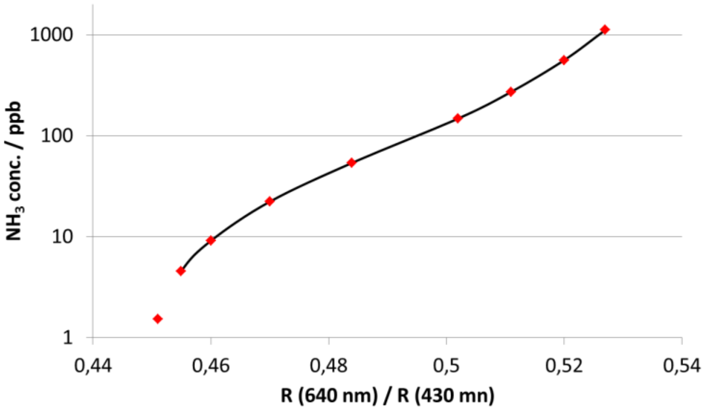






Other chemical sensing technologies

- 2017-2019 New RCN funded project with Aanderaa
  - ”A quantum dot on nanostructured sapphire pH sensor for reliable long-term monitoring applications”



- Promising results with solid state, compact technologies for monitoring NH_3 and H_2O_2 in water
  - NH_3 sensitivity in the low ppb range
  - H_2O_2 sensitivity in the low ppm range
- Also considering if some of the same technologies can be used for H_2S

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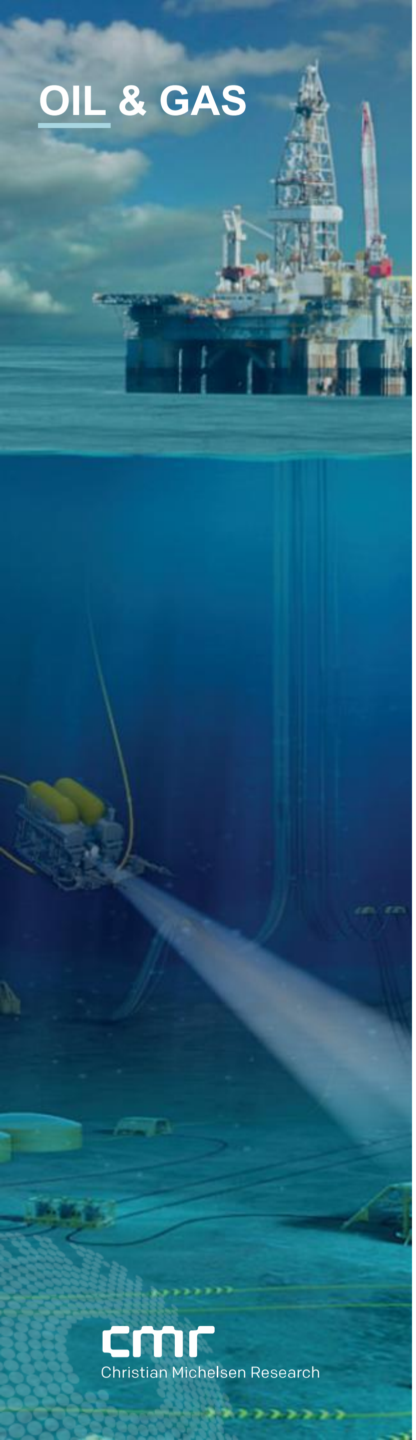
The Michelsen Centre for Industrial Measurement Science and Technology

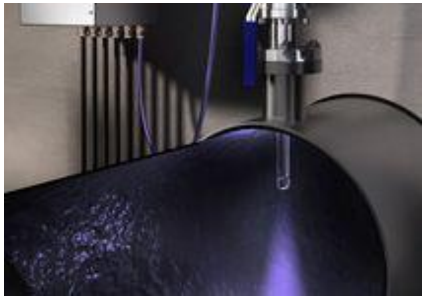


ClearVIEW – Anti fouling optical windows

Fouling of optical windows has hindered the wide spread use of optical sensors in oil and gas applications

- Proanalysis OiW probe uses cavitation to periodically clean a sapphire window
- Window has limited lifetime

Develop sapphire windows that resist oil deposition

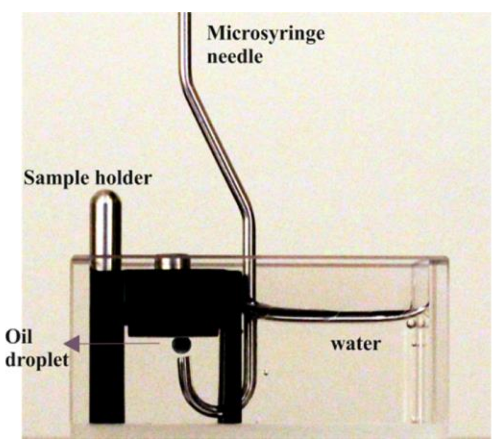


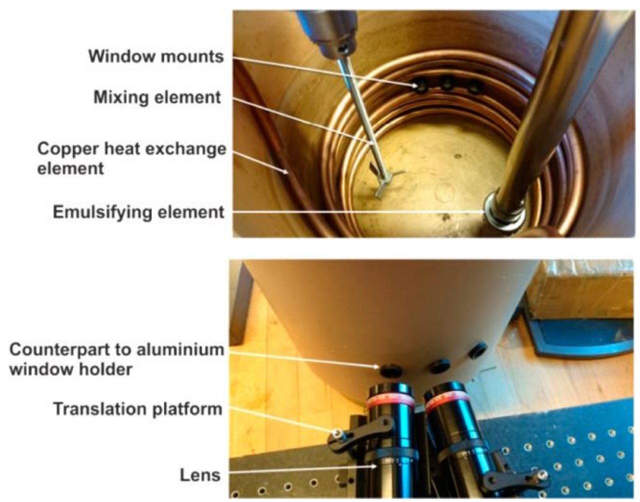
The Research Council of Norway

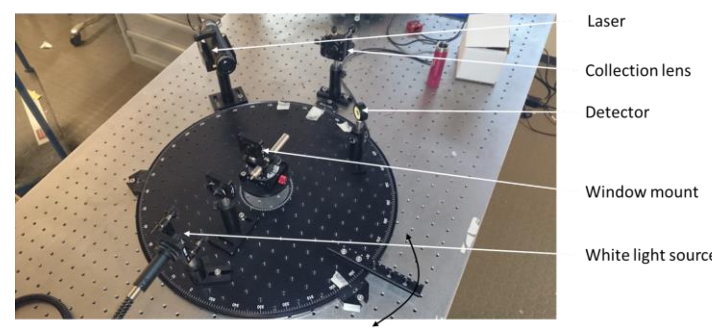
proanalysis

ClearView – Project timeline

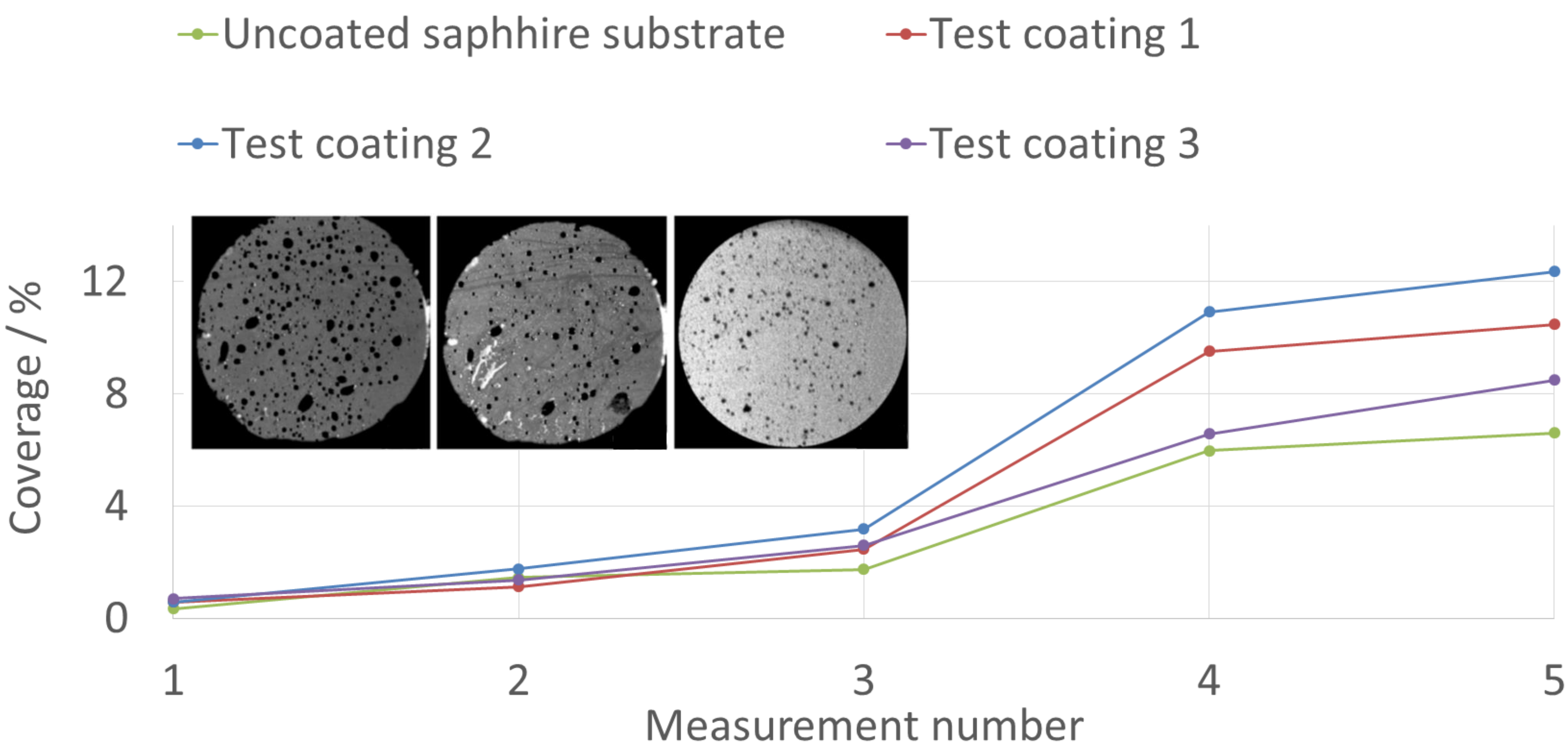
- 2012: Project startup
- 2013: Development of experimental setups for window characterisation
- 2014-2015: Demonstrate influence of sapphire finish, coating and nanostructuring on resistance to oil deposition







ClearView – Results



- EU project application: Anti-iceing optical windows

PROJECTS EXAMPLE
- DECISION SUPPORT

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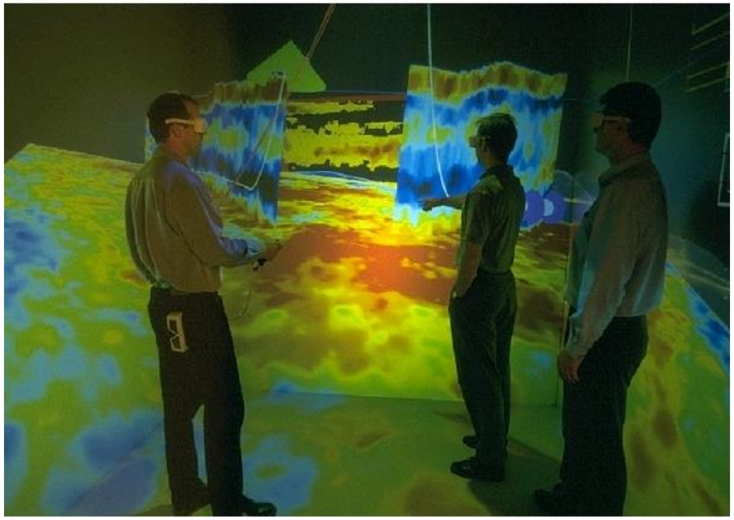
Decision support: Putting knowledge to use

