

## USE OF COLOR IN REMOTE SENSING

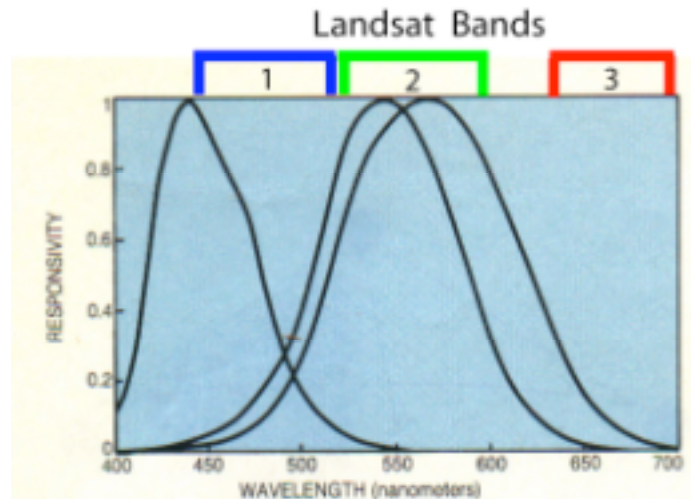
(David Sandwell, Copyright, 2004)

**Display of large data sets** - Most remote sensing systems create arrays of numbers representing an area on the surface of the Earth. The entire array is called an *image* or *scene*, and the individual numbers are called *pixels* (picture elements). The value of the pixel represents a measured quantity such as light intensity (reflected or radiated) over a given range of wavelengths. However, it could also represent a higher-level product such as topography or chlorophyll concentration or almost anything. Some active systems also provide the phase of the reflected radiation so each pixel will contain a complex number. Typical array sizes are 6000 by 6000 pixels so a system with multiple channels may require 300 megabytes of storage per scene. Moreover, a satellite can collect 50 of these frames on a single pass so the data sets can be enormous.

At some point these numbers must be put into a form so a scientist can interpret the image and perhaps publish the results in a journal. The numbers must be transformed into *RGB* (red, green, blue) pixels on a computer monitor or *CMYK* (cyan, magenta, yellow, black) of a printed page. Even though there are many excellent packages for the analysis of large remote sensing data sets, everyone should at least be aware of how this mapping from number to color is done. For a more complete understanding of this and other processes, you should take a course or read a book on image processing (e.g., *Gonzales and Woods*, 1992). Here I discuss three of the more important aspects of visual display of digital data. These are: the strengths and limitations of the human perception of colors; the common color systems; and the standard approaches of mapping numbers into color.

**Color Perception** - The excellent article by *Robertson* [1992] deals with color perception. He discusses how colors are defined in relation to the limitations of the human visual system. The eye has two types of photoreceptors, *cones* and *rods*. There are three types of cones each sensitive to a slightly different band in the visible (Figure 1). The retina contains 6-7 million cones. There is only one type of rod but there are 75-100 million of them. Rods have a broad-band response but are able to resolve details under low light levels.

Figure 1. Spectral responsivity of the three types of photoreceptors - the cones in the human color vision system. Colored boxes above plot show the spectral response of the first three bands of the Landsat Thematic Mapper [modified from *Robertson*, 1992]



Some optical remote sensing systems such as Landsat and Spot are basically modeled after the human visual system: they record images in multiple, rather narrow wavelength bands (similar to cones), they have a broad channel (*panchromatic* similar to rods) to discriminate fine detail, especially in low light levels. In addition, they are capable of stereo vision by imaging the same area on the ground from different look angles. This is analogous to the stereo vision provided by the offset between your eyes.

Because there are only three types of cones, the human visual system can discriminate colors in only 3 spectral dimensions. Consider an object that is emitting light with an intensity function  $L(\lambda)$  that depends on wavelength. Let the wavelength-dependent response function for each of the cones be  $c_r(\lambda)$ ,  $c_g(\lambda)$ , and  $c_b(\lambda)$  (shown in Figure 1) roughly corresponding to their spectral peaks at red, green and blue. The cones on the retina detect the light and send three stimuli through the optic nerve to the brain. This process is approximated by the following linear integral equations

$$r = \int L(\lambda) c_r(\lambda) d\lambda$$

$$g = \int L(\lambda) c_g(\lambda) d\lambda$$

$$b = \int L(\lambda) c_b(\lambda) d\lambda$$

where the limits of integration range over the visible part of the spectrum.

