SCIENCE DATA MANAGEMENT DURING REAL-TIME GEOLOGICAL LUNAR ANALOGUE MISSIONS TO THE SUDBURY AND MISTASTIN LAKE IMPACT STRUCTURES: RECOMMENDATIONS FOR FUTURE GROUND DATA SYSTEMS. M.M. Mader[1],E. McCullough[1], M. Beauchamp[1], J. Clayton[1], C.L., Marion[1], J. Moores[1], A.E., Pickersgill[1], L.J., Preston[1], B. Shankar[1], G.R. Osinski[1], and ILSR team. Centre for Planetary Science and Exploration, University of Western Ontario, 1151 Richmond Street, London, ON, Canada, N6A 5B7 (mmader2@uwo.ca).

Introduction: Future surface lunar missions will operate on faster time scales than the Mars Exploration Rover (MER) missions or other deep space missions. Operators and scientists will be required to maintain real-time situational awareness, quickly assimilate data from a rover or astronaut crew, and be able to plan or re-plan activities in response to incoming information [1].

Keeping track of incoming data products and their modification during a fast-paced exploration campaign is not trivial. Simulating planetary missions on Earth can help test data management procedures, in order to help identify where current needs in data management architectures exist. We conducted three analogue missions, funded by the Canadian Space Agency, over the course of two years[2]. Here, we highlight lessons learned focusing on the management of data productsand their useby the Mission Control (MC) science team to aid surface geological investigations.

UWO Analogue Missions: Two different sample return scenarios were simulated during our analogue mission campaign: (1) A robotic lunar sample return mission; (2) A lunar robotic precursor mission with a follow-on 7-day human sortie mission. Scenario 1 was simulated at a site in the Sudbury impact structure, Ontario, Canada. The two deployments of Scenario 2 were both conducted at the Mistastin Lake (Kamestastin) impact structure, Labrador, Canada (for further scenario details, see [2] this volume and references therein).

A MC team was based at the University of Western Ontario (UWO) located in London, Ontario, Canada for all deployments and communication was via satellite terminal in the field, with daily data budgets of ~100 MB. Neither the MC team nor the 'astronauts' had visited the sites beforehand and relied on remote sensing data of equivalent resolution to present-day lunar data sets for mission planning.

Our scientific approach mirrored terrestrial geological exploration strategies by 1) using orbital and aerial datasets to assess geologic diversity, landing site selection, and accessibility/traverse planning; 2) conducting reconnaissance surface mapping 3) conducting follow-up detailed traverses, to study sites of interest in detail.

A critical constraint for this analogue mission campaign was that real-time Global Positioning System (GPS) capabilities were not used, as we were simulating a potential mission scenario to the far side of the Moon in which a GPS constellation system would not be available. Navigation in the field for the rover was by a vision-based autonomous system that allowed it to autonomously plan paths when given a destination by MC [3]. The system also allowed the rover to be commanded to return to any point it had previously occupied. Astronaut navigation was by visual comparison of basemaps with the surrounding area [4].

A fundamental difference between our strategy and MER and Apollo-style exploration was the frequency of uploading and modifying traverse plans. In the case of robotic exploration [5, 6], we completed multiple command cycles per day. For human exploration, there was essentially one command cycle (a single set of traverse instructions) per day; however, the traverse was typically modified in real-time in order to respond to collected data (including voice descriptions by astronauts) sent from the field to MC [7].

Science Data Products: Standard science data products collected in the field and then sent to MC included: 2D visual images (digital photos), 3D visual models generated from stereo images, 3D laser surface models generated from LiDAR point cloud data, ground penetrating radar (GPR) profiles, X-ray Fluorescence (XRF) spectra, Raman spectra, astronaut geological notes and descriptions [8].

Our analogue mission generated a total of ~4 GB of raw *science* data for a 10 day robotic mission and >15 GB for a 10 day human mission. A daily limit of 100 MB of data was sent from the field to MC (i.e., total of 1 GB for 10 days of operations). The remainder of the data was transferred after the mission.

Modification of Science Data by Mission Control: For geological field mapping, the primary scientific data used by MC were field photographs [9]. In particular, mosaic images were of great value for gaining increased field of view. Digital images, including screen captures of 3D models, were typically modified by science team members in a number of ways: 1) geological features (e.g., contacts) were drawn on the image; 2) image processing: contrast-stretch was optimized for highlighting features in the image; 3) image name was added; 4) images were cropped to highlight key areas; and 5) anaglyphs were made of selected stereo pairs.

