Employing Autonomous Underwater Vehicles to Develop New Techniques for Astrobiological Exploration: Recent Field Results and Future Opportunities. J.C.Kinsey[1], M.V. Jakuba[2], A. D. Bowen[1], D.R.Yoerger[1], L.Whitcomb[3], R. Camilli[1], C.R.German[1] & D.L. Valentine[4], [1]Woods Hole Oceanographic Institution (Woods Hole, MA 02543, USA; jkinsey@whoi.edu), [2]Australian Centre for Field Robotics, University of Sydney (Darlington 2006 NSW, Australia), [3]The Johns Hopkins University (3400 N. Charles Street, Baltimore, MD 21218, USA), [4]University of California, Santa Barbara (Santa Barbara, CA 93106, USA)

Introduction: A key component to astrobiological exploration is the development of methods to autonomously survey planetary environments and transmit data back to Earth for human interpretation. A fundamental challenge in these future explorations is the limited bandwidth available to transmit data, thus motivating the development of novel techniques for analyzing data on the robotic vehicle and only transmitting necessary information. Oceanographic robots, such as autonomous underwater vehicles (AUVs), are ideal test platforms for developing and testing new techniques for astrobiological exploration. We report two recent expeditions funded by NASA's Astrobiology Science and Technology for Exploring Planets (ASTEP) program that demonstrate how advances in telemetry and autonomy can advance investigation of both oceanographic and astrobiological exploration methodologies. The robotic vehicles used on these cruises are discussed as are the preliminary results of data transmission and mission intervention using low-bandwidth acoustic telemetry. This capability was used on both cruises to assess *in-situ* data as it became available and, based on this information, re-program the robotic vehicle to modify their science mission. These field programs demonstrate a new paradigm using ocean robots as proxy test platforms for investigating and testing astrobiological exploration techniques prior to actual planetary missions.

The Sentry AUV and the Seeps ASTEP Program: The Sentry AUV is a 4500m depth-rated vehicle designed for autonomously mapping the seafloor. Sentry builds on the successes of the Autonomous Benthic Explorer (ABE) – which since 1996 has conducted over 250 dives at depths averaging 2000m producing bathymetric and magnetic maps, photographing biological and geological features, and mapping hydrothermal vent plumes [1]. The Sentry AUV moved to operational status in 2008 and possesses superior depth capability and range, is equipped with higher resolution sensors, and is capable of carrying increasingly sophisticated sensors.

In September 2009, Sentry was employed within the context of the ASTEP program to map methane seeps in a series of ocean basins near the S. California coast. Sentry completed 9 dives that included a mix of high-resolution acoustic bathymetric mapping, photo-surveying, and chemical mapping employing the TETHYS in situ mass spectrometer [2]. The maps generated provided scientists with geological context for samples collected using the human-occupied submersible Alvin. These maps were also employed to select sampling locations when Sentry operations at a site preceded Alvin operations. Results of this field program are discussed in [3].

The Nereus HROV and the Oases ASTEP Program: The Nereus hybrid remotely operated vehicle (HROV) is an unmanned underwater vehicle designed to perform scientific survey and sampling to the full depth of the ocean or 11,000m [4]. It can be configured as either an AUV or a tethered ROV. For broad-area survey, the vehicle can operate untethered as an AUV capable of exploring and mapping the sea floor with sonars, cameras, and chemical sensor in a manner similar to Sentry. Nereus can also be converted at sea into a remotely operated vehicle (ROV), thus enabling close-up imaging and sampling. The ROV configuration incorporates a lightweight fiber-optic tether for high-bandwidth, real-time video and data telemetry to the surface enabling high-quality teleoperation under direct real-time control of a human operator.

In Oct-Nov 2009, Nereus was used within the context of the Oases ASTEP Program to explore for hydrothermal activity on the Mid-Cayman Rise [5]. During Leg 1 of the expedition, Nereus was operated as an AUV – its first deep-water deployments in this mode. Two of five science dives were conducted in the mid-water column, approximately 600-700m above the seafloor and the oxidation / reduction potential (Eh) and optical backscatter data obtained on these two dives were used to map hydrothermal plume intensities. On Leg 2, Nereus was operated as an ROV enabling the vehicle to be operated from the ship via its lightweight fiber-optic cable. On both legs, optical backscatter, Eh, and water temperature data obtained with Nereus were combined with similar data obtained from a CTD to provide a more complete map of the hydrothermal vent plume.

