Two Lessons:
Studying Ocean Color From Space

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Lesson 1:
Learn how ocean color satellites ‘see’ the Earth:

Background:

Ocean color satellites do not have cameras, but rather they use electronic instruments (**sensors**) to measure reflected light (**radiances**). These electronic instruments convert photons falling on their light-sensitive elements into electrical signals that are assigned numerical, or **digital**, values. The spacecraft converts the numerical values into a binary data stream that is then transmitted down to receiving stations on the ground.

An ocean color satellite has several sensors sensitive to different **wavelengths** (also called **bands**) of light, allowing the satellite to detect different colors. Computers on the ground translate the stream of numbers from the different sensors back into their original values and combine them to reconstruct the images. Equations are used to calculate chlorophyll concentration values and other parameters from the satellite data by comparing values from different bands.

The following activities will show you how colors are recognized and parameters are calculated using data from different color bands

A. Color Recognition:

Activity Objective:

To show how satellites use monochromatic sensors to collect data on the color of objects on the Earth’s surface.

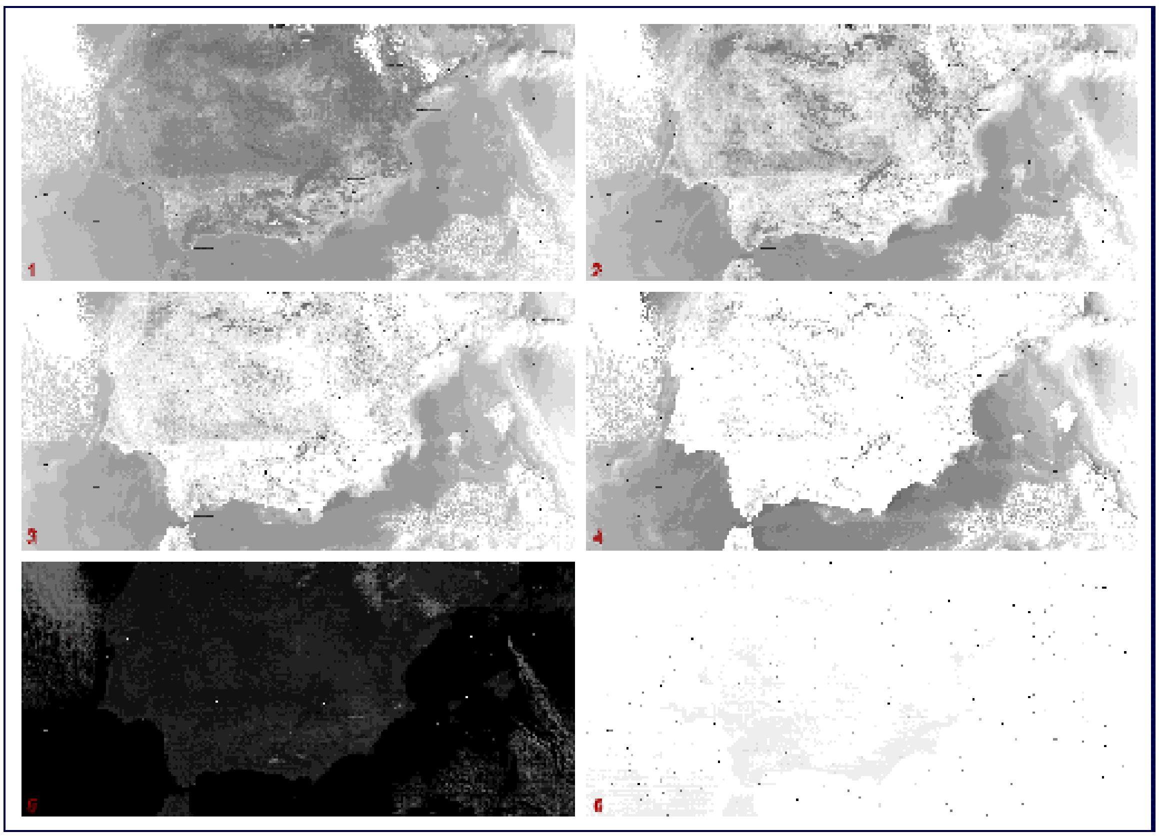
Materials:

Slide projector
Color filters: red-, green- and blue-colored acetate
Various colored objects (fruit, paper cutouts, color photographs, plastic toys, etc.)
Dark room

Background:

An ocean color satellite collects images of the Earth’s surface in various colors. The satellite is equipped with a set of detectors designed to be sensitive to only a narrow color range, so that each detector records only one color and together they collect all of the colors. A numerical value is assigned to the number of photons received by each sensor. This number corresponds to the brightness of the light falling on each pixel and is used to generate the image ‘seen’ by each sensor. The numbers range from 0 to 255. This range yields 256 shades of grey ranging from black (0) to white (255). The grey-scale images in each of the colors are transmitted to Earth as a series of binary numbers, one image from each sensor.

The Strait of Gibraltar as it looked to each of the 6 Coastal Zone Color Scanner (CZCS) sensors, shows how some details are brighter in one color than in others:



Spain and the Strait of Gibralter   Coastal Zone Color Scanner, Bands 1-6

Channel 1: blue
Channel 2: green
Channel 3: yellow
Channel 4: red
Channel 5: far red
Channel 6: infra-red

This activity demonstrates the color imaging process used by ocean color satellites. By examining various objects in red, green, and then blue light, you will note that the brightness varies with the illuminating wavelengths. Using colored light is equivalent to observing the objects through colored filters or using narrow band sensors. The way each object appears relates to its “real” colors as seen in normal light. By noting subtle differences in the brightness in each of the three colored lights, the actual colors of the objects can be identified.

Exercise:
The instructor will give you a closed box of toys. Do not look at them until the room has been darkened.

1. Darken the classroom and cover the lens of the slide projector with the red acetate. Turn on the slide projector light.

2. Open the box and place the toys in a row. Compare their relative brightness. Compared to each other, do they look brighter or darker in the red light?

3. Place the toys in order of relative brightness, from brightest to darkest in the red colored light. Translate your observations into bar chart histograms in the table below, (brightest: value =5; darkest: value=1).

4. Turn off the light and replace the red acetate with the green. Turn on the projector light and repeat with the same objects. Repeat again, but this time use the blue filter. Record your rankings in the table below. Complete your histogram bar charts for the three bands.

Object	Val	R	G	B	Object Name	Actual Color
1.	5 4 3 2 1					**Red**
2.	5 4 3 2 1					**Yellow**
3.	5 4 3 2 1					**Green**
4.	5 4 3 2 1					**Blue**
5.	5 4 3 2 1					**White**

5. Turn on the room lights and verify the actual colors of the objects.

6. Try to identify the colors of 5 new objects. You will not be able to guess their color based on their shape. Look at the unknown objects in the red, green, and then blue lights. Create histograms for these unknown objects and compare to the histograms of the known colors to deduce the actual colors of the unknown objects:

Object	**Val**	**R**	**G**	**B**	**Deduced Color**	**Actual Color**
1.	5 4 3 2 1					
2.	5 4 3 2 1					
3.	5 4 3 2 1					
4.	5 4 3 2 1					
5.	5 4 3 2 1					

7. Turn on the room lights and verify the actual colors of the unknown objects. Were you right? Why or why not?

For Further Research:

• Take home pieces of colored acetate and look through them at a variety of colored objects. How does a show on your color television look through the filters?

• Is anyone in your family color-blind? Interview them and show them several colored objects. Write down how they describe the colors.

B. Calculating Chlorophyll Concentration:

Activity Objectives:
To calculate chlorophyll values by comparing data from two different color bands.

