

# **Ocean Optics: Fundamentals**

**Instructor:**

**Jeffrey H. Smart**

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# Instructor's Background in Ocean Optics

## **1988-1996: Environmental Specialist for a Major Open Ocean Optics-related Project**

- **Acquired and learned how to use multi-spectral radiance/irradiance sensor system, optical backscatter sensors, and beam transmissometers**
- **Developed software to provide analysis products such as optical attenuation profiles vs. wavelength**
- **Tested experimental systems to “measure” nighttime “K”**
- **Participated in 5 major sea tests plus numerous smaller sea tests**
- **Wrote environmental summary reports on temporal & spatial variability**

## **1992-1994: Environmental Specialist for Coastal Optics-related Program**

- **Deployed multi-spectral radiance /irradiance sensor system, optical backscatter sensors, and beam transmissometers in shallow coastal sites off Panama City & off Ocean City, Md**
- **Wrote environmental summary reports on short-term temporal variability (< 1 week) at fixed sites**

# Instructor's Background in Ocean Optics

**1994 to 1997: Project Manager & PI for bio-optical monitoring system**

- Analyzed & documented results for various sensors
- Analyzed data from associated platforms

**1996-2010: Environmental Specialist for various optics programs**

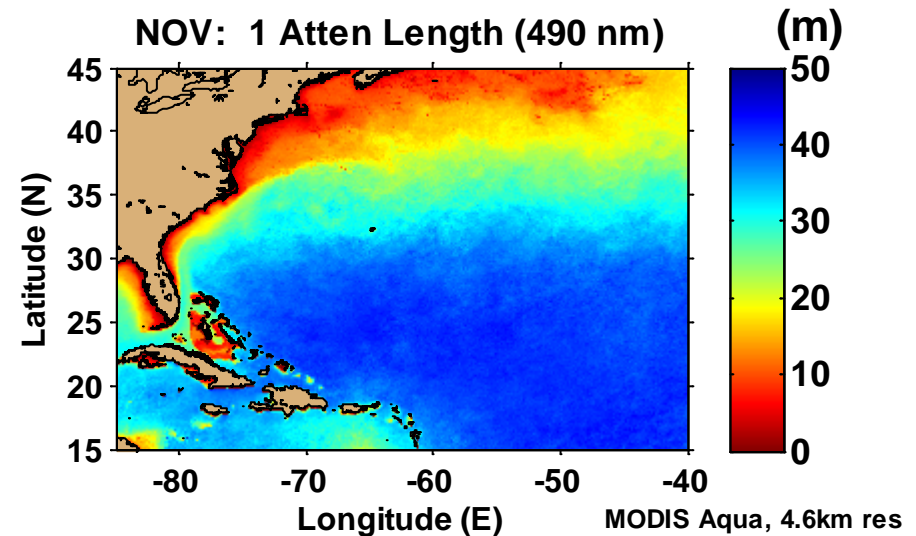
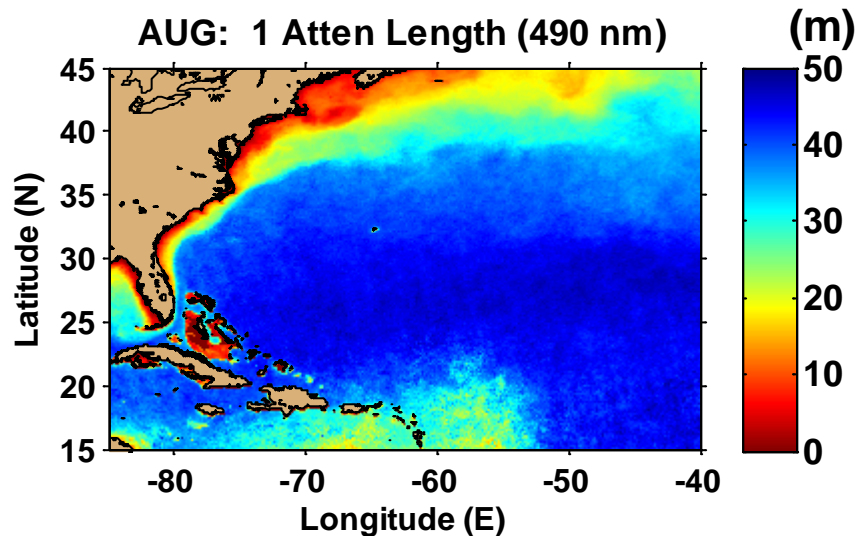
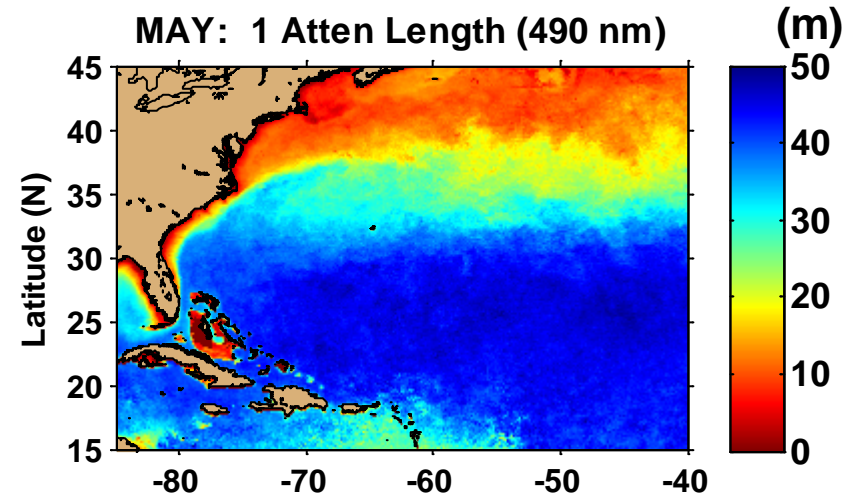
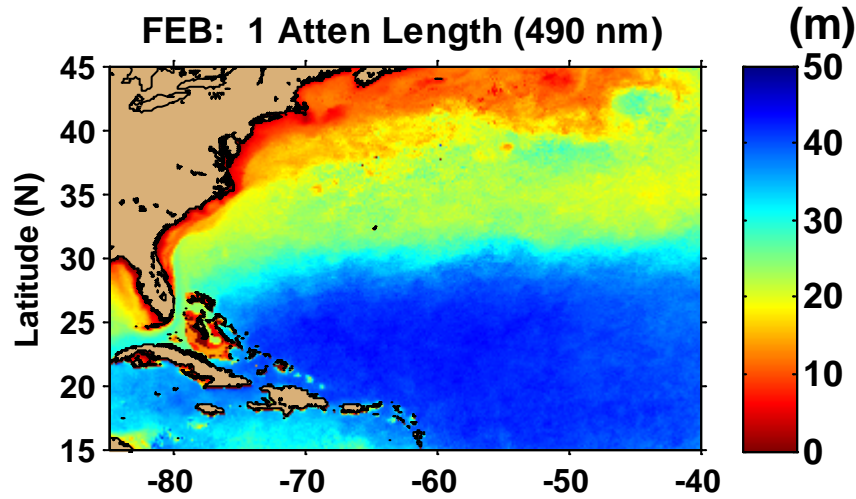
**1995 to 2012: Proj Mgr/PI for ONR World-wide Ocean Optics Database (WOOD)**

