UPDATED SPICE AND NEW TOOLS FOR WORKING WITH KAGUYA TERRAIN CAMERA DATA. L. Gaddis[1], L. Weller[1], L. Adoram-Kerchner[1], T. Hare[1], B. Archinal[1], S. Goossens[2,3], E. Mazarico[3], E. Speyerer[4], J. Haruyama[5], T. Iwata[5], and N. Namiki[6]. [1]USGS Astrogeology Science Center, Flagstaff, AZ 86001, USA; [2]Univ. Maryland, Baltimore County, Baltimore, MD, USA; [3]NASA Goddard Space Flight Center, Greenbelt, MD, USA; [4]Arizona State University, Tempe, AZ, USA; [5]JAXA, Sagamihara, Japan; [6]National Astronomical Observatory of Japan, Tokyo, Japan (lgaddis@usgs.gov)

Introduction: The Terrain Camera (TC) was part of the SELenological and ENgineering Explorer (SELENE) "Kaguya" spacecraft mission to the Moon from the Japan Aerospace Exploration Agency (JAXA). Launched in September 2007, the Kaguya primary mission (PM) was completed at the end of October 2008 and the extended mission (XM) phase started at the beginning of November 2008. During XM Kaguya was in a lower orbit at 50 km average altitude compared to 100 km during PM. Although data collected during Kaguya XM have an increased spatial resolution, the orbit errors during this phase are much larger, up to several km [1] due to larger gravitational perturbations on the spacecraft, a reduction in the amount of tracking after the end of the nominal mission, and spacecraft attitude control problems associated with loss of the reaction wheels. The resulting degradation in orbit quality during XM severely limited the usability and scientific value of higher resolution data such as those from the TC (***Figure 1).*** Here we report on our work to improve the orbital data for the Kaguya mission, update SPICE, develop tools for processing the TC data in the USGS Integrated Software for Imagers and Spectrometers (ISIS3) and building improved mosaics, and to archive the resulting products and tools. TC images and mosaics at ~5 to 12 m/pixel provide an excellent complement to many other lunar datasets and controlled products derived from these data [2] should be part of the suite of data used in future lunar surface science exploration.

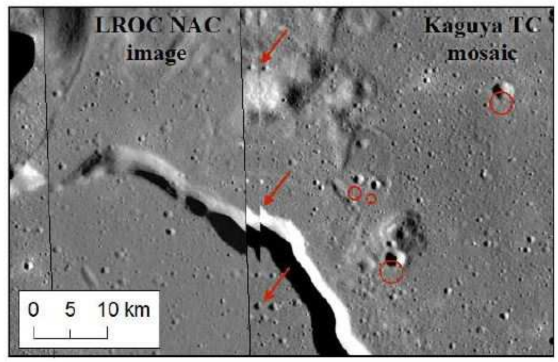

Figure 1. LROC NAC image (M1127106676R, 1.3 m/pixel) of the Apollo 15 landing site area superimposed on a TC mosaic with original degraded quality. We have significantly improved co-registration of TC images, and their registration to other lunar datasets such as LRO/LROC WAC and NAC. Red arrows and circles show duplication of features.

Improved XM Orbits: We recently published results showing a significant improvement for the Kaguya XM orbits [3]. These orbits were redetermined for the main satellite using 1) improved gravity field models of the Moon derived from Gravity Recovery and Interior Laboratory (GRAIL) mission data [4] and 2) adjustments of the spacecraft orbit such that the LALT altimetry tracks fit a precise topographic basemap based on the Lunar Reconnaissance Orbiter's (LRO) Lunar Orbiter Laser Altimeter (LOLA) data [5]. Through analysis of orbit overlaps, we developed geodetically accurate orbits tied to the precise LOLA/LRO frame; the inclusion of altimetry improves the orbit precision from several kilometers to several tens of meters. When altimetry data are not available, the combination of GRAIL gravity and radio tracking results in an orbit precision of several hundred meters for the low-altitude phase of the XM. Our improved orbits result in better geo-location of the Kaguya XM data. These orbit data, as updated trajectory data (SPICE SPK), along with adjusted LALT altimetric and Kaguya LMAG magnetic data are served at NASA GSFC (https://pgda.gsfc.nasa.gov/); the updated SPKs are also available at the JAXA DARTS (https://darts.isas.jaxa.jp/planet/pdap/selene/) archive.

