UNIVERSITY OF Southampton

Innovative sensors for harsh aqueous environments from invention to operation and commercialisation

MATT MOWLEM[1,2] , HYWEL MORGAN[1]

1: UNIVERSITY OF SOUTHAMPTON

2: NATIONAL OCEANOGRAPHY CENTRE

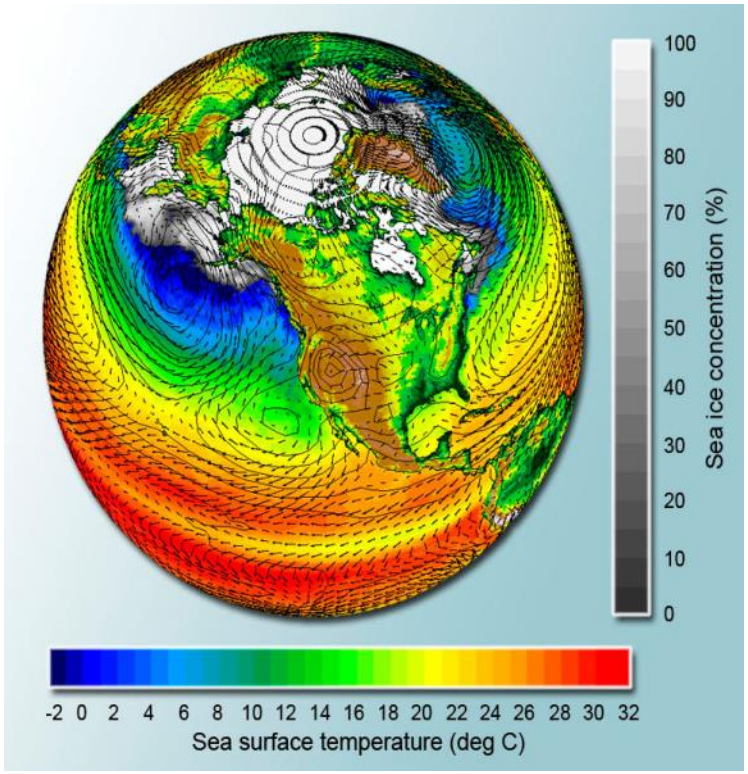
National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

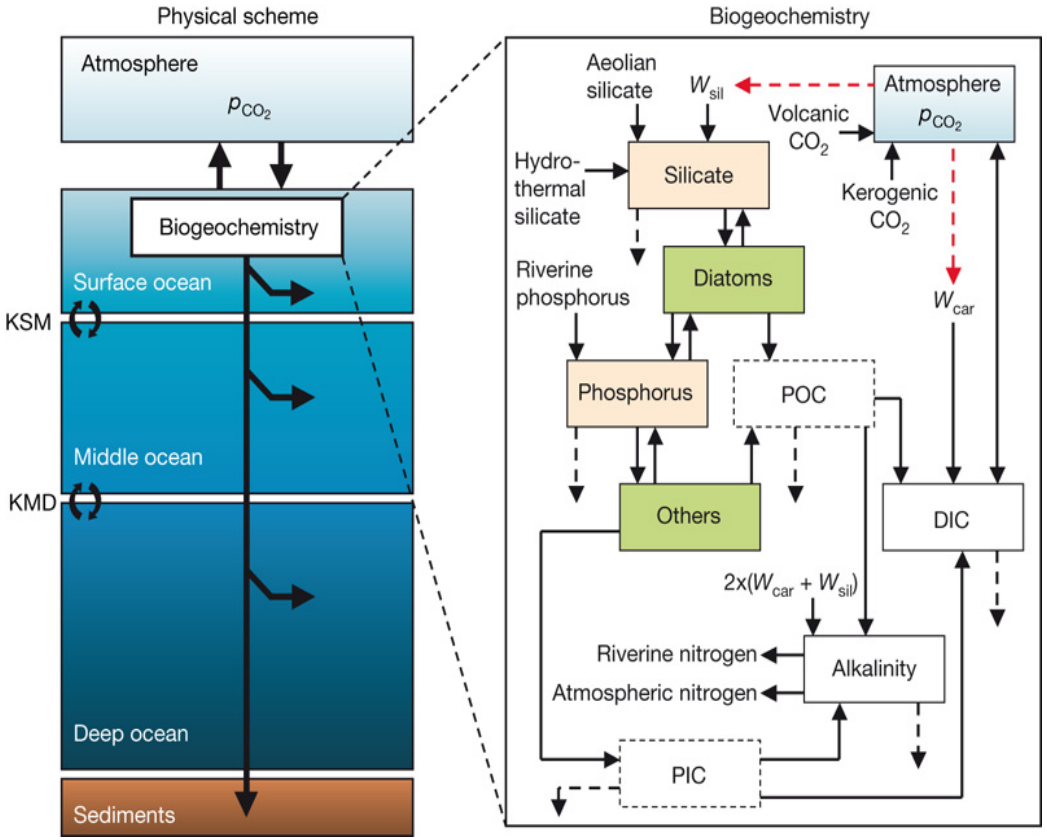
noc.ac.uk

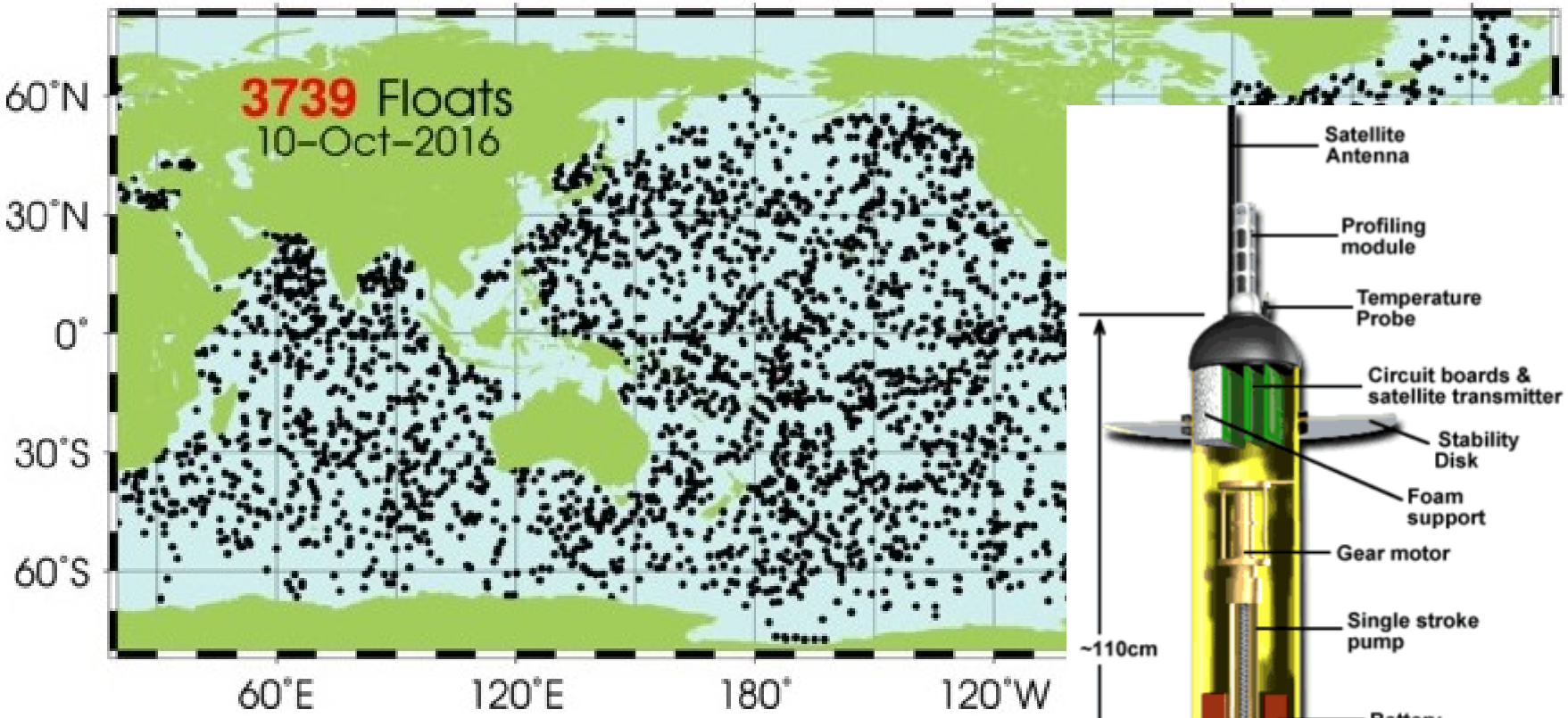
NERC SCIENCE OF THE ENVIRONMENT

http://www.iooc.us/

Biogeochemistry: Global impact, hard to measure







http://www.argo.ucsd.edu/index.html

Sensors must have

- low buoyancy change
- low weight in water
- long-term stability
- >1 sample / 4 minutes in burst mode