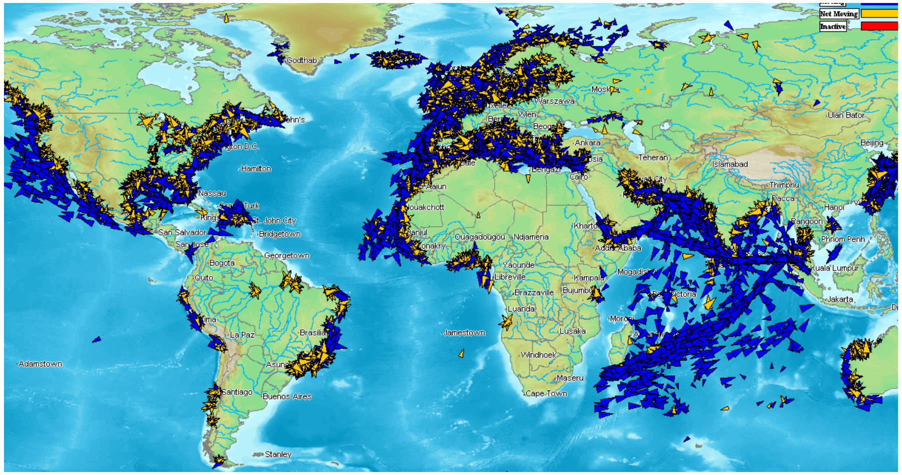
- Data Analysis and Big Data

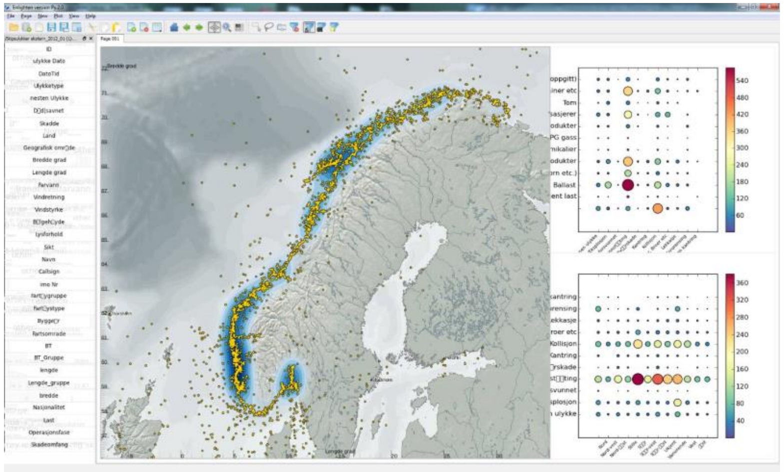
- Decision Support Systems
  - SARA – Search and rescue
  - AIS Online
  - SHIVR
  - Enlighten
  - LSSS



In-house Developed Big Data Technologies

- Interactive Visual Analysis
  - Enlighten
- AIS Track Server
  - Big Data storage, visualization and statistics

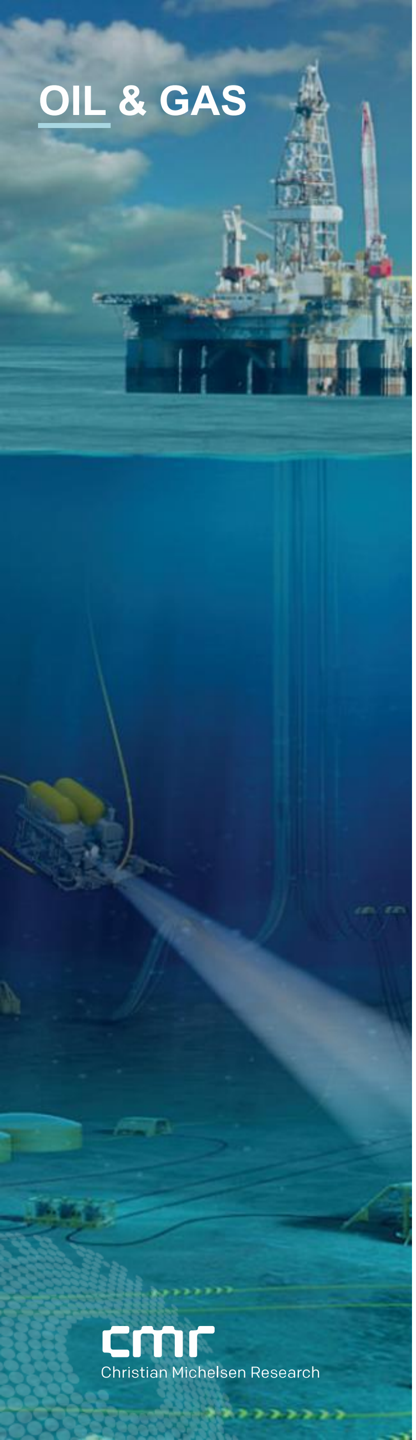




Video - DEMO

- Video - Visual Analysis of Multivariate Movement Data using Interactive Difference Views

DISTRIBUTED FIBRE OPTICAL SENSING (DXS)



Fibre optic dowhole communication

More advanced DH logging equipment

=> Higher bandwidth requirements

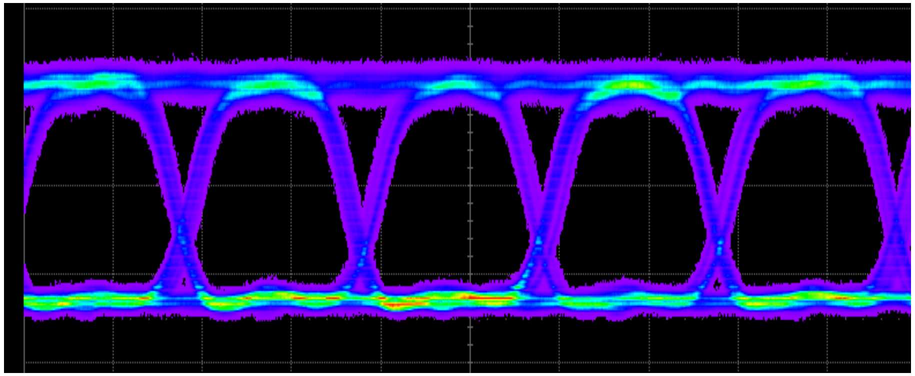
- Electrical communication systems have limited bandwidth
- Local storage eliminate online monitoring
- Downhole data reduction challenging and limit data quality

- Fibre optical communication enable high data rate
- => Fast and reliable operations with advanced logging tools

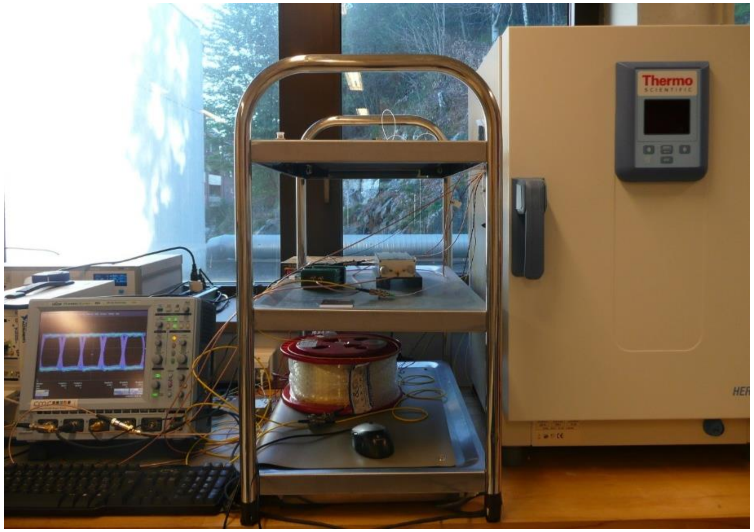
Fibre optic downhole communication - Results

- Successful lab-testing of high temperature, high speed fibre optical communication system

Properties	Performance
Temperature	177°C
Data rate	100Mbps
Length	10km

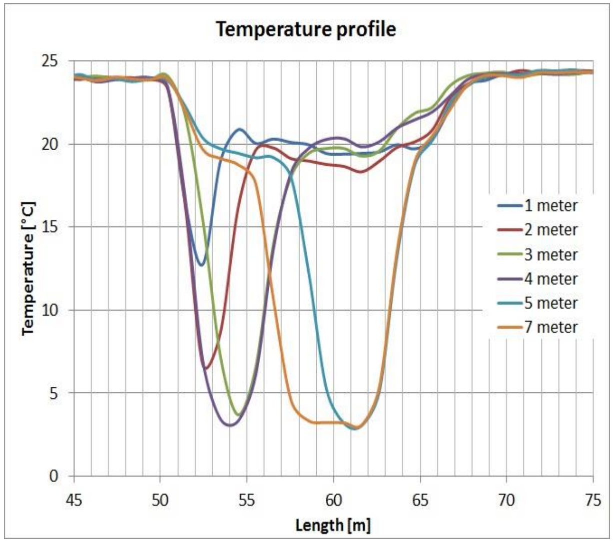


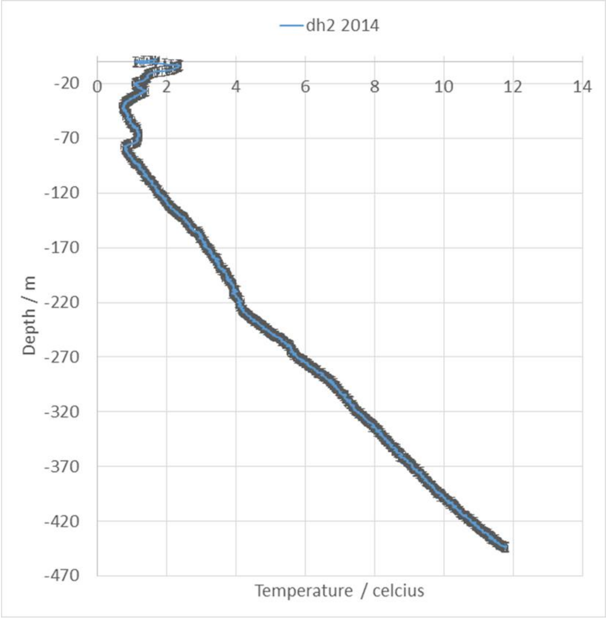
Typical eye-diagram recorded at 177C for 100Mbps

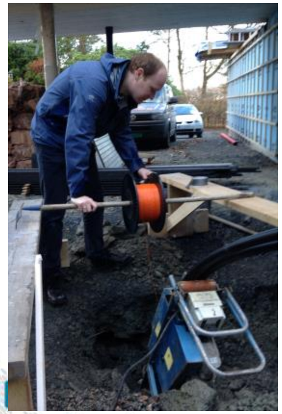


Distributed Temperature Sensing (DTS)