These three equations define a projection from an infinite-dimensional space of all possible color stimulus functions  $L(\lambda)$  into a 3-dimensional subspace ( $r$ ,  $g$ , and  $b$ ). Note there are an infinite

number of stimulus functions that give the same  $r$ ,  $g$ , and  $b$  values. These are called *metamers* (Figure 2).

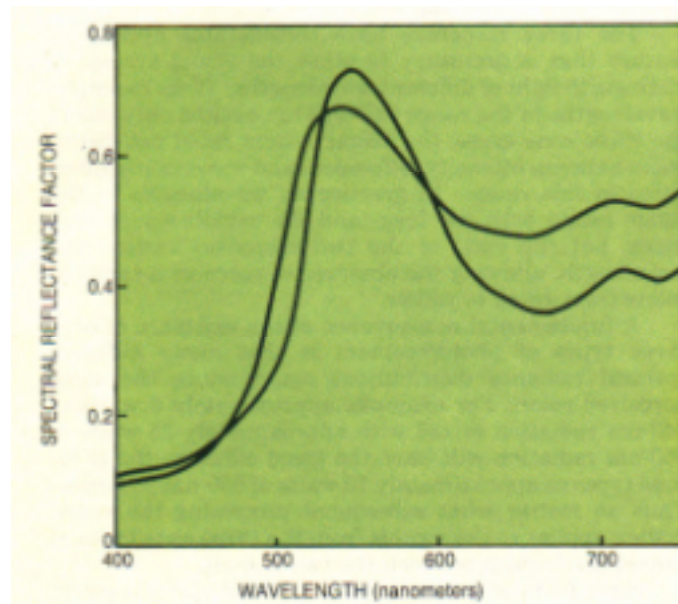


Figure 2 Spectral reflectance factors of a metameric pair of paints. When two paints with these spectral reflectance factors are illuminated by average daylight, they have the same perceived color, despite their physical differences.

**RGB versus HSV** - There are basically two ways to specify colors in a computer. The *RGB* definition is the more natural approach in terms of the human visual system and it is also the approach used to drive computer monitors. Subtractive colors (*CMYK*) are used for printing and are basically a complement to *RGB*. However, if you have every tried to define a color using an *RGB* set of numbers, it is nearly impossible to achieve the desired color unless it is one of the end members. For example, guessing the *RGB* sequence for a color such as orange is nearly impossible. The *HSV* (hue, saturation, value) system provides a more natural way to define a color.

The value of hue ( $h$ ) sets the color according to the colors of the rainbow – red, orange, yellow, green, blue, violet and back to red. The *HSV* system is also commonly used to achieve artificial illumination of colored images by changing the  $s$  and  $v$  coordinates of the color. Decreasing the value ( $v$ ) moves the color toward black and decreasing the saturation ( $s$ ) moves the color toward white. The reason this works is that the *HSV* system allows movements in color space which correspond more closely to what we mean by “tint” and “shade”; an instruction like “add white” is easy in *HSV* and not so obvious in *RGB*. It is instructive to look at the relationship between

*RGB* and *HSV* using a color cube developed by the authors of GMT software [Wessel and Smith, 2004]).

Here I have copied text from the appendix of the GMT manual.

“ We are going to try to give you a geometric picture of color mixing in *HSV* from a tour of the *RGB* cube (next page). The geometric picture is helpful, we think, since *HSV* are not orthogonal coordinates and not found from *RGB* by an algebraic transformation. But before we begin traveling on the *RGB* cube, let us give two formulae, since an equation is often worth a thousand words.

