A More Perceptual Color Palette for Structure Maps*

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Abstract

The spectrum, one of the default color palettes in geophysical software, is inadequate to represent structure because it introduces edges and artifacts that may be interpreted as real changes in the data. This palette also interferes with the use of shading and the perception of relief, and some of its colors are very confusing for viewers with color vision deficiencies. We recommend a new color palette and test it on a Digital Elevation Model and on a gravity dataset to demonstrate it is perceptually superior to the spectrum palette for both standard viewers and viewers with color deficiencies.

Introduction

Seismic interpreters use color palettes to display amplitude and structure (ratio data). In many seismic interpretation or visualization software packages, the default color palettes available for those tasks are the divergent red-white-blue for amplitude and the rainbow, or spectrum, for structure. Welland et al. (2006) argue that the red-white-blue color palette is not linear in perceptual space (they call it psychological space) in that perceptual distance between samples does not vary regularly, and they remap the colorbar to psychological space allowing subtle variations in the data to be discerned.

We would like to take a look at the color palettes used for structure and establish if they are perceptually adequate. There are many articles in literature (for example Borland and Taylor, 2007; Light and Bartlein, 2004; Rogowitz and Kalvin, 2001) showing that the rainbow has perceptual flaws and is in fact inadequate to represent interval data. The medical and biomedical communities have caught up with this idea more rapidly as discussed in Borland and Taylor (2007) and different palettes are used by practitioners in those disciplines. For example, Borkin et al. (2011) argue that using rainbow in artery visualization has a negative impact on task performance, and may cause more heart disease misdiagnoses. Some alternatives to the rainbow are recommended in all these papers.

Theory

Niccoli (2012) makes the case that the spectrum color palette is also inadequate, and introduces a new rainbow-like scheme (cube law lightness color palette - we will call it cube law rainbow in the remainder of this article). This new palette is a better option to use because it has a monotonically increasing lightness (L*) profile; Lightness represents the achromatic, quantitative information in a colormap. It is the vertical axis in HSL and Lab color spaces. In grayscale, lightness corresponds approximately to intensity. It has been shown (for instance Rogowitz and Kalvin, 2001; Montag, 1999) that monotonicity of either luminance or lightness is the most important perceptual quality in a palette. The original figure from Niccoli, 2012 is reproduced (in color, original was grayscale) in Figure 1. The pyramid surface rendered with the new color palette (bottom right) is smooth and without any perceptual edges/artifacts, which should be expected because the pyramid is a solid with perfectly flat surface. Instead, the pyramid rendered with the spectrum (top right) has several artifacts, which are due to the inversions and flats in its lightness profile.

New Examples

We are now going to try this cube law rainbow on real world data, first with a Digital Elevation Model from Mexico. We start out rendering the DEM in standard grayscale because of its nearly linearly increasing L* profile (not shown) and use it as a perceptual benchmark. This is shown in Figure 2 where we assign increasing intensity from lowest elevation in black to highest elevation in white (as labeled next to the colorbar). In this figure we highlight two locations, one marked with a dashed arrow, the other with a solid arrow, where elevation (and thus gray intensity) varies very smoothly suggesting a constant elevation gradient in both cases. Now look at Figure 3, where we use the spectrum to color the data: there is now a brownish edge at the location where the dashed line points, seemingly indicating a sharp elevation gradient change, followed downhill by a region of constant green color suggesting zero or nearly zero gradient. This is an inaccurate representation of the elevation and an artifact introduced by the palette (due to an inversion and a plateau in its L* profile, marked by the arrow and the letter G, respectively in Figure 1, top left). Similarly there is now a sharp cyan edge at the solid arrow in Figure 3, which could be easily mistaken for another change in elevation gradient. These edges (and others, though not as evident) do not exist in the data and are not present in Figure 2. In Figure 4 we color the surface with the cube law rainbow, which preserves the perceptual smoothness of the grayscale image at the chosen locations (and overall), while enhancing the viewer’s ability to perform visual comparisons and detect subtle variations in the surface (because of the color).

In the next three figures we use the same three color palettes with a gravity dataset from an unpublished thesis in geology carried out by one of the authors at the University of Rome (Niccoli, 2000). Gravity prospecting is useful in areas where rocks with different density are laterally in contact, either stratigraphically or tectonically, producing a measurable local variation of the gravitational field. This was the case for the study area of the thesis in the Monti Romani of Southern Tuscany. In this part of the Apennine belt, a Paleozoic metamorphic basement (density ~2.7 g/cm^3) is overlain by a thick sequence of clastic near-shore units of the Triassic-Oligocene Tuscany Nappe (density ~2.3 g/cm^3). The Tuscan Nappe is in turn covered by the Cretaceous-Eocene flysch units of the Liguride Complex (density ~2.1 g/cm^3). During the deformation of the Apennines, a complex tectonic history placed the basement in lateral contact with the less dense rocks of the younger formations and this is reflected in the residual anomaly map of Figure 5 from which it was inferred that in this area a system of normal faults caused differential sinking of the top of basement in different blocks leaving an isolated high in the middle, which is consistent with the known geology of the area.