- CMR have a DTS-unit
  - 5km measurement range
  - 1.5 meter spatial resolution
- General purpose, wide range of applications
- CMR has used it for geothermal energy and process monitoring applications
- Linking DTS to other fibre optical distributed sensing data







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ODIMS – ONLINE DISTRIBUTED INTEGRITY MONITORING SYSTEM

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ODIMS – Project info

- Funded by the Research Council of Norway (RCN) 2015-2018
- Petromaks 2, special «Groundbreaking» call

- Main objective: *"Develop a flexible and scalable technology capable of continuously measuring humidity, water, salinity and temperature with a high spatial resolution (< 10cm) over km length scales."*

- **Project steering comittee:**
  - Kari Marvik, Vice President, CMR S&T
  - Dr. Arne Ulrik Bindingsbø, Leader, production technology, Statoil
  - Geir Harris, Technical director, Senior Vice President Technology and Development, Beerenberg Corperation
  - Magne Husebø, CEO, Xsens AS

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The Research Council of Norway

The CUI challenge

- Aging infrastructure and lifetime extension
- Corrosion under insulation (CUI) especially challenging

- Current fixed interval strategies for **corrosion under insulation (CUI)** leads to:
  - Unnecessary inspection and maintenance
  - Unplanned shutdowns with high costs
  - HSE risk with potentially serious HSE consequences

Example of CUI

News article [Statoil website 2012]

Chevron refinery fire 2012

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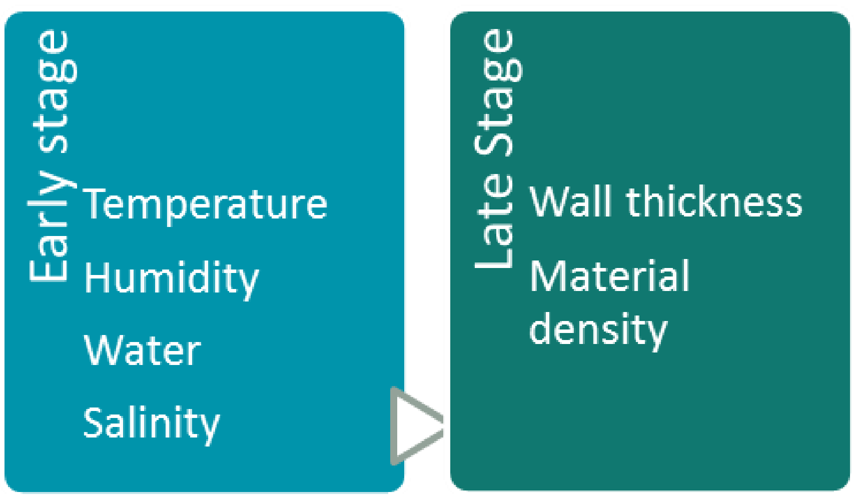
ODIMS - Idea

- Develop a system capable of early detection of CUI

- Key requirements:
  - Truly distributed monitoring covering large structures
  - Online continuous monitoring
  - Early detection of corrosion indicators



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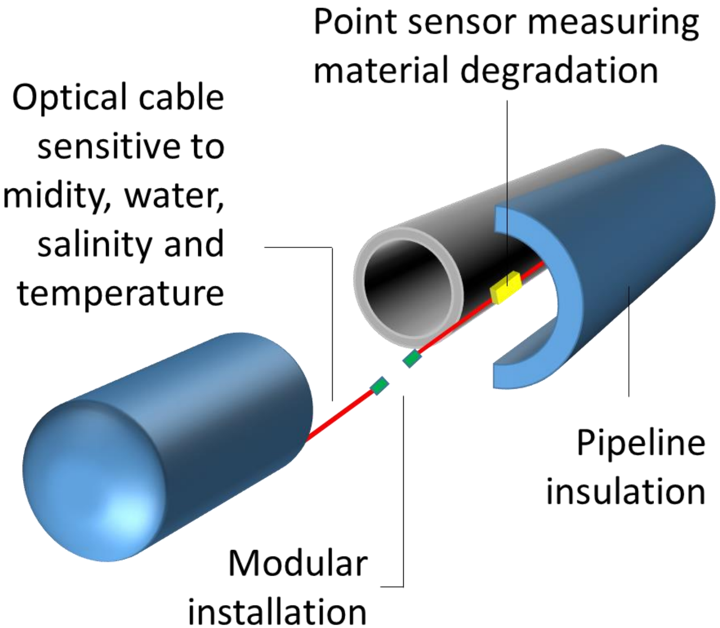
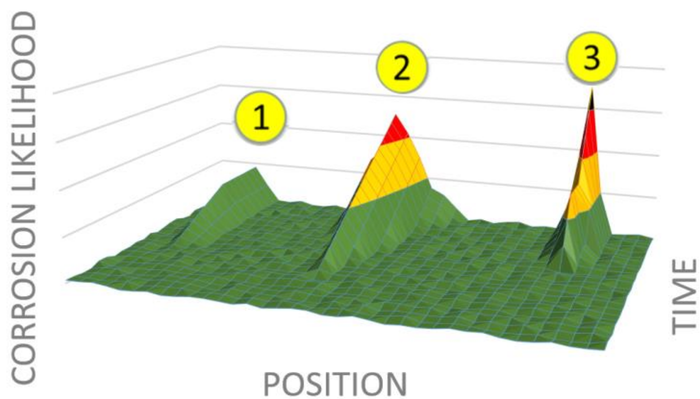
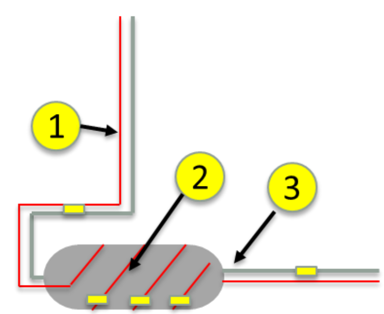
ODIMS - Architecture

- Distributed fibre optic measurement
- Multi parameter
- Flexible, scalable, modular
- Easy integration of point sensors

- **ODIMS will enable targeted and cost efficient CUI inspection and maintanance**

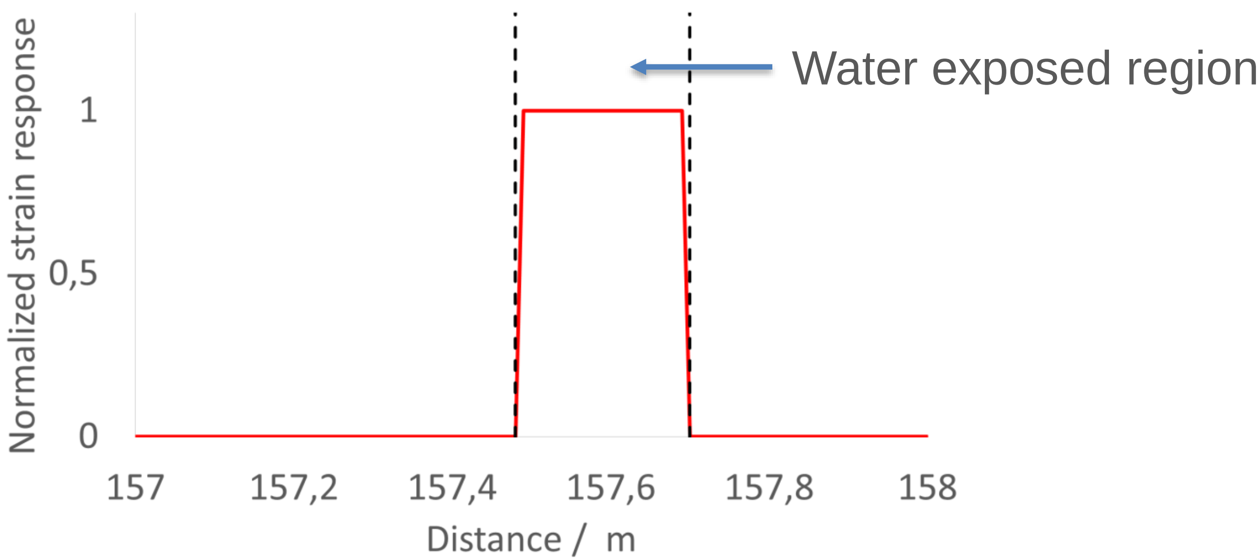






ODIMS - Primary sensing mechanism

- Sensing fibre with hygroscopic coating
- Water uptake by coating leads to strain in fibre
- Strain profile along the fibre is measured via backscattered laser light



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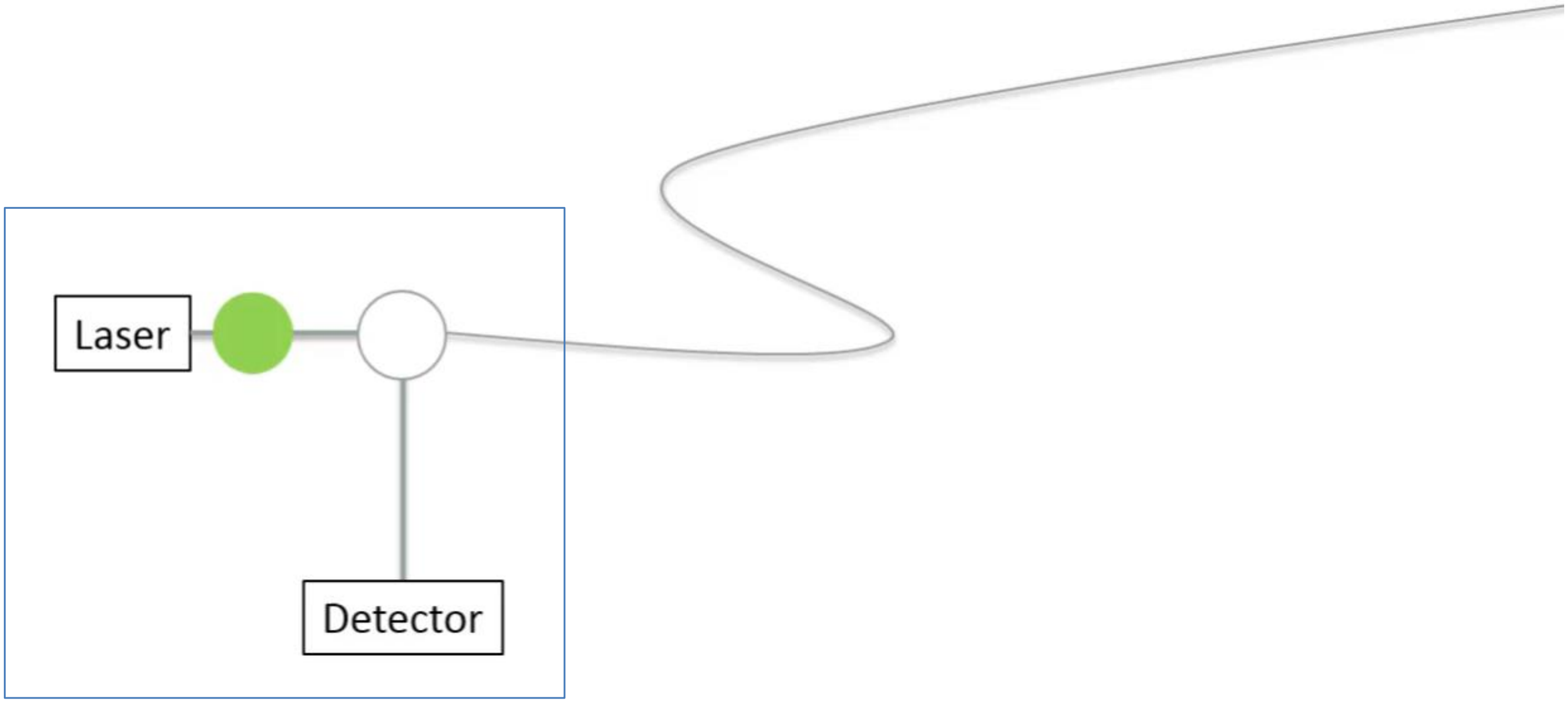
ODIMS - Measurement readout



