Space-to-Ground Interactions While Conducting Scientific Fieldwork under Mars Mission Constraints

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Abstract— **The Biologic Analog Science Associated with Lava Terrains (BASALT) project is a 4-year program dedicated to iteratively designing, implementing, and evaluating concepts of operations (ConOps) and supporting capabilities to enable and enhance scientific exploration for future human Mars missions. BASALT incorporates three field deployments during which real (non-simulated) biological and geochemical field science is conducted at two high-fidelity Mars analog locations under simulated Mars mission conditions, including communication delays and data transmission limitations. BASALT's primary science objective is to investigate how the redox conditions of altered basaltic environments affect the development of microbial communities in these Mars-relevant settings. Field sites include the active East Rift Zone on the Big Island of Hawaii, reminiscent of early Mars when basaltic volcanism and interaction with water were widespread, and the dormant eastern Snake River Plain in Idaho, similar to present-day Mars where basaltic volcanism is rare and most evidence for volcano-driven hydrothermal activity is relict. BASALT's primary science operations objective is to investigate exploration ConOps and capabilities that facilitate scientific return during human-robotic exploration under Mars mission constraints. Each field deployment consists of ten extravehicular activities (EVAs) on the volcanic flows in which two extravehicular and two intravehicular (IV) crewmembers conduct the science while communicating across time delay and under bandwidth constraints with an Earth-based Mission Support Center (MSC) comprised of expert scientists and operators. Communication latencies of 5 and 15-minute one-way light time and low (0.512 Mb/s uplink, 1.54 Mb/s downlink) and high (5.0 Mb/s uplink, 10.0 Mb/s downlink) bandwidth conditions are being evaluated. EVA crewmembers communicate with the MSC via voice and text messaging and provide scientific instrument data, still imagery, video streams, and GPS tracking information. The MSC reviews this data across delay and provides recommendations for presampling and sampling tasks. The scientists used dynamic leaderboards (priority ranking lists), to track and rank candidate samples relative to one another and against the science objectives for the current EVA and the overall mission. Updates to the dynamic leaderboards are relayed regularly to the IV crewmembers to provide scientific feedback from Earth and to help minimize crew idle time (time spent waiting for Earth input during which no productive tasks are performed). EVA timelines are strategically designed to enable continuous (delayed) feedback from an Earth-based science team while simultaneously minimizing crew idle time. Such timelines are operationally advantageous, reducing transport costs by eliminating the need for crews to return to the same locations on multiple EVAs while still providing opportunities for recommendations from science experts on Earth, and scientifically advantageous by minimizing the potential for cross-contamination across sites. This paper will highlight the space-to-ground interaction results from the three BASALT field deployments, including planned versus actual EVA timeline data, ground assimilation times (the amount of time available to the MSC to provide input to the crew), and idle time. Furthermore, we describe how these results vary under the different communication latency and bandwidth conditions. Together, these data will provide a basis for guiding and prioritizing capability development for future human exploration missions.**

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1. INTRODUCTION

The Biologic Analog Science Associated with Lava Terrains (BASALT) project incorporates interdisciplinary field experiments that explore scientifically relevant environments on Earth as an integral part of preparing for future human missions to Mars. The BASALT program includes *Science*, *Science Operations*, and *Technology* goals. The ongoing scientific fieldwork is being conducted under simulated Mars mission constraints based on current architectural assumptions for future Mars exploration missions [1]. The BASALT project is evaluating communication latencies of 5 and 15 min one-way light time (OWLT), which fall within the 4-22 min OWLT delays experienced between Mars and Earth, a low-bandwidth condition of 0.512 Mb/s uplink and 1.54 Mb/s downlink, representing a conservative and lower-cost flight data rate, and a high-bandwidth condition of 5.0 Mb/s uplink and 10.0 Mb/s downlink, representing an upgraded human mission capability that would require additional infrastructure and technology development. The BASALT Science Operations primary research question is: *Which exploration concepts of operations (ConOp) and capabilities enable and enhance scientific return during human-robotic exploration under Mars mission constraints?*

The BASALT project also incorporates relevant technologies and science support tools to aid in effective and efficient mission planning, scheduling, navigation, task execution and documentation, decision making, and communication between "Mars" and "Earth." Many of these capabilities are accomplished through a suite of complementary science operations tools that are collectively referred to as *Minerva*. Minerva includes the Exploration Ground Data System (xGDS), a software package that enables science operations planning, monitoring, documenting, archiving, and searching [2], Playbook, an advanced timeline tracking tool with text messaging capabilities [3], and SEXTANT, a traverse optimization planning tool [4]. Additional technologies for field operations include custom designed extravehicular activity (EVA) informatics backpacks that provide voice, video, and GPS positions from the extravehicular (EV) crewmembers, and EVA graphical wrist displays, so that the EV crew can view their traverses, video camera data, and important text messages from Earth, including annotated images of key features of interest. For more detail regarding *Minerva,* see [5].

