Remote Sensing of Water

Carolina Distinguished Professor
Department of Geography
University of South Carolina
Columbia, South Carolina 29208
jrjensen@sc.edu

Earth: The Water Planet

- 74% of the Earth's surface is water
- 97% of the Earth's volume of water is in the saline oceans
- 2.2% in the permanent icecap
- Only 0.02% is in freshwater streams, river, lakes, reservoirs
- Remaining water is in:
  - underground aquifers (0.6%),
  - the atmosphere in the form of water vapor (0.001%)

Jensen, 2000

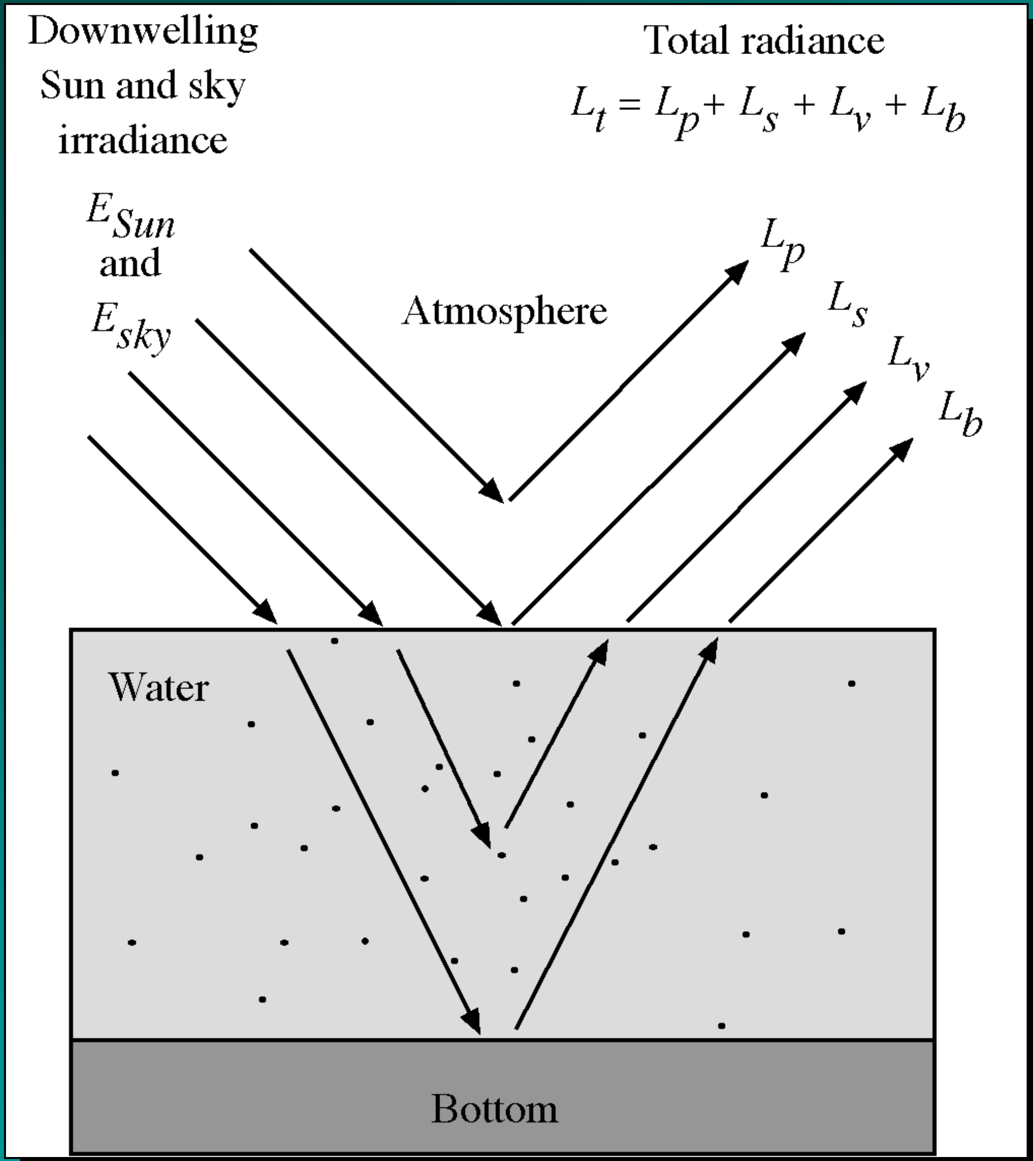
Water Surface, Subsurface Volumetric, and Bottom Radiance

The total radiance, (L_t) recorded by a remote sensing system over a waterbody is a function of the electromagnetic energy from four sources:

$$L_t = L_p + L_s + L_v + L_b$$

- L_p is the the radiance recorded by a sensor resulting from the downwelling solar (E_{sun}) and sky (E_{sky}) radiation. This is unwanted *path radiance* that never reaches the water.
- L_s is the radiance that reaches the air-water interface (*free-surface layer* or *boundary layer*) but only penetrates it a millimeter or so and is then reflected from the water surface. This reflected energy contains spectral information about the near-surface characteristics of the water.
- L_v is the radiance that penetrates the air-water interface, interacts with the organic/inorganic constituents in the water, and then exits the water column without encountering the bottom. It is called *subsurface volumetric radiance* and provides information about the internal bulk characteristics of the water column
- L_b is the radiance that reaches the *bottom* of the waterbody, is reflected from it and propagates back through the water column, and then exits the water column. This radiance is of value if we want information about the bottom (e.g., depth, color).

Jensen, 2000



Total radiance, (L_t) recorded by a remote sensing system over water is a function of the electromagnetic energy received from:

L_p = atmospheric path radiance

L_s = free-surface layer reflectance

L_v = subsurface volumetric reflectance

L_b = bottom reflectance

Jensen, 2000

Water Surface, Subsurface Volumetric, and Bottom Radiance

The total radiance, (L_t) recorded by a remote sensing system over a waterbody is a function of the electromagnetic energy from four sources:

$$L_t = L_p + L_s + L_v + L_b$$

- L_p is the the radiance recorded by a sensor resulting from the downwelling solar (E_{sun}) and sky (E_{sky}) radiation. This is unwanted *path radiance* that never reaches the water.
- L_s is the radiance that reaches the air-water interface *(free-surface layer* or *boundary layer*) but only penetrates it a millimeter or so and is then reflected from the water surface. This reflected energy contains spectral information about the near-surface characteristics of the water.
- L_v is the radiance that penetrates the air-water interface, interacts with the organic/inorganic constituents in the water, and then exits the water column without encountering the bottom. It is called *subsurface volumetric radiance* and provides information about the internal bulk characteristics of the water column
- L_b is the radiance that reaches the *bottom* of the waterbody, is reflected from it and propagates back through the water column, and then exits the water column. This radiance is of value if we want information about the bottom (e.g., depth, color).