- PC sized readout instrument
- $\mu\varepsilon$ measurement resolution (equal to a few % RH)
- ~ cm spatial resolution
- Low energy laser source (Class 1)

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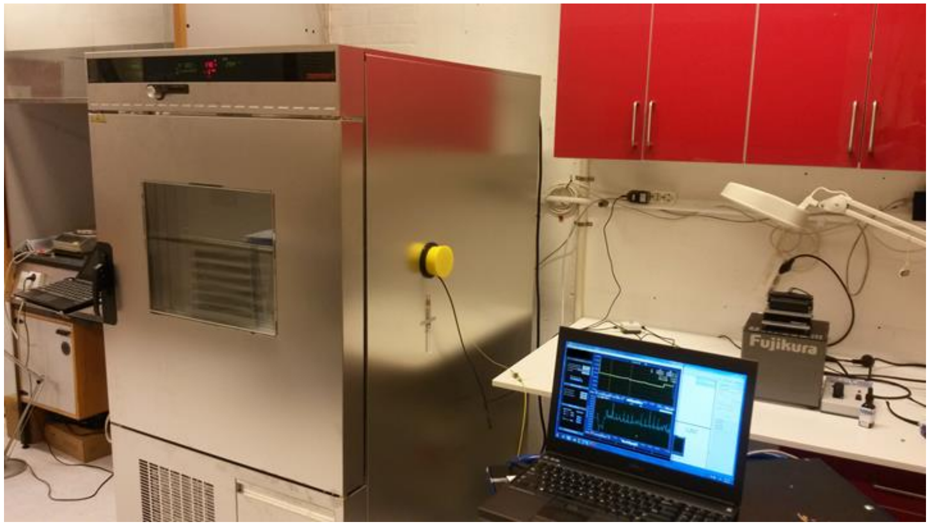
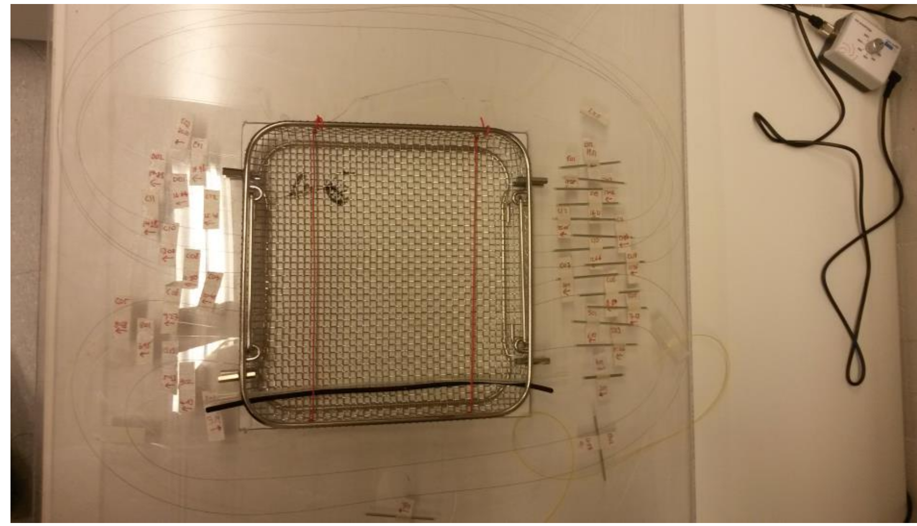
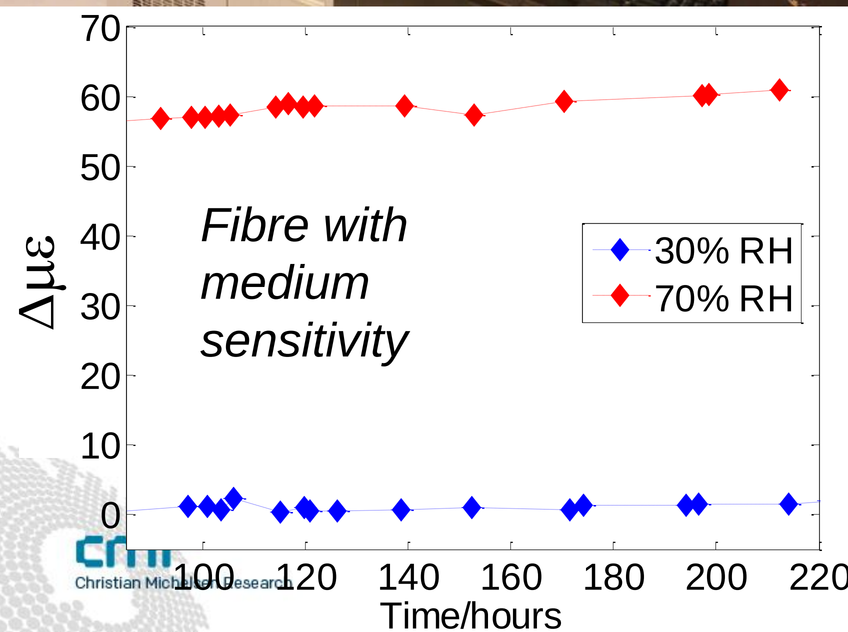
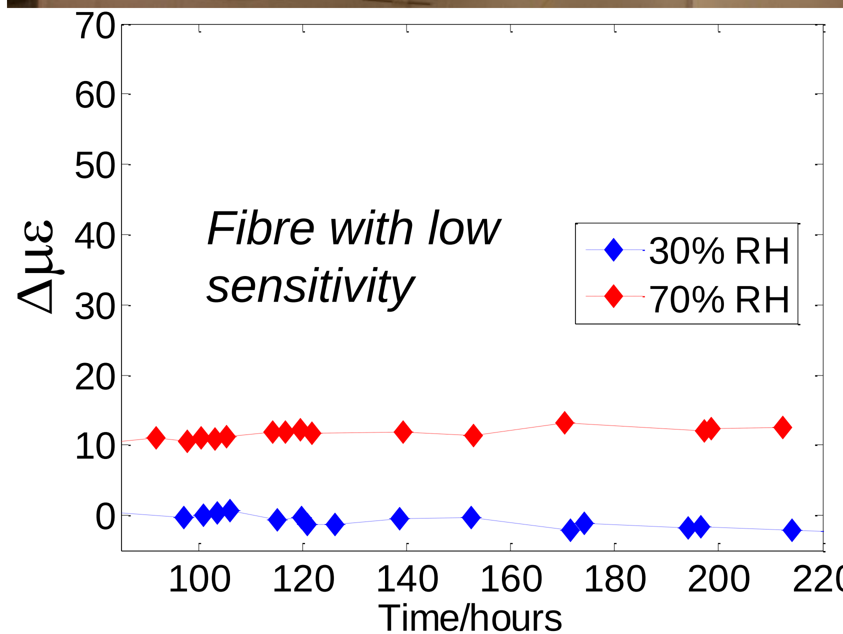
ODIMS - Humidity response









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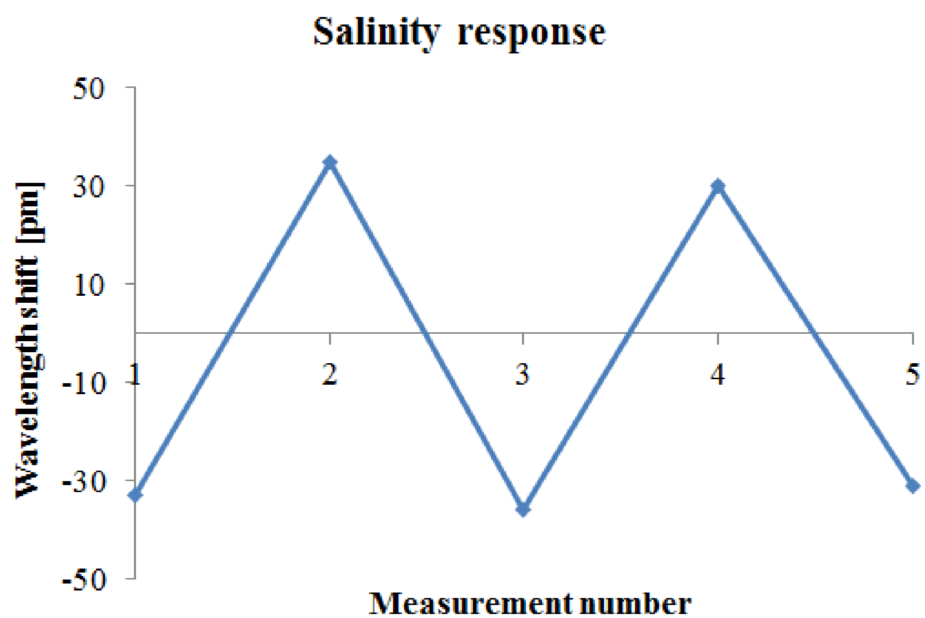
ODIMS – Salinity response

- Water salinity
- Increased salinity reduce water ingress in fibre coating
  => Reduced strain in fibre

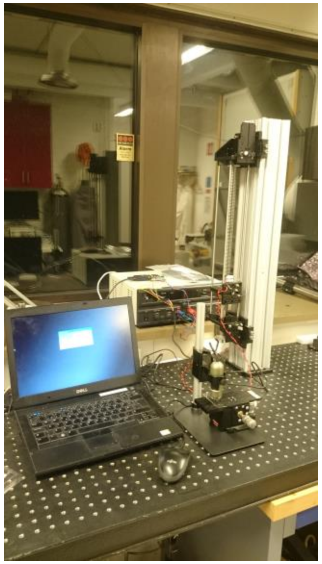
- Figure shows strain in Fibre Bragg Grating (FBG) when alternating between saline water and fresh water