This paper focuses on the Science Operations space-to-ground interaction results, including planned versus actual EVA timeline data, ground assimilation times (the amount of time available to the MSC to provide input to the crew), and idle time, from three BASALT field deployments. Furthermore, we describe how these results vary under the different communication latency and bandwidth conditions.

EVA Personnel and Communication Infrastructure

The BASALT baseline ConOp stems from the results of previous analog studies, including the Desert Research And Technology Studies (DRATS) [6-8], NASA Extreme Environment Mission Operations (NEEMO) [9-11], and the Pavilion Lake Research Project (PLRP) [12, 13]. Our baseline architecture includes two "Mars" EV crewmembers in the field completing the science tasks, two "Mars" intravehicular (IV) crewmembers supporting the EV crew and communicating with "Earth" from an IV workstation (inside a simulated rover or habitat [8, 14]), a Mobile Instrument Platform (MIP) that moves with the EV crew, and an "Earth" Mission Support Center (MSC) that provides scientific expertise (MSC scientists, or science team [ST]) and operational guidance (MSC operators) across communication latency and bandwidth limitations. The use of the word "support" rather than "control" (as in the Mission Control Center that is currently used for ISS operations) reflects the advisory role that the MSC necessarily takes when working under communication latency [1, 11, 15]. **Error! Reference source not found.** in [16] describes the key personnel and their respective roles and responsibilities.

Communication within space (i.e., among EV and IV crewmembers) and between space and ground occurs via multiple voice loops and text messaging data streams. Two primary voice loops are employed during BASALT EVAs: space-to-ground-1 (SG-1), across which the EV and IV crew talk with one another in real-time, and space-to-ground-2 (SG-2), in which the IV crew and the MSC communicate across time delay. The SG-1 loop is transmitted to the MSC across delay so that the MSC can hear the EV-IV crew conversations. EV crewmembers do not listen to the SG-2 loop. Text messaging during the EVAs is provided by the Playbook Mission Log [3]. The Mission Log supports texting across time delay between the IV crew and the MSC and serves as the primary means of communication between space and ground. Further descriptions of EVA capabilities, including video streams, still imagery, and scientific instrument data from the field, is described in [16].

EVA Traverse and Timeline Design

During Apollo, the OWLT communication latency between the Earth and the Moon was minimal (~1.25 s), which allowed for meaningful, near real-time audio interaction between the astronauts and scientists during the EVAs without special consideration for data transmission times. Hence, there was minimal crew idle time (defined as time spent waiting for input from Earth during which no other productive tasks are being performed) [17]. However, as communication latency increases for destinations such as Mars and bandwidth limitations restrict the amount of data, including voice, video, still imagery, text messages, and scientific instrument data, that can be transmitted between Mars and Earth, achieving meaningful input from Earth during EVAs will be more difficult [18]. Based on these challenges, one Mars exploration ConOp could implement a nearly autonomous crew to execute the science objectives with an Earth-based MSC acting primarily as passive observers who only provide opportunistic feedback across latency and under bandwidth constraints during the EVA. In this case, the MSC would primarily provide strategic input between EVAs, as opposed to within EVAs. An alternate ConOp could implement strategically designed EVA timelines with built-in timing accommodations to allow for the MSC to receive, analyze and interpret the data before sending guidance back to the crew for subsequent EVA task execution. This alternative ConOp does not preclude the first ConOp, but also adds the opportunity for tactical MSC input to actively influence intra-EVA execution. While both ConOps offer scientific and operational advantages, the BASALT project focuses on the latter.

Enabling intra-EVA interactions between Mars and Earth under communication latency and bandwidth limitations requires special consideration be given to the design of the EVA timeline. To minimize crew idle time (i.e., non-productive crew time), there must be a clear delineation between EVA tasks that can be performed independent of Earth input and tasks that are either dependent on or could substantially benefit from Earth input. For tasks benefiting from Earth input, dependent task groups can be created and distributed throughout the timeline. Other tasks in the timeline can be decoupled from the dependent task group(s) and may be performed stand-alone.