Materials:
Table of values
Calculator
Colored pencils

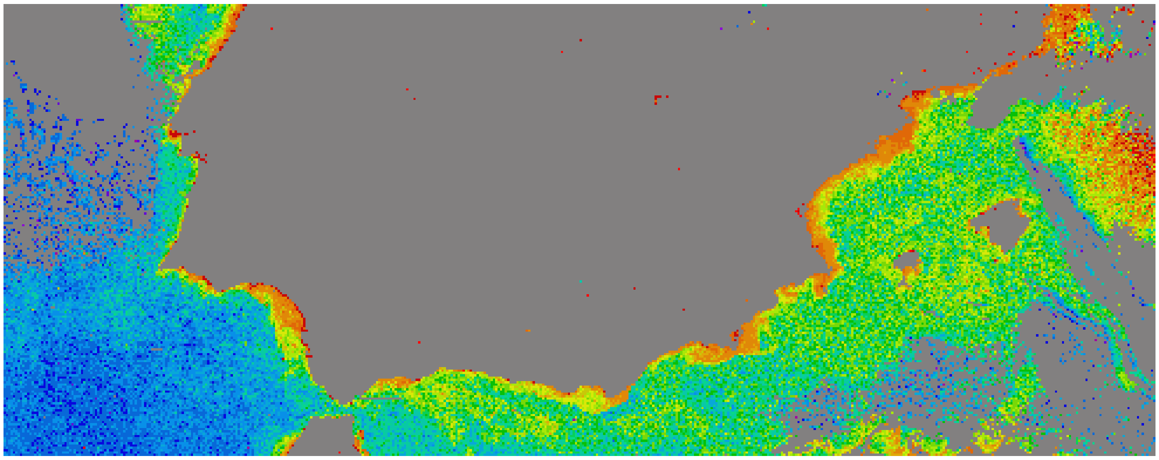
Background:
Because images collected by spacecraft are digital, scientists can use computers to manipulate them and to do calculations using the data. This manipulation is roughly analogous to the adjustment of color, brightness, and contrast controls on a television set. Data collected from different sensors can be combined in an equation to calculate specific values, such as chlorophyll concentration in the sea or dust content of the air. You were employing this principle in Lesson 1A by relating your observations of the brightness of various objects in three different colors to their actual color.

To measure ocean color from space, the blue and green images of a scene are compared to calculate chlorophyll values. This is done by substituting pixel values of a scene collected in the two colors into an equation, or **algorithm**. Algorithms are used to translate pixel values into real geophysical parameters, such as "milligrams of chlorophyll per cubic meter". This is an example of a simple equation used to calculate chlorophyll concentration values by relating the blue and the green values for each pixel:

$$\text{Chlorophyll Concentration } (mg/m^3) = 1.1298 \left[\frac{\text{blue pixel value } (550\ nm)}{\text{green pixel value } (443\ nm)} \right]^{1.71}$$

This is called an **empirical equation** because it was derived from measurements matching ocean color seen from a satellite with actual amounts of chlorphyll pigment measured in water samples collected by a ship at the same place and time. The numbers "1.1298" and "1.71" are put into the equation so that it will give the correct answer for places where there is no ship data.

Once a chlorophyll amount has been calculated for each pixel, a color scale is assigned to cover the range of grey values and the image is redrawn to look like this:



Now each pixel indicates a certain concentration of chlorophyll, and we can begin to study what the data are telling us about the oceanography and the biology of the area shown in the scene. For the CZCS color scale shown here, chlorophyll pigment concentrations were assigned as follows:

Greyscale Value		Color	Pigment Concentration (mg/m^3)
1.	200-252	bright red	p 10
2.	156-199	dark red	3 p<10
3.	131-144	orange-brown	1.5 p<3
4.	117-130	orange	1 p<1.5
5.	113-116	gold	.9 p<1
6.	109-112	yellow-gold	.8 p <.9
7.	104-108	yellow	.7 p<.8
8.	98-103	yellow-green	.6 p<.7
9.	92-97	light green	.5 p<.6
10.	88-91	green	.45 p<.5
11.	84-87	green-blue	.4 p<.45
12.	79-83	light blue-green	.35 p<.4
13.	73-78	blue-green	.3 p<.35
14.	66-72	lightest blue	.25 p<.3
15.	58-65	light blue	.2 p<.25
16.	48-57	grey-blue	.15 p<.2
17.	33-47	blue	.1 p<.15
18.	23-32	blue-purple	.075 p<.1
19.	8-22	purple	.05 p<.075
20.	1-7	lavender	.04 p<.05

Execise:

1. The table below contains pixel value ratios from an actual CZCS scene. The ratio is calculated by dividing the blue channel pixel value by the green channel pixel value, B/G. These ratios values are dimensionless.