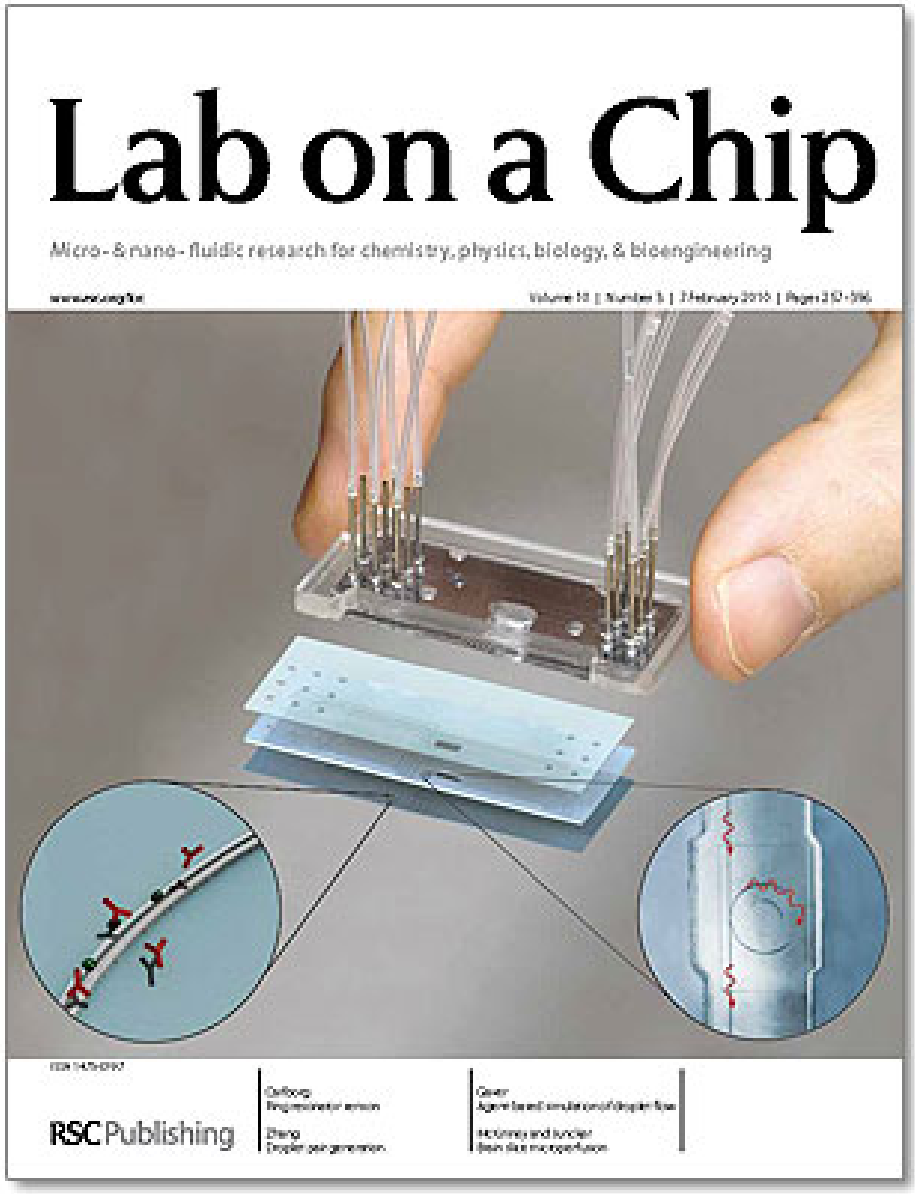
Platforms

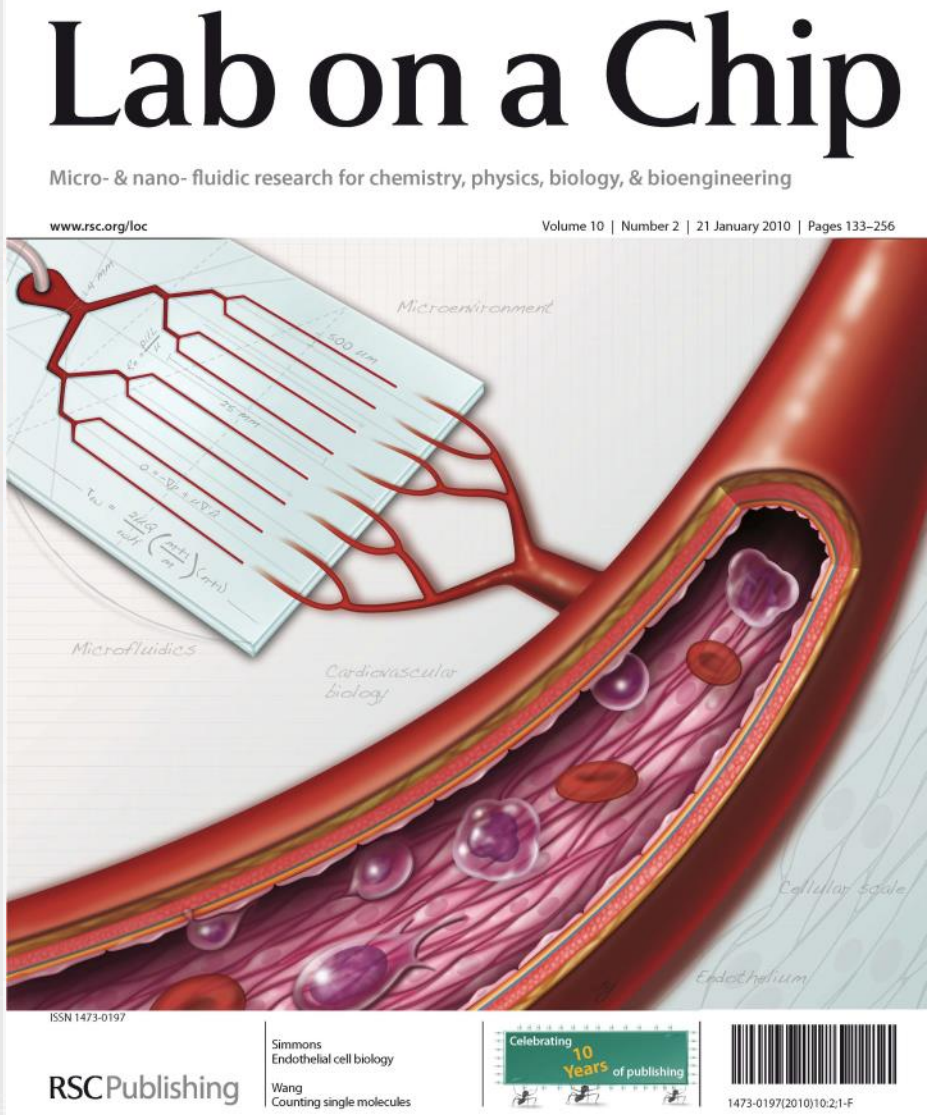
- Profiling (Argo) floats
- AUVs
- Ocean Gliders
  - BRIDGES
- UAVs
- Drop sonde
- Moorings
- Ships of opportunity
- Offshore structures
- Coastal infrastructure
- **Observatories**
- **Data flow**

Water Sensors Analytical Targets

- Salinity (microsensors, 0.006% accuracy)
- Nutrients (uM coastal / deep, nM open ocean)
- **Trace metals** (n -fM)
- **Gases** (n-uM)
- Carbonate system (0.001 pH equiv)

- **Small organics, e.g. PAH, PCBs (f-pM)**
- **Proteins and large organics (copies / L)**
- **Nucleic Acids: organisms, eDNA (copies / L)**
- **Whole cells (cytometry)**
- **Radionuclide**


Lab on a Chip
Micro- & nano- fluidic research for chemistry, physics, biology, & bioengineering
RSC Publishing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www.rsc.org/loc
Volume 10 | Number 2 | 21 January 2010 | Pages 133–256
Microenvironment
Microfluidics
Cardiovascular biology
Cellular Scale
Endothelium
ISSN 1473-0197
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Endothelial cell biology
Wang
Counting single molecules
Celebrating 10 Years of publishing
1473-0197(2010)10:2;1-F

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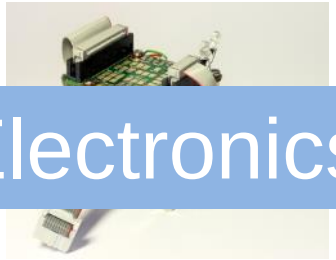
Electronics