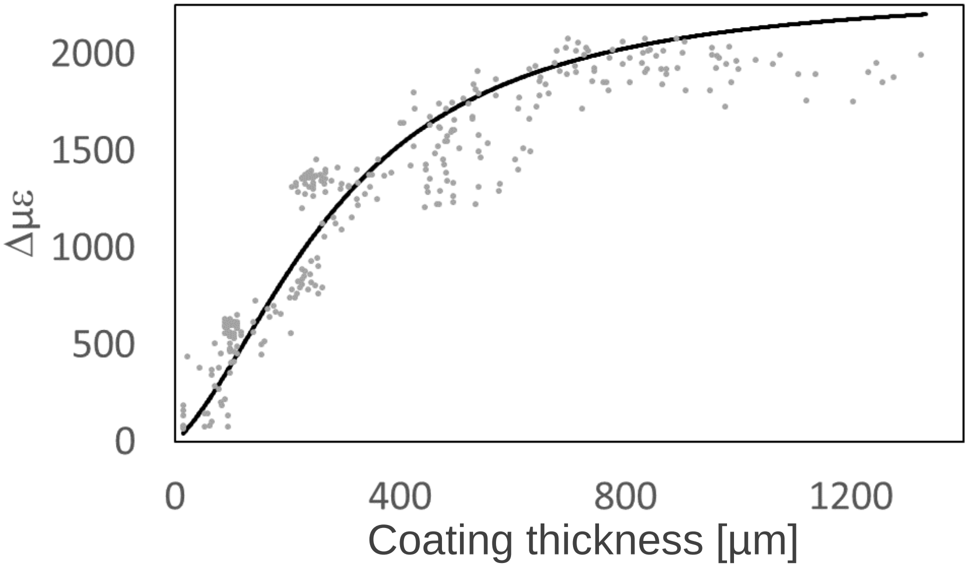
- Quite repetitive response is observed



ODIMS – Enhanced sensitivity coatings

- CMR-built coating setup for investigating effect of coating thickness on sensitivity
- Example of one coating type: Sensitivity levels off when coating thickness > 0.5mm
- Identified theoretical model for describing sensitivity vs thickness
- Increasing thickness reduces response time





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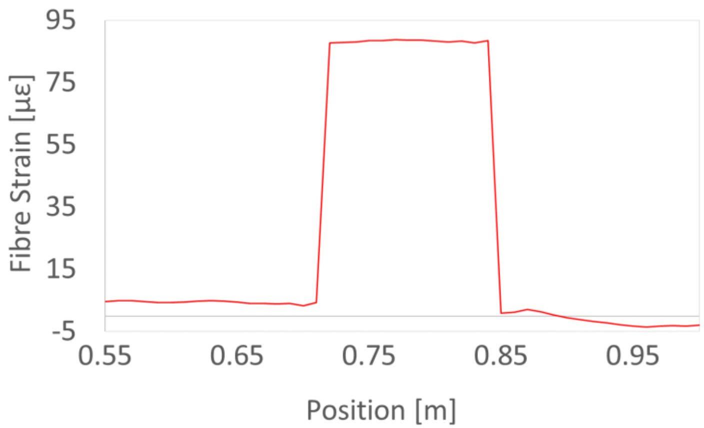
ODIMS – Sensing range

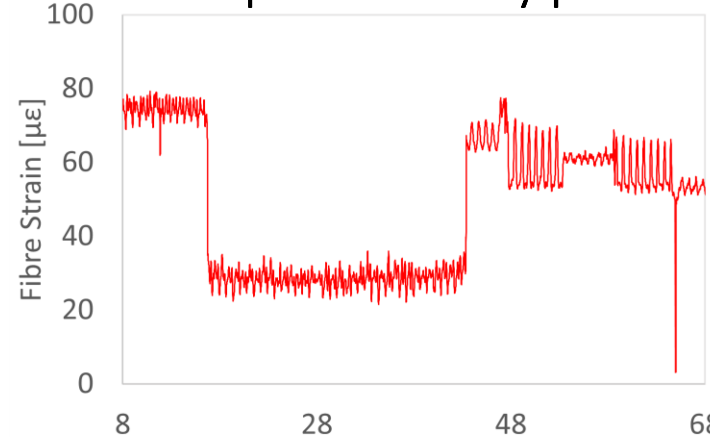
- Have demonstrated excellent measurement resolution over 2 km fiber with high spatial resolution (<10cm)

Mechanical stretch

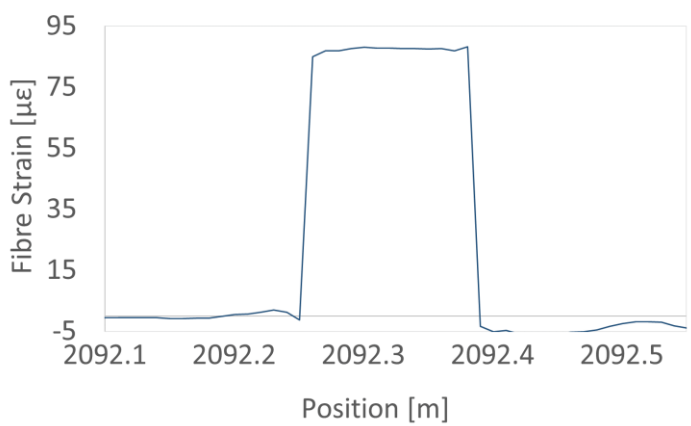
Complex humidity profile

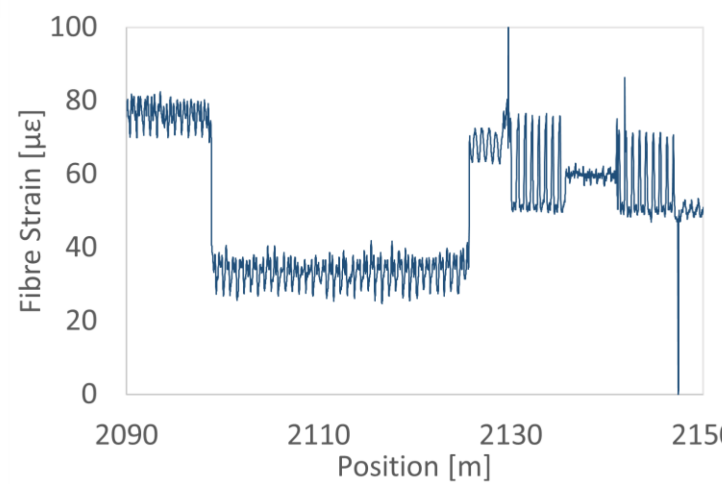
Short range





Long range

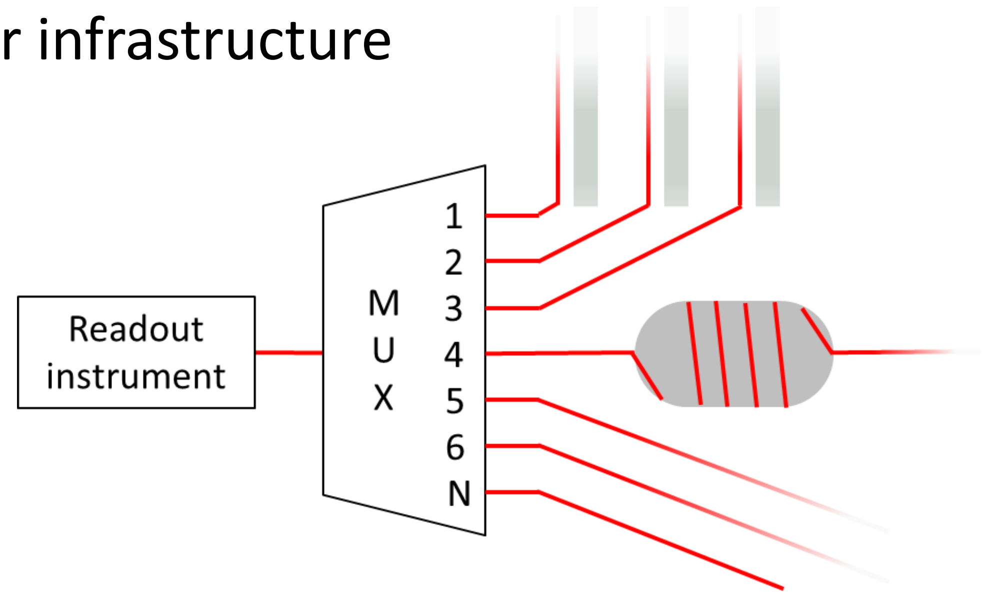




ODIMS – Multiplexing / Sensing range

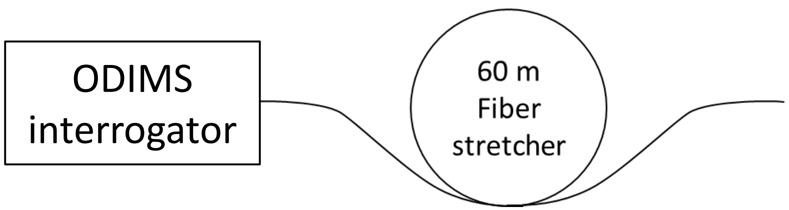
- Multiplexing of optical fibres

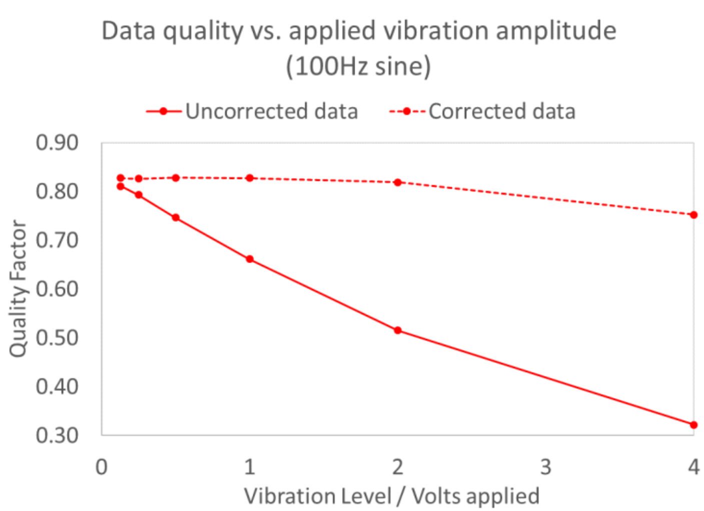
  => Ability to cover larger infrastructure

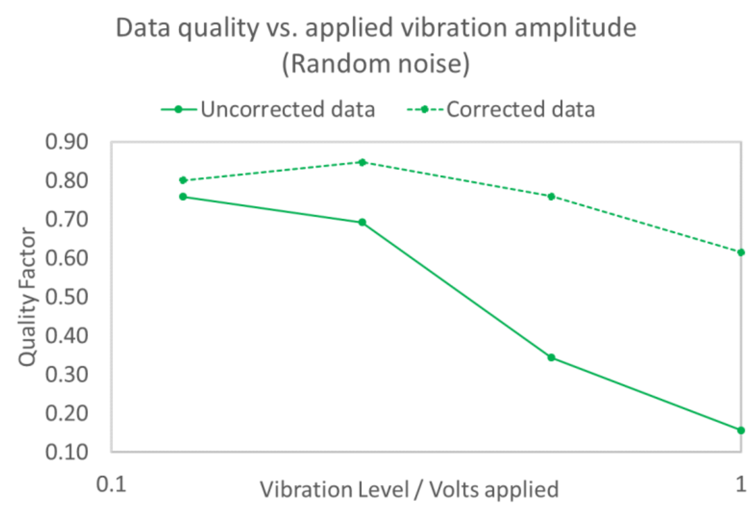


ODIMS - Vibration resistance

- System tested in CMR flow loop rig
- Found vibration might limit sensing range when targeting 2km range combined with cm spatial resolution
- Have successfully tested vibration compensation methodology
- Investigating using ODIMS for making vibration measurements

