The Design of Gray Earth: A Monochrome Terrain Dataset of the World

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INTRODUCTION

Gray Earth is a new terrain dataset available at Natural Earth (**NaturalEarthData.com**), a NACIS-sponsored repository of free map data (Kelso 2009, Patterson 2012). Serving as a monochromatic counterpart to the site's full-color terrain rasters, Gray Earth provides a worldwide depiction of landforms in grayscale. It comes in three resolutions that complement the 1:50- and 1:10-million vector data also available at Natural Earth. In addition to a basic version showing features of the Earth's land surface, visitors can also download deluxe versions that include supplemental ocean fills, bathymetric shading, and major rivers (Figure 1).

Gray Earth is not a final map, but rather an element that mapmakers can use with cartographic and GIS software. It has two primary purposes: to serve as a terrain layer for grayscale maps, and to provide a neutral base for maps that use bright,

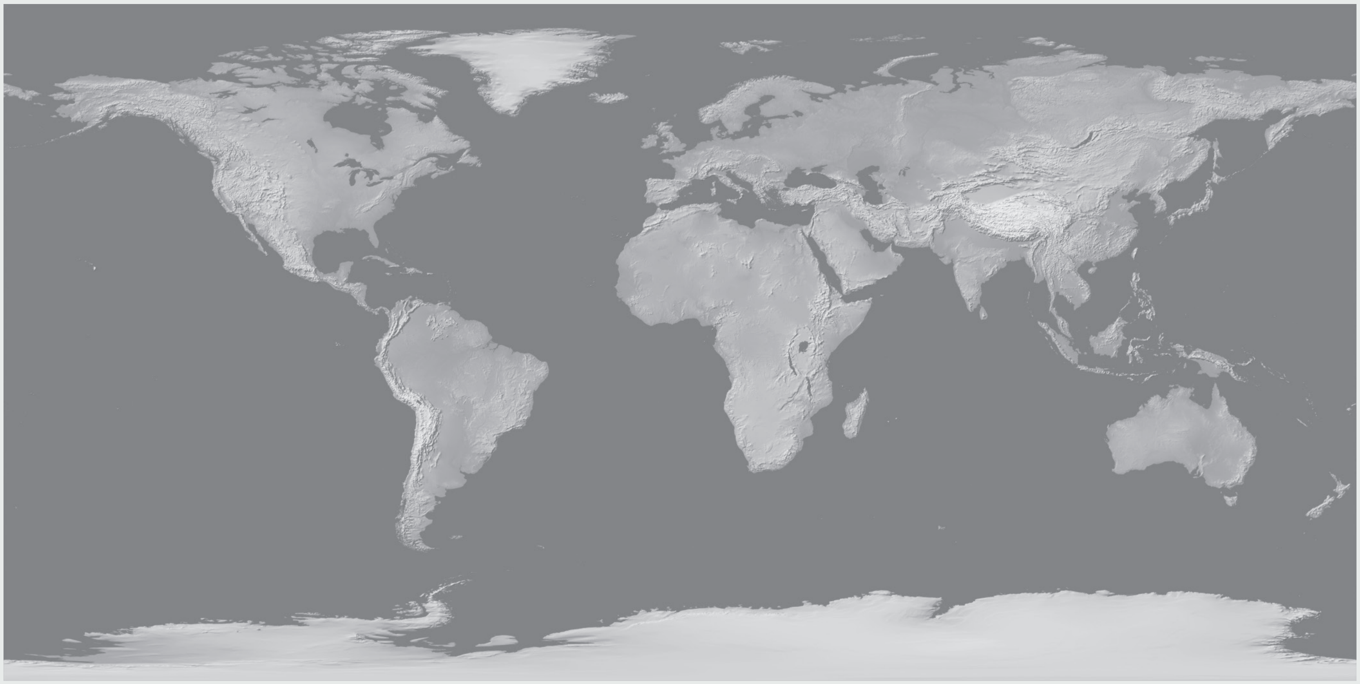

Figure 1: Basic version of Gray Earth with a supplemental ocean fill.