In Figure 5, our benchmark, we use again grayscale to represent the data, assigning increasing intensity from most negative residuals in black to most positive residuals in white (as labeled next to the colorbar). We then use terrain slope to create shading (the higher the slope, the darker the shading assigned) which results in a pseudo-3D display that is very effective.

In Figure 6 we color the pseudo-3D surface with the cube law rainbow. Using this color scheme increases the perceptual contrast allowing viewers to appreciate smaller changes, more quickly assess differences, or conversely identify areas of similar anomaly, while at the same time preserving the peudo-3D effect. Now compare Figure 6 with Figure 7, where we use the spectrum to color the surface: this color scheme introduces several artifacts, two of which (at red and blue positions, indicated by arrows next to the colorbar) confuse the display and interfere with the perception of pseudo-relief, all but eliminating the effect.

Discussion

So far we made a claim that spectrum is a poor choice when used for color representation of a surface. We argued that the new color palette is best suited for that task. Now we go further showing that the spectrum not only has these perceptual artifacts and edges, but it is also very confusing for viewers with deficient color vision, a condition that occurs in about 8% of Caucasian males. We do this in Figure 8 using computer software to simulate how viewers with two types of deficient color vision, Deuteranopia and Tritanopia, would see the two colored surfaces, and we compare the results. In other words, we are now able to see the images as they would see them.

One of the authors (Lynch) does have a form of color vision deficiency called Deuteranomaly, and so he sees red, which in persons with full color vision is a perceptually bright color, as a perceptually dark color. Shades such as purple, which contain red, also become perceptually darker. For him, the full color and the Deuteranopia simulation images are virtually identical in both the spectrum case and the cube law rainbow case. For a viewer with normal color vision, they are quite different. From the point of view of color deficient vision, the additional problem with using the spectrum is illustrated by colors at positions 0 and 2 on the spectrum palette, which are perceptually almost identical. To Lynch, both appear to be a shade of green (yellow for Deuternaopia, as viewers with normal vision can appreciate in the simulation) with an indeterminate shade of brown between them. This results in the spectrum image to be visually very confusing; the same can be said of the DEM spectrum image. The cube law rainbow images, by contrast, do not produce the same confusion.

Another effect we notice in the simulation is that cyan and magenta now look very similar. The second simulation is of Tritanopia, which is less common than Deuteranopia. People with Tritanopia confuse green with blue and yellow/orange with magenta. We can see the effect in the simulated spectrum where one pair of colors, indicated by arrows, is very confusing. Notice it now takes a significant effort, and using pairs of colors (red/white versus white/black), to distinguish highs from lows in the surface. Again, the cube law rainbow images do not produce the same confusion. We do not show the simulation of Protanopia since it is very similar to the simulation of Deuteranopia.

Conclusions

In this article we test a new color palette on a Digital Elevation Model and on gravity data and demonstrate it is perceptually superior to the spectrum color palette for standard viewers and viewers with color deficiencies.

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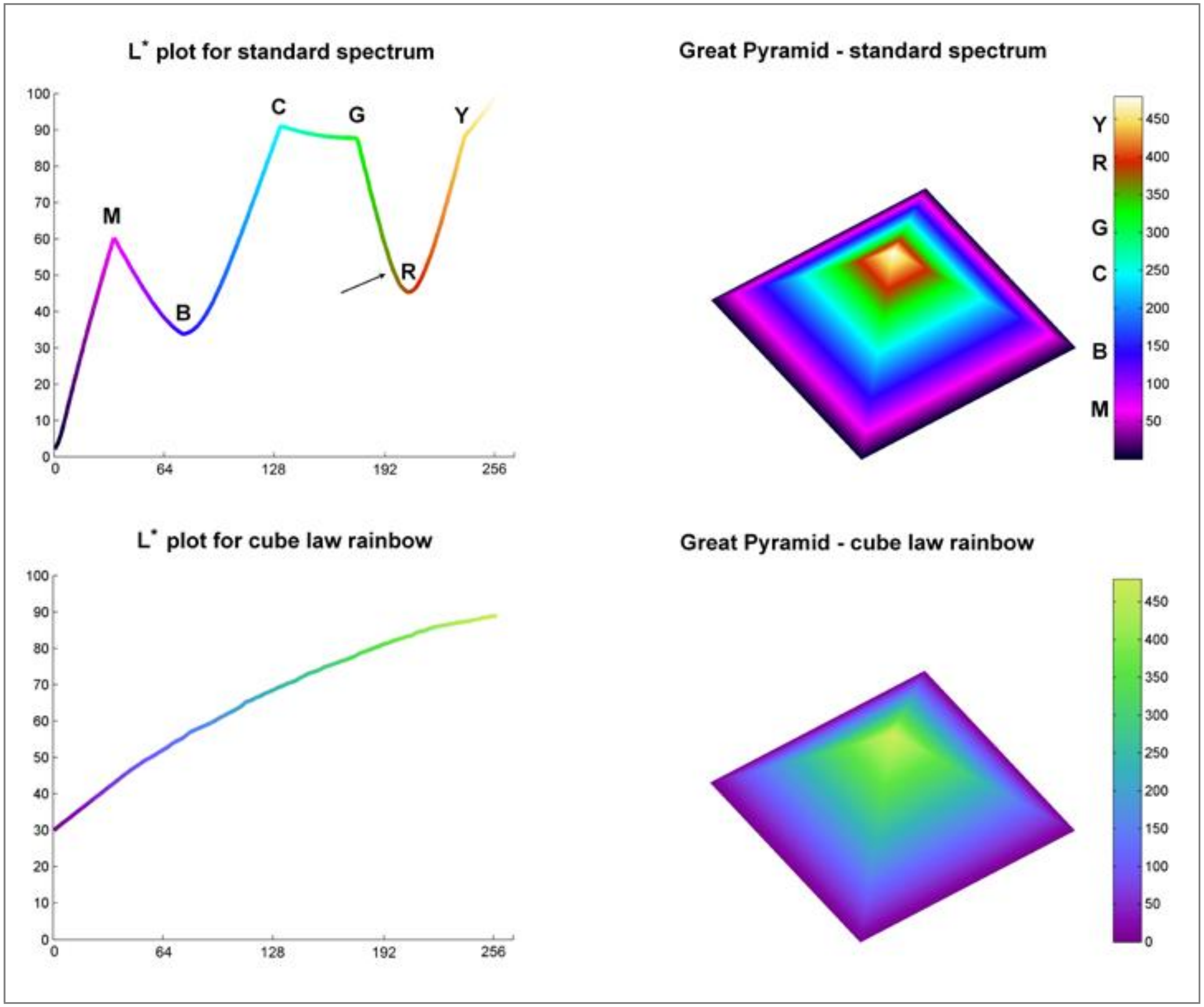