Pressure tolerant electronics

Integrated Analytical systems

Engineering Electronics

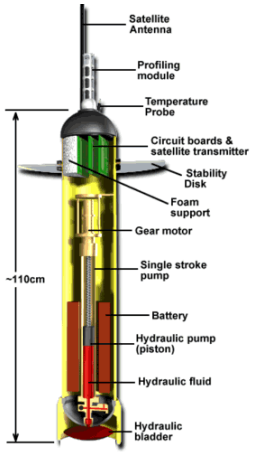
Life Sciences

Chemistry

Bio. Science

Life Sciences

Mass deployed platforms



Optoelectronics

Electronics

High performance low-cost optics

Engineering Electronics

Life Sciences

Engineering Electronics

Low-cost manufacturing

Ocean and Earth Science

Biogeochemical processes

Bio. Science

Life Sciences

biofouling

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

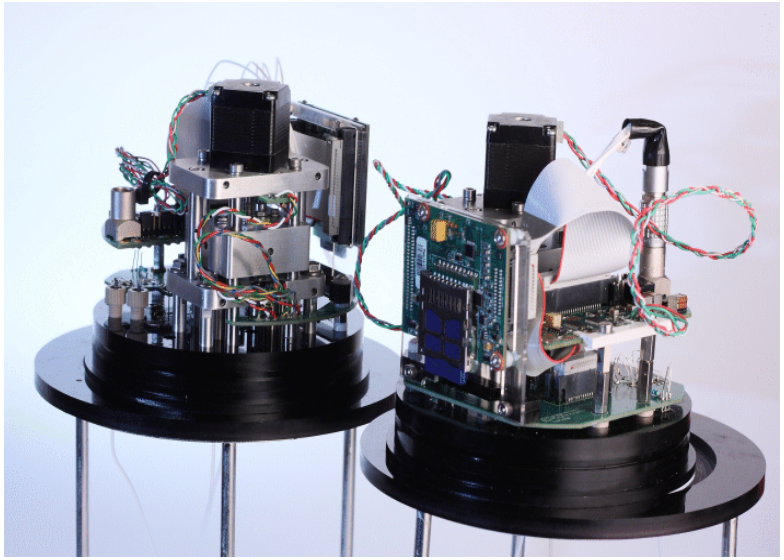
- Whole cells (label free) 5
- Labelled cells 5
- Microplastics 4
- Bead assays 3

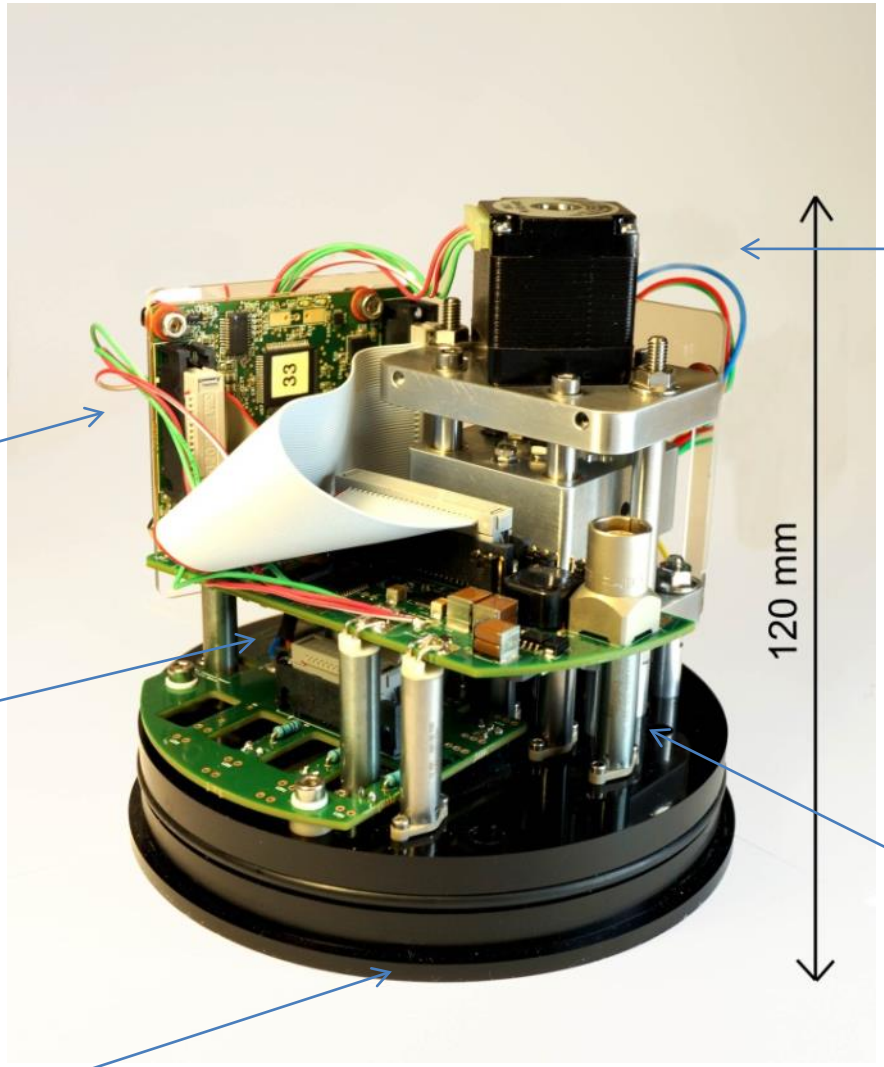
Lab on Chip Chemistry

- 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

Lab on chip

Lab on chip: Nitrate, Nitrite, pH, Phosphate, Silicate, Iron, Manganese, Total Alkalinity, Ammonia, DOP, Dissolved Inorganic Carbon, DON…..