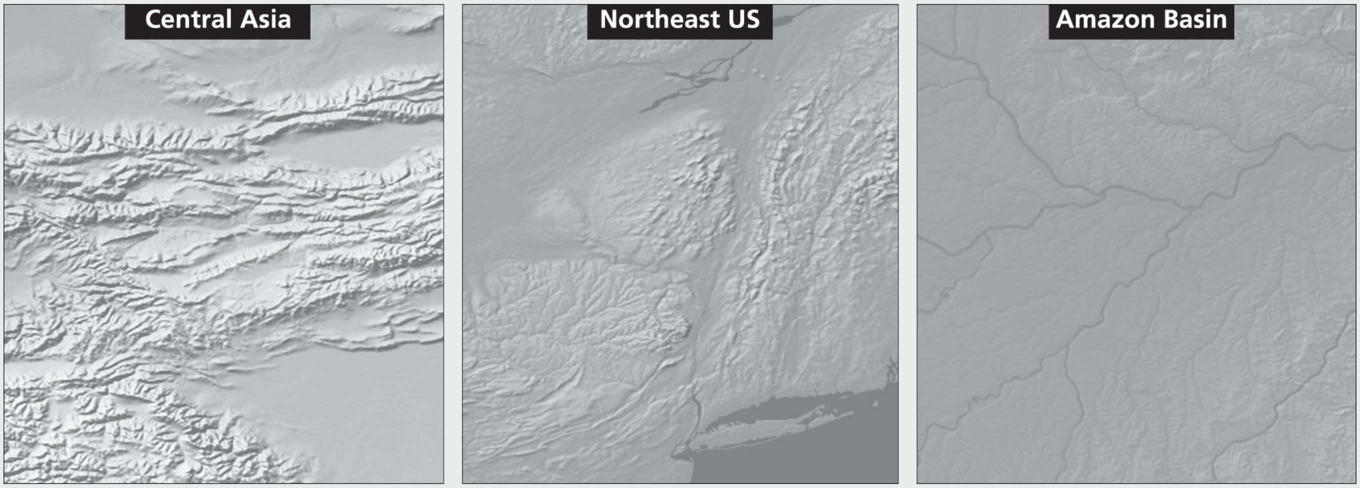

Figure 2: From left to right: high, medium, and low relief as it appears in Gray Earth.

saturated colors to represent thematic and statistical information. Against the gray backdrop, colors will pop.

Land areas in Gray Earth feature relief shading combined with hypsometric tints that blend into one another from darker lowlands to lighter highlands. Tonality of the land is generally light and the contrast is muted to better serve as an inconspicuous base for other map information. Despite being subdued, Gray Earth nevertheless reveals terrain details everywhere on Earth from the high, rugged mountains of Central Asia to the relatively flat lowlands of the Amazon Basin (Figure 2). The lighter land and darker water bodies provide figure-ground contrast.

The final Gray Earth dataset has an outward simplicity that belies the complex techniques that went into its development. We relied on a variety of GIS, mapping, and graphics processing software to develop the layers from which the final image was built.

ELEVATION DATA

Building Gray Earth began with compiling a suitable elevation dataset. For terrestrial elevation data, we used SRTM30 Plus, updated locally in the eastern Himalayas and southern Andes with higher quality data acquired from Viewfinder Panoramas (see References section for URLs). The bathymetry was based on CleanTOPO2, replaced with ETOPO1 data for the Caspian Sea and the Great Lakes. The land and sea layers were composited together, then downsampled from 30-arc second (~1km) to 1 minute (~2km) resolution. The final elevation raster measured 21,600 height samples wide by 10,800 high and employed the Plate Carrée (Geographic) projection, WGS84 datum.

Once the necessary elevation data had been assembled, we turned to developing the foundation of Gray Earth: unique hypsometric tints, designed to accommodate map reading at global and regional levels.