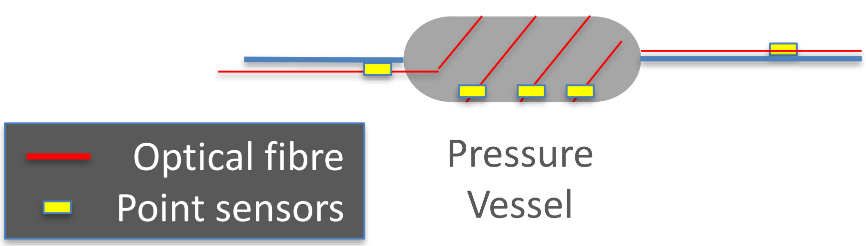


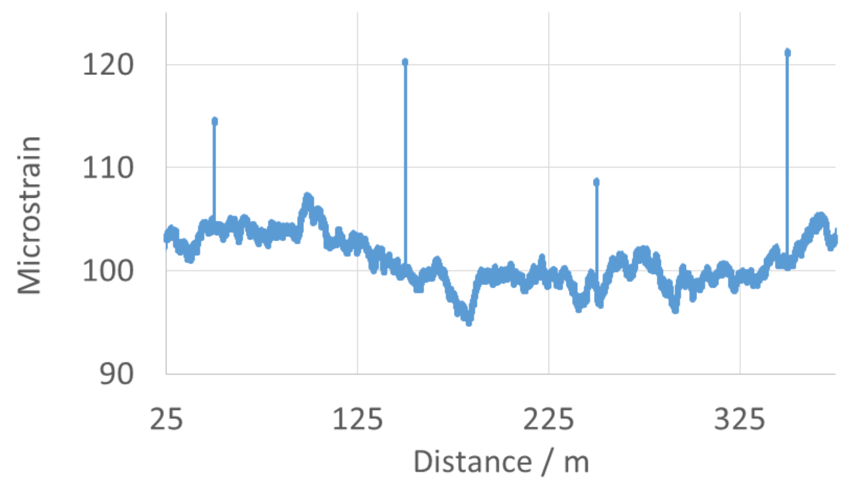




ODIMS - Point sensors option

- Demonstrate the possibility to add point sensors along fibre without the need to break/splice the fibre
- Can be used to add points sensors e.g. wall loss or other types of material degradation
- Can integrate 3rd party sensors



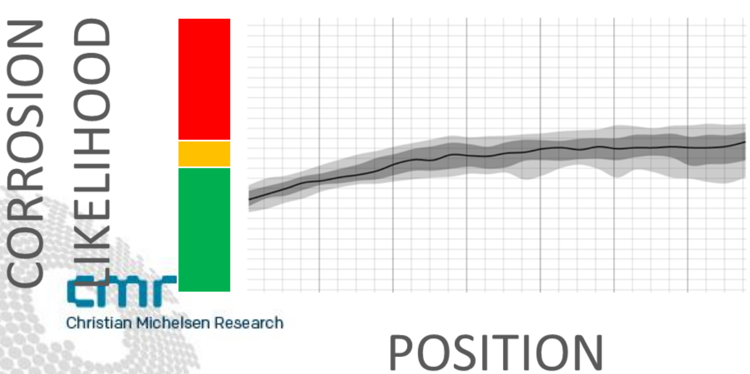


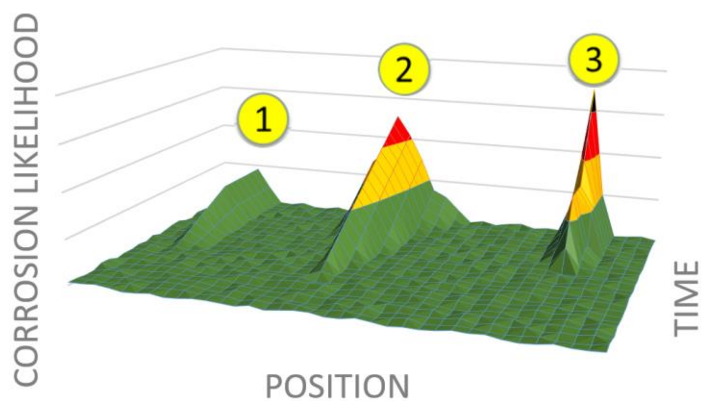
ODIMS - Decision support

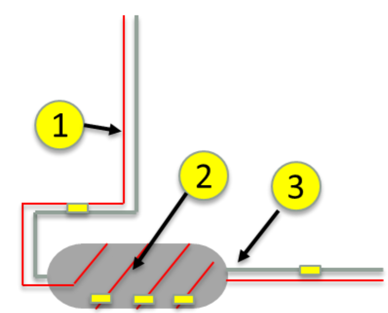
- Decision support system enabling targeted inspection and condition based maintenance

- Statoil and Beerenberg/Benarx will contribute with expertise

- Flexible and scalable decision support system:
  - Automatic calibration
  - Easy expansion and integration of new section or fibres and/or point sensors
  - Visualisation integrated with infrastructure 3D models







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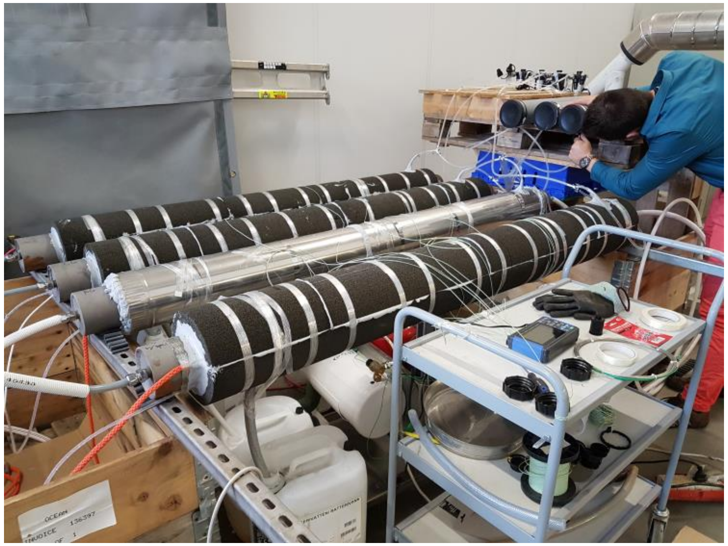
ODIMS – Pilot testing

- 1500 hour test at Benarx's CUI test facilities.
- Humidity sensitive and reference cables installed on carbon steel pipes
- Four different insulation types
- On the fly data analysis



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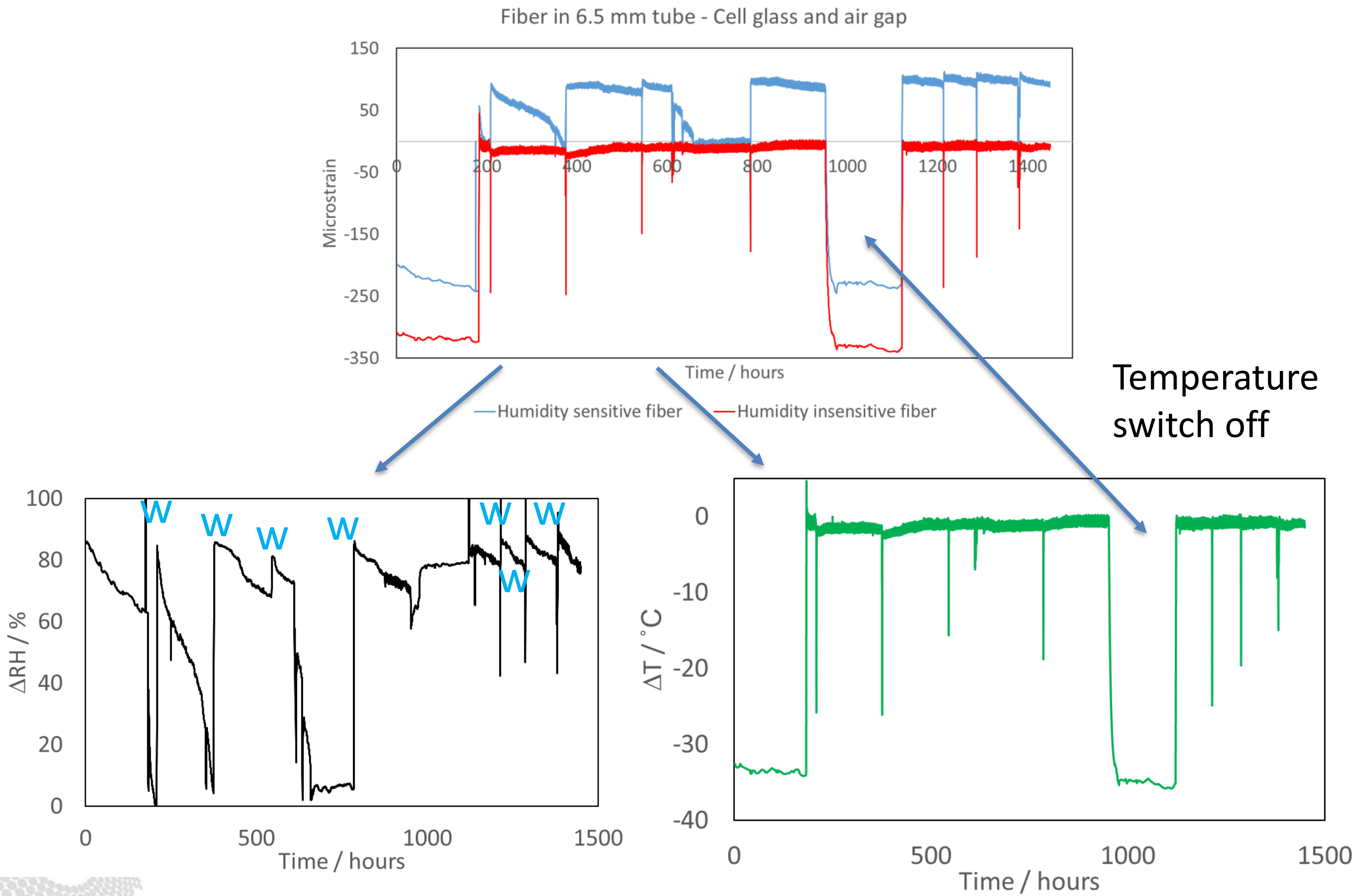
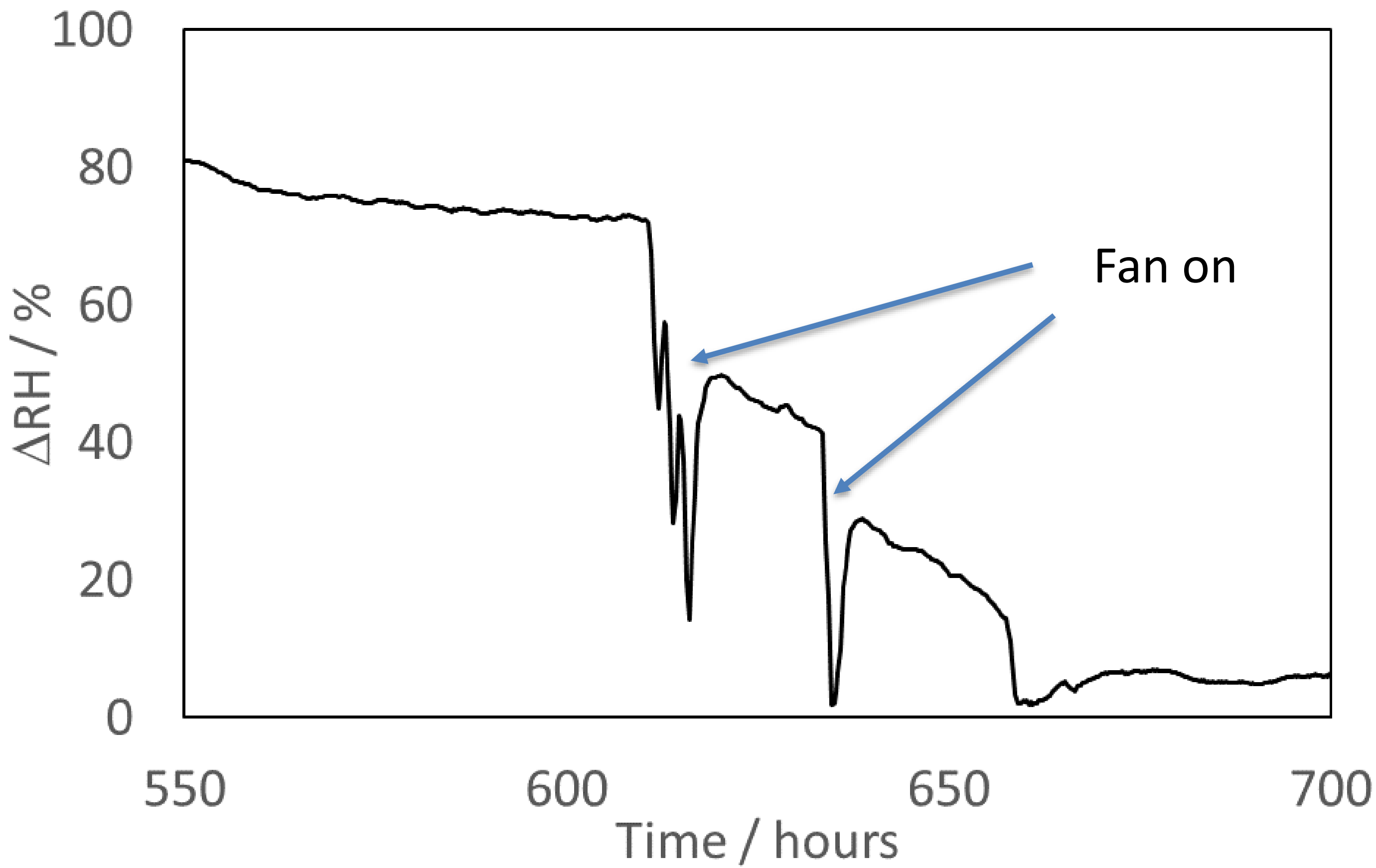
ODIMS - Pilot testing - Results