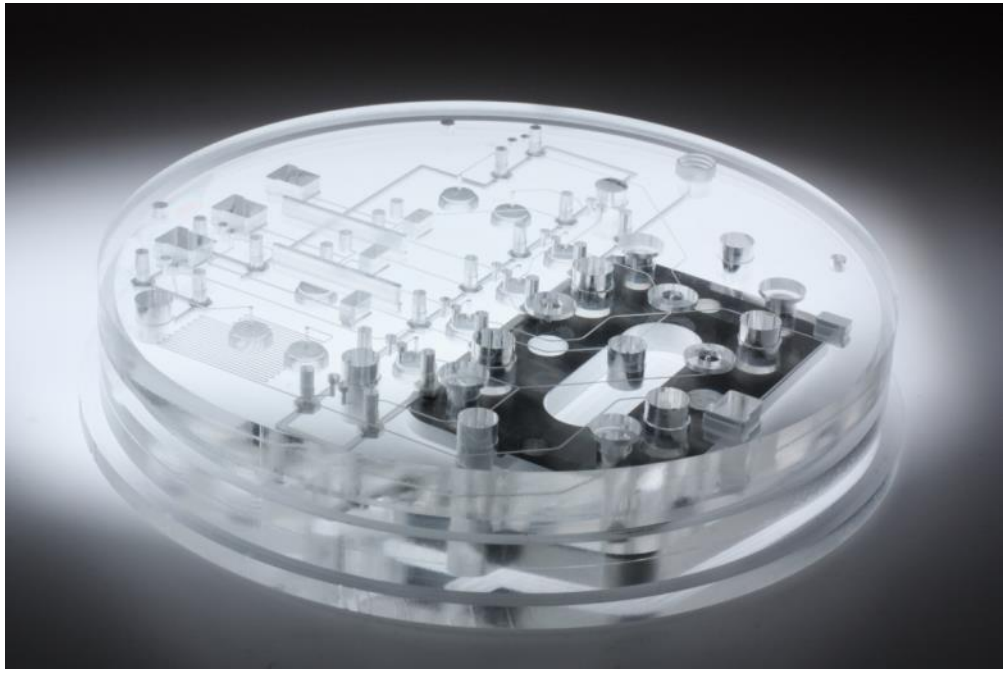
Pump

Optics and processing boards

Valves

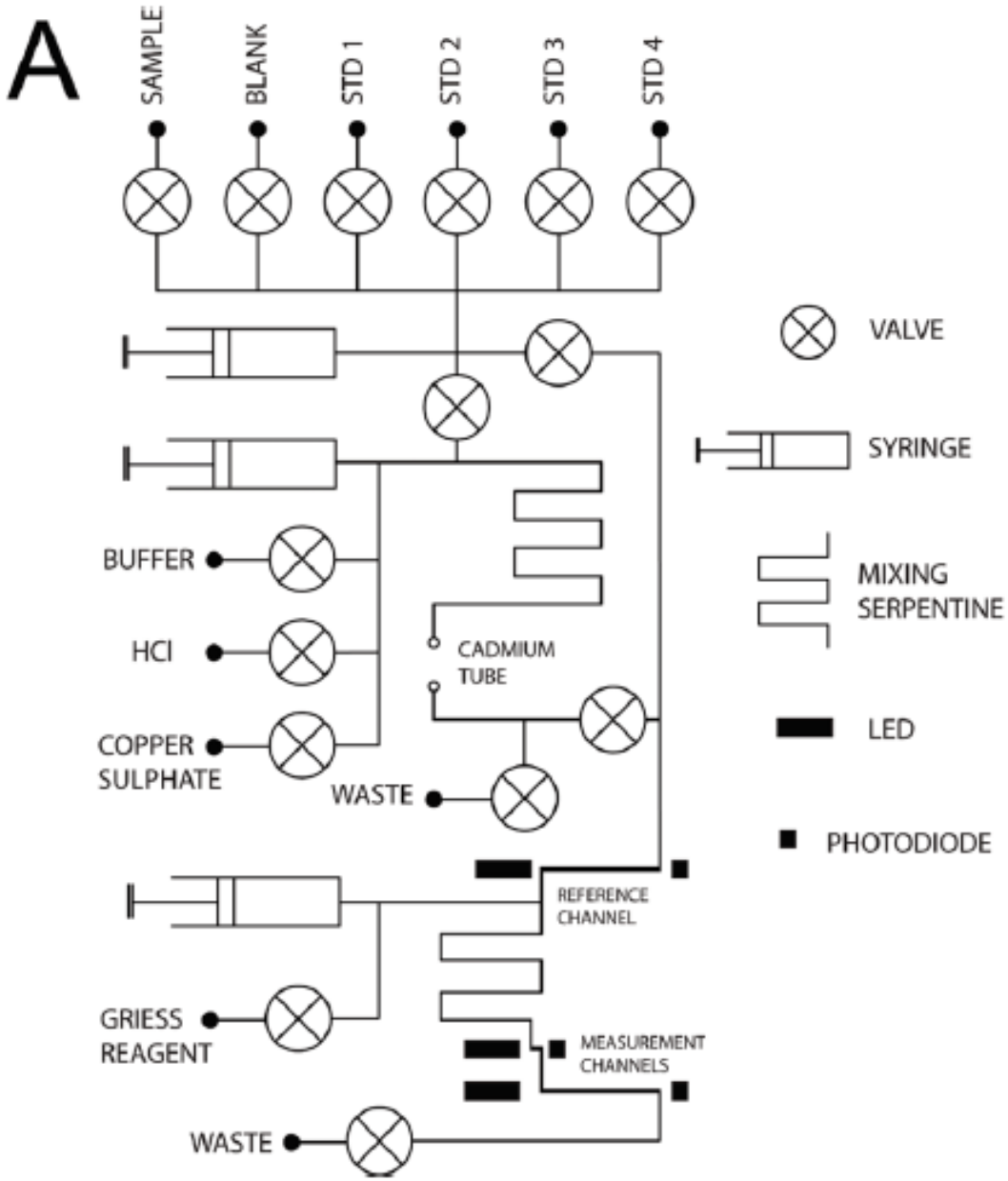
Microfluidic Chip

……..ON CHIP



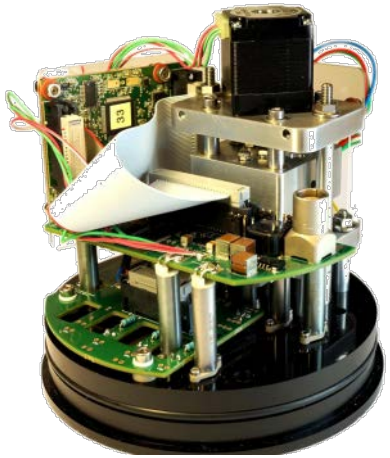
100 mm

- Small footprint
- Low power
- Easy to build
- Low reagent consumption
- No waste emission


A
SAMPLE
BLANK
STD 1
STD 2
STD 3
STD 4
BUFFER
HCl
COPPER SULPHATE
WASTE
CADMIUM TUBE
REFERENCE CHANNEL
GRIESS REAGENT
MEASUREMENT CHANNELS
WASTE
VALVE
SYRINGE
MIXING SERPENTINE
LED
PHOTODIODE

What makes our approach work?

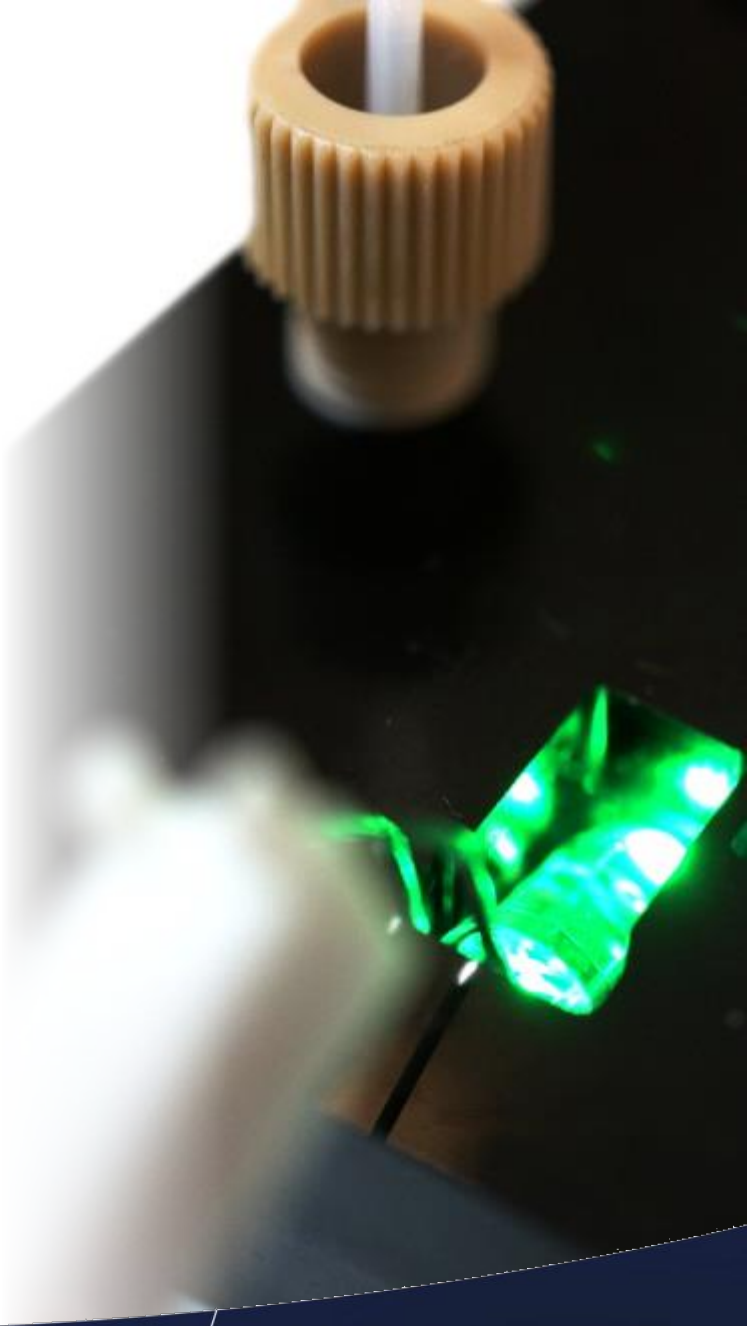
Platform approach



nitrate

pH

Change the assay,
keep the engineering



Mooring implementation

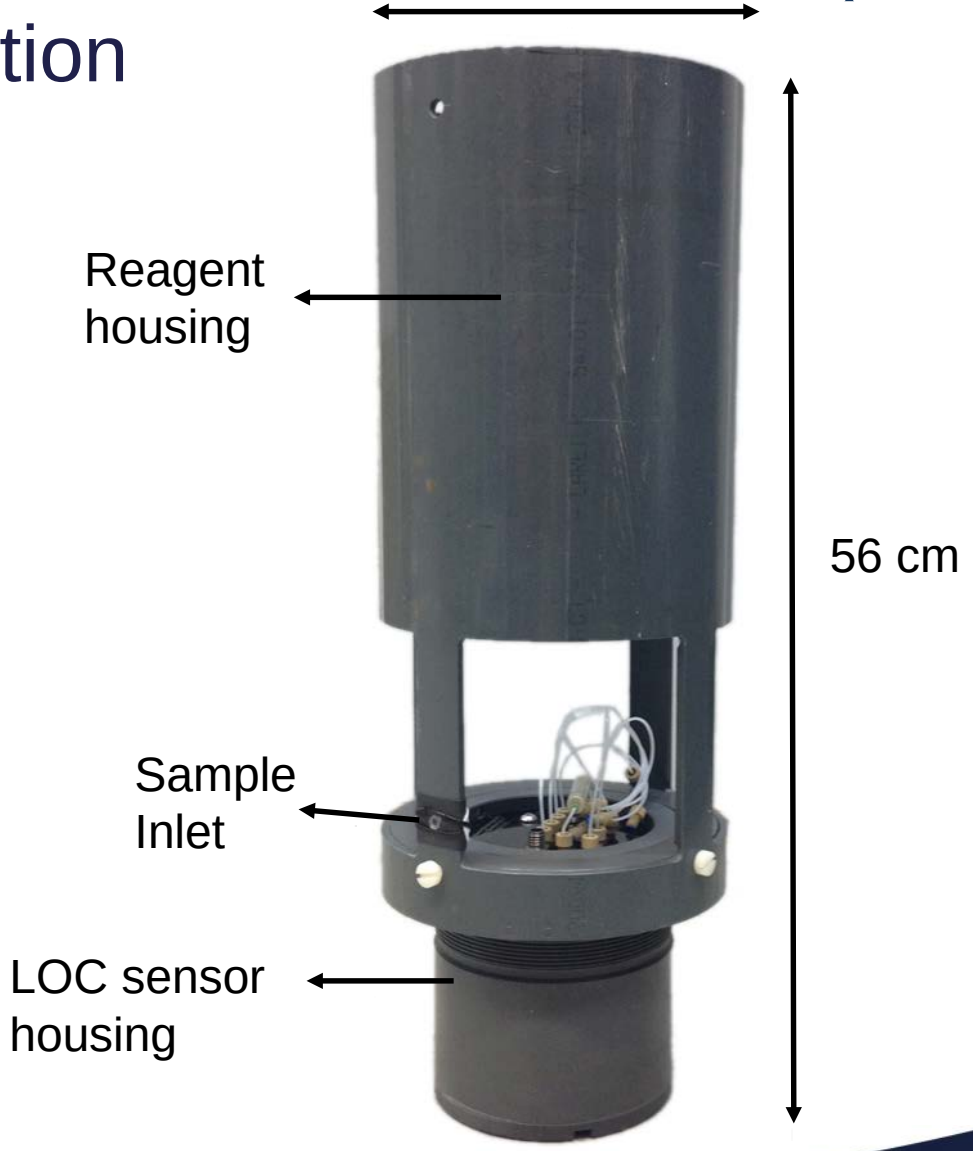
Reagents in housing
(includes blank, standards)

