Sensor Development

ACHIEVEMENTS AND FORWARD LOOK

MATT MOWLEM
HEAD OCEAN TECHNOLOGY AND ENGINEERING GROUP

Ocean Technology and Engineering Group (OTEG)

Mission (***“To develop novel technology and engineering resulting in the greatest impact for environmental and marine science”***)

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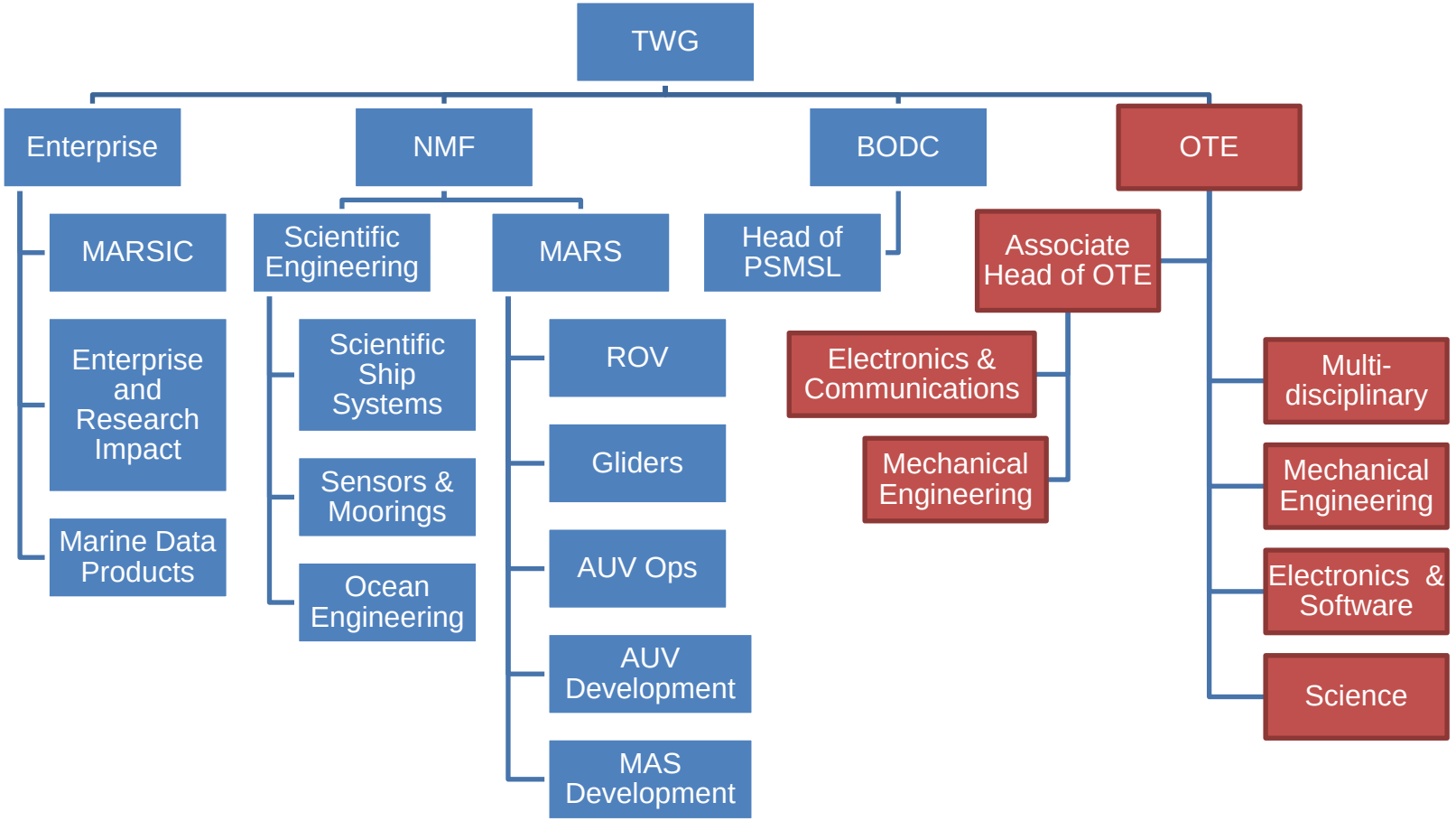
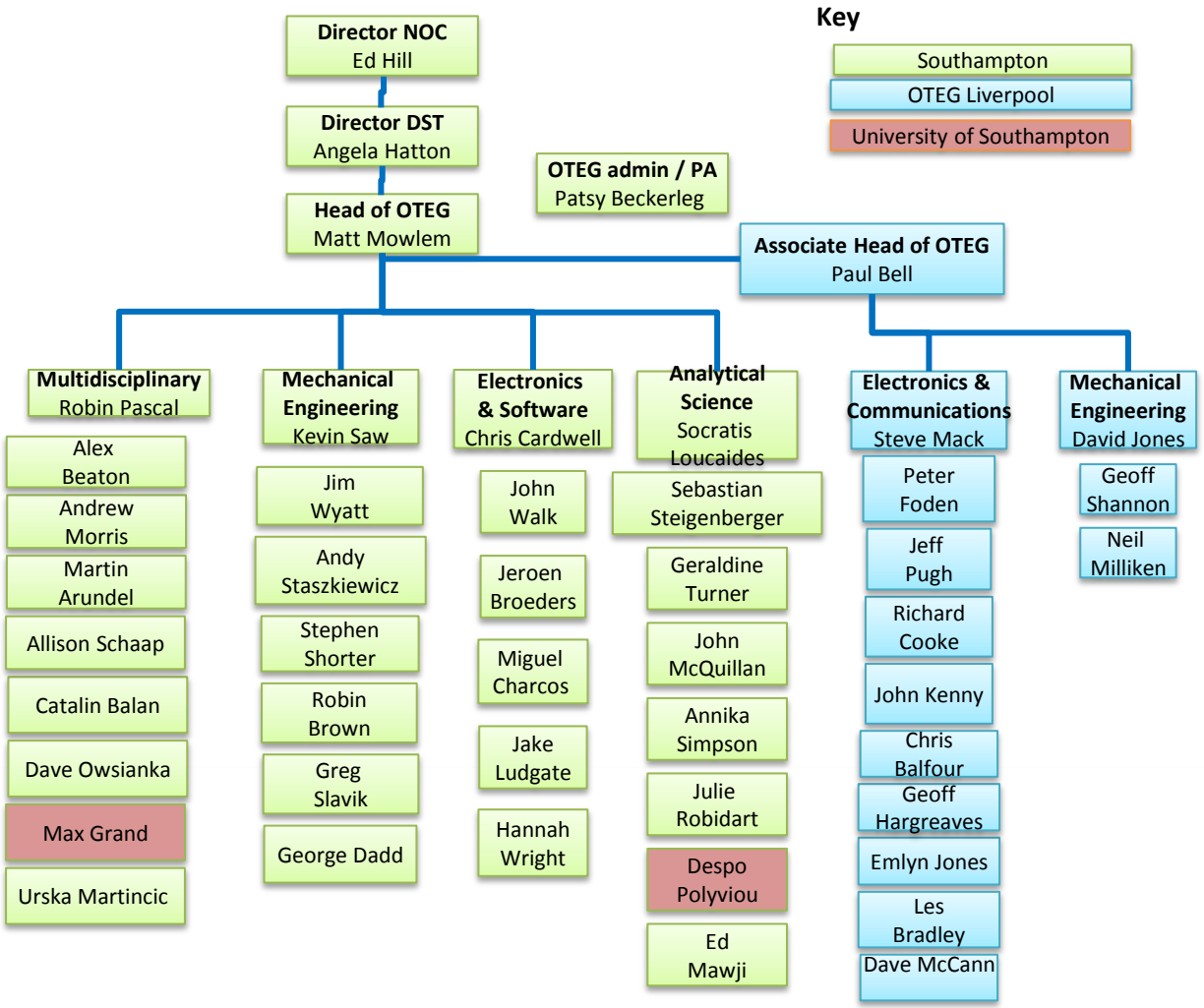

TWG
Enterprise
NMF
BODC
OTE
MARSIC
Enterprise and Research Impact
Marine Data Products
Scientific Engineering
MARS
Scientific Ship Systems
Sensors & Moorings
Ocean Engineering
ROV
Gliders
AUV Ops
AUV Development
MAS Development
Head of PSMSL
Associate Head of OTE
Electronics & Communications
Mechanical Engineering
Multi-disciplinary
Mechanical Engineering
Electronics & Software
Science


Key
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OTEG Liverpool
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Head of OTEG
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Patsy Beckerleg
Associate Head of OTEG
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Alex Beaton
Andrew Morris
Martin Arundel
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Dave Owsianka
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Urska Martincic
Mechanical Engineering
Kevin Saw
Jim Wyatt
Andy Staszkiewicz
Stephen Shorter
Robin Brown
Greg Slavik
George Dadd
Electronics & Software
Chris Cardwell
John Walk
Jeroen Broeders
Miguel Charcos
Jake Ludgate
Hannah Wright
Analytical Science
Socratis Loucaides
Sebastian Steigenberger
Geraldine Turner
John McQuillan
Annika Simpson
Julie Robidart
Despo Polyviou
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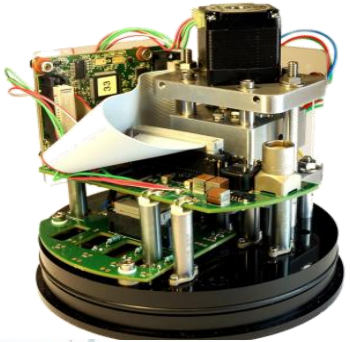
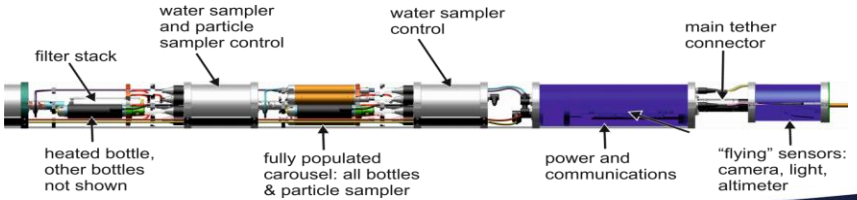
Peter Foden
Jeff Pugh
Richard Cooke
John Kenny
Chris Balfour
Geoff Hargreaves
Emlyn Jones
Les Bradley
Dave McCann
Mechanical Engineering
David Jones
Geoff Shannon
Neil Milliken

Ocean Technology and Engineering Group Post MARS

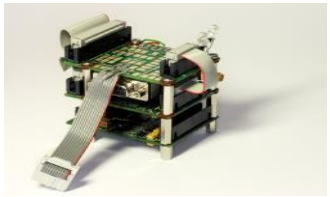
- **Sensors**
- Water physics (CTD)
- Water chemistry
- Water biology
- Sediment flow and properties
- Wave height / breaking
- Sea level
- Sea surface fluxes
- **Enabling systems**
- Metrology standards
- Interoperability and metadata
- Comms & Data flow
- Sensors on platforms
- Autonomous sea level



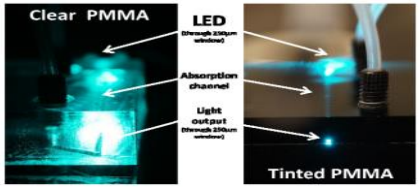


- **Samplers**
- Continuous water
- Gas tight water
- Particles
- Genomics
- Landers and benthic systems
- Communication systems
- Sterile probes / vehicles
- Vehicles: Gliders

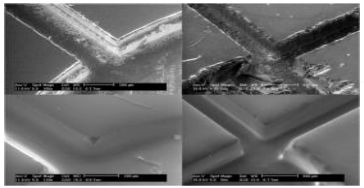
OTEG expertise



electronics



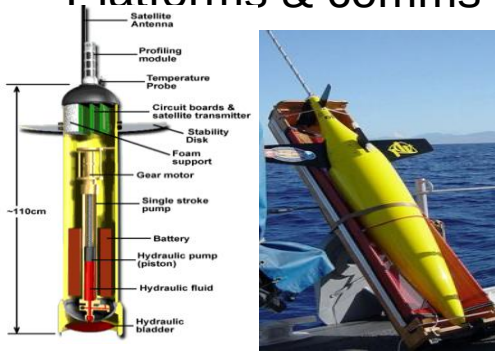
optics



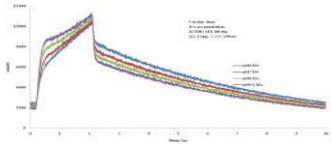
manufacturing

Integrated systems

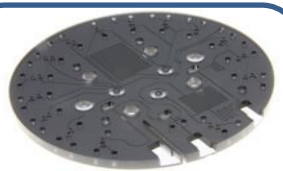
Platforms & comms



Microfluidics



Assay optimisation



Lab on a chip

Biofouling mitigation

GOOS EOV

Readiness level: CONCEPT | PILOT | MATURE [Click on each EOV for their repsective spec sheets]

