The NAGI Fusion Method: A New Technique to Integrate Color and Grayscale Raster Layers

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ABSTRACT

Integrating a color raster data layer, such as elevation tints, with a grayscale raster layer, such as a hillshade, is an important visualization function in cartography, remote sensing, and geographic information systems (GIS). A number of methods have traditionally been used to integrate these types of rasters. In one approach, the input rasters are combined into a new output raster by transforming the original data using, for example, an intensity, hue, saturation (IHS) transformation. Another approach involves the use of layer transparency, in which one raster is transparently draped over the other. However, both these approaches distort the original colors, and layer transparency has the added problem that gradient detail in the hillshaded raster is suppressed. The optimal solution would be to integrate the color and grayscale rasters while retaining the fidelity of the original data.

In this paper, we introduce a new technique, called the NAGI (No Alteration of Gradient or Intensity) fusion method, to integrate color and grayscale rasters in a manner that preserves the original colors from the color raster while retaining the apparent gradient from the grayscale raster. The NAGI fusion method does not require any code or programming, and no software extensions are required. It can be modified easily to suit the characteristics of the input rasters or the requirements for the output raster. It can be implemented using raster processing techniques introduced in ArcGIS10.0; however, the concepts described can be adapted for use with most cartography, GIS, or remote-sensing software.

The method was tested with a variety of datasets, with rasters of varying resolutions, at a range of spatial extents, with diverse types of thematic content, and with different ArcGIS rendering methods, thus demonstrating the versatility and applicability of the NAGI fusion method

Keywords

cartography – DEM – elevation tint – gamma stretch – gradient – hillshade – intensity – linear stretch – NAGI fusion method – pan sharpening – simple mean

INTRODUCTION

Viljoen et al. (2006) describe two primary reasons for integrating related color and grayscale rasters. One is to enhance the visualization of related datasets that are displayed simultaneously. For example, an elevation tint scheme in which ranges of elevation are assigned different colors in a realistic sequence is often visualized along with a hillshaded digital elevation model (DEM) of the same area. This allows the map reader to see the elevation and the terrain form at the same time. The other reason is to visualize the relationship between two different but related datasets. For example, displaying slope and aspect simultaneously may allow map readers to see the relationships between these two characteristics of a surface. In this case, aspect can be visualized as colors whose hue relates to the angle and slope can be visualized in gray tones with darker tones denoting higher slope values.

In both these examples, one raster is rendered as a color image and the other as a grayscale image. The challenge is to visualize the two rasters using a method that retains the original colors and gray tones. Lack of color retention is a problem because the colors often become duller and either lighter or darker, depending on the method used, when the two rasters are integrated. This can have an impact on the intended message because the visual result is not as the map maker intended. Lack of gray tone retention is a problem because the variation in light and dark, which produces the impression of gradient (steepness of slopes) in the terrain, is often subdued when the two rasters are integrated. This results in the hillshade having less apparent gradient.

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In addition, both of these problems create a challenge for the mapmaker because the output is not easy to predict, especially when both problems are combined

TRADITIONAL METHODS FOR INTEGRATING COLOR AND GRAYSCALE RASTERS

A variety of methods have been used to combine color rasters with grayscale rasters. Those methods are discussed and evaluated in this section.

Layer Transparency

Most GIS and remote-sensing software packages have a layer transparency option that can be used to visualize two rasters by simply applying transparency to the layer displayed on top. For example, it is quite common to find maps in which a hillshaded surface is overlaid with a transparently colored thematic layer. The thematic layer could be soils, land use, vegetation, or other types of phenomena, but it is often elevation. In Figure 1a, an elevation tint is used to show greens in the low-lying valleys which transition smoothly to light browns at the lower rocky elevations, to darker browns in the higher treeless areas and finally to white on the snowcapped peaks. The elevation tint can be transparently overlaid on a grayscale hillshade (Figure 1b) to produce a map that displays both the elevation tint and hillshade simultaneously (Figure 1c).

With the layer transparency method, the hillshade is normally displayed as the bottom layer, and the elevation tint is displayed as the top layer with an assigned level of transparency. The advantages are that it does not involve any pixel-by-pixel processing and the results are instantaneous. However, the result is an image in which the colors appear less saturated (i.e., less intense). Additionally, details in the underlying grayscale raster are suppressed thus reducing the apparent gradient. The final output (Figure 1c) has faded colors and diminished terrain gradient.Understanding the limitations of this method at the outset, it is sometimes helpful to use colors that are highly saturated to begin with because they will become less intense (Figure 2a), and a vertically exaggerated representation of the hillshade, knowing that the apparent gradient will be suppressed (Figure 2b). Then the trick is to find the best level of transparency, given that the colors and details are compromised depending on the amount of transparency. Decreasing the layer transparency allows the saturation of colors to be retained (Figure 2c), but the underlying terrain does not appear to have much variation in gradient. Increasing the layer transparency further compromises the intensity of colors; however, the underlying grayscale hillshade does not appear as flat (Figure 2d and e).

