Unit I. Ocean Color- Table of Contents

This material is background information for teachers. This should be read and discussed before presentation. *Student Information Sheets*: This is background material for students. They should be copied and given to students before the video presentation. Activities should be done as a follow-up after the program. Questions should be discussed after the show.

The staff at Project Oceanography would like to thank the following people for their assistance in preparing this packet:

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History and Other Background Information

The first observations of ocean color from space (and the only long-term satellite observations to date) were carried out by the Coastal Zone Color Scanner (CZCS), a radiometer with visible and infrared spectral channels that operated on NASA's Nimbus-7 research satellite from 1978 to 1986. Despite being designed as a proof-of-concept mission with a nominal one-year lifetime, CZCS gathered a rich harvest of new data which have permitted an unprecedented view of the world's oceans. The CZCS global data sets lay the scientific foundation for a new generation of satellite ocean color measurements in the 1990s.

The past ten years have witnessed a revolution in the way oceanographers view the biological, chemical and physical interactions in the world's oceans. Satellite measurements of ocean color have played a key role, permitting a quantum leap in our understanding of oceanographic processes from regional to global scales. The measurement of ocean color from space has revealed, for the first time, the global-scale variability in the distribution and concentration of phytoplankton. As a result of this new capability, determinations of ocean productivity, visualization of surface currents, and the rate at which the oceans sequester atmospheric carbon dioxide are all now within our reach. Such observations are also critical to major new initiatives aimed at establishing the role of the oceans in the biogeochemical cycles of elements which influence both climate and the distribution of life on Earth.

Since phytoplankton pigments absorb energy primarily in the red and blue regions of the spectrum and reflect green light, there is a relationship between the spectrum of sunlight backscattered by upper ocean layers and the distribution of phytoplankton pigments in these layers. Satellite measurements of ocean radiance at selected wavelengths can thus be used to estimate near-surface phytoplankton concentrations and the extent of primary productivity.

In addition to sustaining the marine food chain, phytoplankton strongly influence ocean chemistry. During photosynthesis, they remove carbon dioxide dissolved in seawater to produce sugars and other simple organic molecules, and release oxygen as a by-product. Phytoplankton also require inorganic nutrients (for example*,* nitrogen, phosphorus, silicon) as well as trace elements (for example, iron) to synthesize complex molecules, such as proteins. Ocean productivity thus plays a key role in the global biogeochemical cycles of carbon, oxygen, and other elements critical to both marine and terrestrial life. The rising atmospheric concentration of carbon dioxide, which may produce a global warming (the "greenhouse effect"), underscores the additional importance of the carbon cycle to the Earth's climate. The magnitude and variability of primary production are poorly known on a global scale, largely because of the high spatial and temporal variability of marine phytoplankton concentrations. Oceanographic vessels move too slowly to map dynamic, large-scale variations in productivity; global coverage by ship-borne instruments is impossible. Only satellite observations can provide the rapid, global coverage required for studies of ocean productivity worldwide.

Excerpted from:
http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/ocdst_history_and_other_background_info.html

Ocean Color Lesson I: Energy and Color

Keywords: algorithm, photosynthetic organisms, chlorophyll, particulate matter, ocean color data, MODIS, global carbon cycle, backscatter, electromagnetic spectrum, water-leaving radiance

Why is Ocean Color Important?

The major reason scientists measure ocean color is to study phytoplankton, the microscopic ocean plants which form the base of the oceanic food web. Phytoplankton use sunlight and carbon dioxide to produce organic carbon. This process, called photosynthesis, is possible because plants contain chlorophyll, a green-colored compound which traps the energy from sunlight. Chlorophyll is also responsible for giving most marine and land plants a green color.

Because different types of phytoplankton have different concentrations of chlorophyll, measuring the color of an area of the ocean allows us to estimate the amount and general type of phytoplankton in that area.

Looking at ocean color also tells us about the health and chemistry of the ocean. In addition to light and carbon dioxide, phytoplankton also require nutrients such as nitrogen and phosphorus. The distribution of plants in the ocean also tells us where nutrient levels are high, and shows where pollutants poison the ocean and prevent plant growth. Other conditions can also affect phytoplankton growth, such as subtle changes in the climate due to seasons and variations in salinity in coastal areas. Since phytoplankton depend upon specific conditions for growth, they frequently become the first indicator of a change in their environment. Comparing images taken at different periods tells us about changes that occur over time. Because phytoplankton drift with the water, patterns in ocean color can also be used to study ocean currents.

Why are phytoplankton so important? These small plants are the beginning of the food chain for most of the planet. As phytoplankton grow and multiply, small fish and other animals eat them as food. Larger animals then eat these smaller ones. The ocean fishing industry finds good fishing spots by looking at ocean color images to locate areas rich in phytoplankton. Ocean color is therefore a valuable research tool for the study of ocean biology, chemistry, and physics.

What is Ocean Color?

The "color" of the ocean is determined by the interactions of incident light with substances present in the water. We see color when light is reflected by objects around us. White light is made up of a spectrum or combination of colors, as in a rainbow. When light hits the surface of an object, these different colors can be absorbed, transmitted through the substance, scattered, or reflected in differing intensities. The color we see depends on which colors are reflected. For example, a book that appears red to us absorbs more of the green and blue parts of the white light shining on it, and reflects the red parts of the white light. The light which is scattered or transmitted by most objects is usually not apparent to our eyes.

The substances in seawater which most affect the color reflected are the phytoplankton, inorganic particles, dissolved organic chemicals, and the water itself. Phytoplankton contain chlorophyll, which absorbs light at blue and red wavelengths and reflects green wavelengths. Particles can reflect and absorb light, which reduces the clarity (light transmission) of the water. Dissolved organic matter strongly absorbs blue light, and its presence can interfere with measurements of chlorophyll.

When we look at the ocean or observe it from space, we see that the ocean is blue because water absorbs red and reflects blue light. Using instruments that are more sensitive than the human eye, we can measure a wide array of blue shades, which reveal the presence of varying amounts of phytoplankton, sediments, and dissolved organic chemicals.

Excerpted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1

Ocean Color and Global Warming

Besides acting as the first link in the food chain, phytoplankton are a critical part of ocean chemistry.

The carbon dioxide in the atmosphere is in balance with carbon dioxide in the ocean.

During photosynthesis phytoplankton remove carbon dioxide from sea water, and release oxygen as a by-product. This allows the oceans to absorb additional carbon dioxide from the atmosphere. If fewer phytoplankton existed, atmospheric carbon dioxide would increase.

Phytoplankton also affect carbon dioxide levels when they die and sink to the ocean floor. The carbon in the phytoplankton is soon covered by other material sinking to the ocean bottom. In this way, the oceans may store excess global carbon, which otherwise would accumulate in the atmosphere as carbon dioxide.

Carbon dioxide acts as a "greenhouse" gas in the atmosphere, and therefore may contribute to global warming. Sources of carbon dioxide in the Earth's atmosphere include decomposition of organic matter (such as trees), the carbon dioxide that animals and people exhale, volcanic activity, and human activities such as the burning of fossil fuels and wood.