Pixel Ratio Values (blue pixel value/green pixel value)

.7237	.5606	.5987	.5987	.5606	.6564	.5606	.4782	.5606	.6564
.5987	.7237	.5987	.5206	.4782	.5606	.5206	.4782	.5206	.4782
.5987	.5606	.5606	.5606	.4782	.5606	.5206	.5206	.4782	.4330
.5606	.5606	.5606	.5606	.5606	.4782	.5206	.5606	.4330	.4330
.5987	.5606	.5206	.4782	.4782	.4782	.4782	.4330	.4330	.4330
.5206	.4782	.5606	.4782	.4782	.4330	.4330	.4330	.4330	.4330
.5206	.5606	.4782	.4782	.4330	.4330	.4330	.3841	.3841	.3841
.4782	.5606	.4782	.4330	.4782	.3841	.3841	.4330	.4330	.4782
.5206	.5206	.4782	.3841	.3841	.3841	.4782	.4330	.4330	.4782
.4782	.5206	.4782	.4330	.3841	.3841	.3841	.4330	.3841	.3841

2. Plug the pixel ratio values from the table above into this equation to calculate a chlorophyll value for each pixel in the image.

$$\text{Chlorophyll Concentration } (mg/m^3) = 1.1298\left[\frac{\text{blue pixel value } (550\text{ nm})}{\text{green pixel value } (443\text{ nm})}\right]^{1.71}$$

Write the calculated chlorophyll values for each pixel in this table:

Chlorophyll concentration (mg/m3)

3. For each chlorophyll concentration value, fill in the appropriate color in the corresponding box on the grid below. (Each box contains a number corresponding to the 20 color scale above. Your calculated chlorophyll concentration values should fall within the range of that color.)

Ocean Color Image

8	**11**	**10**	**10**	**11**	**9**	**11**	**13**	**11**	**9**
10	**8**	**10**	**12**	**13**	**11**	**12**	**13**	**12**	**13**
10	**11**	**11**	**11**	**13**	**11**	**12**	**12**	**13**	**14**
11	**11**	**11**	**11**	**11**	**13**	**12**	**11**	**14**	**14**
10	**11**	**12**	**13**	**13**	**13**	**13**	**14**	**14**	**14**
12	**13**	**11**	**13**	**13**	**14**	**14**	**14**	**14**	**14**
11	**11**	**13**	**13**	**14**	**14**	**14**	**15**	**15**	**15**
13	**11**	**13**	**14**	**13**	**15**	**15**	**14**	**14**	**13**
12	**12**	**13**	**15**	**15**	**15**	**13**	**14**	**14**	**13**
13	**12**	**13**	**14**	**15**	**15**	**15**	**14**	**15**	**15**

4. **WOW!** That was a lot of work! Can you recognize anything in your ocean color image? Why or why not?

Answer Key:

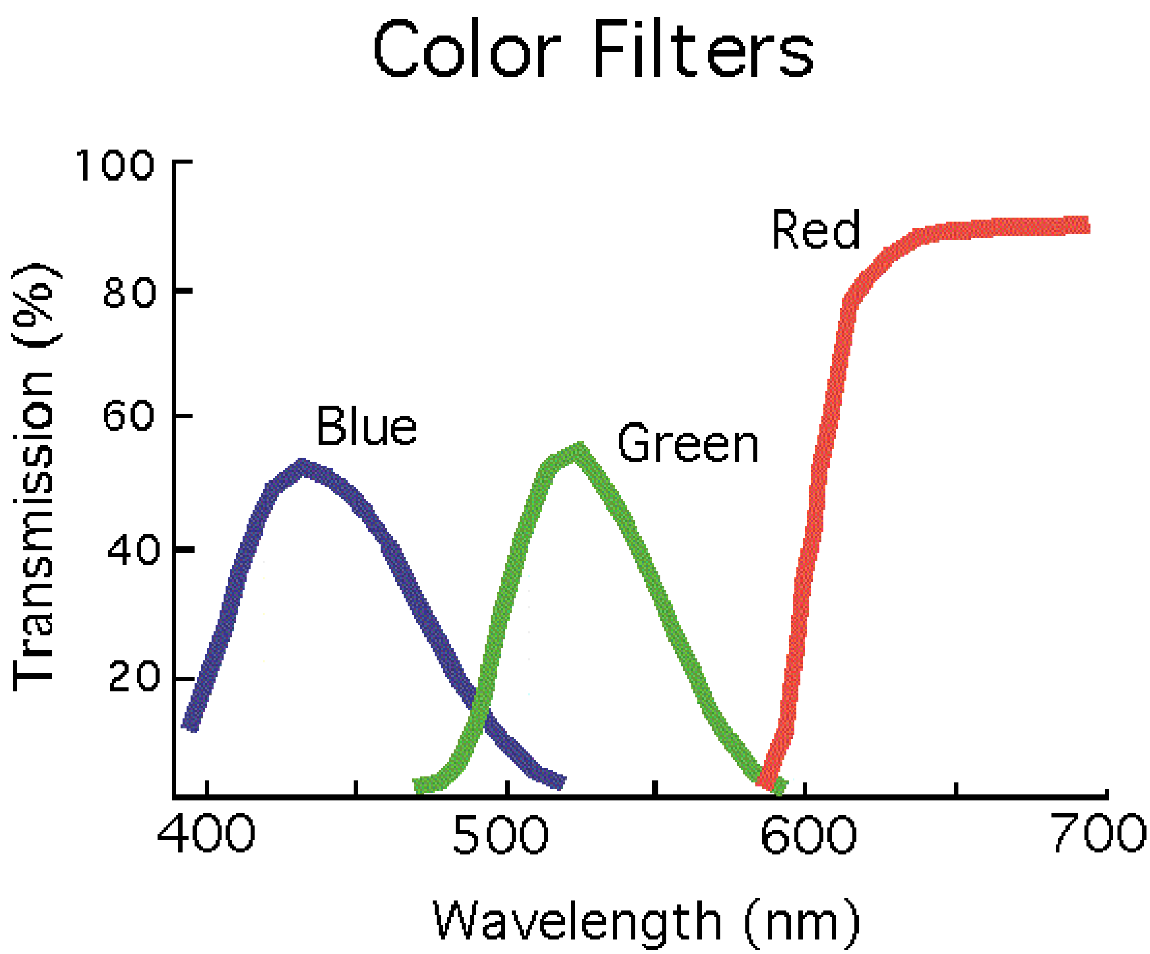
Note: Basic concepts about the electromagnetic spectrum should be understood before teaching these lessons. A simple description of the electromagnetic spectrum can be found in "Space Based Astronomy: A Teacher's Guide with Activities" (EG-102, NASA Headquarters, Education Division, Code FET, Washington DC 20546-0001, August 1994), Unit 2: The Electromagnetic Spectrum (Introduction). The activities in this Lesson were adapted from Unit 4 in this publication.

Lesson 1 A.

Stray Light:

It is very important to use good color filters for this exercise. You may have trouble if you do not use gel filters. Ordinary colored cellophanes and plastics may pass other colors. This is called "stray light". For instance, green objects may actually look green when using the blue filter. This means the blue filter is not blocking all of the yellow light.