Waste products stored on board

Integrated fluidic control

Data storage

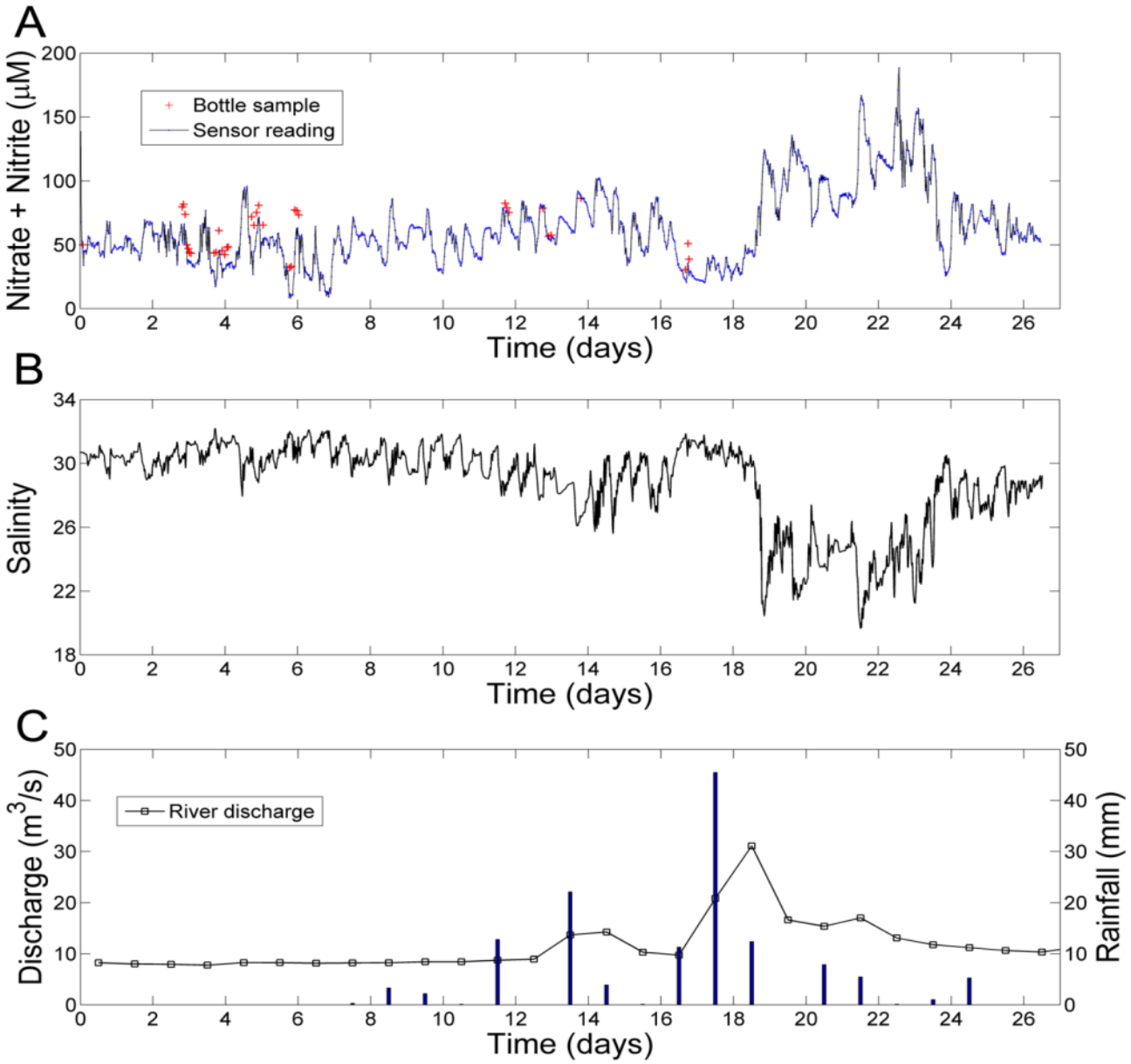
Communication



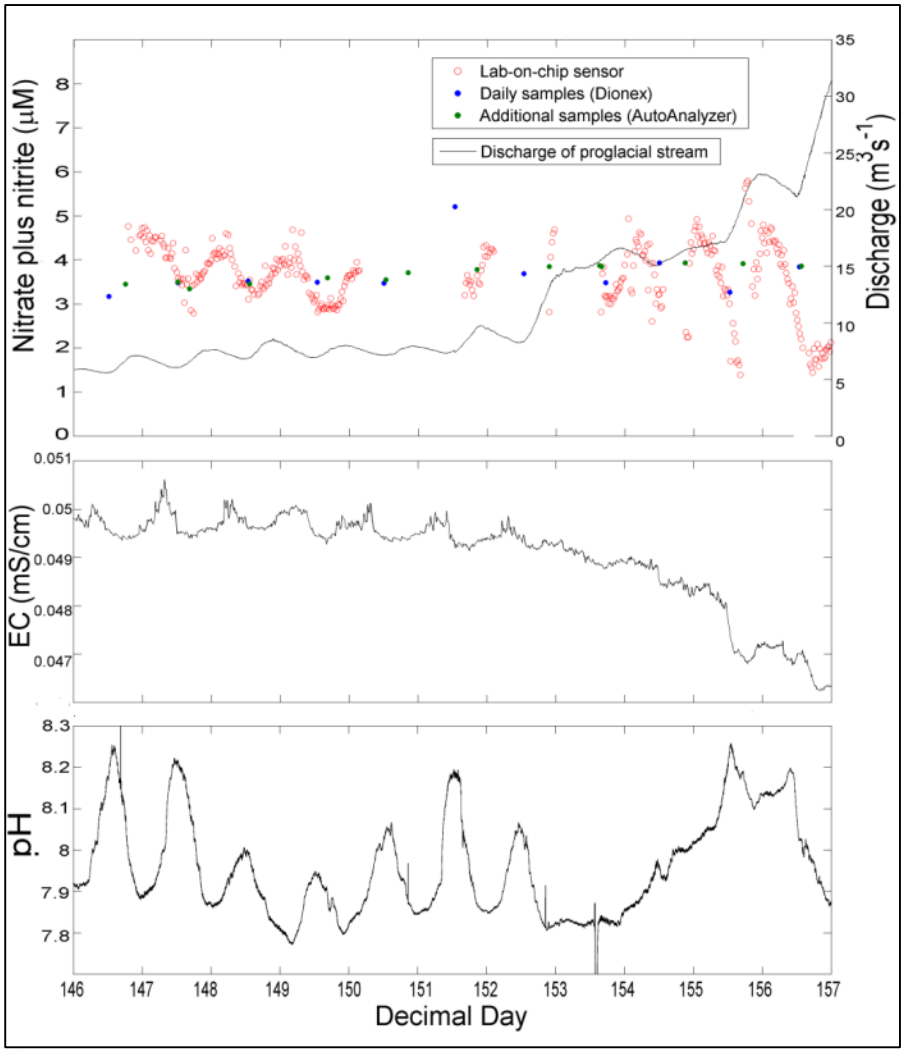
Nitrate + Nitrite data from 26-day deployment Empress Dock

