Correcting Topographic Shadowing Errors in Apparent Thermal Inertia Images

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Introduction

Thermal inertia (TI) is a measure of material's resistance to change in temperature and is calculated using thermal conductivity, heat capacity, and density. It has been used to investigate surface properties of Mars by analyzing the response of materials to heating and cooling [1]. However, model-based TI is more complex in terrestrial applications due mainly to the thicker atmosphere. An approximation, apparent thermal inertia (ATI), is the ratio of 1-albedo to the difference in diurnal temperature [2]. It has been utilized in prior studies to determine grain size, soil moisture, and mantling properties [3-5].

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 artificially raise the ATI value.

Location

A Mars analog site (Fig.1) was selected for this study because ground-based observations were necessary to determine the accuracy of the proposed adjustments. The most recent rhyolitic volcanic activity at the site occurred <1000 BP [6,7]. The North Coulee flow is covered with thick tephra deposits ranging in grain size from ashy to blocky [8]. Even though minor differences in the trace elements exist, the deposits in the area are considered mineralogically homogenous [6, 9].

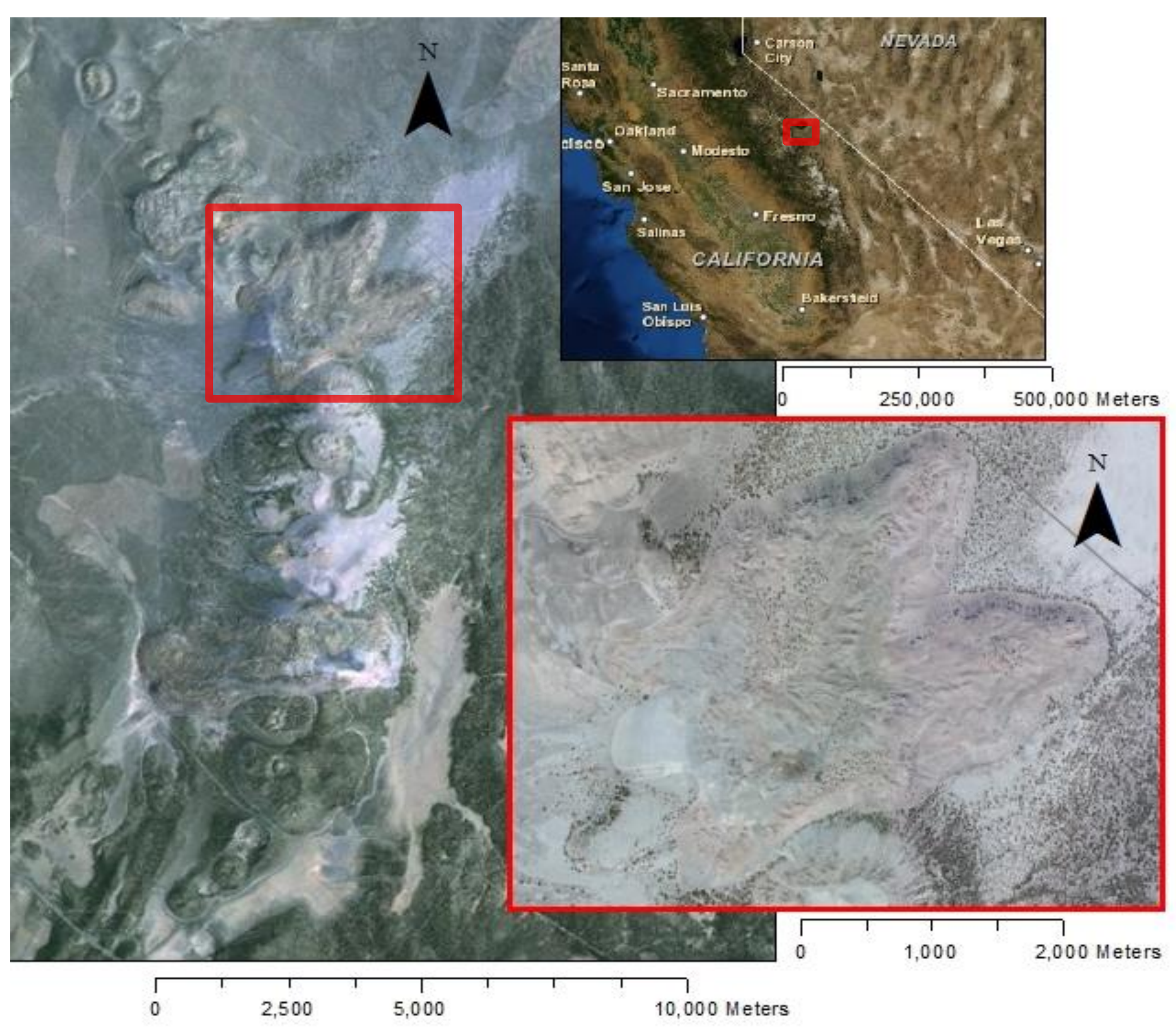

Fig. 1. Aerial image of Mono-Inyo Craters site with the red rectangle showing the North Coulee flow [10]. Context map inset shows the location of the site in eastern-central California.

Images/Data

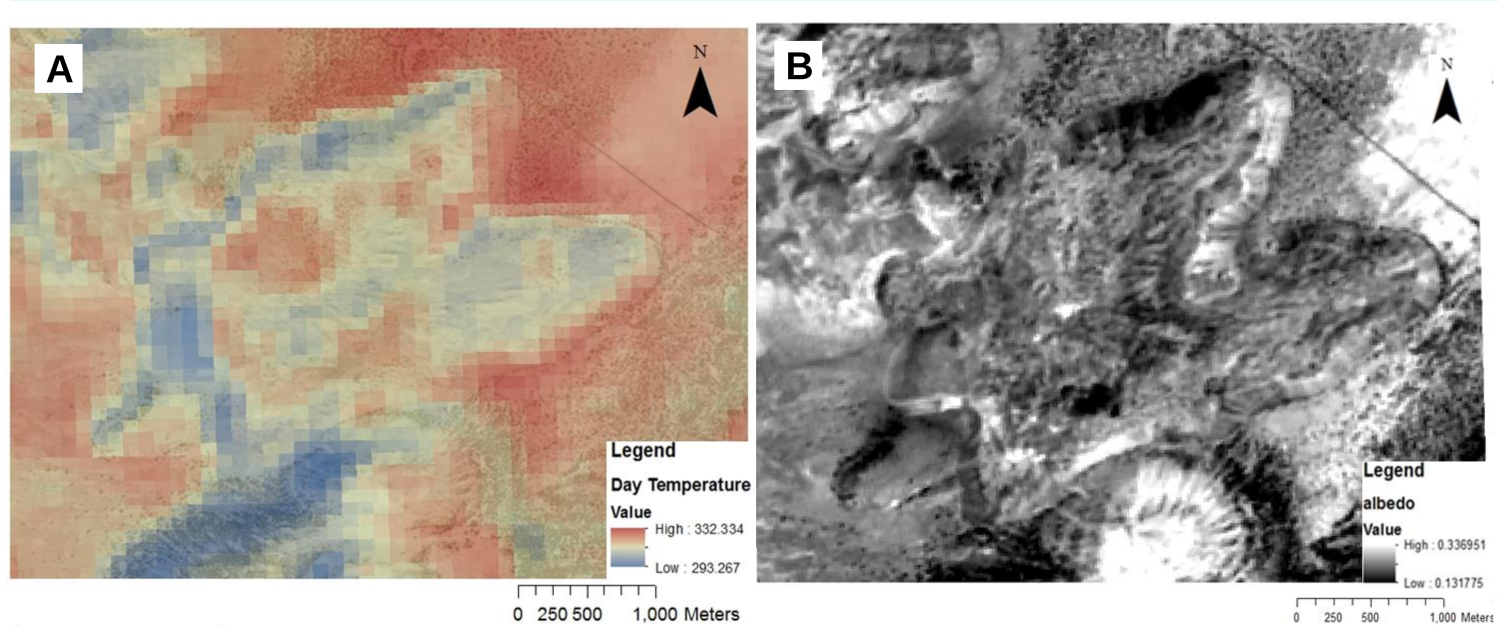

Fig. 2. (A) Calculated daytime temperature from ASTER TIR data and (B) albedo values from VNIR reflectance data. Note the low temperatures in regions of shadow to the NW of the flow.