Clearly, the layer transparency method has limitations. It is difficult to guess what vertical exaggeration to use at the outset, and it is never possible to create a result with saturated colors. The result compromises the input rasters so that the colors are faded and the terrain is flattened.

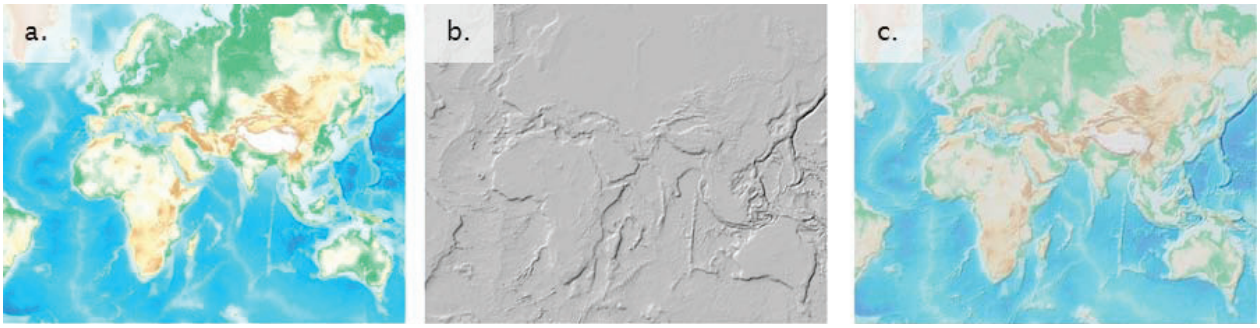

Figure 1. (a) Elevation Tint of the DEM of an Area Centered on Pakistan, (b) Hillshade of the DEM, (c) Elevation Tint Transparently Overlaid on the Hillshade.

Panchromatic Sharpening

Another commonly used technique for combining color rasters with grayscale rasters in GIS and remote sensing is panchromatic sharpening, more commonly known as pan sharpening. Pan sharpening is also known as multisensor data fusion, image fusion, image integration, and resolution merging (Yuhendra et al. 2011). Pan sharpening fuses the spatial properties of panchromatic (grayscale) imagery with the spectral information of multispectral (color) imagery. It is often used to combine higher-resolution panchromatic

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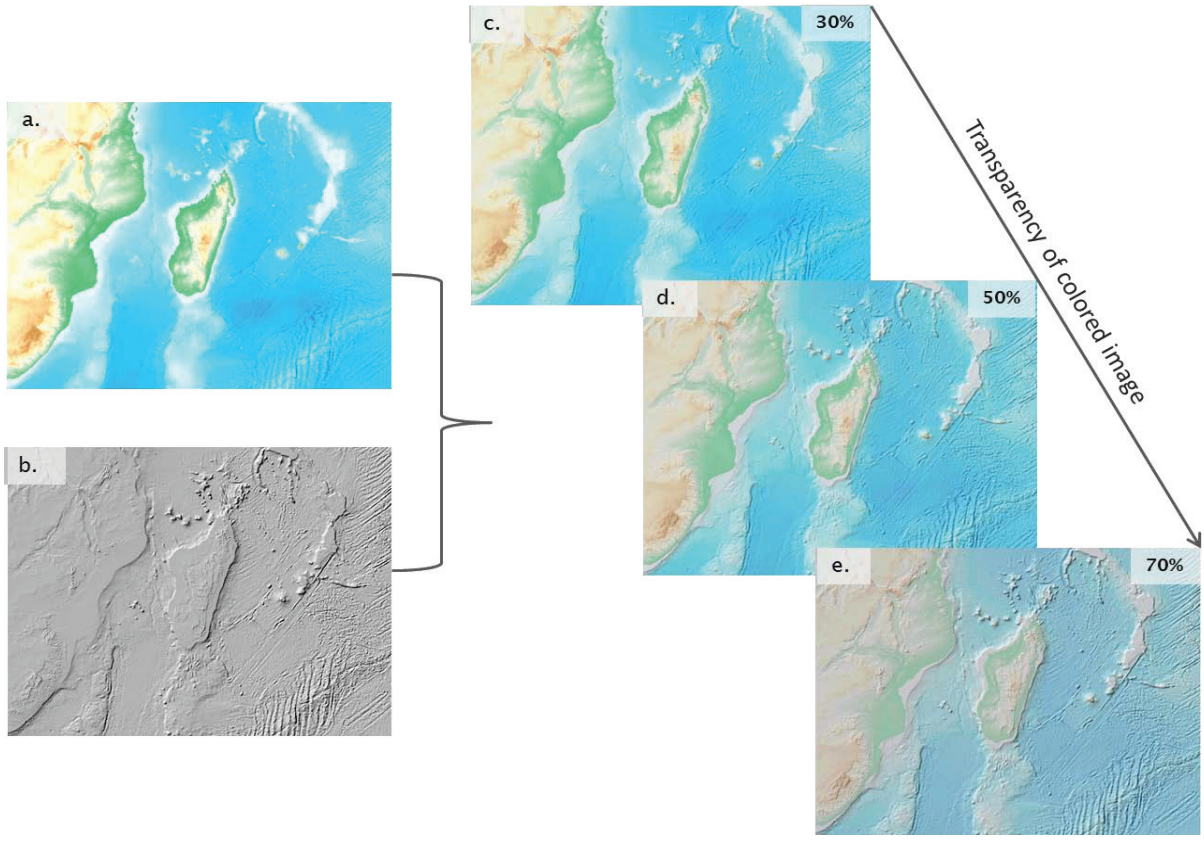