Figure 1. (a) Comparison of lightness versus sample number for the spectrum (top left) and the new color palette (bottom left); (b) Comparison of test surface (the Great Pyramid of Giza – scale is original, pre-erosion elevation) using the spectrum (top right) and the new color palette (bottom right). More details in Niccoli (2012). Notice the marked non-monotonicity of the spectrum lightness profile. As an aside, also notice that interpolation between green and red generates a non-spectral grayish, brownish color (indicated by arrow).

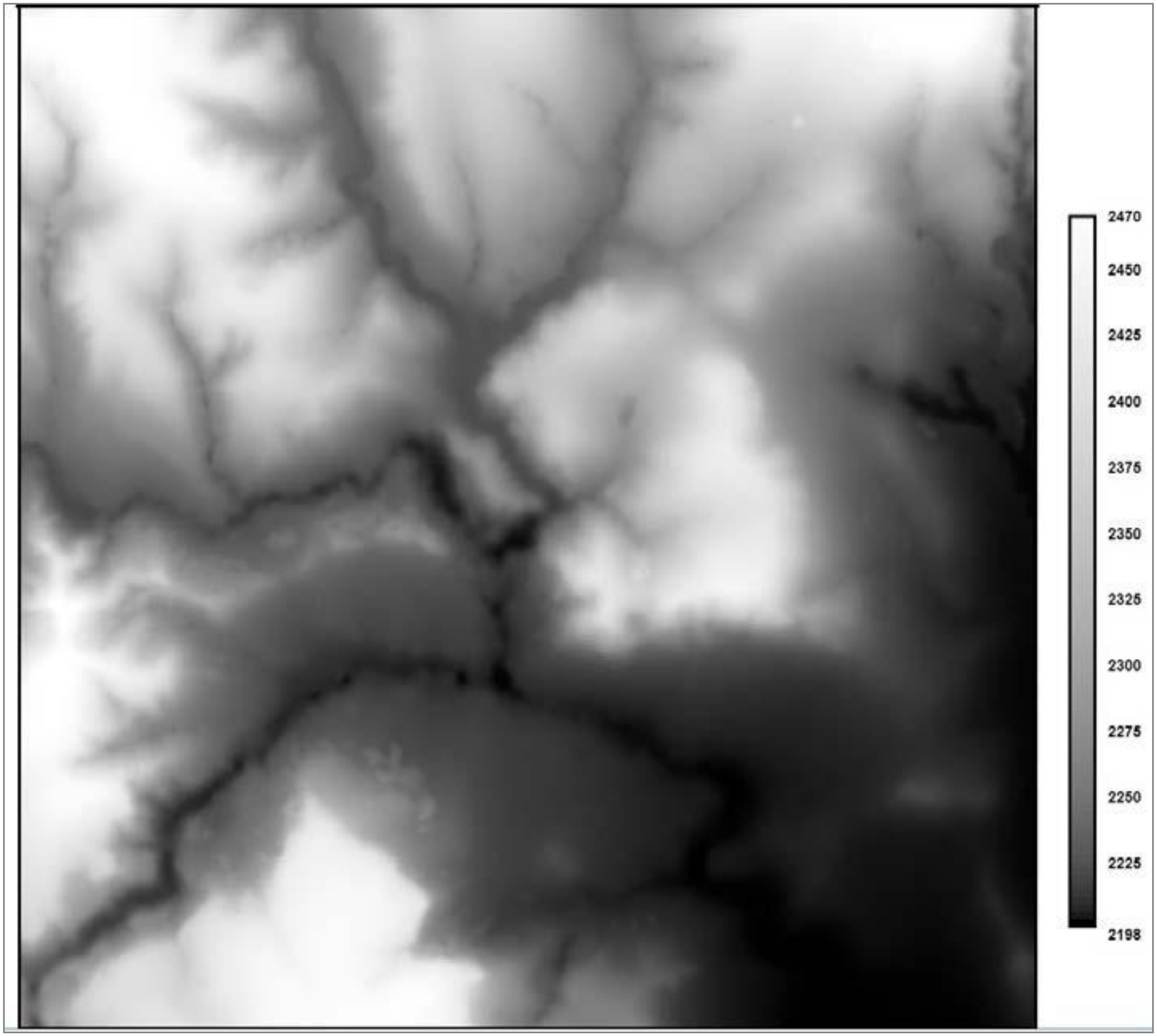

Figure 2. DEM with grayscale (benchmark).

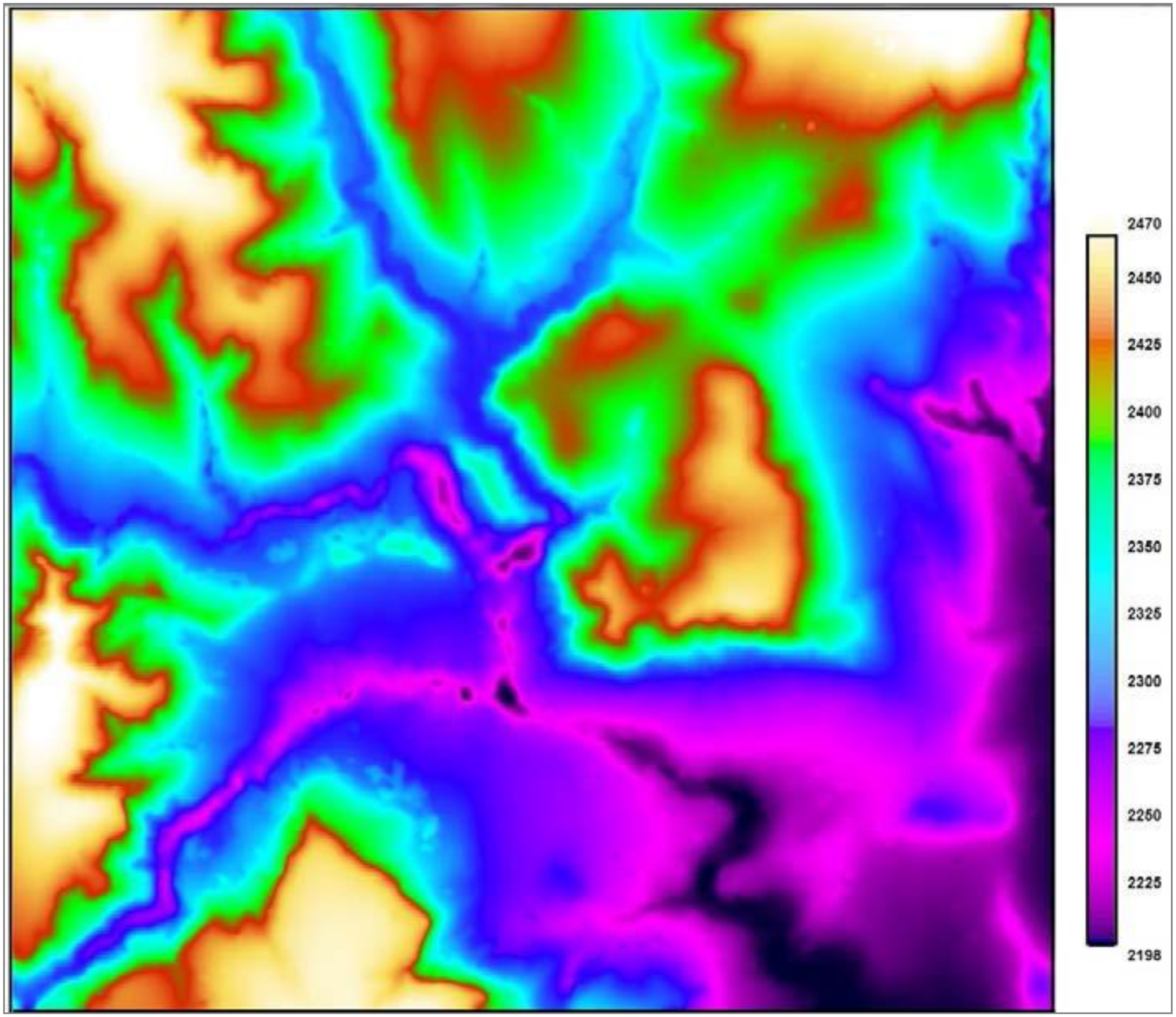

Figure 3. DEM with Spectrum.