**2001-2003: ONR Sea Test Specialist**

- Project Scientist in the Yellow Sea supporting optical measurement systems
- Environmental expert for several sea tests, including exercise in East China Sea

# Example of Optical Attenuation by Season

(Blue light decays to 1/e of its surface value by this depth)



# Examples of Applications of Ocean Optics

- Underwater Communications
  - Optical properties of water directly impacts range & quality of transmission
- Viewing Objects on the Sea Floor & through the Water Column
  - Near-bottom optical properties of water directly impacts visibility of bottom objects
  - Horizontal and vertical diver visibility estimates
- Bioluminescence:
  - How Common is it & How Bright?
  - At what wavelengths does it occur
- Bathymetry Mapping
  - Making depth measurements in very shallow waters is non-trivial; remote sensing may be able to help

# Underwater Laser Communications

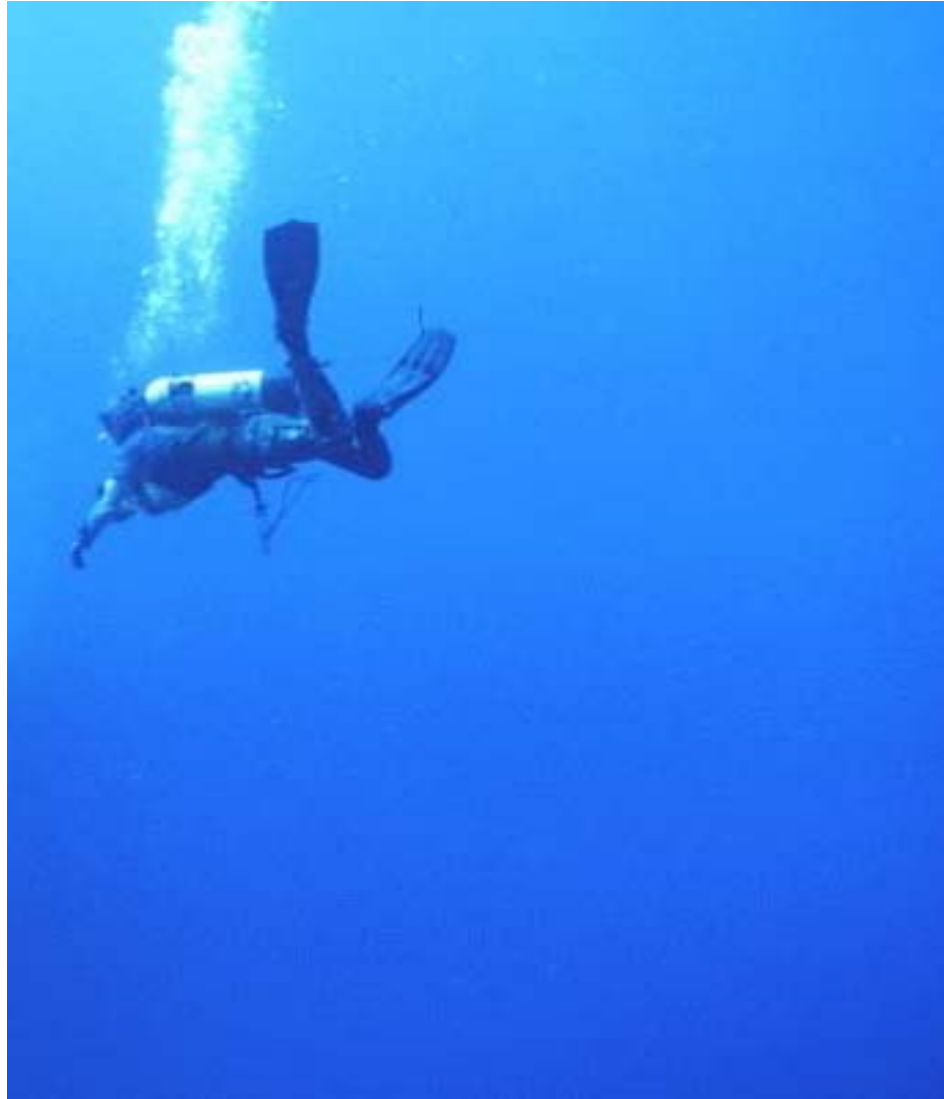
- UUVs need to be able to transfer data to a “docking station” or mother ship without making a physical connection
- Optical communication systems are being tested for high data rate transfer

