CORRECTING TOPOGRAPHIC SHADOWING ERRORS IN APPARENT THERMAL INERTIA IMAGES.

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Introduction: Thermal inertia (TI) represents the resistance of a material to changes in temperature and is calculated using thermal conductivity, thermal capacity, and density. It has been used to investigate surface properties of Mars by analyzing the response of materials to heating and cooling using a modeling approach to predict the surface temperatures at varying latitudes and seasons [1]. TI can then be applied to discriminate bedrock from regolith for example by establishing the threshold at which certain rock sizes dominate [2]. However, model-based TI is more complex in terrestrial applications due mainly to the atmosphere. An approximation, apparent thermal inertia (ATI), has been utilized to determine grain size, soil moisture, and mantling properties [3-5]. ATI is the ratio of 1-albedo to the difference in temperature over a diurnal cycle [6] and materials with small grain size and/or low soil moisture will have a lower ATI.

One problem with the calculation of ATI occurs where pixels are shadowed to some degree for a portion of the day. Shadowing will lower the visible albedo and daytime temperature, which combine to raise the ATI value. To determine the best correction for this source of error, a Mars analog site was selected because ground-based observations were necessary to determine the accuracy of the proposed adjustments. In the ASTER visible near infrared/thermal infrared (VNIR/TIR) images used for this study, most pixels located on north facing slopes were shadowed to some degree with a sun azimuth of 131° and elevation of 68° when the daytime data were acquired.

Background: Located on the eastern edge of the Sierra Nevada, the Mono-Inyo Craters formed from previous rhyolitic volcanic activity that began around 40,000 years ago [7,8]. These craters are an ideal analog for a martian mantled volcanic terrain. The North Coulee flow is covered with thick tephra deposits ranging in grain size from ashy to blocky [9]. Even though minor differences in the trace elements exist, the deposits in the Mono-Inyo Crater area are mineralogically homogenous [7]. However, the minor differences do suggest that the deposits did not erupt from a single chamber [10]. The North Coulee was specifically selected in the Mono-Inyo Crater system as the location of this study due to the range of tephra deposit sizes and mantling thickness.

The original ASTER daytime, nighttime and albedo images used in this study for comparison were taken from a previous study [9]. The diurnal pair was collected on 10 July 2011 at 12:50:47 local time and 11 July 2011 at 21:54:33 local time. The TIR data were corrected for atmosphere using a MODTRAN-based approach and the brightness temperature extracted from both the daytime and nighttime images. Atmospherically-corrected reflectance data were used to create the VNIR albedo image. Results of previous work with these data at this site showed abnormally-high ATI values on all north-facing slopes (Figure 1B) and was recognized as a source of error [5].

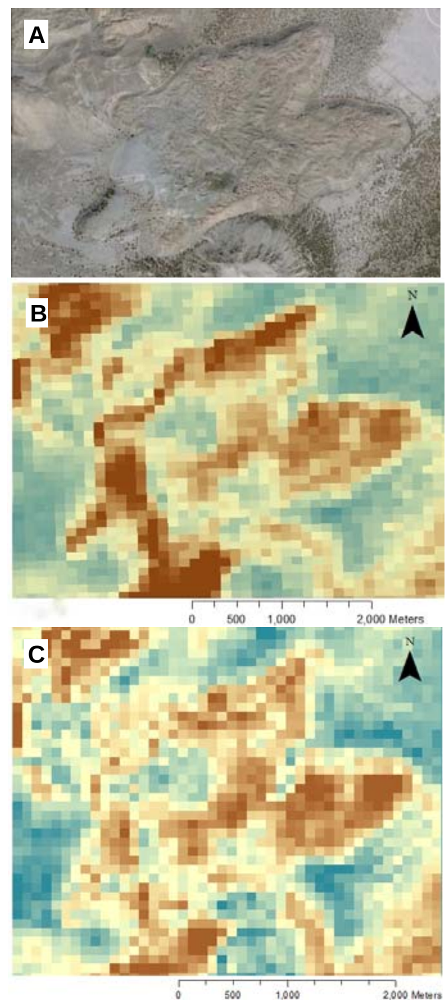

Fig. 1. *(A) Google Earth image of the North Coulee lava flow [11]. (B) ATI map from [5] and (B) newly processed ATI map after the correction. The standard deviation color stretch used resulted in a slight color change for unadjusted pixels in the new processed ATI image.*