PHYSICS	BIOGEOCHEMISTRY	BIOLOGY AND ECOSYSTEMS
Sea state	Dissolved Oxygen	Phytoplankton biomass and productivity
Ocean surface vector stress	Inorganic macro nutrients	Harmful Algal Bloom (HAB) incidence
Sea ice	Carbonate System	Zooplankton diversity
Sea surface height	Transient tracers	Fish abundance and distribution
Sea surface temperature	Suspended particulates	Apex predator abundance and distribution
Subsurface temperature	Nitrous oxide	Live coral cover
Surface currents	Carbon isotope (^{13}C)	Sea grass cover
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity		Macroalgual canopy cover
Subsurface salinity		
Heat flux / radiation		

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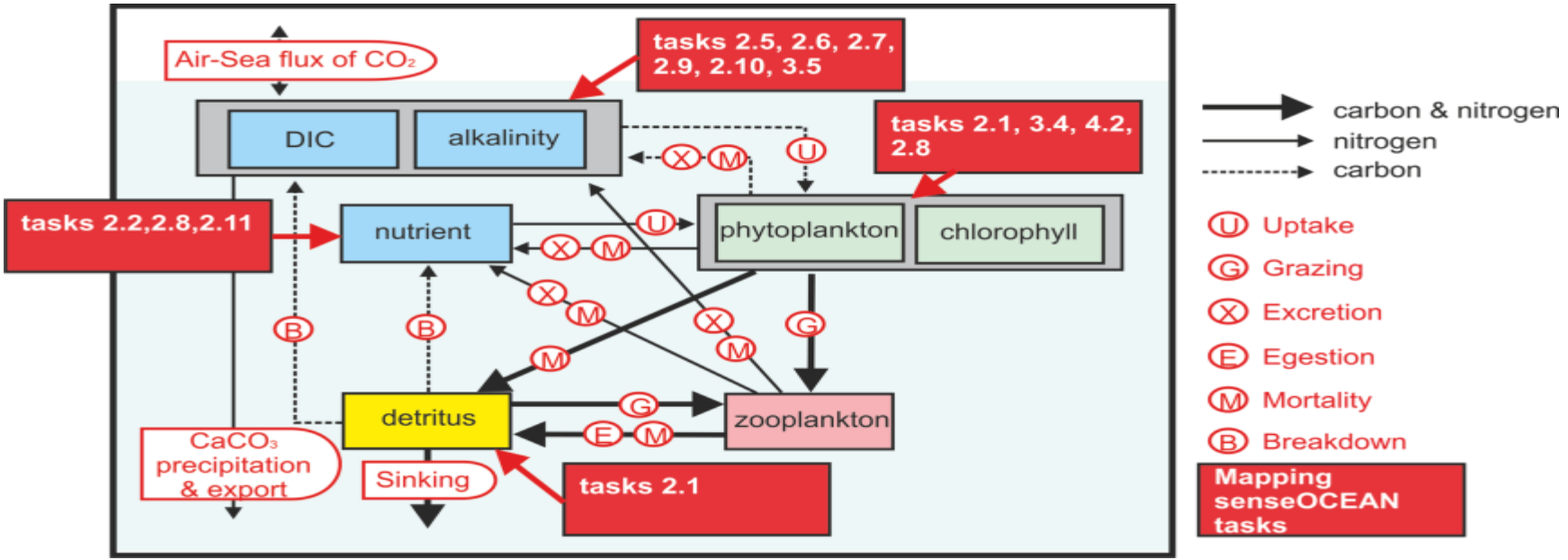
biogeochemical model of the ocean system



Summary of the Tasks outlined in SenseOCEAN mapped onto the current state of the art

Marine Sensors Technologies and TRL

Microfabricated Solid State / Electrochemistry:

- Salinity 7
- Dissolved oxygen 7

Optodes / optical sensors

- Gases inc. methane 6
- pH, pCO_2 7
- Radionuclide 3

Lab on Chip Cytometer

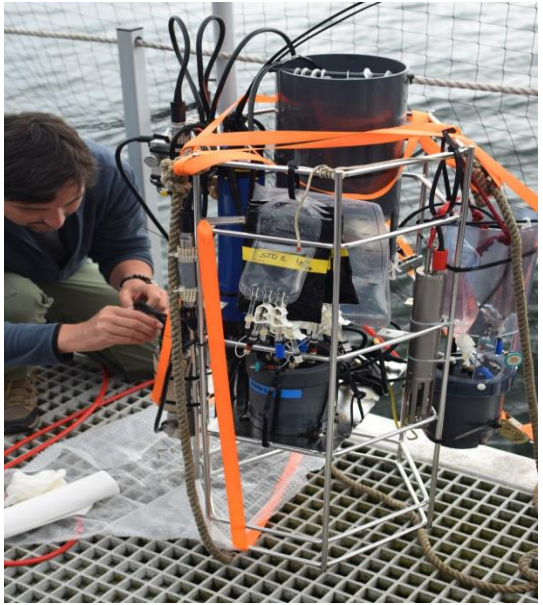
- Whole cells (label free) 5
- Labelled cells 5
- Microplastics 4
- Bead assays 3

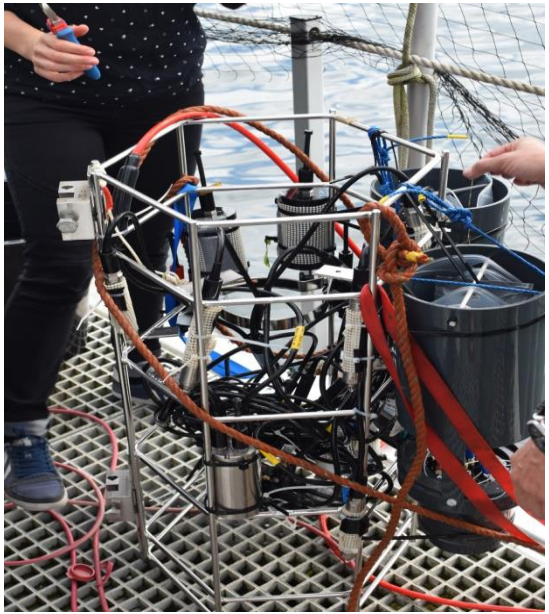
Lab on Chip Chemistry

- Inorganic Nutrients 8
- Organic Nutrients 5
- Trace metals 7
- pH 7, TA 4, DIC 3, pCO_2 4
- Small organics, e.g. PAH, PCBs (f-pM) 5
- Proteins and large organics (copies / L) 4
- Nucleic Acids (copies / L) 6
- Radionuclide 3

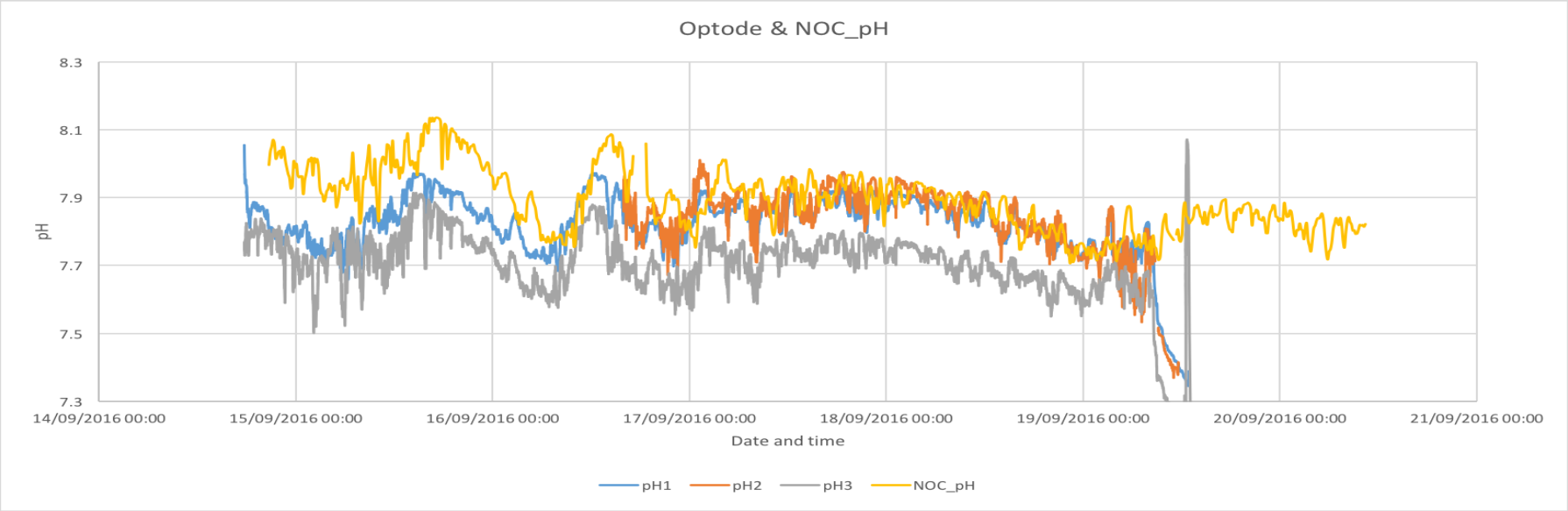
2016 Highlights

Demo / test Kiel Fjord Sept. 2016





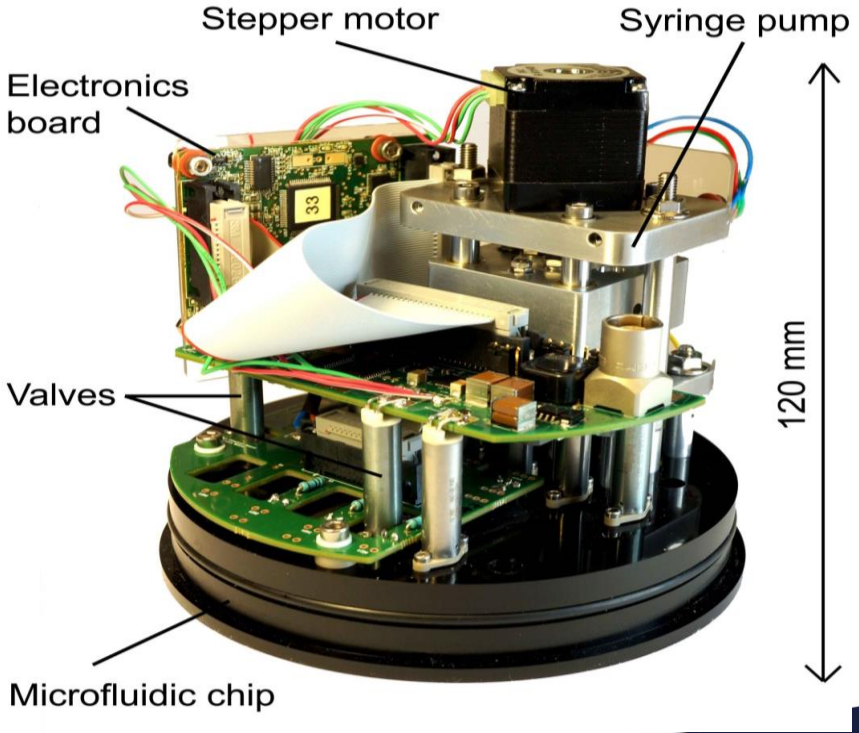
Kiel Preliminary Results: pH



Preliminary LOC data from T. Yin (NOC) and TU Graz team (Optodes)

NOC chemical sensor platform

- Now operational for several parameters
- Platform technology - easy to adapt to other absorbance-based assays
- Works at pressure (deepest deployment to date 4800 m)
- Small enough for glider/AUV deployment
- Low power (year long deployment on batteries achieved)