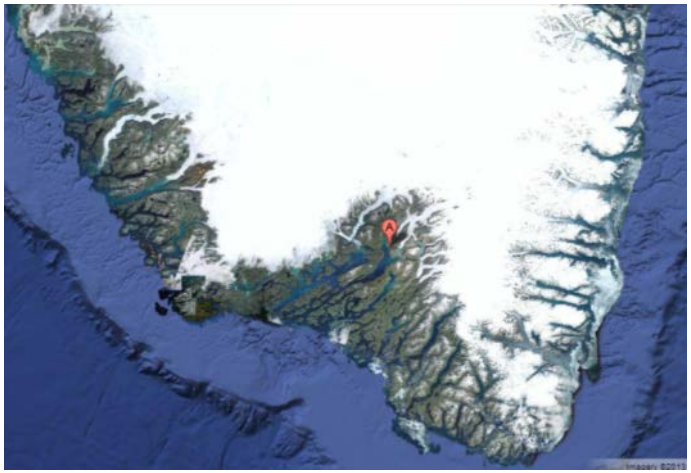
Salinity

River Test discharge and local rainfall



Glacial meltwater





With Jemma Wadham and Martyn Tranter, University of Bristol

noc.ac.uk

Macronutrient cycles

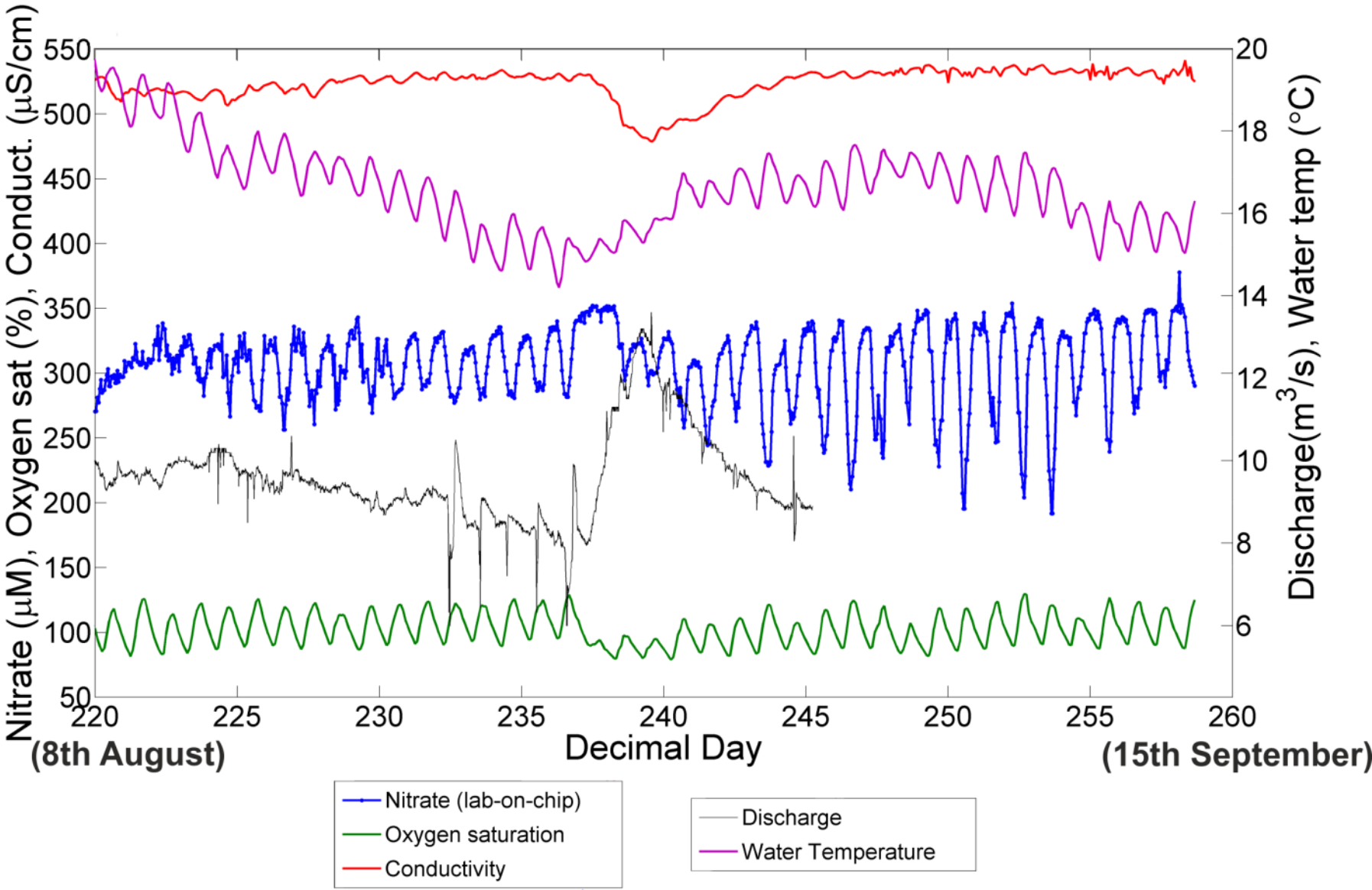
UNIVERSITY OF Southampton

Christchurch harbour, UK

With Duncan Purdie and others as part of the Macronutrient Cycles project

UNIVERSITY OF Southampton

Data from nitrate sensor deployed in Hampshire Avon, UK (blue line)

