MARS 2020 LANDING SITE EVALUATION: DIGITAL TERRAIN MODEL PROCEDURE AND CAPABILITY DEVELOPMENT. R. L. Fergason[1], T. M. Hare[1], D. P. Mayer[1], D. M. Galuzska[1], M. P. Golombek[2], R. E. Otero[2], and B. L. Redding[1], [1]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, USA, rfergason@usgs.gov, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Introduction: The Mars 2020 rover will explore a region of Mars where the ancient environment may have been favorable for microbial life, and will investigate martian rocks for evidence of past life. Three candidate sites are currently being considered as potential landing sites, including Columbia Hills/Gusev, Jezero crater, and NE Syrtis. Columbia Hills/Gusev was the location where the Mars Exploration Rover Spirit landed and operated from 2004 to 2010 [1-2].

The Mars 2020 mission has an ellipse ranging from 18 km by 14 km to 13 km by 7 km, depending on atmospheric conditions, and is oriented roughly east-west. Terrain Relative Navigation (TRN) is a new capability being developed at the Jet Propulsion Laboratory to enable the spacecraft to autonomously avoid small hazards (e.g., rock fields, crater rims) that exceed the relief and rock constraints. This capability allows small-scale hazards to be present in the landing ellipse, providing greater flexibility in spacecraft landing location. We are generating Digital Terrain Models (DTMs) to fulfill two objectives: 1) to facilitate the identification and characterization of potential slope hazards on the surface within the landing ellipse, and 2) to produce a flight-quality DTM for use on-board the spacecraft in conjunction with TRN.

Digital Terrain Model (DTM) Generation Methods: To generate a DTM, the methods used for the evaluation of the InSight mission landing site [3-4] were also employed, and are summarized here. After a series of pre-processing steps using the ISIS3 software system [5], the images, trajectory, and pointing data are transferred to the commercial software system SOCET SET® from BAE Systems [6] where matching software correlates features in each image and uses the known camera orientation to determine topography. The images are then controlled and bundle adjusted using the SOCET SET® program Multi-Sensor Triangulation (MST), and then DTMs are produced by performing high-density area- and feature-based automated matching with the Next Generation Automatic Terrain Extraction (NGATE) module [7]. We then perform manual updates, within a 3D editing environment, to correct errors and remove artifacts (determined by visual inspection) from the automated matching process. This final editing significantly improves the quality of the DTM, and is critical for producing DTMs of high enough quality to certify a landing site.

Surface Topography Characterization: High-resolution DTMs provide critical information regarding the topography of the landing site region, and allow engineering criteria to be evaluated and certified. The Mars 2020 engineering requirements that are addressed using DTMs include: 1) MOLA elevation below -0.5 km for sufficient atmosphere to slow the spacecraft during Entry, Descent, and Landing (EDL), 2) less than ~100 meters of relief at baseline lengths of 1-1,000 meters to ensure proper control authority and fuel consumption during powered descent, and 3) less than 25°-30° slopes at length scales of 2-5 meters to ensure stability and trafficability of the rover during and after landing. The needs described above are addressed by generating both Context Camera (CTX) [8] and High-Resolution Imaging Science Experiment (HiRISE) [9] DTMs at scales appropriate for identifying lander-scale hazards (1-meter baselines) and for EDL simulations (20-meter baselines). We also produce ancillary products, including maps of adirectional slope at 1-, 2-, 5-m baselines for HiRISE DTMs and 20-m baselines for CTX DTMs and orthoimages from each DTM stereo pair image.

At the time of abstract submission, we have generated six CTX DTMs and twenty HiRISE DTMs in support of Mars 2020 landing site evaluation (some DTMs generated cover regions no longer being considered). See **Table 1** for a summary of slope statistics related to each DTM that intersects landing sites currently being considered. Although Jezero and NE Syrtis contain slopes at local scales that pose a hazard to landing and traversability, the regions are small enough to be avoidable using TRN. Thus, all three candidate landing sites meet the criteria required for safe landing.

Flight Quality DTM Mosaic Development: To support landing using TRN capabilities, we will produce a CTX orthoimage mosaic and HiRISE orthoimage mosaic of the landing ellipse and surrounding region. TRN registration requirements include: 1) HRSC to CTX horizontal coregistration less than 60 meters at the 99%tile; 2) CTX to HiRISE horizontal coregistration less than 6 meters at the 99%tile; and 3) HiRISE to HiRISE horizontal coregistration less than 3 meters at the 99%tile. These are significantly stricter horizontal and vertical registration requirements than landing site characterization and have prompted the need to develop new DTM generation procedures and capabilities. We are currently improving our DTM image pre-processing pipeline including capabilities to utilize camera model and jitter-correction improvements, using Ames Stereo Pipeline (ASP) [10] as a means to improve the starting point for DTM generation, and the ability to improve our use of Mars Orbiter

Laser Altimeter (MOLA) [11-12], High/Super Resolution Stereo Color Imager (HRSC) [13], and CTX as ground tie points. We are also exploring existing methods, and developing new approaches, to validate the horizontal and vertical registration for DTMs in a quantitative manner (**Figure 1**). Finally, we are exploring and developing new methods to generate flight-quality DTM mosaics, including utilizing the ASP program *pc_align* in innovative ways to improve the registration between images and generating DTM mosaics using SOCET SET® and/or SOCET GXP®.

