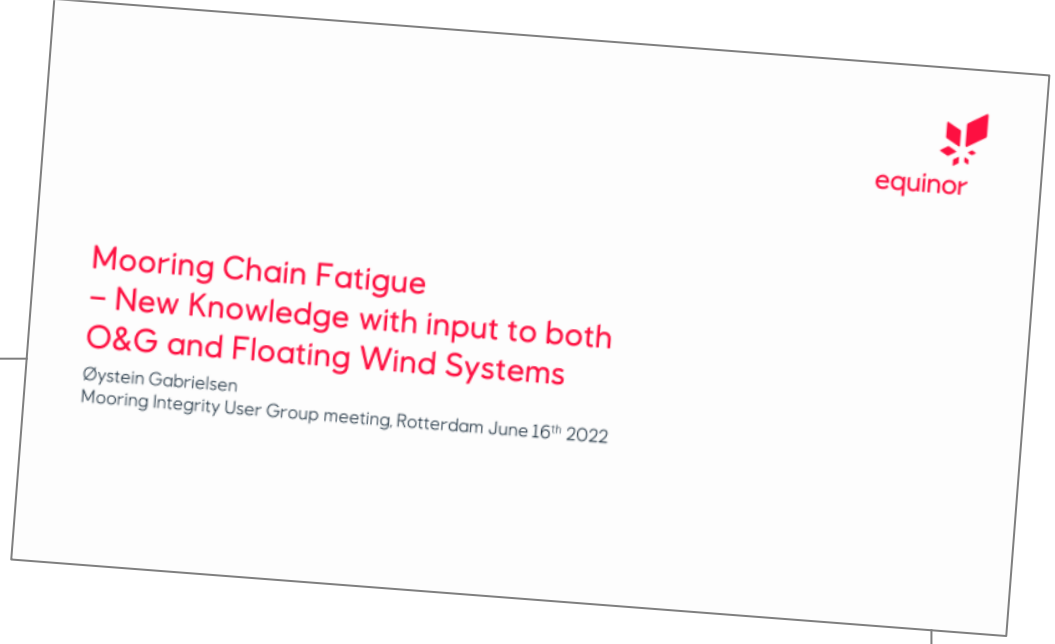
Assessing mooring chain criticality condition from offshore 3D scans - And how to get there!

Øystein Gabrielsen, MIUG Paris, June 29th 2023

Last Years presentation …



Further work

- ✓ Continue full scale testing of used chain
- ✓ Fatigue test chains with significant diameter reduction, especially in combination with pitting
- Increase mean load in tests (new and used chain) to verify fatigue capacity for FWT
- Develop methods to assess chain condition from subsea measurements / 3D scans
- Develop effective chain cleaning and inspection tools
- Verify inspection tools ability to capture corrosion condition (pits, surface roughness, diameter reduction)
  - Subsea 3D scanning
  - Subsea UT (?)

← West Africa asset owners ?

✓ ? ← Lifemoor / Digimoor

Open

Equinor chain conditions

Equinor O&G operates 20 floating assets:

- 270 mooring lines, all with chains
- On average 17 years in operation
- 10 assets older than 20 years (oldest: 28 years)

Recap – conclusions after fatigue testing

Batch	Chain type	Condition	Years in op.	Tests -> 2023	Tests 2023 ->
A	top chain	wear	12	4	
B	top chain	pitting	10	6	
C	top chain	wear	13	9	
D	top chain	contact damages	7	4	
E	top chain	wear	15	4	
F	seabed chain	pitting	14	4	
G	top chain	pitting	5	4	
H	top chain	wear	16	3	
I	seabed chain	pitting	18	9	
J	seabed chain	pitting	17/20	8	
K	top chain	pitting	12	5	
L	top chain	wear	21	3	
M	seabed chain	pitting	19	7	
N	seabed chain	pitting	19	7	
O	midwater chain	pitting	18	4	
P	seabed chain	pitting	19	10	
Q	seabed chain	pitting	22	5	
R	seabed chain	pitting	21	3	
S	seabed chain	pitting	16	3	
T	seabed chain	general + SRB	21	3	
U	seabed chain	general + SRB	25		4

\+ 2023 incoming chains

\+ ND new chain + TWI new chain + Vicinay new chain + FoCCs

- Important for mooring chain fatigue:
  - Mean load
  - Surface condition
    - Effect of corrosion grades 1-7 defined
  - Corrosion loss
    - Ongoing work

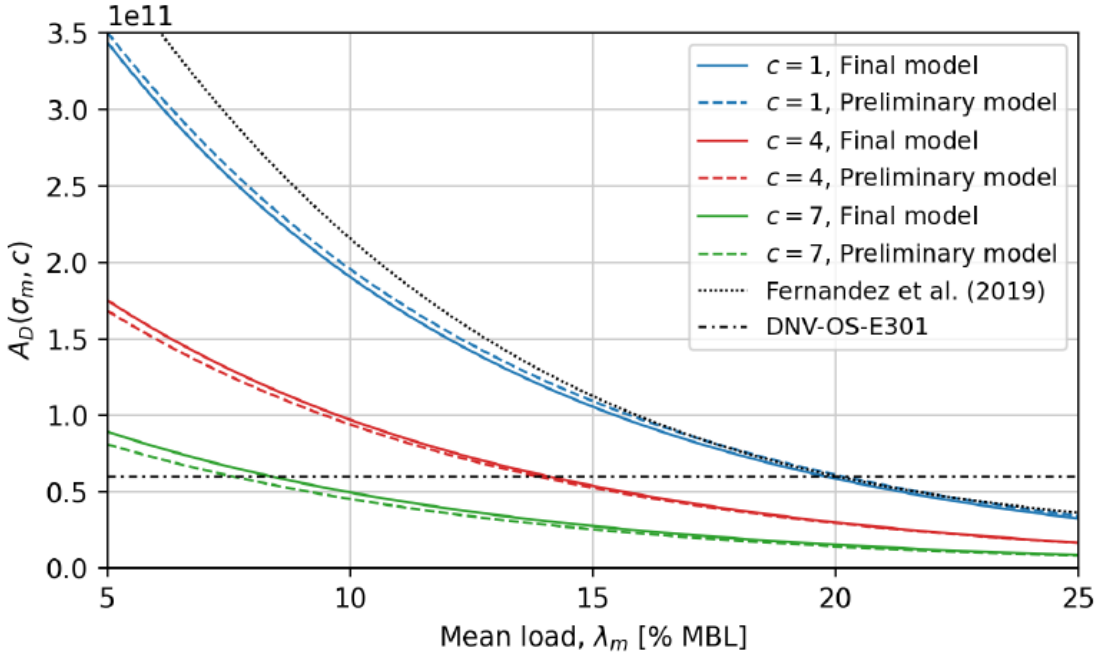
Mean load and surface condition – Lone formula revised

Lone 1.0

$$\log N = 12.249 - 0.0507 \cdot \lambda_m - 0.106 \cdot c - 3.0 \cdot \log S$$

N	Number of cycles
λ_m	Mean load in % of MBL
c	Corrosion condition grade (1-7)
S	Nominal stress range in MPa

- Update of the formula:
  - Advanced hierarchical statistical analysis
  - Including more data
- Presented in Marine Structures, Volume 91, September 2023
  - *103466 - Analysis of S–N data for new and corroded mooring chains at varying mean load levels using a hierarchical linear model*



Preliminary model **Lone 1.0**
Final model **Lone 1.1**

Lone 1.1

$$\log N = 12.236 - 0.0514 \cdot \lambda_m - 0.0977 \cdot c - 3.0 \cdot \log S$$

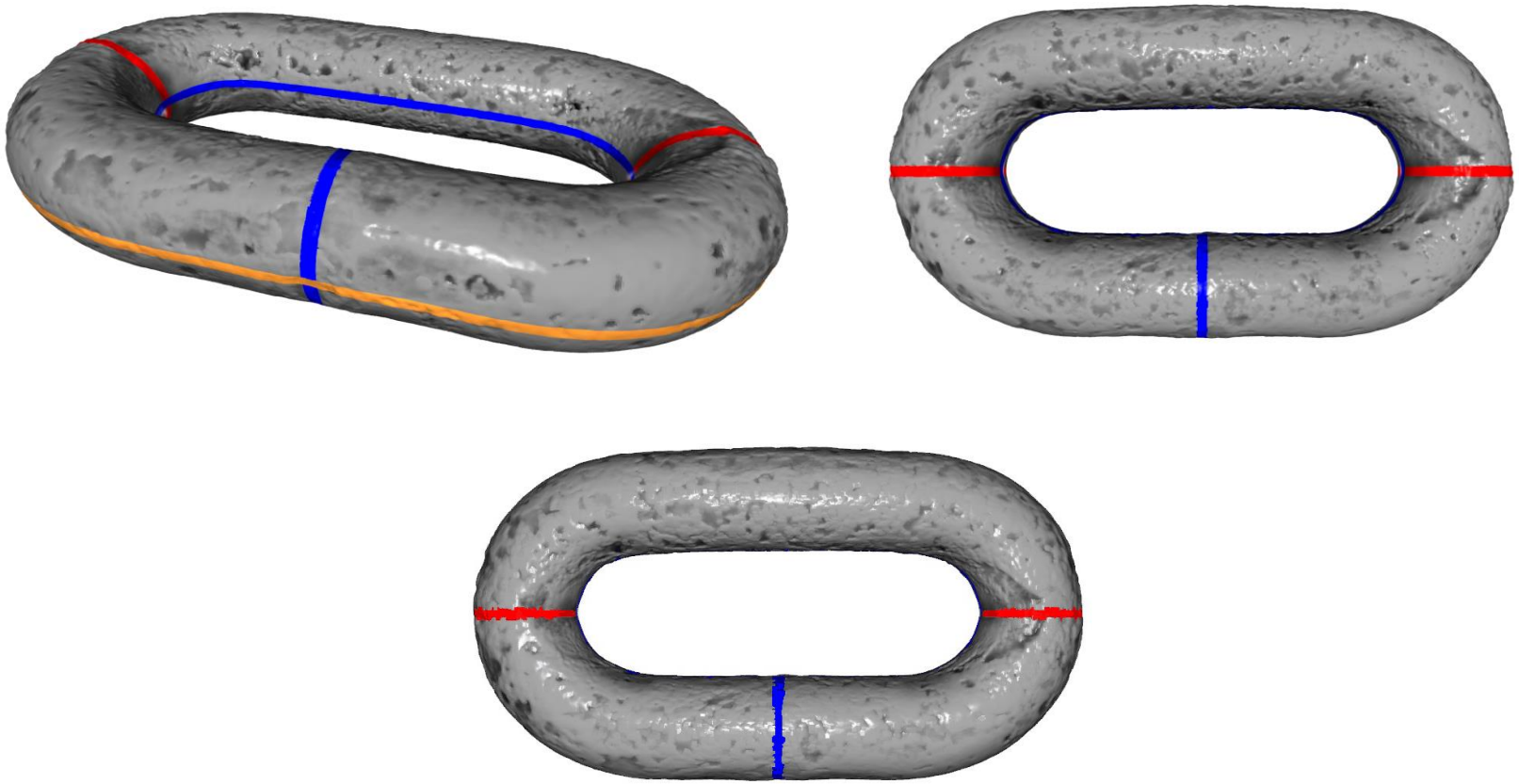
Effect of corrosion loss on fatigue

- Corrosion loss has a significant effect to fatigue capacity
- Worse in combination with rough surface