No one yet knows how much carbon the oceans and land can absorb. Nor do we know how the Earth's environment will adjust to increasing amounts of carbon dioxide in the atmosphere. Studying the distribution and changes in global phytoplankton using ocean color and other tools will help scientists find answers to these questions. ***Excerpted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1***

How is Ocean Color Measured?

The color of ocean water and its constituents (phytoplankton, particles, and dissolved organic matter) can be measured in a variety of ways, and many sensitive instruments have been designed for this purpose. Instruments which measure the light absorbed, transmitted, and scattered can be placed in the water, either lowered on a cable from a ship or moored in place on a buoy and left to collect data for long periods of time. Absorption and scatter measurements can also be made on discrete water samples, by either placing the sample in the sample chamber of the spectophotometer or by having the seawater flow continuously through the instrument while the ship is underway. Still other instruments which measure reflectance, called radiometers, are used above the sea surface, either from the deck of the ship, or from an airplane or satellite. This last type measures a property known as water-leaving radiance – the amount and color (spectral distribution) of light re-entering the atmosphere from the ocean surface.

Water-Leaving Radiance

The radiance received at spacecraft altitudes is actually controlled more strongly by the atmosphere than by the ocean. Solar irradiance (the full spectrum of light emitted by the sun) is scattered and absorbed by the gases in the atmosphere, including water vapor (molecular [Rayleigh] scattering), from particles suspended in the air (aerosol scattering), and ozone (selective absorption). It is this scattered light which is responsible for the blue color of the sky. Sea surface reflections (sun and sky glitter) also decrease the amount of sunlight which enters the ocean. The mathematical equations used to correct the water-leaving radiances for these interactions in the atmosphere are called "atmospheric correction **algorithms**."

After light enters the ocean, it interacts with the phytoplankton, dissolved organic matter, particles, and water molecules. Some of it is eventually scattered back up through the surface. This light is called the water-leaving radiance, and it can be detected from space. Generally, much less than 10% of the total light detected by a satellite sensor will be water-leaving radiance. Because such a large part of the radiance signal the satellite detects comes from the atmosphere, the atmospheric correction factors are extremely important for generating accurate ocean color data. In fact, the atmospheric effect is so large that if we were able to look at the ocean from the height of the satellite, it would appear to us to be blue even if the actual color of the ocean were black. Scientists are continuing to research how best to design the atmospheric correction algorithms.

Because there is a strong relationship between the color of most of the open ocean and the phytoplankton chlorophyll concentration, it is possible to develop a water-leaving radiance equation (algorithm) for calculating phytoplankton biomass in the ocean from satellite data. ***Excerpted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1***

Activities

Activity I. Internet Ocean Productivity

Ocean color sensors measure the amount of plant biomass by measuring the color due to the presence of chlorophyll. The concentration of phytoplankton chlorophyll and other pigments is related to phytoplankton growth rate, also called productivity. Thus, ocean color gives us an indirect measure of ocean productivity. In this activity, you can use images and data available on the internet to draw some conclusions about where and why productivity is high or low.

1.Print out a blank map from internet **(http://seawifs.gsfc.nasa.gov/SEAWIFS/LIVING_OCEAN/LIVING_OCEAN.html)** and outline the ocean regions with higher productivity.
2. Consider the colors in the legend from green to red to be areas high in productivity. Color these areas red on your map using a colored pencil, pen or crayon.
3. Color the less productive areas on your map in blue.
4. Compare/contrast productivity near the coastal areas with that in the mid-ocean regions.
5. Compare the productivity of ocean water near the equator with that in the northern and southern latitudes in these areas:

- the mid-Atlantic
- the mid-Pacific
- eastern coastline of North and South America
- western coastline of North and South America
- western coastline of Asia

Discussion Questions:

1. In the region of the equatorial Pacific, where is the ocean most productive?
2. In the region of the equatorial Atlantic, where is the ocean most productive?
3. Compare/contrast the productivity in the oceans in the northern and southern hemispheres.
4. Can you think of any factors that cause the differences?

5. Predict at least three factors that affect the productivity of the oceans.

Activity II: Make a Greenhouse

Materials:

Two cardboard shoe boxes
Clear plastic wrap
Two regular "weather type" thermometers
Desk light with 75 watt or larger bulb.

Procedure:

Place some paper towels loosely in the bottom of each shoe box, then lay the thermometer on the towels. Cover the open top of one box with plastic wrap, taped to the side of the box; leave the other box with the top off (open). Place the boxes side by side, and move the desk light so it shines evenly into both boxes. Record the temperature in each box every minute for 10 minutes. Plot the temperatures on a graph with time as the "x" (horizontal) axis and temperature as the "y,' (vertical) axis.

Analysis:

Discuss the differences you see in the observed temperatures in the two boxes, and why this is happening.

Variation:
Try replacing the paper towels in each box with black paper. Repeat the experiment. What differences do you note? ***Adapted from:***
http://seawifs.gsfc.nasa.gov/SEAWIFS/LIVING_OCEAN/LIVING_OCEAN.html

Student Information Sheet Lesson 1

Why is Ocean Color Important?

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Looking at ocean color also tells us about the health and chemistry of the ocean. In addition to light and carbon dioxide, phytoplankton also require nutrients such as nitrogen and phosphorus. The distribution of plants in the ocean also tells us where nutrient levels are high, and show where pollutants poison the ocean and prevent plant growth.

Ocean color is therefore a valuable research tool for the study of ocean biology, chemistry, and physics.

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What is Ocean Color

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Ocean Color Lesson II: Data Processing and Imagery

Ocean color observations made from an Earth orbit allow an oceanographic viewpoint that is impossible from ship or shore -- a global picture of biological activity in the world's oceans. In this lesson we will discuss how the data collected by the satellite sensor are processed to obtain useful products for researchers.

