Approaches Of Monitoring Marine Environments in 4-Dimensions

Increased human utilization of the world’s oceans has made it important for industrialized countries to actively monitor marine environments in 4-dimensions. The ocean, like many aquatic environments, is presently under-sampled both spatially (3D) and temporally (+1D) due to current approaches to data gathering. Expeditions are manual and labor intensive, relying on highly-qualified crews and highly-equipped ships that essentially equate to a “lab-on-the-ocean”. Day-rates for these vessels typically range from 15k-100k CAD per day, culminating in millions of dollars for a single expedition. Both the capital cost and day-rates are prohibitive for scaling up to perform routine monitoring.

The current approach of manned missions to sea will not scale very well if we are to observe, understand, and characterize important problems in oceanography in 4D. The surface of the ocean can readily be interrogated with satellite products, providing color and temperature sensing capability on the order of 1 to 10 square kilometers every 10 days; please see MODIS. However, at water depths beyond a few tens to a few hundreds of meters, the scattering and attenuation of electromagnetic waves limits the applicability of satellite spectroscopy techniques. Certain applications necessitate observations of the ocean interior on scales that are similar or better than that measured by satellite. These include: localized aquaculture pen monitoring, offshore oil and gas infrastructure inspection, and charting anthropogenic induced biogeochemical shifts and their impact on ocean ecosystems. Sensing in the deeper part of ocean requires in situ measurement capabilities.

Unmanned water vehicles, or marine drones, offer the ability to perform remote sampling and characterization in 4D for both a) rapid response and b) large-scale persistent networks. Autonomous underwater vehicles (AUV) and surface vehicles have reached a high technology readiness level with more than 200 unique AUVs at present. Examples of long-term deployments include: traversing 4,500mi across the Atlantic Ocean by Teledyne’s SLOCLUM glider (Scarlet Knight) in 2009 and the Pacific Ocean surface crossing of 7,939mi by Liquid Robotics’ surface wave glider (PacX Journey) in 2013. In any case, to maximize deployment duration, payloads need to be small and consume minimal power. Currently, the largest successful demonstration of an autonomous sensing network is that of profiling and drifting floats, namely the international Argo global observation initiative; cited by 3141 papers since 1998. The network is comprised of approximately 3,800 floats as of March-2018 and yields a sensing capability on the order 100,000 square km every 10 days. However, equipping these marine droids with biogeochemical sensing capabilities is challenging.

Commercially available sensors to characterize primary production/phytoplankton, or measure nutrient and trace metal concentrations at nanomolar levels, have limited deployment possibilities on these platforms. Nitrite/nitrate, phosphate, ammonium, manganese, iron, etc., systems are often reagent-based and are large in physical size (e.g. 13cm diameter and 44cm long), highly power consumptive (typically 10-150W), and excessively wasteful with reagent (mL per sample). Similarly, cutting-edge underwater mass spectrometers, like those developed at MIT-WHOI, require 25Watts and are 23cm in diameter and 61cm long—exceeding many low-cost vehicle payload constraints. The in situ HPLCs and Flow Cytometers are even larger and more power hungry. It is not uncommon for the above sensors to cost 50k-200k CAD per unit, further hindering mass uptake.

It is not technically feasible or cost-effective to use these macro-scale sensors systems for thousands or millions of marine-based autonomous sensing drones, which are often similar in size and have limited power capabilities. The current macro-technology for fluid handling and optical interrogation is certainly not scalable, nor affordable for vast sensor networks that perform continuous monitoring. Inexpensive and versatile “lab-on-a-chip” (LOC) sensors will allow us to quickly, effectively, and accurately monitor ocean biogeochemistry over a wide range of deployment scenarios and across an array of locations.