# Optical Clarity & Contrast

- The clarity of the water depends on multiple factors and varies depending on depth, location, currents, outflow from rivers to name a few factors.
- Objects may be visible due to color and configuration. If the object has a high contrast against the background it is more likely to be visible.
- In clear, shallow areas where bottom reflectance is high (e.g., white sand, light colored coral), vertical (downward) observation of relatively dark objects will be enhanced due to contrast.

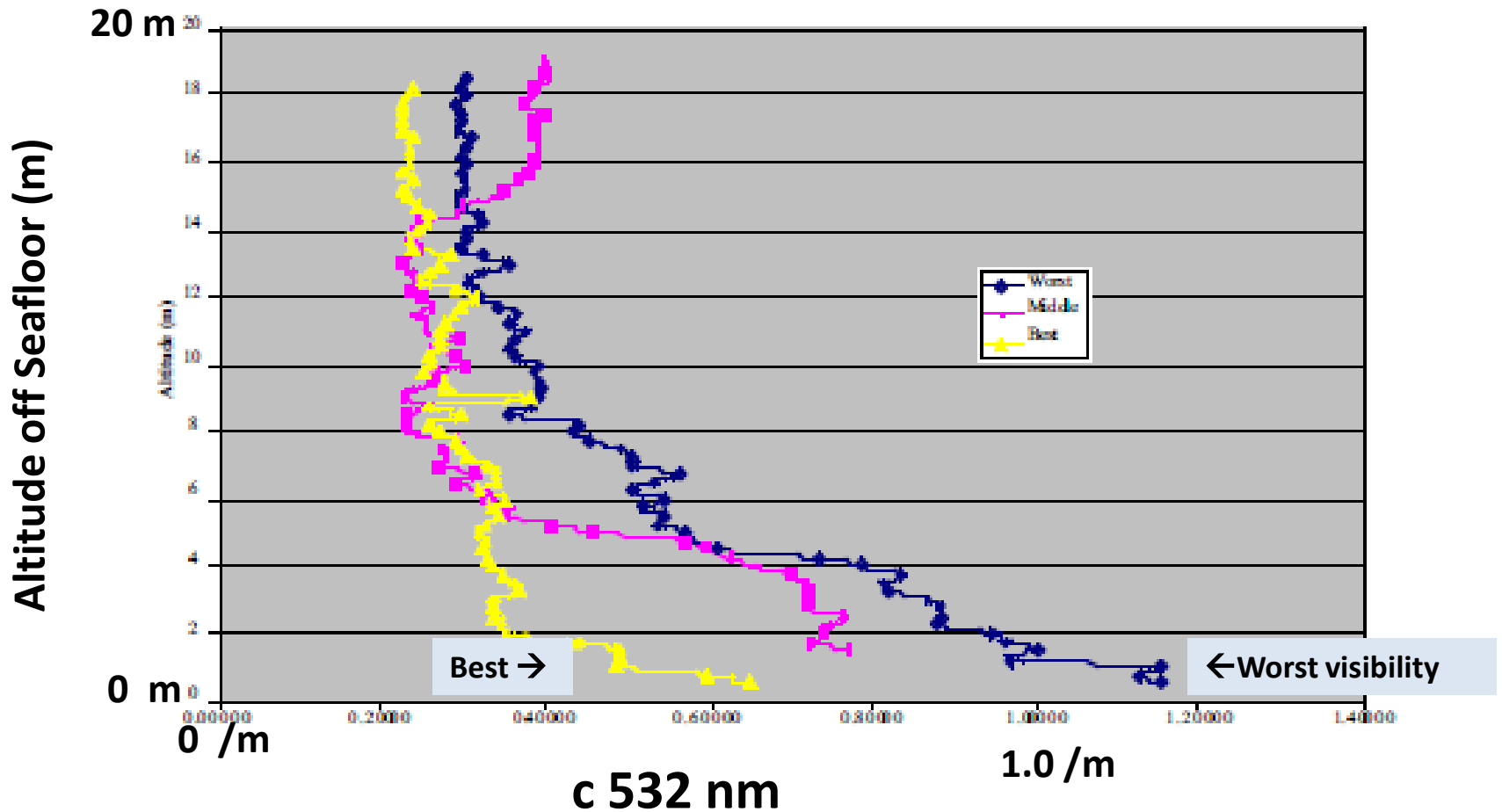


# Example of Underwater Visibility (extremely clear waters)



# Nepheloid Layers Affect Visibility of Objects on the Sea Floor

Variability in c 532 nm



# Model Example of How Optical Values Affect Imagery

Simulated object  
on seafloor

Simulated  
seafloor

$$a = 0.2 \text{ m}^{-1} \quad b = 0.3 \text{ m}^{-1}$$

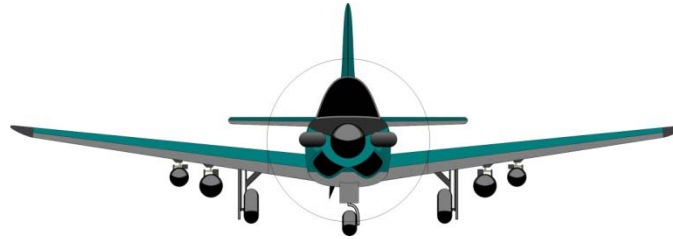