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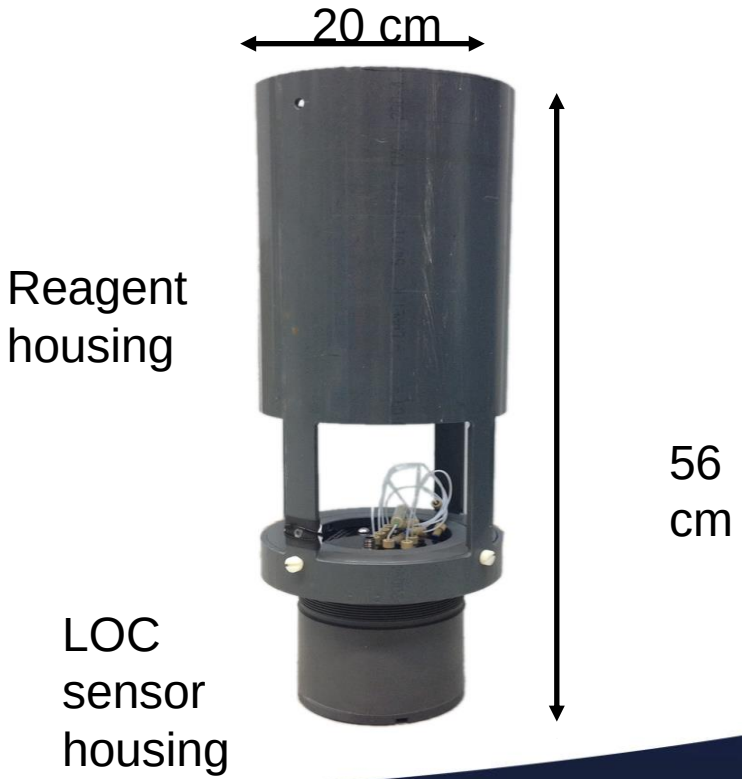


LOC Sensor	Analytical method	Measurement type	LOD/precision*
Nitrate + nitrite	Griess assay (with Cd reduction)	Colourimetry (absorbance)	20 nM
pH	Thymol blue	Dual wavelength absorbance	0.001 pH units*
Phosphate	Molybdenum blue (modified)	Colourimetry (absorbance)	30 nM
Iron (II), Iron (III)	Ferrozine (with ascorbic acid reduction for Fe (III))	Colourimetry (absorbance)	20 nM
Silicate	Silicomolybdic acid	Colourimetry (absorbance)	20 nM
Ammonium	OPA + membrane	Fluorescence	1 nM
Total alkalinity	BCG with TMT or single step	Dual wavelength absorbance	(2 µM)*
DIC	Membrane+ C of NaOH	Conductivity	(2 µM)*
Organic N and P	UV digester + inorganic system	Colourimetry (absorbance)	(20 nM)

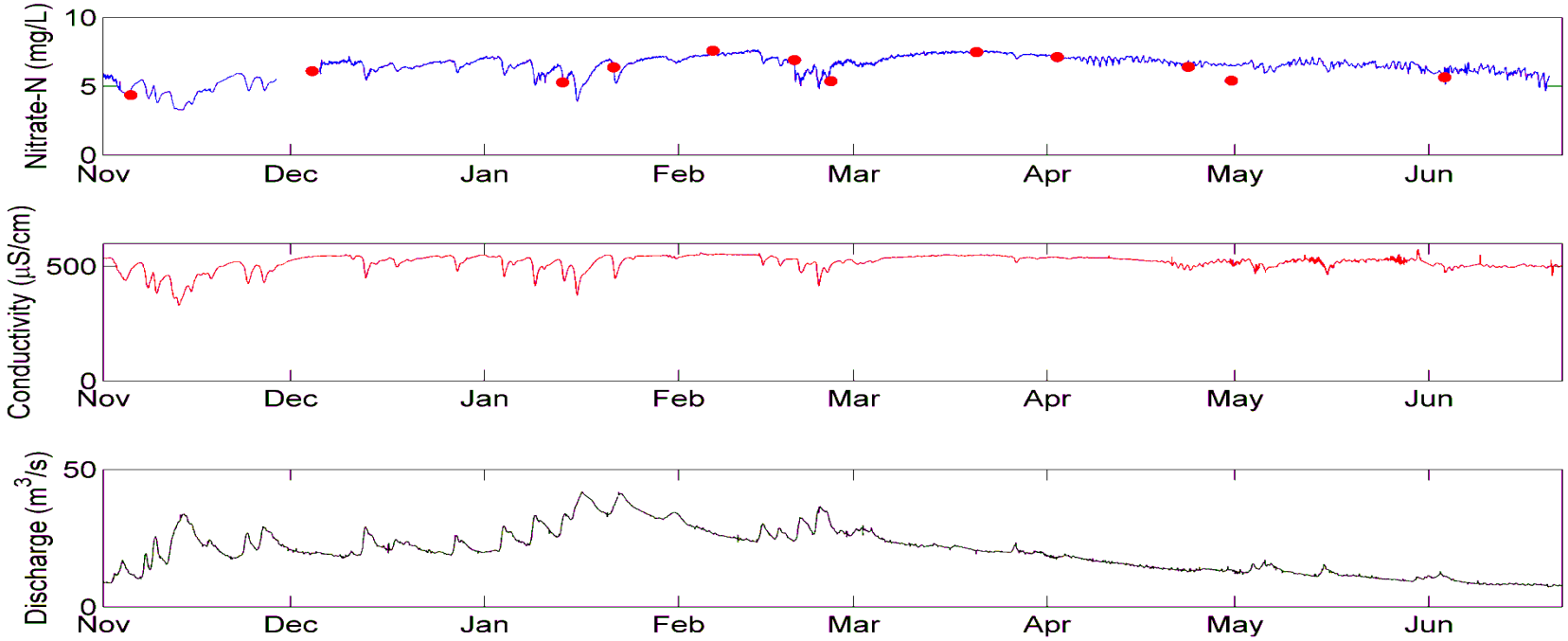
NERC Macronutrient Cycles: Nitrate in a river

Hampshire Avon deployment site

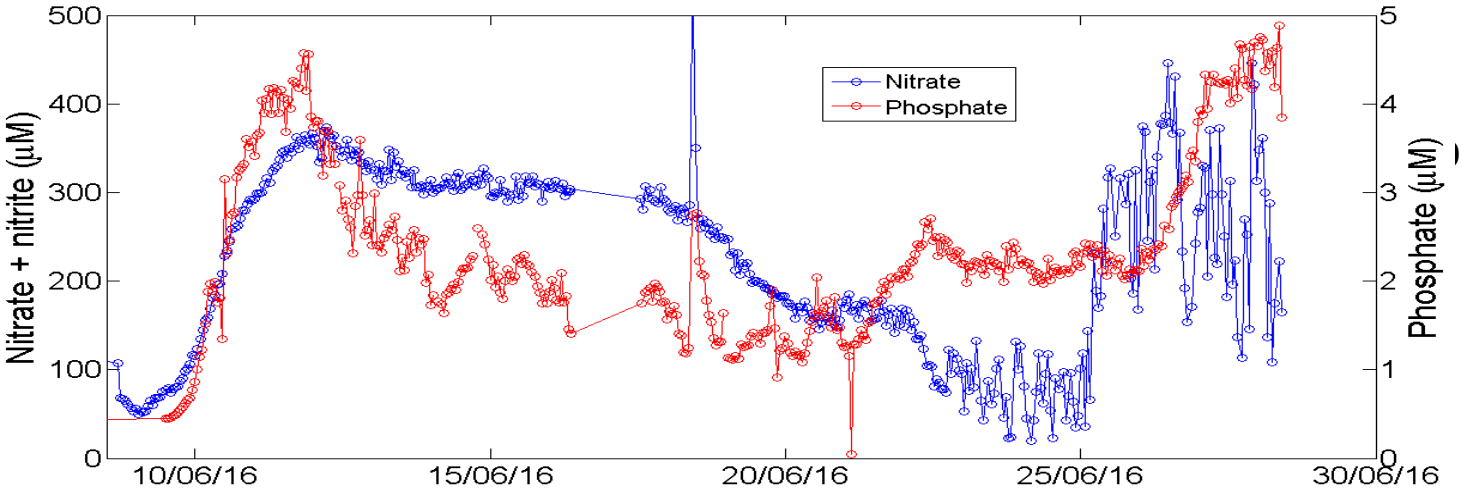
Sensor after deployment in River

Nitrate sensor in river

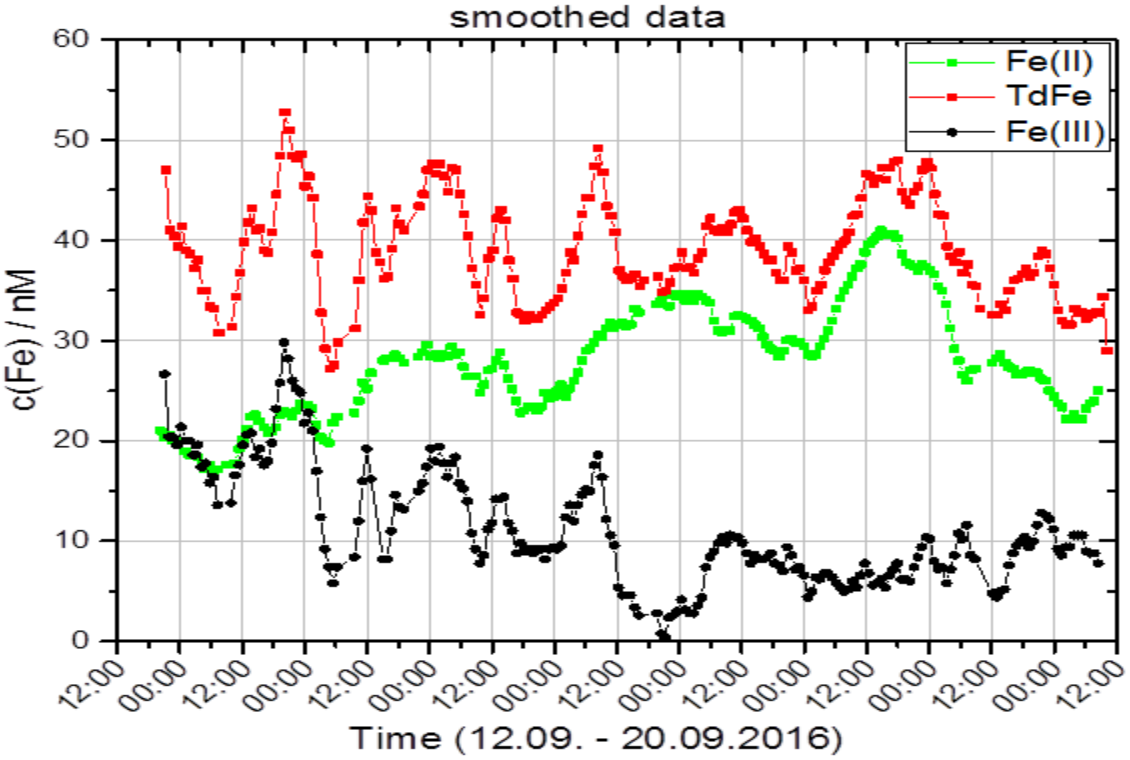
NERC Macronutrient Cycles: Nitrate in a river



