THE THEMIS CONTROLLED MOSIACS OF MARS AND FINAL SMITHED KERNELS. R. L. Fergason[1] and L. Weller[1], Astrogeology Science Center, [1]U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001, rfergason@usgs.gov.

Introduction: Geodetically controlled products at global scales are foundational data products [1] that provide a common reference system to enable the accurate co-registration of multiple data sets. Accurate registration is necessary for the precision science required to answer questions that cross-cut disciplines and are potentially key to understanding fundamental questions about our universe. To provide such a foundational product for Mars, we have geodetically controlled and mosaicked Thermal Emission Imaging System (THEMIS) [2] daytime infrared (IR) and nighttime IR images resulting in improved camera pointing and spacecraft position knowledge. The results of this work are smithed kernel files describing these improvements for each image in the control network and controlled, orthoprojected daytime IR and nighttime IR mosaics of Mars at 100 m/pixel scale for the ±65˚ latitude region of Mars, and constitutes a foundational data product for Mars. These mosaics, and the associated network, have improved the registration of the THEMIS IR data set and enhance our knowledge (position, precision, and accuracy) of image placement and the location of small-scale surface features. These final products are controlled to the current accepted ground data source for Mars, which is Mars Orbiter Laser Altimetry (MOLA [3-4]) digital elevation model. Thus, these products can serve as a 100 m/pixel basemap for Mars (Figure 1).

The horizontal resolution of the MOLA DEM is 463 m/pixel and the overall horizontal accuracy is ~100 meters [5], which is insufficient to confidently register high-resolution images, such as High Resolution Imaging Science Experiment (HiRISE) [6] (spatial scale of 30 cm/pixel), to this base due to large differences in spatial resolution. As a global data set of intermediate spatial scale, we have geodetically controlled and mosaicked THEMIS daytime IR and nighttime IR images to enable the accurate co-registration of higher resolution martian data sets, such as Context Camera [7] and HiRISE [6] images. This accurate base is necessary to facilitate the co-location of data (e.g., data fusion) with known, quantifiable error, and provides such a foundation to which all other martian data sets intersecting the network can then be registered. These controlled products help meet a common need among researchers to accurately co-locate data sets of varying spatial scales and data types to aide in addressing multi-disciplinary questions and allows for precision science to be accomplished.

Methods: The THEMIS instrument [2] has attained near global coverage of Mars in the daytime and nighttime IR at a scale of ~100 m/pixel, providing the needed images to geodetically control (i.e., precisely and accurately register in a consistent solution with estimates of uncertainty) these data into a common reference coordinate frame at the sub-pixel level. Our strategy for generating the global mosaics included generating regional networks and then merging the regional networks together as they were built. We incorporated all viable THEMIS infrared images into the control network that had been acquired when we began work on a regional mosaic. Thus, not all THEMIS images are included in the control network. Images were also excluded from the network if they were of poor quality and the matching software or manual tie pointing methods were unsuccessful in obtaining match points. Often, and particularly at high latitudes and areas with a low thermal inertia surface, this poor image quality was due to cold surface observation temperatures. Those images not included in the network do not have smithed kernels.

We generated the THEMIS IR controlled mosaics by first generating control networks using automatic image-to-image tie point methods and sub-pixel registration (with human oversight) along with bundle adjustment software in ISIS3 [8]. A least squares bundle adjustment of the network solved for the latitude, longitude, and radius uncertainties on each point in the control network, the uncertainties for the exterior orientation of the images (i.e., pointing of the spacecraft and position of each image), and uncertainties associated with these measurements.

After image-to-image ties are completed, we then tied the THEMIS network to ground using an improved Viking MDIM 2.1 network [9-10]. To take advantage of the high accuracy High/Super Resolution Stereo Colour Imager (HRSC) [11] data and the geometric strength of the global Viking MDIM 2.1 [9-10], we reprocessed the original MDIM 2.1 network incorporating available HRSC level 4 data (which have been well controlled to the MOLA reference frame [11]) as additional ground control. Error propagation showed that 80% (~2700 points) of the final enhanced MDIM 2.1 solution tie points have horizontal accuracies better than 200 meters. This methodology results in a control network and an orthorectified product that has broad applicability. In addition to mosaics, updated camera pointing (ck) and spacecraft position (spk) kernels of all THEMIS images included in the control networks have been generated. We will deliver final kernels to the Navigation and Ancillary Information Facility (NAIF).

Results: We have found that errors in image position at the 2-4-pixel level (but as large as 30 pixels) are apparent in uncontrolled data downloaded from the PDS (Figure 2). These errors are primarily due to uncertainties in the THEMIS image start time. This uncertainty is random, and there are no future plans to improve the THEMIS IR sensor model further. Controlling the pointing has enabled the correction of these errors and improves both the registration between images and registration to a known coordinate reference frame (i.e., MOLA) at known levels of precision and accuracy. The accuracy of image position is less than a single pixel, and the 3-sigma residual is also less than a single pixel. The position of a single THEMIS image is commonly adjusted by 5-7 pixels, and adjustments as large as 15 or more pixels have been necessary (Figure 2).