$$v = \max(r, g, b)$$

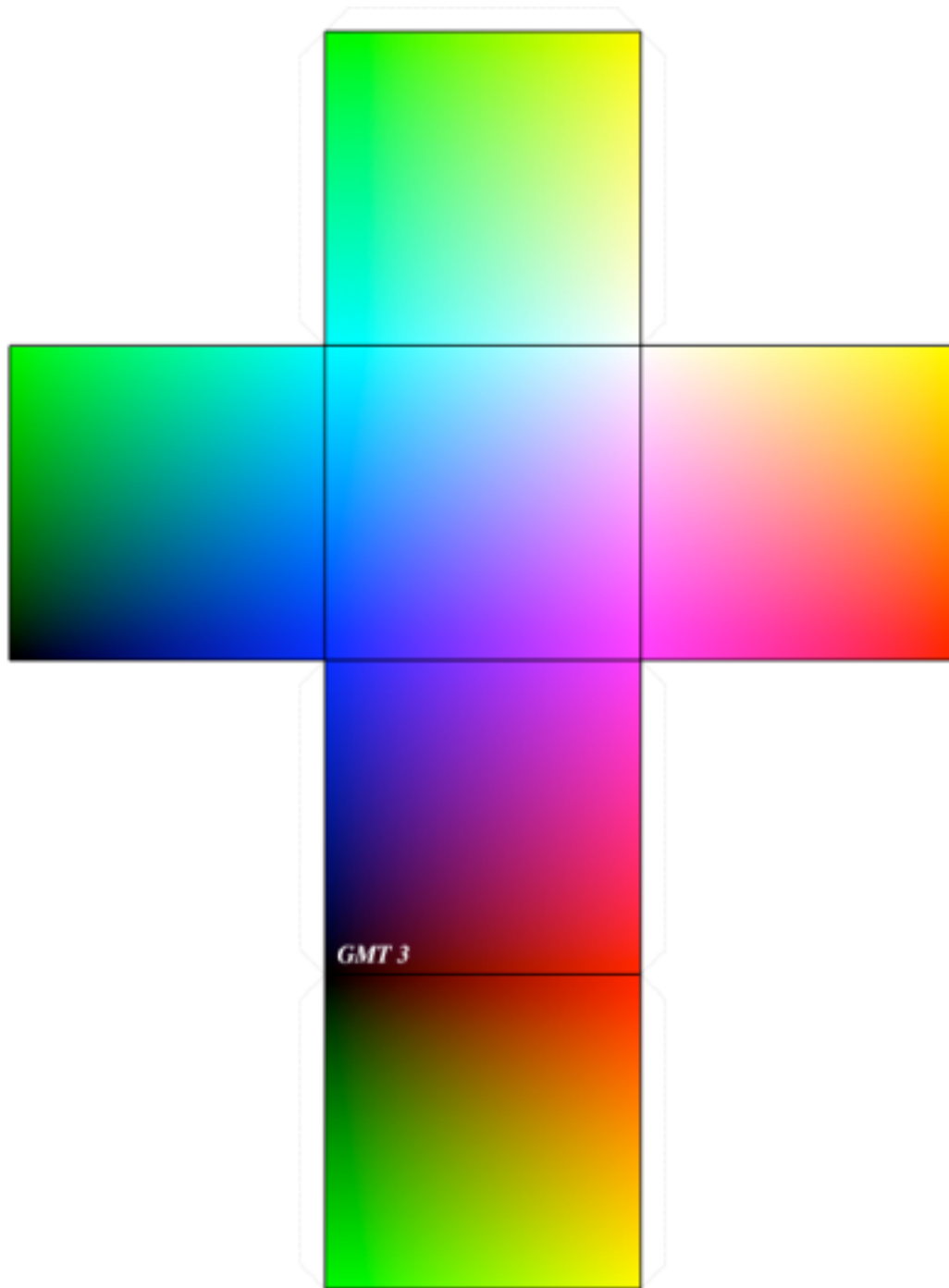
$$s = (\max(r, g, b) - \min(r, g, b)) / (\max(r, g, b))$$

Note that when  $r = g = b = 0$  (black),  $v = 0$ . Similarly when  $r = g = b = 255$  (white),  $s = 0$  (A minor annoyance is that the expression for  $s$  gives  $0/0$ ; black is a singular point for  $s$ .) The expression for  $h$  is not easily given without lots of “if” tests, but has a simple geometric explanation. So here goes: Look at the cube face with black, red, magenta, and blue corners. This is the  $g = 0$  face. Orient the cube so that you are looking at this face with black in the lower left corner. Now imagine a right-handed Cartesian  $(r, g, b)$  coordinate system with origin at the black point; you are looking at the  $g = 0$  plane with  $r$  increasing to your right,  $g$  increasing away from you, and  $b$  increasing up. Keep this sense of  $(r, g, b)$  as you look at the cube. It helps to label the  $r$ ,  $g$ , and  $b$  axes with a black marker.

The *RGB* color cube has six faces. On three of these one of  $(r, g, b)$  is equal to 0. These three faces meet at the black corner, where  $r = g = b = 0$ . On these three faces saturation, the  $S$  in *HSV*, has its maximum value;  $s = 1$  on these faces. (Accept this definition and ignore the  $s$  singularity at black for now). Therefore  $h$  and  $v$  are contoured on these faces;  $h$  in gray solid lines and  $v$  in white dashed lines ( $v$  ranges from 0 to 1 and is contoured in steps of 0.1).

On the other three faces one of  $(r, g, b)$  is equal to the maximum value. These three faces meet at the white corner, where  $r = g = b = 255$ . On these three faces value, the  $V$  in *HSV*, has its maximum value;  $v = 1$  on these faces. Therefore  $h$  and  $s$  are contoured on these faces;  $h$  in gray

solid lines and  $s$  in black dashed lines ( $s$  ranges from 0 to 1 with contours every 0.1).”



