
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

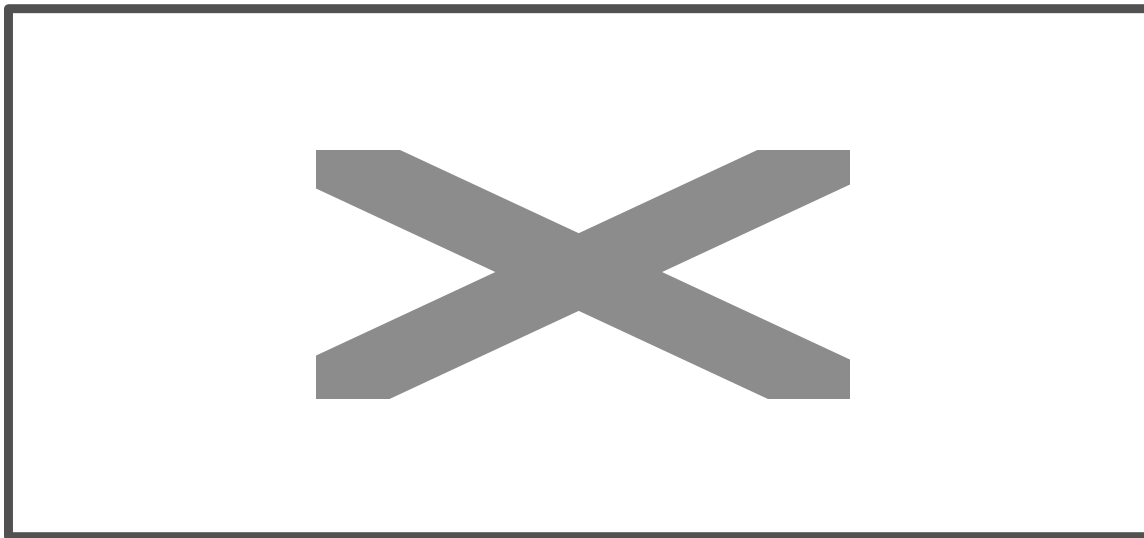
The electromagnetic (EM) spectrum is the term that scientists use to refer to all types of radiation. Radiation is energy that travels and spreads out as it goes. Visible light that comes from a lamp in your house and radio waves that come from a radio station are two types of electromagnetic radiation. 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 $\sigma = 5.67 \times 10^{-8} \text{ w x m}^{-2} \text{ x } ^\circ\text{K}^{-4}$. Where w=watts, m=meters and $^\circ\text{K}$ = 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**:

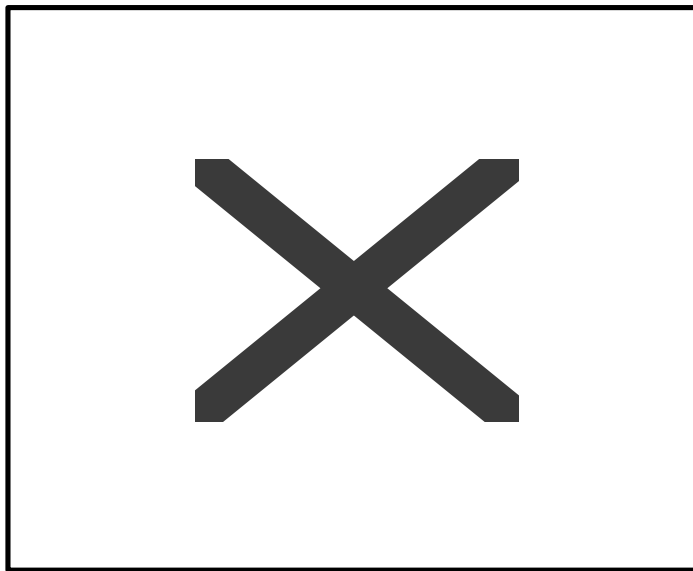
$$\begin{aligned} c &= 299,793 \text{ km s}^{-1} \\ c &= 3 \times 10^8 \text{ m s}^{-1} \end{aligned}$$

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 measured in units called hertz (cycles per second). The speed of light and wavelength can with media, frequency does not.



http://imagine.gsfc.nasa.gov/docs/science/know_12/emspectrum.html

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

Excerpted from:
http://imagine.gsfc.nasa.gov/docs/science/know_12/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

Table 1.3 Electromagnetic spectral regions

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

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/OC DST/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

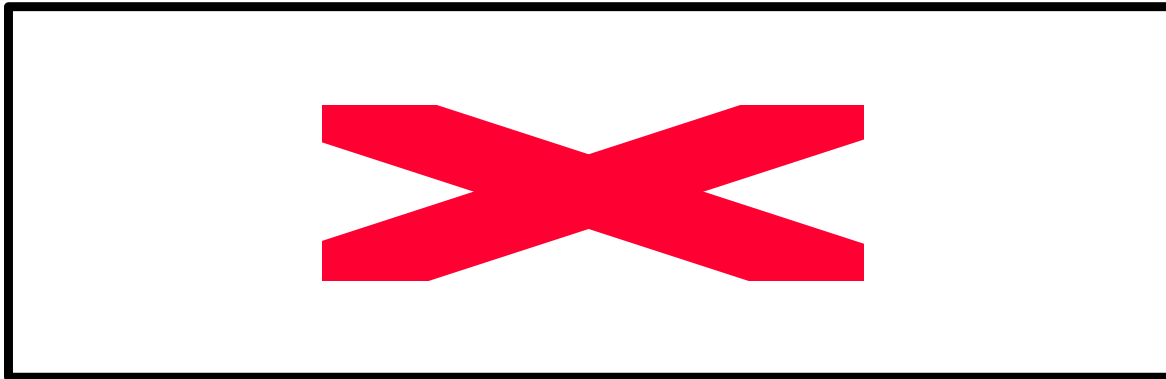
help clarify the magnitude and variability of chlorophyll and primary production by marine phytoplankton. In particular, the data will help determine the distribution and timing of 'spring blooms' -- the rapid increase in phytoplankton populations stimulated by increasing light availability and higher 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