Simulated object  
on seafloor

Simulated  
seafloor

$$a = 0.4 \text{ m}^{-1} \quad b = 1.2 \text{ m}^{-1}$$

Factor of 4X increase in scattering (“b”) completely blurs the image

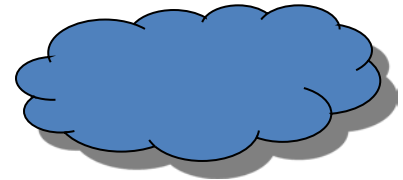
# Physical Factors Affecting Visibility of Objects Below the Sea Surface



Viewing Altitude, Look Angles, Dwell Time



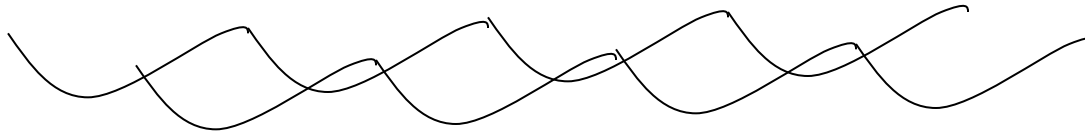
Sun Angle



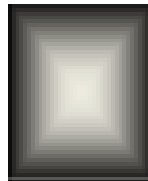
Clouds

Haze

Surface Clutter



Object Depth & Reflectance



Water Clarity  
Water Reflectance

Bottom Depth  
Bottom Reflectance



# Diver visibility range & attenuation

$$\text{visibility range (m), } V = -\frac{\ln|C_L|}{c}$$

$C_L$  contrast detection limit for human being  
 $c$  optical beam attenuation coefficient ( $\text{m}^{-1}$ )

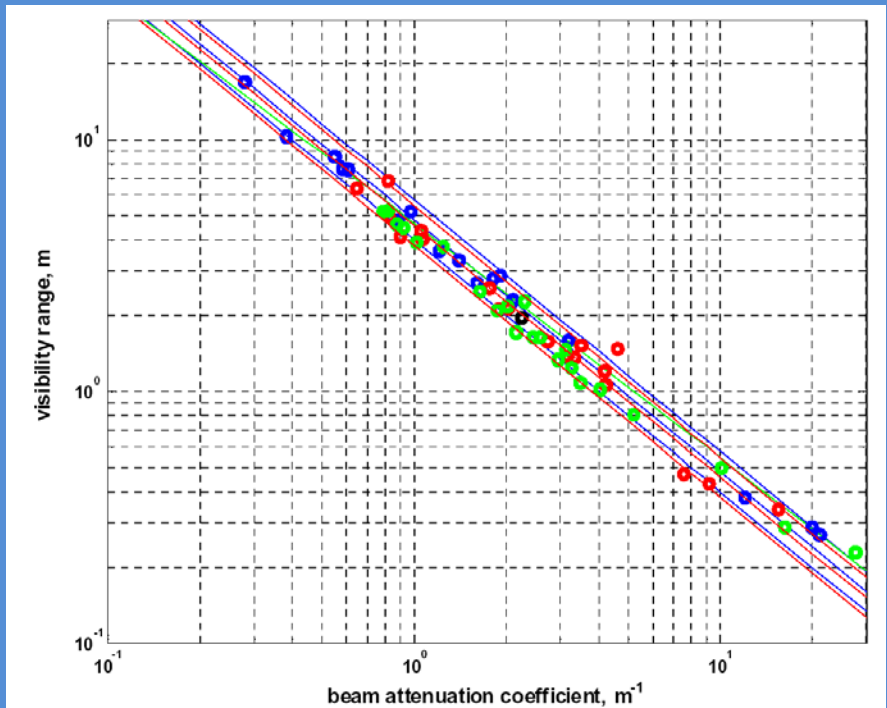
From Radiative Transfer Theory,

- Priesendorfer (1976)
- Duntley (1963)