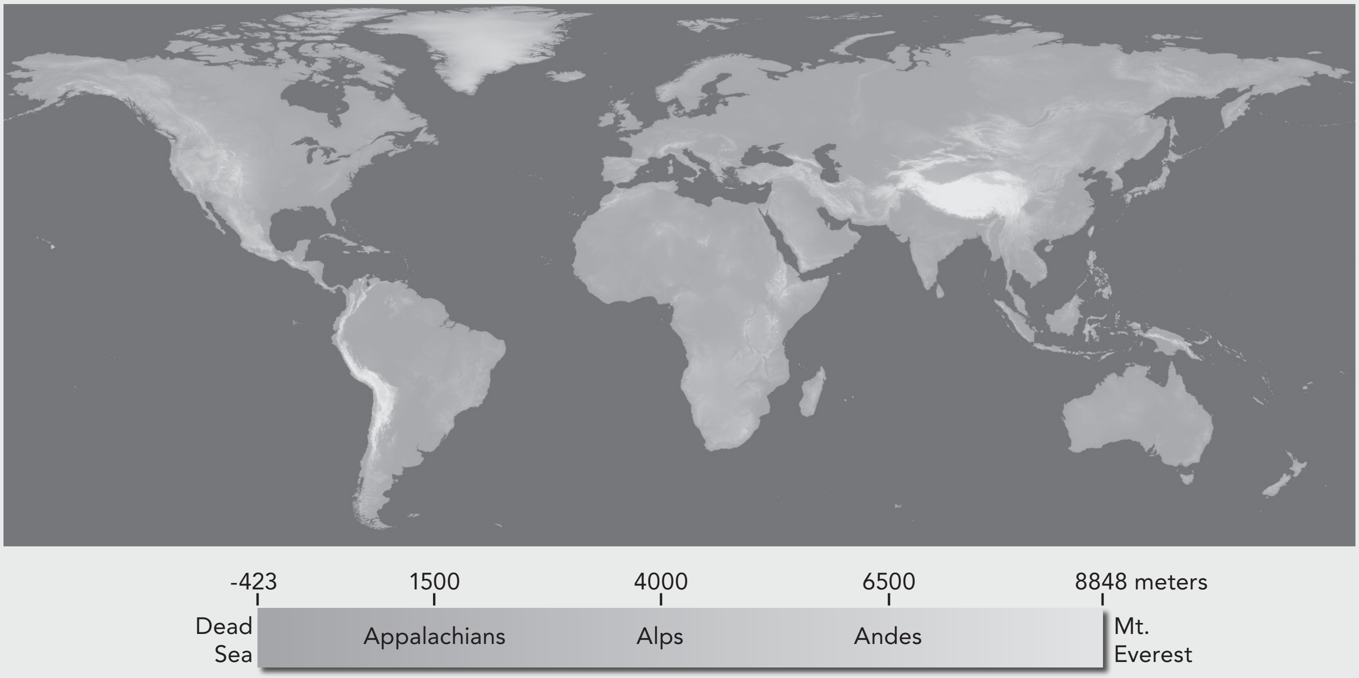

Figure 3: Hypsometric tints with a limited grayscale ramp.

LOCAL AND LOCALLY-ENHANCED HYPSOMETRIC TINTS

One of the primary limitations of working in grayscale, or any monochromatic scheme, is the narrow range of available tones; it's hard to fit a lot of detail into such a constrained color ramp. Creating worldwide hypsometric tints, for example, involves compressing the full range of Earth's elevations to a point where many of its finer features become illegible. Figure 3 demonstrates the challenges. Here, elevations are indicated by a color ramp constrained to the lighter half of the gray-scale spectrum, from 40% black lowlands to 10% black highlands, reserving the darker half for water features.

The Earth's most significant highlands stand out quite legibly: the Tibetan Plateau, the Andes, and the Greenland ice cap. But beyond the most macro of macro-scale features, much of the world looks fairly flat. Gone is Australia's Great Dividing Range, along with the vast plateau of southern Africa; even the imposing Alps are difficult to make out. They are beyond the capacity of the limited color ramp to convey.