Data Telemetry and Vehicle Mission Control over Low-Bandwidth Acoustic Modems: A continuing challenge in AUV operations is the limited bandwidth available for communication between the AUV and the surface vessel. The density of sea water precludes the use of high-bandwidth wireless telemetry systems routinely used in land, aerial, and space robots. Acoustic telemetry is thus the primary method for communicating with submerged AUVs. Recent advances in acoustic modems (e.g., [5]) have increased the bandwidth available for both receiving data from and sending commands to the AUV. This capability enables scientists to monitor *in-situ* data obtained by the vehicle and, in response to this data, transmit commands to alter vehicle behavior.

Acoustic telemetry capability was available on both Sentry and Nereus on the Oases and Seeps ASTEP expeditions. During both expeditions, scientists evaluated data transmitted from the submerged robotic vehicles to the surface support vessel. On several occasions the vehicle was retasked in based upon human interpretations of the received data. Figure 1 shows one such re-tasking. In this case, the ability to retask the Nereus vehicle in real-time permitted hydrothermal anomalies observed on the edge of the preplanned survey (black) to be confirmed and spatially constrained by a second set of tracklines (gray) designed and telemetered to the vehicle on-the-fly. Similarly, mass spectrometry using selected ion monitoring telemetered to operators during the Seeps expedition was used to select seafloor locations at which Sentry was commanded to hover and conduct full-spectrum scans.

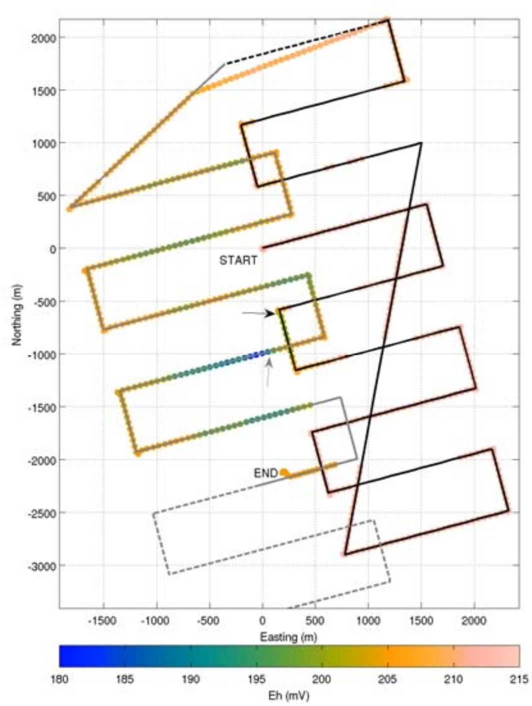

Figure 1: Dive plan and telemetered redox potential (Eh) during a Nereus dive in AUV mode on the Cayman Trough. The arrows indicate rapid decreases in Eh characteristic of nascent hydrothermal plume.

Future Challenges and Opportunities: Both expeditions illustrate the potential of using AUVs as test platforms for developing techniques for future astrobiological exploration missions. One of the central challenges of ocean exploration – the inability during a mission to transmit all of the data on an AUV to humans on a ship – will also be an issue in future astrobiological exploration missions. For example, future planetary missions may explore remote planetary environments (such as Europa) in which the robot has only a limited ability to transmit data. These missions will require new techniques for efficiently processing data on the vehicle and deciding which data is essential for being transmitted over the limited available bandwidth. In addition, software for efficiently processing and visualizing received data will be required to enable humans to make decisions and retask robots accordingly. The operations discussed in this abstract demonstrate a new paradigm for researching these issues along with other astrobiological exploration technologies (e.g., sensors, sampling methodologies, adaptive surveying) prior to their use on planetary missions.

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