GMT 2004 Jan 12 10:24:51 Example 11 in Cookbook

**Transforming Numbers into Color** – Two remote sensing examples are used to illustrate the use of the *RGB* and *HSV* color systems. Perhaps the only time is convenient to use the *RGB* system is when you have a sensor with three bands that approximately coincide with the red, green, and blue regions of the visible spectrum. A Landsat image of San Diego follows where I have done a poor

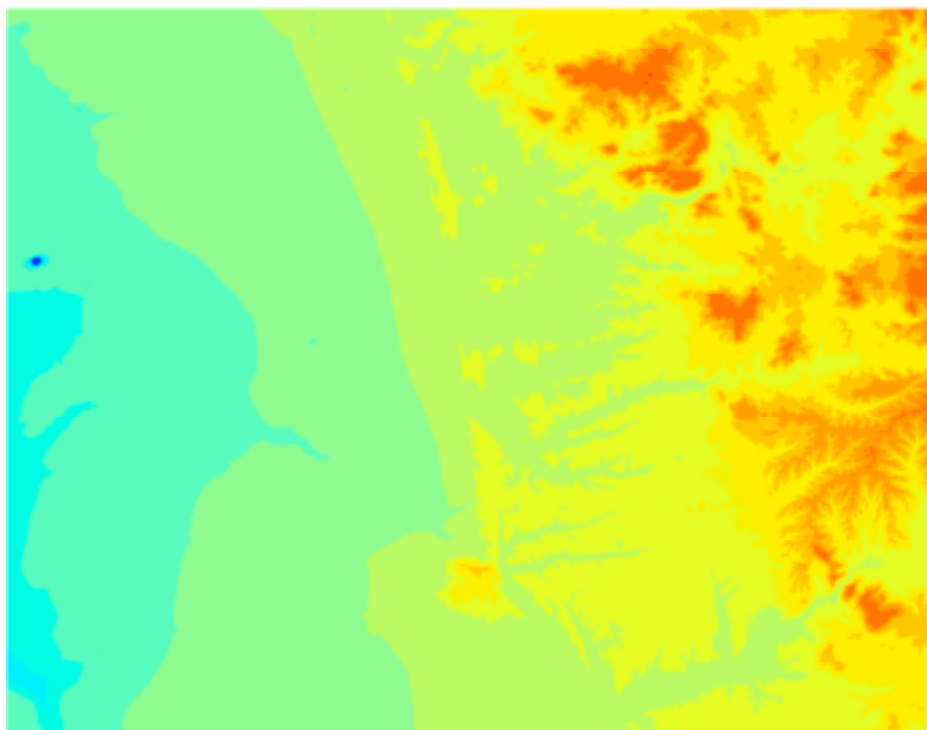
job of mapping bands 1, 2, and 3 into  $b$ ,  $g$ , and  $r$ . Perhaps with guidance from Figure 1 you could do a better job.

Landsat TM - 0.48  $\mu\text{m}$ , 0.56  $\mu\text{m}$ , 0.66  $\mu\text{m}$  (MATLAB)