We ordinarily think of hypsometric tints as encoding absolute elevations. But we can also think of them as encoding relative elevations: how high is an elevation compared to the highest and lowest points on the map. The tallest peak sits at one end of the tinting scheme, the lowest valley the other. Every other location is assigned a color in between, based on how its elevation compares to these two extremes. This is very much in line with how many people read hypsometric schemes on maps; rather than continually checking the legend to determine actual

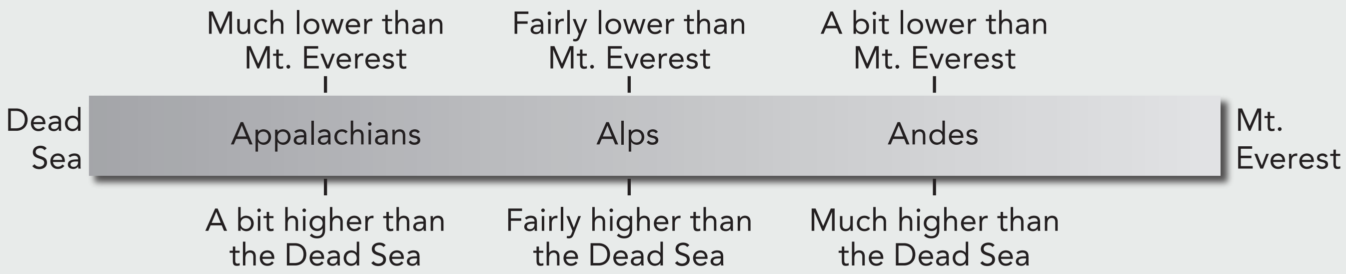

Figure 4: A relative interpretation of a hypsometric tinting scheme.

elevations, we usually look for which places appear higher or lower than others (Figure 4).

Returning to our problem in Figure 3, many of the missing features are comparatively small when measured against the elevation extremes of the Earth. A change in elevation of 2,000 meters may be impressive and regionally significant, but it is only a portion of the 9,271-meter range that the tinting scheme must cover. With such a limited color palette, these lesser features become nearly indistinguishable. It's a technically accurate portrayal, but it is not particularly useful in creating an attractive and informative base map. The grayscale tinting scheme must do more, and for that we need to revisit the idea behind hypsometric tints.

Rather than show elevations relative to maps' extremes, we can instead show elevations relative to their immediate surroundings. A peak may be rather small when