The original ASTER daytime, nighttime and albedo images (Fig. 2) used for comparison were taken from a previous study [8]. The diurnal pair was collected on 10 July 2011 at 12:50:47 and 11 July 2011 at 21:54:33. 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.

Procedure

To model the topographic effects, slope and shaded relief images were created using the ENVI software and a digital elevation model (DEM). Data from these two new images were then compared to the ATI product, daytime temperature, and albedo.

Identifying Incorrect Pixels:

Incorrect pixels were identified using the following: (1) a shaded relief value below the statistical maximum of 200, (2) a pixel value that does 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 was calculated to be 320 K and 0.19 for the albedo.

Identifying Appropriate Adjustments:

To determine what factor should be applied, a series of regions of interests (ROIs) were created along the sloping NW flow fronts of North Coulee on both the daytime temperature and albedo images. Statistics (min, max, and mean) were also calculated and analyzed for ROIs unaffected by shadows. Based on these values, 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.

Extent of Corrected Areas

In the images, most pixels located on NW facing slopes were shadowed to a degree with a sun azimuth of 131° and elevation of 68° when the daytime data were acquired.

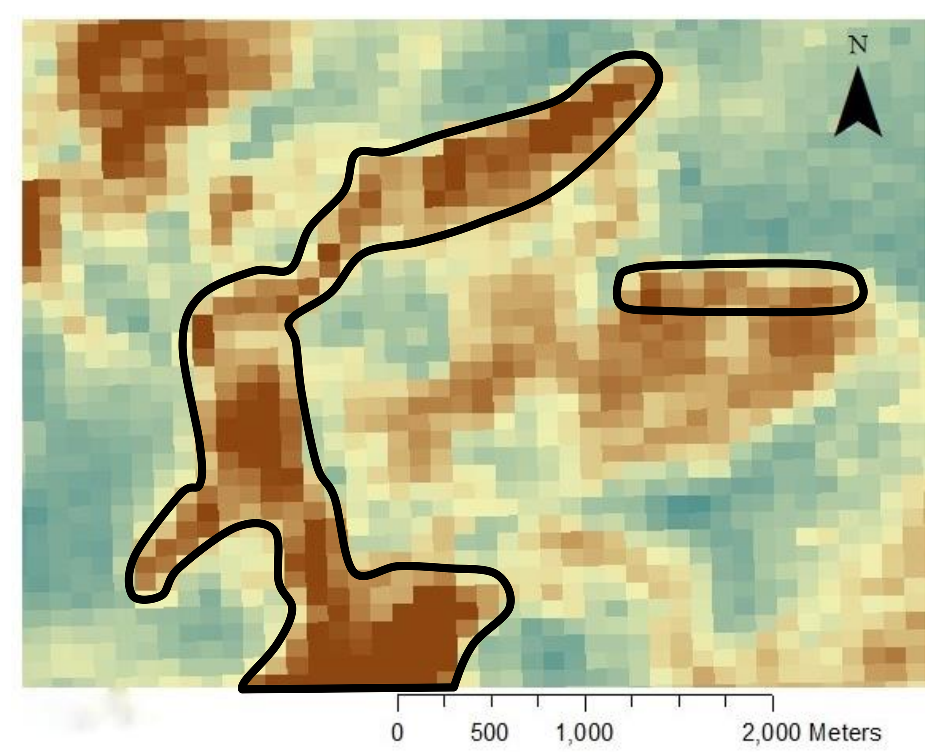

Fig. 3. Original ATI map from [4] highlighting the ROI's impacted by shadowing. Brown represents high ATI, while yellow and blue represent progressively lower values of ATI.