ODIMS - Pilot testing - Results



Fibre in 6.5 mm tube – Cell glass and air gap - Drying out

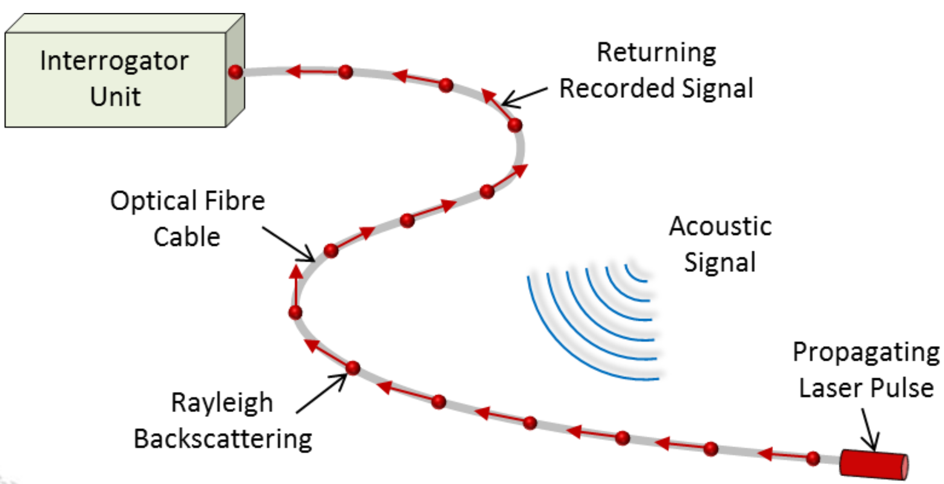
ODIMS - Summary

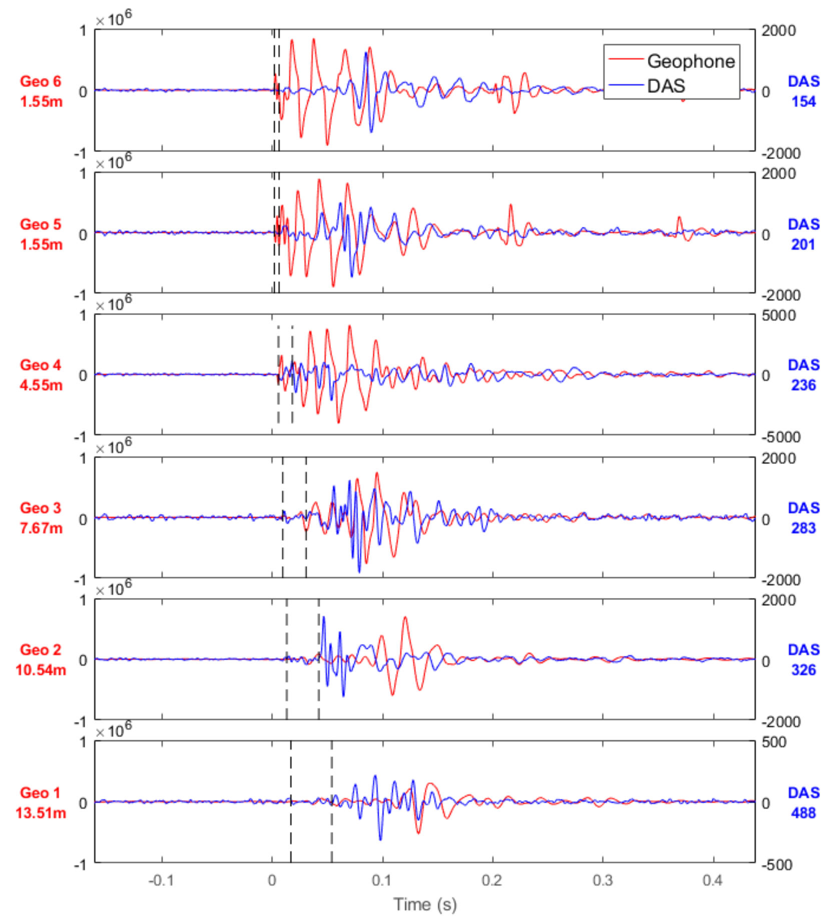
- Demonstrated distributed measurement of;
  - Humidity
  - Water
  - Salinity
  - Temperature
- **ODIMS targeting cost efficient CUI inspection and maintenance**
- Potential to develop ODIMS solutions for other applications
- We are investigating possibility to develop solutions further to monitor more parameters

DISTRIBUTED ACOUSTIC SENSING (DAS)

DAS – CCS Monitoring

- Distributed seismic monitoring for geological carbon sequestration
- Send a fast puls train into the fibre
- Interpret returning Rayleigh backscattering





Geophones vs. DAS

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The Research Council of Norway

CLIMIT

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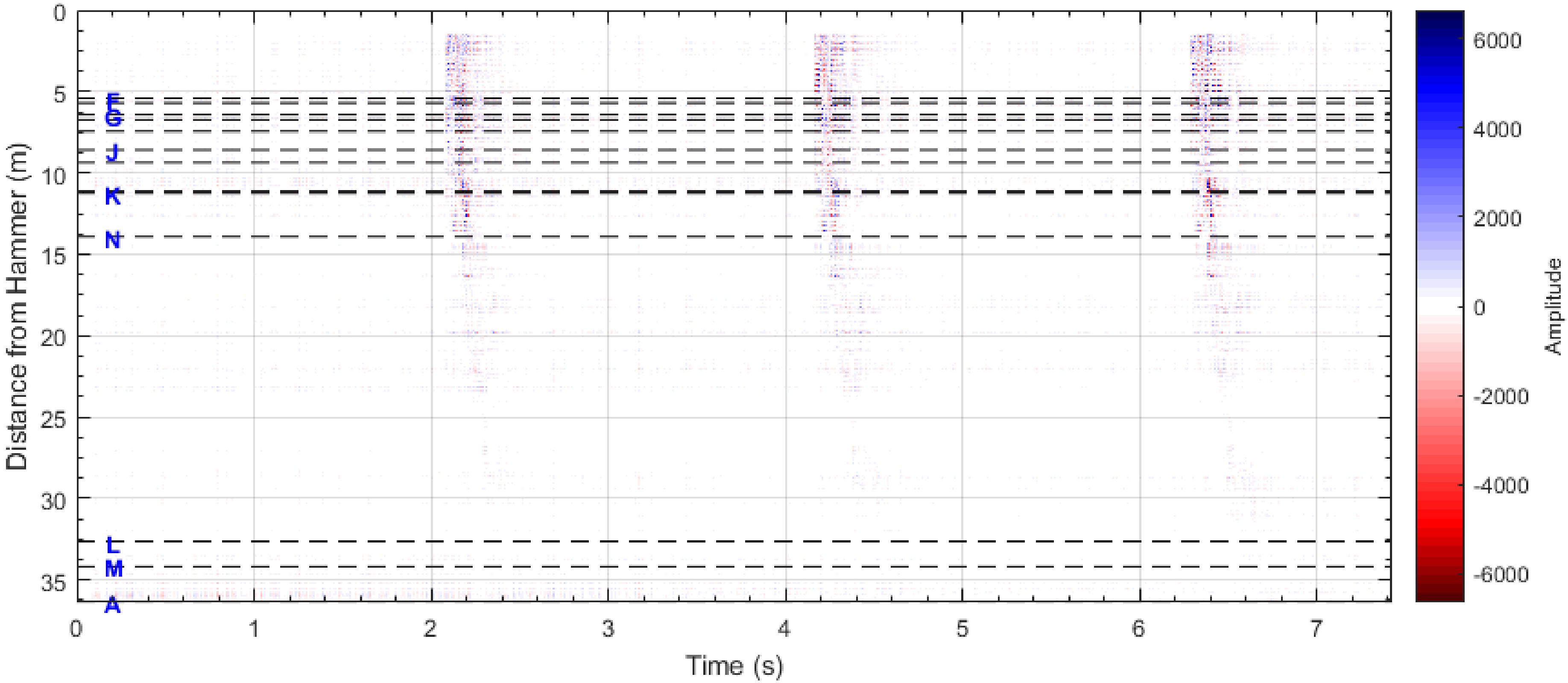
DAS – CCS Monitoring - Example