Corrosion loss not covered by corrosion condition 1-7

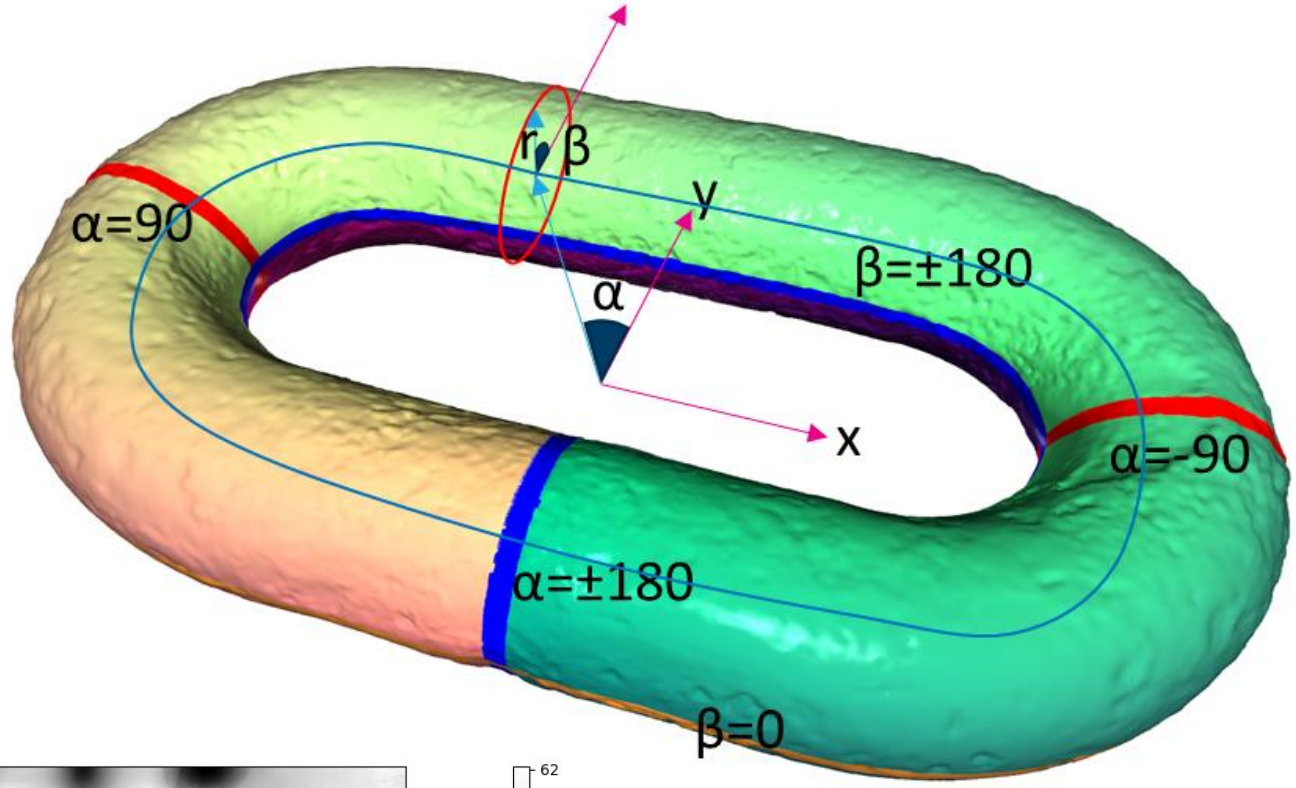
Assessing criticality / Post-processing of 3D scans

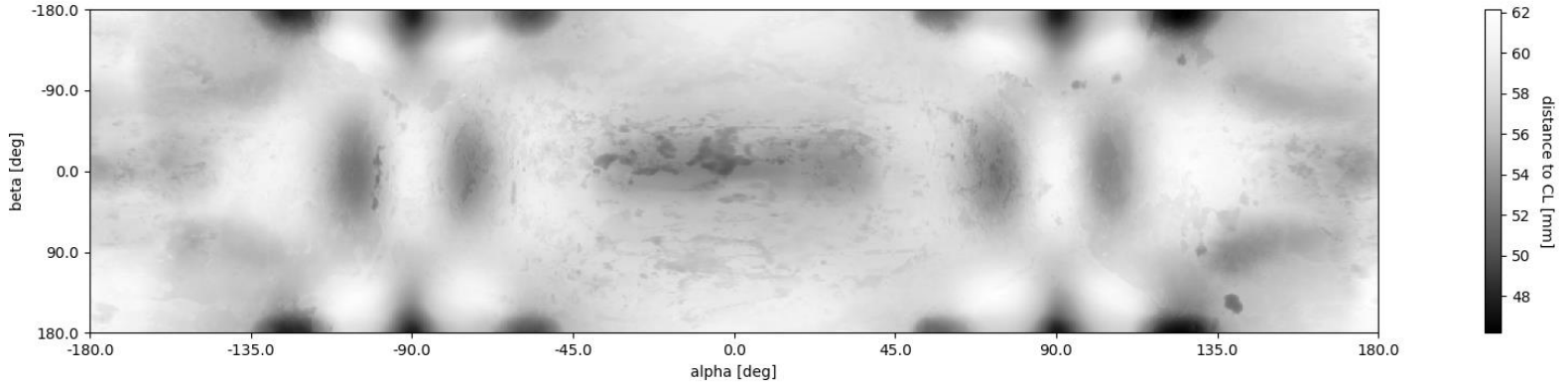
Lifemoor – surface corrosion map – from 3D to 2D



2D coordinate system

- $\mathbf{x}=\mathbf{x}_{cl}(\alpha)+\mathbf{n}_{cl}(\beta)r$
- A transform from (x,y,z)[mm] to the (α,β,r) [deg,deg,mm].
- No loss of information in the mapping.
- Interpolate unstructured (α,β,r) data to structured (α,β,r) data. Can obtain arbitrary resolution.

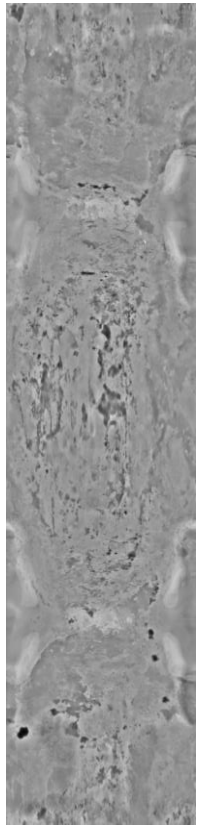




Post-processing surface topology analyses are then performed

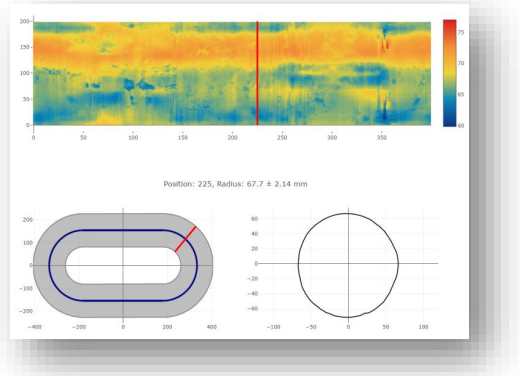
Point clouds

Texture unwrapping

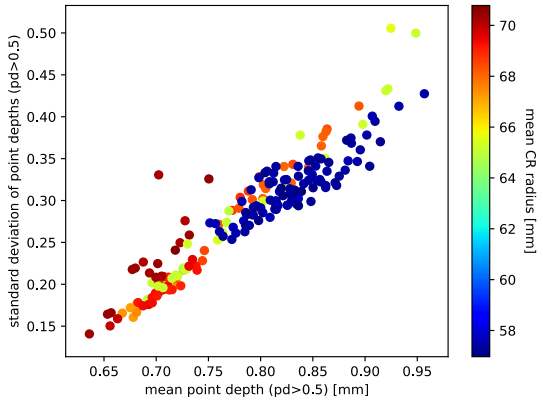


Analysis

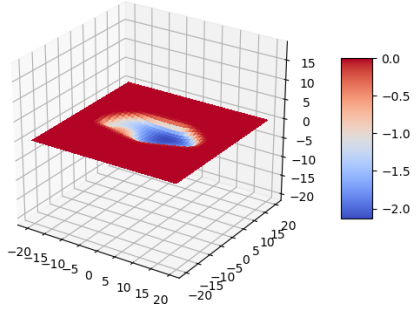
Wear (cross section profile)