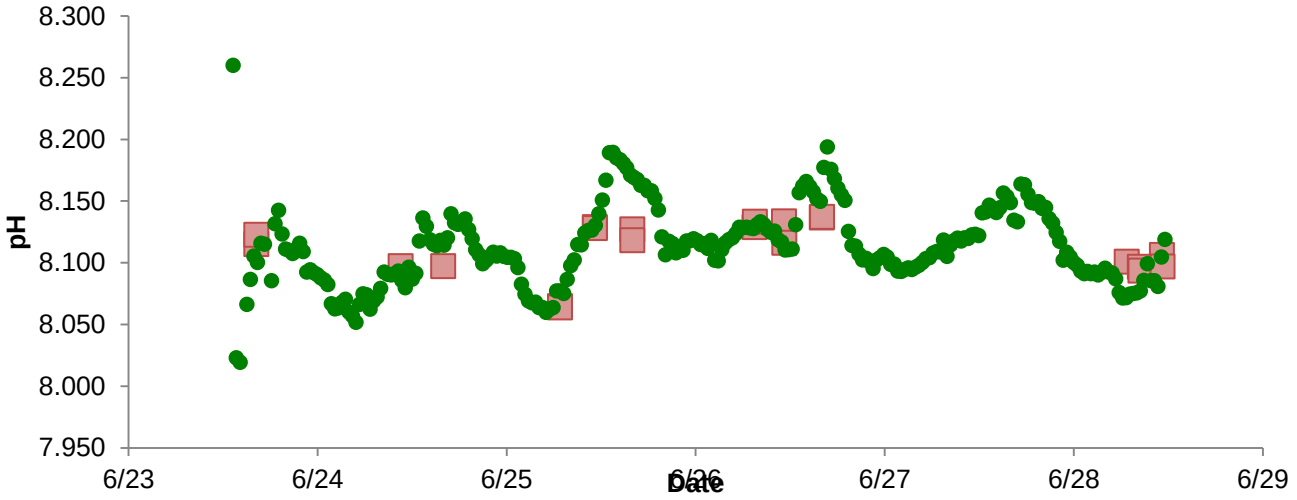
Nutrient Challenge: Nitrate and phosphate in a Maumee River, Ohio



SenseOCEAN: Dissolved iron in Kiel Fjord



NOC pH sensor field tests

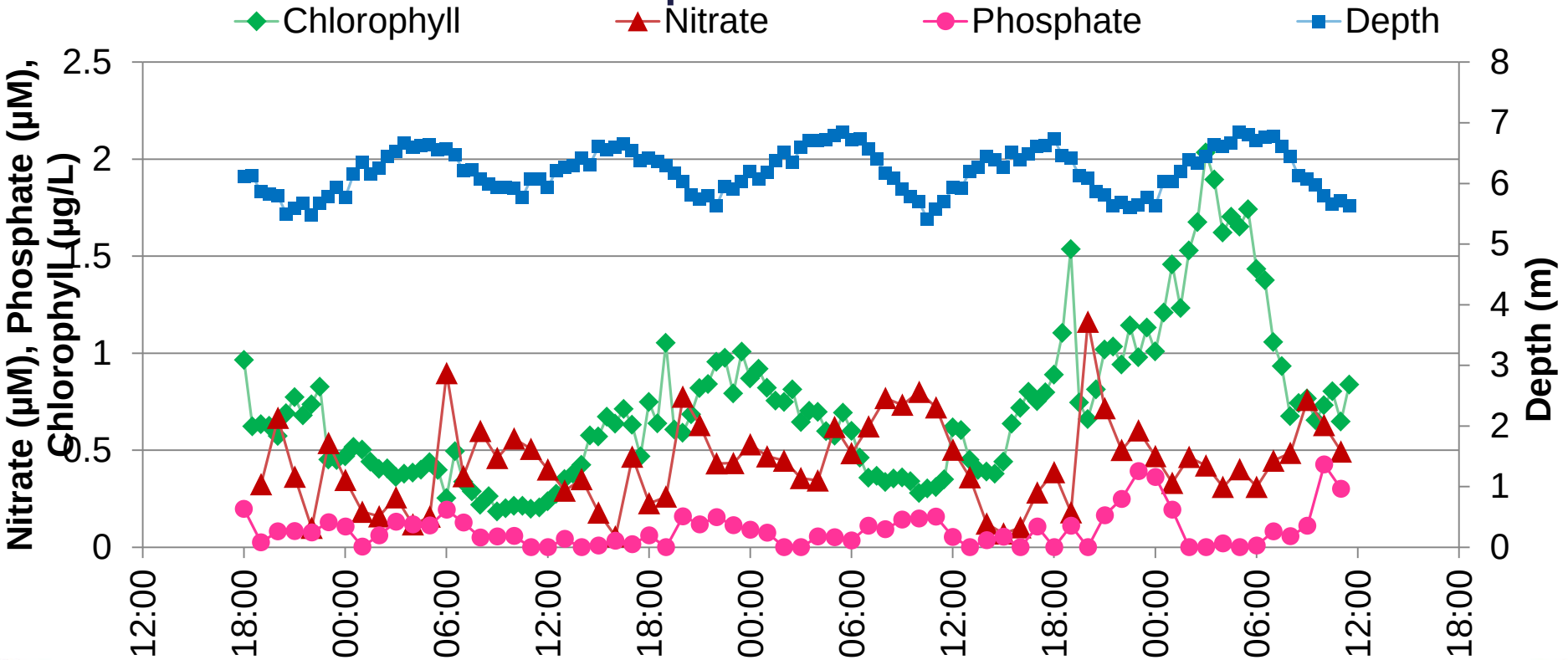


Gullmar fjord, Sweden June 2015

CMEP: Tropical coastal waters

Allison Schaap

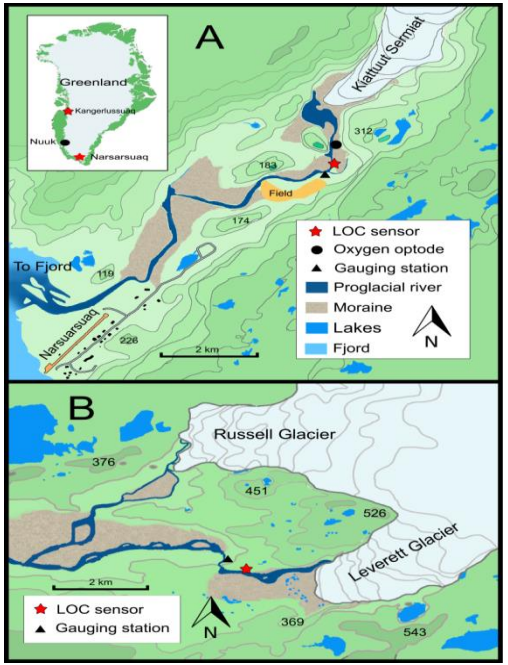
CMEP: Tropical coastal waters

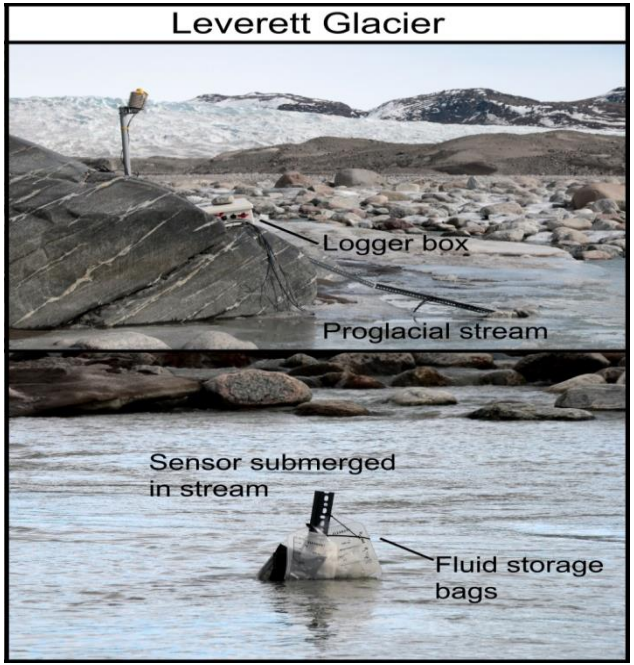


DELVE: Nitrate in glacial meltwater

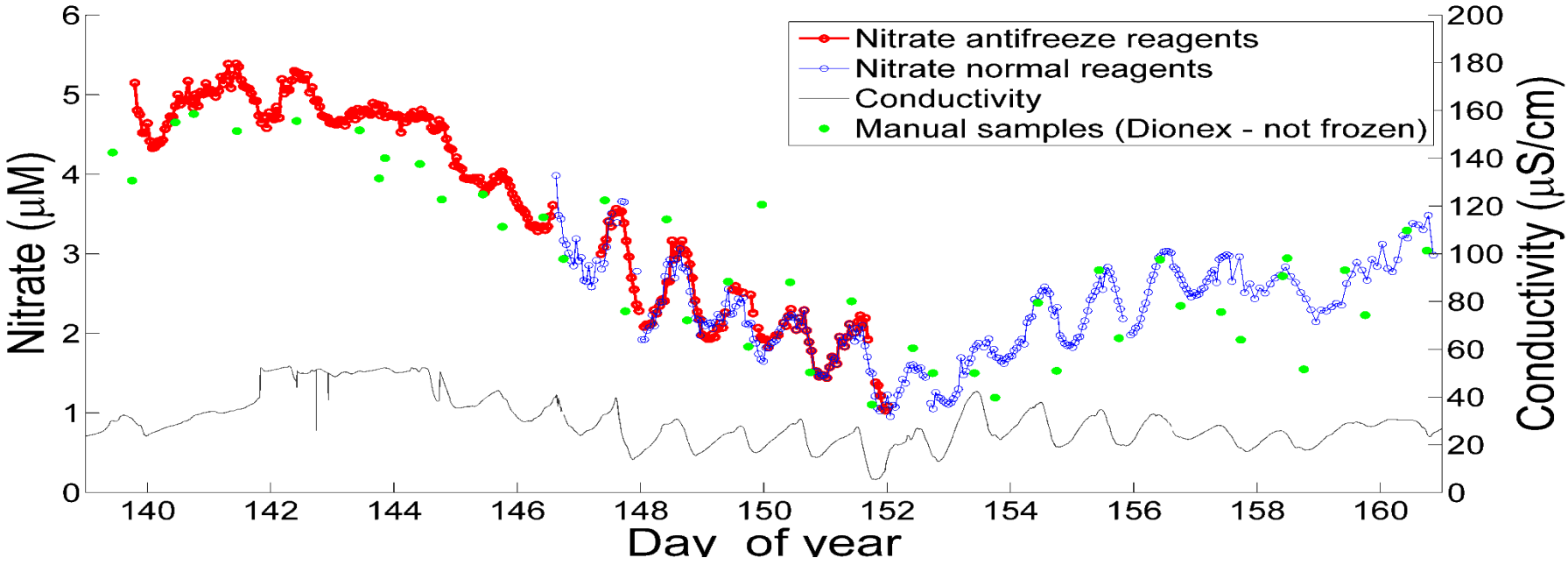
Nitrate sensor deployed in glacial streams draining Greenland Ice Sheet