Figure 1 depicts an example of an EVA timeline designed with both dependent-task groups and stand-alone tasks. For instance, Task A - Parts 1 and 2 represent a dependent task group in which the first part is performed independent of the ground (e.g., pre-sampling survey) and the second part depends on ground input to execute (e.g., sampling). In between the 2 task parts in this group, data from the first part reaches the ST across latency and ground assimilation time (GAT) is allocated for the ST to analyze the data and formulate input. ST input is then sent from the ground to the crew before the input is needed to start Part 2 of the dependent task group. The sample timeline also depicts the interleaving of multiple dependent task groups, as well as the insertion of stand-alone tasks to allow for coordinated interactions without idle time between the crew and MCC. This approach to timeline design is meant to facilitate ground interactions in the presence of communication latency to minimize crew idle time.

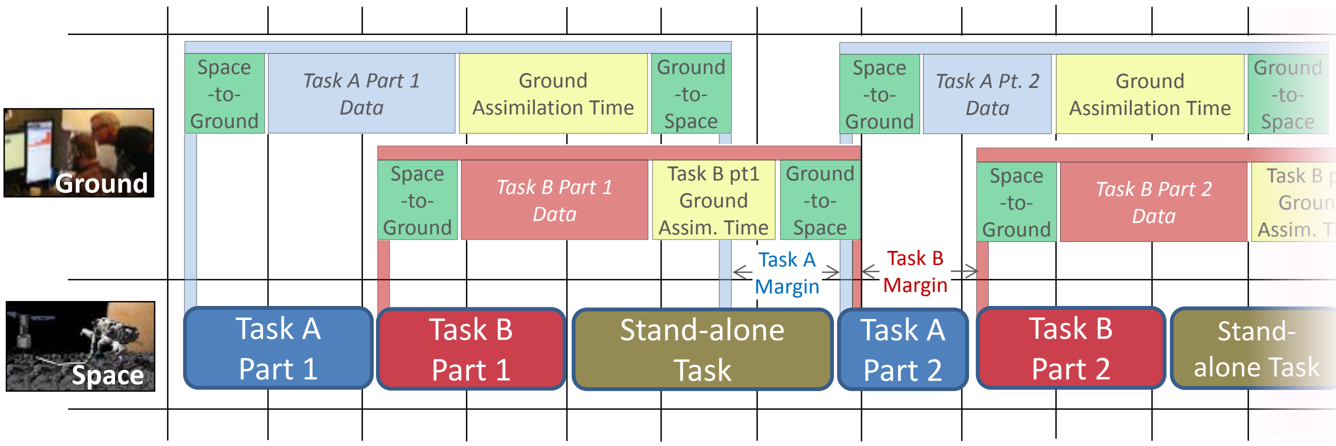

Figure 1. EVA timeline designed with dependent task group approach and stand-alone tasks.

For instance, a dependent task pair could consist of a pre-sampling survey (e.g., contextual descriptions, still imagery, and video footage) and a corresponding sampling task at a particular location of interest. The EV crew could complete the pre-sampling survey and send that data to the MSC. The MSC could use this information to guide the sampling, including details regarding precisely where, how much, etc. While the MSC is formulating their sampling plan based on this pre-sampling information and information is flowing between Mars and Earth across latency, the EV crew can complete a second pre-sampling survey or a separate stand-alone task. With sufficient understanding of EVA task dependencies, task durations, communication latencies, and necessary ground assimilation time (GAT, the amount of time available to the MSC to provide input for dependent tasks), timelines may be created that allow for Earth input on many or most tasks while minimizing or avoiding crew idle time [11]. To validate this concept while performing real, Mars-relevant science, BASALT timelines were strategically designed to enable interactions between crewmembers and the MSC while incurring little or no crew idle time through the strategic incorporation of dependent task groups.