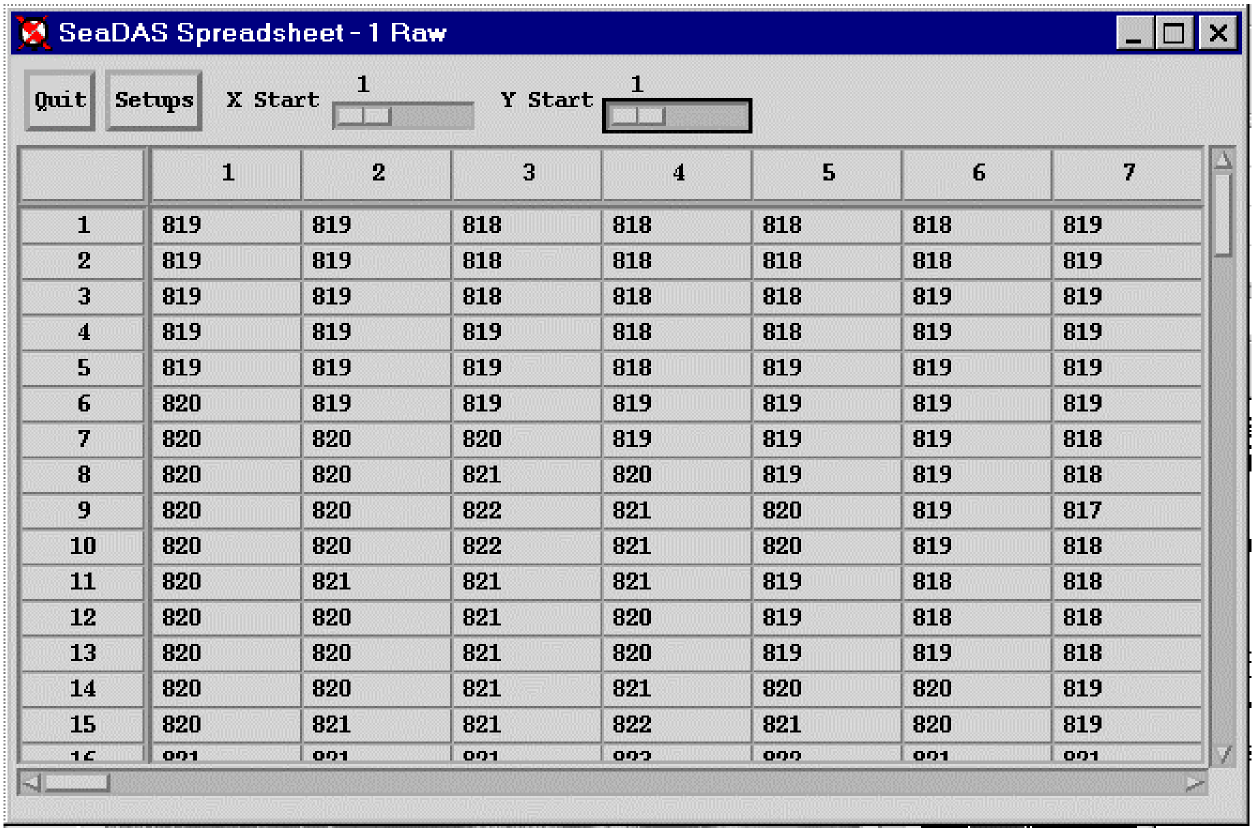
Ocean Color Viewed from Space: What Does the Satellite See?

The satellite radiometer “sees” light entering the sensor. In the case of ocean color measurements, the satellite is viewing some portion of the earth’s surface and measuring the amount and color (wavelength) of sunlight reflected from the earth’s surface. As ocean color intensity is related to the amount of each of the constituents in seawater, data from the satellite sensor may therefore be used to calculate the concentrations of particulate and dissolved materials in surface ocean waters. The sensor has the capability of making measurements at several visible and infra-red (IR) wavelengths, corresponding to different bands of electromagnetic energy. These are called the spectral bands of the sensor. The earliest ocean color sensor had 6 bands, SeaWiFS (Sea-viewing Wide Field-of-view Sensor) has 8 bands, or channels. Future sensors are planned with many more spectral bands, which will allow scientists to determine more seawater constituents and to do so more accurately.

What data do the satellite collect?

Data received from an ocean color satellite like the Sea-viewing Wide Field-of view Sensor (SeaWiFS), a global ocean color mission launched in August 1997, is stored and transmitted in several forms. Global Area Coverage (GAC) data are stored in the satellite's computers and transmitted to receiving stations on earth during the period the satellite is in the dark. (Remember that passive data can only be collected during daylight because sunlight is required for measurements.) Local Area Coverage (LAC) data are transmitted in real-time (as soon as it is collected) to other receiving stations on land where it is stored in land-based computers. Scientists who routinely work with the SeaWiFS data have real-time High Resolution Picture Transmission (HRPT) receivers to collect this LAC data and use it in their research.

One other difference between GAC and LAC data is that they are at different resolutions. Each data point is taken in a particular area of the ocean. This area is called a pixel. LAC data pixels cover an area which is 1 km by 1 km in size. GAC data pixels are larger, and cover an area of 4 km by 4 km. Actual pixel sizes differ slightly, because the earth’s surface is curved, and because the satellite is sometimes looking down at the earth at an angle. We say that LAC data have higher resolution than GAC data. However, GAC data have lower computer storage requirements.



	1	2	3	4	5	6	7
1	819	819	818	818	818	818	819
2	819	819	818	818	818	818	819
3	819	819	818	818	818	819	819
4	819	819	819	818	818	819	819
5	819	819	819	818	819	819	819
6	820	819	819	819	819	819	819
7	820	820	820	819	819	819	818
8	820	820	821	820	819	819	818
9	820	820	822	821	820	819	817
10	820	820	822	821	820	819	818
11	820	821	821	821	819	818	818
12	820	820	821	820	819	818	818
13	820	820	821	820	819	819	818
14	820	820	821	821	820	820	819
15	820	821	821	822	821	820	819
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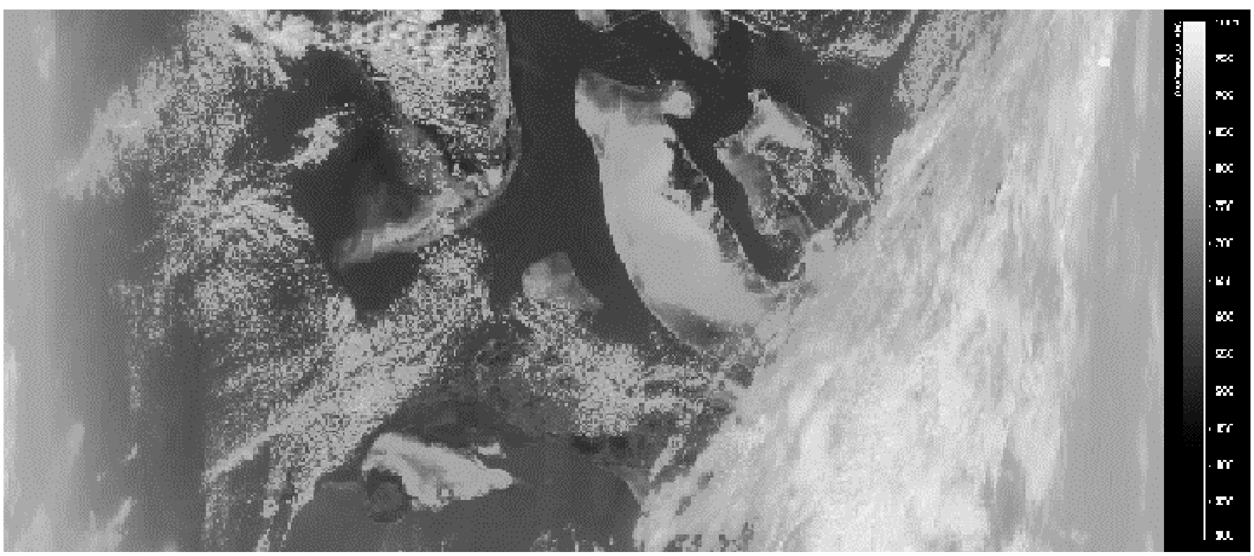


Data Processing from Level 0 to Level 3

At the time when LAC and GAC data are transmitted and stored on computer, they consist of a string of numbers. Each number represents a single reading of one of the sensors onboard the satellite. For example, one number corresponds to the amount of red light reflected from a single pixel. The raw data are classified as Level 0. Fully processed scenes available for you to view on the NASA websites are Level 3 data.

