SURFACE ROUGHNESS DERIVED FROM GROUND AND ORBITAL IMAGERY: A CASE STUDY AT THE MSL LANDING SITE. F. J. Calef III[1] , R. Arvidson[2], R. Deen[1], K. Lewis[3], R. Sletten[4], R. Williams[5], J. Grotzinger[6], [1]Jet Propulsion Laboratory-Caltech, fcalef@jpl.nasa.gov, [2]Washionton University at St. Louis, arvidson@wunder.wustle.edu, [3]Princeton University, kwlewis@princeton.edu, [4]University of Washington, sletten@uw.edu, [5]Planetary Science Institute, williams@psi.edu, [6]California Institute of Technology, grotz@gps.caltech.edu.

Abstract: Surface roughness is one of the main discriminators when identifying unique terrain types and for assessing rover traverse capability on Mars using orbital imagery. We've derived a simple metric based on image texture in a High Resolution Imaging Science Experiment (HiRISE) orthophoto [from 1] to provide a qualitative and semi-quantitative assessment of vertical surface roughness on the decimeter scale. The maximum variation in digital number (DN) brightness over a 3x3 m (12x12 pixel) matrix, the scale-size of the Curiosity rover, segregated into four discrete categories using Natural Breaks (Jenks) from the image histogram provides a good match to mapped terrain types using the same HiRISE image. The surface roughness categories are calibrated using rocks heights measured in stereo engineering cameras onboard the Mars Science Laboratory (MSL) compared to the visible roughness values to specify the centimeter to meter vertical scale expected in each roughness pixel. Ground and orbital roughness metrics appear to correlate.

Hypothesis and Assumptions: Our hypothesis states that each terrain type has a unique surface roughness at a given length-scale that is synonymous with brightness variations (i.e. image texture) from high-frequency feature shading. We define surface roughness as the variation in vertical height between objects in a unit area. The main assumption in this technique is image DN value variations/texture are a direct response to shading from rocks or terrain microrelief over decimeter scales. Each unique terrain type is assumed to have a unique DN 'relief'; a neighborhood of similar textures constitutes a terrain type. We are less concerned about the roughness distribution (e.g. median roughness) in the matrix as we are with the maximum roughness (i.e. tallest rock) at the rover scale; thereby the larger the DN difference, the greater the feature height.

Methodology: Our input is a section of a 0.25 cm/pixel HiRISE orthophoto from [1] georeferenced to the MSL HiRISE basemap covering Bradbury Landing to Yellowknife Bay and MSL's traverse as of sol 440 to the geologic waypoint Darwin (Figure 1). The DN range is 8-bit (0-255); thereby we're using indexed brightness, not IOF or radiance. Other than the inherent radiometric correction in HiRISE image processing, we've performed no further photometric corrections.

We run the ArcGIS Block statistics tool from [2] with a rectangular matrix of 12 x 12 pixels (3x3 m) for the range (highest minus lowest DN) in the matrix. Each matrix is non-overlapping, i.e. a 'moving window' incremented by the matrix dimension. The resolution of the data is 3 m^2. The resulting brightness range raster is subdivided into four categories using a Natural Break (Jenks) classification method. We calibrated the first category break by comparing the range value to the height of a known feature, Jack Matijevic, a ~30 cm high pyramidal shaped rock approached on sols 43-45, to get the first category to represent feature roughness in the low decimeter range (~10 cm high or less). The other categories were quantified by comparing the range values to known scarp heights derived either from rover engineering cameras (i.e. NAVCAM) or HiRISE 1m/pixel elevation models. The other categories are: 'low roughness' at ~10-30 cm scale heights, 'moderate roughness' at ~30-50 cm, and 'high roughness' at ~>50 cm.

Caveats: This technique appears immune to broad scale slope brightness/darkening related to sun opposition and minor changes in elevation greater than the matrix size. The largest caveat comes from true albedo/tone differences among terrain units or rocks and the underlying terrain. One can imagine a case where a perfectly dark flat rock lying on a flat bright surface would cause a false positive result in assessing rock height. However, this case is not born out in the real world: shadow darkness is typically much darker than rock tone and the underlying surface and/or dust tends to attenuate most tonal differences. For defining terrain types, the sharp contrasts are a positive. Surface cracks filled with dark sand in a bright surface again could lead to inflating surface heights (to be discussed), but much like the aforementioned scenario, provide an excellent signal for identifying unique terrains. While there are specific cases where this technique doesn't work, they 'fail' towards assessing roughness over terrain uniqueness or vice versa. Therefore, when using this technique one needs to assess the resulting roughness values with these two properties in mind.

Results: As seen in Figure 1 and 2, the roughness parameter qualitatively correlates with terrain types as delineated in the MSL landing ellipse geology map [3]. The 'hummocky plains' terrain typified by subdued crater landforms and a few decimeter scale rocks is predominately categorized as 'smooth' with patches of 'low roughness' matching well with the pebbly lag seen in rover imagery near the landing site. Yellowknife Bay 'bedded fractured' terrain has more 'low roughness' values with some 'moderate' to 'high roughness' at the sub-meter scarps at Gillespie Lake, Point Lake, and ringing the drill sites. The fractured floor in Yellowknife Bay may look somewhat rougher than it actually is because of darker sand or soil filling fractures in the low-relief bright-toned plates within it. In these cases, it may be that we're seeing more terrain type differentiation than actual surface roughness variations. The 'cratered surface' terrain is somewhere in between the others with ~equal numbers of 'smooth' and 'low roughness' values with some crater rims being 'moderately' rough. 'Rugged' terrains like Twin Cairns Island, observed on sols 342-344, has one 'high roughness' pixel associated with meter scale boulders topping the east end of this ridge. A cursory examination of the actual rover traverse versus the roughness categories shows MSL stayed mostly on 'smooth' terrain types until it descended into Yellowknife Bay, but continued to traverse 'smooth' terrains on it's way towards geologic waypoint Darwin, and entered rougher terrain at Cooperstown.