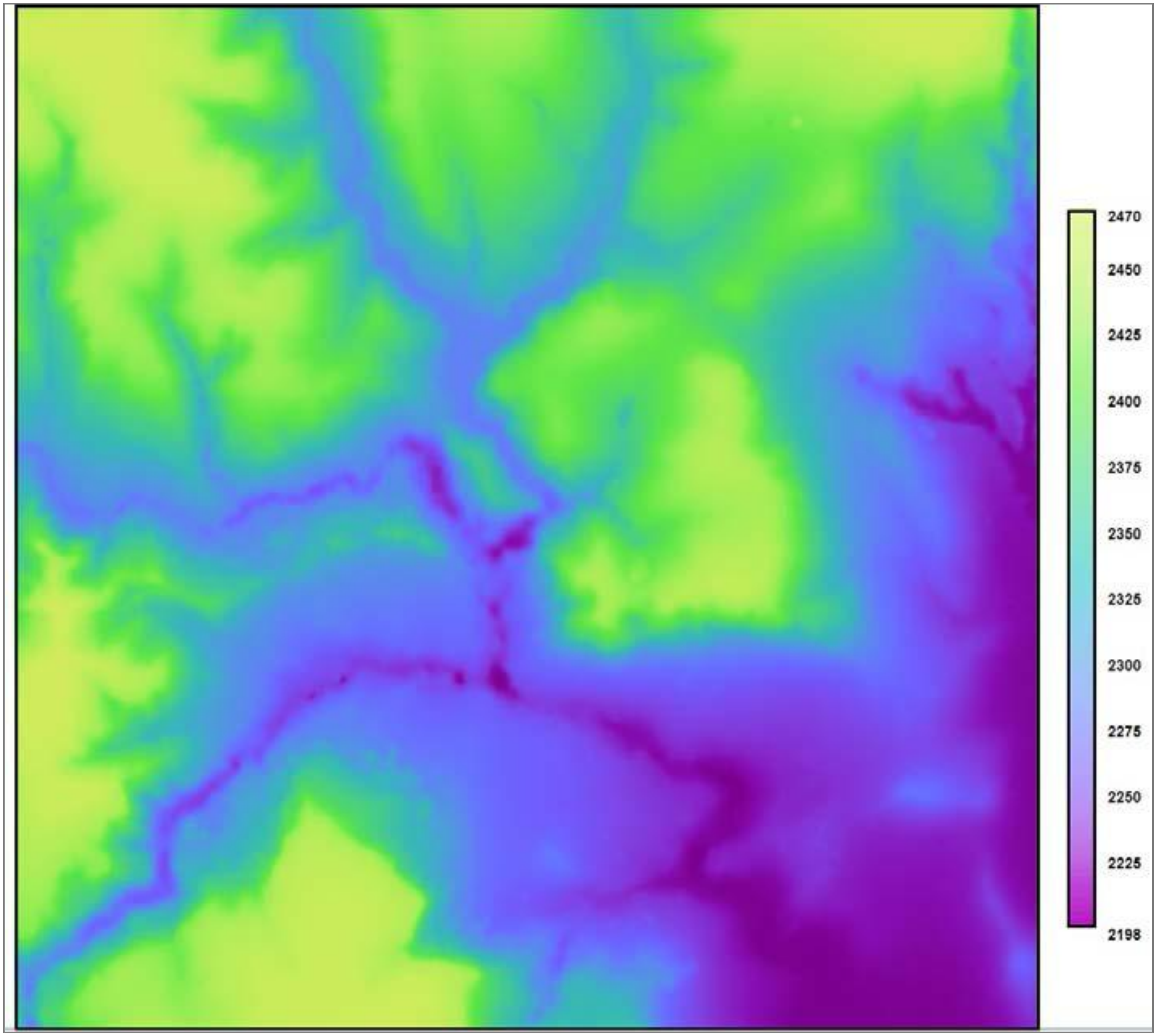

Figure 4. DEM with cube law rainbow.