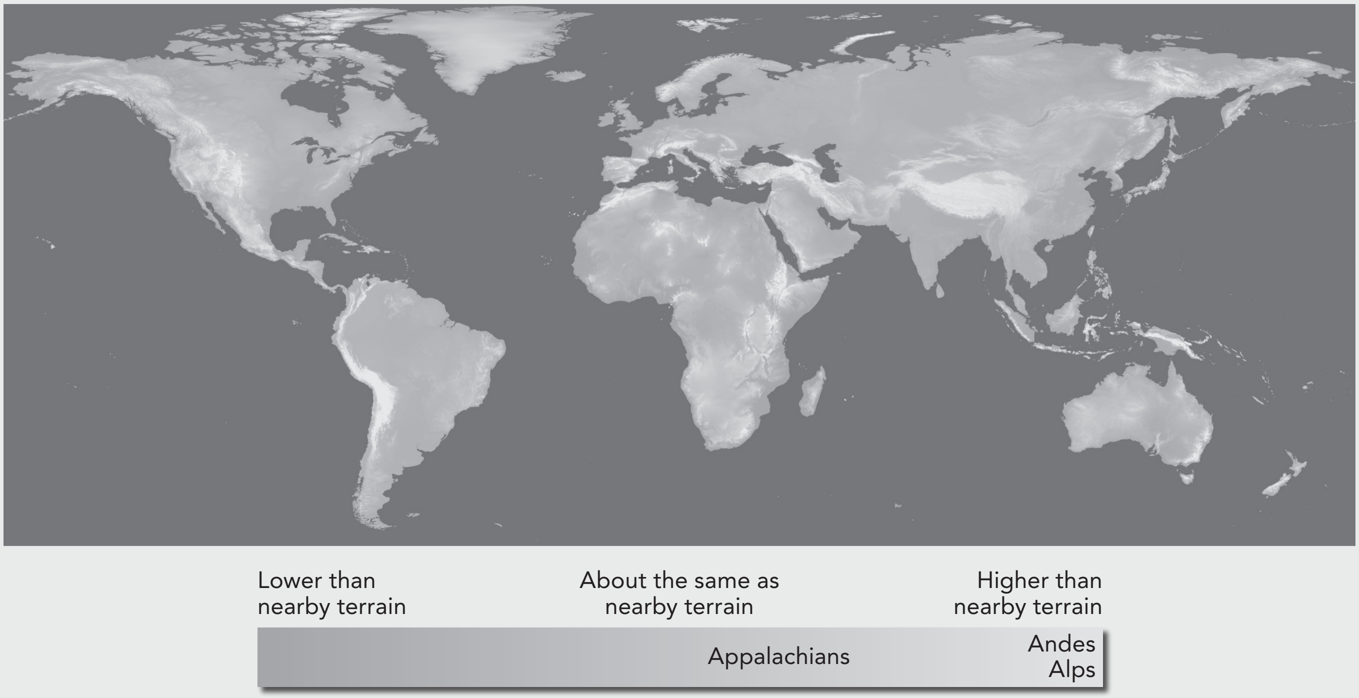

Figure 5: Local hypsometric tints.

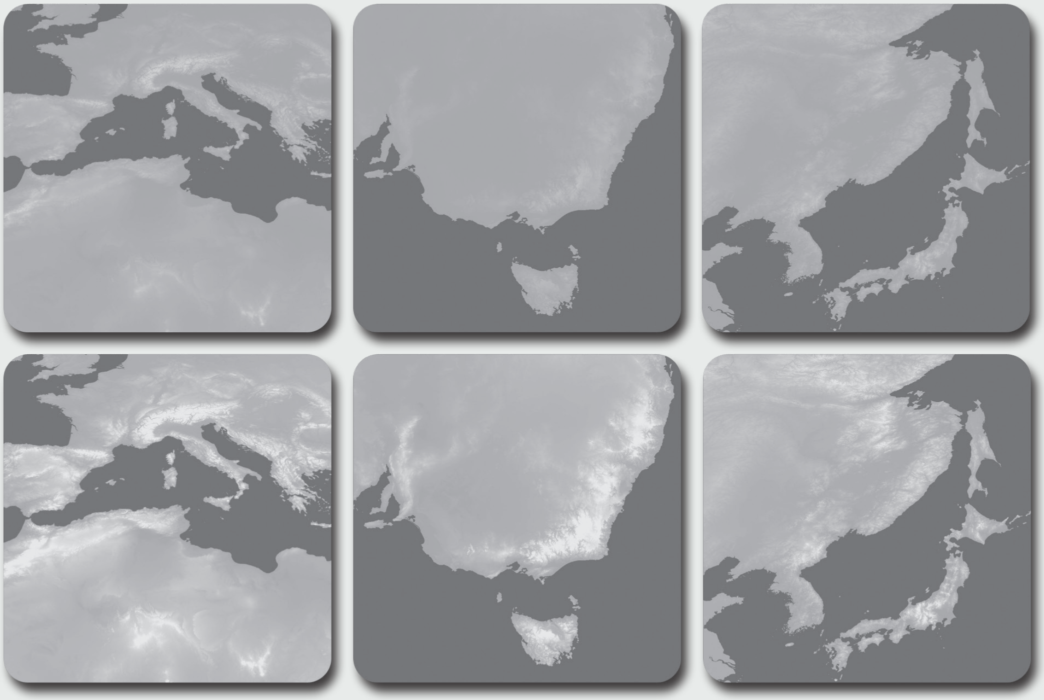

Figure 6: Detail images from Figures 3 and 5.

compared to Mt. Everest, but does it become significant when measured against nearby terrain? Figure 5 demonstrates what happens when we show only whether the elevation of a place is higher or lower than its neighbors, what we might call **local hypsometric tints**.

No longer hindered by the need to portray everything relative to the highest and lowest points on Earth, much of what was missing in Figure 3 becomes clear. In places like Australia or eastern North America, detailed terrain is revealed where there was previously only a flat gray. The result is a base map that is more visually interesting and more informative about the world's landforms. The local hypsometric tints make more efficient use of the limited tonal range of a grayscale color ramp.

