HEIGHTS AND SLOPES ON MARS NORTH POLAR SCARPS USING HIRISE POINT-TO-POINT STEREO MEASUREMENTS.

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Abstract: Given the challenge and scientific importance of measuring vertical elevation distances and slopes in high-relief environments over 100s m- to ~1 km- scales (such as steep north polar scarps), we develop a technique to make such measurements that yields results more accurate than MOLA (in these situations) yet is not as complex and resource-intensive as producing a full scale DEM. The technique yields height and slope between two given points within a stereo pair of images. Estimates of errors and examples of results are given.

Introduction: The High Resolution Imaging Science Experiment on Mars Reconnaissance Orbiter has recently completed its second season of observation of Mars' north polar region [1]. Among other accomplishments, HiRISE has imaged polar layered deposits in unprecedented detail and shown steep polar scarps to be geologically dynamic environments [2-4].

Steep scarps (found around the perimeter of the north polar topographic dome and Chasma Boreale, as opposed to gentler interior polar troughs) generally include the best sections through the two main types of layered deposits: the classic polar layered deposits of ice with varying dust content, and the underlying "basal unit" composed of alternating bright, resistant, likely ice-rich beds and dark, sandy, relatively easily eroded dark layers [3,6]. While some of the questions raised in pre-MRO descriptions of the basal unit [7-9] have been cleared, the basal unit remains complex. Much of the irregular, discontinuous, and pinching-out behavior of bright layers can be seen to likely result from highly contrasting erosional styles of bright and dark layers, intermittent cover by loose dark material, and greatly varying amounts of scarpwards erosion along the exposed section (forming alcoves where layers recede towards the cliff face and promontories where the layers extend away from the cliff face) [3,6]. Large-scale bright layers are seen to be relatively parallel and continuous, although some evidence for possible gentle undulations exists. This complex expression complicates interpretation of layering. In addition, high-resolution imaging now allows us to identify specific features for which dimensional measurements would advance our understanding of the stratigraphy and erosional processes. Examples include layer thicknesses, from which relative fractions of bright and dark materials in the basal unit may be estimated; vertical distribution of layers, from which regular frequencies or cycles of deposition may be identified; and slopes of exposures or secondarily emplaced material, from which dynamic aspects of currently active mass-wasting processes can be described [2-4].

Current MOLA-derived topographic data is insufficient for such studies, especially in terrain of high-frequency relief. With a shot spacing of ~300-400 m, a spot size of ~150 m, and interpolation of combined measurements to 512 pixels per degree (~110 m per pixel), neither MOLA profiles or gridded products are for topographic studies on the scale of $\leq$ 100 m [10].

Methods: There are three main ways in which HiRISE image data can be used to gain relief information for a scene.

Anaglyphs are image products in which a "stereo pair" of images taken from different viewing angles are projected in identical fashion and then viewed in red and blue channels of an RGB image. Anaglyphs spectacularly display how differential erosion has shaped steep scarp exposures, and relative relief and slope information help make sense of otherwise confusing stratigraphy as mentioned above. While extremely helpful, anaglyphs still leave open questions such as: how high are certain scarp sections? how thick are layers (packages), and what are the slopes involved?. The most thorough topographic analysis requires construction of a full digital elevation model, or DEM [11]. This process is very time and computer intensive, and hence production is limited. The one DEM in polar region so far is in a polar trough [12]

The third way to glean relief information gives the height and horizontal distance between a chosen pair of points (say, points A and B) using a pair of stereo images (images 1 and 2) along with known spacecraft observation parameters and the relative pixel locations of the points in each image. Our current method balances precision with simplicity of function. The main parameters involved are emission angle (the angle between the normal to the local surface and a line to the spacecraft) and pixel scale (distance covered by an individual pixel) in each image. Sensitivity of this calculation to the input parameters has been preliminarily assessed. Over distances of several thousand pixels, the resulting height difference between two points is minimally sensitive to perturbations of the emission angle on the scale of .01 degrees, giving variations of height measurements on the order of $\pm$ .1%, and moderately sensitive to perturbations of the pixel scale on the scale of .0001 m/pxl, giving variations of height measurements on the order of ± 1-10%. While a scale difference of 0.1 mm/pxl would seem small, the error accumulates over the number of pixels between the two points. The cause of the spread in height variations and possible effects of distance and relative relief will be further quantified.