The raw, or unprocessed, Level 0 data include total radiances for ocean, land, clouds, and ice measured by the satellite. It also includes actual SeaWiFS spectral responses, saturation responses, telemetry data, global positioning data and other data.

Data processing is complicated, but it is greatly facilitated by the use of SEADAS, a software package developed by NASA scientists for processing and viewing ocean color data. All the data for a Level 0 scene are stored as a single file. Each scene consists of many pixels, which define a rectangular area of the ocean. A typical scene may be thousands of pixels on a side.

Using SEADAS, Level 0 data are converted to Level 1 data by transforming the string of numbers into a data table, or matrix. The data matrix has columns corresponding to each pixel in a scene and rows which correspond to a scan line. There are 8 of these data matrices for each scene--one for each color band of SeaWiFS. Each number, or element, in the matrix represents a raw radiance value. Other data such as latitude and longitude for each pixel, date, time, and all the other information required to calibrate and process the data, are stored separately for each scan line.

The table on page 17 is a very small part of an actual Level 1 data file. The raw radiance values only vary between 817-822 in this portion of the scene. Level 1 data can be plotted on a map using SEADAS. Each radiance value in the matrix can be displayed as a shade of gray corresponding to the magnitude of the number. High numbers are light, low numbers dark, and intermediate numbers are some shade between these two. One map can be made for each color of light measured, that is for each radiance channel. The values on the map correspond to the intensity of radiance measured for each individual pixel.

On page 17 is an actual Level 1 image taken over the southern tip of Florida. The brightest areas are clouds. Can you find Florida and the Bahamas in this scene? Level 1 data still largely consist of light scattered by atmospheric components, and this must be removed to study ocean color. Level 2 processing applies the atmospheric correction algorithms, and also applies other algorithms to convert the Level 1 data to concentrations of substances of interest, for example chlorophyll concentration. Algorithm development is still an active area of research, since many of the correction factors are not well known, and can vary due to environmental factors.

Level 2 images often contain black areas, where all the radiance was removed from pixels after atmospheric corrections. These are areas where clouds, ice or land were present. The area and shape of individual pixels in Level 1 and Level 2 data may also be distorted because of the angle at which the satellite views the earth's curved surface. Level 3 data processing by SEADAS removes the distortions and also combines multiple scenes in a given area to reduce the cloud cover. This is called "binning" the data, and is similar to taking the average of several numbers. Scenes can be binned over time intervals, or over intervals of space. Spatial binning is used to combine incomplete scenes of a particular area of interest.

True Color and False Color Images

Since white light is a combination of different colors, we can add SeaWiFS data collected in single bands to get a true color image of the ocean. There are 3 blue bands, 2 green bands, and a red band. One of each color of Level 1 data can be added in SEADAS to get a true color image.

One other way to enhance images for easier interpretation is to make false color images. This is similar to grayscale images, except that several colors are used to scale the data. How do we assign colors to the data? For temperature, it might seem logical to let blue represent cold (low temperatures), green intermediate, and red hot (high temperatures), but any scheme could be used. Usually color is chosen to make the image easy to interpret. A scale or legend by the figure defines the meaning of the colors. Depending on the circumstances, the colors may look real; that is, they may look like we imagine the scene appears to the eye. False color results when some scheme other than natural color is used for displaying images.

The term "false color" does not mean that the data are wrong or that the picture is deceiving you. It only means, don't be deceived; this figure is not a color photograph. You should look at the scale or legend to interpret it.

Ground Truth Measurements and Instruments

While the advent of ocean color satellites has revolutionized the way ocean scientists study the ocean, it has not totally eliminated the need to study the ocean from ships. In fact, the measurement of ocean color parameters in and just above the water is now more important than ever to be sure that data from the satellite are interpreted correctly. Data collected in the field to verify and calibrate data from satellite ocean color sensors is called "ground truth." Without ground truth data, scientists could not develop the algorithms they use to calculate such parameters as chlorophyll concentration.

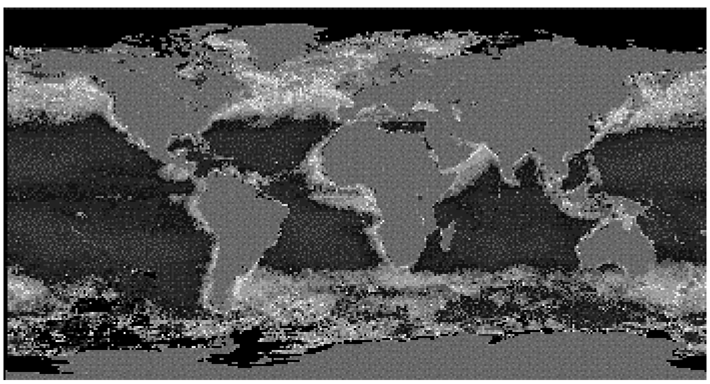
A variety of instruments have been developed to collect the required ground truth data. The basic measurements needed are absorption and scatter of the main substances responsible for ocean color, namely phytoplankton, detritus particles, and dissolved organic substances; water-leaving radiance; and incident solar irradiance (the amount of sunlight striking the sea surface). These properties change with seasons, with depth in the water column, and from one area of the ocean to another. So, scientists must make their measurements at different times and places. They are constantly trying to verify that chlorophyll concentrations calculated from satellite sensors accurately represent chlorophyll concentrations in the ocean.

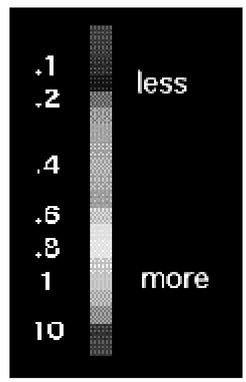
Activity III. Analyzing the Satellite Image

Use the world wide web (www) to find a false color image of the entire ocean.

Sites: **http://seawifs.gsfc.nasa.gov/SEAWIFS.html**
http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html
http://observe.ivv.nasa.gov/nasa/education/reference/main.html

False Color Images of Ocean Color





Since phytoplankton are just tiny microscopic plants they need the same things to grow that the plants in your house or outside need. Your favorite houseplant needs water, sunlight, carbon dioxide and nutrients (these come from the soil it grows in) in order to grow through the process of photosynthesis. In some parts of the ocean there are a lot of these things that plants need to grow and other places which lack one or more of these important ingredients. Now for the fun stuff: remember what you read about using satellites to study the phytoplankton concentrations in the ocean? Now you are going to use one of these REAL satellite images to conduct your own investigation!

