LROC NAC TOPOGRAPHY: SUPPORTING HIGH PRIORITY LUNAR LANDING SITES. M. R. Manheim[1], M. R. Henriksen[1], and M. S. Robinson[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281 (mmanheim@ser.asu.edu).

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Cameras (NACs) provide some of the highest resolution images of the lunar surface with pixel scales of 0.5 to 2.0 m. While not designed as a stereo camera, geometric stereo images are acquired by slewing off-nadir on separate orbits [1]. The digital terrain models (DTMs) derived from these images are critical for planning and supporting landed missions.

DTMs and derived slope maps are used to calculate surface roughness, identify landing hazards, determine line-of-sight for communication, and map traverses for rovers [2,3,4]. In fact, NAC DTMs have been generated to support many recent lunar lander missions, including JAXA's Smart Lander for Investigating the Moon (SLIM), SpaceIL's Beresheet lander, and ISRO's Chandraayan-2.

The findings report from the 2018 Lunar Science for Landed Missions workshop at NASA Ames summarized key science goals identified by participants as well as presenting several potential landing sites for investigating these goals [5]. For each of the individual sites identified in the report, we describe the LROC NAC products currently available to support landed exploration. We also address future LROC acquisition and production of supporting data products.

Data Sources: Stereo images require incidence angles between 35° and 65° to create DTMs [1], limiting imaging opportunities to ~8 months per year. Until April 2018, LROC was also limited to a maximum of four slews per day; due to an instrumental anomaly, slewing has since been further curtailed [6]. In the 10 years since the launch of LRO, a total of 3869 stereo pairs covering 4% of the lunar surface were acquired. While only 11% of the stereo pairs have been processed into DTMs by the LROC SOC team, DTMs can be created as needed for future missions from available stereo images.

LROC DTMs have precisions better than their post spacing and are sampled to ~3x the pixel scale (usually 2, 3, or 5 m/px) of the source images [1]. For each DTM, orthophotos, a confidence map, a color-shaded relief map, and a slope map are provided, as well as the DTM's precision and accuracy relative to LOLA data.

The LROC SOC team has processed and archived 456 NAC DTMs to date (archived in the NASA Planetary Data System). Of these DTMs, 43 are mosaics built of at least two individual NAC DTMs.

Support to Date: JAXA's SLIM mission, planned to launch in 2021, aims to demonstrate a pinpoint landing within a 100 m radius. Its landing site was chosen from a larger region SW of Theophilus crater [7]. LROC acquired 9 stereo pairs to support site targeting and the LROC SOC team has produced 5 DTMs (4 at 3 m/px, 1 at 5 m/px) covering the SLIM landing region, including the site that was ultimately chosen (Fig. 1).

LROC has also acquired stereo to support ISRO (13 pairs), ESA (19), Roscosmos (4), and Google X-Prize teams (15). These are supplemented with nadirs, obliques, and featured mosaics [8], for a total of 940 individual observations as of April 1, 2019.

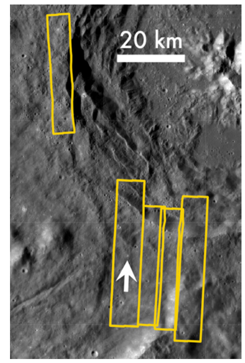

Figure 1: Theophilus SLIM site; DTM coverage shown in orange. The target landing site (arrow) is a small fresh crater ~200 m in diameter (13.3°S, 25.2°E) [7].

High Priority Sites: Of the high priority landing sites outlined in the Lunar Science for Landed Missions Workshop report, ten are specific sites, albeit of widely varying sizes (ranging from tens to thousands of km in diameter). Three are categorical targets: irregular mare patches (IMPs), magnetic anomalies (swirls), and mare pits (Table 1). IMPs and pits can generally be covered by <1 NAC pair while swirls are often larger, with indistinct boundaries. For IMPs and pit craters we list overall coverage for all the known features, as well as separately listing coverage for one of the most well-known IMPs, Ina. We describe coverage for just one of the most well studied magnetic anomalies, Reiner Gamma.

The polar regions are treated as an additional site [5]; we exclude the south pole from the SPA basin site. Polar stereo can be significantly more time consuming to process into DTMs due to the large incidence angles and thus increased shadowing; shadows result in "holes" in the DTMs.

The Ames report also describes three global objectives: the establishment of two global monitoring networks, and dating large impact basins. While we do not include these targets here, the basin chronology objective does include the individual target sites Mosconvise, Orientale, Schrödinger, and SPA (Table 1).