Figure 2. (a) Elevation Tint of the DEM of an Area around Madagascar, (b) Hillshade of the DEM, (c) Elevation Tint Overlaid on the Hillshade Using 30% Transparency, (d) 50% Transparency, and (e) 70% Transparency.

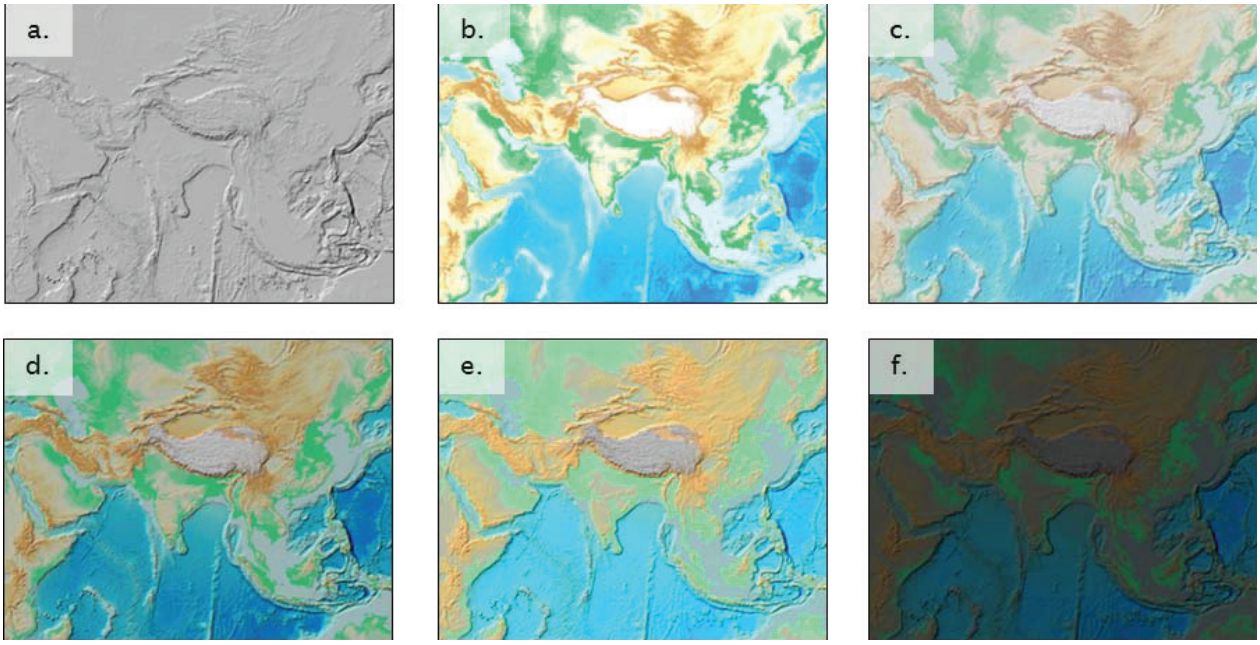

Figure 3. (a) Hillshade of the DEM of an Area Centered on India, (b) Elevation Tint of the DEM, (c) Elevation Tint Overlaid on the Hillshade Using 50 Percent Transparency, (d) IHS Fusion Method Output, (e) Esri Fusion Method Output, and (f) Brovey Fusion Method Output.

images with lower-resolution multispectral images to produce higher-resolution color images (Klonus et al. 2008). This technique can also be used to integrate other grayscale and color rasters, such as hillshades and elevation tints.