Sub-zero temperatures and highly turbid waters



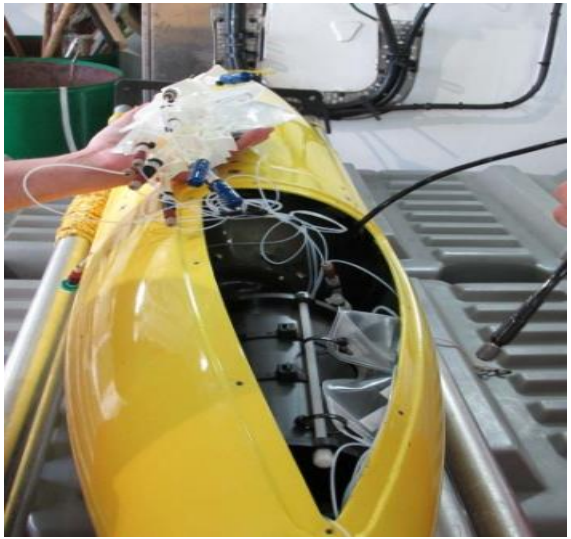


DELVE: Nitrate in glacial meltwater



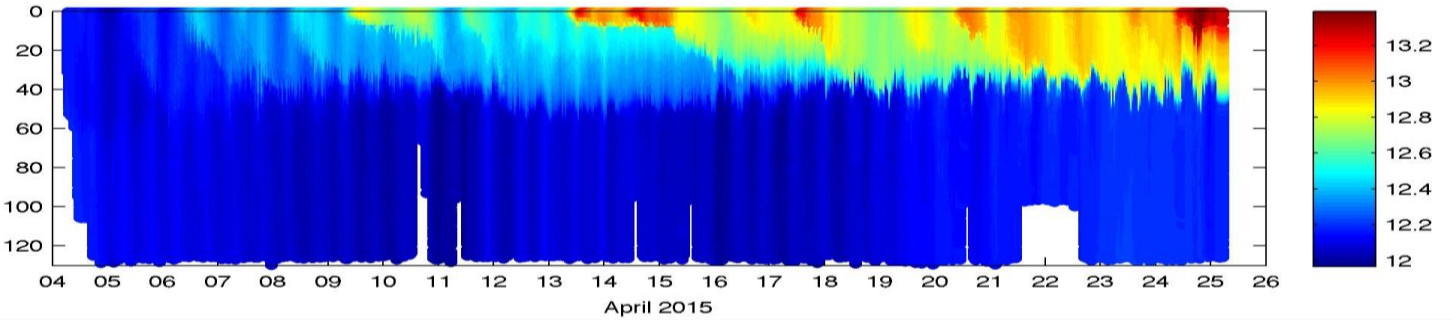
Nitrate deployment on gliders

Celtic Sea, April 2015

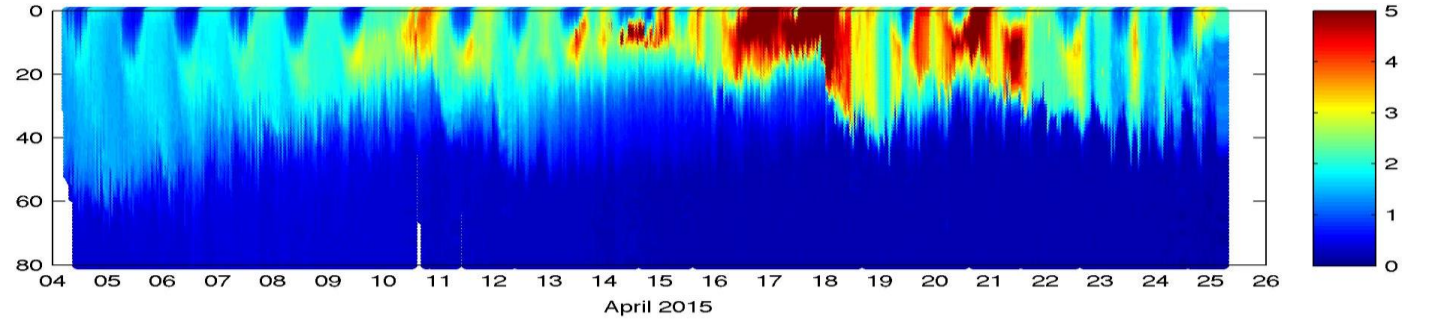


Alex Vincent & Maeve Lohan, NOC / SOES (U. Soton)

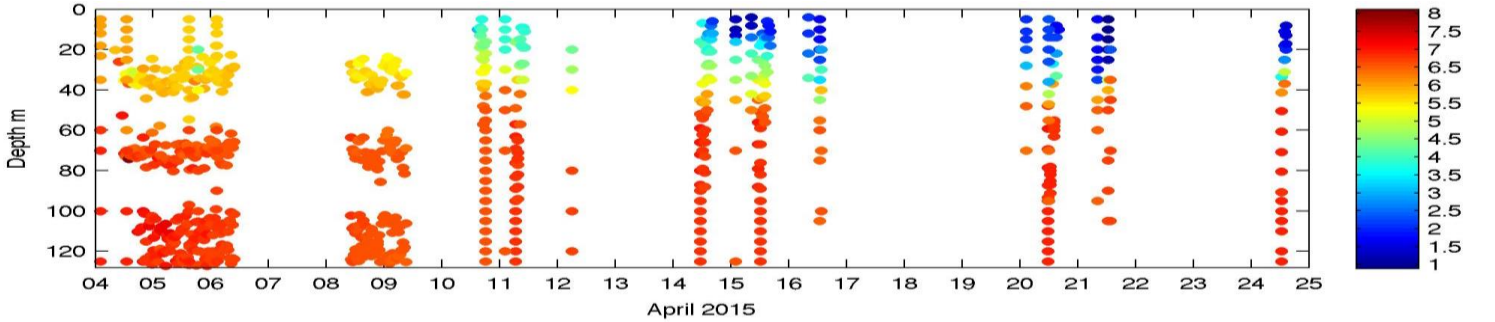
Temperature (°C)



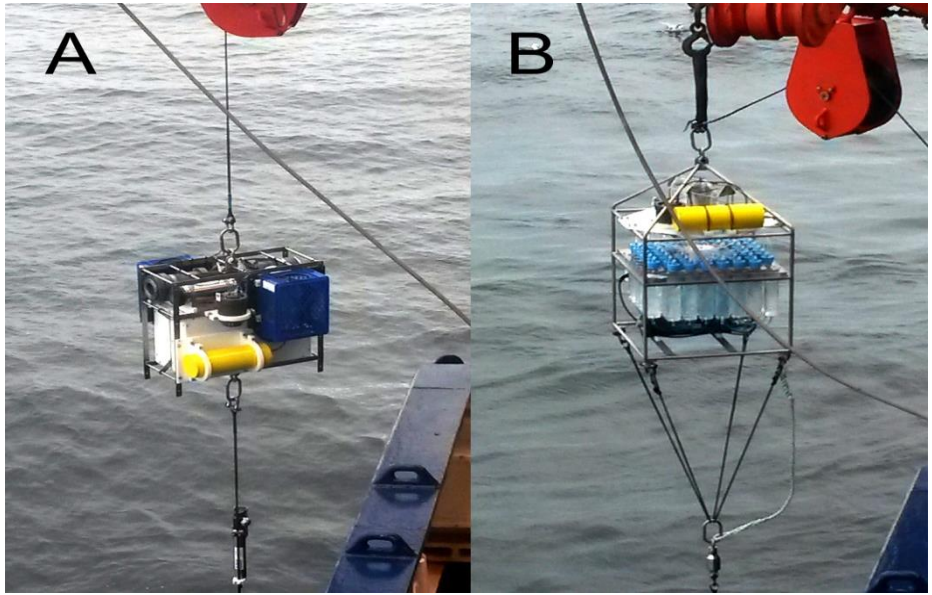
Chlorophyll (mg/m^3)



Nitrate (µM)



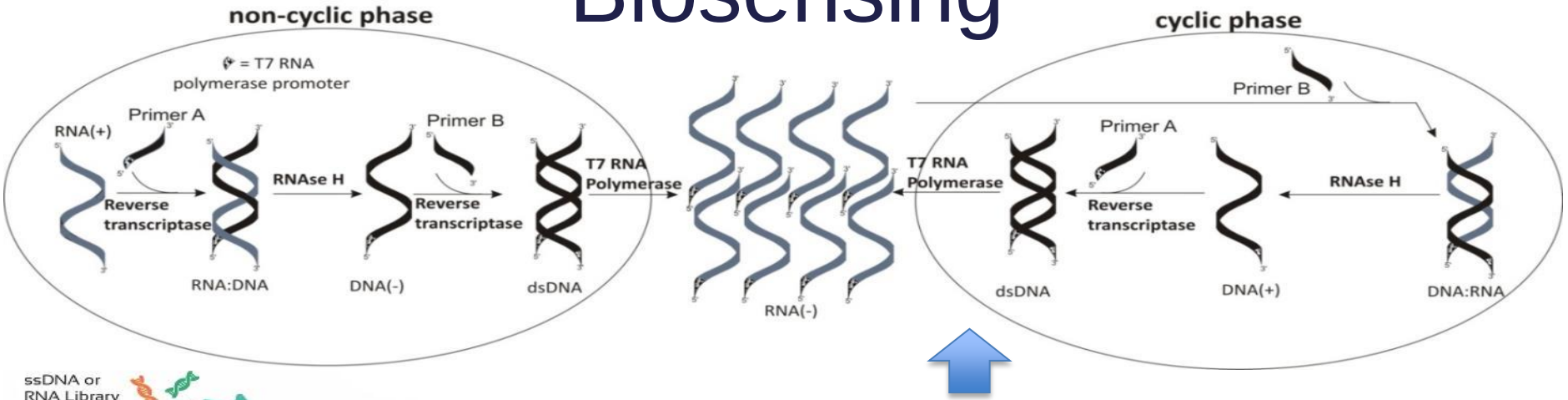
FixO3 TNA: Year-long unattended in the Arctic



LOC nitrate sensors deployed in two moorings on Fram Straight for one year (50 – 80 m deep, two measurements per day)

Funded by FixO3

Biosensing



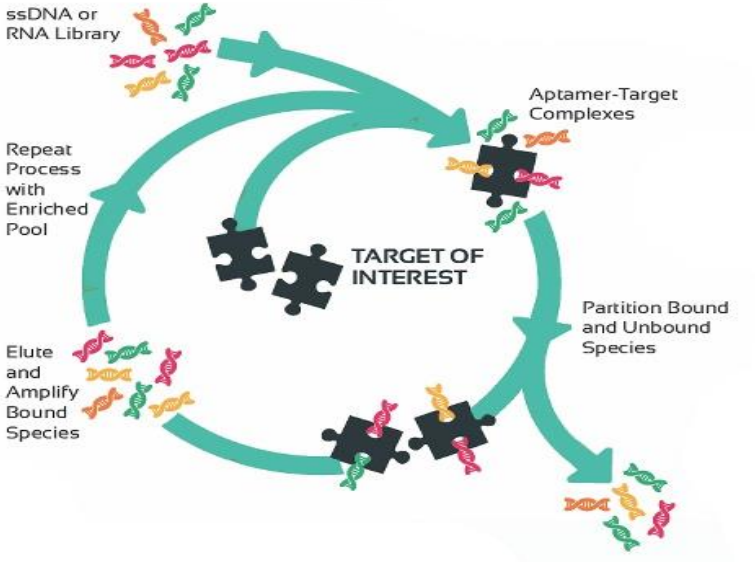
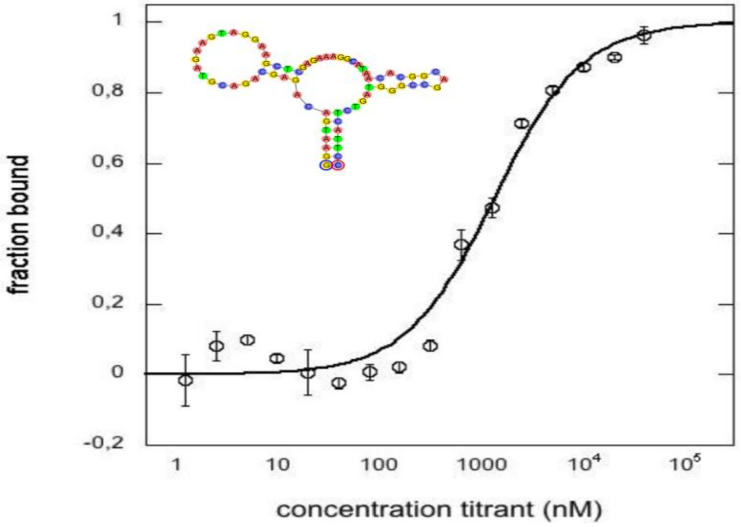


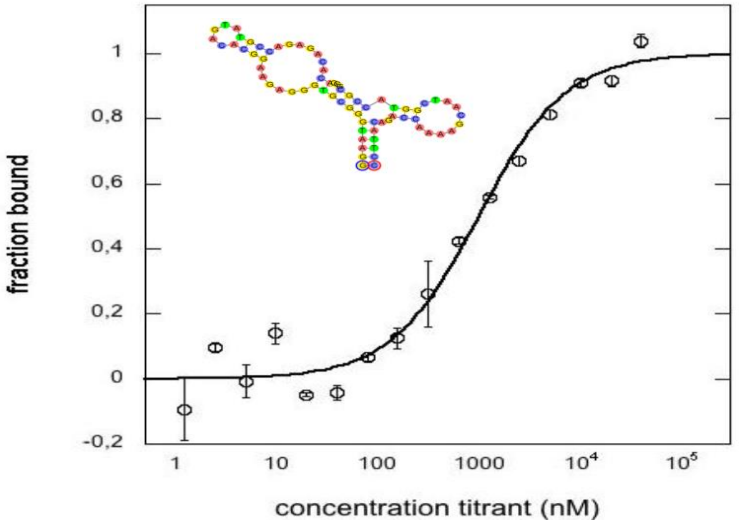
Figure and work by M.N. Tsaloglou

Image courtesy of our partners Aptamer solutions
http://www.aptamersolutions.co.uk/