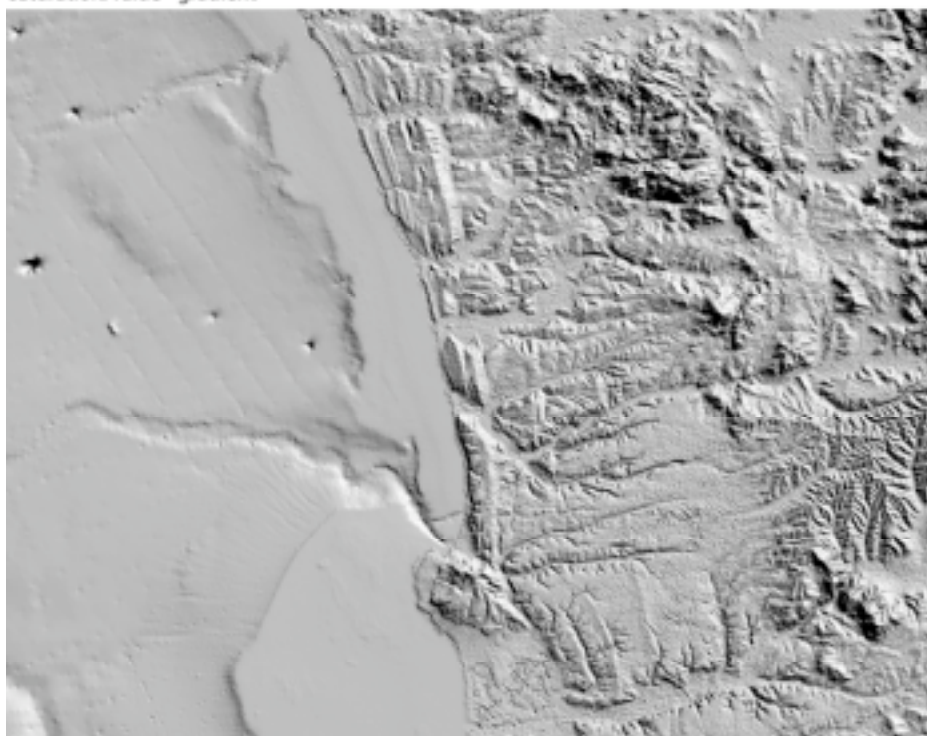


The second example is topography of the La Jolla area derived from the Shuttle Radar Topography Mission (SRTM) as well as all available offshore data to create the bathymetry. Here the *HSV* system is used to map elevation into hue and the slope of the topography into saturation/value. Three examples are provided. The first is simply a mapping of elevation into hue. The second is a mapping of slope into shading. The third is a combination of hue and shading.

La Jolla Topography  
hue- elevation

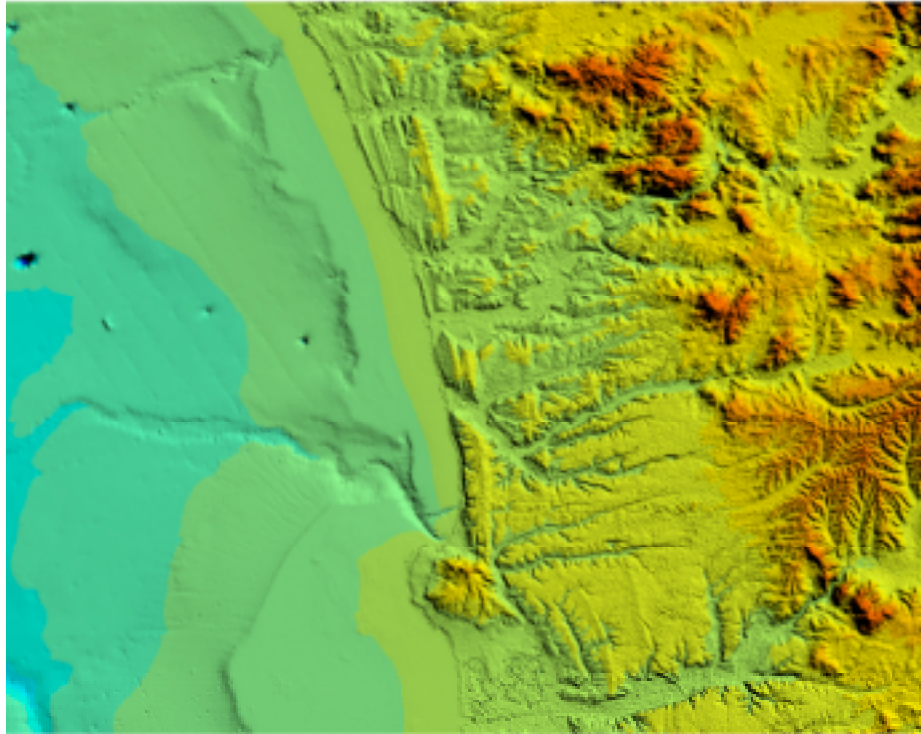


La Jolla Topography  
saturation/value - gradient





La Jolla Topography  
hue- elevation  
saturation/value - gradient



Some final thoughts about color:

- 1) Don't use color unless it is necessary. If you want to show just one parameter such as radar backscatter or topography use black and white. Your eyes do not see details in color as well as in black and white, especially at low light levels. Color is expensive to print in journals and difficult to photocopy.
- 2) Use color if you need to show 2 or three parameters in the same image. It is best to use hue to represent the parameter that varies more slowly across the image and use saturation/value to show the high spatial wavenumber components.
- 3) It is impossible to show more than three parameters on the same image unless you use stereo images.

## References

- Gonzalez, R. C. and R. C. Woods, Digital image processing, Reading, Mass. : Addison-Wesley, Reading Mass., 716 p. 1992.
- Robertson, A. R., Color Perception, *Physics Today*, p. 24-29, Dec. 1992
- Wessel, P. and W. H. F Smith, Generic Mapping Tools, <http://gmt.soest.hawaii.edu/>, 2004.