A variety of pan sharpening methods are available to fuse grayscale and color rasters (Son, et al. 2005; Chikr El-Mezouar 2011; International Institute for Aerospace Survey and Earth Sciences 2001). Here we describe three that are available in Esri's ArcGIS software. Each of these methods allows optional weighting for the three bands allowing the user to give multispectral bands varying levels of influence on the output.

The IHS fusion method converts the color image from the red, green, blue (RGB) color model to the IHS color model. It replaces the intensity values with those obtained from the grayscale raster. Then the modified IHS color values are transformed back to the RGB color model in the output raster (Esri 2012a).

The proprietary Esri fusion method "uses a weighted average and, optionally, the near-infrared band to create the pan sharpened output image. The result of the weighted average is used to create an adjustment value that is then used in calculating the output values" in the resulting image (Figure 3e; Esri 2012a). Further, "the weights for the multispectral bands depend on the overlap of the spectral sensitivity curves of the multispectral bands with the panchromatic band. The weights are relative and will be normalized when they are used. The multispectral band with the largest overlap with the panchromatic band should get the largest weight. A multispectral band that does not overlap at all with the panchromatic band should get a weight of 0. By changing the near-infrared weight value, the green output can be made more or less vibrant."

The Brovey fusion method (Figure 3f) was developed to increase visual contrast in the very dark and very light areas of an image. "It uses a method that multiplies each resampled, multispectral pixel by the ratio of the corresponding panchromatic pixel intensity to the sum of all the multispectral intensities. It assumes that the spectral range spanned by the panchromatic image is the same as that covered by the multispectral channels" (Figure 3f; Esri 2012a).

When the results of these pan-sharpening fusion methods are compared with the result of layer transparency (Figure 3), it is clear that none provides an optimal solution due to alteration of the colors and suppression of apparent gradient.

Other solutions have also been suggested. For example, Viljoen et al. (2006) developed SatValMod, a Visual Basic for Applications (VBA) extension to ArcGIS 9.3, to address this problem. They used a method that transforms the RGB color coordinates to the hue, saturation, value (HSV) color model. Then the saturation and value color components are modified and combined with the original hue when the colors are transformed back to the RGB color model. This solution has not been updated for ArcGIS 10.x and was therefore not tested in this study.

STEPS IN THE NAGI FUSION METHOD

The NAGI fusion method overcomes the limitations of the layer transparency and pan-sharpening approaches discussed earlier. This method involves the serial use of three standard processes that are available in many GIS or remote-sensing software platforms (Nagi 2012b). It provides a solution that does not require programming or the use of a software extension. Parameters in the processes can be modified to meet the requirements of the desired output or characteristics in the input rasters. It can be implemented in ArcGIS using functions for mosaic datasets or image analysis, and it can also be used with various rendering methods, including color ramps and color map files.

The three steps in the NAGI fusion method are (1) pan sharpening using the simple mean method, (2) application of a gamma stretch, and (3) application of a minimum-maximum linear stretch. The inputs required are (1) a single-band panchromatic image or raster, and (2) a multiband RGB multispectral image. Grayscale and color rasters in other formats can be converted to meet these requirements. The multispectral raster could be any thematic layer, such as land cover/land use, soils, or geology; in the example described below, it is an elevation tint of the DEM. The grayscale raster could be any related raster; in the example below, it is the hillshaded DEM.

Detailed instructions for some raster conversions and for the steps in the NAGI fusion method implemented in ArcGIS are provided in Nagi (2012a, 2012c). Here we provide general instructions for fusing an elevation tint and a hillshade using this method.

Simple Mean Pan Sharpening

The first step in the NAGI fusion method is to create a pan-sharpened image using the simple mean method to fuse the panchromatic and multispectral images.