Contract Research Aptamer / Antibody PAH sensor proof of concept

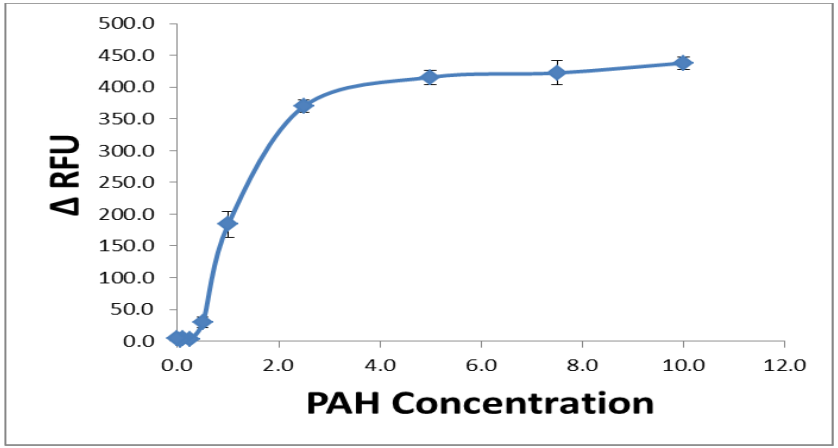


Naphthalene aptamer sensor
(K_d = 1.3 ± 0.3 nM)



Phenanthrene aptamer sensor
(K_d = 995 ± 208 nM)

Fluorescence Curves for Aptamer Beacons in Seawater



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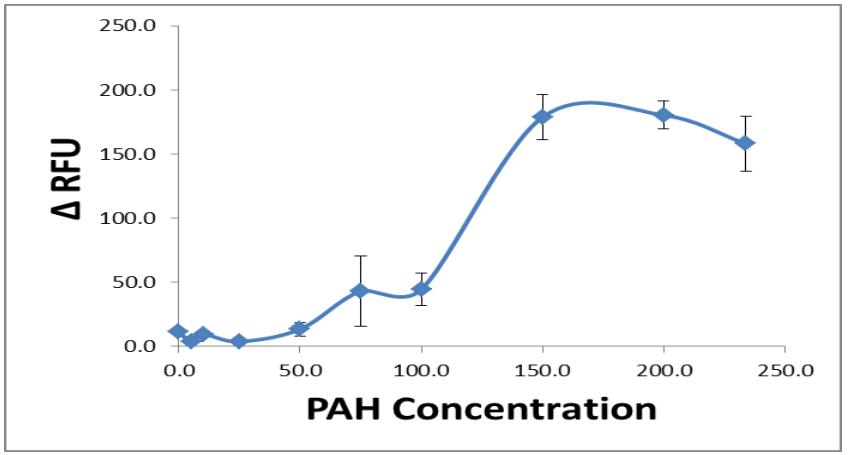

Phenanthrene aptamer sensor
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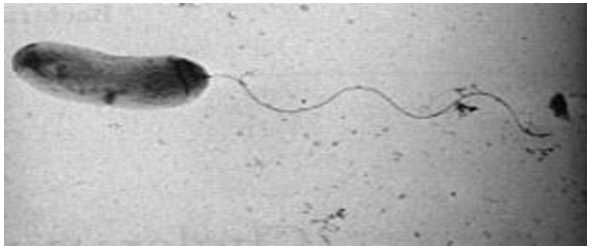
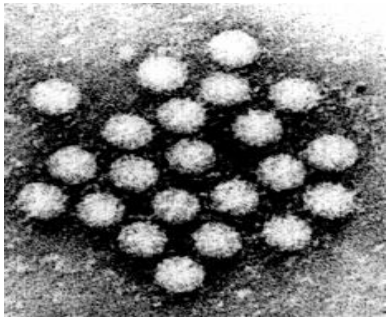
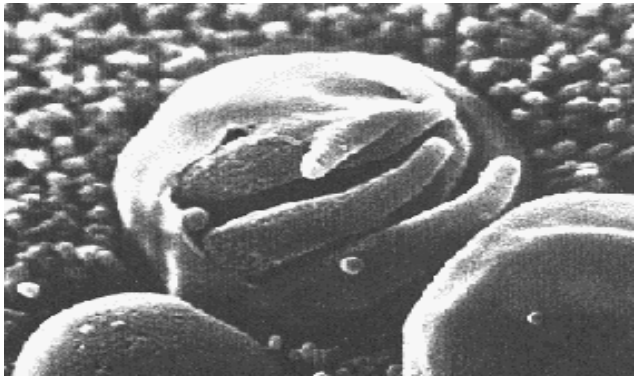
BBSRC sustainable aquaculture: Pathogens in Shellfisheries Water



Salmonella spp.



Norovirus

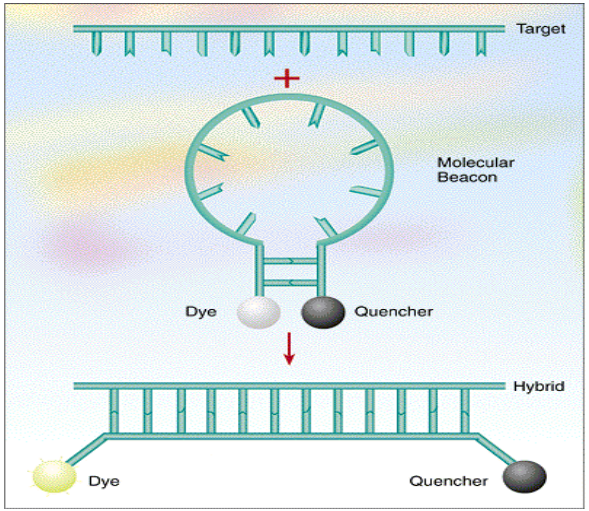


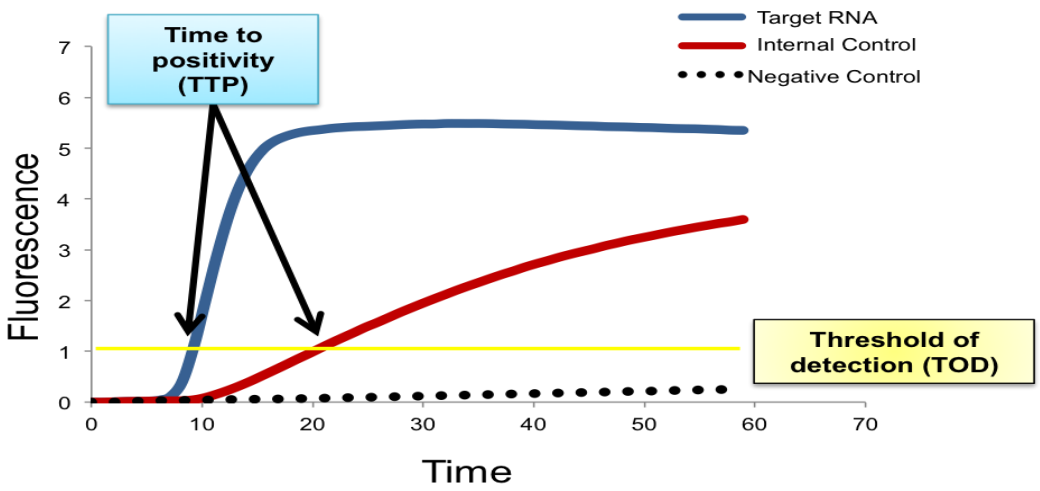
Cryptosporidium

Water-borne pathogens are (typically) difficult to measure

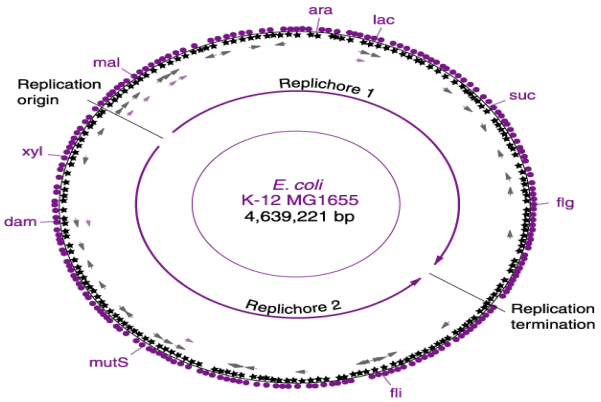
- Very diverse (bacteria, viruses, parasites, virulent and non-virulent strains)
- Low concentration / low infectious dose (e.g. Norovirus; ≥18 viral particles)
- Lack of good bio-analytical methods (many can't be cultured)
- Diseases of unknown origin

Quantitation of Microorganisms in Natural Waters using the LabCard NASBA





New NASBA Assays for *E. coli* DNA



Challenges:

- High genomic diversity In the environment.
- Genome size is approx. 4,000-5,000 unique genes.
- >2,000 sequenced genomes
- Approx. 300 core genes*
- Target sequences are not always unique

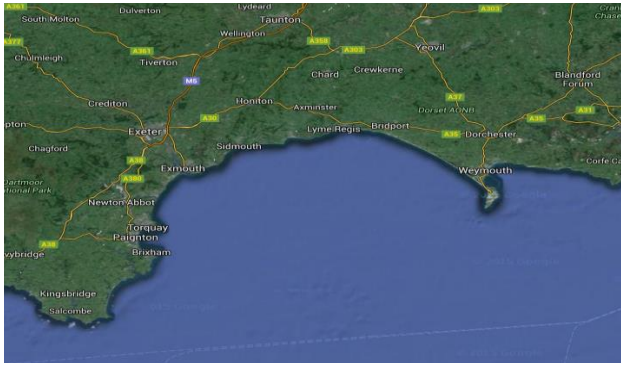
*Miriam Land *et al* (2015) Funct. Integr. Genomics 15, 141-161

Bioinformatics methods were employed to find *E. coli* sequences that were…

- Unique to *E. coli*
- Ubiquitous in *E. coli* strains

Confirmed experimentally using library of *E. coli* (ECOR) and non-*E. coli* bacteria from different hosts and geographical locations

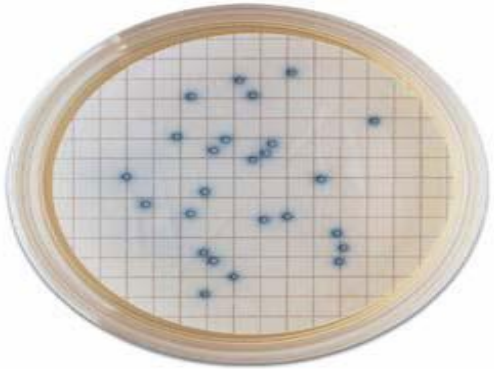
Monthly evaluation of the existing and new assays using “real” water samples

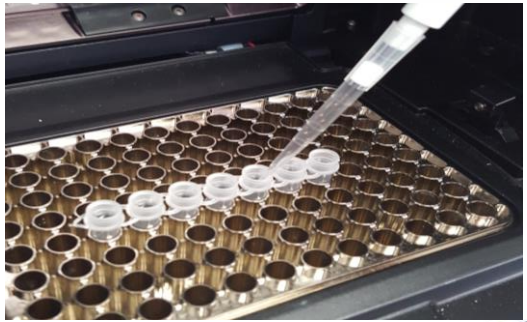


Samples Collected in Southwest England

Culture (Cefas)

NASBA (NOC)