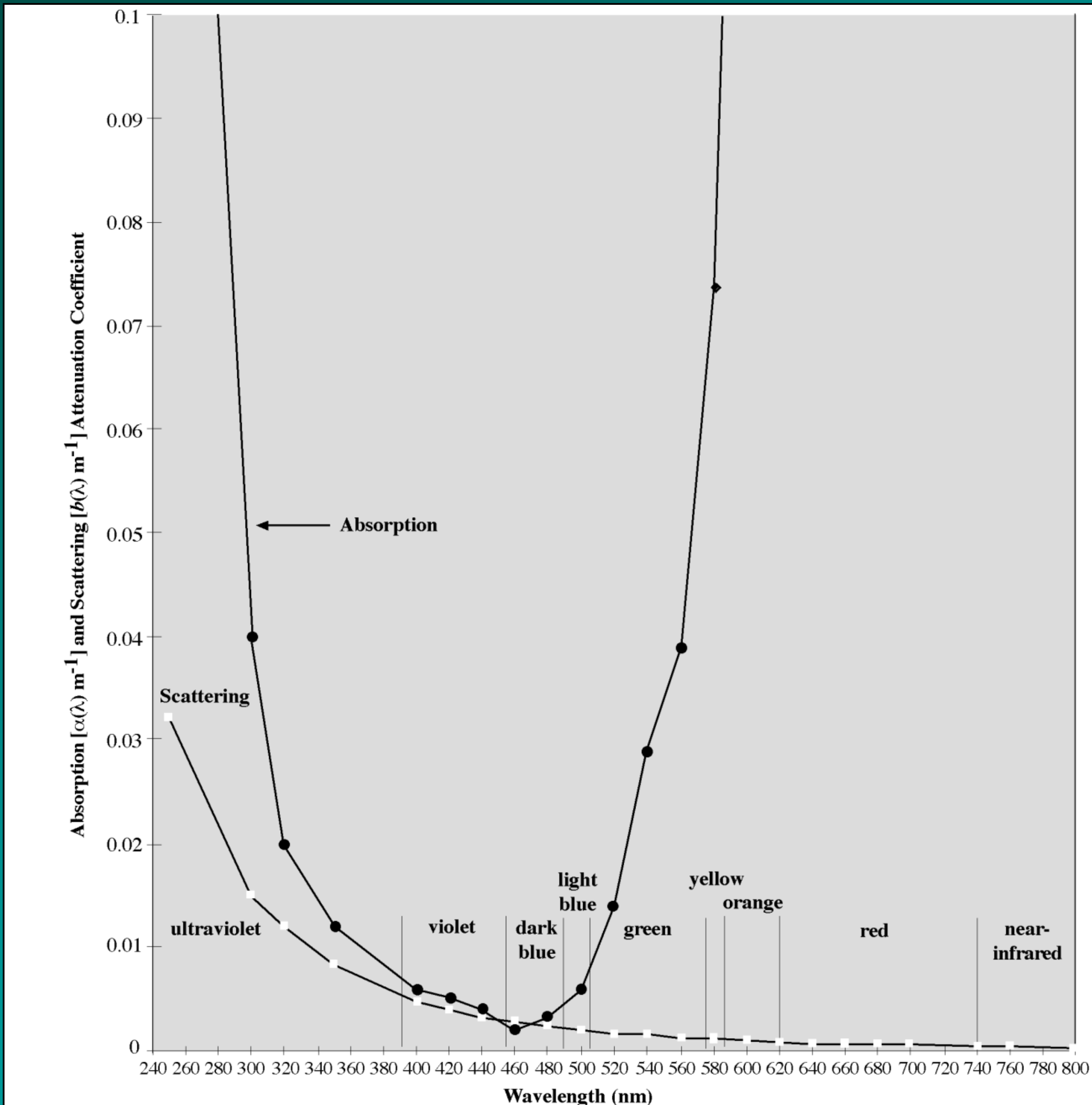
Jensen, 2000

Examples of Absorption of Near-Infrared Radiant Flux by Water and Sunglint

Black and white infrared photograph of water bodies in Florida

Black and white infrared photograph with sunglint

Jensen, 2000

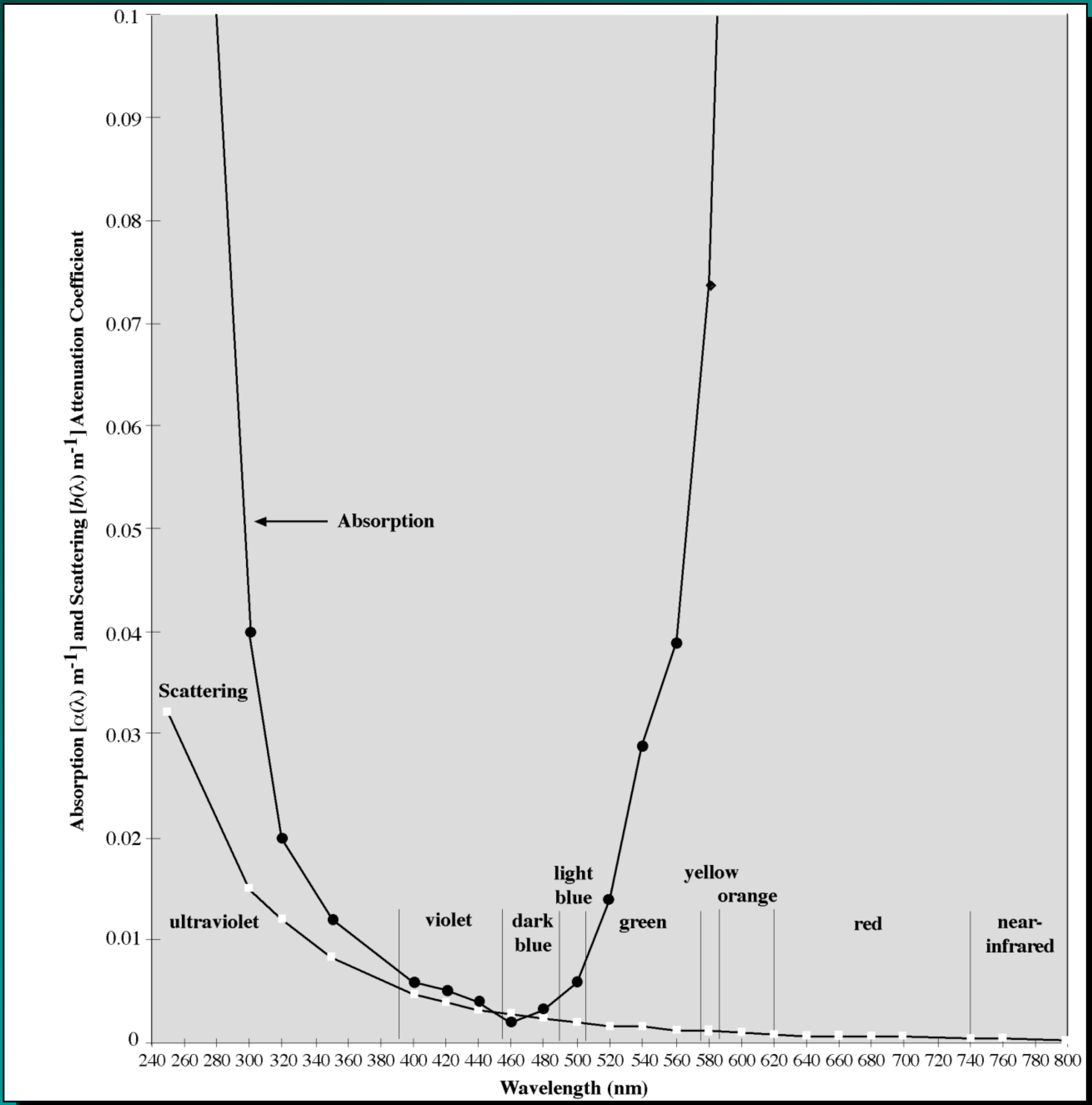


Absorption and Scattering Attenuation in Pure Water

Molecular water *absorption* dominates in the ultraviolet (<400 nm) and in the yellow through the near-infrared portion of the spectrum (>580 nm). Almost all of the incident near-infrared and middle-infrared (740 - 2500 nm) radiant flux entering a pure water body is absorbed with negligible scattering taking place.

Jensen, 2000

Absorption and Scattering Attenuation in Pure Water



Scattering in the water column is important in the violet, dark blue, and light blue portions of the spectrum (400 - 500 nm). This is the reason water appears blue to our eyes. The graph truncates the absorption data in the ultraviolet and in the yellow through near-infrared regions because the attenuation is so great.

Jensen, 2000

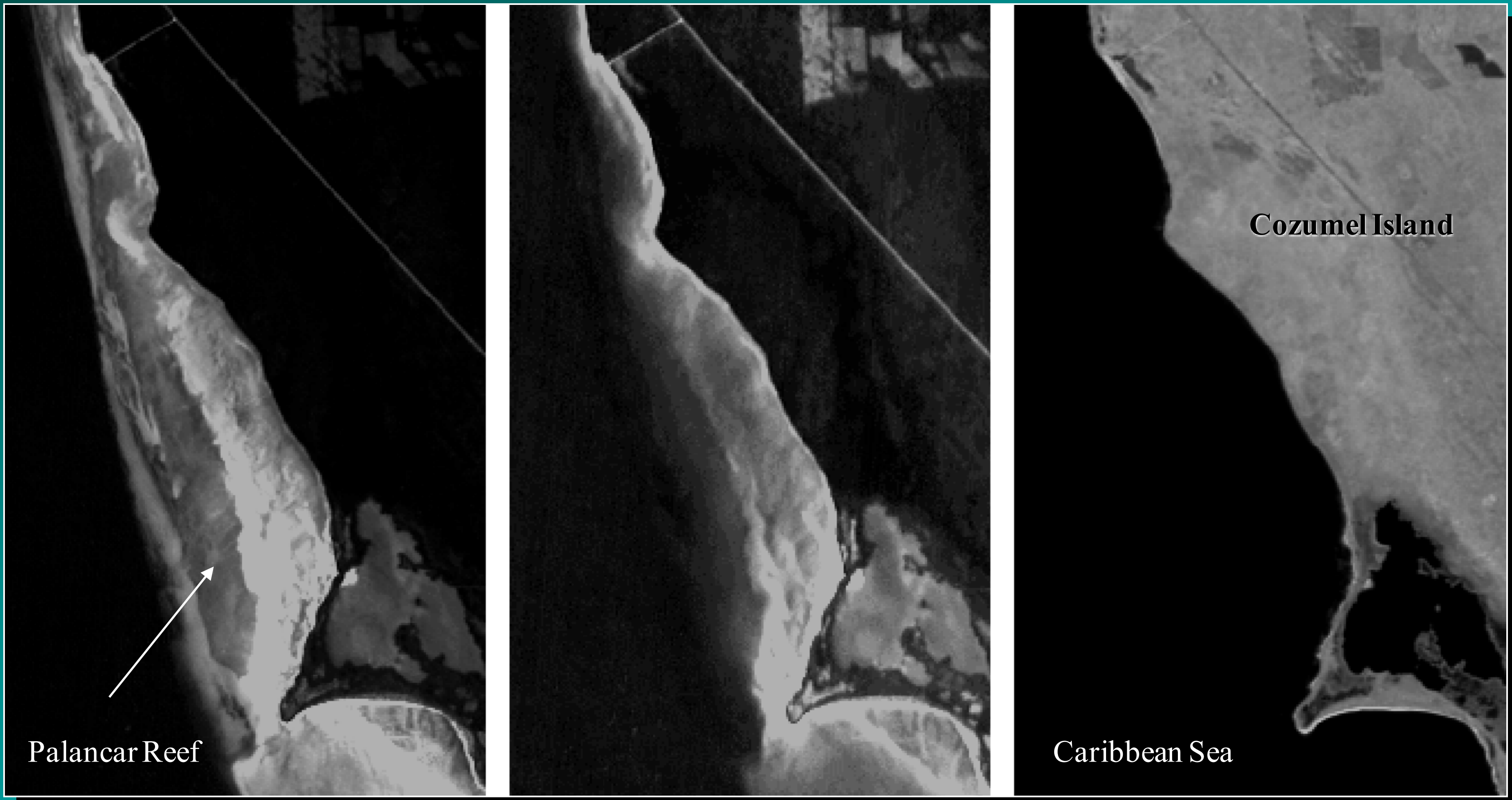
Monitoring the Surface Extent of Water Bodies

The best wavelength region for discriminating land from pure water is in the near-infrared and middle-infrared from 740 - 2,500 nm.

In the near- and middle-infrared regions, water bodies appear very dark, even black, because they absorb almost all of the incident radiant flux, especially when the water is deep and pure and contains little suspended sediment or organic matter.

Jensen, 2000

Water Penetration



SPOT Band 1 (0.5 - 0.59 μm) green

SPOT Band 2 (0.61 - 0.68 μm) red

SPOT Band 3 (0.79 - 0.89 μm) NIR

Jensen, 2000

Spectral Response of Water as a Function of Organic and Inorganic Constituents - Monitoring Suspended Minerals (Turbidity), Chlorophyll, and Dissolved Organic Matter

When conducting water-quality studies using remotely sensed data, we are usually most interested in measuring the subsurface volumetric radiance, L_v exiting the water column toward the sensor. The characteristics of this radiant energy are a function of the concentration of pure water (*w*), inorganic suspended minerals (*SM*), organic chlorophyll *a* (*Chl*), dissolved organic material (*DOM*), and the total amount of absorption and scattering attenuation that takes place in the water column due to each of these constituents, $c(\lambda)$:

$$L_v = f\,[w_{c(\lambda)},\ SM_{c(\lambda)},\ Chl_{c(\lambda)},\ w_{c(\lambda)}\ ].$$

It is useful to look at the effect that each of these constituents has on the spectral reflectance characteristics of a water column.