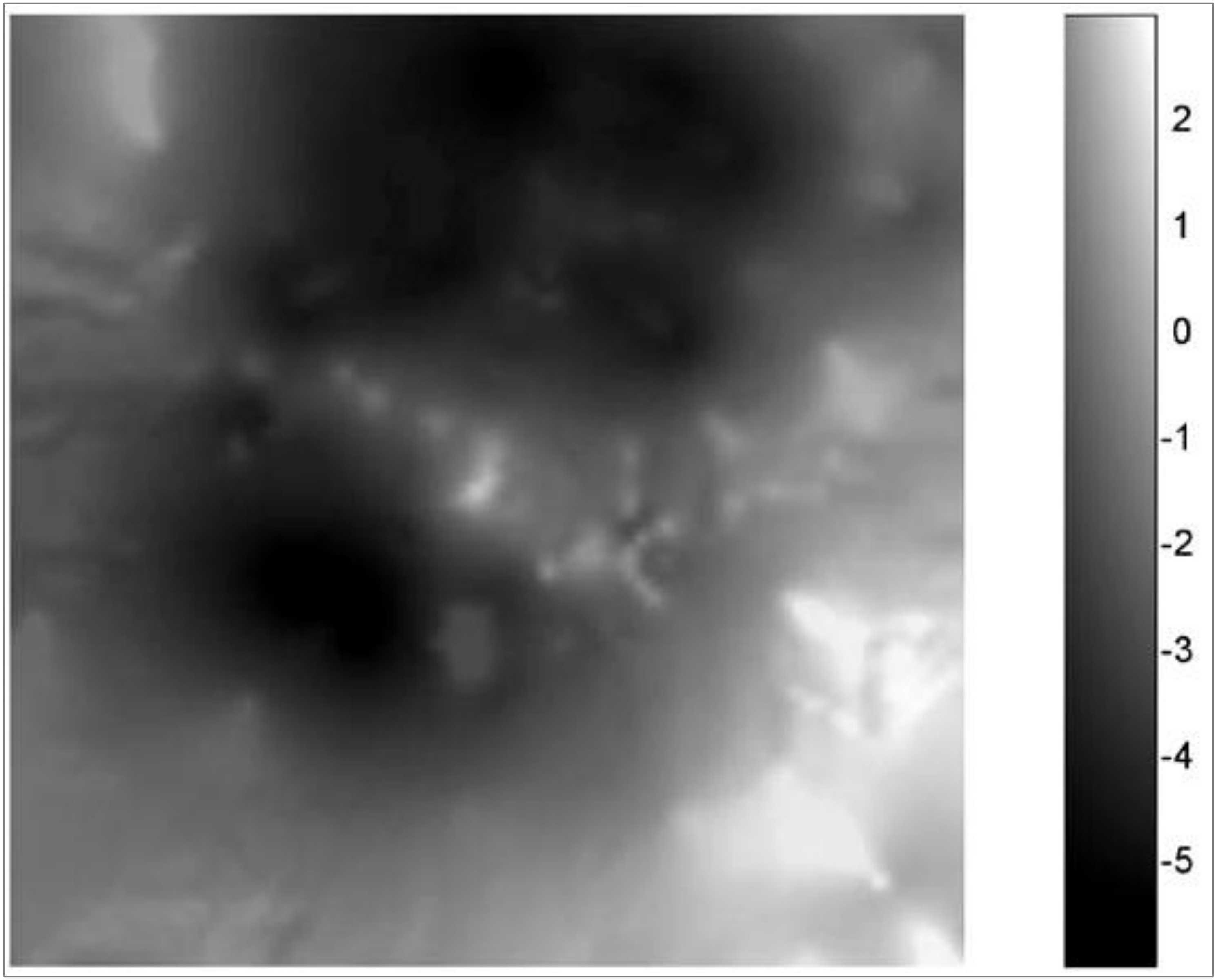

Figure 5. Map of residual gravity anomaly displayed in grayscale.

