NEW DYNAMICALLY GENERATED COLOR-SHADED RELIEFS FOR NARROW ANGLE CAMERA DIGITAL TERRAIN MODELS. M. R. Henriksen, M. R. Manheim, M. S. Robinson, and the LROC Team, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (mhenriksen@ser.asu.edu).

Introduction: For each high-resolution digital terrain model (DTM) produced from the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) team from stereo images and archived on the LROC Planetary Data System (PDS) node (http://wms.lroc.asu.edu/lroc/rdr_product_select), a set of sub-products, including a color-shaded relief and a color slope map, is also generated and released [1]. Color-shaded reliefs are common visualizations of topographic data wherein hypsometric tints, or colors representing elevation, are combined with a grayscale shaded relief map. They provide an easily accessible and visually pleasing way to quickly understand and represent elevation data [2,3]. Color slope maps are similar to color-shaded reliefs, but color represents slope rather than elevation.

Color-shaded reliefs should provide as much information as possible about topographic features of importance while remaining both easily interpretable and accessible to those with color vision deficiency (CVD). There are two areas of concern with previously-published color products: First, the color ramps for both color-shaded relief and slope maps are rainbow color ramps, a style long known to be difficult to interpret for those with CVD (Figure 1) [4,5,6]. They are also perceptually nonlinear as the luminance varies randomly [5,6]. Second, the mapping of elevations to colors in the shaded relief maps is linear across the full elevation range. This strategy often works well, but in some cases leaves large areas of interest largely the same color, an inefficient use of the colors in the color ramp (Figure 2). We present new color ramps and methodology to address these issues.

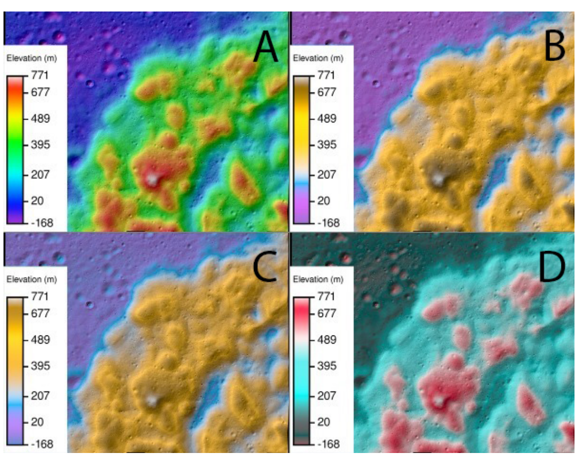

Figure 1: Rainbow color-shaded relief of the Apollo 16 landing site (NAC_DTM_APOLLO16) and the accompanying legend in *A)* common, *B)* protanopia *C)* deuteranopia and *D)* tritanopia vision simulations [8]. Also note how the luminance of yellow (~489 m elevation) creates an artificial contour in *A*. There is a similar effect in *C* and *D*.

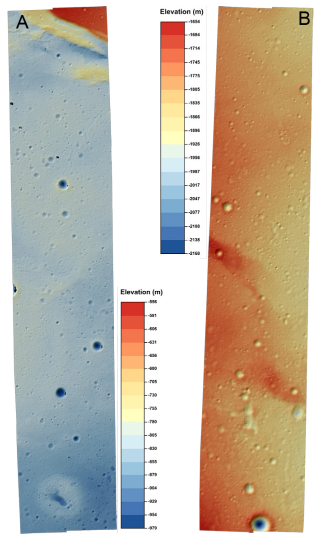

Figure 2: Continuous hypsometric tinting where colors are distributed evenly over the entire elevation range using the new color ramp for the DTMs *A)* NAC_DTM_CAUCHY and *B)* NAC_DTM_ARAGO2_1. Note how large areas appear relatively bland because the shades of color are not utilized optimally to show details in the DTM.

Color Ramp Selection: Conventional strategies for choosing colors include basing color ramps on humidity, vegetation, or natural color of the terrain [3,7]. These strategies are inappropriate for the Moon, which has no vegetation or liquid water and whose gray terrain has no significant hue to base a color ramp on. Thus, our primary goal for the color ramp was to maximize the number of distinct shades while accommodating CVD users.

We selected a diverging color ramp containing 17 shades starting at dark blue (lowest elevation or slope), passing through pale yellow, and ending in bright red (Figure 3). It was derived from a set of 11 shades provided on colorbrewer2.org [5], extrapolated until it became difficult for both users with CVD and without CVD to distinguish between the shades. The final palette was checked for the three most common types of CVD using the CVSimulator app for Android and iPhone [8]. The color ramp is also perceptually linear, with the shades decreasing in luminance towards the extremes of the color ramp. This linearity can be seen in the grayscale version of the color ramp (Figure 3). A diverging color ramp, rather than a sequential color ramp, was chosen to maximize the number of shades possible, allowing for more detail in the color-shaded relief, especially in discrete applications.

Color Mapping for Color-Shaded Reliefs: Continuous hypsometric tinting with color shifts at equal intervals works well for some regional DTMs, and is intuitively understandable. In some cases, however, much of the important detail is lost due to a majority of the colors being applied in regions that are not the primary focus (Figure 2). As an alternative, we have implemented the algorithm presented in [9], which creates a nonlinear stretch that increases the number of colors in ranges with many pixels (flat regions), decreases the number of colors where there are large value ranges with few pixels (steep slopes and small, deep craters), and keeps values that are very different from having too-similar colors. This increases visible detail over most of the image (compare Figures 2B, 4A).