The problem with local hypsometric tints, as many readers may have already noted, is their lack of consistency worldwide. Low mountains are portrayed as though they are as high as great ones, and there's no way to create any sort of legend that allows a conversion between color and elevation. While it may be technically inaccurate, this method can be more narratively accurate than applying standard hypsometric tints. Figure 5 is better able to give an informative reply to a reader who asks, "What sort of terrain shapes the lives of people in various parts of the world or influences its phenomena?" The low-detail image of Figure 3 may correctly convey which places are the tallest on the Earth, but it suggests a planet that is mostly smooth. This may be true when it is seen from space, but the Earth becomes very rugged when experienced by a person on the ground. Figure 5 is a terrain representation with a more human scale.

For Gray Earth, we employed a blend of local and standard hypsometric tints. This allowed regionally significant terrain details to show up clearly while maintaining a more consistent vertical scale worldwide; lower features are visible, but—unlike in Figure 5—they are depicted as clearly less lofty than Tibet. We call this blended approach locally-enhanced hypsometric tints. The resulting terrain representation is quite versatile. Many users of the Natural Earth datasets create regional and local maps. Places such as Tibet or the Andes may not appear on a user's map and, by reducing their influence on the overall color scheme, Gray Earth will look good in a wide variety of contexts.

CREATING LOCAL HYPSOMETRIC TINTS

Creating local hypsometric tints is fairly straightforward, and can be done in most any GIS package. We used ArcGIS to create those used in Gray Earth. To mathematically represent the idea of measuring a place's elevation relative to that of its neighbors, we can create a raster dataset that provides, for each location, the number of standard deviations above or below the neighborhood mean. Getting there involves three steps.

1. **Neighborhood mean and standard deviation.** In order to compare a location to its surroundings, we need to learn a couple of things about those surroundings by using neighborhood analysis functions. These functions look at each pixel in a raster dataset (in this case a DEM) and determine its neighborhood: the group of all pixels within a chosen distance of that pixel. Then, they compute statistics, such as the mean, for that group. The first step in preparing a local hypsometric tint is to generate two new rasters based on our initial DEM: one with a neighborhood mean and one with a neighborhood standard deviation. The choice of the neighborhood size determines how large of a surrounding area we'd like to consider when applying local hypsometric tints to each location.

Figure 7: Neighborhood statistics and the calculation for step 2.

2. **Compare each elevation to its neighborhood mean.** For each location, we have an elevation and the mean elevation of its neighborhood. The second step is to compare them by subtracting the neighborhood mean from the elevation. This yields a new raster showing how much higher or lower than its surroundings a location is.

3. **Divide by the neighborhood standard deviation.** The standard deviation statistic measures how much variation there is in the neighborhood. A small standard deviation means that the area is fairly flat: most values are close to the mean. A larger number suggests a more rugged terrain. This measurement allows us to add some important context to our analysis of local elevations. We may find in step 2, for example, that a particular pixel is 500 meters taller than its neighborhood mean. It could be a significant local prominence standing out on a flat plain (if the standard deviation were small), or perhaps it is just part of an undulating range of small mountains (if the standard deviation were large). The standard deviation determines whether the elevation differences we are measuring are significant. Our final step in preparing the local hypsometric raster is to divide the results from step 2 by the neighborhood standard deviation.

-28	2	7	-16	13	7
-2	2	-1	-8	16	-10
9	12	18	-13	16	-7
-10	1	12	-18	0	-2
-9	8	-4	9	-2	-15
-12	5	-18	-9	10	16

Difference

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15	14	16	12	12	14
14	13	11	14	12	12
17	10	12	13	14	13
14	13	14	12	12	12
11	14	14	11	12	9
11	11	13	12	13	11

Neighborhood standard deviation

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-1.9	0.2	0.5	-1.4	1.0	0.5
-0.1	0.2	-0.1	-0.6	1.3	-0.8
0.6	1.3	1.5	-1.0	1.2	-0.6
-0.7	0.1	0.9	-1.4	0.0	-0.2
-0.8	0.7	-0.3	0.8	-0.2	-1.8
-1.1	0.4	-1.4	-0.8	0.8	1.4

Local hypsometric raster

Figure 8: Computing the final local hypsometric raster.

The end result is a raster dataset that encodes how significantly the elevation of each pixel differs from that of its surroundings. We can apply a simple color ramp, as we would to a DEM, and the end result is a set of local hypsometric tints.

