Super-Resolving THEMIS Data for Improved Temperature, Composition, and Spatial Resolution. C. G. Hughes[1], M. S. Ramsey[1], and H. Tonooka[2], [1]Dept. of Geology and Planetary Science, Univ. of Pittsburgh, Pittsburgh, Pa 15260 USA, cgh1@pitt.edu, ramsey@ivis.eps.pitt.edu; [2]Ibaraki University, 4-12-1 Nakanarusawa, Hitachi, Ibaraki, Japan 316-8511, tonooka@mx.ibaraki.ac.jp.

Introduction: Super-Resolution is the process of obtaining a spatial resolution greater than that of the original (or native) resolution of a data source. This can be done through the fusion of original data with an additional source that has the desired resolution. There are a variety of techniques that can be used to fuse data sources; however, a tradeoff has been noted between techniques that are the most visually appealing and those that are most radiometrically accurate [1]. The technique for super-resolution presented here is a modification of an algorithm [2] that was tested successfully using multi-resolution data from the Earth orbiting Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument (Fig. 1, Fig. 2) [3]. The spatial and spectral resolution of this instrument is broadly similar to the Mars orbiting Thermal Emission Imaging System (THEMIS) instrument [4]. The current study investigates the applicability of this technique to the fusion of THEMIS visible (VIS) and thermal infrared (TIR) data. Successful super-resolution of the 100 m/pixel THEMIS TIR bands would allow for improved spatial resolution (18-36 m/pixel) in order to enhance image interpretation and aid in the search for sub-pixel scale temperature and/or compositional anomalies.

Data and Methods: Data from both the ASTER and THEMIS instruments can be organized into wavelength regions. Both instruments have bands within the VIS and TIR spectral ranges, with the VIS spectral range having fewer bands but better spatial resolution on both instruments. The standard deviation of each VIS band is calculated, and these results are averaged to create a threshold value. Following this, the VIS bands are degraded to the spatial resolution of the co-located IR bands. The standard deviations of the members of the degraded pixel are calculated on a per-band basis. Those pixels whose values are less than the threshold (across all VIS bands) are considered to be homogenous.

Clustering. Once all homogenous visible pixels have been identified, they are clustered using a modified ISODATA algorithm [5]. The initial clusters are assigned with a random homogenous pixel as the first cluster center. The remaining initial cluster centers are assigned by choosing the pixel with the maximum Mahalanobis distance (MD) to all previously assigned centers.

Each homogenous pixel is assigned to the cluster that minimizes the MD to the associated cluster center. After this, the algorithm removes clusters which have less then the specified minimum number of members. Every remaining cluster then has a new cluster center calculated by averaging the values of all pixels assigned to the cluster on a per-band basis. If any clusters were removed, the process of assigning pixels to clusters and calculating centers is repeated. After all pixels have been assigned to clusters, and no clusters were removed, the algorithm calculates the density of the remaining clusters by measuring the MD from each member to the cluster center. The overall average cluster distance is then calculated by weighting the average by the number of members in a cluster.

The user specifies values for the maximum number of clusters, the maximum number of iterations for the algorithm, and the maximum standard deviation within a cluster before starting the algorithm. These values determine when to split clusters. If there are less than or equal to twice the maximum number of clusters specified during odd-number iterations, any cluster with a standard deviation greater than the specified maximum standard deviation becomes a candidate to be split. The candidate clusters are examined for one of two conditions. Before splitting a cluster, either its average distance must be greater than the overall average cluster distance or the current number of clusters must be less than the specified maximum number of clusters. If any clusters are split, the algorithm repeats again, starting from the assignment of pixels to cluster centers.

During even numbered iterations, when no clusters are split, or after the maximum number of iterations has been reached, the MD between each cluster is measured. These distances are compared to the user-specified minimum distance between clusters, and up to the user-specified maximum number of pairs are then joined. A new cluster center is specified by the weighted averaging of the two cluster centers, and all members are assigned to the new cluster

After completion of the higher resolution bands, a tree is created by clustering the lower resolution pixels on a per-cluster basis. This is done by selecting all lower-resolution pixels co-located with pixels in a given cluster, and sending those pixels through the ISODATA algorithm. The tree created through this process is the key to this super-resolution algorithm.

Post-clustering. After completion of clustering, it is possible to super-resolve the image. Pixel values are assigned by measuring the MD of the co-located higher resolution pixel to any degraded homogenous pixels within a fixed radius, typically equal to 10 degraded pixels. Next, the MD is computed from the co-located higher resolution pixel to the higher-resolution cluster centers within the tree. If there are no homogeneous pixels within the radius, or if the minimal MD is to a cluster center, it is necessary to compute which lower resolution cluster center to assign to the super-resolved pixel. This is done by calculating the MD from the original lower resolution pixel to the lower resolution clusters, and assigning the super-resolved pixel the values of the cluster center which minimizes that distance.