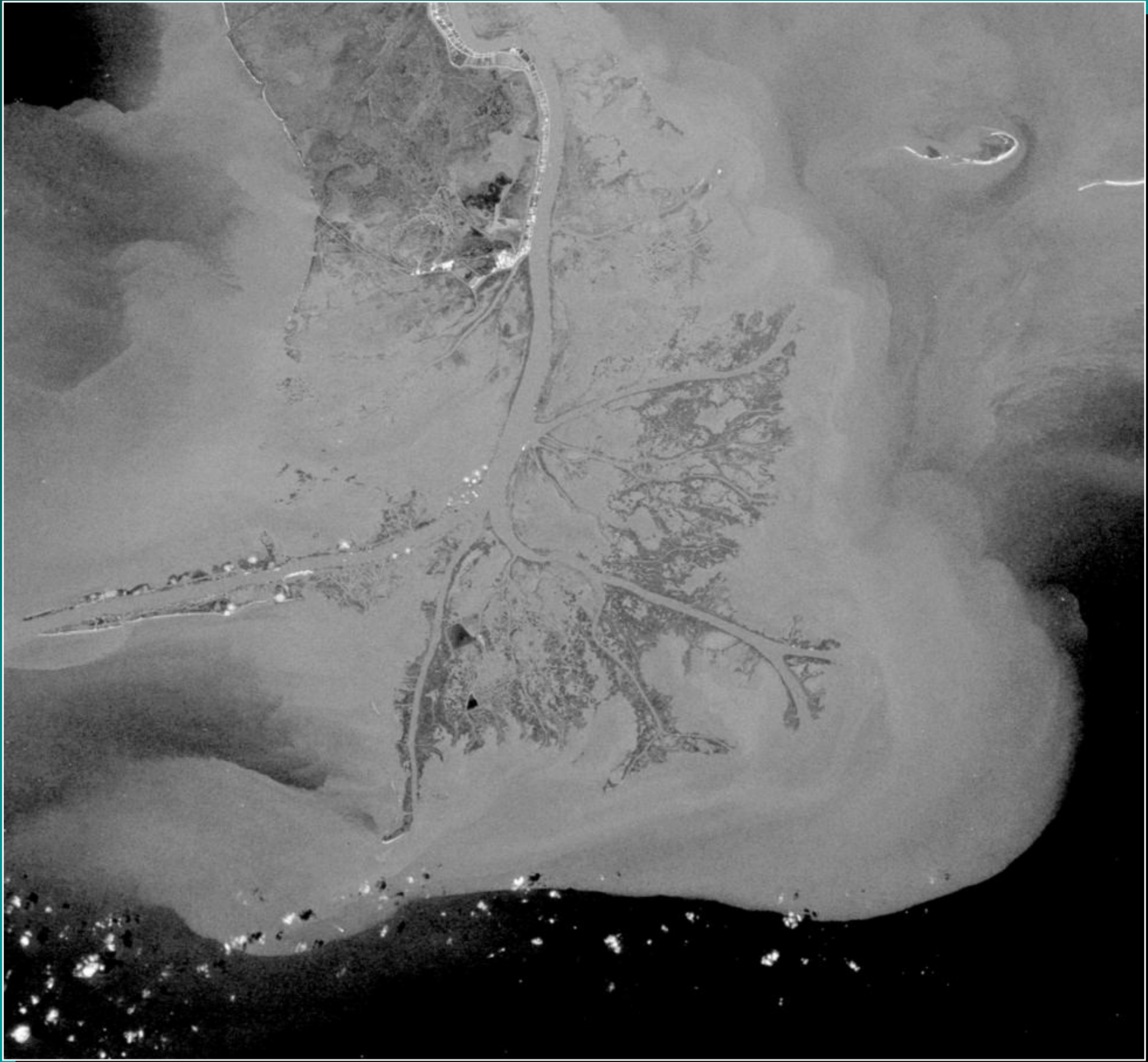
Jensen, 2000

Spectral Response of Water as a Function of Inorganic and Organic Constituents

Minerals such as silicon, aluminum, and iron oxides are found in suspension in most natural water bodies. The particles range from fine clay particles (3 - 4 μm in diameter), to silt (5 - 40 μm), to fine-grain sand (41 - 130 μm), and coarse grain sand (131 - 1250 μm). Sediment comes from a variety of sources including agriculture erosion, weathering of mountainous terrain, shore erosion caused by waves or boat traffic, and volcanic eruptions (ash). Most suspended mineral sediment is concentrated in the inland and nearshore water bodies. Clear, deep ocean (Case 1 water) far from shore rarely contains suspended minerals greater than 1 μm in diameter.

Jensen, 2000

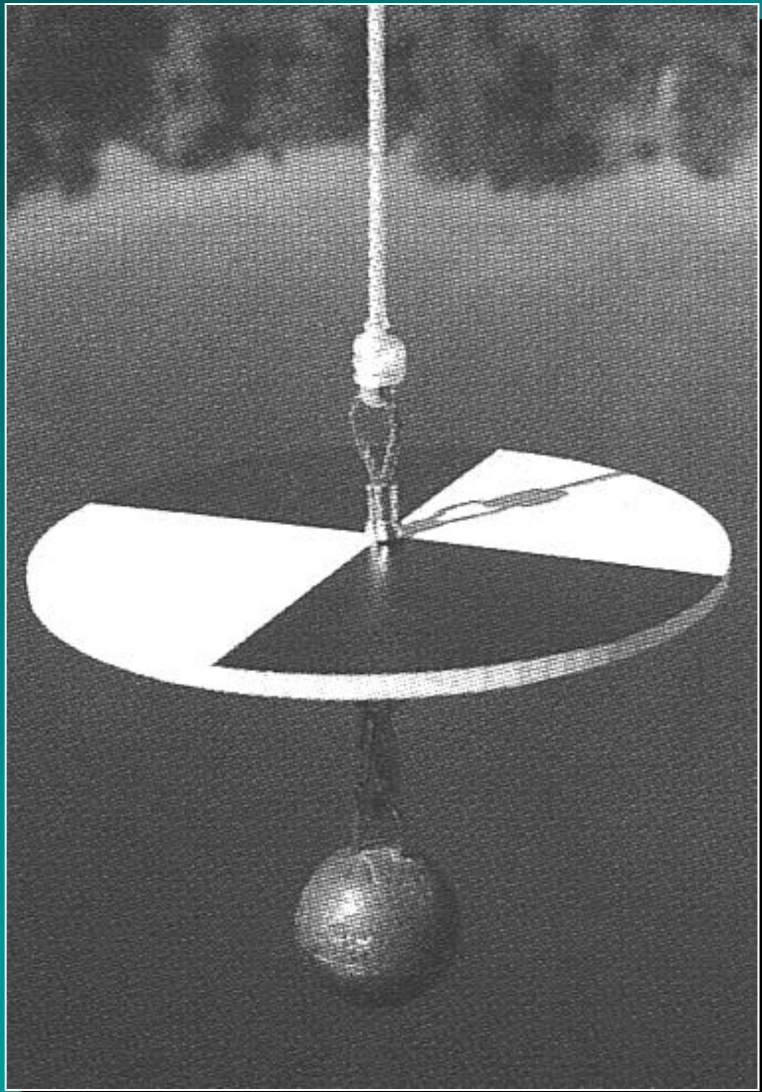
Space Shuttle Photograph of the Suspended Sediment Plume at the Mouth of the Mississippi River near New Orleans, Louisiana



STS #51

Jensen, 2000

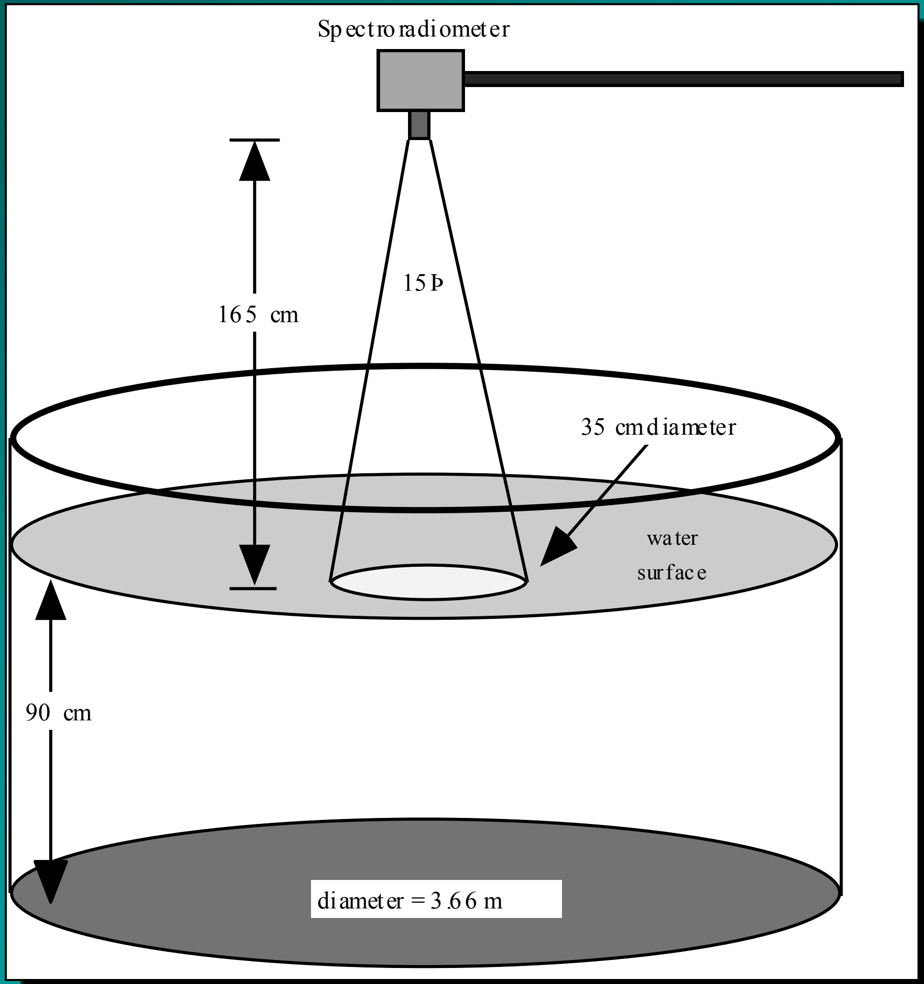
Secchi Disk



Jensen, 2000

Used to measure suspended sediment in water bodies

In situ Spectroradiometer Measurement of Water with Various Suspended Sediment and Chlorophyll *a* Concentrations

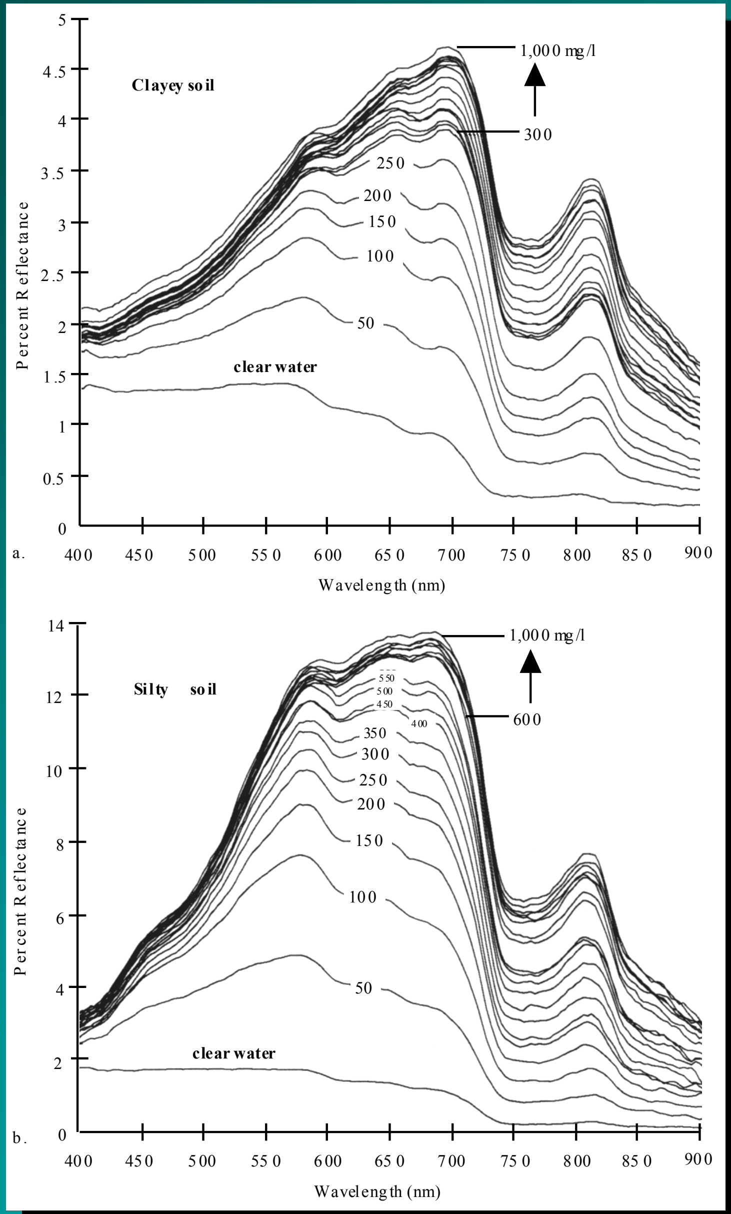


Lodhi et al., 1997; Jensen, 2000;