Methods: To model the topographic effects, slope and shaded relief images were created using the ENVI software and a digital elevation model (DEM) from the USGS National Map Viewer with 10 m resolution. The slope image displayed the average steepness of each pixel on the coulee and the shaded relief image indicated the amount of shadowing over the coulee.

To determine possible correlations between the slope or shaded relief values and the pixels with ATI errors, data from these two new images were compared to ATI product, daytime temperatures, and albedo. Statistics computed for different combinations of all these values yielded no significant correlation that could be used as a mathematical operator to adjust incorrect values. However, these comparisons did reveal that the shaded relief image could be used to determine those pixels that required a correction.

Incorrect pixels were identified for the daytime temperature and albedo images using the following three criteria: (1) a shaded relief value below the statistical maximum of 200, (2) the pixel value did not exceed the maximum in the image minus the proposed adjustment, and (3) the difference between a cell and the surrounding neighbors did not exceed the proposed adjustment. The maximum pixel value for the daytime temperature image was calculated to be 320 K and 0.19 for the albedo image.

Aerial photographs and images taken in the field confirmed the structural, morphological and compositional similarity between the south and north facing slopes. Thus, pixels should display roughly similar ATI values with only minor variations. Further, south facing slopes should serve as indicators of values expected on the north slopes. To determine what factor should be applied to pixels identified as incorrect, a series of regions of interests (ROIs) were created along the sloping flow fronts of North Coulee on both the daytime temperature and albedo images. Statistics (min, max, and mean) were calculated for ROIs unaffected by shadows. These statistics for both daytime temperature and albedo were analyzed and the following adjustments were made to the shadowed pixels: daytime temperature values were increased by 5 K and albedo values were increased by 0.06. Once both the daytime temperatures and albedo values were corrected, ATI was recalculated using the same approach as [5].

Results and Discussion: The corrections applied to the daytime temperature and albedo images significantly improved the ATI values of the pixels influenced by shadowing (Figure 1C). The new ATI values were more reasonable than the original result. North facing slopes more closely resembled those on slopes unaffected by shadowing (e.g., previously high ATI values represented by red are now yellow in color). Although the correction appears visually more satisfying, detailed analysis of the revised image also shows that a limited number of the identified pixels seem to still display incorrect values. In addition, the boundary between corrected and surrounding pixels is distinct in certain areas suggesting that this first-order approach of a single numeric correction may not be the best approach. The correction did not account for the fact that pixels are influenced by shadows differently depending on their location on the slope as well as shadowing caused by larger blocks at the sub-pixel scale. Those pixels covering areas at the top and bottom of a slope will be less affected by shadows over the diurnal cycle than those in the middle. Furthermore, this process is not easily applied to other locations and would require subjective analysis of pixels to determine which should be adjusted.

Conclusion: Even though the process generated a significantly improved ATI image, the method proposed is a basic approach to a complex problem. A single numerical correction does not take into account the all the shadowing complexities in an image. Thus, a more complex mathematical operation is needed and a current project focuses on the difference between the shadowing values of incorrect and neighboring pixels.

A possible approach has been identified in which pixels with shadowing errors at each end of a slope would receive a different correction value than those in the middle. And sub-pixel roughness elements could be extracted from shadowing seen in the VNIR data. Both of these will be explored in the future. Ultimately, the best method will take into account how slope, elevation, and roughness vary to determine a mathematical operation that corrects the effect of shadowing on pixel values. Once this more advanced correction is tested, the process will be applied to TIR data of Arsia Mons and Syria Planum mantled lava flows to further investigate the composition and mantling history of these volcanic sites.

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