$$V = \frac{4.8}{[1.18c(650) + 0.081]}$$

Accuracy better than 10%

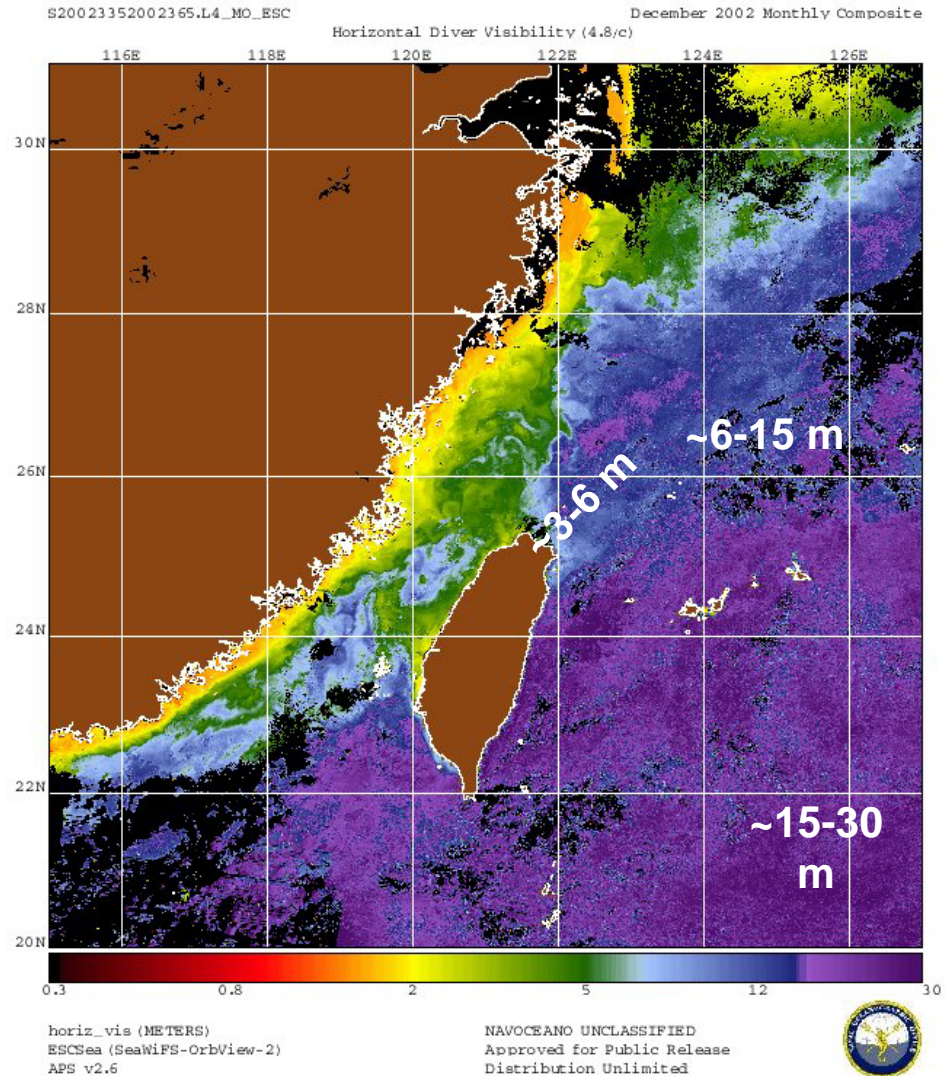
Backscattering is *NOT* a good proxy for visibility



Zaneveld and Pegau (2003)

# East China Sea & Philippine Sea: Example of Variability in Horizontal Visibility

- Turbid in coastal areas, very clear offshore
- Straits high spatial and temporal variability, with vertical visibilities from 5-30 ft. Values can be artificially low due to shallow bathymetry off the west coast of Taiwan.
- Vertical visibility 40-80+ ft offshore
- Vertical visibility 0-10 ft coastally
- Summer rainy season, clearer waters in winter months