Table 1. Statistics for CTX and HiRISE DTMs in support of Mars 2020 landing site selection.

Name	Sensor	Mean Slope	Standard Deviation
ColumbiaHills_XE	CTX	1.7	2.9
ColumbiaHills_W	HiRISE	4.6	3.0
ColumbiaHills_WC	HiRISE	4.5	3.7
ColumbiaHills_EC	HiRISE	3.6	3.2
ColumbiaHills_E	HiRISE	3.2	2.5
Jezero_XW	CTX	5.5	5.1
Jezero_W	HiRISE	4.5	4.2
Jezero_C	HiRISE	6.7	4.9
Jezero_CE	HiRISE	4.0	3.6
Jezero_E	HiRISE	4.2	3.3
NE_Syrtis_XC	CTX	5.8	4.6
NE_Syrtis_N	HiRISE	6.2	4.7
NE_Syrtis_NW	HiRISE	5.1	4.0
NE_Syrtis_W	HiRISE	5.8	4.5
NE_Syrtis_WC	HiRISE	4.7	4.1
NE_Syrtis_C	HiRISE	5.0	3.9
NE_Syrtis_CE	HiRISE	5.6	4.6
NE_Syrtis_E	HiRISE	5.5	4.4

Mars 2020 Spatial Data Infrastructure (SDI): We are developing an SDI that describes the foundational data sets and accuracy requirements to evaluate landing site safety, facilitate the successful operation of TRN, and assist in the operation of the rover once it has successfully landed on Mars. An SDI is a robust framework for data and data products, metadata, data access mechanisms, standards, policy, and a user community that helps to define and standardize the data necessary to meet some specified goal [e.g., 14]. The primary objective of this SDI is to aid in the identification of any potential gaps in knowledge, facilitate communication between the different institutions involved in landing site evaluation and TRN development, and help ensure a smooth transition from landing to surface operations. In addition, this SDI can serve as a means to document current requirements for foundational data products and standards for future landed missions to Mars and other planetary bodies.

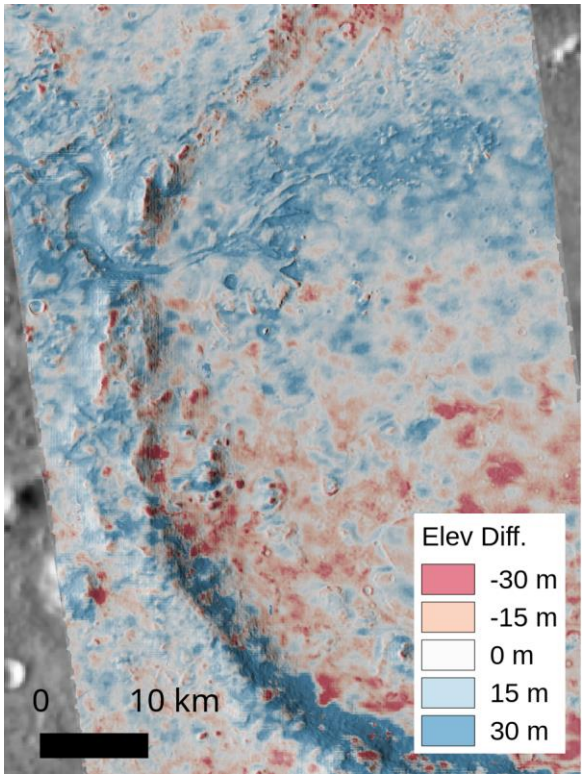

Figure 1. Elevation differences between CTX DTM of Jezero crater and HRSC reference DTM, overlain on CTX hillshade.

Acknowledgements: Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. References to commercial products are for identification purposes and do not imply an endorsement by the U.S. Government.

References: [1] Squyres S. W. et al. (2004) *Science*, *305*(5685), 794-799. [2] Arvidson R. E. et al. (2010) *JGR*, *115*(E7), doi:10.1029/2010JE003633. [3] Fergason R. L. et al. (2016) *SSR*, doi:10.1007/s11214-016-0292-x. [4] Golombek M. et al. (2016) *SSR*, doi:10.1007/s11214-016-0321-9. [5] Sides, S. C. et al. (2017) *LPS*, *XLVIII*, 2739. [6] Miller S. B. and Walker A. S. (1993) *ACSM/ASPRS Annual Conv*., *3*, 256–263. [7] Zhang B. (2006) *GeoCue Corporation 2nd annual Technical Exchange Conference*. [8] Malin M. et al. (2007) *JGR*, *112*(E05S02), doi:10.1029/2005JE002605. [9] McEwen A. S. et al. (2007) *JGR*, *112* (E05S02), doi:10.1029/2005JE002605. [10] Moratto Z. M. et al. (2010) *LPS*, *XLI*, 2364. [11] Smith D. et al. (1999) *Science*, *284*, 1495-1503. [12] Smith D. E. et al. (2001) *JGR*, *106*, 23,689-23,722. [13] Jaumann R. et al. (2007) *Planet and Space. Sci*., *55*, 928-952. [14] Laura J. R. (2016) *Int. J. of Geo-Inf.*, *6*, 181, doi:10.3390/ijgi606181.