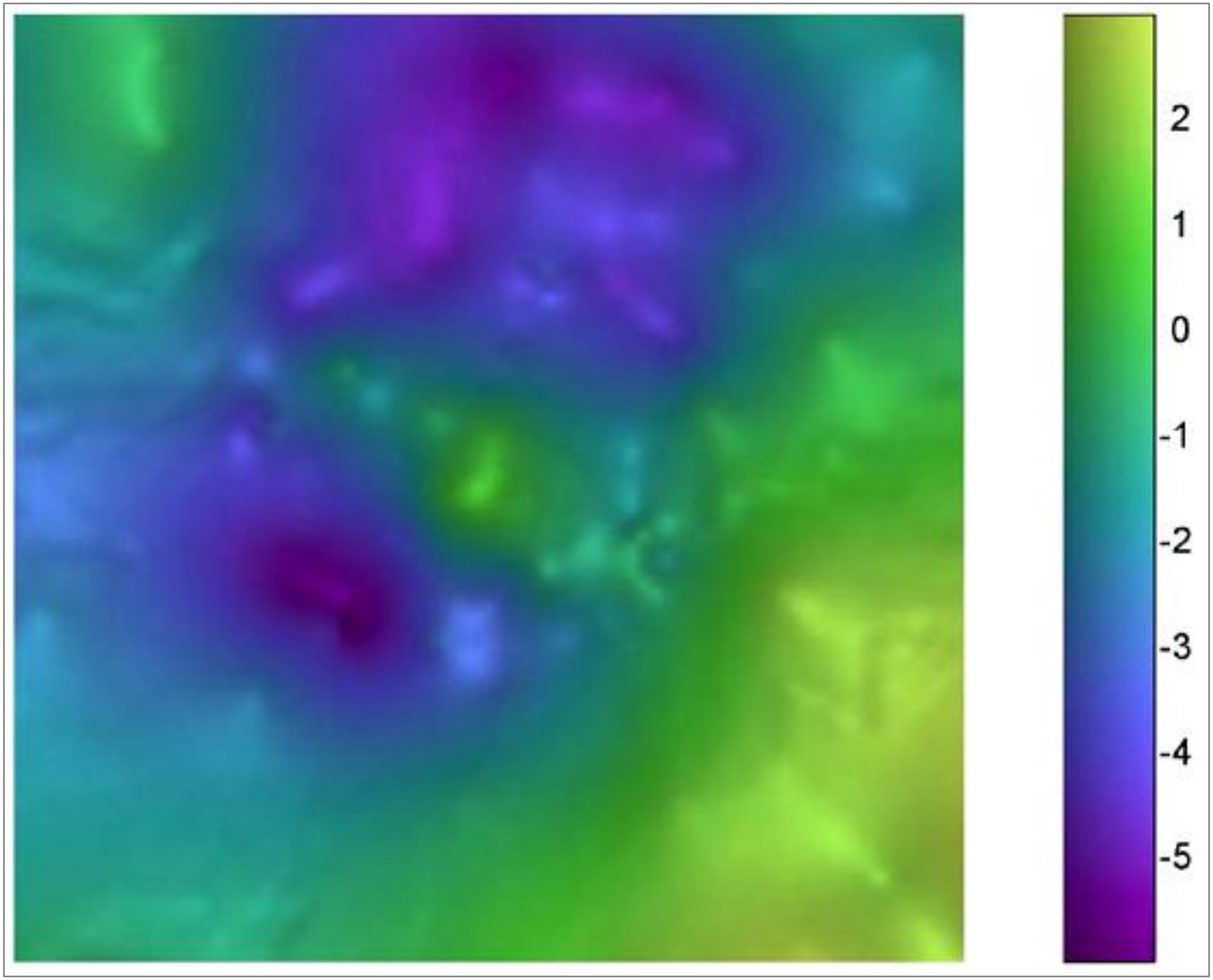

Figure 6. Map of residual gravity anomaly displayed with cube law rainbow.

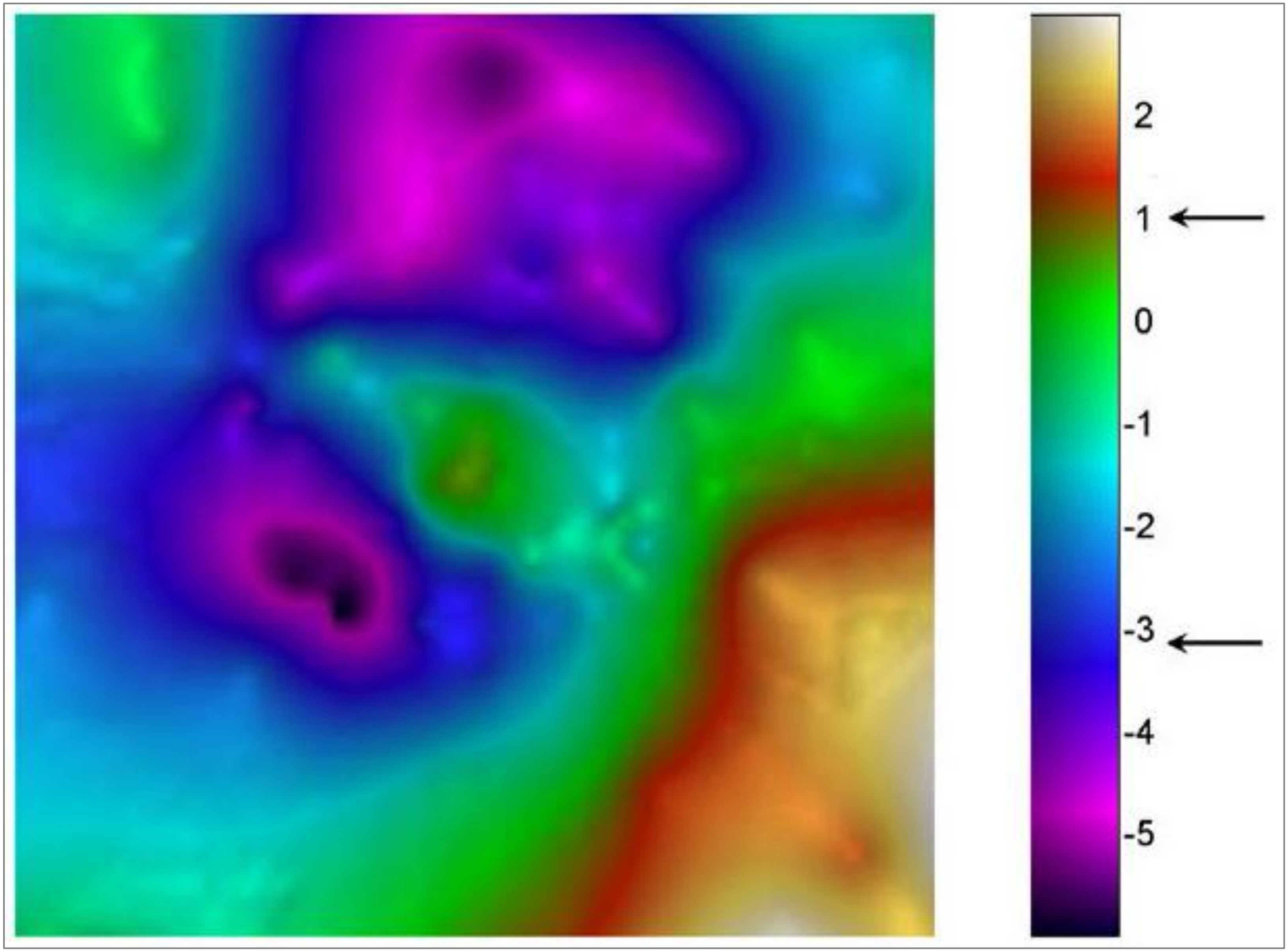

Figure 7. Map of residual gravity anomaly displayed with spectrum.

