SUB-ICE EXPLORATION OF AN ANTARCTIC LAKE: RESULTS FROM THE ENDURANCE PROJECT

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August 21, 2011

Abstract

The ENDURANCE autonomous underwater vehicle was developed and deployed to explore and map a unique environment: the waters of Lake Bonney in Taylor Valley, one of the McMurdo Dry Valleys of Antarctica. This permanently ice-covered lake presented several unique challenges and opportunities for exploration and mapping with an AUV. ENDURANCE was successfully deployed in the west lobe of Lake Bonney in the 2008–2009 and 2009–2010 austral summer seasons, completing the first full synoptic 3-D chemical profile and high-resolution 3-D geometric mapping of such a body of water. ENDURANCE successfully traversed the entire $\sim$1 km $\times$ $\sim$2 km lobe of the lake, including successful automated spooling of a science payload and automated docking into a deployment/recovery melt hole 0.25 m larger in diameter than the vehicle.

ENDURANCE was operated in several modes during these campaigns. These include both down-looking and forward-looking multi-beam sonar configurations for different mapping tasks, a super-ballasted configuration for two missions penetrating into the super-saline lower lake layers near the glacier front, and supervised and fully autonomous modes employing a fiber-optic data line as needed.

Following the 2008 campaign, several upgrades were made to the vehicle to improve its exploration capabilities. The most significant of these was replacement of two battery packs. The improved energy capacity of these batteries coupled with analysis of in-situ transit speed efficiency tests resulted in an almost tripled range of the vehicle. This fact, combined with a longer fiber-optic data tether enabled vastly more ambitious missions during the 2009 campaign. In addition, improvements were made to the profiling drop sonde system in the form of an improved algorithm to determine height of the sonde above the lake bottom to compensate for poor returns from the sonde altimeter. This enabled completely autonomous profiling missions.

Post-processing of the data gathered on the two campaigns has made available a never-before-seen level of detail greatly enhancing the understanding of the lake biogeochemistry and other processes. The ENDURANCE mission has demonstrated new underwater mapping capabilities to enhance the understanding of extreme, unique environments.

The sonar mapping at Lake Bonney required full 3-D capabilities as the glacier face was an important focus of the study, and in fact turned out to contain significant overhangs and cavities. Creating the full high-resolution map of the lake and glacier face geometry required first correcting navigation data using GPS fixes of location obtained with an active magnetic beacon tracking system, as well as lake level and pressure-depth corrections. The sonar data were corrected for the extensive bending caused by the extreme sound speed gradients, producing a corrected point cloud containing approximately 256×10^6 points. To obtain the final 3-D surface, The point cloud was gridded and noise-filtered using an octree clustering algorithm, generating a final nearly-homogeneous point cloud of about 1 million points. A modified poisson surface reconstruction algorithm was used to generate a mesh of the entire lake, capturing the full 3-D details of the glacier region with a final resolution down to 50 cm.

During the two 10-week deployments to Antarctica, ENDURANCE logged 243 h of sub-ice operational time, traversing a cumulative total of 74 km beneath the ice cap of West Lake Bonney. It conducted 275 aqueous chemistry sonde casts covering the entire west lobe, including short forays through the lake narrows into the east lobe, and several high-resolution profiling runs near the glacier face to localize inflows to the lake. ENDURANCE completed a full 3D bathymetry and glacier face geometry survey over a horizontal area of 1.06 km^2 at an average resolution of 22 cm, including detailed scans at less than 3 m range of the glacier grounding line obscured from the surface by overhanging ledges.

ENDURANCE successfully navigated in the presence of ice cover and large density gradients—including precise approach amd negotiation of narrow passageways—and demonstrated autonomous melt hole location, position lock and auto recovery on a routine, daily basis. It performed general automated mapping and profiling surveys, as well as detailed studies of localized phenomena, operating in an extreme, remote, unknown environment. Many of the characteristics and capabilities of ENDURANCE—now successfully demonstrated in complex under-ice settings beneath West Lake Bonney—are the types of behaviors that will be needed for sub-ice autonomous probes to Europa, Enceladas, and other outer planet watery moons.