2. METHODS

Science Operations Study Design

Each BASALT field deployment (3) consisted of a plan for 10 simulated EVAs in which scientifically significant samples of basalt were extracted from "Mars" (i.e., specially permitted areas in Craters of the Moon National Monument and Hawaii Volcanos National Park) by the EV crewmembers, who were guided by the IV crew and the MSC during the EVAs. Each EVA was conducted under one of the four communication study conditions which combined 5 or 15 min latency with either high or low bandwidth. Each deployment's planned schedule assigned two EVAs to each study condition, leaving the last two EVA opportunities as contingency days. EVA teams were established for each deployment based on the key roles described in **Error! Reference source not found.** of [16], including EV and IV crewmembers, Flight Directors, Science Team Leads, science communicators (SCICOM); and capsule communicators (CAPCOM). The personnel who were assigned to these teams came from the BASALT team of investigators and all have extensive experience in operations through other analog work or field science. Each team was scheduled to experience each study condition at least once.

The data that was passed between EV and IV crewmembers and between Mars and Earth included EV and IV voice communication channels, video footage from the EV crew video cameras, video footage from a mobile situation awareness

(SA) camera, still imagery captured by the EV crew, GPS position tracks of the EV crew, physiological monitoring data of the EV crew, text messages between the IV crew and the MSC, scientific field notes, and annotated images between the MSC and the crew. For 2 of the 3 field deployment, scientific instrument data was communicated through still images of the relevant instrument results screens. The data rates and resolutions associated with each of these capabilities were selected such that all capabilities were used in full during EVAs conducted under the high bandwidth study condition. EVAs executed under the low bandwidth condition did not pass any video data from the EV crew to the MSC, and the rate and resolution of still images and text messages between the crew and the MSC were limited to less than 0.512 Mb/s uplink and 1.54 Mb/s downlink. Estimates of data product sizes were made prior to the mission and post-EVA network analytics were run to ensure bandwidth traffic stayed within the bandwidth constraints defined above.

EVA Field Equipment and Facilities

During the EVAs, the EV crewmembers wore custom informatics backpacks [16], which housed the hardware that enabled 2-way voice communication with the IV crew and 1-way transmission of video, still imagery, GPS position data, and physiologic monitoring data to the IV crew and the MSC [16].

A specially outfitted trailer (Idaho) or facilities at the Kilauea Military Camp (KMC) were used to house the IV crewmembers and the MSC. The IV crew and MSC were physically separated during the EVAs. An IV workstation was established inside the trailer that included a laptop computer and two additional display screens for each IV crewmember. Audio headsets with push-to-talk capabilities were used for voice communication with the EV crewmembers (across the SG-1 communication loop) and with the MSC (across SG-2). The MSC accommodated individual laptops for all MSC members, additional display screens for the Flight Director, Science Team Lead, SCICOM, and several ST members, and a central computer with large external display for all members of the MSC to view (Figure 2; software elements for each position are described in [5]). Network connectivity from the EV informatics backpacks and mobile SA camera to the IV workstation and MSC was enabled through the use of fixed antennae and mobile repeaters located between the field sites and the MSC trailer.

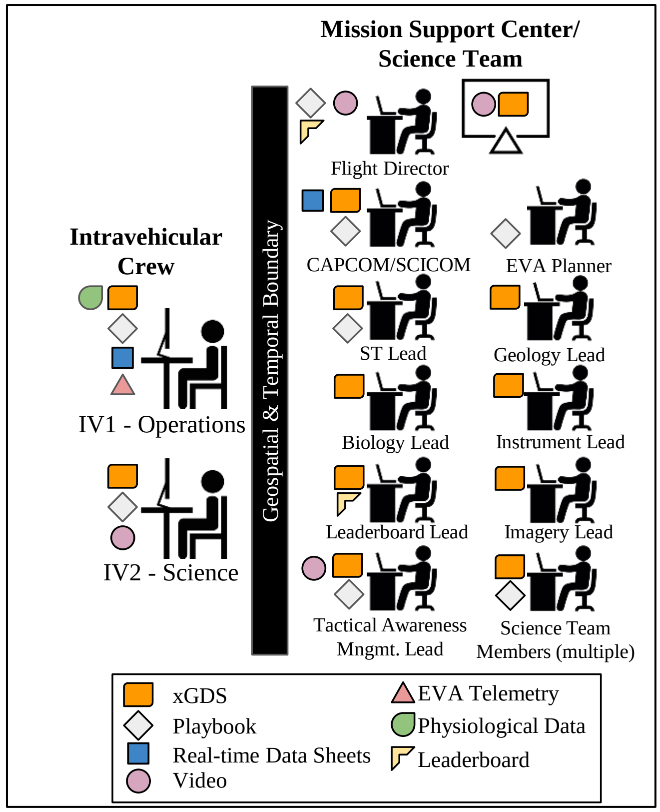

Figure 2. BASALT IV workstation and MSC workspace diagram [16].