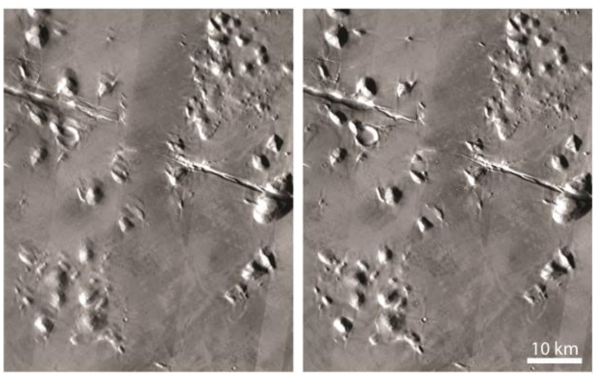

Figure 2. Comparison of uncontrolled (left) and controlled (right) image averaged mosaic products. Portion of the Elysium mosaic, 15.4° N, 162.4° E. A 16-20-pixel shift was necessary to match features in this area. The projection is simple cylindrical with a longitude domain of 0° to 360°.

Data Availability: Final mosaics, smithed ck and spk kernels, metadata, and file lists are publicly available through the PDS Annex (https://astrogeology.usgs.gov/maps/mars-themis-controlled-mosaics-and-final-smithed-kernels/) in GeoTiff format with ISIS3 and PDS3 labels. Instructions for use are also provided at the above website.

Acknowledgements: References to commercial products are for identification purposes and do not imply an endorsement by the U.S. Government.

References: [1] Laura J. R. et al. (2017) *Inter. J. Geo-Info.*, 6, doi:10.3390. [2] Christensen P. R. et al. (2004) *Space Sci. Rev.*, *110*, 85-130. [3] Smith D. et al. (1999) *Science*, *284*, 1495-1503. [4] Smith D. E. et al. (2001) *JGR*, *106*, 23,689-23,722. [5] Neumann G. A. et al. (2001) *JGR*, *106*, 23,752-23,768. [6] McEwen A. S. et al. (2007) *JGR*, 112, E05S02. [7] Malin M. et al. (2007) *JGR*, *112*(E05S02), doi:10.1029/2005JE002605. [8] Edmundson K. L. et al. (2012) *ISPRS Annals*, I-4, 203-208. [9] Archinal B. A. et al. (2003) *LPS* XXXIV, Abstract #1485. [10] Archinal B. A. et al. (2004), *XXth ISPRS Congress*. [11] Jaumann R. et al. (2007) *Planet and Space. Sci*., *55*, 928-952.

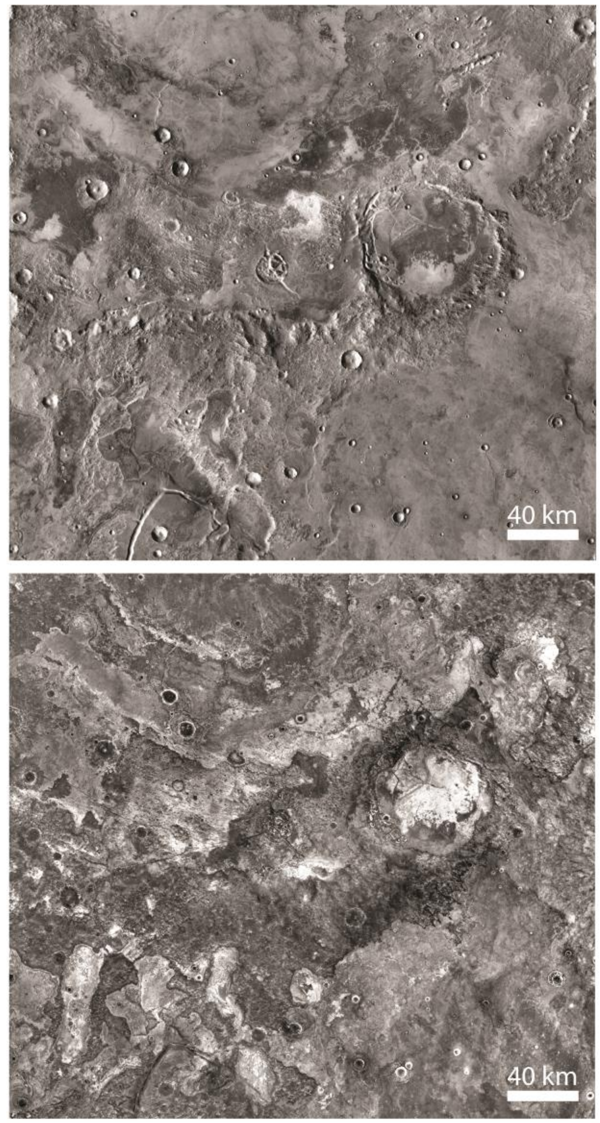

Figure 1. Syrtis Major controlled mosaic example. The projection for is simple cylindrical with a longitude domain of 0 to 360 degrees. These mosaics have been tied to the improved Viking MDIM 2.1 as ground control. (top) THEMIS daytime IR controlled mosaic example. (bottom) THEMIS nighttime IR controlled mosaic example.