Generalized Flow of Data: A typical flow of science data between MC and the field team was:

1) Data from the field was requested by MC.
2) Data was uploaded from the field using a remote satellite terminal by a field team member to an FTP site. Folders were organized by date and included subfolders for each science instrument.

3) A designated MC member transferred the files from the FTP site to a UWO server. Two copies were saved – one in an Archived folderfor storage of unmodified data, and another in a Working Data folder, for storage of modified data products.
4) The Science Team in MC then viewed all of the data and renamed each file, adding the place name (either designated by astronauts or previously assigned by MC) and data description to the end of the filename.
5) A separate folder of "Browsable Products" in the Working Data folder was designated for key images that the science team needed to share with each other (e.g., labeled photographs, plotted geochemical data) and that were useful as a quick reference.
6) Astronaut notes were manually transcribed (from handwritten notes to typed, digital format). Notes and photos were manually linked to a map produced using GIS software (ArcMap) [4].
7) New data products (e.g., labeled images) were used in instructions sent to field members.

Evolution of Data Management Process: Several data management elements evolved throughout the analogue mission campaign.

File naming: During the first analogue mission file naming was completed by the field team on site and this proved to be a time consuming process (~30-60 min each command cycle). For the second and third missions this task was completed by the MC team.

File naming conventions were modified for each subsequent mission. Initially, file names included codes for type of instrument, date, time, command cycle number, and level of processing. The latter two missions used hierarchical folder structures. During the second analogue mission, file names included the uplink number as well as the downlink number. For the last mission, browsable image file names also included the locality name and brief description of the image modification (e.g., stitched, stretched).

Data transfer from field: Due to data budget limitations (~100 MB/day) not all of the data collected each day could be sent back to MC. Additionally, some data products logically needed to be studied before others, therefore as the analogue missions evolved, MC started to prioritize requests for data in order to streamline the data interpretation process. The field team would try to send back prioritized data first.

Data Management Difficulties: Choosing an effective file naming system that eased searchability in a fast-paced environment was difficult. Finding particular data products was often a bottleneck in MC. In addition, long filenames and even changing original file names,was problematic for some software applications.

Manually transcribing astronaut field descriptions, and linking these notes and corresponding photos into a GIS platform, was time consuming [4]. During this time lag, new data products were generated by modifying initial data (e.g., annotating images) and thus could not be incorporated into the map in realtime.

During days with multiple command cycles, it was difficult for the science team to keep track of what data was requested for each command cycle and what data was returned, especially when data from one cycle was returned over several downlinks. Overall, it proved to be extremely beneficial to have an active record of what data was requested by MC, what data was returned, and what data was either returned corrupted (due to incomplete file transfer) or did not arrive at all. A low-tech solution was to keep an ongoing log posted on paper in a highly visible location in MC. A wiki format was attempted but proved inefficient.

Recommendations for Design of Ground Data Systems: We did not construct or use a specific software program for managing science data (e.g., NASA xGDS, [1]). Much of our data management was done manually. A customized system could automate many key processes, such as file naming and storage, aid in recording data history, and enable effective searching of raw and modified data. Key recommendations for designing and/or adding to existing systems include:

- Allow multiple ways of searching data, for example use "Tags" that would allow data to be queried by: instrument, date and time, site (e.g., site name, station number), location (e.g., enter coordinates or draw a point or area on map), who modified it, type of modifications, and if data (e.g. image) was used in instructions to the field team.
- Link raw and modified versions of the same data.
- Develop an indicator signal that informs MC that data has arrived from the field.
- Automate file naming, archiving, and sorting of data into appropriate file structure.
- Create conventions addressing which software programs will be used to modify data (e.g., Photoshop, Adobe Illustrator) and ensure that file formats being used are compatible across applications.

References:[1] Deans, M.C. et al (2011) 42nd LPSC, Abstract #2765, [2] Marion, C.L. et al. (2012) 43rd LPSC (this meeting), [3] Furgale, P. and Barfoot, T. (2010) *Field Robotics*, *27*, [4] Kerrigan, M. et al. (2012) 43rd LPSC (this meeting), [5] Moores J. et al. (2011) *EPSC-DPS Joint Mtg. 2011*, Abstract #1728, [6] Francis, R., et al. (2012) 43rd LPSC (this meeting),[7] Tornabene, L.L. et al. (2012) 43rd LPSC (this meeting), [8] Pickersgill et al. (2012) 43rd LPSC (this meeting), [9] McCullough E. et al., (2012) 43rd LPSC (this meeting).

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