pits depth distribution



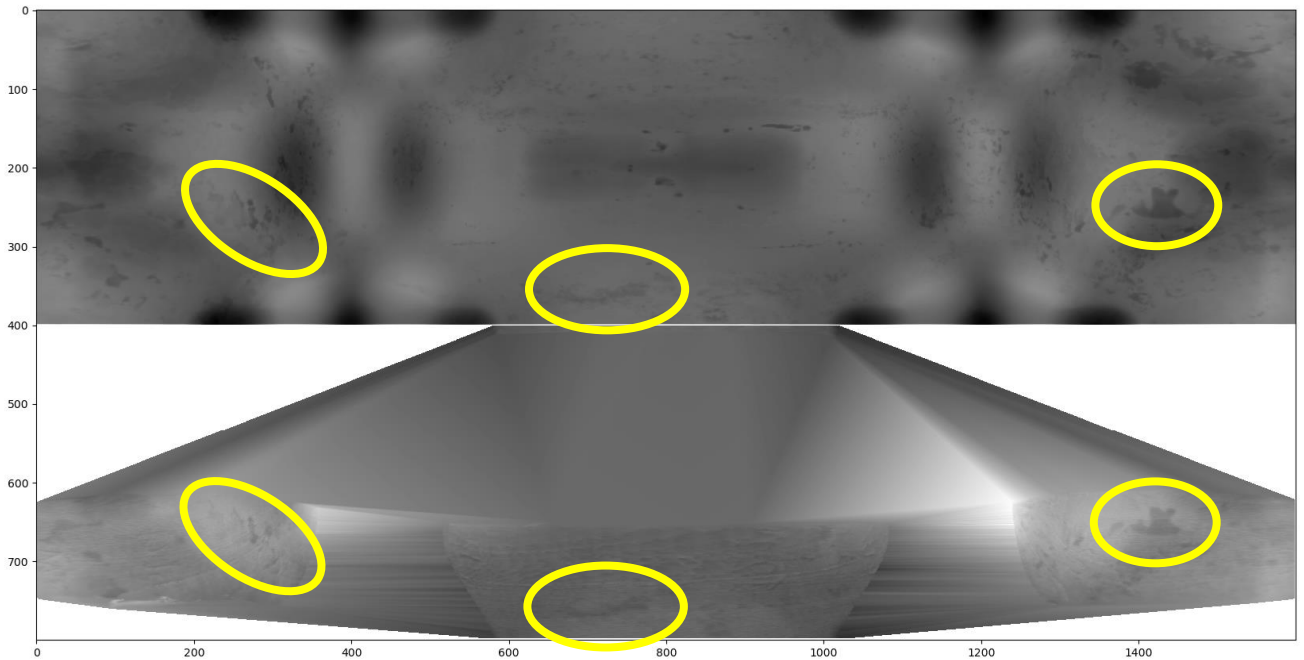
Single pit morphology

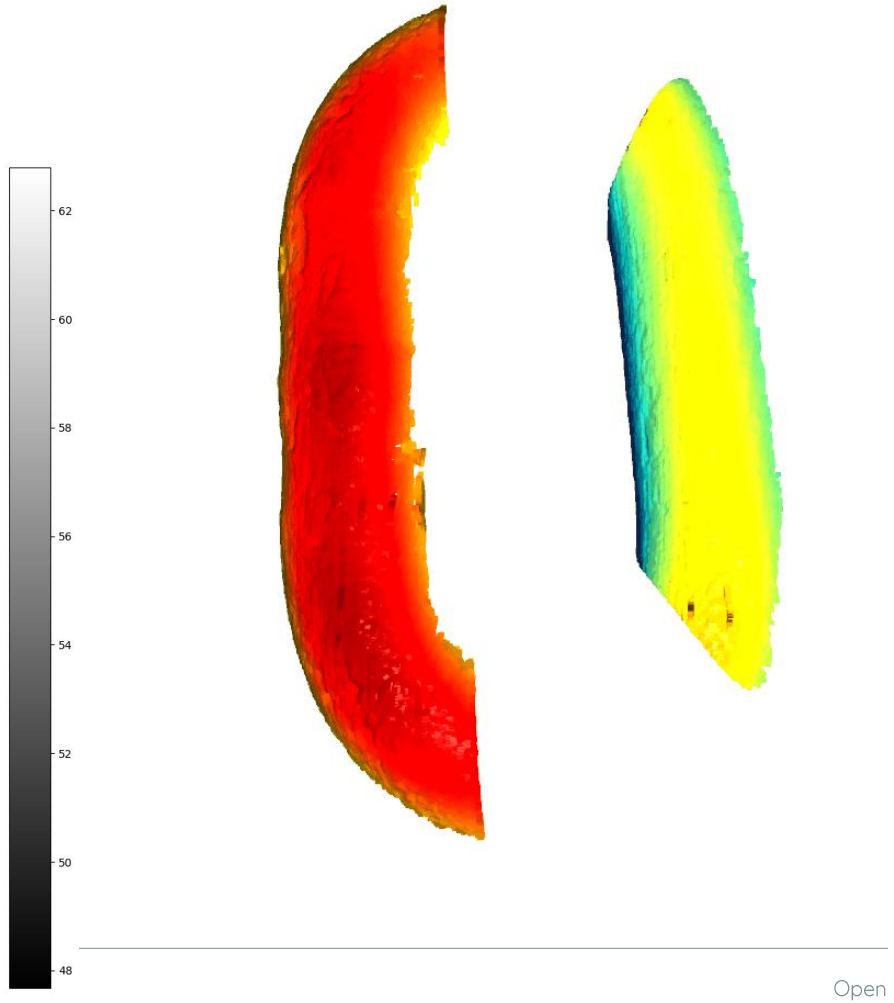


Objective Corrosion indicator(s)

Comparison – lab scan vs submerged scan (Kraken SeaVision)

- Single pass scan
- 150k points
- Inside/outside crown not vissible
- 40% area coverage

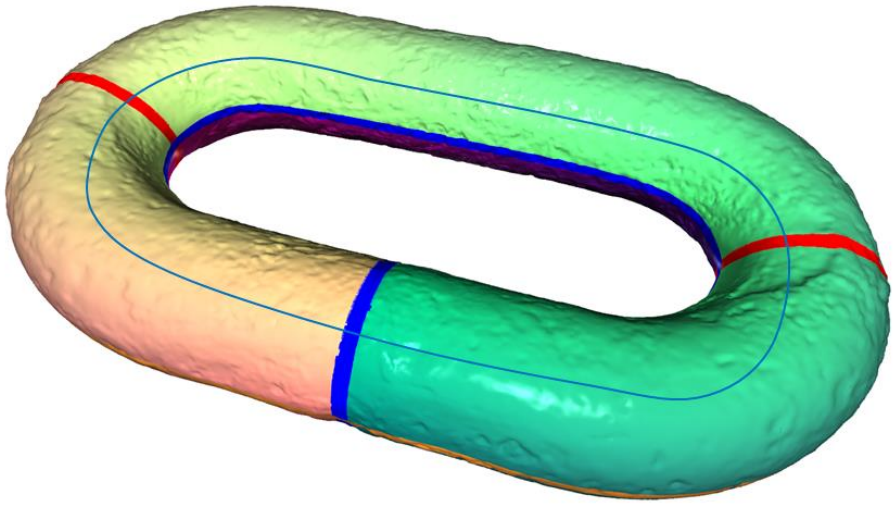


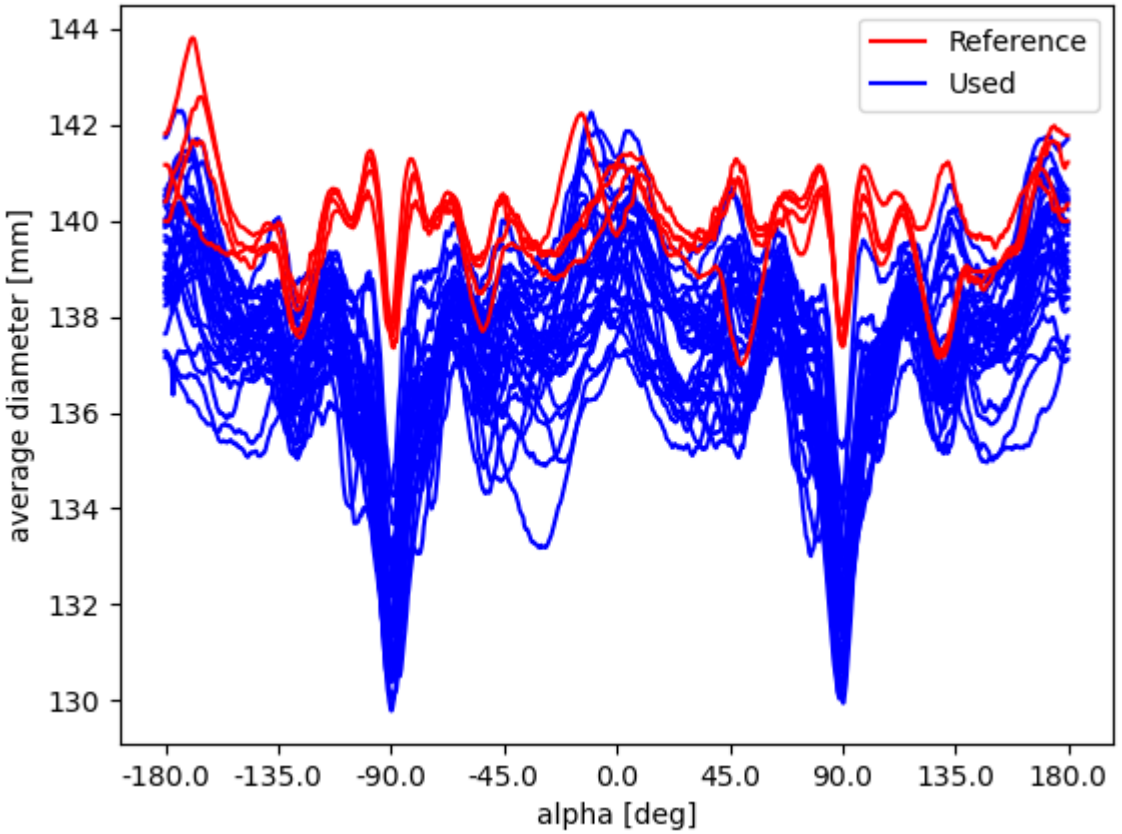


ObjoCorr – expanding to include significant corrosion loss

- Expanding algorithm to include:
  - Define centerline for subsea scans
  - Define corrosion loss including location
- Calibration with full scale fatigue tests with significant corrosion loss