In situ Spectroradiometer Measurement of Clear Water with Various Levels of Clayey and Silty Soil Suspended Sediment Concentrations

clay

silt



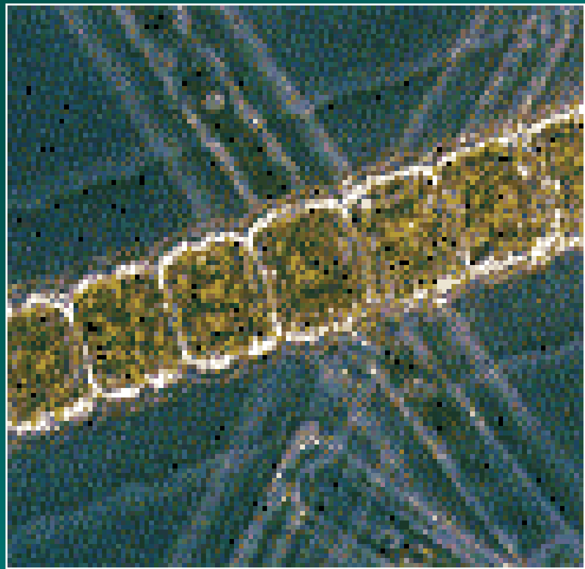
Reflectance peak shifts toward longer wavelengths as more suspended sediment is added

Lodhi et al., 1997; Jensen, 2000

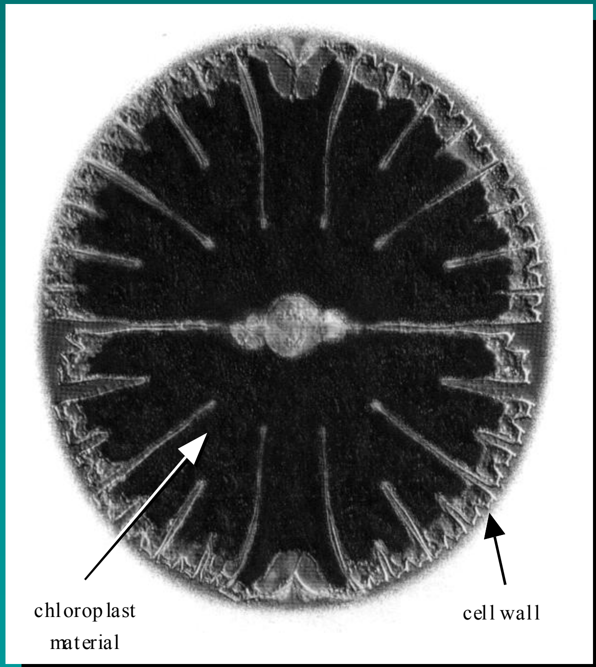
Spectral Response of Water as a Function of Organic Constituents - Plankton

Plankton is the generic term used to describe all the living organisms (plant and animal) present in a waterbody that cannot resist the current (unlike fish). Plankton may be subdivided further into algal plant organisms (*phytoplankton*), animal organisms (*zoolankton*), bacteria (*bacterio-plankton*), and lower platn forms such as *algal fungi*. *Phytoplankton* are small single-celled plants smaller than the size of a pinhead. Phytoplankton, like plants on land, are composed of substances that contain carbon. Phytoplankton sink to the ocean or water-body floor when they die. All phytoplankton in water bodies contain the photosynthetically active pigment *chlorpohyll a*. There are two other phytoplankton photosynthesizing agents: carotenoids and phycobilins. Bukata et al (1995) suggest, however, that *chlorphyll a* is a reasonable surrogate for the organic component of optically complex natural waters.

Jensen, 2000

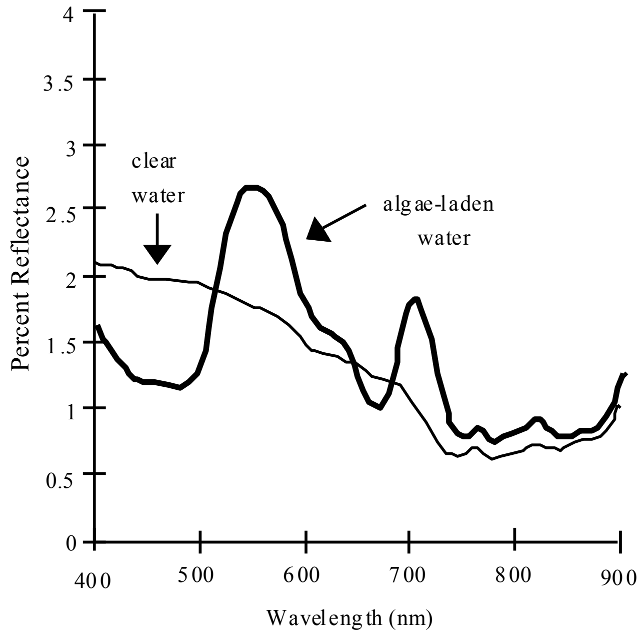


Micrograph of A Photosynthesizing Diatom

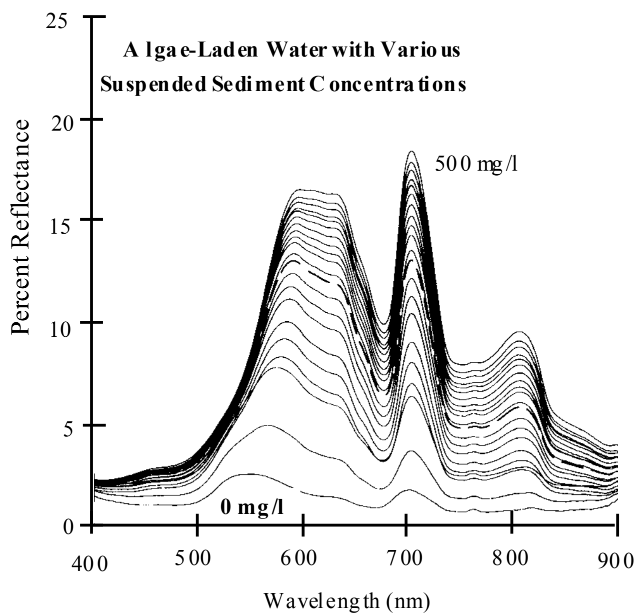


Micrograph of Blue Reflected Light from a Green Algae Cell (*Micrasterias sp.*).

Jensen, 2000



Percent reflectance of clear and algae-laden water based on *in situ* spectroradiometer measurement. Note the strong *chlorophyll a* absorption of blue light between 400 and 500 nm and strong *chlorophyll a* absorption of red light at approximately 675 nm



Percent reflectance of algae-laden water with various concentrations of suspended sediment ranging from 0 - 500 mg/l

Han, 1997;
Jensen, 2000

Chlorophyll in Ocean Water

A remote estimate of near-surface chlorophyll concentration generally constitutes an estimate of near-surface biomass (or primary productivity) for deep ocean (Case 1) water where there is little danger of suspended mineral sediment contamination.

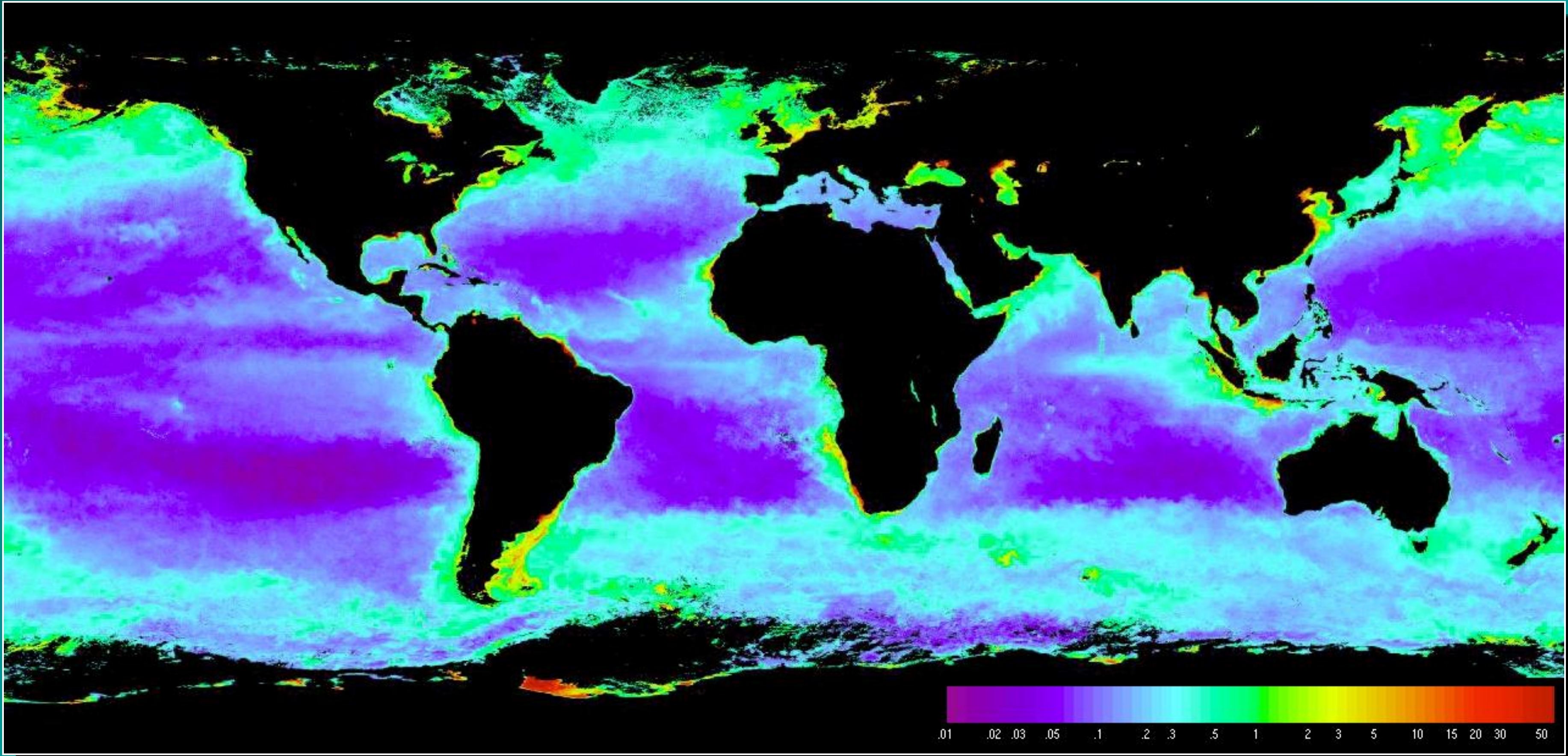
Numerous studies have documented a relationship between selected spectral bands and ocean chlorophyll (*Chl*) concentration using the equation:

$$Chl = x\,[L(\lambda_1)/L(\lambda_2)]^y$$

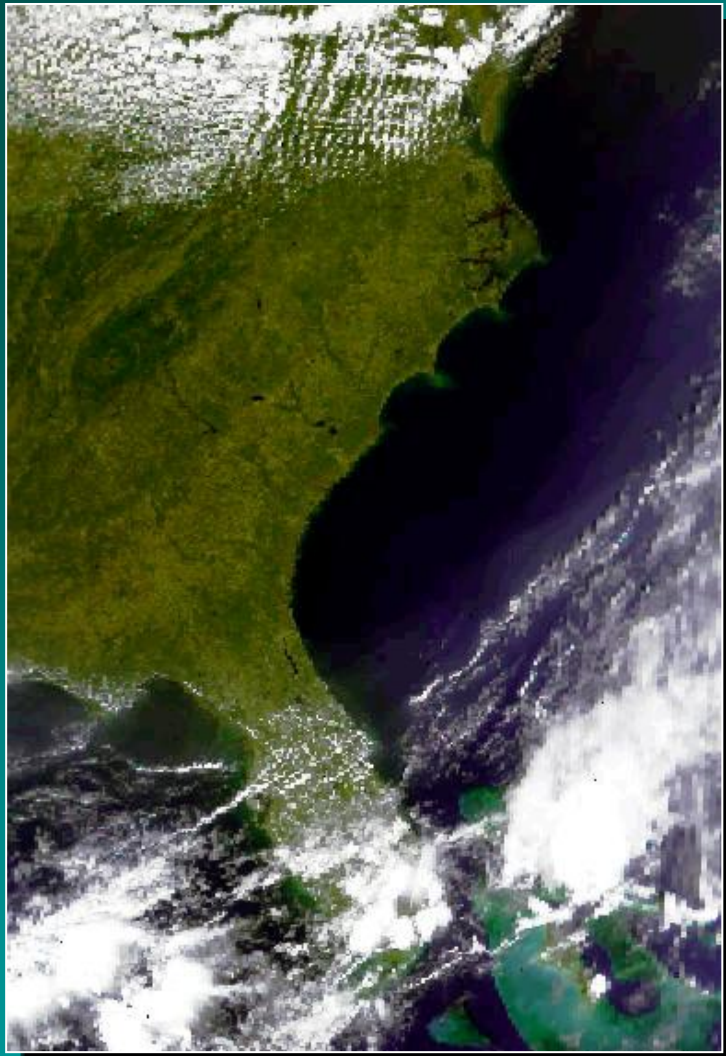
Where $L(\lambda_1)$ and $L(\lambda_2)$ are the upwelling radiances at selected wavelengths recorded by the remote sensing system and x and y are empirically derived constants.

The most important SeaWiFS algorithms involve the use of band ratios of 443/355 nm and 490/555 nm.

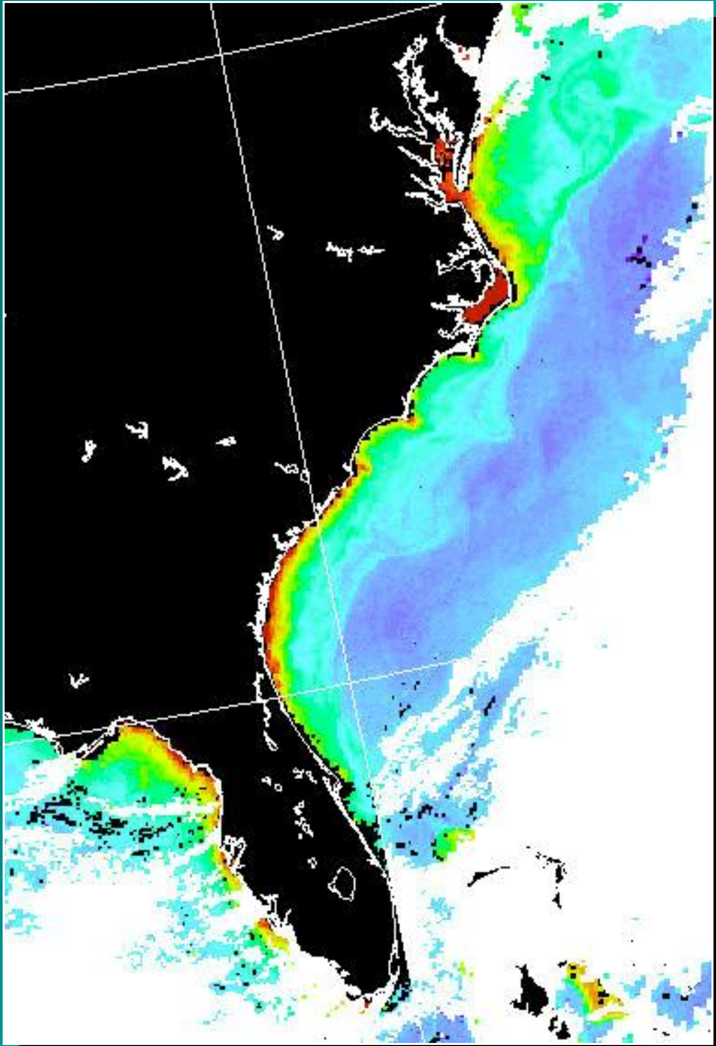
Global Chlorophyll *a* (g/m³) Derived from SeaWiFS Imagery Obtained from September 3, 1997 through December 31, 1997



Jensen, 2000



True-color SeaWiFS image of the Eastern U.S. on September 30, 1997



Chlorophyll *a* distribution on September 30, 1997 derived from SeaWiFS data

Jensen, 2000

Spectral Response of Water as a Function of Dissolved Organic Constituents

Sunlight penetrates into the water column a certain *photic depth* (the vertical distance from the water surface to the 1 percent subsurface irradiance level). Phytoplankton within the photic depth of the water column consume nutrients and convert them into organic matter via photosynthesis. This is called *primary production*. Zooplankton eat the phytoplankton and create organic matter. Bacterioplankton decompose this organic matter. All this conversion introduces *dissolved organic matter* (*DOM*) into oceanic, nearshore, and inland water bodies. *In certain instances, there may be sufficient dissolved organic matter in the water to reduce the penetration of light in the water column* (Bukata et al., 1995). The decomposition of phytoplankton cells yields carbon dioxide, inorganic nitrogen, sulfur, and phosphorous compounds.

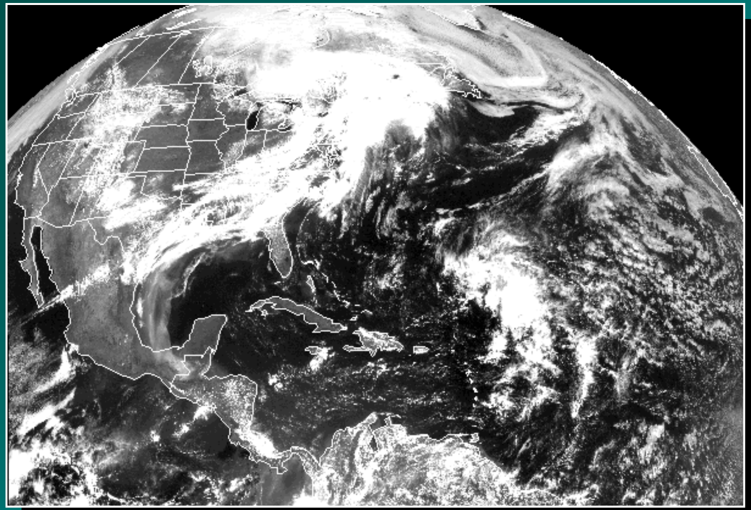
Jensen, 2000

Spectral Response of Water as a Function of Dissolved Organic Constituents

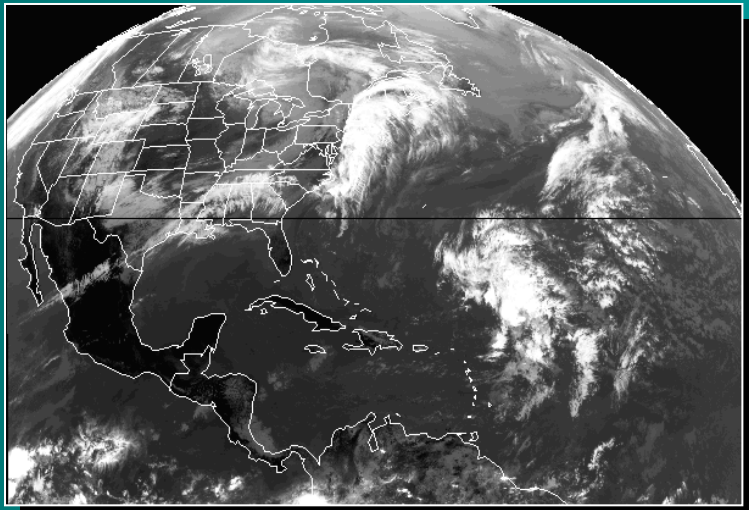
The more productive the phytoplankton, the greater the release of dissolved organic matter. In addition, *humic* substances may be produced. These often have a *yellow* appearance and represent an important colorant agent in the water column, which may need to be taken into consideration. These dissolved humic substances are called *yellow substance* or *Gelbstoffe* and can 1) impact the absorption and scattering of light in the water column, and 2) change the color of the water.

There are sources of dissolved organic matter other than phytoplankton. For example, the brownish-yellow color of the water in many rivers in the northern United States is due to the high concentrations of *tannin* from the eastern hemlock (*Tsuga canadensis*) and various other species of trees and plants grown in bogs in these areas (Hoffer, 1978). These tannins can create problems when remote sensing inland water bodies.