To make these unequal bin sizes more interpretable (in contrast to those in Figure 1), the calculated break points for each bin are rounded to the nearest 1, 5, 10, 25, 50, or 100 m, depending on which scale is needed to accommodate the smallest difference between the break points. This rounding scheme could be adapted to include larger values if deemed necessary for the elevation range of the DTM. A lookup table compatible for use with *gdaldem color-relief* is then produced from this list of break points [10]. Examples of the new color-shaded reliefs can be seen in Figure 4.

Due to the unequal bin sizes, this new color ramp is applied discretely, instead of continuously, to facilitate accurate interpretation of elevations. An accompanying color scale bar with increments that correspond to the bin sizes in the DTM is then produced from the color lookup table using ImageMagick (Figures 3, 4) [11].

Summary and Future Work: Color-shaded reliefs and slope maps for new DTMs and for the 456 DTMS currently archived in the LROC PDS will be provided in the June 2019 PDS release.

Future work will involve determining the best CVD accessible color ramp break points for slope maps. We will also be refining bin size selection for the discrete color-shaded relief maps to minimize the variation in bin sizes while retaining important detail, reproducing the “intuitively understandable” characteristic of equal interval color mapping as much as possible.

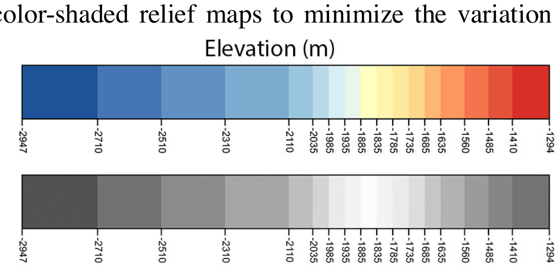

Figure 3: An example of a color legend from the new color ramp in both full color (top) and in grayscale (bottom). Note that both versions are perceptually linear, with the color version proceeding from cool to warm colors and both versions increasing in luminance towards the center of the diverging color ramp.

There is one type of scenario where this uneven bin algorithm is not optimal: when the feature of interest is both a small portion of the overall DTM and a large portion of the overall elevation range (e.g. a DTM of a 10 km crater on an otherwise bland mare surface), equal bin sizes display the topography better than the unequal bin sizes. Therefore future refinements include automatically determining what bin distribution algorithm to use.

References: [1] Henriksen, M. R. et al. (2017) *Icarus, 283,* 122-137. [2] Jenny, B. and Hurni, L. (2006) *Cartogr. J.* 43(3), 198-207. [3] Patterson, T. and Kelso N. V. (2004) *Cartogr. Perspect., 47,* 28-55. [4] Shusterman, M. L. (2019) *LPSC L,* Abstract #2670. [5] Brewer, C. A. et al. (2003) *Cartogr. Geogr. Inf. Sc. 30(1)*, 5-32. [6] Borland, D. and Taylor II, R. M. (2007) *IEEE Comput. Graph. 27(2)*, 14-17. [7] Patterson, T. and Jenny, B. (2011) *Cartogr. Perspect. 69*, 31-46. [8] https://asada.website/cvsimulator/e. [9] Eisemann, M., et al. (2011) *Intl. Wkshp. on Visual Analytics.* [10] GDAL/OGR Contributors (2018). http://gdal.org. [11] https://www.imagemagick.org/.

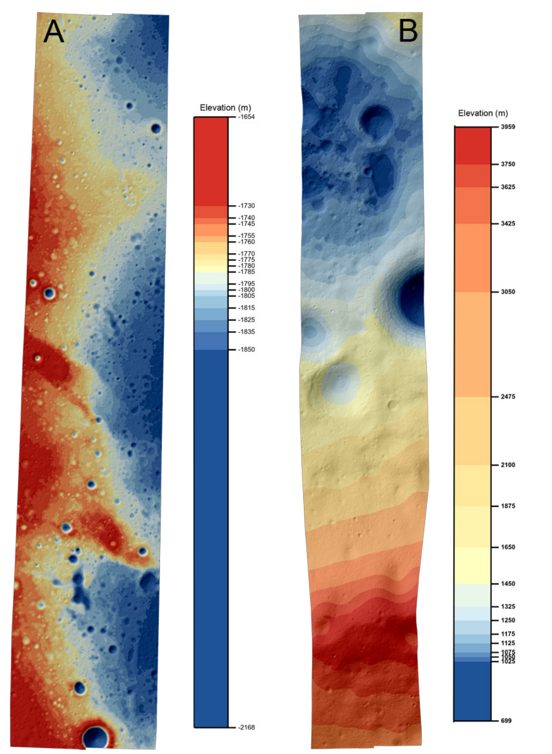

Figure 4: Examples of the new dynamically generated color-shaded relief maps and scale bars. A) NAC_DTM_ARAGO2_1; this uses the same DTM as Fig. 2B above. B) NAC_DTM_HPONDS11.