- First phase ongoing (Equinor funding)

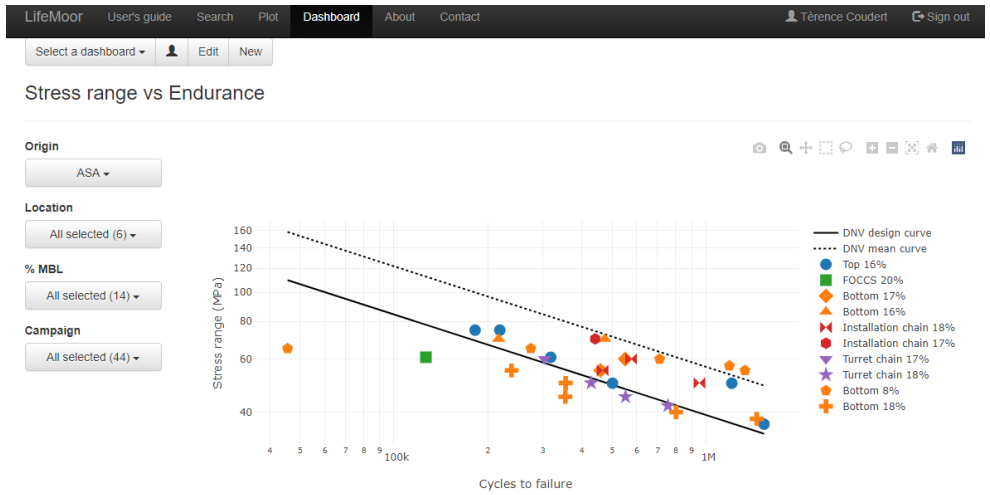


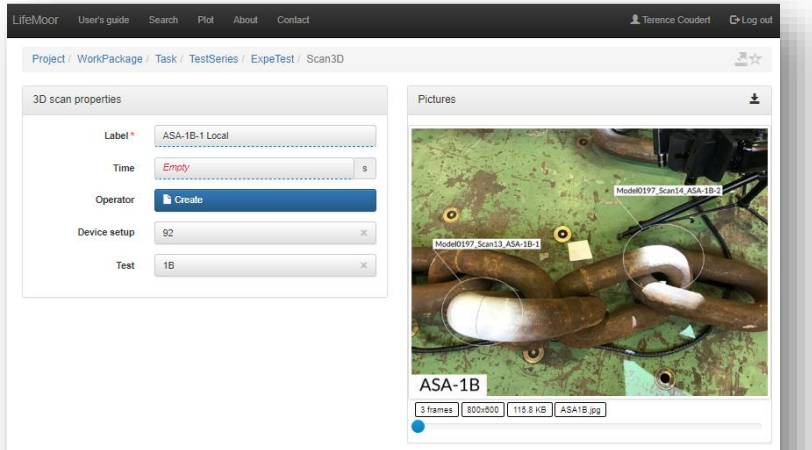


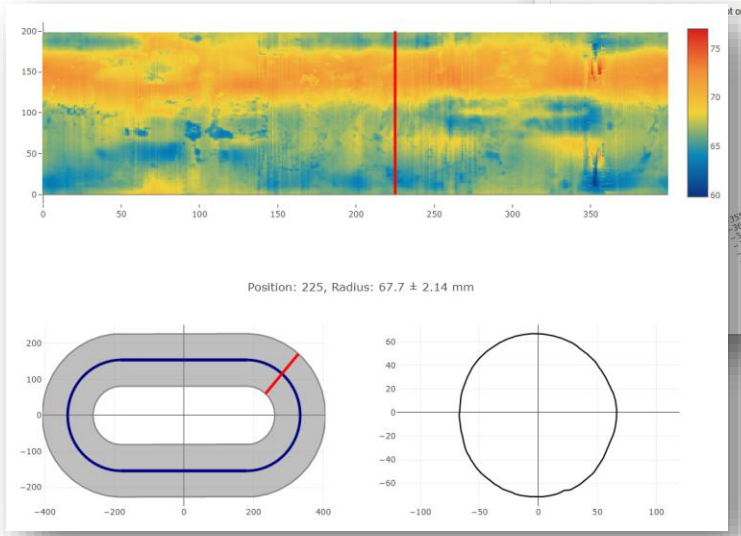
ObjoCorr – location of corrosion loss

Lifemoor/ObjoCorr Database

- Dashboard
- Interactive radius map
- Python interface (data processing)
- ~650 3D scans







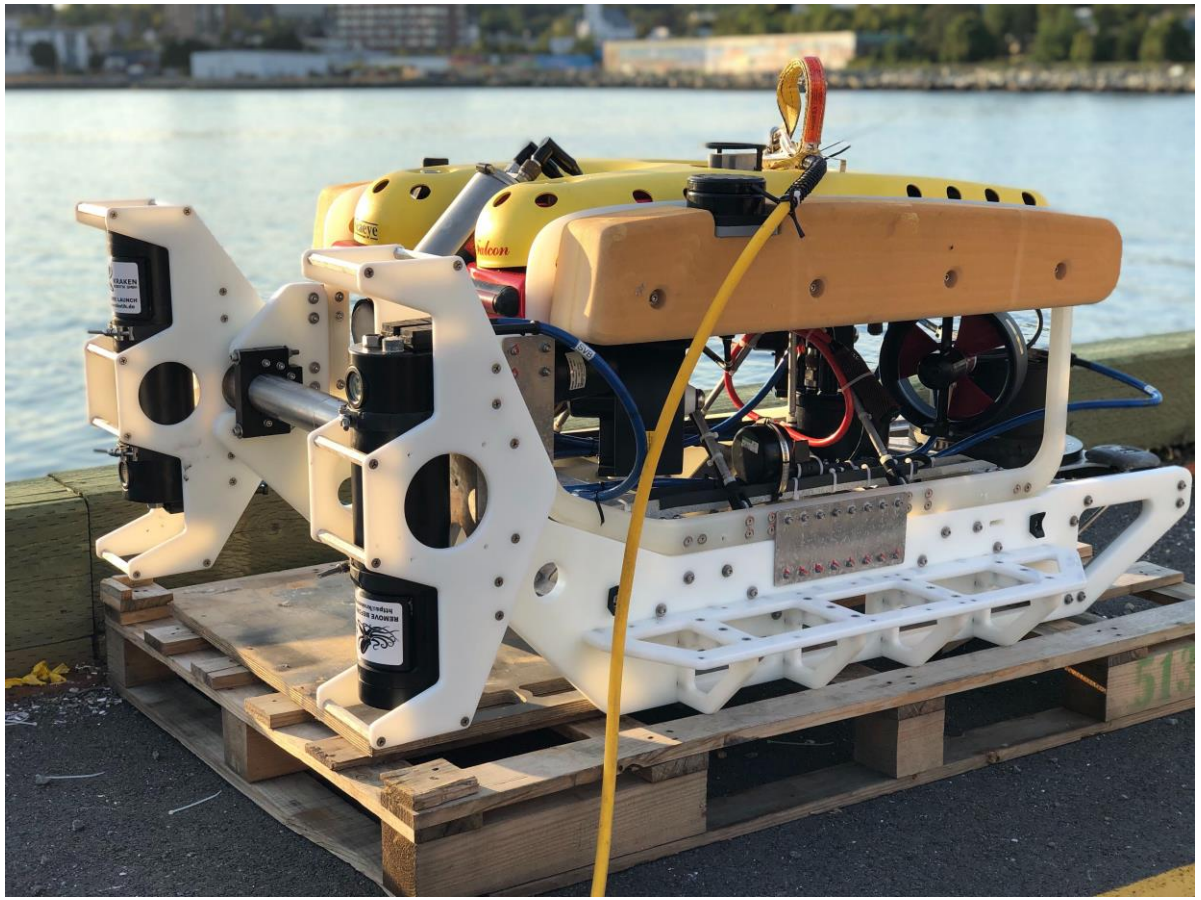
Offshore 3D scanning

3D scanning – What is the status?

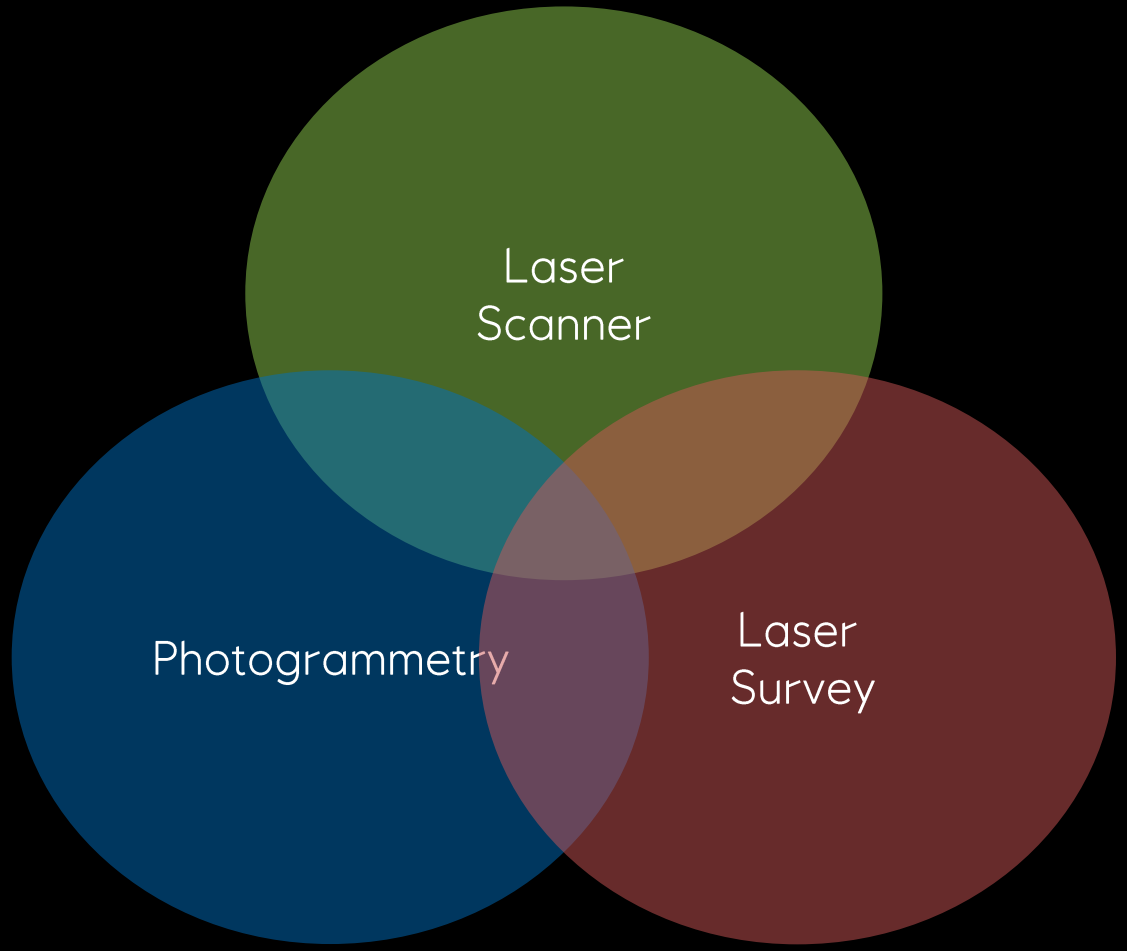
- 3D scanning requirements is established for enable use of post processing tools:
  - Max offshore 3D surface grid of 1-2mm is required (the smaller the better)
  - All visible surface needs to be scanned – including crown
- Class measurements are of lesser value !!