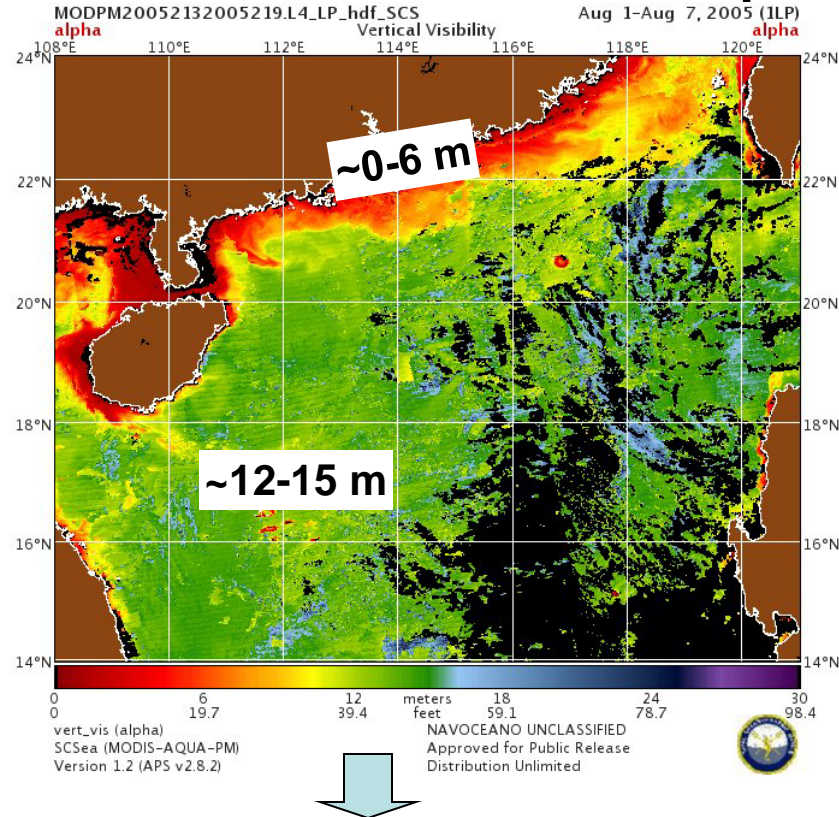




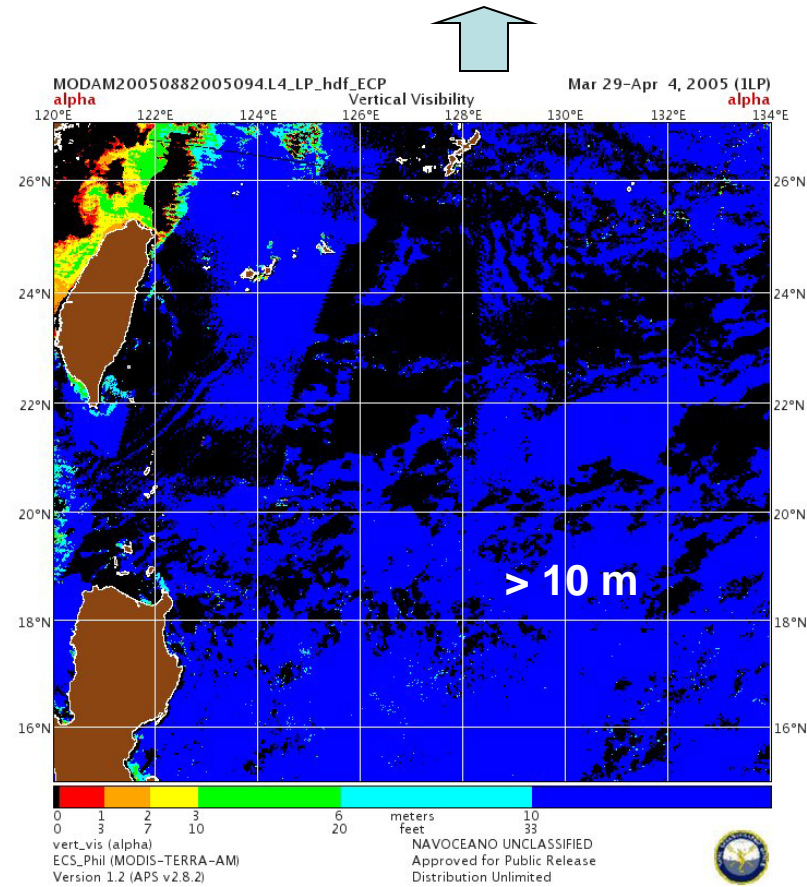
# South China Sea and Philippine Sea

## Historical Optical Clarity/Vertical Visibility

- Very clear waters in all of Philippine Sea
- Vertical visibilities 30-80+ ft throughout
- Minimal effects of tides and summer rainy season
- More turbid pockets around Northern Philippine Islands, but generally very clear with little variability

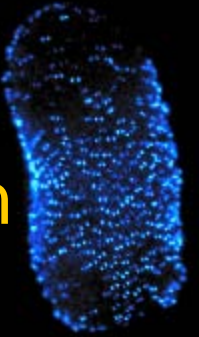
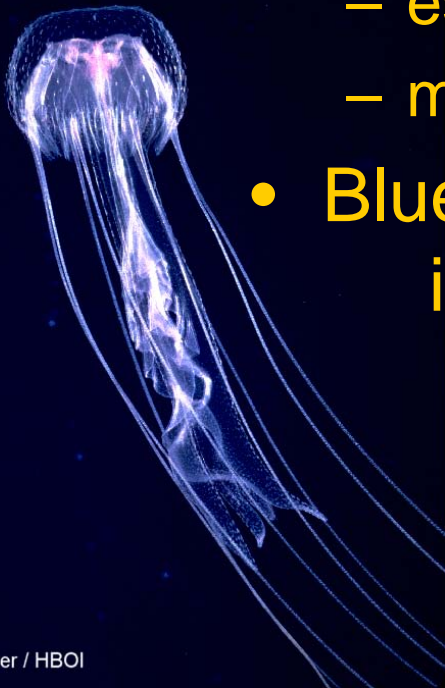