There are two different ways in which the emission angle and pixel scale may not be accurately captured in these calculations. One is the nominal value at each surface point. The emission angle is dependent on the surface-point location, the sub-spacecraft location, and the spacecraft altitude. The pixel scale is dependent on the slant distance from the surface point to the spacecraft (and the constant instantaneous field of view of one pixel, 10^-6 radians). To be most accurate, both of these should take into account the local elevation of the surface point (or local planetary radius), which is, of course, not exactly known. In HiRISE image processing, parameters such as emission angle and pixel scale are determined using smoothed MOLA gridded topography. Thus, the true accuracy of the emission angles and pixel scales is probably largely dependent on this topographic estimation, especially on high-relief terrain.

The second accuracy issue involves how to use or modify a nominal emission angle and pixel scale value for different point-to-point measurements within a given image pair. For purposes of these stereo calculations, the curvature of the planet and range of topography within a given image must be taken into account, and this includes variation over the area covered by a HiRISE image (typically ~6 x 12 km). This is especially true for high-relief images with large roll (off-nadir pointing) angles. The simplest approximation of emission angle and pixel scale for a given calculation would be to adopt the values of each at the center of each image (4 values per image pair) for all calculations made with those images. The most detailed approach would extract emission angles and pixel scales for each individual surface point used in a given calculation (8 values per calculation). This would employ the most calculation-specific values, although the values at each point within an image would still have to be averaged as our method assumes parallel emission lines from surface point to spacecraft. However, our goal was to attempt reasonably good measurements with a simple procedure. We are currently using a method between the two just mentioned. We take the emission angles and pixel scales at the center and both edges of each image, along the central image line (12 values per image pair), and interpolate among them over each image sample (or column). An average of the values at the sample coordinate of Points A and B is then used in that calculation. Thus, the number of values initially needed is minimal, but the values used are moderately tailored to each calculation. A variation on this approach is to derive the emission angle and pixel scale at the image edges from the center values and the known HiRISE total field of view, and then interpolate across all samples (4 values per image pair). While often producing reasonable estimates, the edge values obtained with this last method sometimes differ from the extracted values produced by HiRISE processing by more than the above error limits.

Results: As discussed hereto, this relatively simple method can provide useful information with minimal computation. Even a few point-to-point elevation differences within a study can be useful. A few examples are briefly given here.

The headscarp of Chasma Boreale is particularly rich with erosional activity within the basal unit, some forms of which are currently active [2]. Two measurements of basal-unit thickness, taken ~2.18 km apart yield 300 and 330 m. We find the basal unit here to be ~300-330 m thick, and maintain overall slopes of ~30° degrees. Within the basal unit, the lower reaches are frequently covered with depositional fans sloping 20-30°, and the upper reaches, with less debris cover, are typically 35-40°. This configuration is not only consistent with the model of debris from the PLD cascading over the basal unit and coming to rest on the lower slopes to form the debris fans, but is also consistent with the varying degrees of fluidization of debris on these fans. Within a section of particularly regular layering at the base of the basal unit, 4 layers make up ~ 50 m of section, yielding ~13 m per layer. While clearly not of the accuracy of a DEM, and with more inherent errors, this technique may allow elevation-difference estimates to the nearest ~100 m made with MOLA to be improved to estimates to the nearest ~10-20 m.

Integration of more such results will aid our ongoing work examining the stratigraphy and processes of steep polar scarps. As mentioned above, we also continue to explore the limits of this method and sources and magnitudes of error.

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