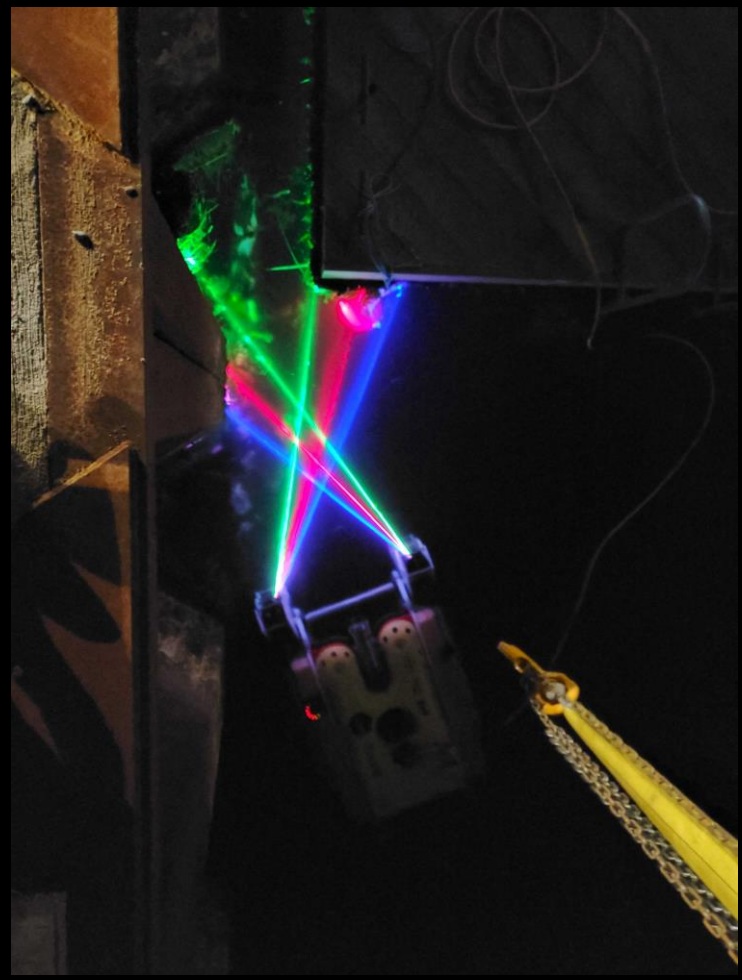
- Equinor verification of offshore scanning tool: Kraken SeaVision
  - Accuracy is verified
  - In-pool scanning confirm 1mm grid as acceptable
  - Offshore scanning confirms accurate 1-2mm grid – with heavy chain motions
  - Scans are verified for Sintef post-processing

Kraken SeaVision



SeaVision - Combine multiple aspects of computer vision in one sensor

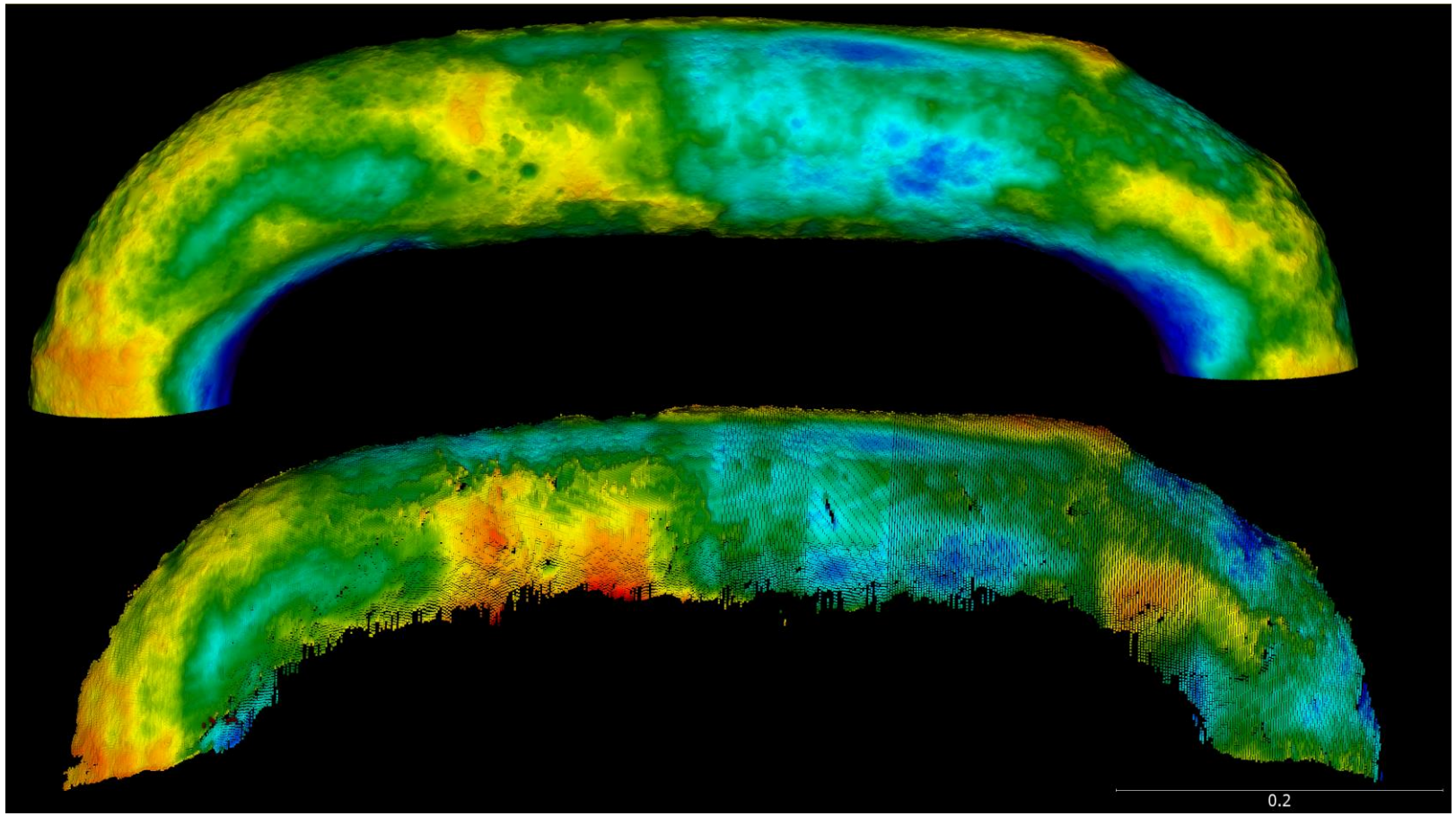




Corrosion Detection
In details at 2m distance, 2mm step

Post replacement
lab-scan (dry)

SeaVision
offshore @ 2m



Kraken SeaVision

- Laser scanning technology
- Fast scanning allowing moving objects
- 1mm step / grid
- Meets class measurements requirements
    - Approval ongoing
- Own postprocessing tool
- Verified accuracy
- Scans OK for post-processing by Sintef algorithms