1. Analyzing the satellite image...

Take a look at the image above. It shows the entire world and the concentrations of phytoplankton in the world's oceans. Next take a look at the color scale beside the image; this tells you what the colors on the map mean. The purple color indicates very low amounts of phytoplankton, the green indicates medium amounts and the red indicates very high amounts or concentrations of phytoplankton. Now scroll down below the images and see if you can answer the questions.

Adapted from: ***http://k12science.stevens-tech.edu/curriculum/oceans/seawifs.html***

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Questions

1. There are areas of the ocean with relatively large concentrations of nutrients that animals and plants use as food substances. In these areas you see a lot of phytoplankton, especially in the spring. Why do some areas have greater amounts of phytoplankton? Where would be the best place for deep-sea fishing?

2. If a zooplankton, a very small animal type of plankton, eats a phytoplankton, generally speaking, what happens to the carbon that was in the phytoplankton? What happes to the carbon in the zooplankton when it dies?

3. What is an example of the lowest level of the "food chain" on land?

4. Scientists use two types of satellites to study the environment. A geostationary satellite remains above the same spot on the Earth's equator from an altitude of about 22,500 miles and can "see" an entire hemisphere all the time. A polar-orbiting satellite travels in a circular orbit, passing above the North and South Poles while the Earth rotates beneath it. This type of satellite can "see" details as small as a mile or less. Which of these satellites probably would be better for our ocean color instrument? Would one prove better than the other to track hurricanes and other large weather systems?

5. How do the atmosphere and the ocean interact?

6. How could global warming affect sea level? Why is global warming important?

7. Where do plankton grow?

ANSWERS:

1. When wind-driven surface currents carry water away from continents, an upwelling of deep ocean water occurs. These cold waters have high concentrations of nutrients, leading to phytoplankton growth and creating a highly productive fishing area. Ocean plants live within 200 meters from the surface where there is sunlight.

2. Most zooplankton migrate to the surface at night to feed on phytoplankton and then sink to greater depths during the day. The phytoplankton carbon they eat is connected to carbon dioxide incorporated into their bodies, are excreted as fecal pellets which sink to the ocean floor. When zooplankton die, they carry carbon with them as they sink to the bottom of the ocean.

3. Plants and bacteria are at the bottom of the food chain. Animals that eat grass, such as sheep, belong to higher food web levels.

4. A polar-orbiting satellite potentially can "see" everywhere in the world in about two days, and its orbit is low enough so that it can detect smaller details than a geostationary satellite. It will pass over a certain area once daily at the same time of day, which is important for instruments that use sun illumination for measurements of ocean color or land vegetation. A geostationary orbit can view almost an entire hemisphere at the same time, is able to track hurricanes and weather systems by making measurements every half hour or so, and also is used for meteorological purposes.

5. Differences in the heating and cooling rates of land and ocean affect air circulation. Land and water temperatures rise and fall at different rates because land absorbs and loses heat faster than water does. During the day, hot air rises and is replaced by cooler air. This small-scale circulation is called a sea breeze, and usually starts three or four hours after sunrise, reaching its peak by early afternoon. At night, the land is cooler than the water because the land has given up its heat to the atmosphere. The cool air flows over the warmer water and rises as it is warmed. This circulation

is called a land breeze, and usually starts to form in the late evening. It reaches its peak intensity near sunrise.

6. Global warming may cause sea levels to rise by several mechanisms. Temperature increases may cause some of the ice in the polar regions to melt, which would raise sea levels. Higher water temperatures also may cause the oceans to expand. This expansion would cause a sea-level rise. Scientists are studying how global warming would affect sea levels, because a substantial rise in the sea level may flood coastal cities and other low-lying areas.

6. Plankton (microscopic drifting plants and animals) live near the ocean surface where there is sunlight. Satellites will see changes in the color of water that indicates growth of ocean plants. ***Adapted from:*** **http://seawifs.gsfc.nasa.gov/SEAWIFS/LIVING_OCEAN/LIVING_OCEAN.html**

Student Information Sheet Lesson 2

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Since white light is a combination of different colors, we can add SeaWiFS data collected in single bands to get a true color image of the ocean. There are 3 blue bands, 2 green bands, and a red band. One of each color of Level 1 data can be added in SEADAS to get a true color image.
One other way to enhance images for easier interpretation is to make false color images. This is similar to grayscale images, except that several colors are used to scale the data.

Data Processing from Level 0 to Level 3

At the time when LAC and GAC data are transmitted and stored on computer, they consist of a string of numbers. Each number represents a single reading of one of the sensors onboard the satellite. For example, one number corresponds to the amount of light in channel 1 in a single pixel. The raw data are classified as Level 0. Fully processed scenes available for you to view on the NASA websites are Level 3 data.

Ground Truth Measurements and Instruments

While the advent of ocean color satellites has revolutionized the way ocean scientists study the ocean, it has not totally eliminated the need to study the ocean from ships. In fact, the measurement of ocean color parameters in and just above the water is now more important than ever to be sure that data from the satellite are interpreted correctly. Data collected in the field to verify and calibrate data from satellite ocean color sensors is called "ground truth." Without ground truth data, scientists could not develop the algorithms they use to calculate such parameters as chlorophyll concentration.

Lesson III: Ocean Color: Energy, Temperature, and the Big Picture

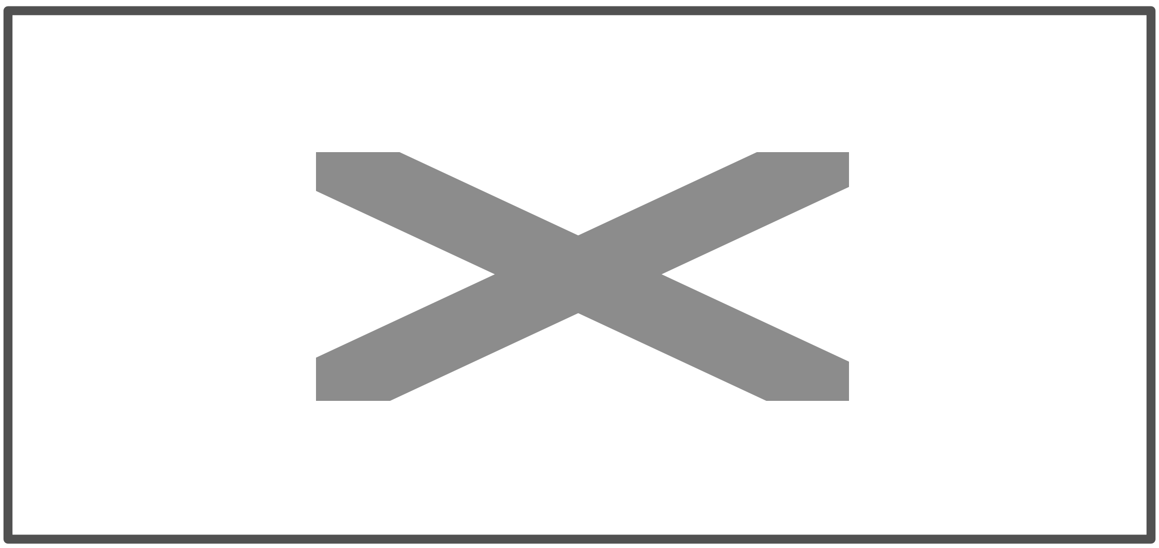
In this lesson we will discuss the Electromagnetic spectrum, electromagnetic energy and sea surface temperature.