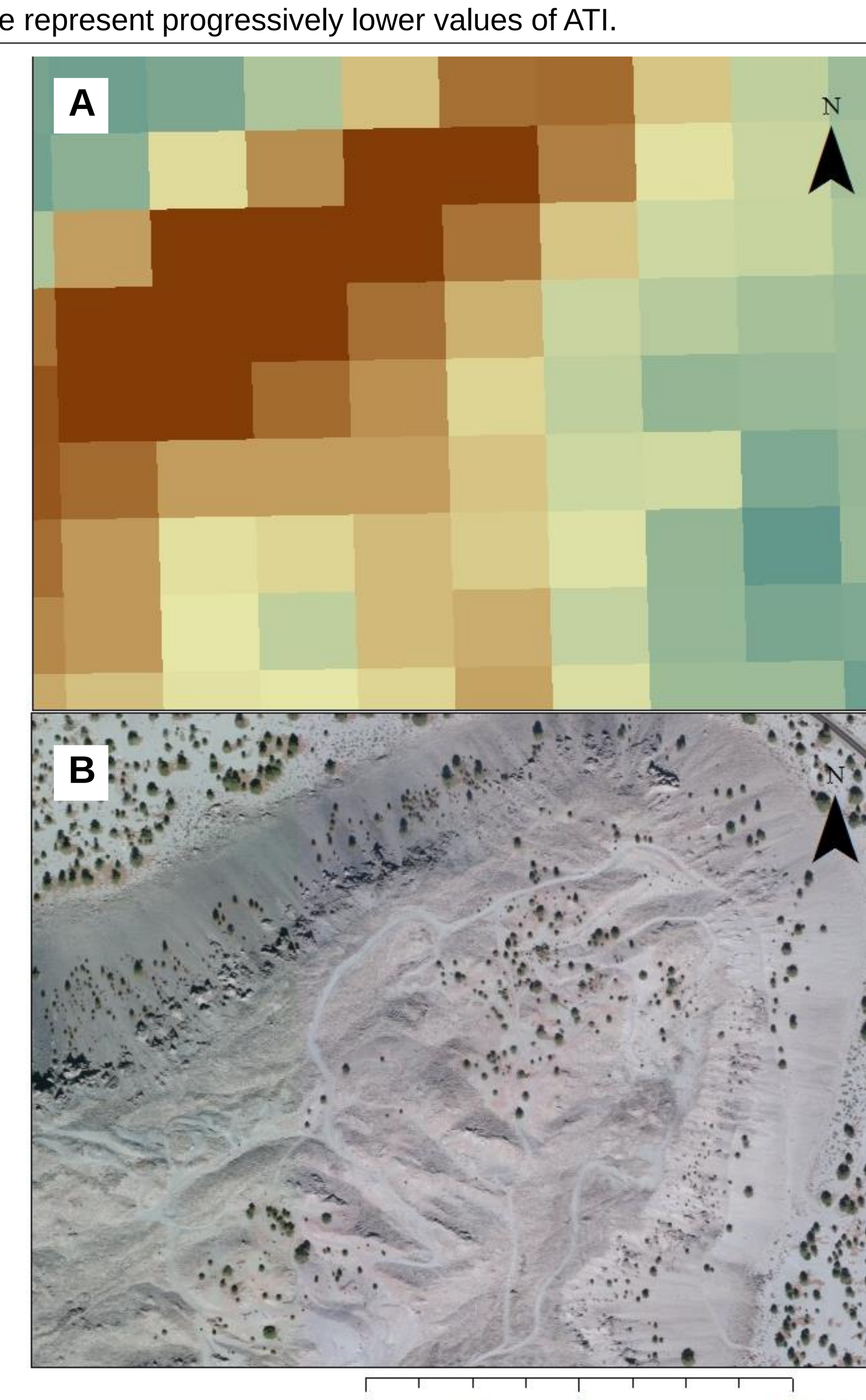

Fig. 4. (A) Original ATI map from [4] zoomed on the northeast corner of North Coulee. (B) Aerial image of the same region and spatial extent.