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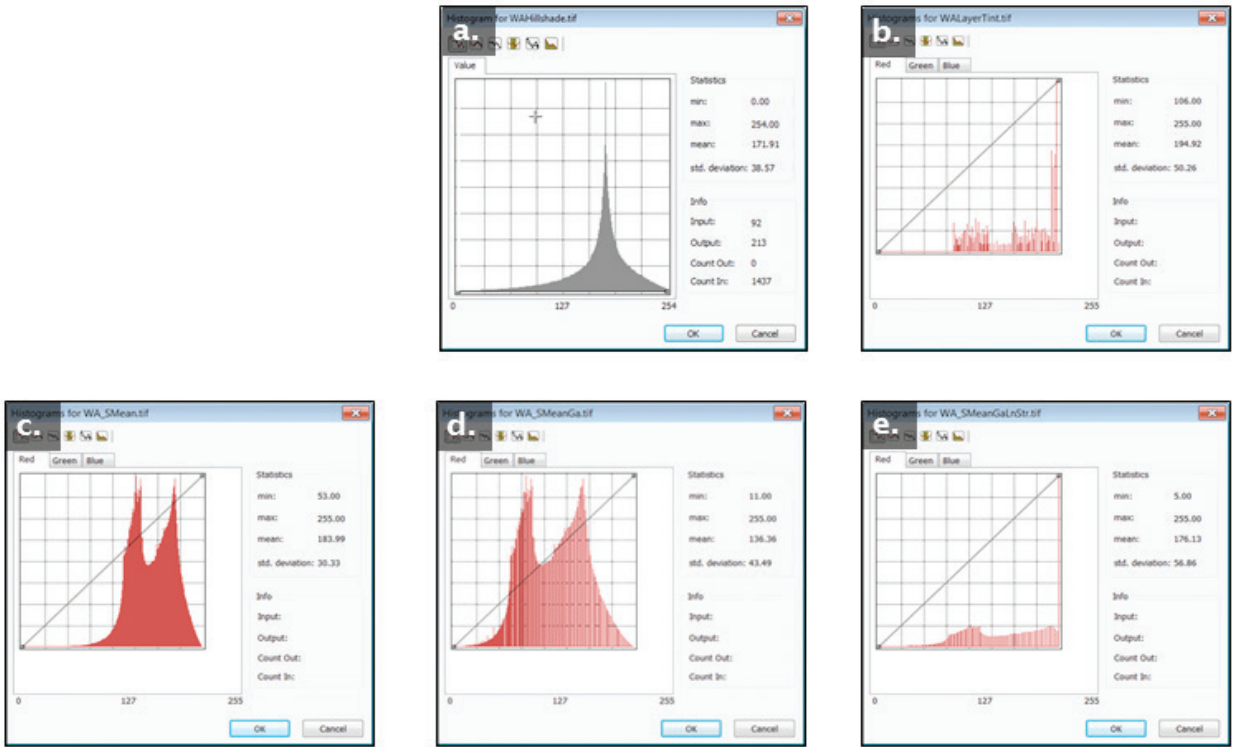

Figure 4. Histograms for the (a) Hillshade, (b) Red Band of Multispectral RGB Image, (c) Red Band-Hillshade Combination after Pan Sharpening Using a Simple Mean, (d) Output from the Simple Mean Pan-Sharpening Image Modified Using a Gamma Stretch of 0.5, and (e) Output from the Gamma-Stretched Image Modified Using a Minimum-Maximum Linear Stretch with Values of 10 and 220.

The pixel value for the panchromatic image (i.e., the hillshade) is added to pixel values for each of the three bands of the multispectral (RGB) image (i.e., created from the color raster), and then the mean is calculated for the combination of the panchromatic image and multispectral band pixel values.The simple mean function transforms the three bands of the input image by applying a simple mean averaging equation to each of the output bands using the default equation (Esri 2012a):

$$Red_{out} = 0.5 * (Red_{in} + Pan_{in})$$

$$Green_{out} = 0.5 * (Green_{in} + Pan_{in})$$

$$Blue_{out} = 0.5 * (Blue_{in} + Pan_{in})$$

where Red_{in}, $Green_{in}$, and $Blue_{in}$ are the RGB bands of the input multispectral image, and Pan_{in} is the panchromatic image.

Figure 4 illustrates the NAGI fusion method steps using histograms of the distribution of pixel values in the input and output images. Pixel values range from 0 to 255. In a panchromatic image, pixel values of 0 are shown as black, and pixels with a value of 255 are shown as white. For the hillshade (Figure 4a) the values are usually concentrated around a mean that is between 170 and 180. Figure 4b is a histogram of the red band of the multispectral RGB image. Because this figure is for illustration purposes only, histograms for the blue and green bands are omitted for clarity. Figures 4c, 4d, and 4e are histograms of the outputs of the three steps in the NAGI fusion method for the red band of the multispectral image as it is fused with the hillshade.

The result of the simple mean panchromatic sharpening is an image that has more contrast and is lightened up because there are more pixels within a greater range (the bimodal red area in Figure 4c) and more values higher than the mean of the hillshade.