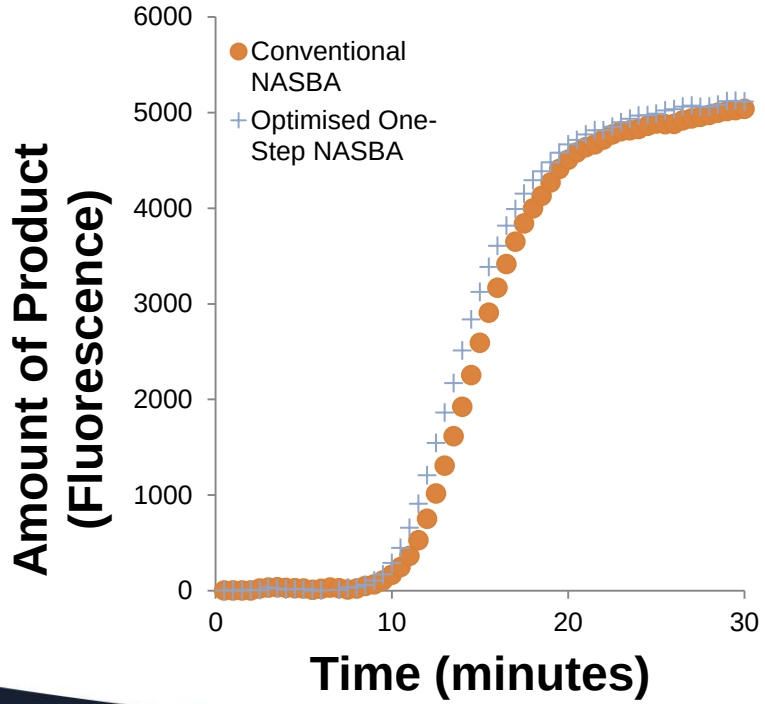




Preliminary Results from Month One

Sample	Plate Assay Mean (n=3) (CFU / 100 mL)	RNA Assay after thermal induction (Cell Equivalents / 100 mL)	DNA assay (Genome Copy / 100 mL)	Comment
Saline, inshore (bathing water)	**21**	**Not Detected**	**Not Detected**	Possible to detect ≥ 10 cells in pure culture. Negative result due to inhibitors?
Spiked saline (*E. coli* type)	**6533**	**3,100**	**8,500**	RNA underestimation; DNA overestimation
Estuarine	**1933**	**900**	**3,200**	RNA underestimation; DNA overestimation
Spiked estuarine (*E. coli* type)	**6600**	**400**	**8,700**	RNA underestimation; DNA overestimation
Tertiary sewage treatment works (post UV)	**121,500**	**Not Detected**	**Not Detected**	Sample inhibition
Tertiary sewage treatment works (pre-UV)	**274,667**	**Not Detected**	**Not Detected**	Sample inhibition
Secondary sewage treatment works	**149,000**	**Not Detected**	**Not Detected**	Sample inhibition
Positive control (*E. coli* type)	**274,667**	**211,500**	**430,200**	RNA underestimation; DNA overestimation
Negative control	**0**	**Not Detected**	**Not Detected**	

Other developments: A New One-step NASBA

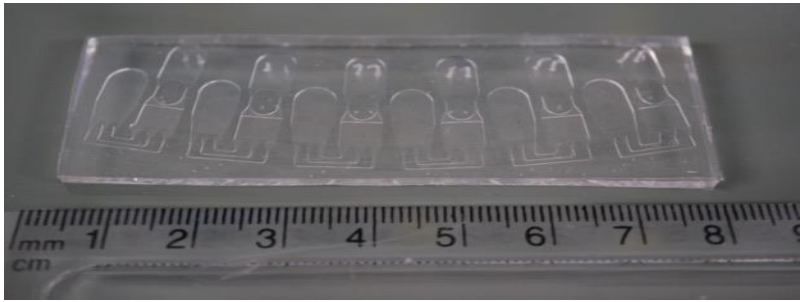


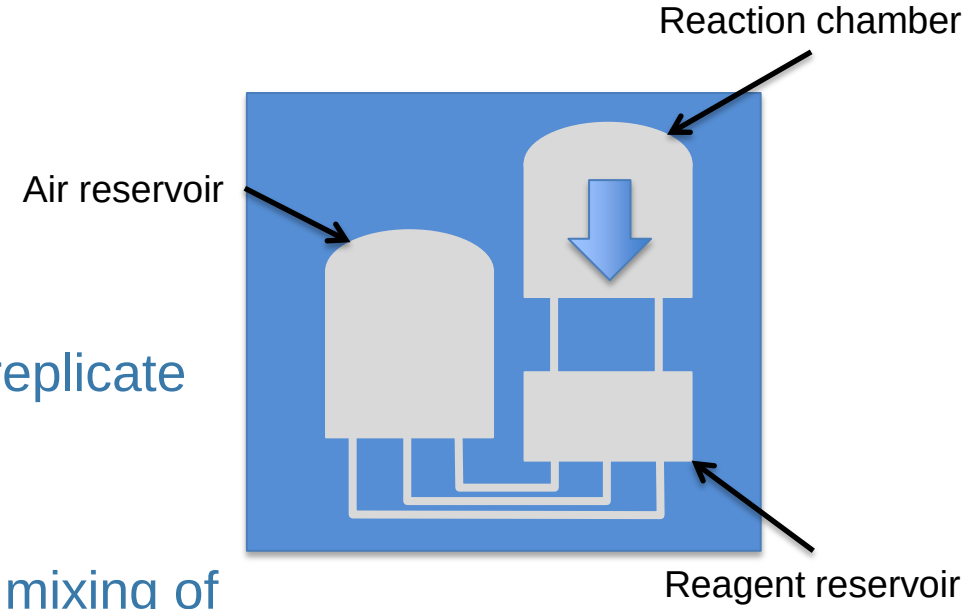
Development of new reagent preservation methods

Optimisation of primer annealing

zymes

A New LOC for Spacial Multiplexing on Chip

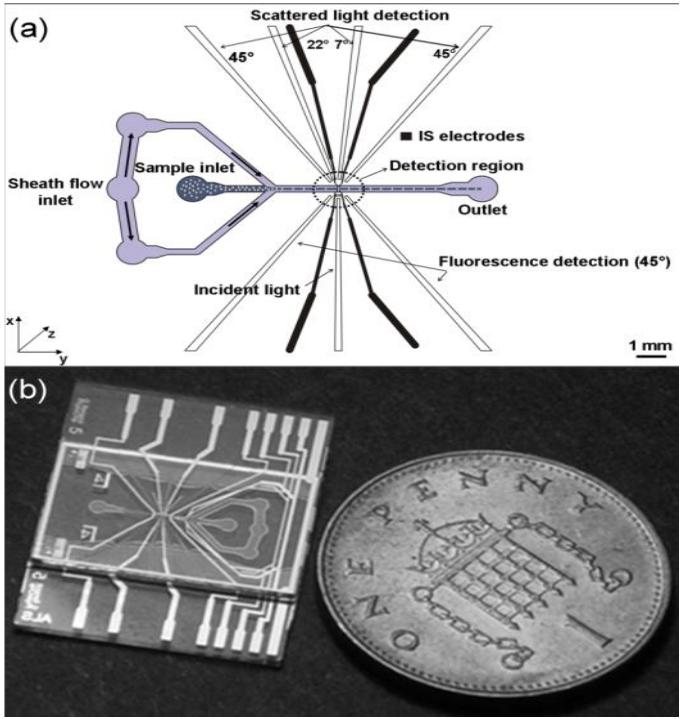




Six chamber chip supporting six replicate One-step NASBA reactions.

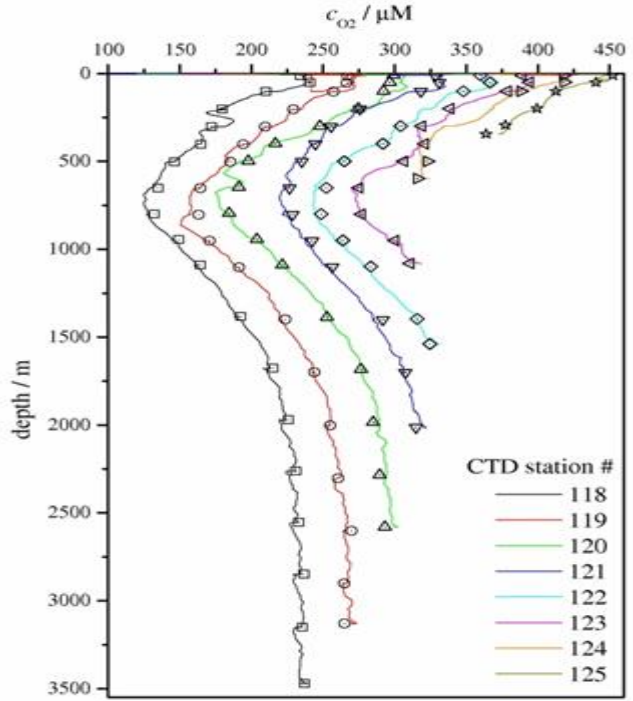
Uses centrifugal force to achieve mixing of sample with dehydrated reagents

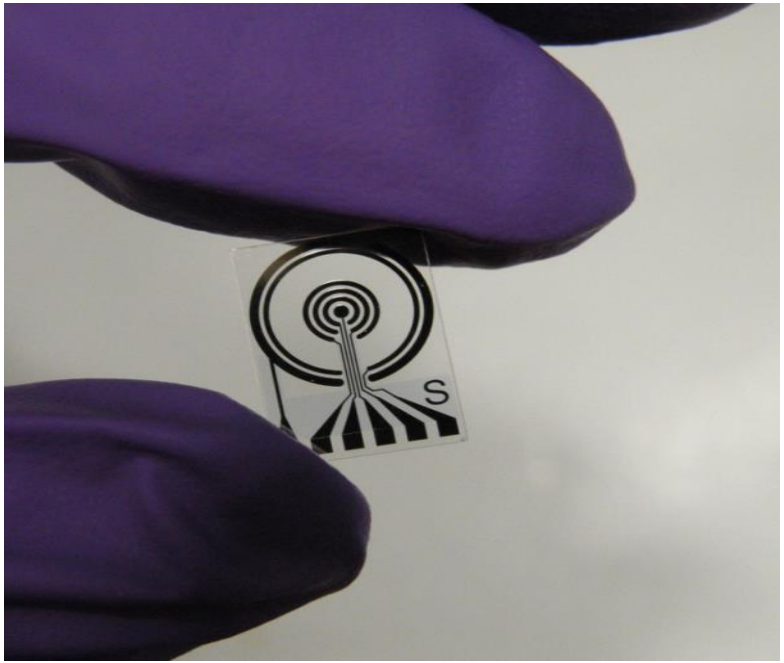
BBSRC sustainable aquaculture: Cytometer for HAB detection and quantification

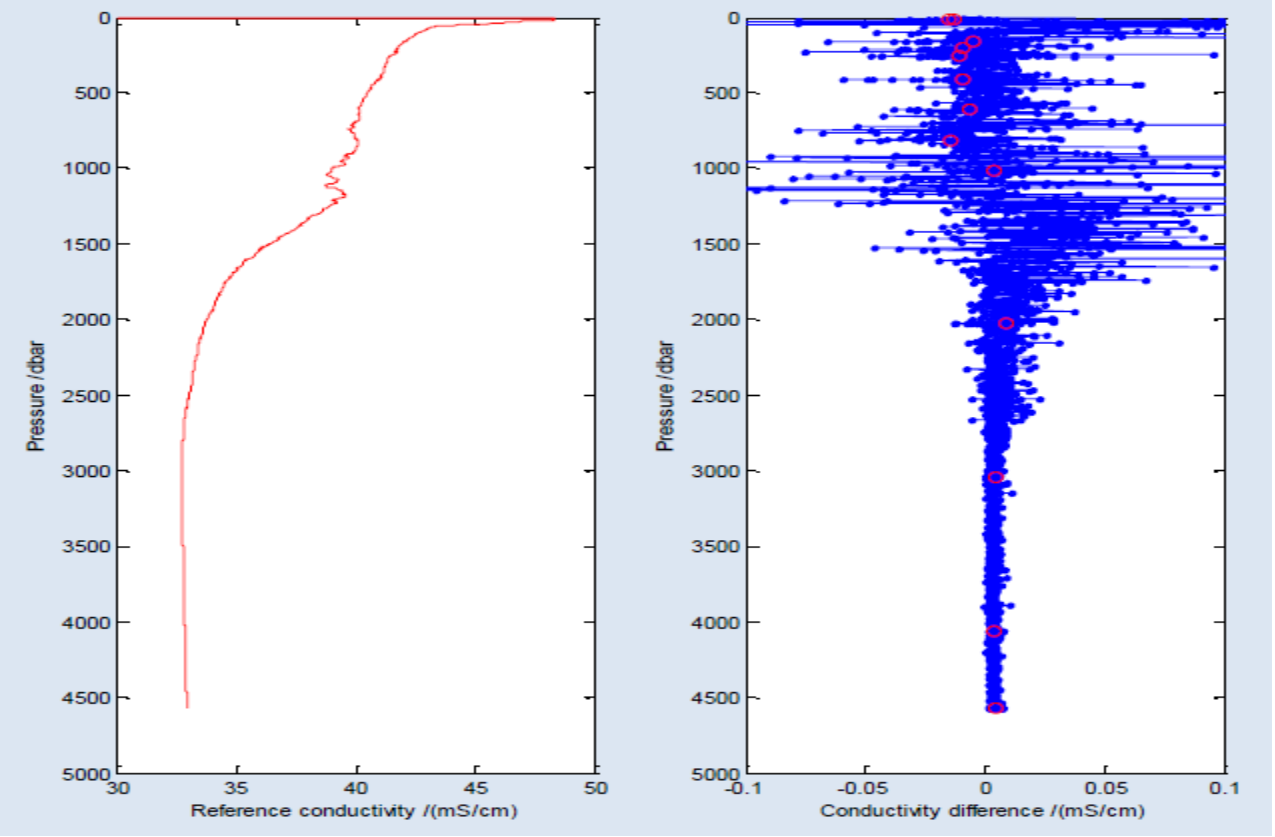


- Simultaneous measurement of electrical (impedance) and optical properties of individual cells
- In-lab prototype
- No air required for optics or operation (suitable for deep sea)
- Challenges include sample concentration, and optical detection limits (power in chip)

CT-DO Sensor: Commercialisation






Pressure /dbar
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
30
35
40
45
50
Reference conductivity /(mS/cm)
Pressure /dbar
-0.1
-0.05
0
0.05
0.1
Conductivity difference /(mS/cm)

Data Flow

- Easily discover sensors and their metadata
- Sensors and sensor observations discoverable, accessible and useable via the web
- Seamlessly integrate sensors from Sense Ocean Network with sensors from other networks

The standards

netCDF

Turtle

GeoSPARQL

OGC®
Making location count.