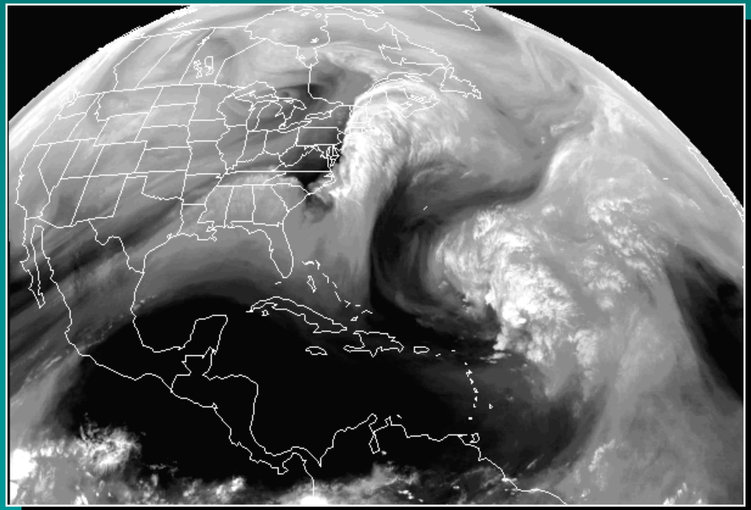
Jensen, 2000



GOES-East Visible



GOES-East Thermal Infrared

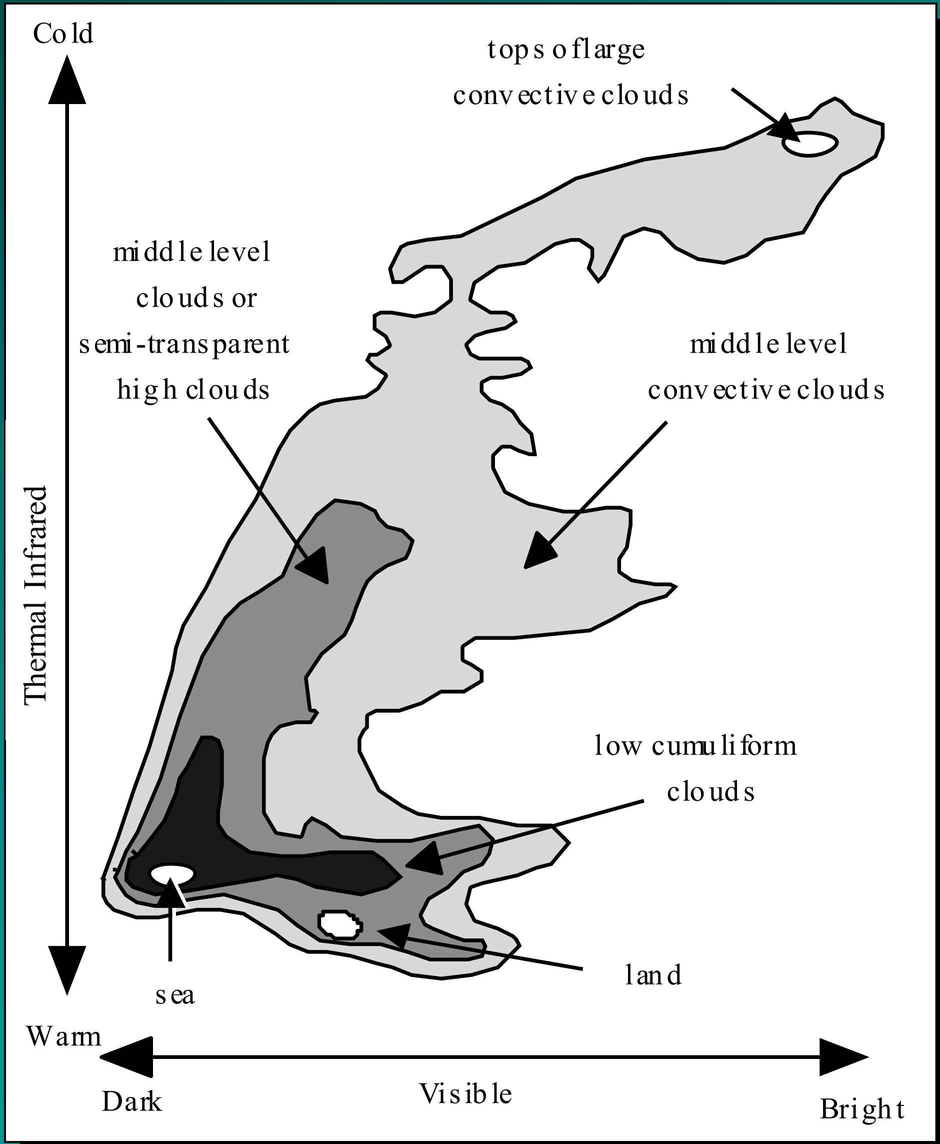


GOES-East Water Vapor

GOES-East Images of the United States and Portions of Central America on April 17, 1998

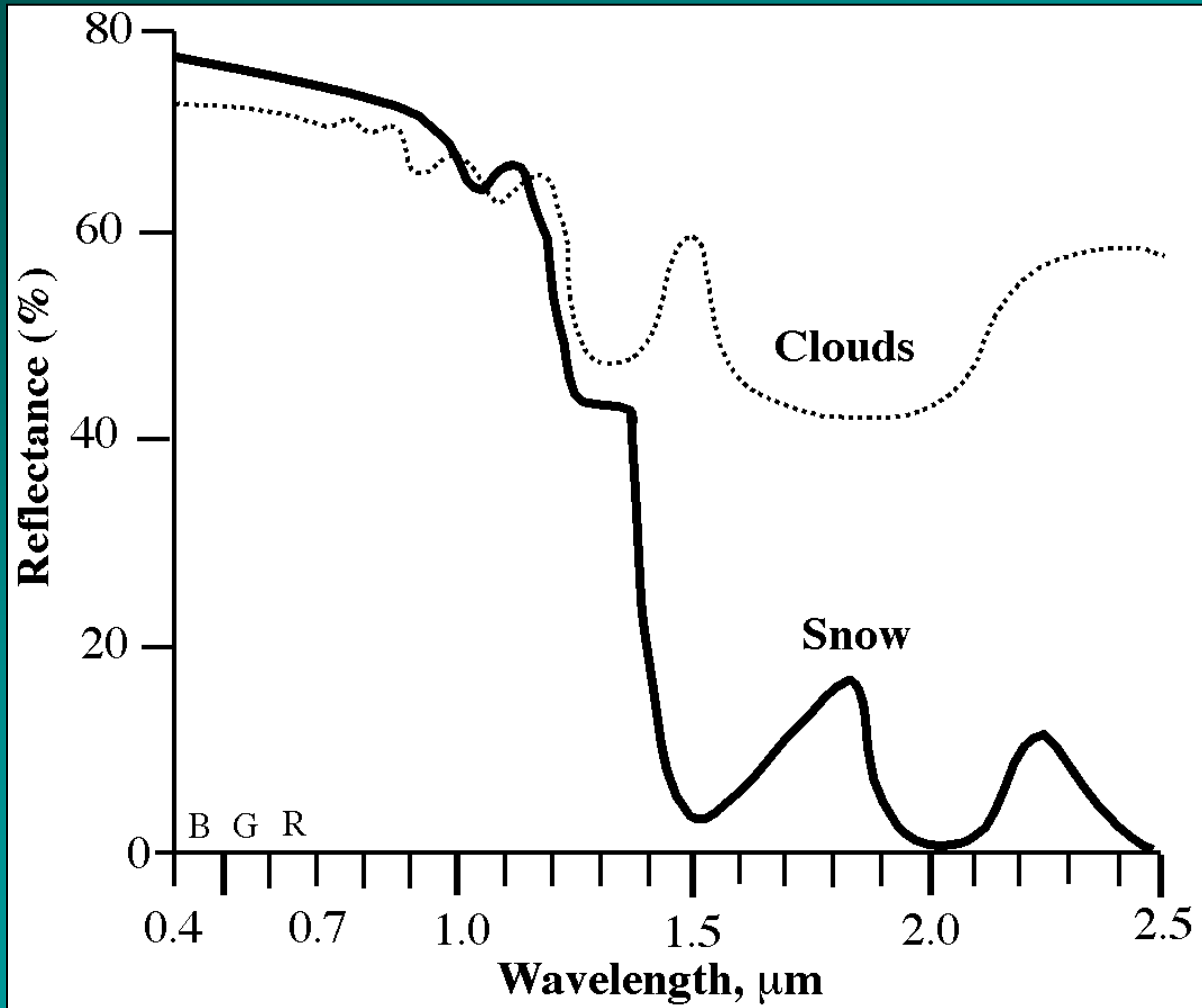
Jensen, 2000

Cloud Type Determination Based on Multispectral Measurements in the Visible and Thermal Infrared Regions of the Spectrum



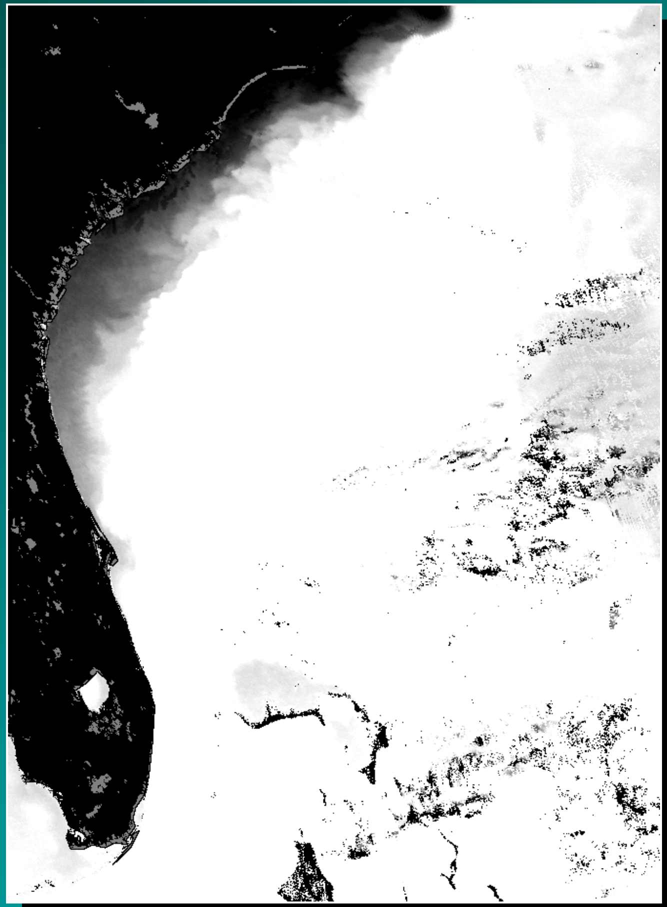
Jensen, 2000

Reflectance of Clouds and Snow in the Wavelength Interval 0.4 - 2.5 μm

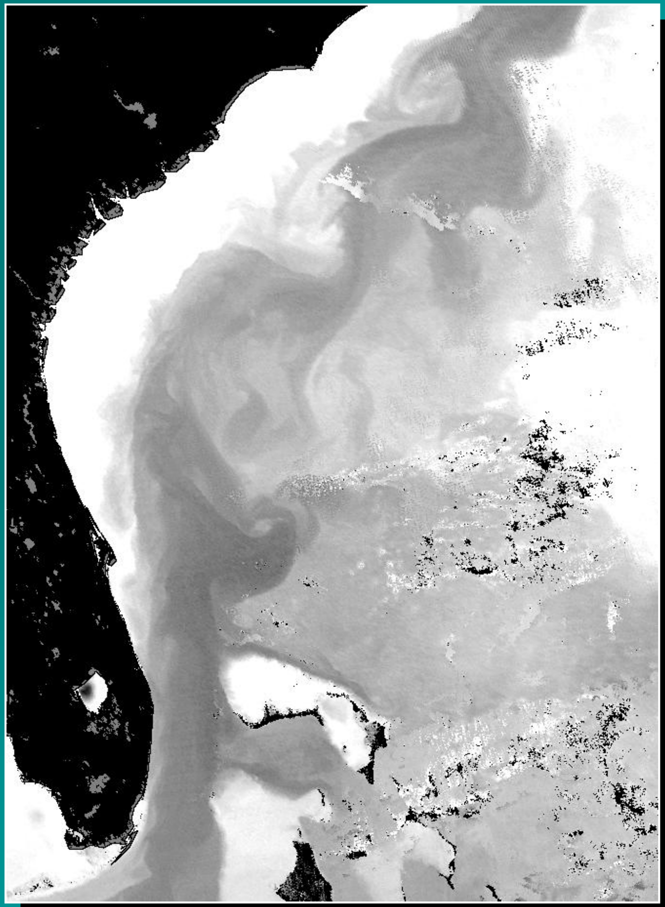


Jensen, 2000

Sea-surface Temperature (SST) Maps Derived from A Three-day Composite of NOAA AVHRR Infrared Data Centered on March 4, 1999