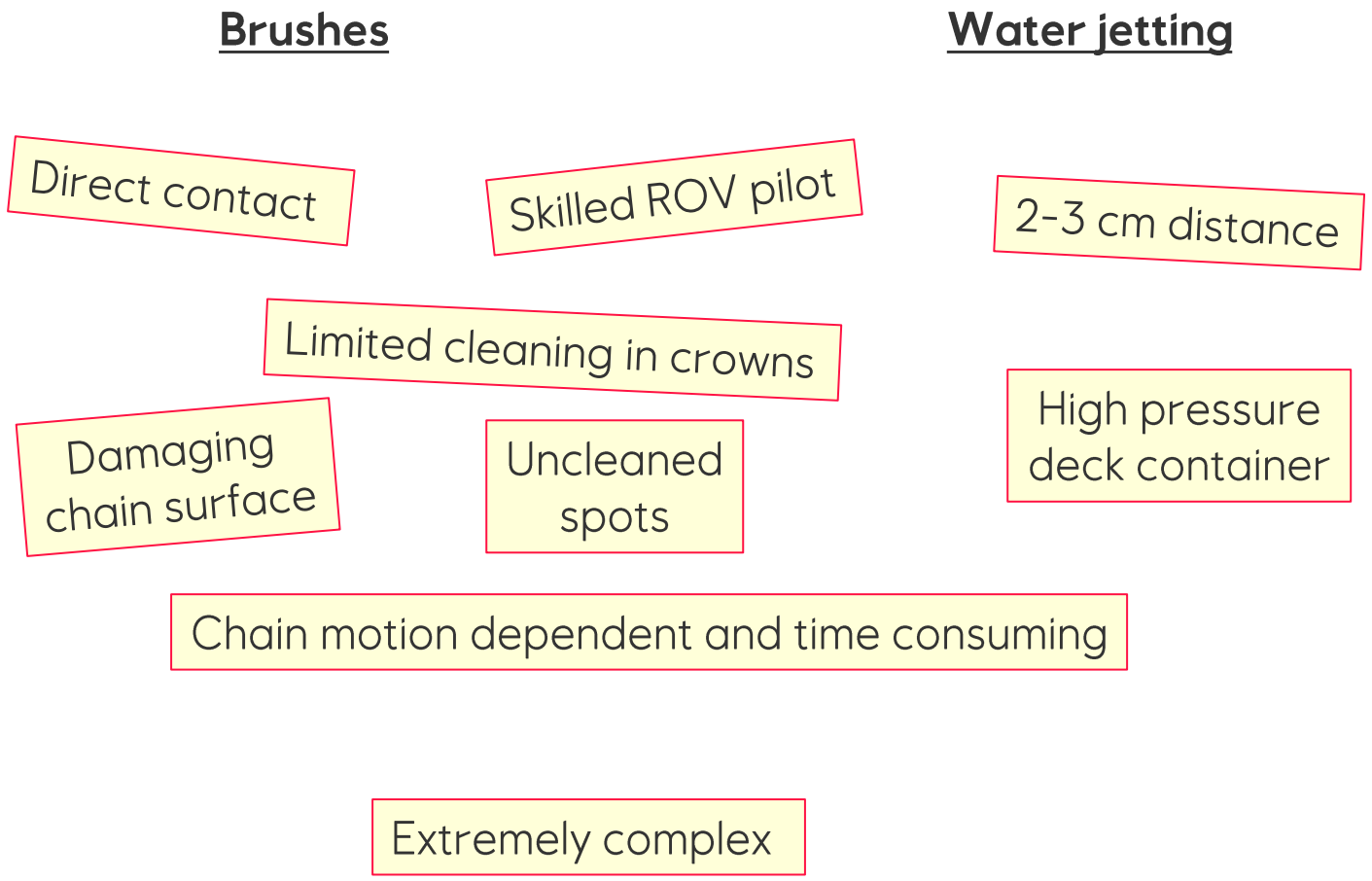
Onshore verification:
Submerged scanning of lab-scanned chain

Offshore verification:
Chain re-scanned onshore (by DNV)

Cleaning of chains (access for scanning)

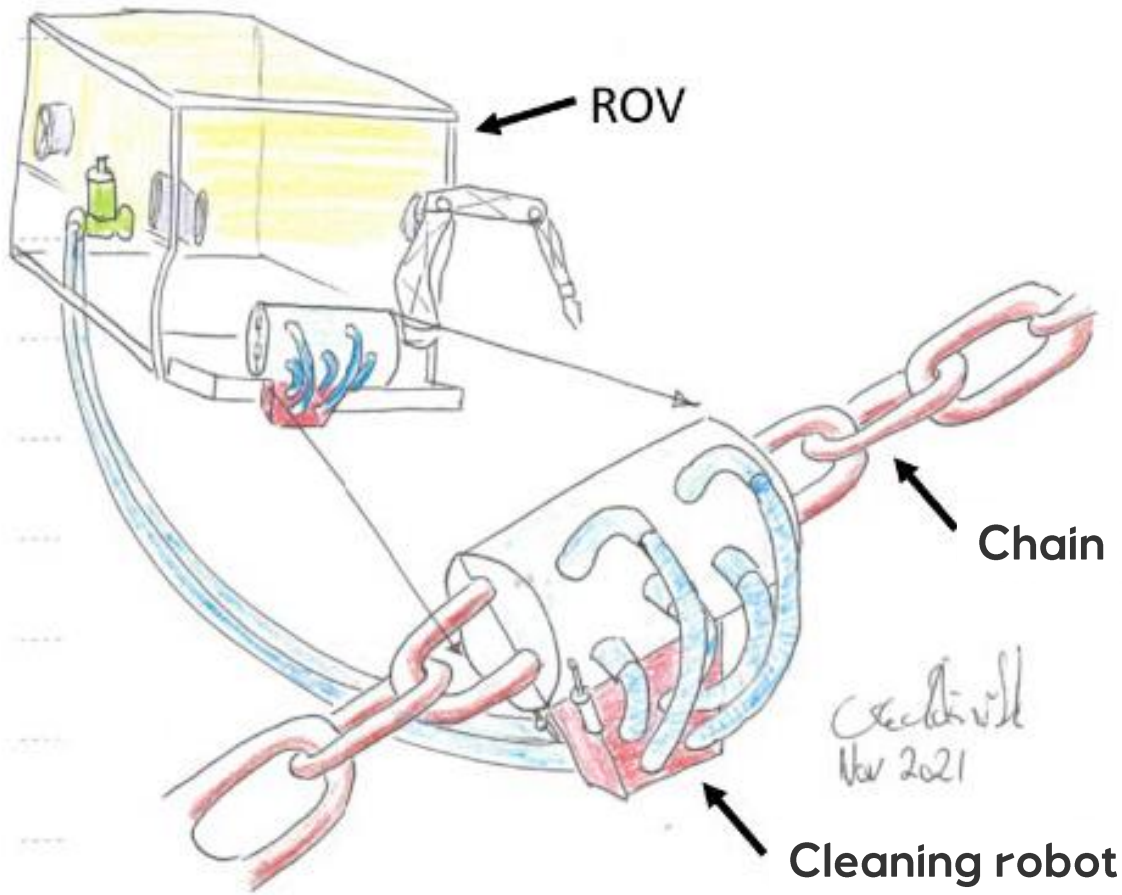
Chain cleaning

- Manual cleaning options:



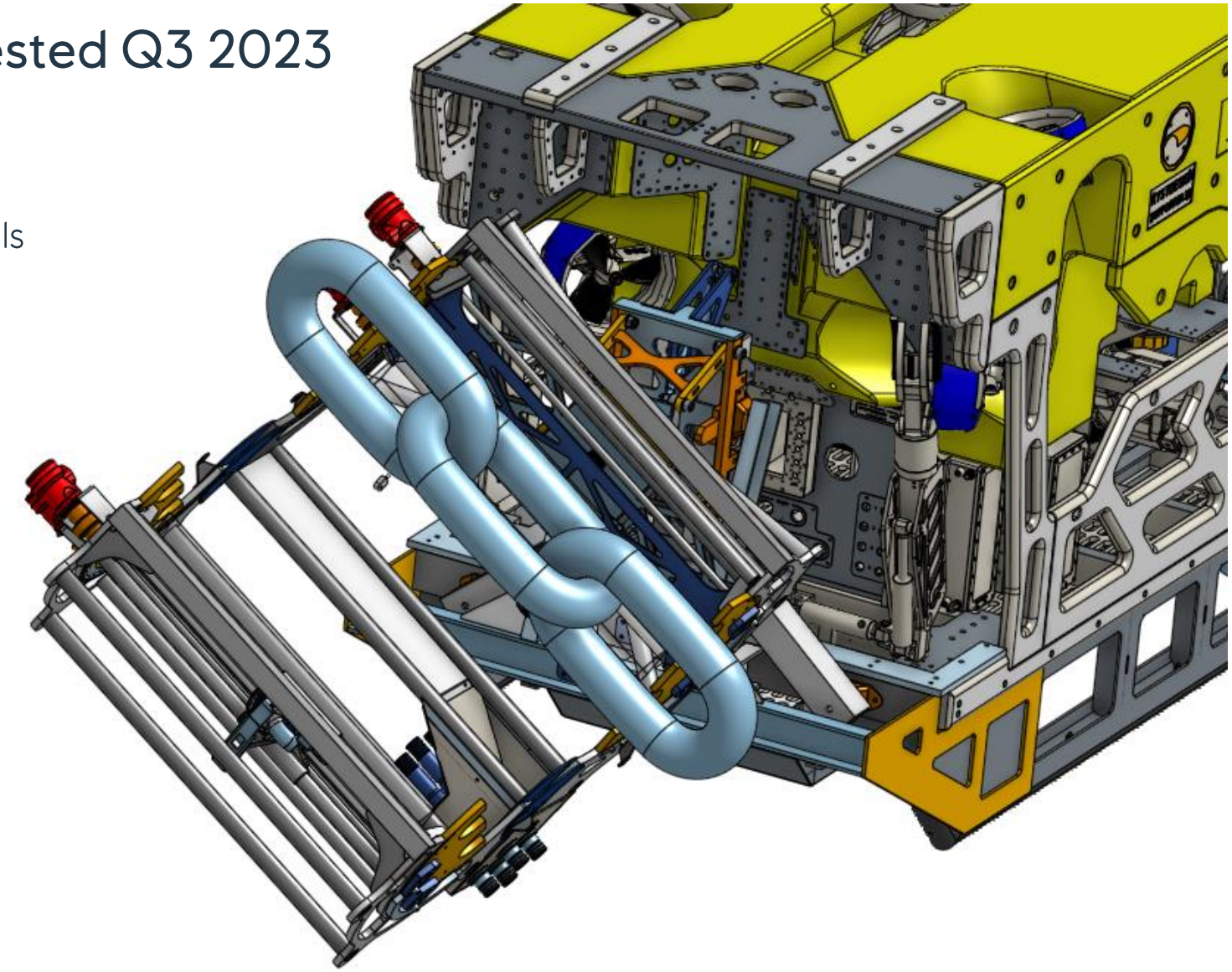
- Robotizing?

