SUBSEA – A JOINT NASA-NOAA PLANETARY AND OCEAN SCIENCES ANALOG RESEARCH PROGRAM. D.S.S. Lim[1], Z. Mirmalek[1,2], N. Raineault[3], D.S. Lees[1,4], C. German[5], and the SUBSEA Team. [1]NASA Ames Research Center, Moffett Field CA, [2]BAERI, Moffett Field, CA, [3]Ocean Exploration Trust, URI, RI, [4]KBR, Moffett Field CA.[5]WHOI, MA.

Introduction: The SUBSEA (Systematic Underwater Biogeochemical Science and Exploration Analog) is a NASA-NOAA supported research program that blends Ocean Exploration with Ocean Worlds research, along with NASA analog and work studies research to address Science, Science Operations, and Technology knowledge gaps related to the exploration of our Solar System. Our ocean science objectives focused on venting fluids at isolated seamounts and spreading ridges in the Pacific Ocean as analog environments to putative volcanically-hosted hydrothermal systems on other Ocean Worlds (defined as places in the outer Solar System that could possess subsurface oceans). Science Operations studied and tested how the E/V *Nautilus* architecture, distributed teams, communication, and telepresence environment would fare as an analog environment for developing human space exploration. The Technology research group provided Exploration Ground Data Systems (xGDS) software to the shore team to support the integration and visualization of diverse data products during the cruise. SUBSEA conducted two expeditions: 1) Lō`ihi seamount, Hawai`i (expedition NA100) from August 21-September 12, 2018, and 2) SeaCliff hydrothermal field, Gorda Ridge, Oregon (expedition NA108) from May 22 to June 9, 2019. This abstract focuses on the evolution of the integrated science-ops-tech research activities over the 2018-2019 period, including both expeditions.

**Lō`ihi Expedition:** During the 2018 SUBSEA Lō`ihi expedition, the Ops research team used ethnographic and cognitive systems research methodologies to collect data on the workflow and daily practices for a work domain analysis of the pre-existing E/V *Nautilus* telepresence architecture. The 2018 study focused both on the science-driven activities aboard E/V *Nautilus* as well as at the Inner Space Center, University of Rhode Island, where the majority of the SUBSEA Science team was co-located to provide directives to the ship-based personnel. The Operations research team characterized the E/V *Nautilus* telepresence architecture and many of the operational practices by documenting situated observations of the science activities and operations in each of the two work spaces. Through this work, the Operations research team constructed an information flow model and models of workgroup environments supporting scientific return and productivity, and assessed how and if each element of the telepresence architecture supported an acceptable level of science return.

SeaCliff Expedition: The resulting analysis of the 2018 expedition informed the test methodology for the 2019 SUBSEA SeaCliff vent expedition and led to an operational environment for the NA108 expedition that was significantly different from the Lō`ihi seamount cruise. For NA108, the Ops research team tested how the telepresence environment would fare as an analog environment for developing human space exploration by distributing SUBSEA science team members across two worksites and establishing two modes of operations: 1) at the ISC, which included Science and Technology group members; 2) onboard *Nautilus,* which Science and Operations group members and experts in navigation, robotics, mapping, and ship's crew. Communication across distributed teams was subject to protocols for ship-to-shore and shore-to-ship communications and data sharing. Mode 1 protocols included an imposed a time delay between ship and shore and the use of written exchanges for communicating between ship and shore workgroups via specific documents sent at a prescribed time daily. This was a radical departure from the use of typical *Nautilus* telepresence architecture with near real-time (low-latency) oral and text chat-style communications. Mode 2 protocol lifted all restrictions.

For the 2019 expedition, the Technology group enhanced the telepresence architecture by integrating their web-based xGDS open-source software into shore-side science activities. xGDS supported planning, situational awareness and data visualization for the ISC team, and was tailored specifically to support *Nautilus* datasets. xGDS leveraged OET's data broadcast infrastructure (from *Nautilus* to shore) to record and display real-time positioning of the ROVs and *Nautilus*, oceanographic data (e.g. CTD, O_2), and observations logs within the xGDS interface. The team on shore used xGDS to search and replay dives with a unified context of a site map, video, telemetry and event data. xGDS was also used to simulate the distance and duration of upcoming dives including specific activities to generate a human readable dive plan, and to export the plan in formats for delivery to various navigation software.

SUBSEA's operations experiment outcome was a measurable success. The target number of days in each mode was achieved with both natural and social science data collection objectives reached. Technology enhancements proved to support remote operations in delayed (Mode1) and near-real time (Mode2) operations.

Acknowledgments: This work was supported by NASA Planetary Science and Technology Through Analog Research (PSTAR) Program (NNH16ZDA001N-PSTAR) grant (16-PSTAR16_2–0011) to Dr D. S. S. Lim, NOAA Office of Ocean Exploration and Research, Ocean Exploration Trust and NOAA-OER grant NA17OAR0110336.