As the final step, it is necessary to radiometrically correct the super-resolved values so that these pixels, when degraded back the original resolution, continue to have the original values. As super-resolved pixels with a large MD tend to contribute more to error, this corrective step is weighted proportionally to the MD of each super-resolved pixel from its source.

Preliminary Results: The modified super-resolution algorithm has been run on a number of ASTER (Mars analogs) images with various levels of success (Fig. 1, Fig. 2). These areas reveal some problems, which are either minor or correctable with the application of the algorithm to Mars. Performance of the algorithm deteriorates somewhat in spectrally bland conditions due to a lack of branches within the cluster tree. This has not significantly reduced the usefulness of the algorithm on the analog images. Figure 2 shows a sharper image than Figure 1, despite a largely homogeneous environment. Although Fig. 2 is sharper, some noise (speckling) is visible. This noise is most likely attributable to the radiometric correction step over-correcting super-resolved pixels with significantly larger MD than their neighbors. These over-corrections are balanced out by corrections of similar magnitude in adjacent super-resolved pixels which leads to this effect. Further constraining the magnitude of the corrections should remove most of this noise, while still producing radiometrically accurate results.

Future Work: This process has been successfully tested on Earth-based ASTER images, with both the VIS to SWIR to IR and the VIS to IR super-resolution pathways. No significant difference was found in these two methods and therefore the lack of SWIR bands on THEMIS should have little impact. Based on these results, it should now be possible to apply the algorithm to THEMIS data with only minor changes being implemented for this transition. These changes include creating a programmatic Point Spread Function (PSF), based on both the instrument PSF and any resampling of the higher resolution data needed to completely overlap the lower resolution data. High priority targets, where there is likelihood for small-scale compositional difference, will then be the focus of our testing. The first target for super-resolution is the olivine and phyllosilicate rich regions near Nili Fossae [6], [7].

References: [1] B. Zhukov et al. (1999), *IEEE Trans. Geol. and RS, 37,* 1212-1226. [2] H. Tonooka (2005), *Proc. SPIE, 5657,* 9-19. [3] Y. Yamaguchi et al. (1998), *IEEE Trans. Geol. And RS, 36,* 1062-1071. [4] P. Christensen et al. (2004), *Space Science Reviews, 110,* 85-130 [5] G. Ball and D. Hall (1967), *Behavioral Science, 12,* 153-155. [6] F. Poulet et al. (2006), *Nature, 438*, 623-627. [7] V. Hamilton et al. (2005), *Geology, 33,* 433-436.

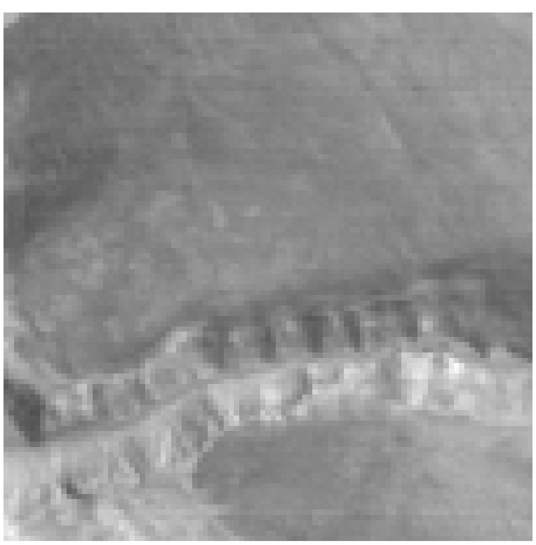

Figure 1. Original 90m resolution image, near Arica, Chile

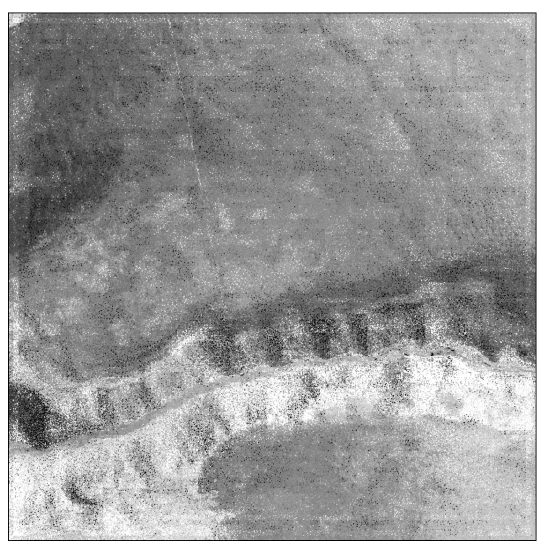

Figure 2. Super-resolved 15m image of Fig. 1