Chain cleaning – grit blasting – prototype (2022)

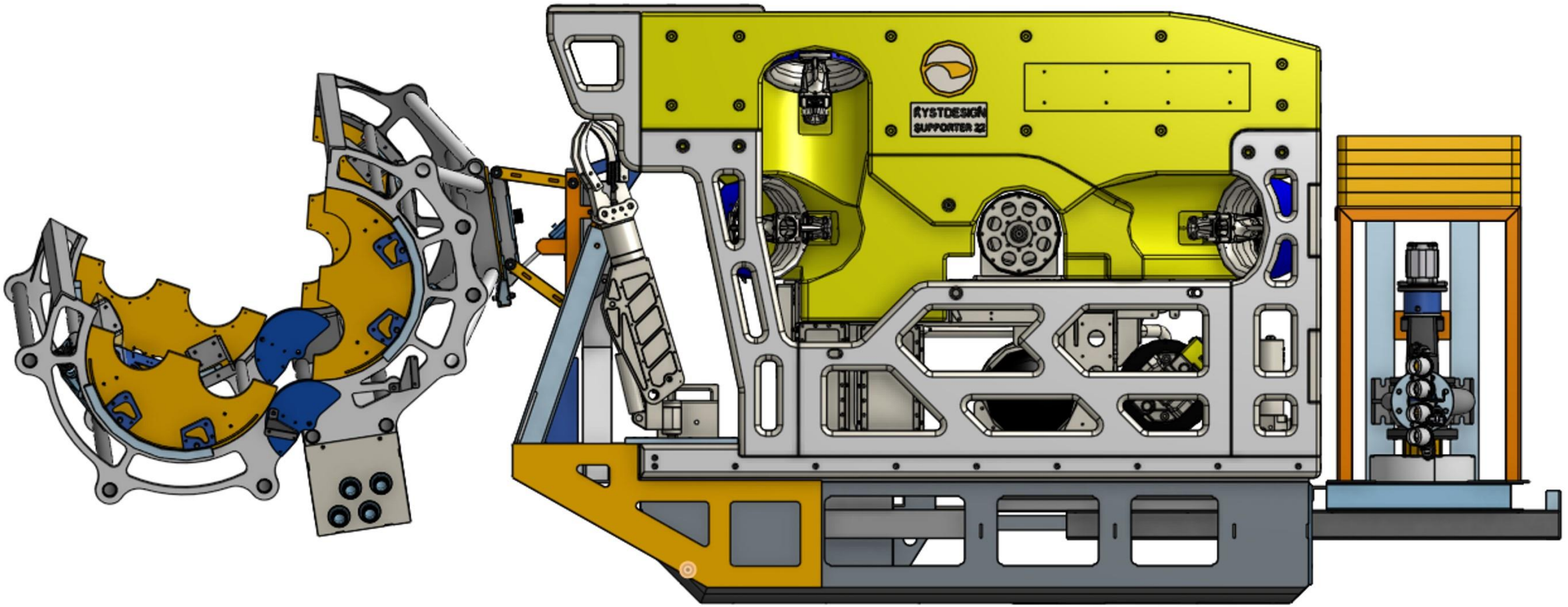


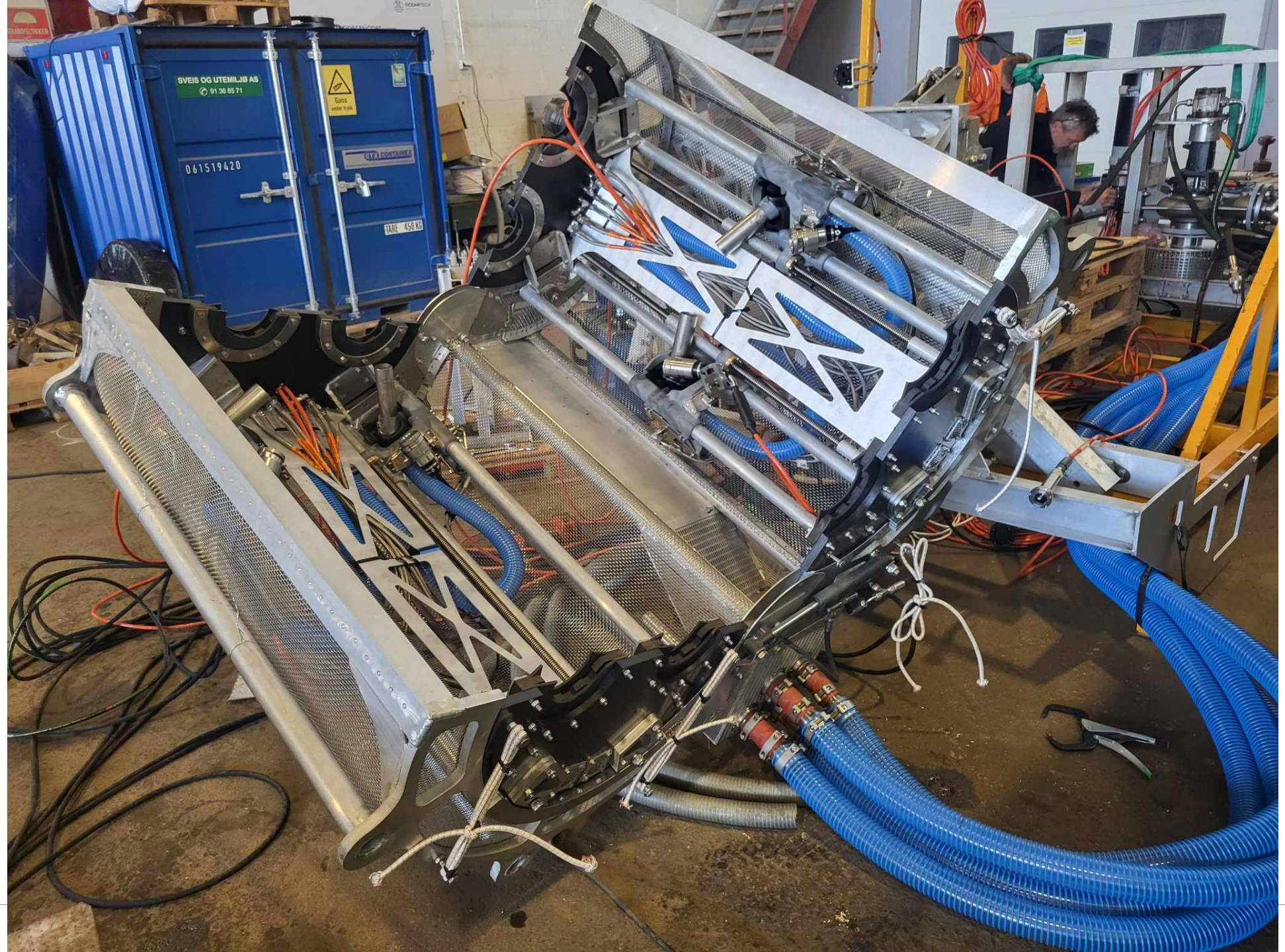
Chain cleaning pilot – to be tested Q3 2023

- ROV operated habitat
- Wet "grit blasting" with aluminium pellets/balls
  - re-use of pellets/balls
- 4 travelling nozzles
  - all visible surface
  - 2 links



