THE IMPORTANCE OF GEODETICALLY CONTROLLED DATA SETS: THEMIS CONTROLLED MOSIACS OF MARS, A CASE STUDY.

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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 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, enhance our knowledge (position, precision, and accuracy) of image placement and the location of small-scale surface features, and provide for improved targeting for current and future orbital acquisition of data and spacecraft landings and planning of spacecraft surface operations.

Definitions and Background: Controlled data are defined as data that have been precisely co-registered relative to one another and to some datum (e.g., altimetry data in planetary science), such that rigorous accuracy and precision information is quantifiable (most often using photogrammetric bundle adjustment techniques). This is in contrast to oft utilized "rubber sheeting" techniques that can result in aesthetically pleasing image mosaics, but lack rigorous statistical information that must be available to quantify the image adjustment. Without rigorous accuracy information, the propagation of error to additional co-registered (e.g., fused) data sets is impossible, making scientific assessments that require accurate positional information problematic. A key output of photogrammetric control is adjusted image pointing knowledge that can be used to generate improved spacecraft position and instrument pointing information (i.e., CK and SPK kernels; SPICE). This updated SPICE can be used by other researchers to properly geometrically locate their data, but meet their specific data processing needs.

Global and regional control networks and mosaics, and the products that result from the improved pointing and position information, are critical for a broad range of applications, such as precision landing on a planetary body and surface change detection studies. An accurate base at the highest resolution reasonable is necessary to facilitate the co-location of data (e.g., data fusion) with known, quantifiable error, and controlled data products provide such a foundation to which all other data sets intersecting the network can then be registered. Controlled products helps 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.

A common practice of simply co-registering images to one another (automatic or manually) without using a controlled base to tie to, and retaining the accuracy of that registration, can only be considered a "semi-controlled" product. This process may produce a product that is "good enough" for many science investigations, and is certainly less costly to produce, but the resulting product does not achieve sufficient accuracy, and more importantly the knowledge of that accuracy, to be a controlled product and its value is significantly reduced. As described above, without rigorous accuracy assessments, analyses that depend upon positional accuracy or geometric relationships can be incorrect when hypotheses are tested within the error thresholds.

Methods: The current accepted ground data source for Mars is Mars Orbiter Laser Altimetry (MOLA [3-4]) digital elevation model. The horizontal resolution of this product 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 [6] (spatial scale of 30 m/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 martian data sets. 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.

We generated the THEMIS IR controlled mosaics using automatic sub-pixel registration (with human oversight) and bundle adjustment software in ISIS3 [7]. We then perform a least squares bundle adjustment of control point image measurements and generate the control networks. We also solve for the formal uncertainties for the exterior ordination of the images (i.e., pointing of the spacecraft and position of each image), the latitude/longitude/radius uncertainties on each point in the control network, and uncertainties in the constrained ground points.

After image-to-image ties are completed, we then tied the THEMIS tiles to ground using an improved Viking MDIM 2.1 network [8]. To take advantage of the high accuracy High/Super Resolution Stereo Colour Imager (HRSC) [9] data and the geometric strength of the global Viking MDIM 2.1 [10-11], we reprocessed the original MDIM 2.1 network incorporating available HRSC level 4 data (which have been well controlled to the MOLA reference frame [9]) 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 [8]. This methodology results in a control network and an orthorectified product that has broad applicability. In addition to mosaics, updated camera pointing and spacecraft position 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) so they can include it on the PDS NAIF FTP site.

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 1). 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 camera model further. Controlling the pointing has enabled the correction of these errors and improve both the registration between images and registration to a known coordinate reference frame (i.e., MOLA) at known levels of precision and accuracy. In all tiles, 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 1).

Data Availability: We are currently generating final mosaics, which will be available in September 2018. Preliminary mosaics and pointing kernels based on the individual networks have been distributed to the planetary science community through the PDS Annex (http://astrogeology.usgs.gov/) in GeoTiff format with available ISIS3 and PDS3 labels, and have been ingested into the JMars software [12].

Future Needs: A globally controlled image data set, and an appropriate base (e.g., altimetry), is necessary for all solid planetary bodies where significant data collection efforts are being made and precision science is desired. This controlled base will allow for the accurate co-registration of all data sets and will enhance the science return and cost-effectiveness of data for that body. For Mars, the THEMIS controlled mosaics, and the associated network, have improved the registration of the THEMIS IR data set and enhanced our knowledge (position, precision, and accuracy) of image placement and small-scale feature location. In addition, these precision products provide for improved targeting for current and future orbital acquisition of data and spacecraft landings and planning of spacecraft surface operations.

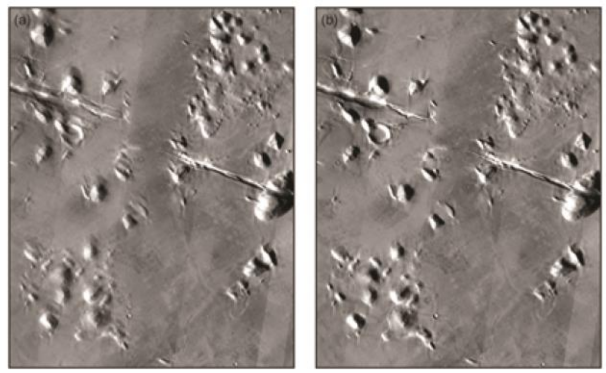

Figure 1. Comparison of uncontrolled (a) and controlled (b) image averaged mosaic products. Portion of the Elysium mosaic, 15.4° N, 162.4° E. A 16-20 pixel shift was necessary to match features in this area. The projection is simple cylindrical with a longitude domain of 0° to 360°.

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