Stray light at other color frequencies allows the students see the actual colors of the objects making the exercise much easier and ruining the desired effect. Good filters will pass only the colors desired while minimizing stray light. Inexpensive professional color filters are available from vendors like Edmund Scientific. This chart illustrates the frequencies of light passed by KODAK gel filters:



Try out your filters ahead of time to make sure they work well with the objects you have chosen. You will find the red filter is most effective at blocking light from other parts of the color spectrum. It is best to start this activity with the red filter first.

For the first part of this exercise, it's fun to use toys that have a certain color associated with them eg: a red fire hat, a yellow school bus, green Kermit the frog etc....I like to raid my son's toybox for large, colorful objects.
For the second part, use geometric shapes, boxes or other uncharacterizable objects for the unknowns eg: a blue swimsuit, a red ball, a green glove, a yellow box etc. Have fun; bring in some unusually colored objects, like a blue banana, a yellow apple...Any fluorescent colored object will throw the class off. These colors reflect light in quite a different way from 'standard' colors like blue, red or green.

Results:

Here is an example of some results drawn as histograms:

Object	Val	R	G	B	Name	Actual Color
1.	5 4 3 2 1				**Fire Hat**	**Red**
2.	5 4 3 2 1				**School Bus**	**Yellow**
3.	5 4 3 2 1				**Kermit the Frog**	**Green**
4.	5 4 3 2 1				**Cookie Monster**	**Blue**
5.	5 4 3 2 1				**Space Shuttle**	**White**

Discussion:

Remote Sensing Realities:

You will find it practically impossible to find two objects from different sources with exactly the same color. The class will even notice a difference in the histograms of objects that appear to be nearly the same color in white light, illustrating the power of this analytical spectral technique for color recognition.

If slight color differences can be seen using this technique with toys and the naked eye, imagine how discerning satellites are!! Satellite digital spectral analysis is sensitive enough to allow analysts to discern the different chemical make-up, and thus origins, of paint on vehicles on the ground miles below.

Students may complain about glare on an object, lack of reflectivity from a furry toy, or lack of discernability because the object is too small. These complaints illustrate three important limiting factors in characterizing objects using satellite remote sensing:

• Aspect, or surface area visible
• Surface roughness or reflectivity and
• Sun glint

Because of the small sampling size of this exercise, it will not be totally clear to everyone that a ‘red’ unknown object can be correctly deduced from the histogram of a known red object. Three important remote sensing ideas can be presented here:

• Data analysis is a subjective process based on data collection, analysis and hypothesis.

• This subjectivity can be lessened by taking more data and applying statistical analysis.

• Ground truth data provide the only key to understanding the rest.

Someone may ask ‘Why not just use a color camera rather than a whole collection of sensors sensitive to different bands of color?’ The early Landsat satellites did indeed have both a black and white camera and a digital sensor called a Multi-Spectral Scanner (MSS). At that time, the camera was actually more dependable than the electronic sensor. Over the years, researchers and engineers have perfected digital sensors and continue to refine them. Today’s Earth satellites use digital sensors almost exclusively.

Digital sensors have two main advantages over film or televison cameras:
1. Cameras produce **analog images**, not **digital data**. This means you cannot perform mathematical calculations or manipulations on analog images, making it impossible to derive quantities such as chlorophyll concentration from the image, even though cameras can be equipped with color filters to collect data in several color bands.

2. While the resolution of a camera is limited by the chemistry of its film emulsion, the resolution of electronic sensors gets better every year with advances in technology.