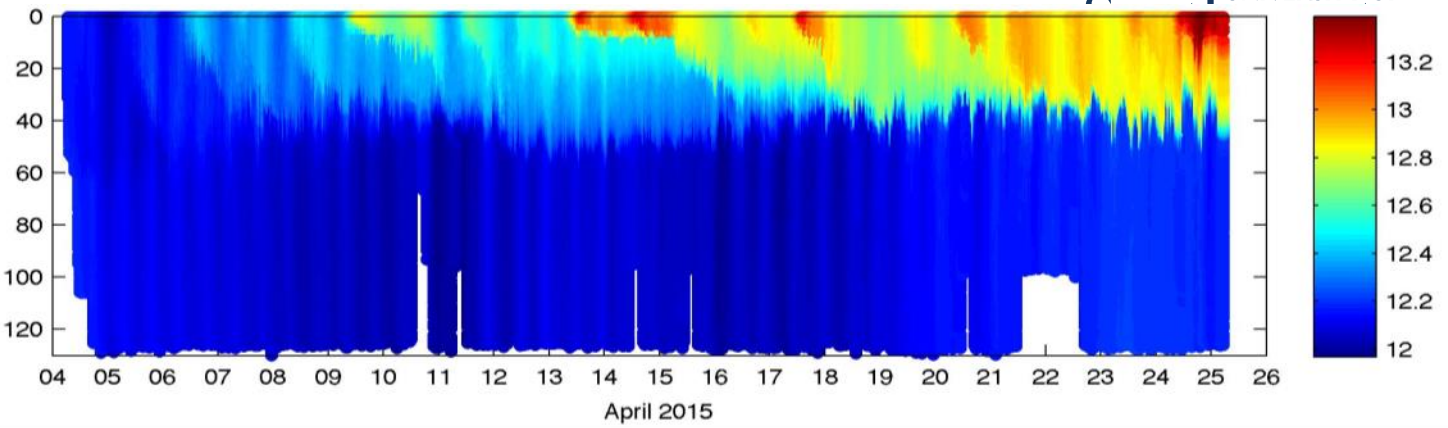


Nitrate deployment on gliders

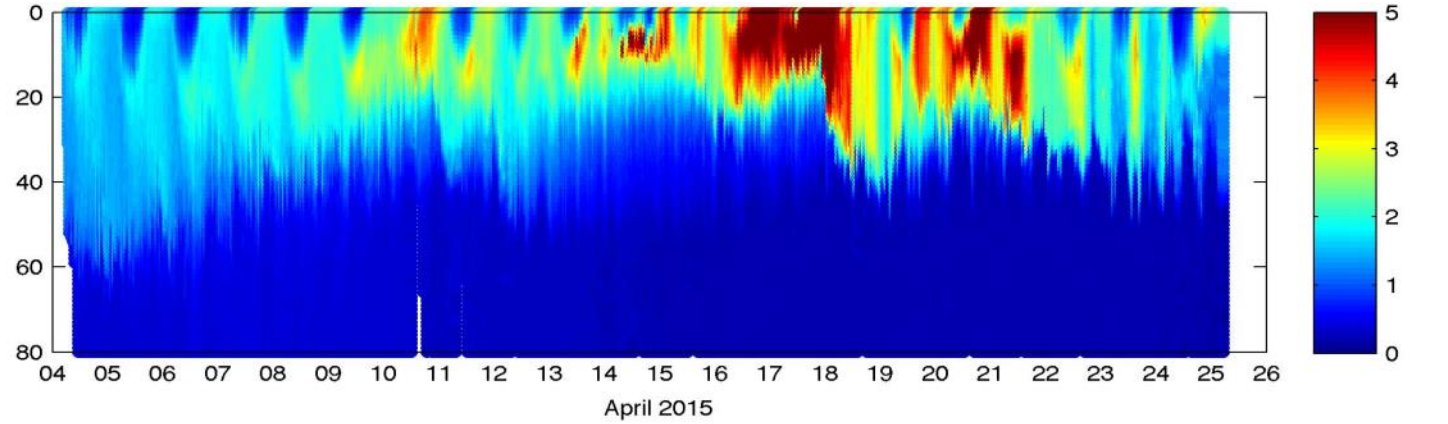
Celtic Sea, April 2015

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

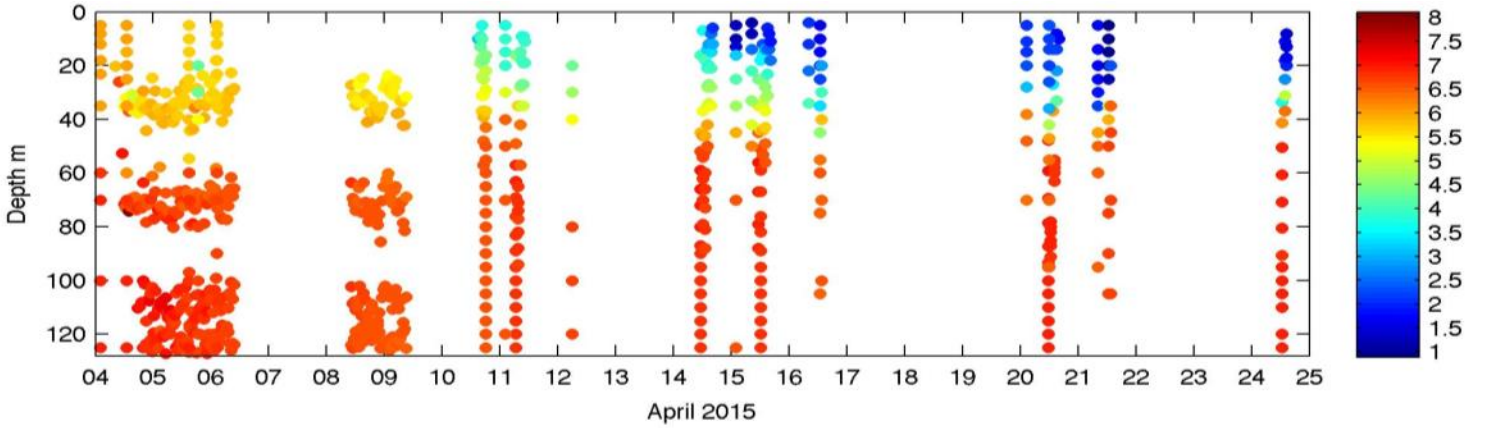
Temperature (°C)



Chlorophyll (mg/m^3)



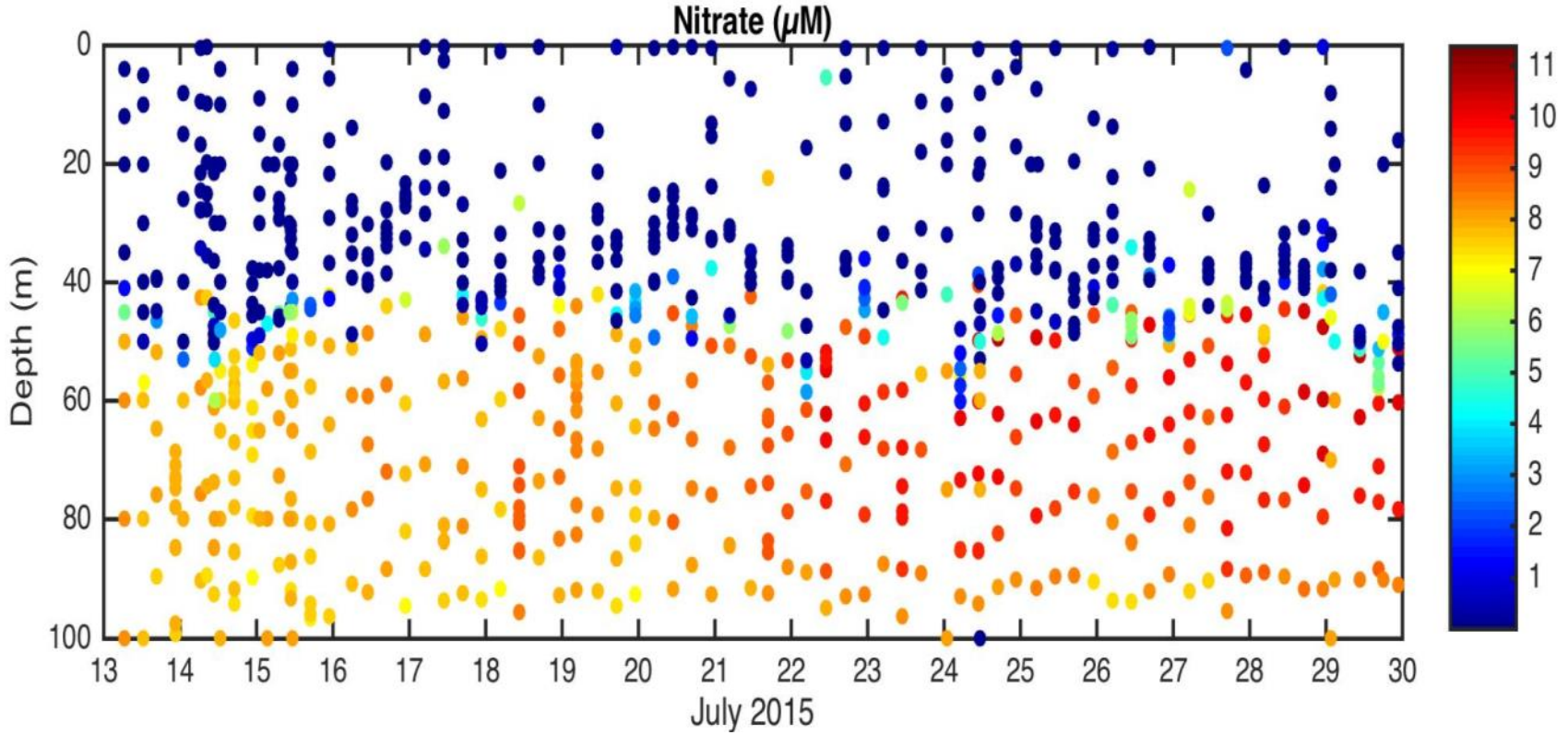
Nitrate (µM)



National Oceanog
NATURAL ENVIR

Celtic Sea July 2015
SOG Glider Data

- Combined CTD and Nutrient sensor on glider data
- LoC deployed on Ship's CTD frame for 3 casts showed good agreement with bottle data



Applications for water sensors

- Waterborne diseases
- Public health protection
  - Fish / shellfish / aquaculture safety
  - Drinking water safety
  - Bathing water safety
- Protection of fish / aquaculture stocks/industry
- Protection of the environment and tourism industry
- Regulatory and statutory testing requirements
- Agriculture management and effluent checking
- Measuring and understanding climate change
  - Deoxygenation, acidification, productivity

What is in the water? What do you need to measure?

- Pathogens
- Parasites
- Pesticides, Herbicides
- Pharmaceuticals
- Industrial effluent or runoff
- Toxic metals
- Agricultural effluent or runoff
- Toxic (Harmful) Algal Blooms (HABs)
- Sewage
- Excess nutrients causing environmental damage and HABs
- Acidification, deoxygination

water for drinking, bathing, fisheries / aquaculture, industry, or agriculture

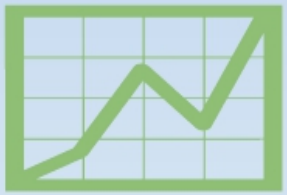
Commercialisation

- University of Southampton Research and Innovation Support (R&IS)
- National Oceanography Centre as an IP and exploitation partner
- IP auction
- Licensing
- Spinout / Joint Venture / Start up

WHAT IS THE MARKET POTENTIAL?

REPORT - Market Outlook for In-Water Nutrient Sensors

Affordable, accurate and reliable nutrient sensors that meet the Challenge targets are in **HIGH DEMAND** by agencies, states, utilities, watershed managers, researchers and various industries across the United States and around the world.



Preliminary market research indicates:

- Interviews and surveys of potential users has revealed interest from a wide **variety of market segments** including industrial, agricultural, academic research, government, resource management, and non-profit research.
- Assessments of likely market segments suggests that overall demand for the next-generation of nutrient sensors will be **24,000 to 30,000 units** in the United States alone, over the next five years.
- With a $5,000 purchase price, this represents a potential US market of **$120-$150 million**.