Observations

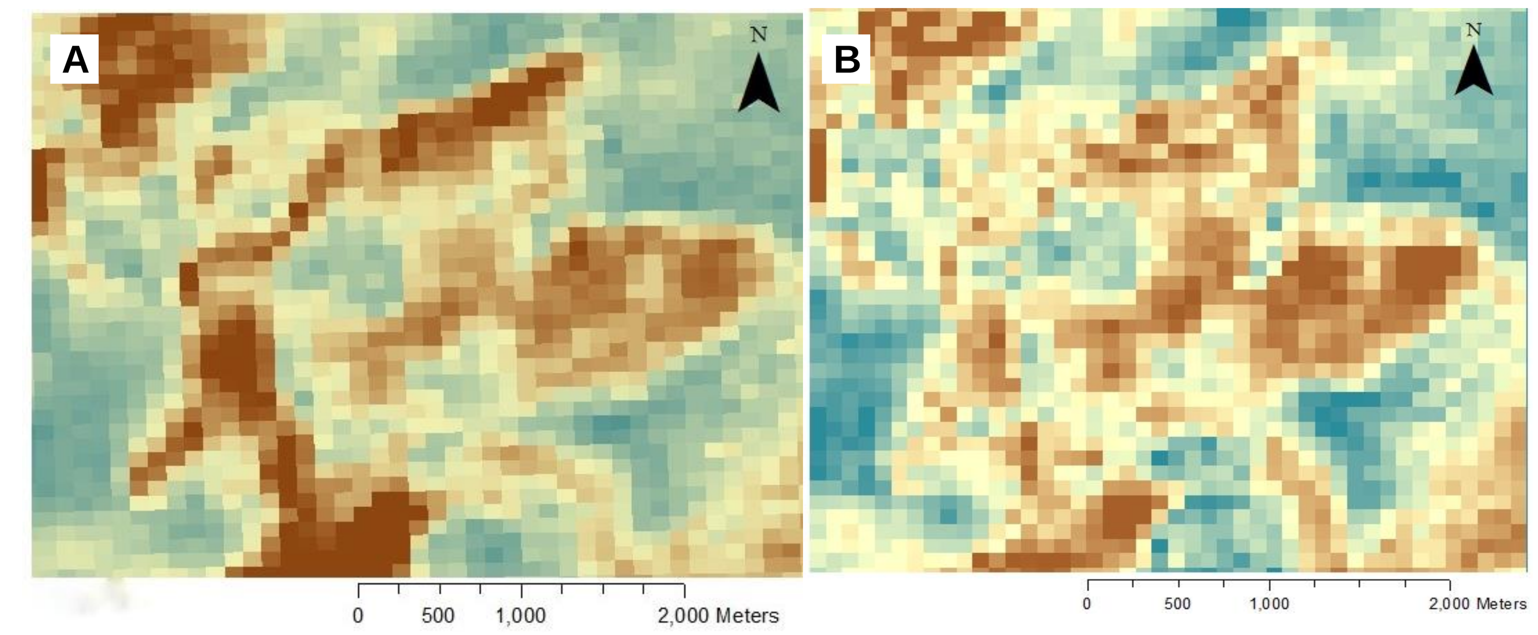

Fig. 5. (A) ATI map from [4] and (B) newly processed ATI map after the correction. The standard deviation color stretch used resulted in a slight color change for unadjusted pixels in the new processed ATI image.

The corrections applied to the daytime temperature and albedo images significantly improved the ATI results of the pixels influenced by shadowing (e.g., previously high ATI values represented by red are now yellow in color) (Fig. 5). However, detailed analysis of the revised image also shows that a limited number of the identified pixels seem to still display incorrect values. The single numeric 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.

Future Applications

We are developing an automated process to complete the first-order correction approach. This will make the process easily applied to new locations and remove the need for subjective analysis previously used to identify incorrect pixels.

In regards to the errors in a single numeric correction, 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. 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.

Once this more sophisticated 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, mantling presence and thickness of these volcanic sites.

