ID33 - STUDYING THE PACIFIC SUBTROPICAL FRONT WITH MULTIPLE ASSETS

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Abstract
We describe a novel approach to physical oceanography by coordinating remote sensing, multiple autonomous vehicles and ship borne sensors. In contrast with conventional oceanography where ships are the single point of sampling in the middle of a big ocean or are used simply as the base of operations from where autonomous vehicles are deployed, we propose a new approach where ship and autonomous vehicles are coordinated together via satellite communications. We conclude with results and lessons learned from a real-world deployment of the R/V Falkor oceanographic ship together with multiple autonomous vehicles to study the Pacific's Subtropical Front, 800 miles off the coast of San Diego.

Keywords – Physical Oceanography, Autonomous Vehicles, Remote Sensing.

I. INTRODUCTION
Our world is covered by a large, deep and mostly unknown ocean. A vast amount of physical oceanography uses scientific models together with remote sensing to grasp the complexity of its processes but this has several limitations. For instance, many properties of the water cannot be sensed remotely and satellites can only measure a few meters on the surface of the water. As such, in-situ sensing is still required to have a deeper understanding of processes and their manifestation under the water surface.
Oceanographic ships such as R/V Falkor from Schmidt Ocean Institute (SOI), have the capability to sample water down to hundreds of meters but only at one point at a time. Autonomous vehicles can acquire similar data at a fraction of the cost and do it at physically distributed locations simultaneously, contributing to a synoptic observation of the ocean.
Study of submesoscale ocean phenomena such as eddies, filaments and meanders requires high resolution in-situ sampling that can be addressed only with the coordinated movement and sampling of multiple assets over these regions. Our approach uses a proven software infrastructure to plan, command and monitor execution of all assets while keeping scientists in the loop either on site or remotely via the Internet.

II. FRONT MAPPING WITH MULTIPLE ASSETS
Our work builds upon the LSTS Toolchain [1], the Light Autonomous Underwater Vehicle (LAUV) [2] and Flightwave's Edge aerial platform. For the sake of this campaign, 3 new LAUV vehicles were developed from scratch for longer endurance and Iridium-only operation. Moreover, a dimethyl sulphite (DMS) sensor was mounted on the aerial platforms to detect this by-product of cyanobacteria, commonly found on ocean fronts. The LSTS Toolchain has been improved with new planning, communication, situation awareness and integrated data from multiple new sources.
Three long-range surface vehicles have been deployed prior to our departure to first scout the location of the STF. These robots transmitted data over Iridium which was received and plotted in real-time using Neptus (part of LSTS Toolchain). A WaveGlider departed from San Francisco on May 1st and was sent directly to the estimated position of the front (roughly 800 miles away). Two Saildrone ASVs that were in the area were also tasked to go to the area and, as a result, all 3 ASVs were able to cross the front before the departure of R/V falkor on May 28th, giving a precise target on where to go with the ship.
As soon as the ship arrived at the location, 4 days after departure from San Diego, 3 of the AUVs were deployed to map the front with unprecedented resolution (5 miles apart from each other), and were later replaced with other 3 to continue the survey for 5 days. Even though direct communication was not viable over the distance of 5 miles, the collected data was decimated and transmitted in near real-time to the internet over satellite communications.
The data from the AUVs and the ship's salt water system, allowed the scientists to perceive in real-time features from the front such as a filament which was targeted next.
In a later deployment, 2 of the AUVs did a coordinated survey together with the ship and an UAV, with the ship travelling at 2 knots for 5 miles. This approach resulted in a high-resolution map of the filament with sensors crossing the front from the air, at the surface and underwater.

III. CONCLUSIONS
The developed system was successfully used onboard R/V Falkor to detect the STF front and later map with unprecedented resolution a filament of this front. This was possible only by having the scientists on ship and in land driving the campaign with access to both real-time data coming from the vehicles overimposed with oceanographic models. The software developments were fundamental to be able to coordinate the vehicles over Iridium while maintaining good situational awareness. In the end, a very good map of the front was produced and our knowledge of the STF front has improved considerably.

REFERENCES
[1] J. Pinto, P. S. Dias, R. Martins, J. Fortuna, E. Marques and J. Sousa, "The LSTS toolchain for networked vehicle systems," 2013 MTS/IEEE OCEANS - Bergen, Bergen, 2013.
[2] L. Madureira et al., "The light autonomous underwater vehicle: Evolutions and networking," 2013 MTS/IEEE OCEANS - Bergen, Bergen, 2013.

Fig 1. Fleet of autonomous vehicles deployed from R/V Falkor (left) and Scientists using real-time data from vehicles and oceanographic models to decide next surveys (right)