Gamma Stretch

The next step in the NAGI fusion method is to modify the outputs for each of the bands in the image using a gamma stretch. A gamma stretch is a non-linear stretch that affects the degree of contrast between the mid-level gray values of a raster without affecting the black or white values. A gamma stretch alters the overall brightness of a raster (Esri 2012b). Gamma values lower than 1 decrease the contrast in the darker areas and increase the contrast in the lighter areas. This dark-

ens the image without saturating the dark or light areas of the image, and it helps bring out details in lighter features, such as illuminated hill slopes. Conversely, gamma values greater than 1 increase the contrast in darker areas, lighten the image, and bring out details in the darker areas.

Gamma values lower than 1 (e.g., 0.5) are used in the NAGI fusion method.

The result of the gamma stretch is a darker image that has increased contrast in the lighter areas because the pixel values are shifted toward the lower (darker) end of the histogram and middle range of values are stretched over a greater range (Figure 4d).

Minimum-Maximum Linear Stretch

The final step in the NAGI fusion method involves applying a minimum-maximum stretch to the results obtained from the gamma stretch. A linear stretch linearly expands the range of the input image values to fill the total possible range, 0-255 (Lillesand et al. 1994). A linear stretch is used to distribute the input pixel values across the total possible 256 values, from 0 to 255 (Esri 2012b).

A linear stretch can be applied in a number of ways. One is a minimum-maximum stretch in which pixels below a threshold value at the low end of the original histogram are assigned to black (a pixel value of 0), and pixels above a threshold value at the high end of the original histogram are assigned to white (a pixel value of 255). The remaining pixel values are distributed linearly between these thresholds. Features in the image are easier to distinguish because the pixel values are distributed across the entire histogram range, thus brightening and increasing the contrast of the image (Esri 2012b).

Minimum-maximum values of 10 and 220 were used for some of the tests we conducted with NAGI fusion method. The result of the minimum-maximum stretch is an image that is lightened up and has more contrast because the relatively small number of pixels with values below 10 are shifted to 0 and shown in black, and the relatively larger number of pixels with values above 220 are shifted to 255 and shown in white; the remaining pixels are stretched between 1 and 254 causing the majority of values to shift to higher numbers because the maximum stretch value was set farther from the maximum value possible (Figure 4e).

RESULTS

After following these steps, the final output will have colors with nearly the same saturation as the input color raster, and gradient variation that is nearly the same as in the input hillshade raster. The results of testing this method with a variety of color and grayscale raster combinations are discussed below.

In the first test, ETOPO1 1 arc-minute (~2-kilometer resolution) global elevation / bathymetry data were used to create a global hillshade and an associated elevation tint. The elevation tint was displayed using a color map file. Color map files contain a set of pixel values (e.g., elevation values) and the red, green, and blue components of a color defined in

