Unveiling Planet Ocean: A Look to 2031

Henry Stommel's visionary article, *The Slocum mission*, was published in Oceanography in 1989. Stommel anticipated fleets of autonomous vehicles roaming the ocean over long periods of time and collecting unprecedented oceanographic data sets. With the ongoing success of autonomous gliders, growing fleets of wind, wave, and solar powered uncrewed vessels, and the deployment of thousands of Argo floats, Stommel's vision has been demonstrated, and arguably achieved in practice. The field of oceanography has been fundamentally changed by the evolution of technology. The power of vision may be a force for change or simply a lens of a different color for viewing progress. In the tradition of Henry Stommel, we offer this vision applied on the future of seafloor mapping as Seabed 2030 reaches its conclusion.

In 2022 we lack adequate maps of the majority of our planet's surface. Of the 71% of Earth that is under water, roughly 20% has been mapped. Thus, even as we launch telescopes to view the furthest reaches of our galaxy and send tourists into space, more than half of our own planet's topography remains unmapped. Noting that "one can't manage what is not measured" there is a clear gap to be closed.

At the same time, atmospheric and earth data, epitomized by the weather channel on cable television and web sites full of satellite imagery and zip code tailored forecasts, is pervasive and utilized by everyone from professional meteorologists to real estate agents. By 2030 this "data consumer" culture will expand to include the vast realms of the World ocean. Technologies under consideration today will change the way people interact with ocean data and deliver the vision of a fully mapped planet Earth.

The technical base for this evolution rests upon truly adaptive sampling, pervasive networked systems (ala today's *internet of things* concepts), and globally abundant bandwidth even far at sea. On shore, these technologies currently combine to offer an intelligent navigation system in every automobile, or at least on every smartphone. Today's solutions track emerging weather conditions, current traffic patterns, and historic trends for a driver's route. They build upon detailed base maps to guide drivers along the fastest, safest, and most economical route to their destination. The results are displayed in ever growing in-dash screens, or on heads up displays, and often include local landmarks rendered in three dimensions. An ecosystem of associated information such as local restaurants, their hours of operations, and customer reviews are layered on top of a base map. The value of terrestrial mapping is palpable on a daily basis. In the ocean, similar dramatic benefits will be derived from a comprehensive seafloor data set. But how will that data be collected?

Our vision is inspired by the tools of today. Collaborative teams of uncrewed surface vehicles (USVs) and uncrewed underwater vehicles (UUVs) will methodically "mow the lawn" in coastal regions. Renewable energy, including solar wind and wave, combined with improved batteries derived from electric vehicles ashore will ensure these systems remain deployed for months, not days. Reliable launch and recovery solutions will make UUV to USV docking as common as parking a car in a garage while new connector standards will bring USB like connectivity to the "guts" of the systems. These sophisticated robotic teams will also be ever more affordable as enabling robotic and manufacturing technologies mature. Coastal mapping will look much like today's warehouse and fulfillment centers. A few people will work alongside a host of digitally enabled systems to deliver huge productivity improvements.

But what about the deep sea? Far from shore where the mapping scales can relax, just a bit, the technologies may look different. Here a derivative of the Argo float network will be one of the key platforms. Using the ocean's own thermal gradient these floats will slowly rise and fall while drifting along with ocean currents. Equipped with echosounders and low-cost inertial sensors, derived from pervasive fitness wearables, and biodegradable components inspired by plastic reducing packaging these systems will be both affordable and pervasive. Their individual depth data inputs will be coarse, but they will merge to form a powerful grid. In addition, wind and solar powered USVs will move the lawn and collect depth data along systematic paths. Far-ranging, large, UUVs will fill gaps in the ice-covered polar regions where data acquisition from the surface only can be made by vessels with ice-breaking capacity. In analogy to the Argo floats, buoys designed to drift with the sea-ice will contribute by capturing a coarse mech of depth data.

While these many, diverse, ocean systems deploy to collect ever more data the shoreside will evolve to manage a deluge of data. This vast fleet of ocean observers will be made possible by the use of cloud computing and machine learning. Ever increasing bandwidth of both subsea and satellite telemetry will combine with large, interconnected nodes of ocean observing systems. Just as today's internet users can move from one WiFi hot spot to the next, the robots exploring and monitoring our ocean will be continuously connected to the servers on dry land. This reduction in the power and processing requirements will make vast fleets of autonomous vehicles practical. Immediate and constant connection between vehicles will allow new synthetic aperture techniques yielding improved data and facilitating adaptive behavior of individual units and cooperative behavior amongst multiple units. Robots, becoming ubiquitous as delivery drones in the skies of 2022, will provide truly synaptic views of our ocean in 2030. The increased data produced by new platforms and sensors will be complemented by advanced processing systems and data stewardship tools. Cloud and crowd sourced processing power and algorithms will deliver massively scaled processing and visualization of seabed data. This will deliver an ecosystem of data presentation, and processing, tools analogous to today's Google Maps. A detailed base map will be wrapped in an ecosystem of meta-data enabling powerful new engagement of the physics of our ocean planet.

These systems will deliver on the vision of Seabed 2030, and more. Autonomous vehicles will roam the ocean not just monotonously "mowing the lawn" but truly sampling and studying the sea. While they complete the baseline map of our ocean planet these systems will pull back the opacity of the ocean and yield key insights for society. Emerging tropical storms will be detected by networked systems that will then adjust to follow the storm and provide superior modeling and warning to coastal communities. Other systems will detect pollution in fragile ecosystems and follow it back to the source, calling in appropriate enforcement and cleanup nearly instantaneously. Fisheries will be monitored by robotic underwater herders guiding fisherman to the most efficient catches and resource managers to truly sustainable use of these natural resources. New energy and biopharmaceutical resources will be discovered and evaluated by autonomous underwater agents circling the globe, and making new maps and charts as they go.

Tsunami propagation models and predictions of future sea-level rise will be much improved from the complete map of the World ocean floor.

Connecting the mobile sensors of autonomous vehicle with a far-ranging network of ocean observing systems will yield significant benefits to society. Shipping will improve as captains, much like the driver with new navigation systems, will find information on weather, port operations, tides, changing currents, and vessel traffic at their fingertips on the bridge. Even small improvements in shipping efficiency will yield significant economic gains and environmental benefits in reduced fuel consumption and emissions. Beach goers, scuba divers, surfers and other coastal users will have immediate access to real time conditions and highly accurate forecasts of winds, waves, currents, water temperatures and any hazardous conditions. Knowledge that the next beach over offers warmer waters or better surf, available through cell phones or wearable devices, will increase the satisfaction of marine recreation.

The abundant, and regularly updating ocean data will touch lives even far inland. The weather channel will broadcast three-dimensional models of the fluid (air and water) earth and viewers will come to recognize the flow of the Gulf Stream as they do the Jet Stream in 2022. Detailed climate models will improve agriculture around the globe. Citizens will visit their undersea national parks through immersive telepresence experiences that will make today's virtual reality look like black and white television does in this age of 4K screens. Through such experiences and constant connection to the ocean and its impacts society in 2030 will recognize what another visionary, Arthur C. Clarke noted some time ago:

"How inappropriate to call this planet Earth when it is clearly Ocean."