Examination of bathymetric data and SAS imagery collected through collaborative autonomous operations between a USV mothership and a deep water AUV equipped with a HISAS Synthetic Aperture Sonar and EM2040 Multibeam System

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The Shell Ocean Discovery XPRIZE competition is aiming to push the boundaries of ocean technologies by soliciting solutions to the grand challenge of mapping our oceans. The Round One challenge in 2017 for the Shell Ocean Discovery XPRIZE was to develop a complete system that could map 100 km^2 at 5 m horizontal resolution in 16 hours and produce images the elicited excitement in the general public. The designated survey area for the XPRIZE challenge could be up to 50 nautical miles offshore and operations had to be remotely coordinated from a land-based operation center. The entire mapping system must fit into a standard 40-foot shipping container.

The GEBCO-NF Alumni Team is an international team working on solution towards autonomous Ocean Mapping operations. The team was initiated and led by alumni of the Nippon Foundation / GEBCO training program at the University of New Hampshire. The alumni worked closely with international partners and suppliers to develop and advance their concept created for the Shell Ocean Discovery XPRIZE.

The aim of the GEBCO-NF Alumni Team was to leverage existing technology, wherever possible, and to integrate them to achieve the competition requirements. Their strategic approach was to develop strong partnerships with technology and services providers to augment the hardware, integration and software needs of the team. The GEBCO-NF Alumni team conceived a two-system, Autonomous Underwater Vehicle (AUV) and Uncrewed Surface Vehicle (USV), concept to autonomously map the seafloor in a wide variety of ocean environments. The AUV-USV idea will lead to more efficient, safer and cost-effective seafloor mapping operations.

The Team chose the industry leading HUGIN AUV developed by Kongsberg Maritime for this project, specifically Ocean Floor Geophysics' HUGIN AUV *Chercheur*. This vehicle is equipped with a Kongsberg EM2040 Multibeam and a Kongsberg HISAS

1032, a deep-water interferometric synthetic aperture sonar, that can collect bathymetric and imagery data. The Hushcraft SEA-KIT USV *Maxlimer* was designed and built to act as a surface support vessel for the AUV, including the capacity to launch and recover the AUV and to provide subsea communications and positioning.

Sea trials of the concept were conducted at Kongsberg Maritime AS facilities in Horten Norway in the second half of 2017. This allowed the Team to fully research the capabilities and limitations of the concept system to maximize sonar coverage and performance as well as to understand the integration and management of the AUV and USV systems to ensure reliable operations without physical intervention at sea.

To validate the system's mapping capabilities, the Team conducted multiple characterisation dives to compare the bathymetric data obtained by the HISAS with that obtained by the EM2040, allowing them to compare the performance of the two sensors in several survey scenarios. In addition, the team worked with Kongsberg Maritime to develop a new wide area survey mode that dramatically increased the swath width and more than doubles the coverage rate of the HISAS 1032 while maintaining the same data integrity and across-track resolution as obtained using traditional HISAS survey methods. The AUV can switch between the two modes on the fly, allowing the vehicle to capture both ultrahigh-resolution imagery of the sea-floor and conduct high-speed bathymetry collection, using the new wide area mode, during the same mission.

The complete AUV/USV mapping system developed by the GEBCO-NF Alumni Team and their partners for the Shell Ocean Discovery XPRIZE competition has lead to many ground breaking advances including the demonstration of a collaborative autonomous USV/AUV mission (including launch and recovery) and the development of a new way to operate the HISAS Synthetic Aperture Sonar, so that one can conduct high-speed bathymetric surveys and still obtain ultra-high quality SAS imagery in areas of interest.