- Least historical data available of 4 areas
- Highly turbid along northern boundaries, much clearer offshore
- Vertical visibilities 40-60+ ft offshore in deep waters
- Vertical visibilities 0-20 ft coastally
- Summer rainy season, clearer waters in winter months
- Clear waters around Philippines and further south



# What is Bioluminescence: An optical parameter

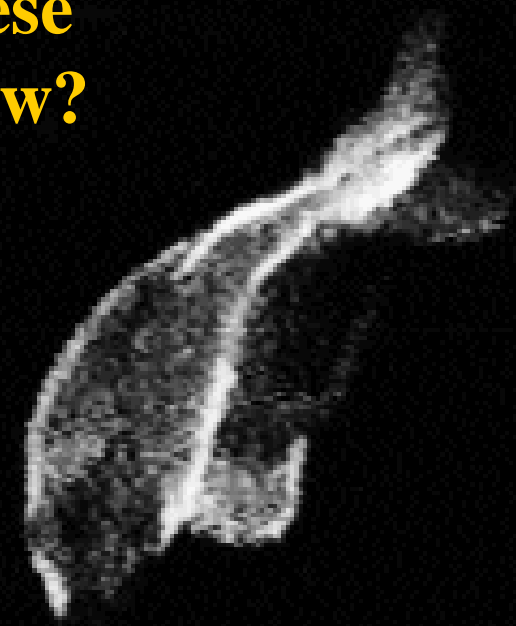
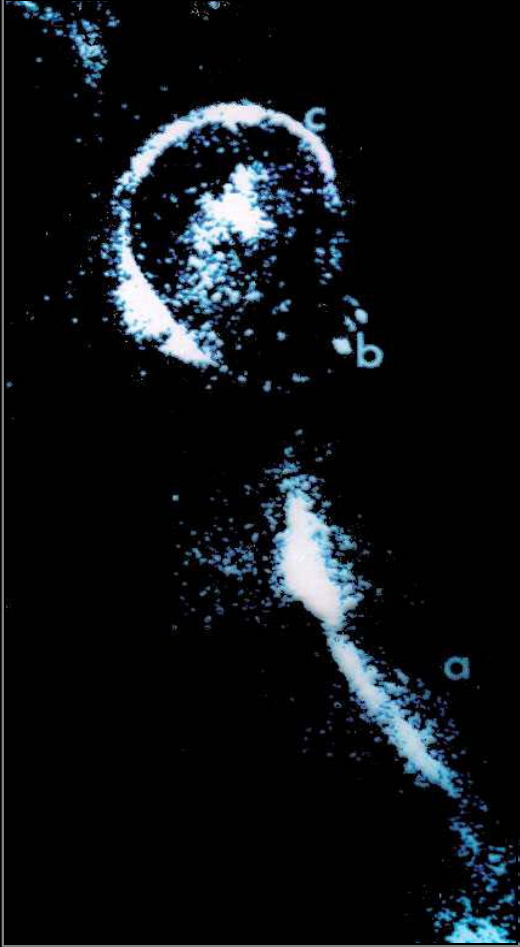
- Emission of light by living organisms
- Turbulence initiated **chemical** reaction
- Globally distributed phenomenon
  - est. 70% of marine organisms bioluminesce
  - measured from equator to Arctic pack ice
- Blue-green in color which travels furthest in the ocean



All images, Harbor Branch (E. Widder)



## What causes these organisms to glow?



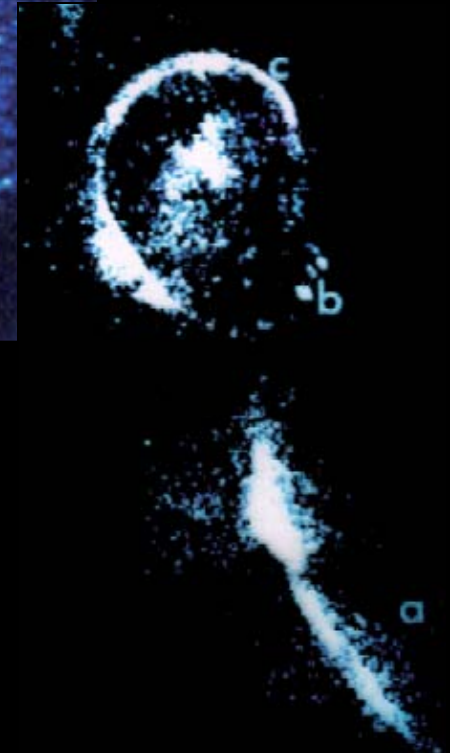
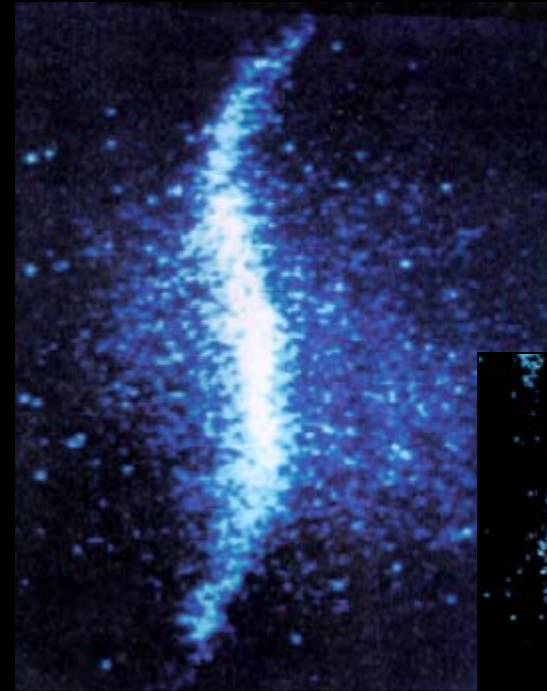
Bioluminescent organisms can be mechanically stimulated to produce light. Turbulence generated by a ship's passage or even the movement of dolphins and fish is enough to create the glow.