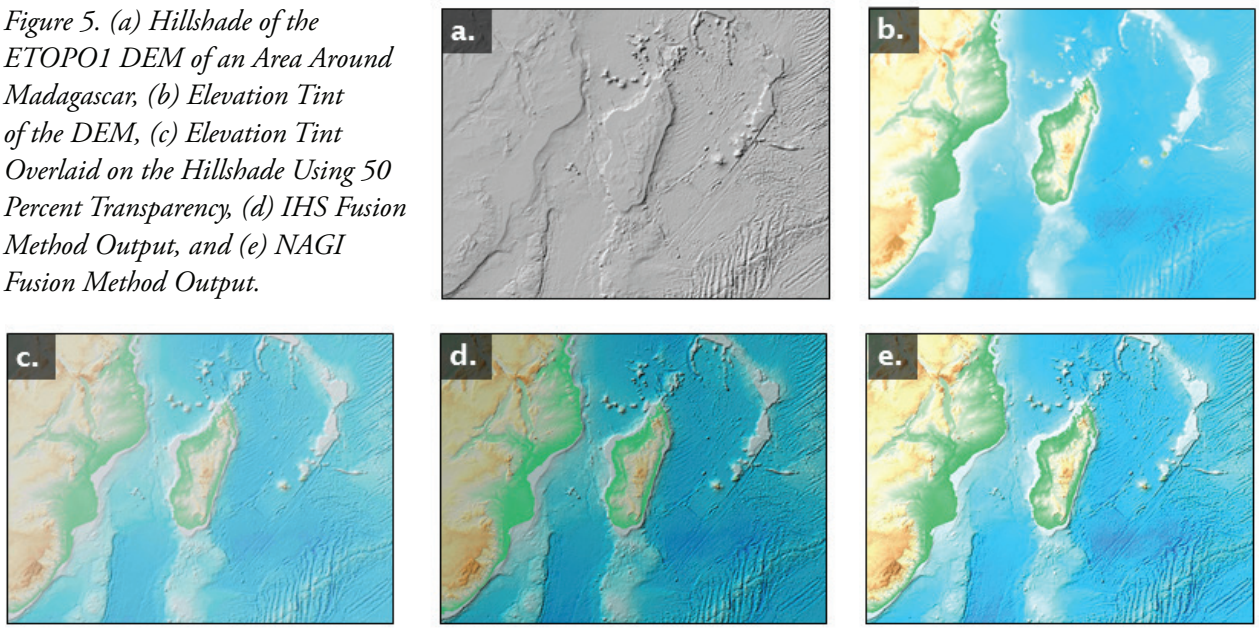

Figure 5. (a) Hillshade of the ETOPO1 DEM of an Area Around Madagascar, (b) Elevation Tint of the DEM, (c) Elevation Tint Overlaid on the Hillshade Using 50 Percent Transparency, (d) IHS Fusion Method Output, and (e) NAGI Fusion Method Output.

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RGB color space that is used to display the pixel values. Smoother gradation between colors is obtained when more pixel values are included in the color map file and there is less variation between adjacent colors. Below is an portion of the contents of a color map file, where the first column is the pixel value, and the second, third, and fourth columns define the red, green, and blue components of the RGB colors, respectively:

1	255	0	0
2	100	0	100
3	50	200	10
4	45	60	100

Figure 5 shows the results of the NAGI fusion method compared to those obtained using the layer transparency and IHS pan-sharpening fusion methods for an area centered on Madagascar.

In the second test, GTOPO30 30 arc-second (~1-kilometer resolution) data were used to create a hillshade and an associated elevation tint for the state of Washington in the United States. In this case, the elevation tint was displayed using a color ramp rather than a color map file. Whereas a color map file specifies the exact RGB color for each pixel value, a color ramp is a symbol selected from a style that is applied to a range of values. The color ramp has gradually varying colors that, when applied to the raster, are used to display the range of pixel values. With this method of symbolization, there is no exact assignment of a color to a pixel value; rather, the range of pixel values is rendered using the range of colors in the ramp.

Figure 6 shows the results of the NAGI fusion method compared to those obtained using the layer transparency and IHS pan-sharpening fusion methods for northwestern Washington State.

In the third test, a rasterized color geology map was combined with a 30-meter hillshade of an area near Mount Baker in northwestern Washington State. Figure 7 shows the results of the NAGI fusion method compared to those obtained using the layer transparency and IHS pan-sharpening fusion methods.

In all of the tests, the NAGI fusion method produced potentially superior results than either the layer transparency or IHS pan-sharpening fusion methods on the basis that there was no alteration of the saturation in color, and apparent gradient variation was retained.