Chain cleaning pilot – to be tested Q3 2023

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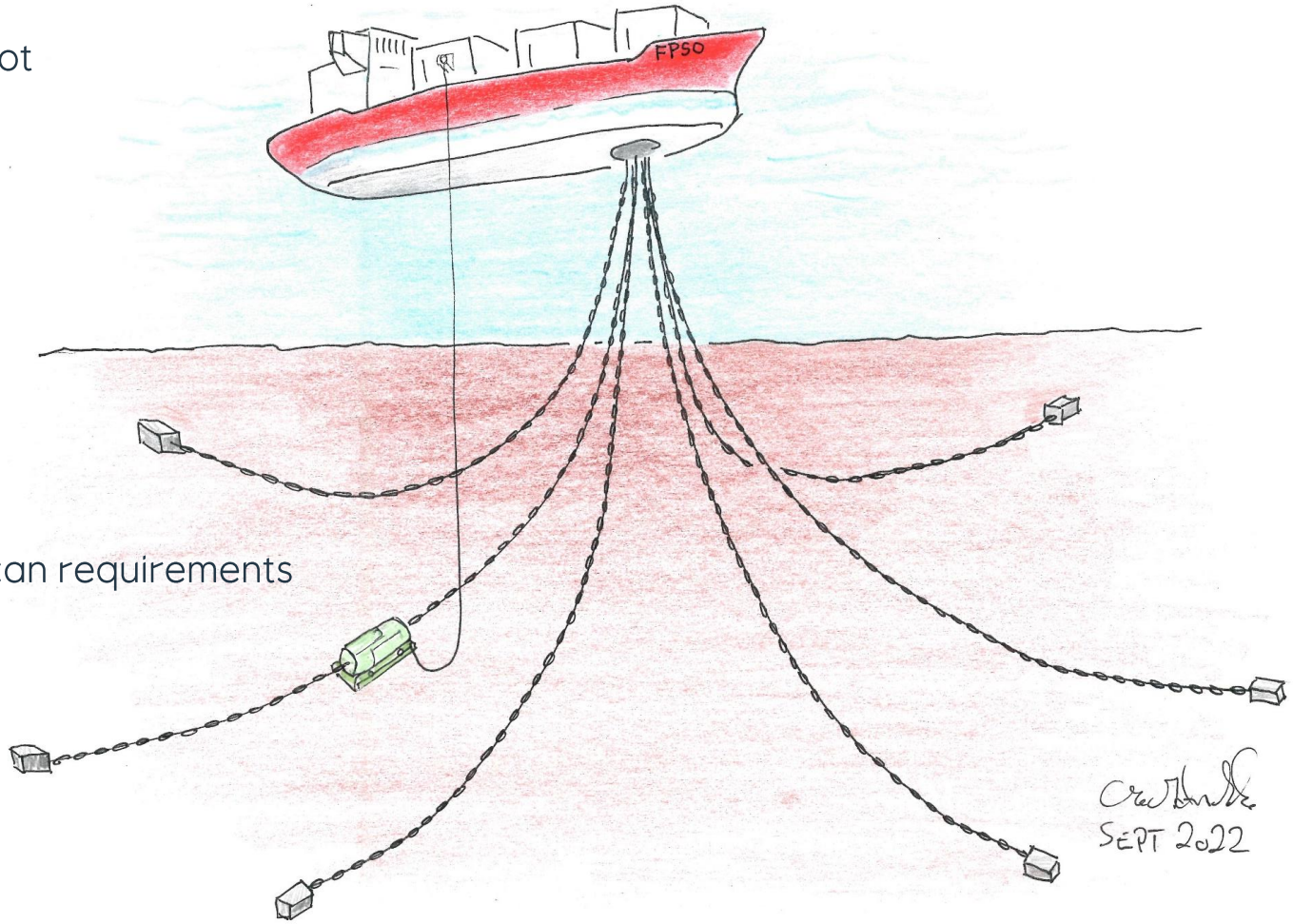
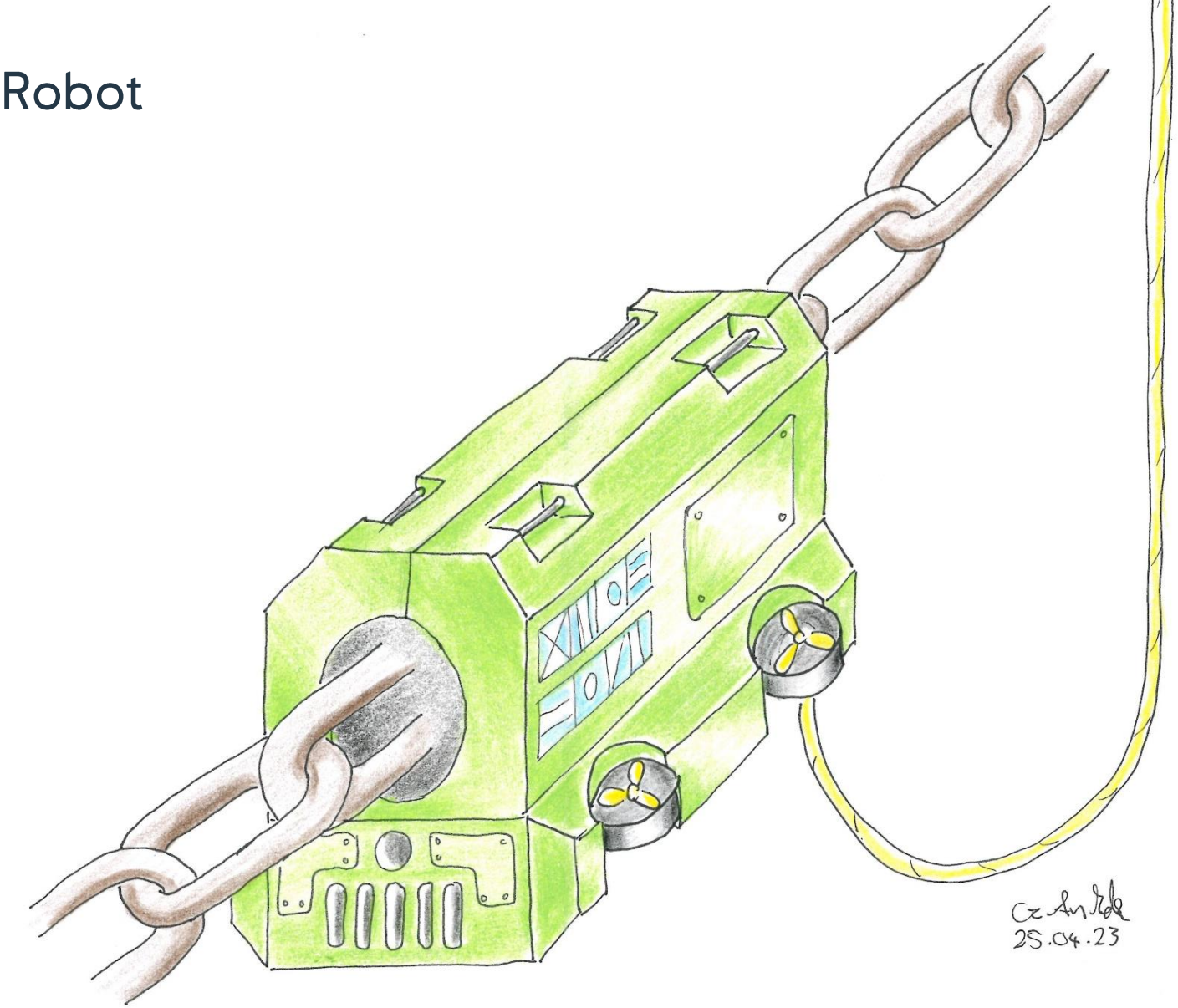
Chain Cleaning Robot – SeeMoor IPN

- Development of commercial Chain Cleaning Robot
  - Stand-alone or ROV operated
  - June 2023 -> May 2026
- Funded by
  - Norwegian Research Council
  - OceanTech Innovation
  - Equinor
- Preparing for integrating 3D scanning
- In cooperation with Sintef wrt cleaning and 3D scan requirements and post processing possibilities



Chain Cleaning Robot



So, what is the status?

Ongoing / further work

• Further development of 3D scan post processing: • Locate corrosion loss	Ongoing
• Establish relation between corrosion loss and fatigue capacity (from tests)	Ongoing + ObjoCorr JIP / Digimoor
• Further research on mooring chain fatigue mechanisms	Digimoor
• Class update on 3D scan requirements	DNV?
• Develop efficient cleaning of chains	Ongoing
• Normoor phase 4	Ongoing

Inspection/post processing projects – ongoing and proposed

ObjoCorr	Extend and apply the Lifemoor methodology and algorithms to severe general corrosion.	**Ongoing** Start: Feb. 2023 End: Jan. 2024	equinor, SINTEF
SeeMoor	Further develop and demonstrate an innovative technology for automatic and in-situ (deep water) cleaning of mooring chains.	**Ongoing** Start: June. 2023 End: May. 2026	OCEANTECH INNOVATION, equinor, The Research Council of Norway, SINTEF
ObjoCorr JIP extension	3 one-year phases in continuation of ObjoCorr: Further development of algorithms, tuning in offshore inspection requirements, calibrating with fatigue test data and 3D scans. +++	Start: Q4 2023 End: Q2 2027	equinor, SINTEF (pending partners)
DigiMoor	Continuation of Lifemoor: Further study/research on mooring chain fatigue mechanisms, inspection, probabilistic approach...	Deadline subm.: Feb. 2024	KPN project (up to 80% RCN funding) SINTEF, equinor (pending partners)

Status on chain integrity assessessment by 3D scans

Access for 3D scanning

Ongoing: Chain cleaning robot

Verified 3D scanning

Computer algorithms:
assessing corrosion condition

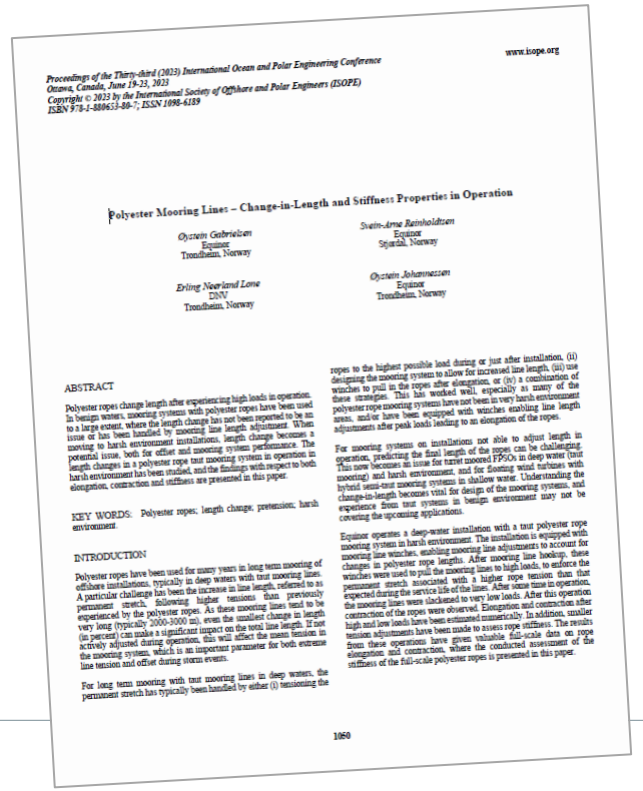
Ongoing: Corrosion loss
Future: FEA / fracture mechanics

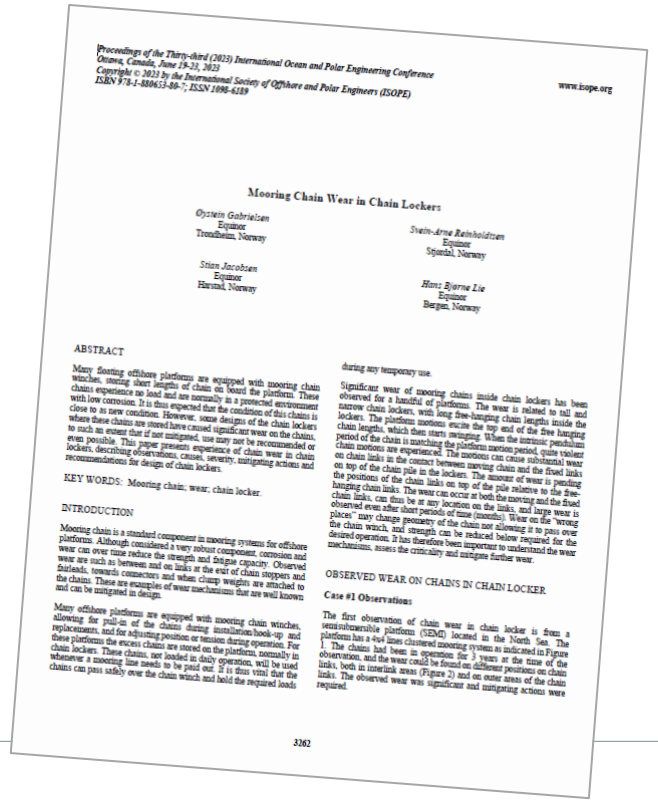
Mean load and surface condition SN curves
Assessment Methodology

Ongoing: Corrosion loss
Future: FEA / fracture mechanics

New papers

- ISOPE-TPC-0583 - Mooring Chain Wear in Chain Lockers
- ISOPE-TPC-0632 - Polyester Mooring Lines – Change-in-Length and Stiffness Properties in Operation
- Marine Structures Sept 2023 - Analysis of S–N data for new and corroded mooring chains at varying mean load levels using a hierarchical linear model





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Øystein Gabrielsen, MIUG Paris June 29th 2023