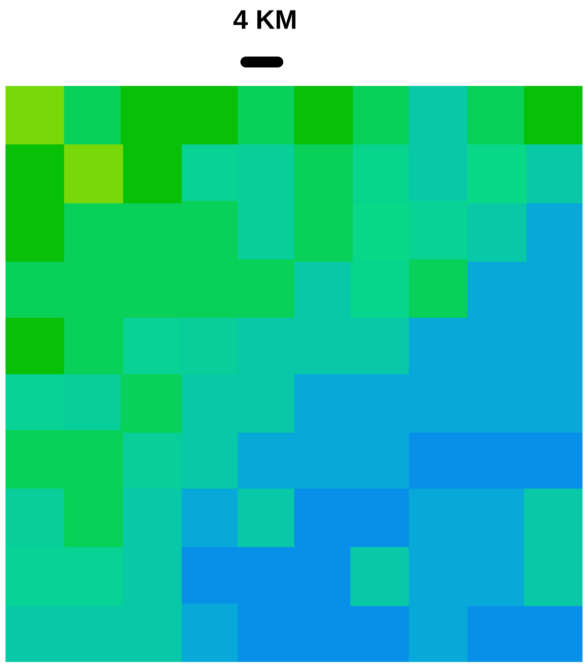
Someone may ask if three or more discreet spectral sensors can really see everything. The answer is “No, but it’s the best we can do for now.”. The ideal sensor would cover a broad and continuous spectral range. Until recently, this has not been possible because of limitations in sensor and spacecraft technologies. However, new designs for future satellite sensor systems employ this idea. These new satellites are called “hyperspectral” satellites.

It is somewhat likely you will have at least one student in the class who cannot distringuish the difference between red and green. This is a genetic trait known as red-green color blindness, and it occurs in approximatey 8/100 of males. His observations will be different from those of the other students. Discuss how they are different. The class should soon realize that he is not perceiving the red and green in the same way.

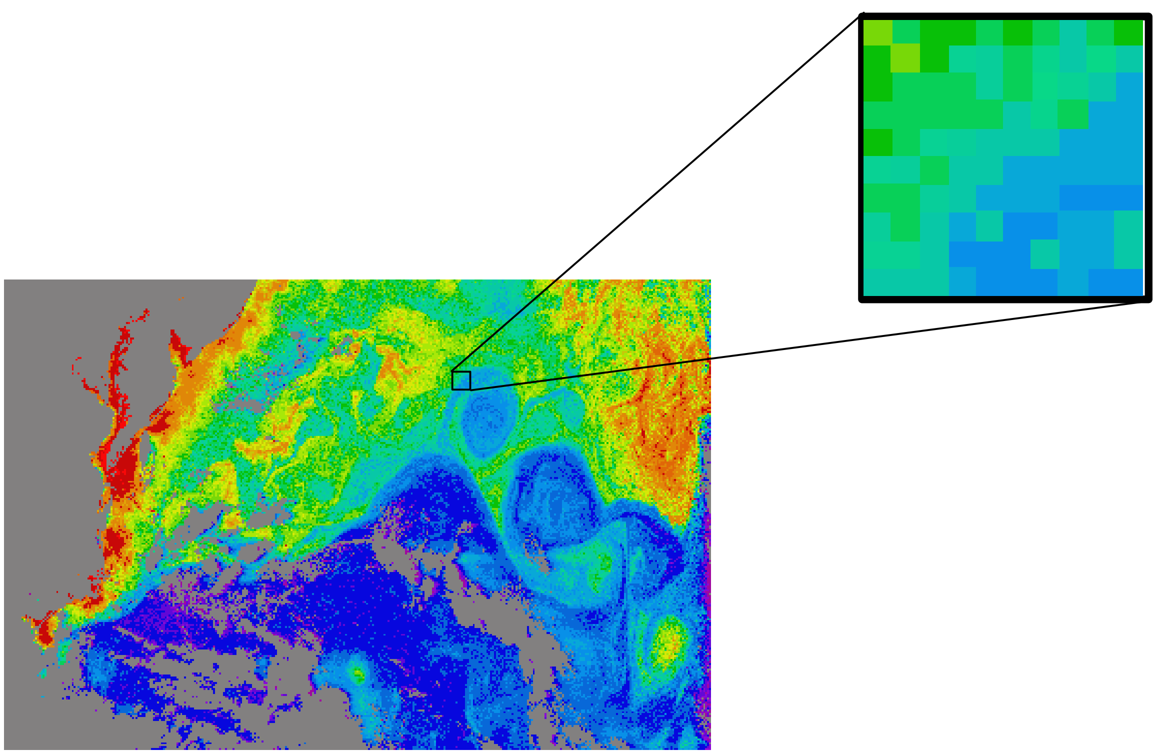
Lesson 1 B.