Correlation with ground measurements: Ground measurements using engineering camera data within 1-3 m of the rover were used to quantify roughness from stereo images that can resolve down to a few mm. Using stereo Navigation (NAVCAM) and Hazard (HAZCAM) images, two roughness parameters were derived: relief in the arm workspace volume (max-min height) over a 6 cm area (from R. Deen) from HAZCAM and surface convexity (from K. Lewis) derived from the finite approximation of a Laplacian using the XYZ mesh from NAVCAM data:

$$\nabla^2 z \approx \frac{\partial^2 z}{\partial x_p^2} + \frac{\partial^2 z}{\partial y_p^2}$$

then calculating the percent area of that coverage. Trends of surface convexity and workspace relief match well with the orbital roughness (Figure 3) showing good qualitative correlation. More quantitative data from the rover traverse will help calibrate the orbital roughness.

Conclusions and Future Work: Terrain types, to first order, correlate with image texture variations in HiRISE. Calibrating the image texture variations to measured ground heights or rocks and scarps provides a useful metric to evaluate similar features throughout the image. Future work will look at phase angle affects and comparisons with other landing sites, like Mars Exploration Rover (MER) Opportunity.

References: [1] Golombek et al., (2012) *Space Science Review,* DOI:10.1007/s11214-012-9916-y. [2] Environmental Systems Research Institute, esri.com, [3] Grotzinger et al. (2013), *Science*, DOI: 10.1126/science.1242777.

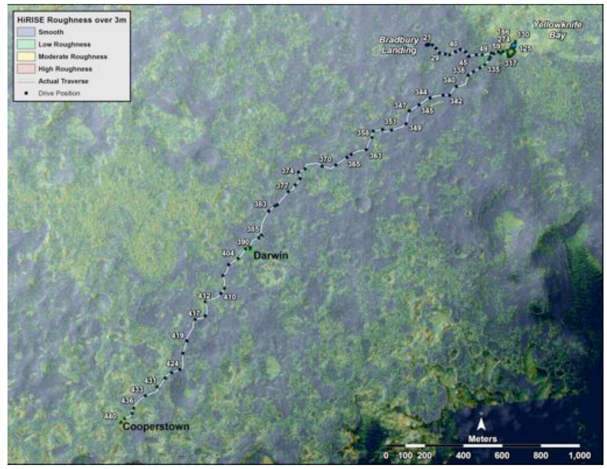

Figure 1: HiRISE Roughness from image texture.

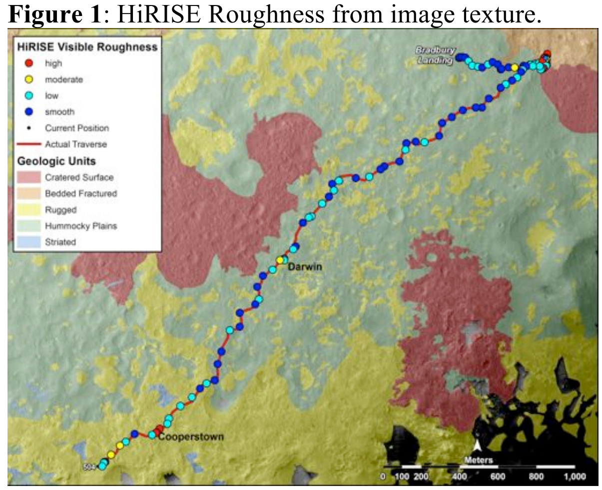

Figure 2: Terrain types near Bradbury Landing [3] and HiRISE roughness at each drive location (dots).

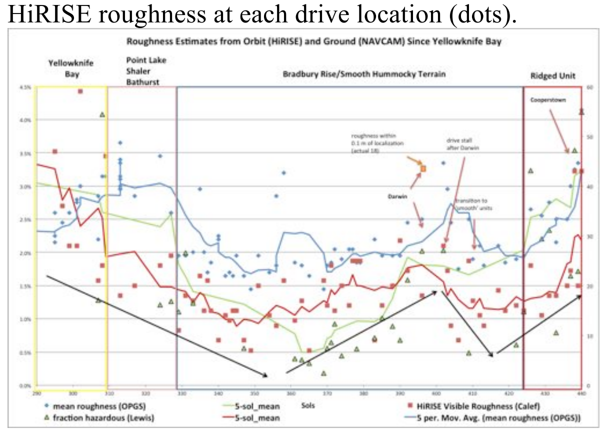

Figure 3: Comparison between orbital and ground roughness. Roughness trends between surface convexity (green triangles, K. Lewis), rover arm workspace (blue diamonds, R. Deen) and HiRISE roughness (red squares, F. Calef) appear correlative.