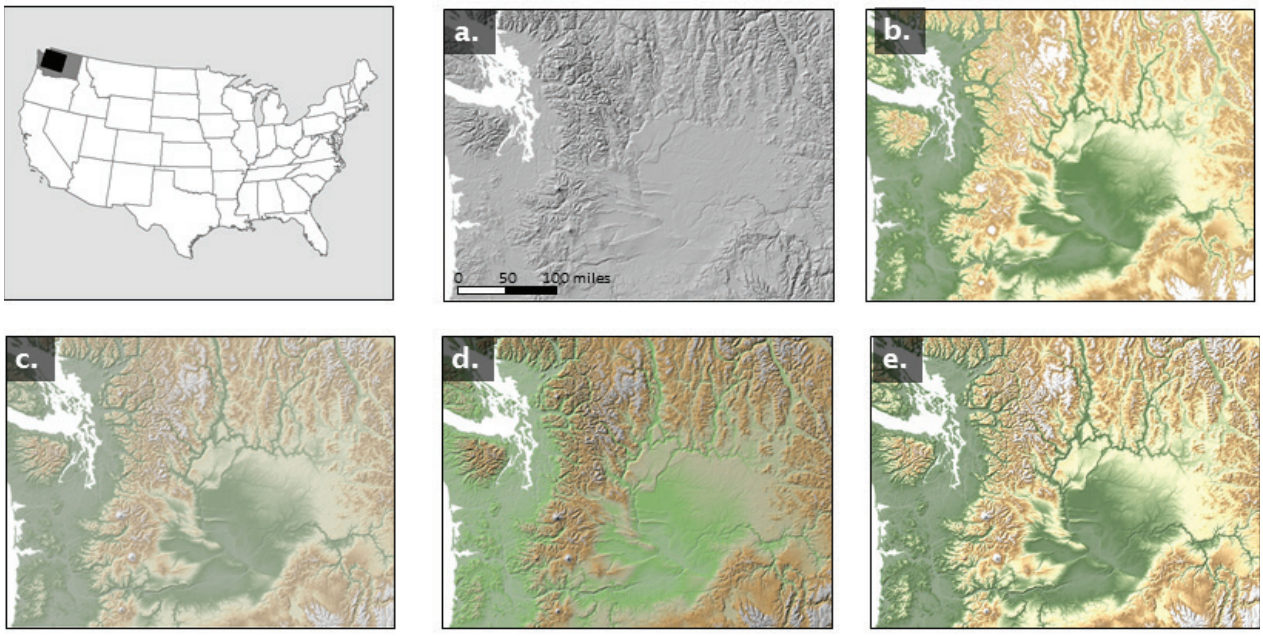

Figure 6. (a) Hillshade of the GTOPO 30 DEM of Northwestern Washington State, (b) Elevation Tint of the DEM, (c) Elevation Tint Overlaid on the Hillshade Using 50 Percent Transparency, (d) IHS Fusion Method Output, and (e) NAGI Fusion Method Output.

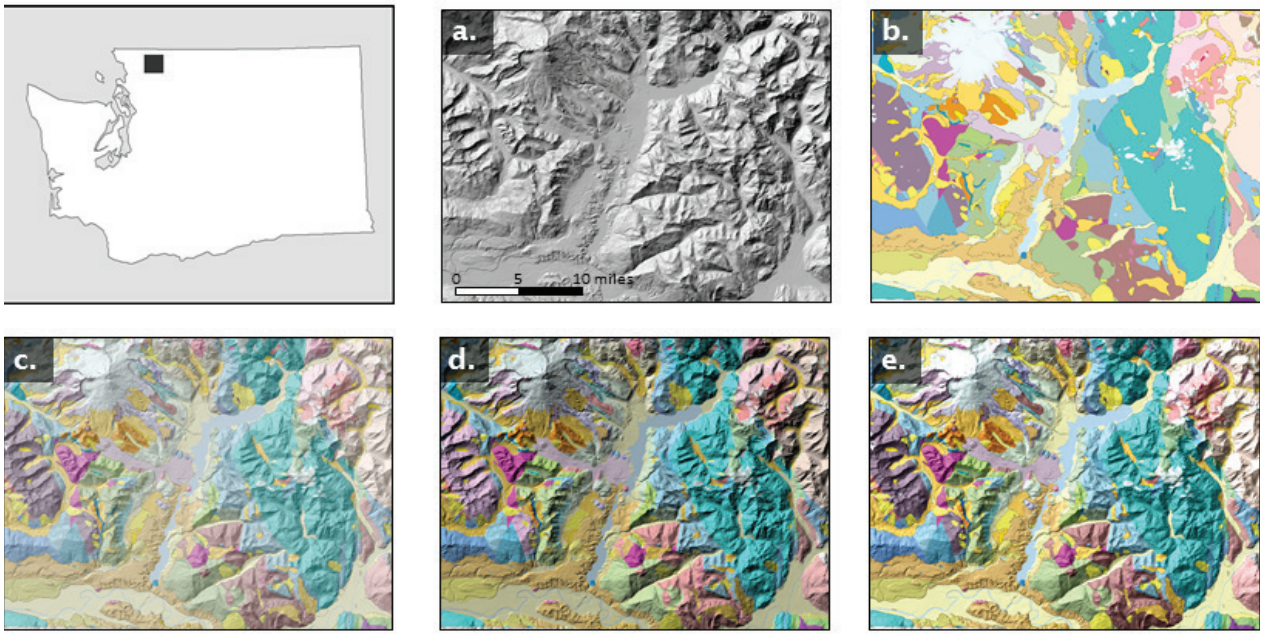

Figure 7. (a) Hillshade of the Mount Baker Area, (b) Rasterized Geology Map of the Mount Baker Area, (c) Geology Map Overlaid on the Hillshade Using 50 Percent Transparency, (d) IHS Fusion Method Output, and (e) NAGI Fusion Method Output.

CONCLUSION

The NAGI fusion method integrates color and gray-scale rasters while preserving the original colors from the color raster and retaining the apparent gradient variation from the hillshade raster. The three steps in this method involve the use of standard processes available in many GIS or remote-sensing software packages. It is a solution that does not require programming or the use of software extensions. It can be implemented in ArcGIS using functions for mosaic datasets or imageanalysis, and it can be used with various rendering methods, including color ramps and color map files. The NAGI fusion method also provides user control over the parameters in each process, such as the gamma and minimum-maximum contrast stretch values, thus allowing the method to be modified to accommodate the characteristics of the input rasters and the requirements for the output raster.

The tests conducted show that the method works well with a variety of datasets, with raster layers of varying resolutions, at many spatial extents, with diverse types of thematic content, and with different ArcGIS rendering methods, thus demonstrating the versatility and wide applicability of the NAGI fusion method.

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