Electromagnetic Spectrum

The electromagnetic (EM) spectrum is the term that scientists use to refer to all types of radiation. Radiation is energy that travels and spreads out as it goes. Visible light that comes from a lamp in your house and radio waves that come from a radio station are two types of electromagnetic radiation. Other examples of EM radiation are microwaves, infrared and ultraviolet light, X-rays and gamma-rays. The rainbow of colors that we see in visible light represents only a very small portion of the electromagnetic spectrum.

The EM spectrum is the continuum of energy that ranges from meters to nanometers in wavelength and travels at the speed of light. On one end of the spectrum are radio waves with wavelengths billions of times longer than those of visible light. On the other end of the spectrum are gamma rays. These have wavelengths millions of times smaller than those of visible light.

All matter (except at absolute zero temperature) radiates EM energy with peak intensity shifting toward shorter wavelength with increasing temperature. The amount of energy (R) radiated by a black body per unit time per unit area is proportional to temperatures (T) to the fourth power: $R = \sigma t^4$ This is the Stefan-Boltzman Law and the constant σ has a value of $\sigma = 5.67 \mathbf{x} 10^{-8}$ w $\mathbf{x}$ m^{-2} $\mathbf{x}$ $°K^{-4}$. Where w=watts, m=meters and °K = temperatures in degrees Kelvin.



Electromagnetic Energy

Adapted from: **Frank Mueller**

Electromagnetic (EM) energy is energy that moves at the velocity of light in a harmonic wave pattern (waves that occur at equal intervals of time). EM energy can only be detected as it interacts with matter. EM waves can be described in terms of velocity, wavelength, and frequency.

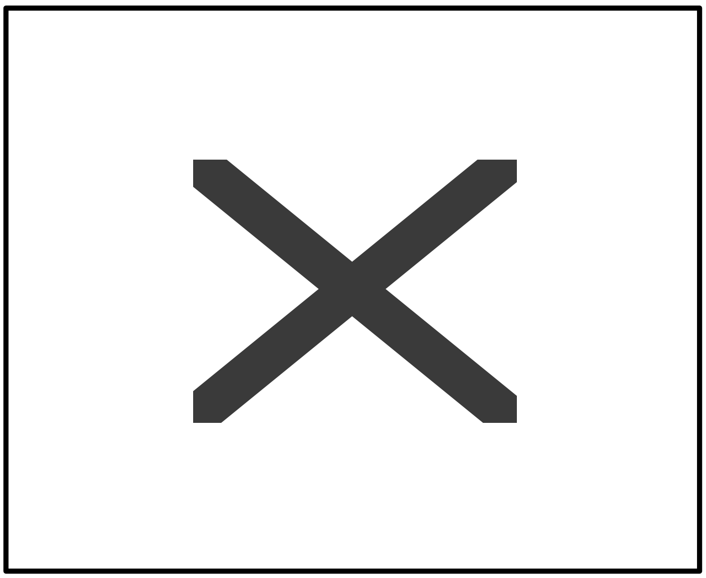
EM waves travel at the velocity (speed) of light, **c:**

c= 299,793 km s-1
c= 3x10^8 m s-1

Wavelength (λ) is the distance from any point on one cycle or wave to the same position on the next cycle or wave.

Units: **μm=micrometers or microns=10^{-6} meters (VIS,IR)**
nm= nanometers= 10^{-9} meters (VIS)

Frequency (ν) is the number of wave crests passing a given point in a specified period of time. It is imeasurend in units called hertz (cycles per second). The speed of light and wavelenth can with media, frequency does not.



http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html

Space, Earth and Ocean Observatories in Different Regions of the EM Spectrum

Excerpted from: http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html

Radio observatories

At present, there is one radio observatory in space. There are plans, however, for one more in the next year. Radio waves can make it through the Earth's atmosphere without significant obstacles (In fact radio telescopes can observe even on cloudy days!). However, the availability of a space radio observatory complements radio telescopes on the Earth in some important ways. Radio astronomers can combine data from two telescopes that are very far apart and create images which have the same resolution as if they had a single telescope as big as the distance between the two telescopes! That means radio telescope arrays can see incredibly small details.

Microwave observatories

The sky is a source of microwaves in every direction, most often called the microwave background. This background is believed to be the remnant from the "Big Bang" scientists believe began our Universe. It is believed that a very long time ago all of space was scrunched together in a very small, hot ball. The ball exploded outward and became our Universe as it expanded and cooled. Over the course of the past several billion years (the actual age of the Universe is still a matter of debate, but is believed to be somewhere between ten and twenty billion years), it has cooled all the way to just three degrees above zero. It is this "three degrees" that we measure as the microwave background. (Remember that temperature, energy and EM wavelength are related).

Infrared observatories

Currently in orbit is the biggest infrared observatory currently in orbit is the Infrared Space Observatory (ISO), launched in November 1995 by the European Space Agency. It has been placed in an elliptical orbit with a 24 hour period which keeps it in view of the ground stations at all times, a necessary arrangement since ISO transmits observations as it makes them rather than storing information for later playback. ISO is able to observe from 2.5 to 240 microns.

Visible spectrum observatories

The only visual observatory in orbit at the moment is the Hubble Space Telescope (HST). Like radio observatories in space, there are visible observatories already on the ground. However, Hubble has several special advantages over them.

HST's biggest advantage is that because it is above the Earth's atmosphere, it does not suffer distorted vision from the air. If the air were all the same temperature and there were no wind (or the wind were perfectly constant), telescopes would have a perfect view through the air. Alas, this is not how our atmosphere works. There are small temperature differences, wind speed changes, pressure differences, and so on. This causes light passing through air to suffer tiny wobbles. It gets bent a little, much like light gets bent by a pair of glasses. But unlike glasses, two light beams coming from the same direction do not get bent in quite the same way. You've probably seen this before -- looking along the top of the road on a hot day, everything seems to shimmer over the black road surface. This blurs the image telescopes see, limiting their ability to resolve objects. On a good night in an observatory on a high mountain, the amount of distortion caused by the atmosphere can be very small. But the Space Telescope has NO distortion from the atmosphere and its perfect view gives it many many times better resolution than even the best ground-based telescopes on the best nights.

Ultraviolet observatories

Right now there are no dedicated ultraviolet observatories in orbit. The Hubble Space Telescope can perform a great deal of observing at ultraviolet wavelengths, but it has a very fairly small field of view. Water vapor in the atmosphere completely absorbs incoming UV, so Earth-based UV observatories are not feasible.

X-ray observatories

There are several X-ray observatories currently operating in space with more to be launched in the next few years.