Ocean Color Image Chlorophyll Value Answer Key (mg/m3)

.65	.42	.47	.47	.42	.55	.42	.32	.42	.55
.47	.65	.47	.37	.32	.42	.37	.32	.37	.32
.47	.42	.42	.42	.32	.42	.37	.37	.32	.27
.42	.42	.42	.42	.42	.32	.37	.42	.27	.27
.47	.42	.37	.32	.32	.32	.32	.27	.27	.27
.37	.32	.42	.32	.32	.27	.27	.27	.27	.27
.42	.42	.32	.32	.27	.27	.27	.22	.22	.22
.32	.42	.32	.27	.32	.22	.22	.27	.27	.32
.37	.37	.32	.22	.22	.22	.32	.27	.27	.32
.32	.37	.32	.27	.22	.22	.22	.27	.22	.22



The resulting plot should look something like this. Each square pixel covers approximately 16 square kilometers, (an area about the size of Washington D.C.). The whole image of 100 pixels covers about 1600 square kilometers (576 square miles). The next figure illustrates the scale of the problem. The 10x10 square completed in the first part of the exercise is actually only one small part of a much larger and very interesting image of the Gulf Stream:



Gulf Stream, May 8, 1979

Discussion:

The Gulf Stream image above has four kilometer resolution. In other words, each pixel is four kilometers on a side. This means you cannot resolve the shape of any feature smaller than four kilometers. Thus, a four kilometer resolution satellite image cannot show many small scale features that exist in the ocean. Most satellite images have four kilometer or lower resolutions. One kilometer resolution is considered 'good' resolution, but is more expensive to collect and process. The image resolution of satellite data is increasing as sensor technology and data processing techniques evolve.

Someone in the class may notice that there are actually only eight different chlorophyll values in this exercise. Real data would be a lot more variable...give that student a gold star! You should expect each pixel to reveal a different chlorophyll value in real data. (For this exercise, the author chose to use only eight values in order to reduce student effort.)

You will probably find that the students spend a lot of time agonizing over the accuracy of their calculations. However, even if they make errors, by doing this exercise they will understand the following important principles in remote sensing:

• It takes a lot of calculations to reveal information about even a small 10x10 pixel area.

• You can't really recognize anything with only 100, 4km pixels.

• This tedious work explains why we use computers to process satellite images and also why satellite remote sensing was not really possible before the advent of computers.

Some additional information on color blindness...
(adapted from an article by Joe Pfeiffer, pfeiffer@nmsu.edu)

Color blindness is a general term for a deficiency in the visual system that leads to a distorted color perception. Speaking very loosely, we have three types of color receptors in our eyes, sensitive to red, green and blue. We also have black and white receptors (these last are more sensitive than the color receptors, which is why we have deficient color vision at night). Color blindness comes as a result of a lack of one or more of the types of
color receptors. There is a normal variance in color reception; nobody's color vision is "perfect" -- whatever that might even mean!

Trying to describe how the color sense of a color blind person differs from that of a color sighted person is frustrating and fruitless (a conclusion based on nearly four decades of trying to understand how the world looks to my color blind father!). The best I can do is to try to describe effects.

The most common form of color blindness is red-green color blindness, which affects approximately 8% of the male population and some very small percentage of the female. This form of color blindness is a result of a lack of red receptors (what? not green? just trust me -- if you ask, I'll start talking about opponent color theories). If a red-green color blind person sees a red object and a green object which are about equally bright, the red object will seem much darker than the green one. This person will find the display of
an old LED calculator almost unreadable A good approximation to the world of a color blind person can be obtained by unplugging the red cable from a graphics display.

There can also be other forms of color blindness -- yellow-blue is the second most common form, but it's very, very rare. And it is possible to have the color receptors missing entirely, which would indeed result in somebody having monochrome vision."