EVA Planning and Execution

The EVA timelines consisted of three phases: approach/contextual survey/sample location search, pre-sampling survey, and sampling. During each EVA phase, the IV crewmembers assisted the EV crew through the timeline tasks in real-time and conversed (primarily via text messages and recorded field notes) with the MSC across delay. Both IV1 and IV2 monitored the mobile SA and EV crewmember video feeds streaming from the field. IV1 focused on the operational aspects of the EVA while IV2 focused on the detailed science. The primary role of IV2 was to ensure that the scientific objectives of the EVA were met. Responsibilities included (1) distillation and communication of sampling priorities and rationale of the MSC to EV2 (compilation of master list of pre-sampling and sampling priorities), (2) clarification of scientific queries between MSC and EV2 (critical to mitigating any misunderstanding that may occur under latency), and (3) providing expertise-based interactive science guidance centered on direct questions from EV2 and viewable video feeds, with local redirection based on GPS position and pre-cursor data.

Role of the MSC

Throughout the EVA, the MSC monitored and reviewed incoming data from the field across delay, recorded additional field notes in Minerva, and provided recommendations for resampling and sampling based on their collective expertise.

The ST used dynamic priority ranking lists, referred to as *dynamic leaderboards*, to track and rank candidate samples relative to one another and against the science objectives for the current EVA and overall mission [13]. The ST built the dynamic leaderboards by integrating and interpreting the incoming verbal descriptions, still imagery, video footage, and instrument data from the field. Updates to the dynamic leaderboards were relayed regularly to the IV crew via the Mission Log, who could then discuss these rankings with the EV crew; the number of relays of the leaderboards to the crew for each EVA is shown in **Error! Reference source not found.**. The use of these leaderboards enabled the crew to track the dynamic nature of MSC recommendations and helped minimize crew idle time. Separate dynamic leaderboards were built for both the pre-sampling and sampling phases of the EVA.

Science Operations Research Data

Objective data were collected during and after the EVAs to address the Science Operations research questions. Objective data included details regarding the interactions between the crew and MSC, including (1) the quality and type of interactions, (2) the timing of the interactions relative to the EVA timeline, (3) MSC assimilation time available before incurring crew idle time, and (4) MSC assimilation time utilized. Assimilation time data were derived from dynamic leaderboard and Mission Log entries.

3. RESULTS AND DISCUSSION

Sufficient EVAs were completed across all deployments to enable meaningful evaluations of the ConOp (i.e. simulation quality between 1 and 3 as described in [16]), although only three study conditions were tested during BASALT-1: 5 min latency high bandwidth, 5 min latency low bandwidth, and 15 min latency high bandwidth.

EVA Timeline Execution

During each EVA, the MSC was faced with two critical no-later-than (NLT) "deadlines" in which MSC input regarding pre-sampling and sampling recommendations had to be sent to the EV/IV crew so that they would not incur idle time while waiting on ground input. These deadlines were based on the operational communication latency and assumed that the EV crew would be operating on timeline. Hence, the MSC needed to send pre-sampling and sampling guidelines NLT 5 or 15 min prior to the start of these phases. However, with the dynamic leaderboard approach, the MSC was encouraged to send multiple pre-sampling and sampling priority rankings. In theory, these rankings can be sent every time the MSC modifies the leaderboard. However, the MSC moderated their updates based on what additional information they expected to receive from the field as well as how close to the planned timeline the crew were performing their tasks. The advantage of the dynamic leaderboard and sending regular updates to the crew is that if the crew happen to start working ahead in the timeline or if the communication network encounters dropouts, the crew can still have some understanding of the MSC priorities and rationales.

Table 1 and Table 2 present a summaries of the statistics related to the ST and EV/IV interaction for pre-sampling and sampling priorities across the latency and bandwidth conditions tested for the Idaho 2016 and Hawaii 2016 deployments, respectively; means and standard deviations (SD) are shown for all parameters. Parameters shown are the number of leaderboard inputs sent by the ST via the Mission Log to IV/EV, pre-sampling ST assimilation times, sampling ST assimilation times, and EV idle time (due to waiting for ST input). In most cases, multiple leaderboard inputs were sent by the ST for both pre-sampling and sampling with the reasons for the variation explained earlier. The ST assimilation times for both pre-sampling and sampling are presented in terms of a first and last NLT time. These NLT times represent the times to affect the start of each phase and the last half of each phase, respectively. The first and last NLT times are also presented in terms of the *planned*, *available*, and *used* times; *planned* times are based on the planned timeline, *available* times are based on actual as-executed timeline, and *used* times represent the actual time that the ST used.