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

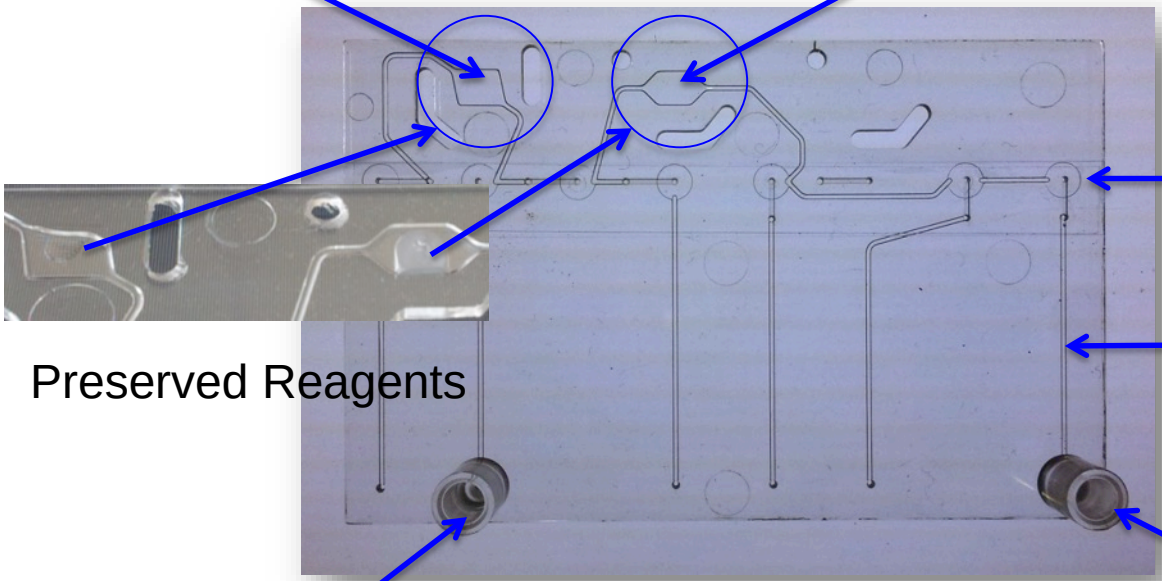
School of Ocean & Earth Sciences (Southampton)

Plymouth Marine Laboratory

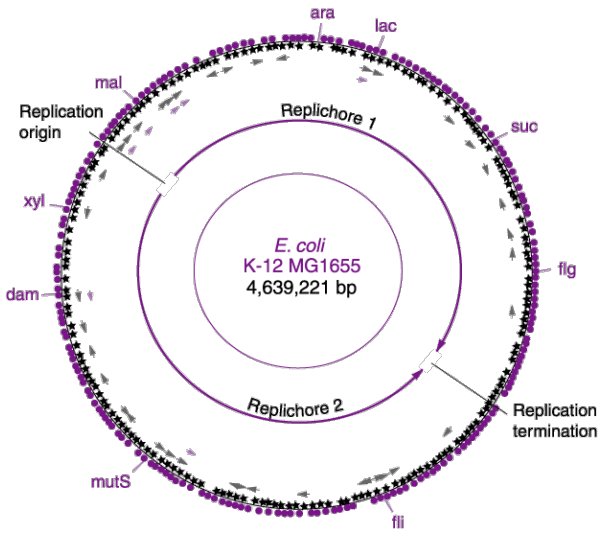
Scottish Marine Institute

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

“LabCards” for LOC-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

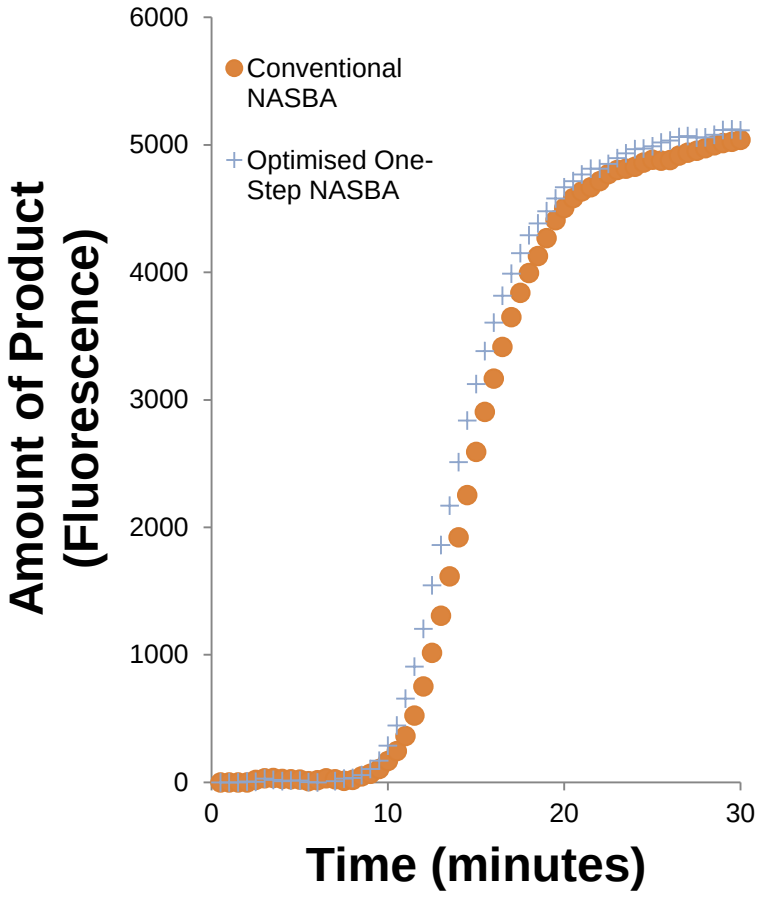
*Miriam Land *et al* (2015) Funct. Integr. Genomics 15, 141-161

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

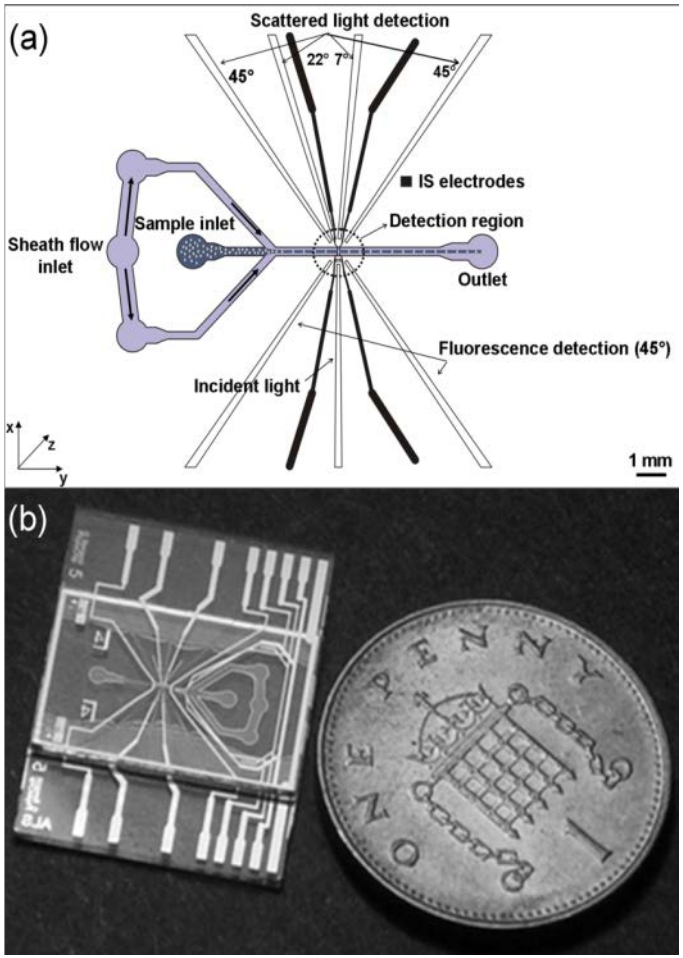
Other developments: A New One-step NASBA



Development of new reagent preservation methods

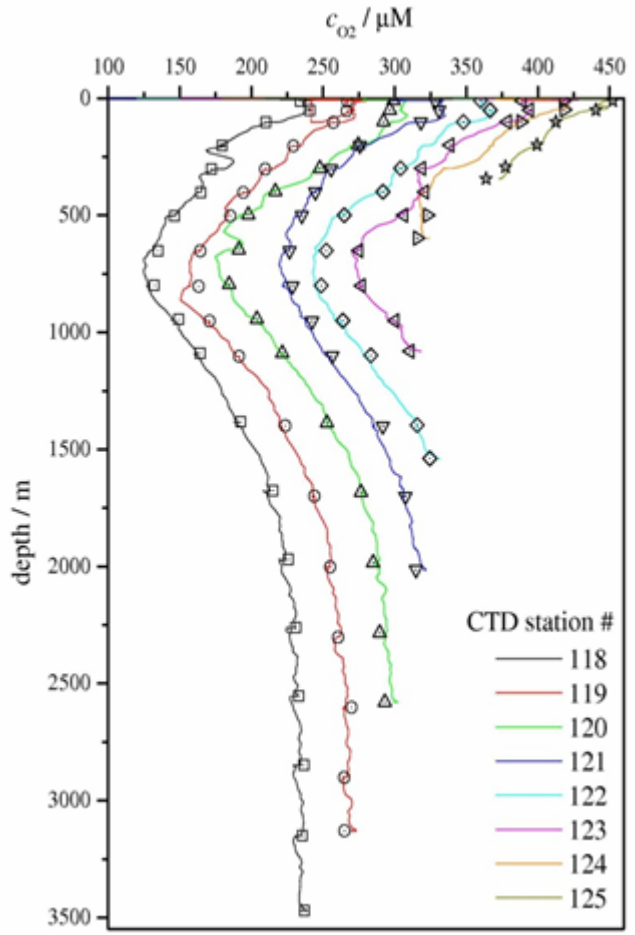
Optimisation of primer annealing and thermo-tolerant enzymes

Cytometer



- 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


c_{O2} / µM
100
150
200
250
300
350
400
450
0
500
1000
1500
2000
2500
3000
3500
depth / m
CTD station #
118
119
120
121
122
123
124
125


S

Scalable

Additional analytes

Deployments

Scale up production

Commercialization