Exploring ocean biogeochemistry using a Lab-on-Chip phosphate analyser on an underwater glider

Lab-on-Chip phosphate analyser technical description

The LoC analyser is composed of a three layer poly(methyl methacrylate) chip with precision milled micro channels (150 µm wide, 300 µm deep; LPKF Protomat S100, Gerbsen, Germany) and bonded using solvent vapour exposure methods developed in house [*Ogilvie et al.*, 2010]. The movement of fluid through the chip is controlled by microinert solenoid valves (LFN Series, The Lee Company, Connecticut, U.S.A.) and a custom-designed syringe pump containing three 3.28 mm internal diameter glass barrels. Each barrel contains a plunger composed of proprietary perfluoro-elastomer sliding seal bonded to a stainless steel shaft. All three pump channels were mechanically linked to operate simultaneously and are driven by a high torque stepper motor (Haydon Kirk, U.S.A.).

The optical components consist of 700 nm light emitting diodes (LED700-02 AU, Roithner) and measuring photodiodes (TSLG257-LF, TAOS, Texas, U.S.A.). The fluidic manifold contains one reference channel and long (91.4 mm), medium (34.4 mm) and short (2.5 mm) measuring channels, each with a LED at one end and measuring photodiode at the other (Fig. 1). In addition, there are also monitoring photodiodes perpendicular to the LEDs to enable correction of drift in the intensity of the LEDs. Increased path length corresponds with increased sensitivity, in accordance with the Beer-Lambert-Bouguer law. The short channel features an LoD of around 0.5 µM PO_4^{3-}, and is not useful for most marine environments. The long and medium channels feature a LoD of 0.04 µM PO_4^{3-} calculated in low nutrient seawater [*Grand et al.*, 2017]. In this study, the long channel was exclusively used.

The chip was encased in a mineral-oil-filled, watertight pressure–compensating PVC housing rated to 6000 dbar. The maximum depth of the Seaglider (1000 m) is therefore not limited by the sensor. Pressure is transferred from the external environment to the mineral oil by a flexible membrane in the bottom of the housing. This prevents the formation of differential pressures between the ambient environment and the sensor interior. All electrical and mechanical components are pressure-tolerant to 6000 dbar. The chip forms the top end cap of the housing and was connected to reagent storage bags by polytetrafluroethlyene (PTFE) tubing (1.6 mm O.D, 0.5 mm I.D.) and ¼ in-28 UNF fluidic connectors (LT-115X, IDEX Health and Science LLC, Washington, U.S.A.).

Table S1. Gliders for Research, Ocean Observation and Management (GROOM) approach to sensor development classification

Table S1. Gliders for Research, Ocean Observation and Management (GROOM) sensor development classification. Ocean Sciences Technology Readiness Levels (OS-TRL), as defined by *Waldmann et al.* [2010], matched by development status as described by *Johnson et al.* [2000]. The nine TRL definitions originate from NASA [*Mankins*, 1995]. Table modified from *Hannides et al.* [2015] where description of listed glider sensor parameters can also be found.

TRL	TRL Description	Status of development	Glider sensor parameters
OS-TRL 1: Proof-of-concept/development			
1	Basic principles observed and reported		
2	Technology concept and/or application formulated		
3	Analytical and experimental critical function and/or characteristic proof-of concept		
OS-TRL 2: Research prototyping		**IV** Bench-top prototype in operation	Nutrients, NO_3^-, Unexploded ordinance, HAB toxins, pCO2, CH4, Hydrocarbons, Bioluminescence
4	Component and/or breadboard validation in laboratory environment		
5	Component and/or breadboard validation in relevant environment	**III** Early stage of development with successful short-term deployments in the marine environment	Radioactivity, Video imagery
6	System/subsystem model or prototype demonstration in a relevant environment		
OS-TRL 3: Commercial product			
7	System prototype demonstration in a space/ocean environment		
8	Actual systems completed and “mission qualified” through test and demonstration	**II** Successfully deployed in the marine environment for extended periods (>1 month) with oceanographically consistent results but not commercially available	**This study: PO_4^{3-} LoC-AUV (fulfilment with the exception of extended deployment > 1 month)**
OS-TRL 4: Mission proved			
9	Actual system proven through successful mission operations	**I** Currently operational and available commercially	Pressure, Conductivity, Temperature, O2, Chl *a* fluorescence, Phycobilins, Turbidity backscatter, CDOM fluorescence, Current, Radiance, Irradiance, Animal biomass, Marine mammals, Turbulence, Wind, NO_3^-

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