SOS

O&M

RDF

W3C® M2M

N-triples

W3C®

w3id

Controlled Vocabularies

SKOS

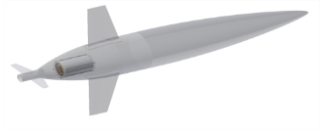
JSON-LD

W3C® SPARQL

SensorML

Proposed approach

Sensor passes UUID through to base station



Platform

NERC Linked data (RDF, SPARQL) server

Satellite

Base station/ Data centre

UUID

SensorML
SSN (OWL)
JSON LD

netCDF EGO 1.1, CF1.6, LD

Data delivery by SOS server and linked ocean data server

Reference for netCDF Link Data conventions:
Yu J. et al. Towards Linked Data Conventions for Delivery of Environmental Data Using netCDF: pages 102-112; Springer., ISBN: 978-3-319-15993-5

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Publication & Discovery

SOS

SPARQL

Linked data

Mainly for machine to machine access!!!

2017 Forward look

Marine Sensors Technologies and TRL
2011,2016,2021,2026

Microfabricated Solid State / Electrochemistry:

- Salinity 5-8-9-9
- Dissolved oxygen 4-7-9-9

Optodes / optical sensors

- Gases inc. methane 6-6-8-9
- pH, pCO_2 4-6-8-9
- Radionuclide 1-3-5-8

Lab on Chip Cytometer

- Whole cells (label free) 4-5-7-9
- Labelled cells 3-5-6-8
- Microplastics 2-4-7-9
- Bead assays 2-3-6-8

Lab on Chip Chemistry

- Inorganic Nutrients 6-8-9-9
- Organic Nutrients 2-5-7-9
- Trace metals 4-7-8-9
- pH 5-7-9-9, TA 2-4-7-9, DIC 2-4-9-9, pCO_2 2-4-6-8
- Small organics, e.g. PAH, PCBs (f-pM) 2-5-6-8
- Proteins and large organics (copies / L) 2-4-6-7
- Nucleic Acids (copies / L) 5-6-7-9
- Radionuclide 1-3-5-7

OTEG LOC sensors development status

LOC Sensor	Subsystems developed	Benchtop system	Shipboard measurements	In situ deployment
Nitrate	✓	✓	✓	✓
pH	✓	✓	✓	✓
Phosphate	✓	✓	✓	✓
Iron	✓	✓	-	✓
Silicate	✓	✓	2017	2016
Ammonium	✓	✓	✓	Late 2017
Total alkalinity	✓	✓	2017	2017
DIC	✓	very close	2017	Late 2017
Organic N and P	✓	✓	2017	2017

OTEG LOC sensors – *in situ* deployments projected

LOC Sensor	River/ estuary	Coastal	At depth	Glacial melt	Year- long (unattended)	Glider or AUV	Argo float
Nitrate	✓	✓	✓	✓	✓	✓	2017
pH	✓	✓	✓			2017	
Phosphate	✓	✓	✓	2017	2018?	2017	2017
Iron	✓	✓	✓	2017			
Silicate	2016	2017	2017	2018		2017	

2017 Forward look highlights

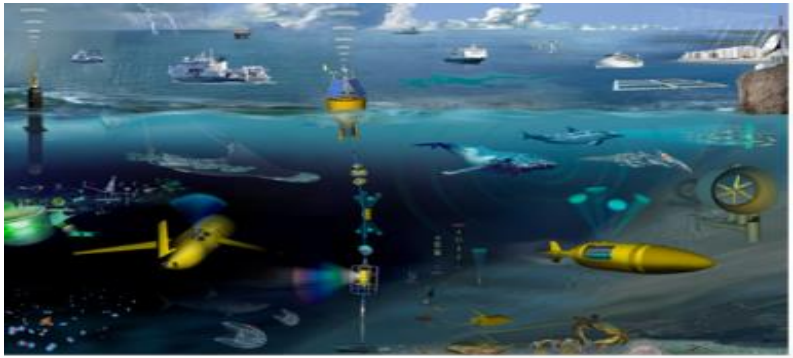
SenseOCEAN final year / deployments / demonstrations

- Demonstration on Apex (PROVOR) (Nitrate, Phosphate, pH)

Platforms targeted for demonstration

Floats
(LEGOS-CNRS)

Shallow cabled and
deep sea observatory
(AWI)



Bouys
(ILEGOS-
CNRS)

AUV
(AWI)

2017 Forward look highlights

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Integration into SLOCUM glider

2017 Forward look highlights

SenseOCEAN final year / deployments / demonstrations

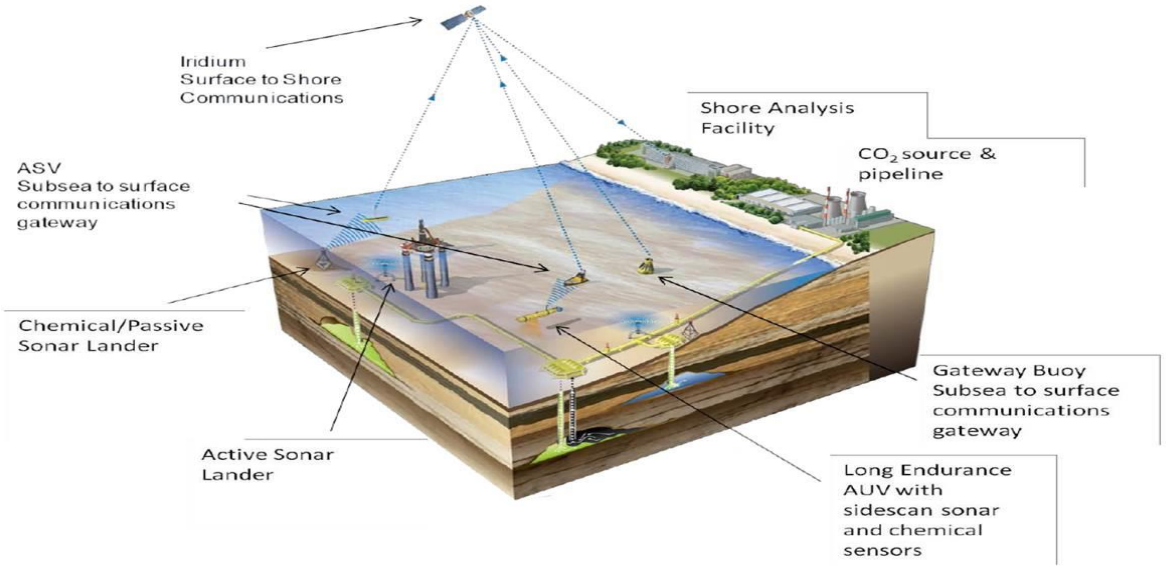
- Demonstration on Apex (PROVOR) (Nitrate, Phosphate, pH)

Integration into SLOCUM glider

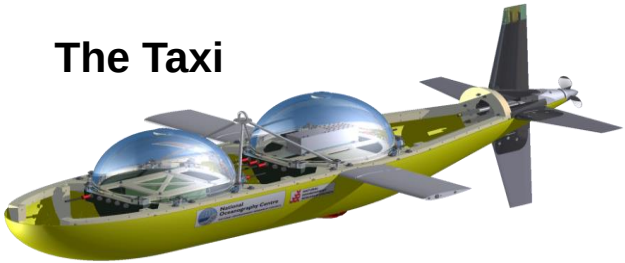
Integration into ALR and trials for ETI

ETI CCSMV - Project

The Concept



The Taxi



The sensors

CCS Sensors package: commercial

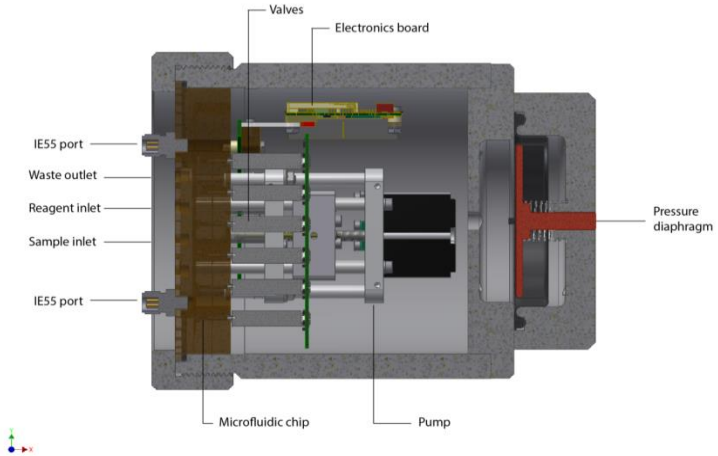
SeapHOx

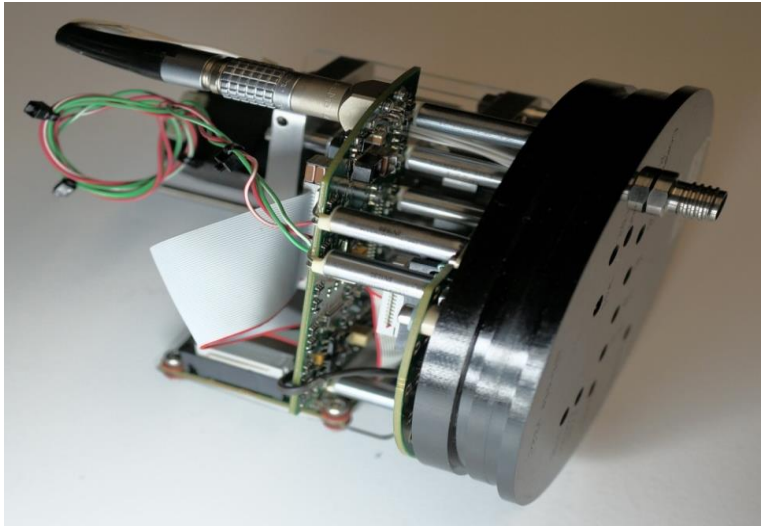
SBE52 CTD

SEAFET

SBE43F DO

CCS Sensors package: NOC





lab on a chip

TRL 7: pH, Phosphate, Nitrate

TRL 4-7: TA, DIC

2017 Forward look highlights

SenseOCEAN final year / deployments / demonstrations

- Demonstration on Apex (PROVOR) (Nitrate, Phosphate, pH)

Integration into SLOCUM glider

Integration into ALR and trials for ETI

Pathogen detection in the field

CTDO product launch

LOC license agreement / commercialisation

Acknowledgements

Work by current and past members of OTEG

Group head: Matt Mowlem

Subgroup heads:

Robin Pascal (Multidisciplinary)

Socratis Loucaides (Analytical science)

Chris Cardwell (Electronics & Software)

Kevin Saw (Mechanical)

NERC SCIENCE OF THE ENVIRONMENT

Collaborators at:
University of Southampton
NOC
Plymouth Marine Laboratory
Scottish Marine Institute
GEOMAR and others

Photos from Dave Owsianka, Alex Beaton, Martin Arundell and others