CREATING THE FINAL HYPSOMETRIC TINTS

To create the hypsometric tints used in the final Gray Earth product, we next moved our work into Adobe Photoshop. We combined several layers of local hypsometric tints with differing neighborhood sizes (1000 to 3000 pixels) along with one of standard hypsometric tints. We then blended all of these parts together to

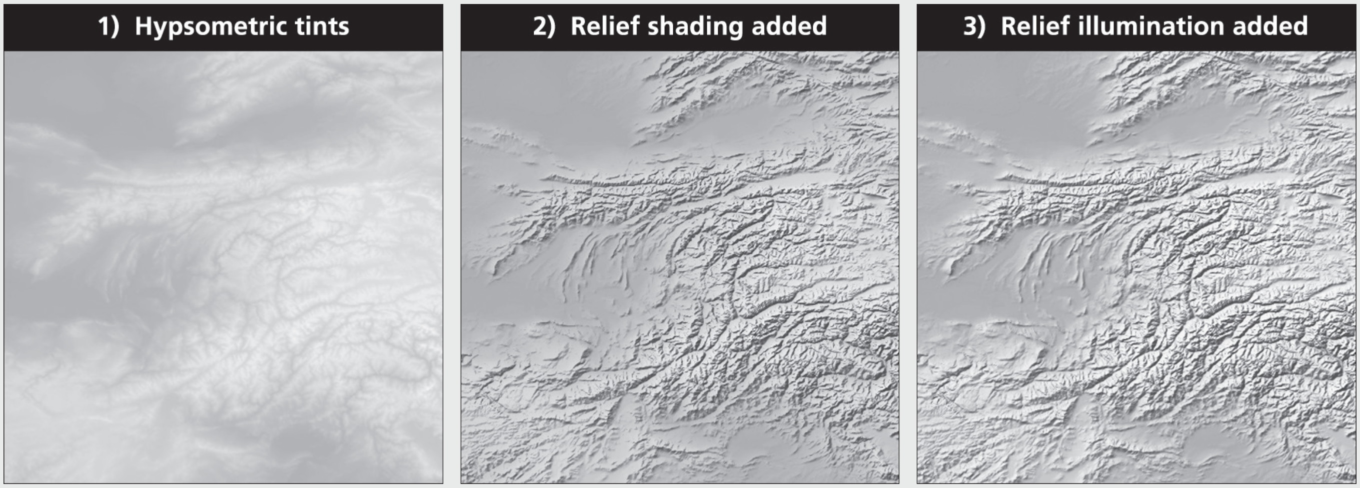

Figure 9: Light touch: Gray Earth combines hypsometric tints, relief shading, and relief illumination.

create locally enhanced hypsometric tints, adjusting the composition until we were satisfied with the balance between macro- and micro-scale features.

Next, we brought additional lowland darkening to areas below approximately 200 meters in elevation. Large areas of land on Earth are relatively low and flat, such as the Amazon Basin, northern Eurasia, and the southeastern United States. Showing these areas slightly darker accentuated the subtle elevation differences. To accomplish this in Photoshop we converted the SRTM30 Plus elevation data to a 16-bit grayscale raster—16 bits of data provided smoother transitions—and then used the Curves adjustment to remove areas over about 200 meters. By setting the layer to the Multiply blending mode at a low opacity, we subtly darkened the lowland areas where the raster was not choked.

Following a similar procedure, we also brought slightly darker tones to the deepest valleys on the Tibetan Plateau. This very large region would have looked too uniformly light without this adjustment. We drew a feathered layer mask in Photoshop to confine the darkening to this region.

SHADED RELIEF

Once we had developed and fine-tuned our hypsometric tints, we were ready to prepare the shaded relief—the other half of Gray Earth. We generated a separate relief for each of Gray Earth's three final sizes, measuring 10,800, 16,200, and 21,600 pixels wide. Each was rendered in Natural Scene Designer Pro 6.0 from the same elevation raster that we used to prepare the hypsometric tints, and then downsampled as necessary to fit our target size. We used the default light settings in Natural Scene Designer, a 15% gray background, and two applications of DEM smoothing. Smoothing the elevation data before rendering took place yielded a more generalized shaded relief with fewer artifacts and noisy textures. Varying the vertical exaggeration factor—smaller scales received more vertical exaggeration—created shaded reliefs that look consistent between the different resolutions of

Gray Earth, an important consideration for multi-scale web mapping. The shaded reliefs produced for Gray Earth are now the standard for all Natural Earth 2.0 raster products.