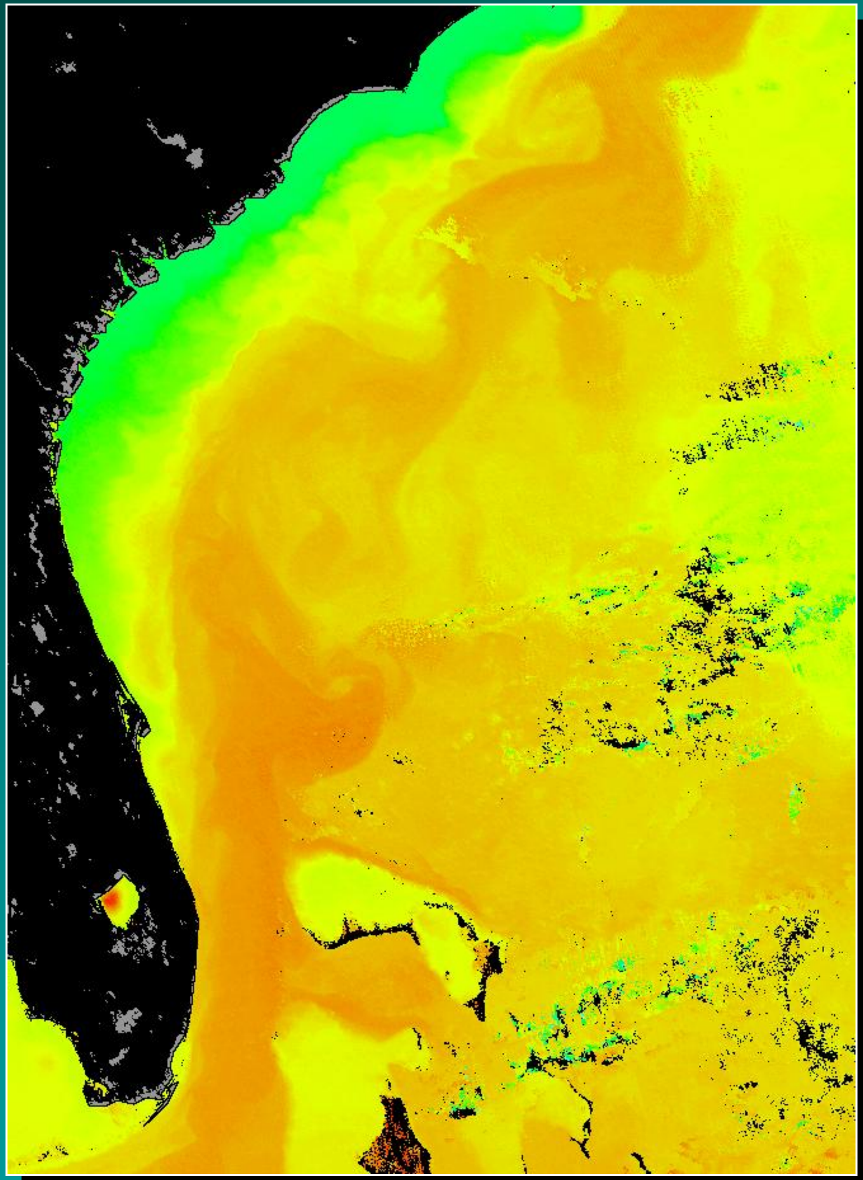
Adjusted to highlight nearshore temperature differences

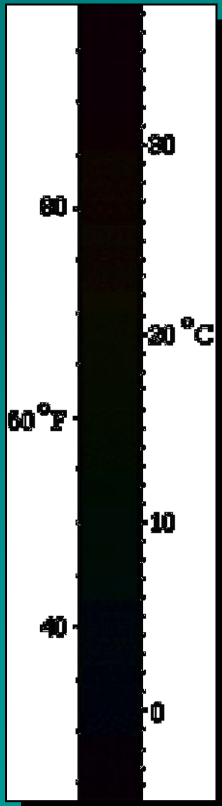


Adjusted to highlight Gulf Stream temperature differences

Jensen, 2000

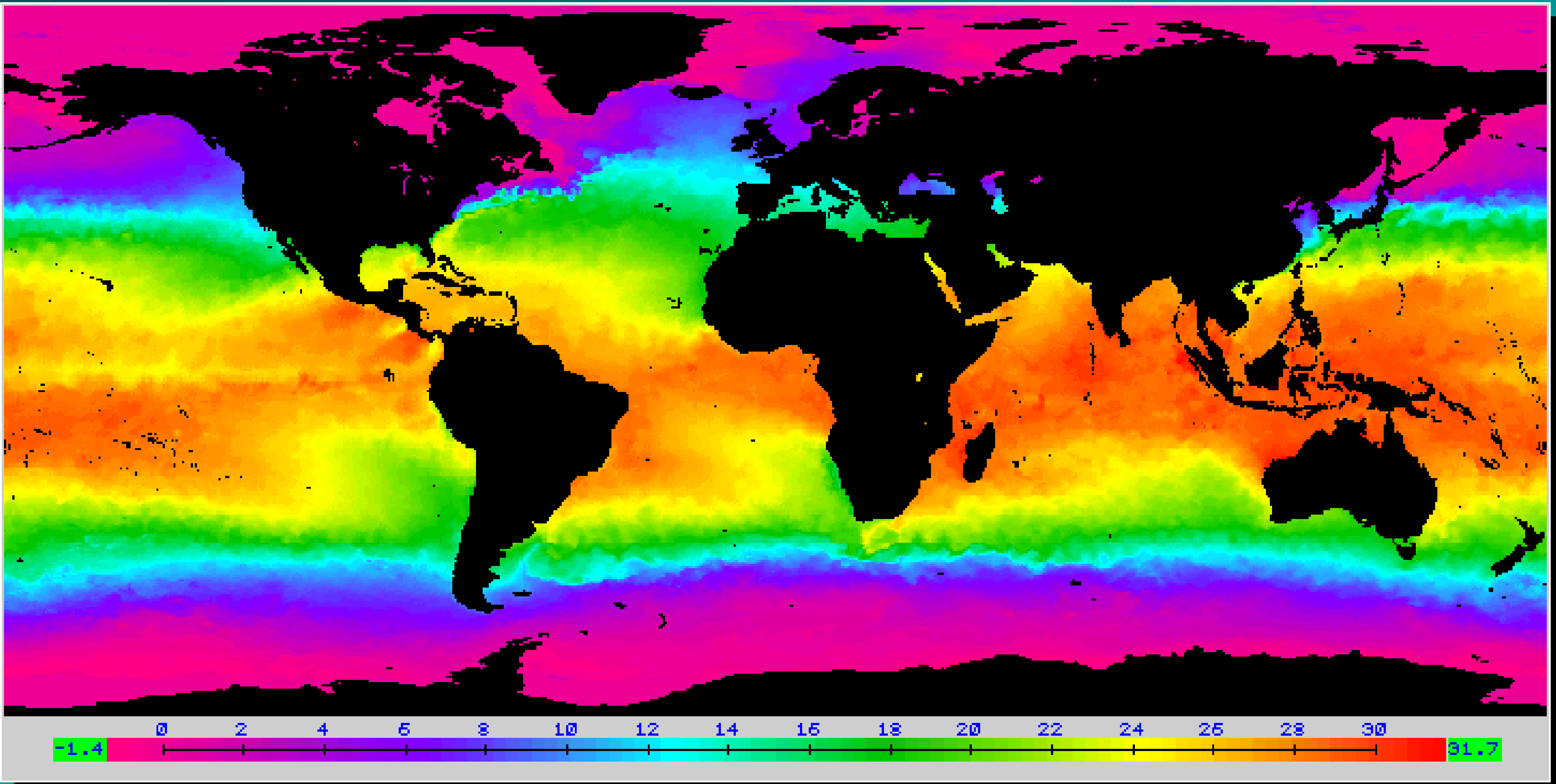
Composite Sea-surface Temperature (SST) Map of the Southeastern Bight Derived from AVHRR Data





Jensen, 2000

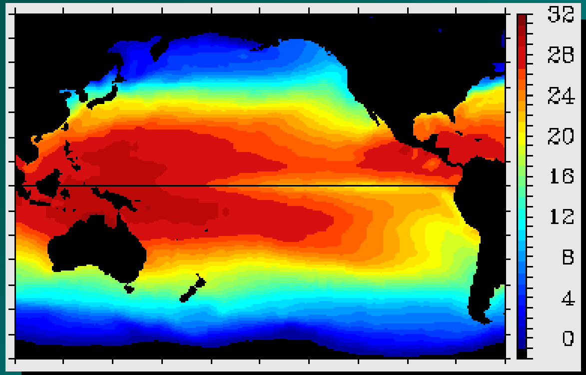
Worldwide Sea-surface Temperature (SST) Map Derived From NOAA-14 AVHRR Data



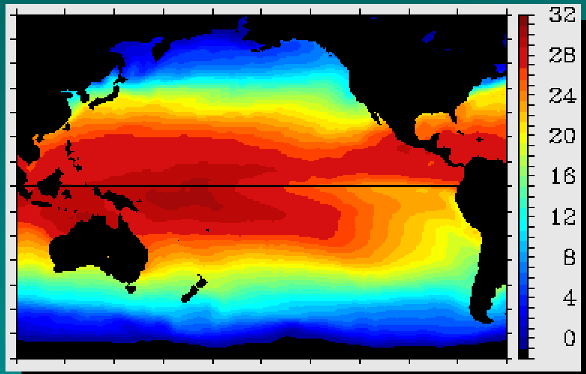
Three-day composite of thermal infrared data centered on March 4, 1999. Each pixel was allocated the highest surface temperature that occurred during the three days.