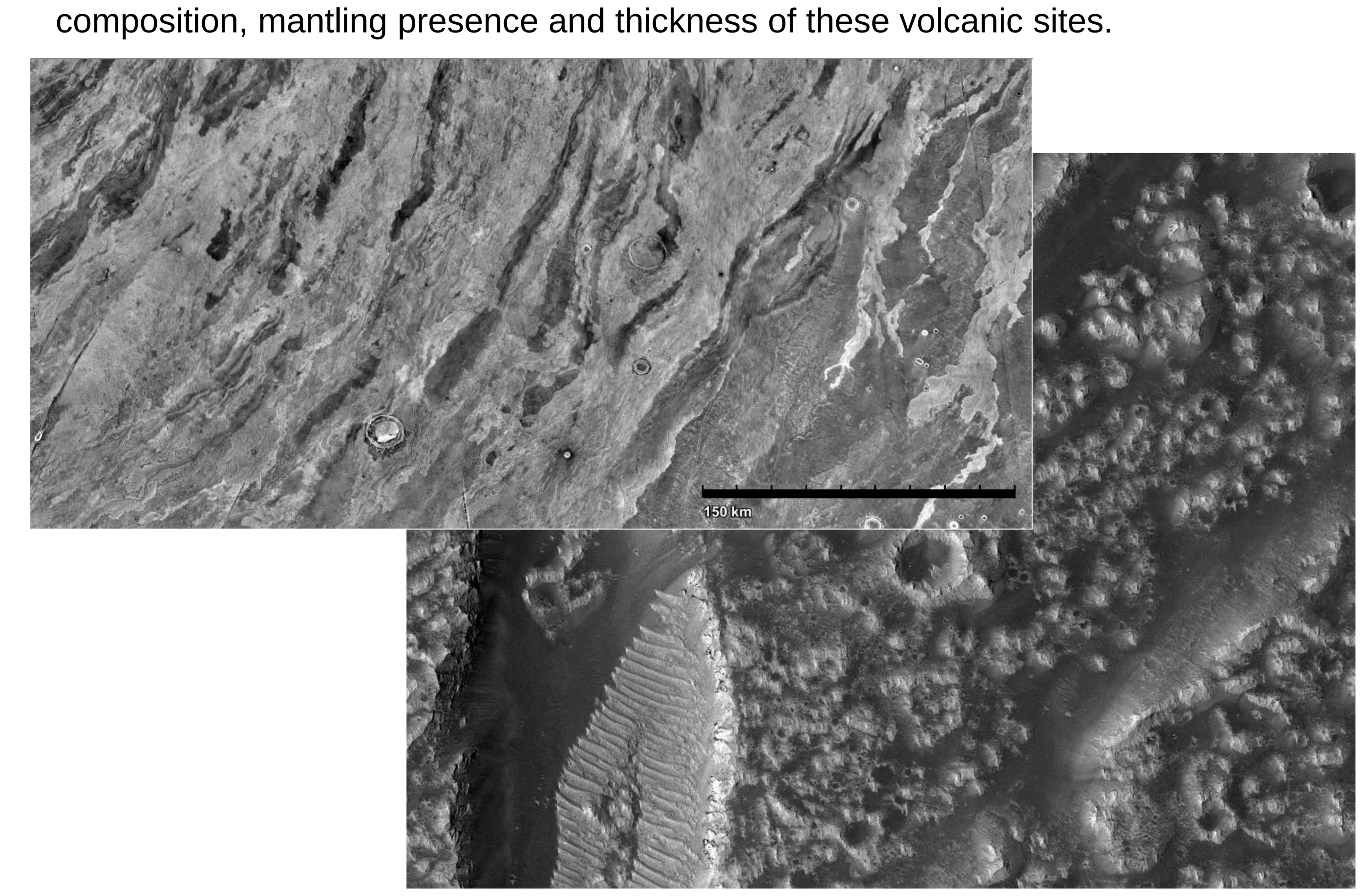

Fig. 6. Daytime THEMIS infrared mosaic of the southwestern Arsia Mons flow field [11]. HiRISE image (PSP_005704_1600) *(graben width = 800 m)*.

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 all the shadowing complexities in an image. Thus, a more robust mathematical operation is needed and a current project focuses on the difference between the shadowing values of incorrect and neighboring pixels.

Acknowledgements

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