Finally, we added the shaded relief to the background hypsometric tints as separate shading and illumination layers in Photoshop. This approach creates a relief depiction with a more three-dimensional and lighter appearance overall. As the last step in creating the final Gray Earth product, we added secondary shading and illumination layers to give the highest peaks slightly more emphasis.

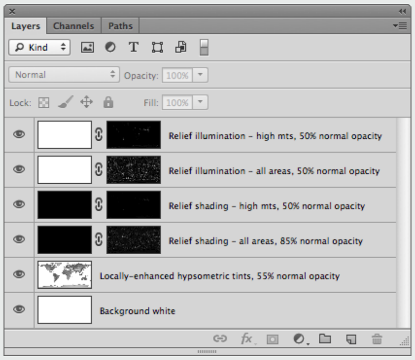

Figure 10: Gray Earth composite layers in Photoshop.

Figure 10 shows the Photoshop layers and layer masks used to composite the Gray Earth shaded relief. Pasting the shaded relief rendering into the layer masks—where it behaves much like a photographic negative—allows the printing of black shading or white illumination on top of the background hypsometric tints. Adjusting the opacity of these layers yielded a delicate balance of shadow, light, and background tints.

CONCLUSION

When making Gray Earth, we had in mind a product that could serve a wide range of cartographic design needs and appeal broadly to many users' tastes. While it is quite versatile, we encourage you to modify it as needed if you find that it does not exactly meet your project requirements. Only a few minutes of Photoshop tinkering can alter its appearance dramatically, even colorizing it (Figure 11). You can also easily add a layer of rasterized Natural Earth vector data—glaciers, reefs, urban areas, etc. We hope that you will find Gray Earth to be an attractive new addition to the Natural Earth data library, and that it will be a valuable element in your future projects.

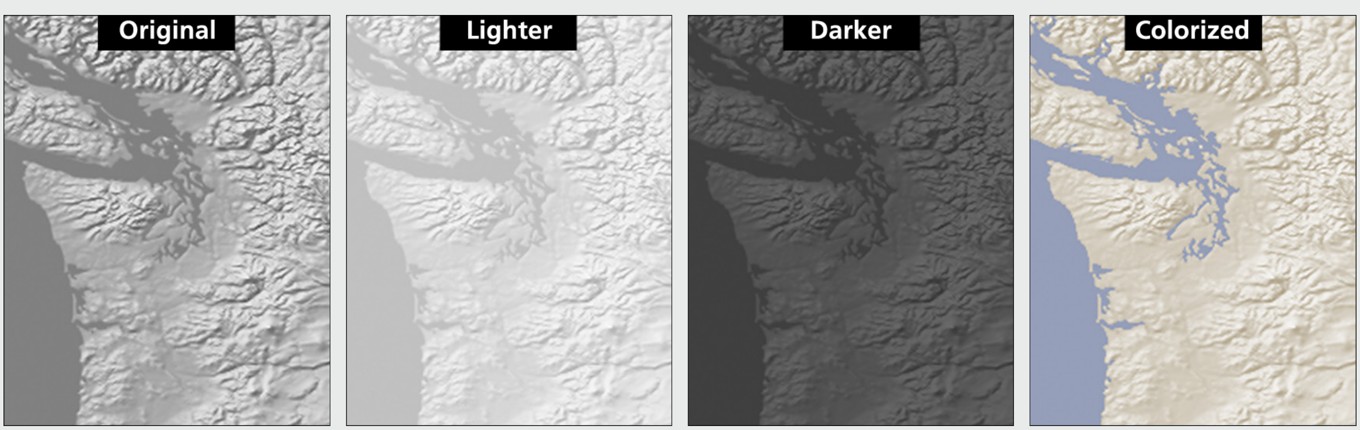

Figure 11: Possible Adobe Photoshop adjustments to Gray Earth.

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