The main take away from this data is that the MSC was successful in utilizing the ConOp, training and tools at their disposal such that the EV crew did not incur any idle time due to waiting on ST input. The leaderboard approach to provide guidance to EV/IV from the ST was utilize heavily to provide early indications of ST priorities and regular updates such that EV/IV always had guidance that was as current as the round trip communication latency allowed.

Table 1. Pre-sampling and Sampling ST assimilation time for Idaho 2016. Presented as planned and actual times up to first and last NLT input to affect the start and end of EVA phases. EV idle time and translation time also presented. Duration means and SD in hr:min.

Idaho 2016	***5min Latency, Low BW***			***15min Latency, High BW***			***5min Latency, High BW***		
	Mean	**±**	**SD**	**Mean**	**±**	**SD**	**Mean**	**±**	**SD**
# of Leaderboard Inputs from ST to EV									
Pre-sampling	3	±	1	4	±	0	2	±	0
Sampling	3	±	0	2	±	0.5	1	±	0

Pre-sampling ST Assimilation Time									
Planned for first NLT ST input	0:55	±	0:00	1:42	±	0:02	1:55	±	0:10
Actual available for first NLT ST input	1:13	±	0:09	1:10	±	0:49	2:21	±	0:07
Used for first ST input	0:50	±	0:10	1:17	±	0:02	1:29	±	0:10
Planned for last NLT ST input	1:40	±	0:00	2:22	±	0:02	2:35	±	0:02
Actual available for last NLT ST input	1:48	±	0:07	2:31	±	0:00	2:52	±	0:06
Used for last ST input	1:15	±	0:12	1:59	±	0:11	2:09	±	0:00
Sampling ST Assimilation Time									
Planned for first NLT ST input	2:05	±	0:00	2:42	±	0:02	2:55	±	0:10
Actual available for first NLT ST input	2:09	±	0:08	2:51		0:00	3:12		0:06
Used for first ST input	1:54	±	0:33	2:27	±	0:02	2:54	±	0:10
Planned last NLT ST input	2:35	±	0:00	3:27	±	0:17	3:37	±	0:02
Actual available for last NLT ST input	3:56	±	0:29	3:38	±	0:12	3:58	±	0:12
Used for last ST input	3:07	±	0:13	3:02	±	0:00	2:59	±	0:00
EV Idle Time (due to late ST input)	0:00	±	0:00	0:00	±	0:00	0:00	±	0:00
EV Translation Time	1:02	±	0:07	0:48	±	0:10	1:14	±	0:00

Table 2. Pre-sampling and Sampling ST assimilation time for Hawaii 2016. Presented as planned and actual times up to first and last NLT input to affect the start and end of EVA phases. EV idle time and translation time also presented. Duration means and SD in hr:min.

Hawaii 2016	***15min Latency, Low BW***			***5min Latency, Low BW***			***15min Latency, High BW***			***5min Latency, High BW***		
	Mean	**±**	**SD**	**Mean**	**±**	**SD**	**Mean**	**±**	**SD**	**Mean**	**±**	**SD**
# of Leaderboard Inputs from ST to EV												
Pre-sampling	6	±	2	5	±	1	3	±	0	8	±	1
Sampling	2	±	0	2	±	1	2	±	0	2	±	1
Pre-sampling ST Assimilation Time												
Planned for first NLT ST input	1:50	±	0:05	2:10	±	0:00	2:00	±	0:00	2:10	±	0:00
Actual available for first NLT ST input	2:17	±	0:24	2:20	±	0:05	2:01	±	0:00	2:18	±	0:02
Used for first ST input	1:12	±	0:11	1:24	±	0:26	1:23	±	0:02	1:18	±	0:00
Planned for last NLT ST input	2:20	±	0:05	2:40	±	0:00	2:30	±	0:00	2:40	±	0:00
Actual available for last NLT ST input	2:51	±	0:24	2:57	±	0:00	2:32	±	0:03	2:47	±	0:03
Used for last ST input	2:43	±	0:20	2:47	±	0:02	2:26	±	0:05	2:41	±	0:00
Sampling ST Assimilation Time												
Planned for first NLT ST input	2:50	±	0:05	3:10	±	0:00	3:00	±	0:00	3:10	±	0:00
Actual available for first NLT ST input	3:26	±	0:25	3:34	±	0:06	3:03		0:00	3:17		0:02
Used for first ST input	3:07	±	0:27	3:02	±	0:12	3:05	±	0:02	3:04	±	0:00
Planned last NLT ST input	3:27	±	0:12	3:40	±	0:00	3:30	±	0:00	3:40	±	0:00
Actual available for last NLT ST input	3:58	±	0:30	3:58	±	0:10	3:30	±	0:03	3:35	±	0:03
Used for last ST input	3:37	±	0:21	3:44	±	0:00	3:21	±	0:05	3:19	±	0:00
EV Idle Time (due to late ST input)	0:00	±	0:00	0:00	±	0:00	0:00	±	0:00	0:00	±	0:00
EV Translation Time	TBD	±	TBD	TBD	±	TBD	TBD	±	TBD	TBD	±	TBD