The Rossi X-ray Timing Explorer (RXTE) was launched on December 30, 1995. RXTE is able to make very precise timing measurements of X-ray objects, particularly those which show patterns in their X-ray emissions over very short time periods, such as certain neutron star systems and pulsars

Table 1.3 Electromagnetic spectral regions

Region	Wavelength	Remarks
Gamma Ray	< 0.03 nm	Incoming radiation is completely absorbed by the upper atmosphere and is not available for remote sensing.
X-Ray	0.03 to 3.0 nm	Completely absorbed by atmosphere. Not employed in remote sensing.
Ultraviolet	0.03 to 0.4µm	Incoming wavelengths less than 0.3 µm are completely absorbed by ozone in upper atmosphere.
Photographic UV Band	0.3 to 0.4 µm	Transmitted through atmosphere. Detectable with film and photo detectors, but atmospheric scattering is severe.
Visible	0.4 to 0.7 µm	Imaged with film and photo detectors. Included reflected energy peak of earth at 0.5µm.
Infrared	0.7 to 100 µm	Interaction with matter varies with wavelength. Atmospheric transmission windows are separated by absorption bands.
Reflected IR band	0.7 to 3.0 µm	Reflected solar radiation that contains no information about thermal properties of materials. The band from 0.7 to 0.9 µm is detectable with film and is called a photographic IR band.
Thermal IR band	3 to 5 µm, 8-14µm	Principle atmospheric windows in the thermal region. Images at these wavelengths are acquired by optical - mechanical scanners and special vidicon systems but not by film.
Microwave	0.1 to 30 cm	Longer wavelengths can penetrate clouds, fog and rain. Images may be acquired in the active or passive mode.
Radar	0.1 to 30 cm	Active form of microwave remote sensing. Radar images are acquired at wavelength bands.
Radio	>30 cm	Longest wavelength portion of electromagnetic spectrum. Some classified radars with very long wavelength operate in this region.

Sea Surface Temperature

Excerpted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1

Sea surface temperature (SST) measures the infrared radiation emitted by the ocean surface. It is simply a measure of the intensity of this radiation and relies less on *in situ* verification. However, atmospheric correction and comparison to in-situ sensors for calibration is still quite important. Because oceanic currents and water masses can vary considerably in temperature, SST data is particularly useful in observing currents and circulation in the oceans. The data are quite sensitive to atmospheric effects, and are also obscured by clouds.

SST data are most commonly obtained from polar-orbiting satellites operated by the National Oceanic and Atmospheric Administration. There is no direct relationship to convert sea surface temperature to sea surface topography, or vice versa. Although a change in sea surface temperature will cause a change in sea surface topography, and this can be computed approximately via an equation, one can’t compute the total topography from the temperature. If this were possible, no one would be interested in satellite altimetry.

SST directly influences and is influenced by atmospheric processes, such as wind, temperature, precipitation and cloud formation. In short, there is a dynamic interrelationship between the ocean and the atmosphere, which in turn impacts the ocean's carbon and heat reservoirs. Storms or cold upwelling currents may bring up deeper, nutrient-rich waters, which serve as "fertilizer" to enhance biological productivity.

SST algorithms are used to determine sea surface temperature, generate mapped SST fields, study spatial and temporal variation and development of simple models to study specific scientific problems, such as the El Niño phenomenon and global warming.

Instruments Used for Ocean Color Sensing

Adapted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1

Coastal Zone Color Scanner (CZCS)

CZCS was an experimental ocean color instrument launched aboard NASA's NIMBUS-7 satellite. It shared satellite resources and power with many other sensors, and therefore collected data only sporadically. Additionally, fewer scenes were collected as the instrument aged. The data are used to study the regional and seasonal variation in primary productivity, environmental change, oceanic features and even outbreaks of infectious disease.

Data and more information are available from the Goddard DAAC's ocean color web site: Ocean Color Data and Resources.

Modular Optoelectronic Scanner (MOS)

MOS is a sensor developed by the German Aerospace Research Establishment (DLR) Institute for Space Sensor Technology. The specific goals of MOS include improved compared to CZCS) corrections for atmospheric, sea surface, and turbidity effects. MOS data will also be correlated with SeaWiFS data.

Two MOS instruments have been launched, one aboard the Indian Remote Sensing Satellite (IRS) P3, and the other in the Russian Priroda module, a component of the Mir space station. The IRS MOS has an extra channel, used to enhance determination of surface roughness. Data collection is limited to ground stations, and therefore does not provide global coverage.

Ocean Color and Temperature Scanner (OCTS)

OCTS was an instrument aboard Japan's Advanced Earth Observing Satellite (ADEOS). It collected chlorophyll and sea-surface temperature data. High resolution and low resolution data were transmitted separately. Global coverage was achieved by OCTS every three days, which provided information on rapidly changing phenomena. ADEOS was lost on June 30, 1997.

Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

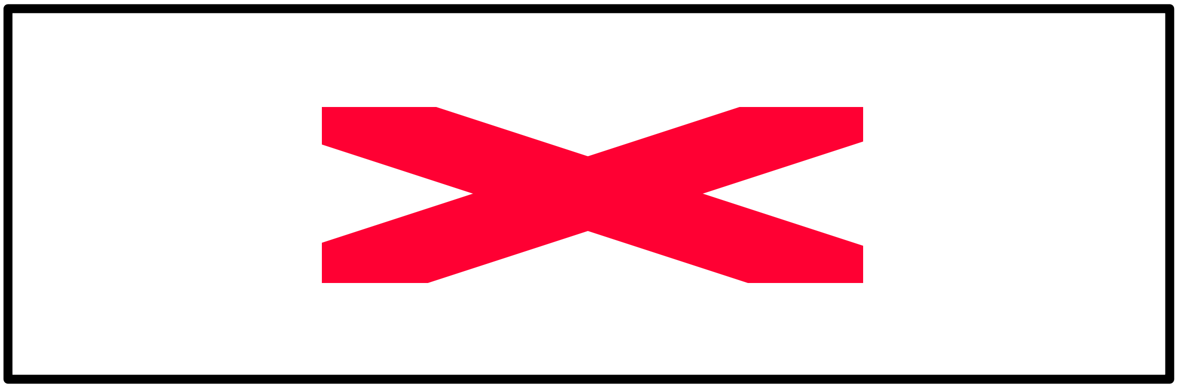
SeaWiFS is an ongoing ocean color mission operated by Orbital Sciences Corporation (OSC) for NASA. SeaWiFS data is being used to help clarify the magnitude and variability of chlorophyll and primary production by marine phytoplankton. In particular, the data will help determine the distribution and timing of 'spring blooms' -- the rapid increase in phytoplankton populations stimulated by increasing light availability and higher nutrient concentrations characteristic of the spring season.

Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS is an instrument that will orbit aboard the Earth Observing System (EOS) AM and PM series of satellites, resulting in 15 years of continuous ocean color data. It will also sense sea-surface temperature. Hardware and algorithm improvements will result in data that are more accurate than either CZCS or SeaWiFS.