DAS signal recorded after 3 hammer blows

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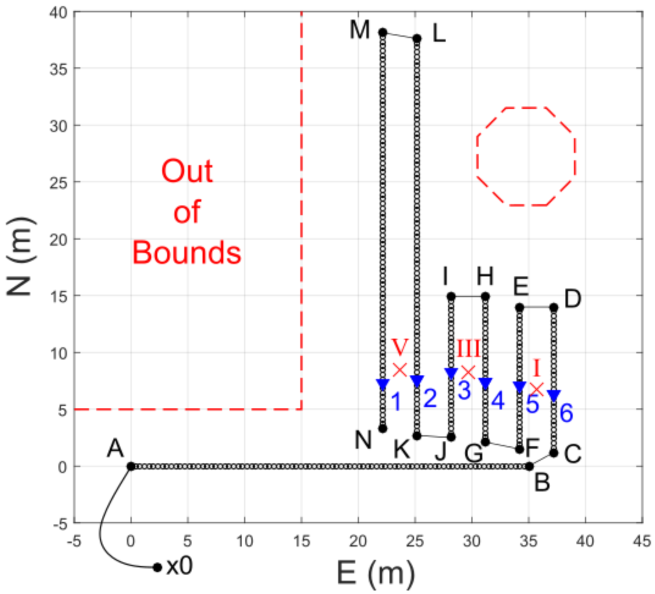
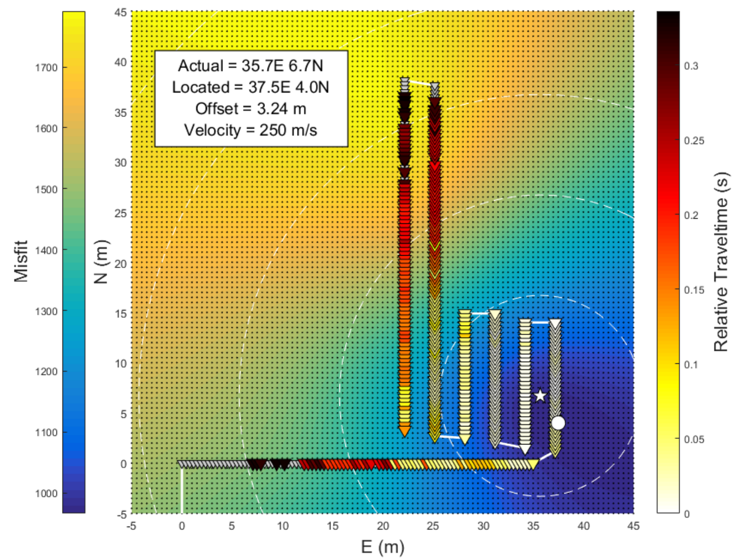
DAS – CCS Monitoring - Shot location test

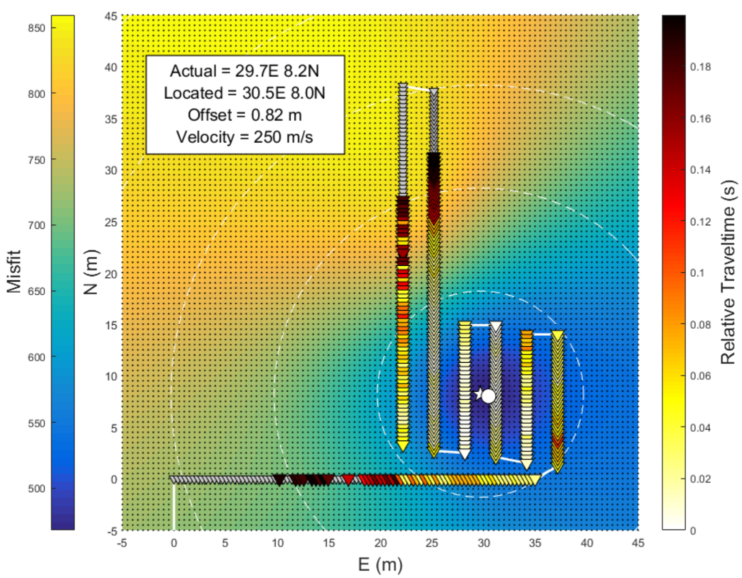


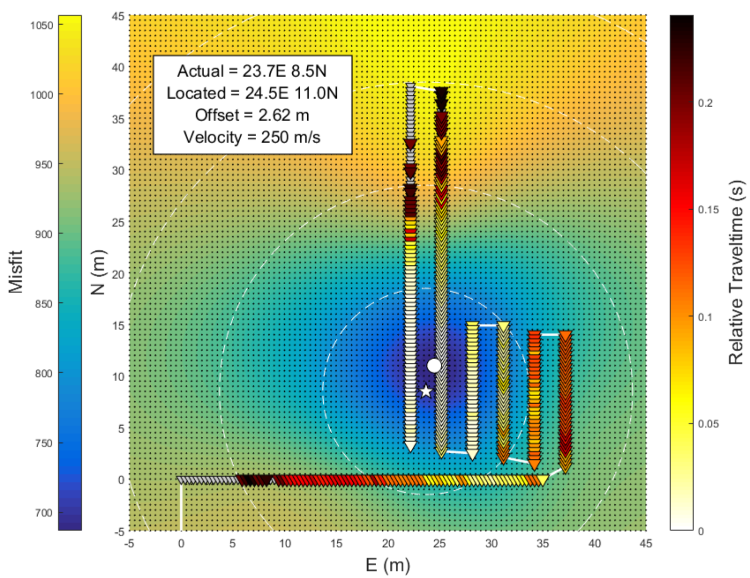


Circles = Source

Star = Location identified by DAS

Quite good agreement. Offset only a few meter

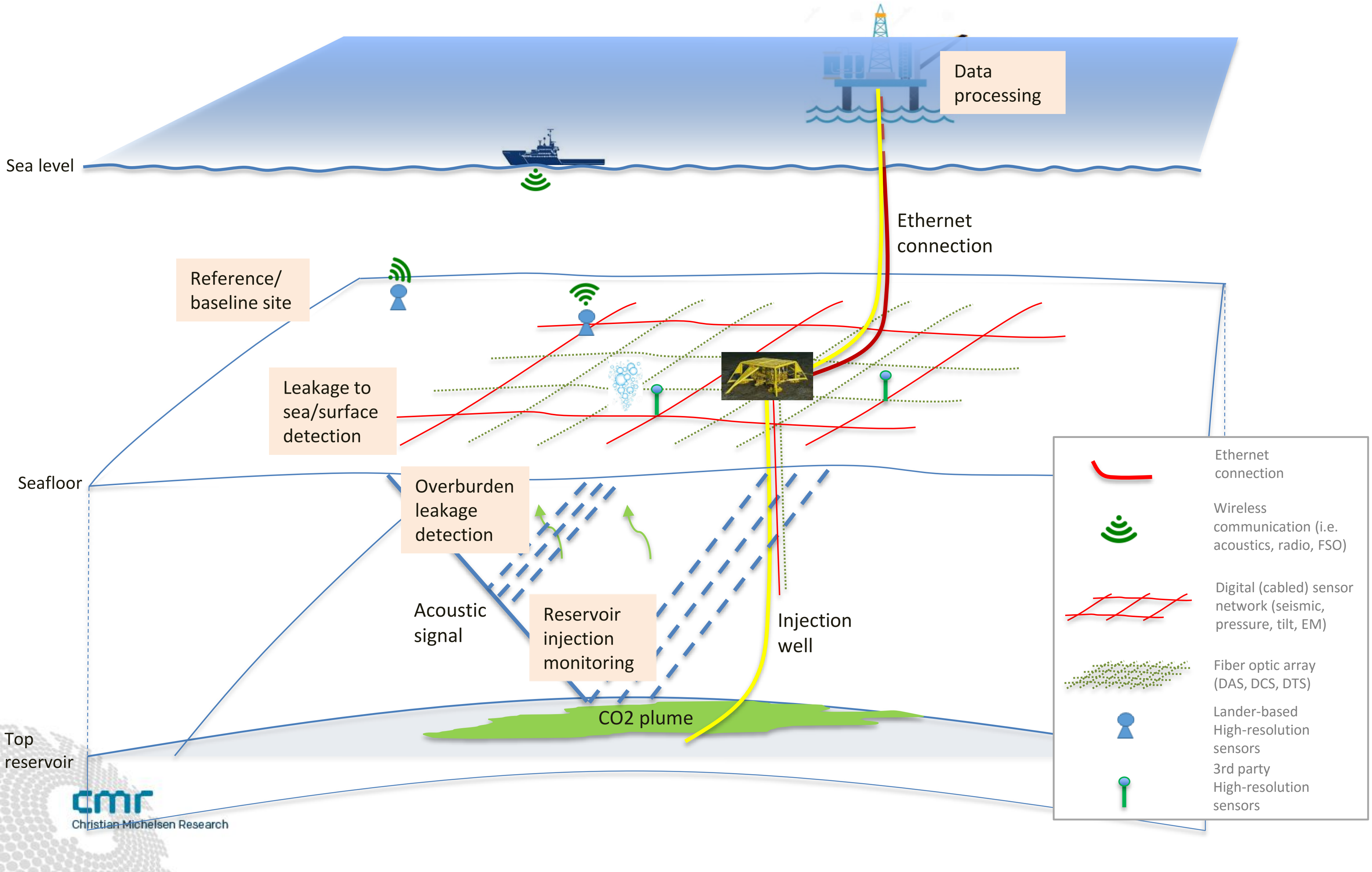




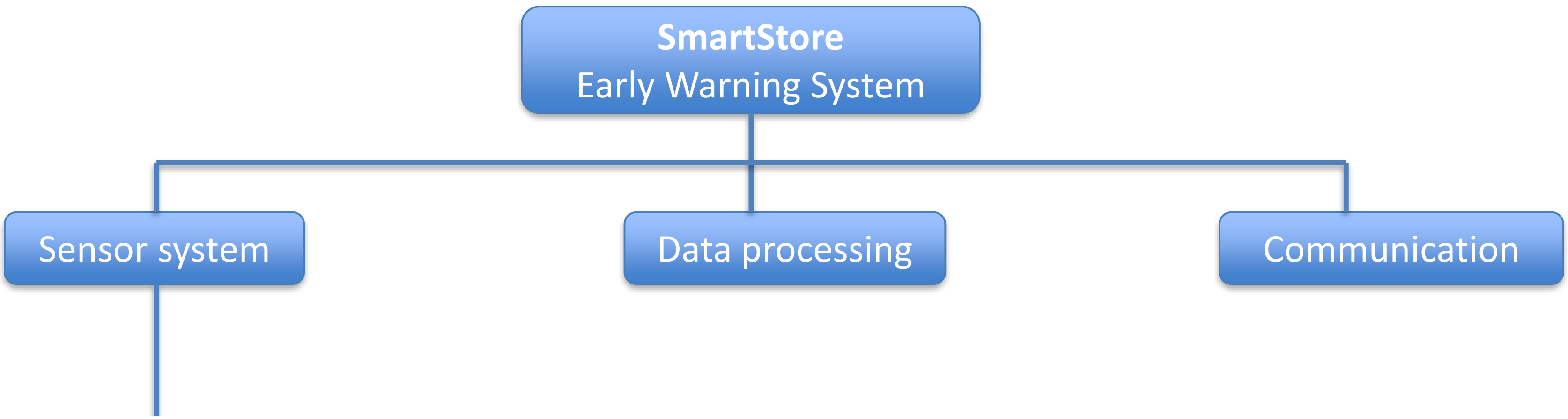
New initiative

DISTRIBUTED SENSING (DXS)

ACT proposal: CO_2 Early Warning System «SmartStore»



SmartStore system and sensor sub-systems



Sub-system/ sampling domain	Seismic/EM	DxS	3rd pty sensors
Water/Air		x	x
Seafloor/surface		x	x
Overburden	x	x	
Reservoir	x	x	

Sub-system/ sensors	Seismic/ EM	DxS	3rd pty sensors
Acoustic signal	x	x	
Chemical signal		x	x
Pressure		x	
Temperature		x	