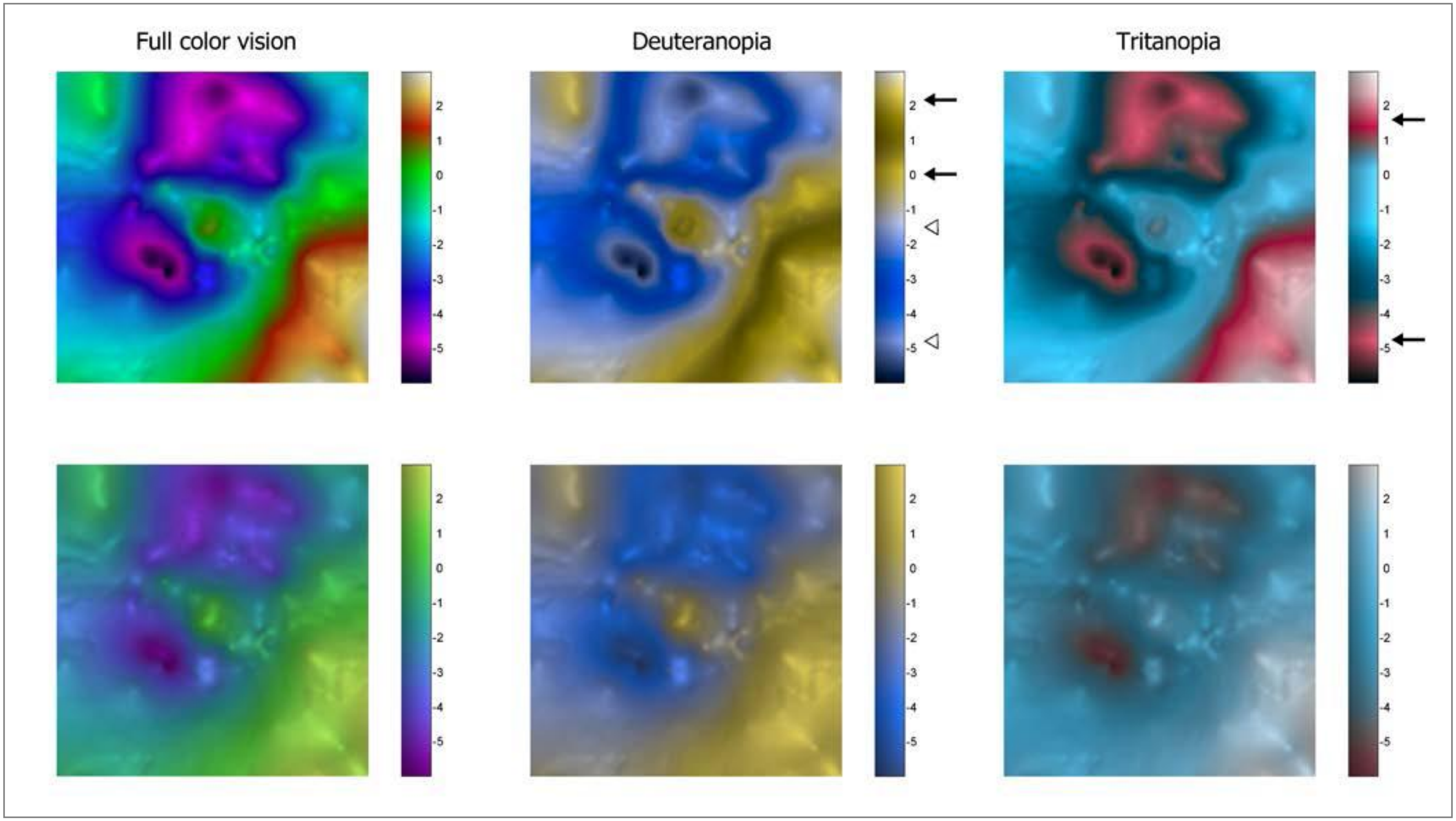

Figure 8. Comparison of spectrum and cube law rainbow for all viewers. Left column: full color vision – for the spectrum (top left, same as Figure 7) we observe the previously described artifacts; for the cube law rainbow (bottom left, same as Figure 6) we observe no artifacts. Centre column: simulation of Deuternaopia for spectrum (top centre) and cube law rainbow (bottom centre) - for the spectrum in addition to edges we now notice two pairs of colors, indicated by arrows and triangles, which are confusing. Right column: simulation of Tritanopia for spectrum (top right) and cube law rainbow (bottom right). Confusing colors are indicated by arrows.