Comparison of Wavelength & Bandwidth for Spaceborne Ocean Color Instruments

Adapted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/instruments.html



Comparison of Ocean Color Instruments

Instrument	Satellite	Dates of Operation	Spatial Resolution	Swath Width
CZCS	Nimbus-7	10/24/78- 6/22/86	825 m	1556 km
SeaWiFS	SeaStar	5/97	1100 m	2800 km
MODIS	EOS AM-1	6/98	1000 m	2330 km
MOS	IRS P3	3/18/96	520 m	200 km
Low Resolution Camera	KOMPSAT	scheduled 1999	1000 m	800 km

Student Information Sheet- Lesson 3

Sea Surface Temperature

Excerpted from: http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1

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Electromagnetic Spectrum

The rainbow of colors that we see in visible light represents only a very small portion of the electromagnetic spectrum. EM spectrum is the continuum of energy that ranges from meters to nanometers in wavelength and travels at the speed of light. On one end of the spectrum are radio waves with wavelengths billions of times longer than those of visible light. On the other end of the spectrum are gamma rays. These have wavelengths millions of times smaller than those of visible light. All matter (except at absolute zero temperature) radiates EM energy with peak intensity shifting toward shorter wavelength with increasing temperature.

Vocabulary

Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS)- Experimental airborne along track multispectral scanner under development at JPL to acquire 224 images in the spectral region from 0.4 to 2.4 µm.

Atmosphere- layer of gases that surrounds some planets.

Atmospheric Correction- image processing procedure that compensates for effects of selectivity scattered light in multispectral images.

AVHRR- Advanced Very High Resolution Radiometer, a multispectral imaging system carried by the TIROS/NOAA series of meteorological satellites.

Electromagnetic Radiation- Energy propagated in the form of and advancing interaction between electric and magnetic fields. All electromagnetic radiation moves at the speed of light.

Electromagnetic Spectrum- Continuous sequence of electromagnetic energy arranged according to wavelength or frequency.

False Colour Image- a colour image where parts of the non-visible EM spectrum are expressed as one or more of the red, green and blue components, so that colours produced by the Earth's surface do not correspond to normal visual experience. Also called a false-colour composite (FCC). The most commonly seen false colour images display the very near infrared as red, red as green and green as blue.

Frequency- (v) the number of wave oscillations per unit time or the number of wavelengths that pass a point per unit time.

HIRS- High Resolution Infrared Spectrometer, carried by NOAA satellites.

Incident Energy- Electromagenetic energy inpinging on a surface.

Multispectral scanner- scanner system that simultaneously acquires images of the same scene at a different wavelength.

Non-selective scattering- the scattering of EM energy by particles in the atmosphere which are much larger than the wavelengths of the energy, which causes all wavelengths to be scattered equally.

Passive Remote Sensing- Remote sensing of energy naturally reflected or radiated from the terrain.

Photodetector- Device for measuring energy in the visible-light band.

Photographic IR- Short-wavelength portion (0.7 to 0.9 μm) of the IR band that is detectable by IR color, film or IR black and white film.

Radar Scattering Coefficient- a measure of the back-scattered energy from a target with a large area. Expressed as the average radar cross section per unit area in decibels (dB). It is the fundamental measure of the radar properties of a surface.

Radar Scatterometer- A non-imaging device that records radar energy backscattered from terrain as a function of depression angle.

Rayleigh Criterion- In radar, the relationship between surface roughness, depression angle, and wavelength that determines whether a surface will respond in a rough or smooth fashion to the radar pulse.

Rayleigh Scattering- Selective scattering of light in the atmosphere by particles that are small compared with the wavelength of light.

RBV- Return-Beam-Vidicon

Reflected IR- EM energy of wavelengths from 0.7 to 3μm that consists primarily of reflected solar radiation.

Remote Sensing- collection and interpretation of information about an object without being in physical contact with the object.

Scan Line- Narrow strip on the ground that is swept by IFOV of a detector in a scanning system.

Scanner- an imaging system in which the IFOV of one or more detectors is swept across the terrain.

Scattering- multiple reflections of electromagnetic waves by particles or surfaces.

Scattering Coefficient Curves- Display of scatterometer data in which relative backscatter is shown as a function of incidence angle.

Scatterometer- Non-imaging radar device that quantitatively records backscatter of terrain as a function of incidence angle.

Spectrometer- Device for measuring intensity of radiation absorbed or reflected by material as a function of wavelength.

Spectroradiometer- A device which measures the enegry reflected or radiated by materials in narrow EM wavebands.

Spectrum- continuous sequence of EM energy arranged according to wavelength or frequency.

Surface Phenomena- Interaction between EM radiation and the surface of a material.

Visible Radiation- Energy at wavelengths from 0.4 to 0.7 mm that is detectable by the human eye.

Volume Scattering- in radar, interaction between electromagnetic radiation and the interior of a material.

Wavelength- distance between sucessive wavecrests or other equivalant.

References and Acknowledgements

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http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/seawifs_raq.html#Q1:
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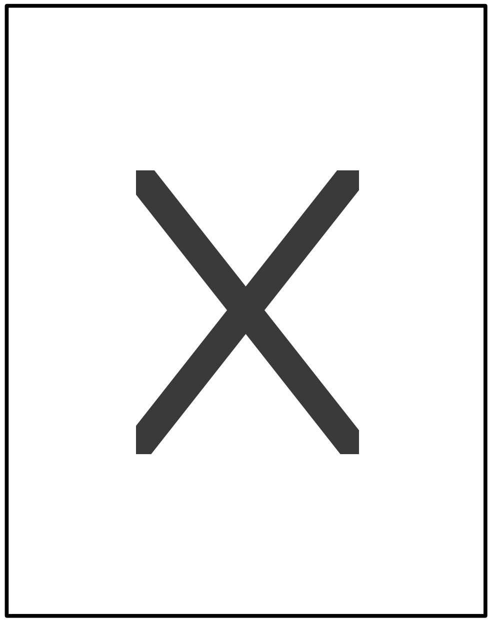

Frank E. Muller-Karger, Biological Oceanography

Assistant Professor, Ph.D., University of Maryland, 1988

My research on primary production in the sea takes advantage of the new technologies based on satellite remote sensing, archiving of large data sets, networking, and high-speed computing. This research helps in the location and monitoring of large-scale phenomena, of phenomena important in climate control and climate change and in the interpretation of numerical models of the ocean. In my lab we pursue an intensive analysis of data from various satellites, the space shuttle, ships, buoys, and other platforms. This process has helped my students to develop international collaborative programs to collect ground data as well as to disseminate satellite data. The focus of my present work is to determine if satellites that measure ocean color and sea surface temperature can be used to assess the importance of continental margins, including areas of upwelling and river discharge in the global carbon budget. Within this context, I work closely with NASA scientists and colleagues at other institutions to help develop reliable algorithms for measurement of phytoplankton and other materials in sea water from space. Of specific interest have been the plumes of the larger rivers of the world, as these provide a cause for the abundance of materials present in addition to phytoplankton. The academic program built around this research is forming with the scientists that will use the data from the satellites coming on line during the decade of the 1990s and beyond.