ISIS3 Software: To support the validation of the improved SPICE, we used ISIS3 (https://isis.astrogeology.usgs.gov/) to develop a TC test mosaic of the Apollo 15 landing site area near Hadley Rille. The Apollo 15 region has been a standard test site for many lunar mapping products. For example, high-resolution mapping of the central portion of this area was done under the Lunar Mapping and Modeling Project [6], including a ~20 x 20 km, 0.50 m/pixel image mosaic, and a 1.5 m/pixel Digital Terrain Model [7].

Two ISIS3 programs were developed: 1) an ingestion program (*kaguyatc2isis*) that reads a TC file header and imports data into a single-band ISIS3 cube file and label, and 2) a linescan camera model for the two TC instruments (used in *spiceinit*). Geometric camera models describe the mathematical relationship between the coordinates of a 3D scene and its projection onto the image plane of a camera; for orbital imaging systems such models must also account for spacecraft coordinates and movements. The goal is to be able to treat data from the two TC cameras as ISIS3 cube files so that they can be geometrically rectified and map-projected accurately onto the lunar surface. Both "singlescopic" (L2B0, s) and stereo (L2B0, w) TC data are supported. The camera model includes camera parameters such as focal length, pixel pitch, boresight coordinate, affine coefficients for focal plane mapping, and optical distortion coefficients. These programs are publicly released with ISIS3.

Test Mosaic: To develop a 10°x10° TC mosaic for the Apollo 15 site, we first assessed the coverage of the PM and XM data from the L2B0 collection, both for morning and evening (left- and right-look) illuminations and stereo and monoscopic viewing. Spatial resolution of the input TC images varies from 4.5 to ~11.2 m/pixel. We determined that good coverage of the Apollo 15 site is afforded from the morning illumination stereo XM data, but completion of a full mosaic requires use of both XM and PM stereo and monoscopic data.

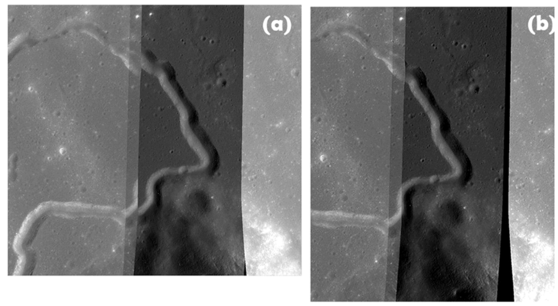

Figure 2. Kaguya TC views of Hadley Rille (1.5 km across, 400 m deep), using XM data (~5 m/pixel). (a) Uncontrolled, unequalized mosaic before updating the orbits. (b) Uncontrolled, unequalized mosaic after updating the orbits.

Future Work: We are completing three regional TC mosaics: an uncontrolled mosaic, using the a priori SPICE data (Figure 2a); an uncontrolled mosaic, using our updated SPK (orbit) data in ISIS3 (Figure 2b); and a controlled mosaic highlighting the XM data, where we refine corrections to the SPK and CK (pointing) data. We expect to control ~381 images (268 stereo XM, 91 mono PM, and ~16 mono XM), with ~300 of those visible on top in the controlled mosaic. The third mosaic will be archived with the PDS as a final product in late 2020.

References: [1] Goossens et al. (2009) Proceedings of the 19th Workshop on JAXA Astrodynamics and Flight Mechanics, 247–256, Inst. Space Astronautical Sci., JAXA. [2] Fergason et al. (2020) this meeting. [3] Goossens et al. (2019) *Icarus, 226*, doi:10.1016/j.icarus.2019.113454. [4] Zuber et al. (2012) *Science*, doi:10.1126/science.1231507. [5] Smith et al. (2017) *Icarus*, doi:10.1016/j.icarus.2016.06.006. [6] Noble et al. (2009) *LEAG Annual Meeting*, abs. #2014. [7] Rosiek et al. (2012) *LPS XLIII*, abs. #2343. [8] Archinal et al. (2011) *LPS XLII*, abs. #2316.