Study Limitations and Lessons Learned

The BASALT-1 field deployment (Idaho 2016) was the first of three currently planned for the BASALT project, and there were several study limitations, as well as many important lessons learned. Due to limited availability of BASALT personnel and travel budgets before the BASALT-1 deployment, all hardware and software capabilities could not be tested in an integrated, operational environment in advance. As a result, there were significant communications and networking issues that occurred between the EV crew in the field, the IV crew in the IV workstation, and the MSC during the early EVAs. These issues precluded meaningful evaluation of the research questions for four of the ten EVAs, which also resulted in one study condition (15 min latency low bandwidth) being excluded from assessment in BASALT-1 as it was originally planned. During the remaining six EVAs, some communication dropouts occurred, which occasionally made it difficult to assess all intended capabilities thoroughly. Furthermore, because all capabilities were not fully operational during the training and engineering dry run days prior to the first EVA day, various training effects were observed throughout the deployment: personnel became more familiar with their required roles and responsibilities from the first EVA to the last EVA, and best practices and strategies evolved from the start of the deployment to the end. The following BASALT deployments (Hawaii 2016 and 2017) were able to prioritize integrated hardware and software testing in the field prior to the deployments and minimal changes were made to the personnel role assignments to take advantage of the training achieved.

4. CONCLUSIONS

Vetted design principles and operational methodologies for managing communication latencies and bandwidth limitations are critical for mitigating risks associated with future Mars human exploration missions. There were three BASALT field deployments, in which the primary Science Operations goal was to critically evaluate various concepts of operations and capabilities in light of future human exploration missions to Mars. All science objectives were met for the deployment utilizing the science operations ConOp designed to allow ST interaction with EV/IV without incurring crew idle time. The leaderboard approach for providing ST input for OWLT up to 15 minutes was validated while performing real, Mars-relevant science.

ACRONYMS

ARC	Ames Research Center
BASALT	Biologic Analog Science Associated with Lava Terrains
CAPCOM	Capsule Communicator
COTM	Craters of the Moon
DRATS	Desert Research and Technology Studies
ERT	engineering readiness test
EV	extravehicular
EVA	extravehicular activity
FD	Flight Director
FST	Field Support Team
FTIR	Fourier transform infrared
GAT	ground assimilation time
hr	hour
IV	intravehicular
m	meter
min	minute
MIP	mobile instrument platform
MMT	Mission Management Team
MSC	Mission Support Center
NEEMO	NASA Extreme Environment Mission Operations
NIR	near infrared
NLT	no-later-than
ORT	engineering readiness test
OWLT	one-way light time
PLRP	Pavilion Lake Research Project
RATS	Research and Technology Studies
s	second
SA	situational awareness
SD	standard deviation
SCICOM	Science Communicator
SIMCOORD	Simulation Coordinator
SG-1	space-to-ground-1
SG-2	space-to-ground-2
ST	science team
TOP	target of opportunity
xGDS	Exploration Ground Data System

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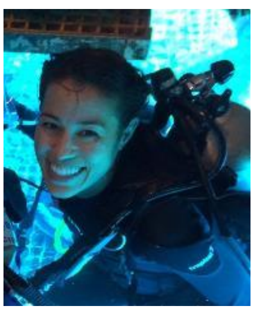
BIOGRAPHY



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