Jensen, 2000

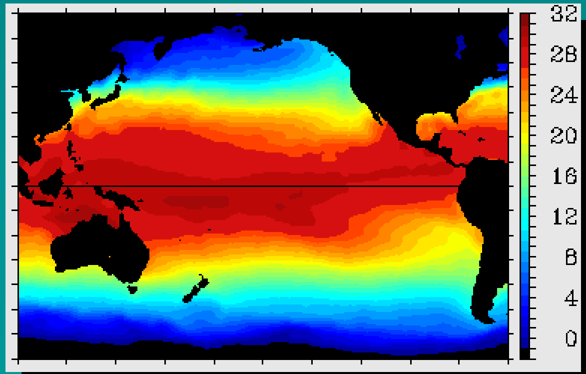
Reynolds Monthly Sea-surface Temperature (˚C) Maps Derived from *In situ* Buoy and Remotely Sensed Data



La Nina
December, 1988



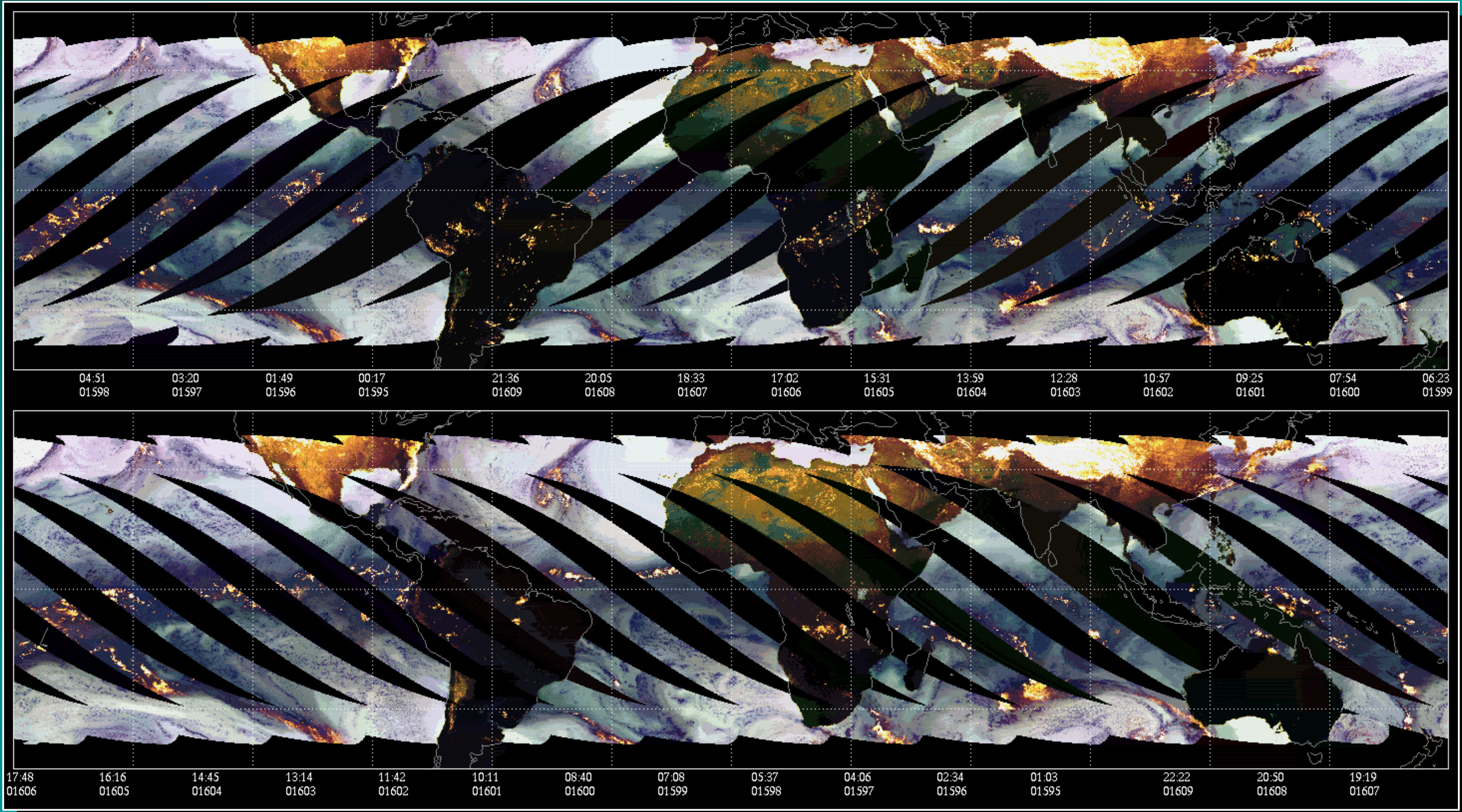
Normal
December, 1990



El Nino
December, 1997

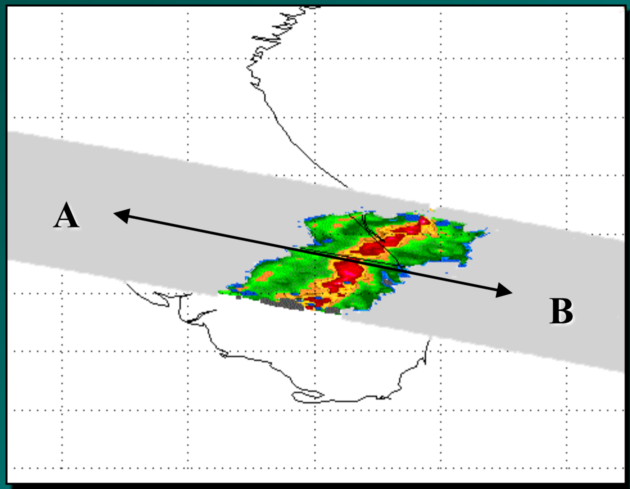
Jensen, 2000

Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI) Data Obtained on March 9, 1998

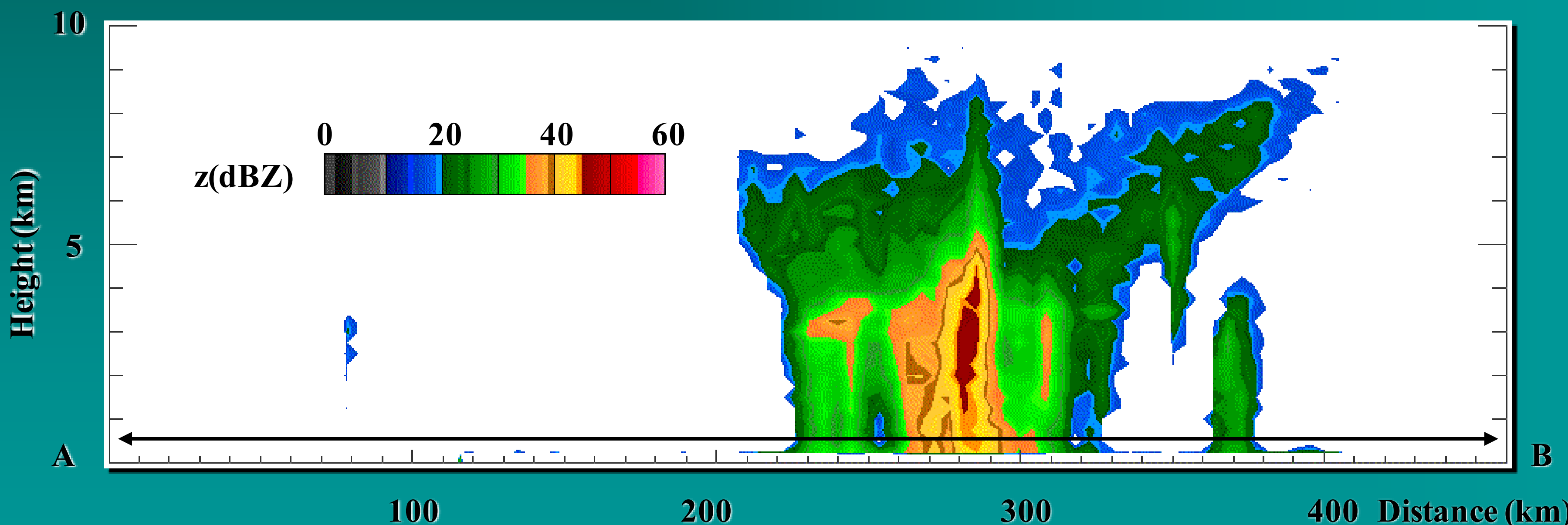


A passive microwave sensor that measures in five frequencies: 10.7 (45 km spatial resolution), 19.4, 21.3, 37, and 85.5 GHz (5 km spatial resolution). It has dual polarization at four of the frequencies. Swath width is 487 miles (780 km). The 10.7 GHz frequency provides a a linear response to rainfall.

Jensen, 2000

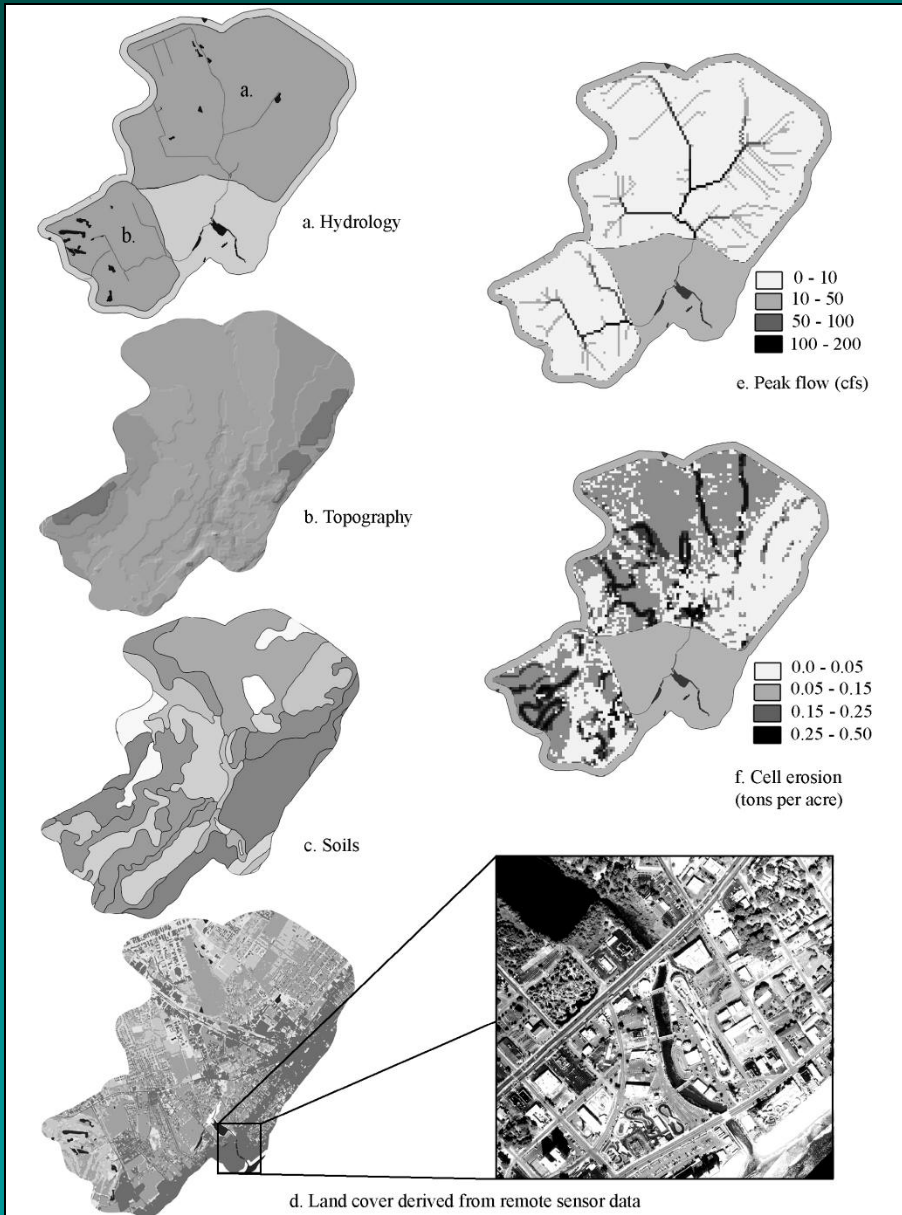


TRMM Precipitation Radar (PR) data obtained on March 9, 1998



Along-track cross-section of TRMM Precipitation Radar data obtained on March 9, 1998

Jensen, 2000



Nonpoint Source Pollution Modeling Based on the Agricultural NonPoint Source (AGNPS) Pollution Water Quality Model Applied to Two Subbasins in the Withers Swash Watershed in Myrtle beach, SC