NEW ISIS SOFTWARE FOR WORKING WITH MOON MINERALOGY MAPPER DATA. L. R. Gaddis[1], R. Kirk[1], B. Archinal[1], K. Edmundson[1], L. Weller[1], S. Sides[1], J. Boardman[2], E. Malaret[3], and S. Besse[4]. [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ, 86001, USA (lgaddis@usgs.gov). [2]Analytical Imaging and Geophysics, LLC, Boulder, CO, USA. [3]Applied Coherent Technologies, Herndon, VA. [4]ESA/ESTEC, Noordwijk, the Netherlands.

Introduction. The NASA Moon Mineralogy Mapper (M^3) instrument returned hyperspectral data for ~95% of the Moon from the ISRO Chandrayaan-1 spacecraft [1-4]. The M^3 data are uniquely valuable for characterizing surficial water [2, 5] and surface mineralogy at high spatial resolution (140 m/pixel) at wavelengths to ~3.0 µm [6-9]. However, the archived M^3 data were processed with a preliminary global digital elevation model from the Lunar Orbital Laser Altimeter (LOLA) on the Lunar Reconnaissance Orbiter (LRO). The goal of this work is to use the higher spatial resolution (~100 m/pixel) and improved geodetic accuracy of the LRO Wide Angle Camera (WAC) stereo-derived topographic model [i.e., the GLD100 digital terrain model (DTM), 10] to improve the selenolocation of the M^3 data. Root-mean-squared (RMS) positional errors will be reduced from ~200 m relative and 450 m absolute to a pixel (~140 m) or better, and the many images with positional errors of kilometers will be corrected.

This project has several goals: (1) Reprocess M^3 data through the original mission's Level 1B (L1B) pipeline using the improved DTM to improve selenolocation accuracy; (2) Develop USGS ISIS3 software [11] for processing M^3 data (including a physically rigorous camera model); (3) Control the global M^3 dataset to obtain higher/known positional accuracy and generate new L1B products; (4) Reprocess L1B data through the mission's level 2 (L2) pipeline using the DTM to improve thermal and photometric accuracy; (5) Improve the photometric modeling; (6) Create orthorectified and mosaicked (Level 3) data products; and (7) Deliver interim and final products, including NAIF SPICE kernels [12] and calibrated, map-projected M^3 products to the Planetary Data System (PDS). Goals 1 and 2 have been completed and work is ongoing on goals 3, 4 and 5. *Here we describe the ISIS software tools developed and now available for working with M^3 data, and preliminary results of our restoration of the M^3 data using these tools and capabilities.*

ISIS Software. The USGS ISIS planetary cartographic software [11] is free to users (see http://isis.astrogeology.usgs.gov/) and it is used for this work because it supports rigorous physical modeling of the geometry of image formation from planetary cameras and the use of photogrammetric bundle-adjustment techniques to control images (***Figure 1***). The resulting cartographic products have precision and accuracy that is not only as high as possible but well understood and documented by statistical error estimates.

For working with M^3 data, ISIS software has been developed to support (1) ingestion of M^3 L1B data (both old and new products) using the ***chan1m32isis*** program, (2) creation of pointing, instrument, spacecraft, and frames kernels (CK, IK, SPK, and FK) from updated LOC (M^3 seleno-location) files, and (3) development of a camera model with characterization of optical distortion of the M^3 camera (used by the program ***spiceinit***). Information in the labels (e.g., the different resampling of data in the spatial and spectral dimensions in M^3 Global and Target Modes) is translated by the ingestion program to an ISIS-friendly format. The appropriate spacecraft position kernel (SPK, trajectory for an image) is associated with the frame, and an initial CK (pointing) kernel is computed from the LOC file. "No data" lines are inserted in the hyperspectral image cube where data are missing, previously truncated clock start and stop times are updated using NAIF SPICE library and spacecraft clock counts, and the preliminary CK and SPK kernels are revised to encompass the earliest start time and latest stop time. A reconstructed kernel database file supporting M^3 frame processing in ISIS is available as part of the April 2015 release of ISIS.

We are currently using these ISIS capabilities to generate improved spacecraft position and pointing data for M^3 and to support derivation of a rigorous solution of the camera pointing and generation of improved CK kernels. The M^3 camera model provides the ability to calculate image coordinates (line, sample) of a point in three dimensions or the reverse. A key part of the new ISIS camera model for M^3 is an improved optical distortion model that provides an accurate representation of the M^3 camera geometry in terms of physical parameters (i.e., boresight orientation, focal length, radial and decentering distortions).

The ISIS ***jigsaw*** program performs a bundle adjustment using tie point measurements from overlapping images to simultaneously refine image geometry (i.e., camera pointing, spacecraft position) and control-point coordinates (lat, lon, & radius) to reduce boundary mismatches in mosaics. Planned new *jigsaw* tools will provide an advanced adjustment capability that allows simultaneous improvement of the camera parameters and modeling of timing biases. Controlling the M^3 data with these tools is valuable as an independent check of the solution derived with the team processing pipeline, but this work also will improve the accuracy and precision of products to an extent that will be well documented by rigorous modeling of error propagation. A result of these new tools will be significantly updated SPK kernel data for M^3. New SPK data and other updated kernels for M^3 will be delivered to PDS and NAIF [12]. These data will document the position and pointing of the spacecraft at all phases of the mission during collection of M^3 data. This information has been lacking because of the loss of one and then both star tracker instruments during the mission, and errors in the spacecraft clock information.

Preliminary Results: The revised seleno-location process resulted in local per-pixel topography models that are overall improved but localized multi-pixel offsets remain. These will be addressed with detailed ISIS cartographic processing (***Figure 1***) of M^3 data in the coming year. As was the case in the original M^3 archived data in PDS, the OP1B data are the best behaved geometrically and most closely match the WAC mosaic and GLD100 DTM. The OP1A data appear equally well-behaved in our test mosaic, and the OP2A, B, and C data will likely need the most work to geometrically controlled. Although ISIS uses more automated, feature-based matching tools, control is primarily evaluated through an iterative process of orthorectification of images and examination of consistency of placement of overlapping images in map coordinates of test mosaics. We are working with a single wavelength (band 9, 750 nm) to establish and evaluate global control, but the results are expected to be fully applicable to the multiband M^3 dataset. The goal is to produce a geometrically improved hyperspectral mosaic of all M^3 Global Mode data, along with updated kernels and metadata.

Next Steps: In parallel with this geometric work, we are re-examining the photometric correction of the M^3 data with the goal of improving it. The photometric correction is based on imaging parameters derived from the GLD100 and is applied to the L2 data. We are researching application of the Hapke and Akimov photometric models [13]. Once a photometric model is selected, it will be applied to L2 data from which a thermal correction has been removed [e.g., 14].

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Figure 1. *Schematic view of end-to-end data processing in ISIS (after [14]). The "Geometric Control" steps are iterative and often extensively and multiply interconnected, but detail is not shown here. Thus far we have begun to create and evaluate uncontrolled M^3 mosaics in preparation for establishing a more rigorous single-band ~global controlled mosaic.*