Future support: LROC NAC observations will continue to be targeted and processed for upcoming mission support and regions of interest to the lunar science community. However, due to the restrictions on the number of slews, and lighting condition con-

Center Coordinates	**Site**	**Region Size or # of Features**	**# DTMs**	**Stereo Coverage**	**# Stereo Pairs**
50°W, 25°N	Aristarchus plateau	~250 x 150 km	6	see Fig 2.	25
99.5°E, 61.1°N	Compton-Belkovich	~25 x 35 km	3	100%	14
40.2°W, 36.5°N	Gruithuisen domes	3 domes in region ~ 25 x 65 km	12	~100%	16
-	IMPs: all	70[1]	16 covering 19 IMPs	40 IMPs	~26
5.3°E, 18.66°N	IMPs: Ina Caldera	~2x3km	3	100%	5
59°W, 7.5°N	Reiner Gamma	~40 x 80 km	5	>75%	10
53°W, 13°N	Marius Hills	~150 x 200 km	6	see Fig. 3	20
147°E, 26°N	Moscoviense basin	>445 km diameter	2	<0.01%	27
95°W, 20°S	Orientale basin	1100 km diameter	7	<0.01%	126
53.8°W, 22.5°N	P60 basalt unit	see Fig. 2	4	see Fig. 2	10
-	Mare pits	16 mare pits	4	11 pits	~11
-	Polar regions: North Pole	>80° latitude	0	0	3
-	Polar regions: South Pole	<-80° latitude	0	0	51
3.5°W, 12°N	Rima Bode	~7000 km^2	0	0	3
135°E, 75°S	Schrödinger basin	315 km diameter	0	0	20
170°W, 53°S	SPA basin	~2500 km diameter	24	<0.01%	>400

Table 1: Available coverage by LROC NAC stereo and DTMs for potential landing sites. [1][9].

straints, it is necessary to refine the coordinates of interest for larger regions, such as SPA, Orientale, and Schrödinger, in order to be able to strategically acquire sufficient imagery to plan landings.

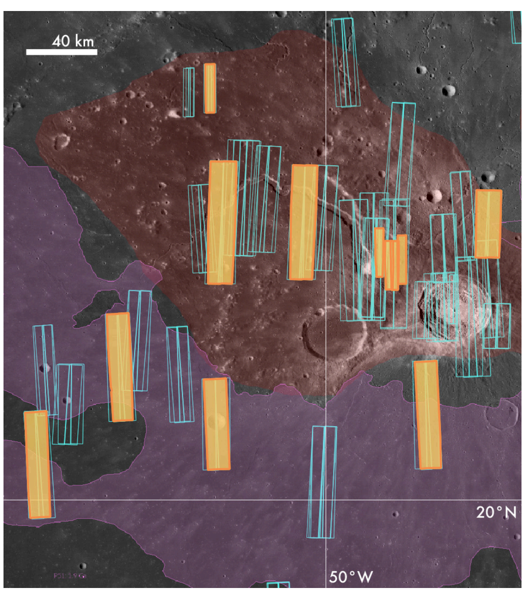

Figure 2: Aristarchus Plateau (indicated in red) and the P60 basalt region (pink) [10]. Teal outlines indicate stereo coverage and orange fill indicates DTMs.

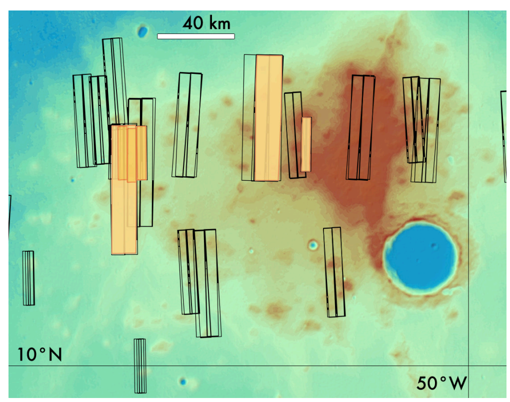

Figure 3: Stereo (black outlines) and DTM (orange fill) coverage for the Marius Hills region (LROC WAC GLD100).

References: [1] Henriksen, M. R. et al. (2017) *Icarus 283,* 122-137. [2] Speyerer, E. J. et al. (2016) *Icarus 273*, 337-345. [3] Lawrence, S. J. et al. (2015) *LPS XLVI,* #2074. [4] Mahanti, P. et al. (2013) *LEAG* #1748. [5] Jawin, E. R. et al. (2019) *Earth Space Sci. 6(1),* 2-40. [6] https://www.nasa.gov/feature/goddard/2018/lro-mission-status-report. [7] Ohtake, M. et al. (2019) *LPS L*, #2342. [8] Klem, S. M. et al. (2014) *LPSC XLV*, #2885. [9] Braden, S. E. et al. (2014) *Nat. Geosci. 7(11)*, 787-791. [10] Hiesinger, H. et al. (2011) *Geol. Soc. Spec. Pap. 477*, 1-51.