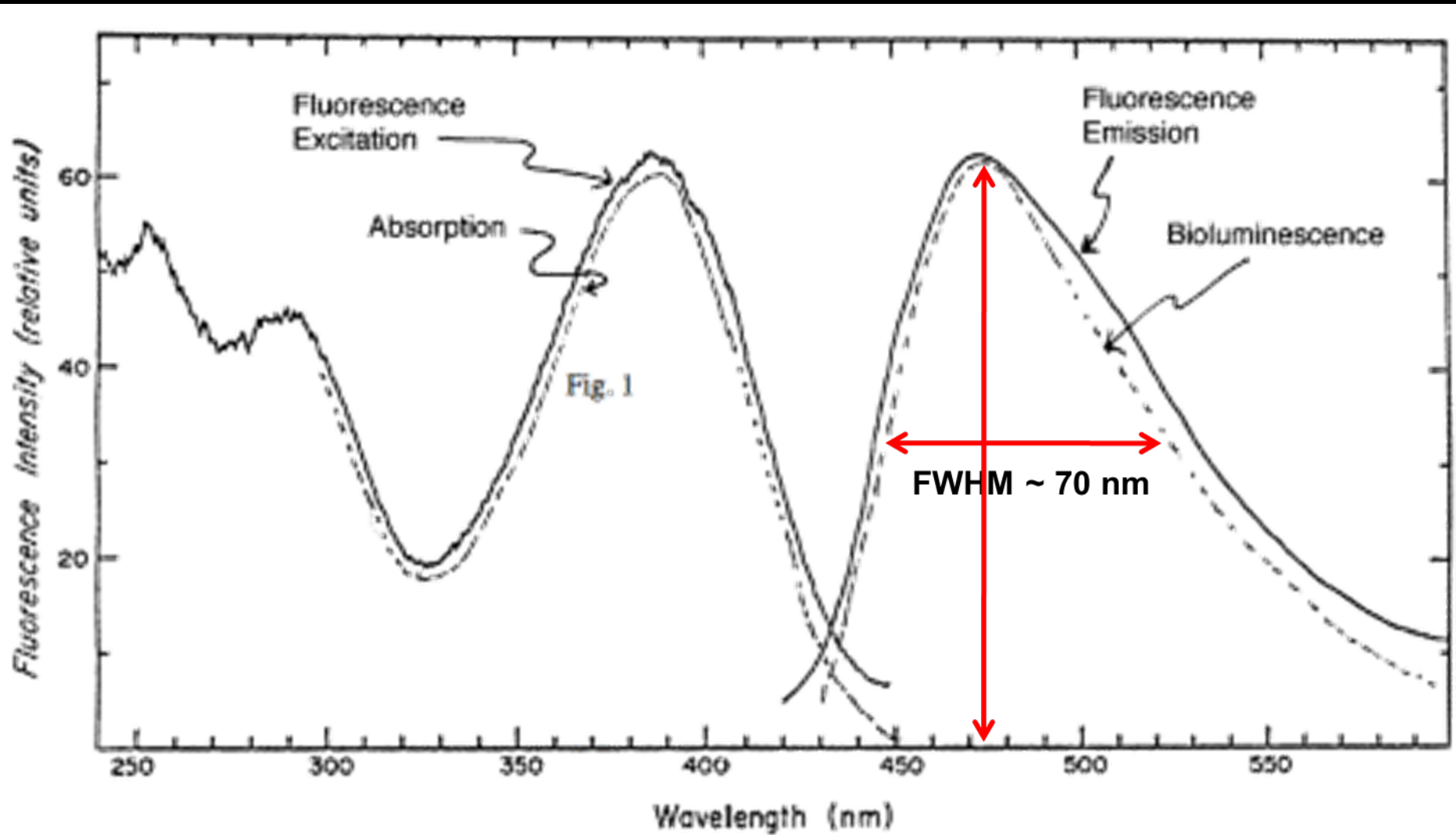
# How bright can it be? Those cells are so small...

The luminescence of a single dinoflagellate is readily visible to the dark adapted human eye. Most dinoflagellates emit about  $6 \times 10^8$  photons in a flash lasting only about 0.1 second.

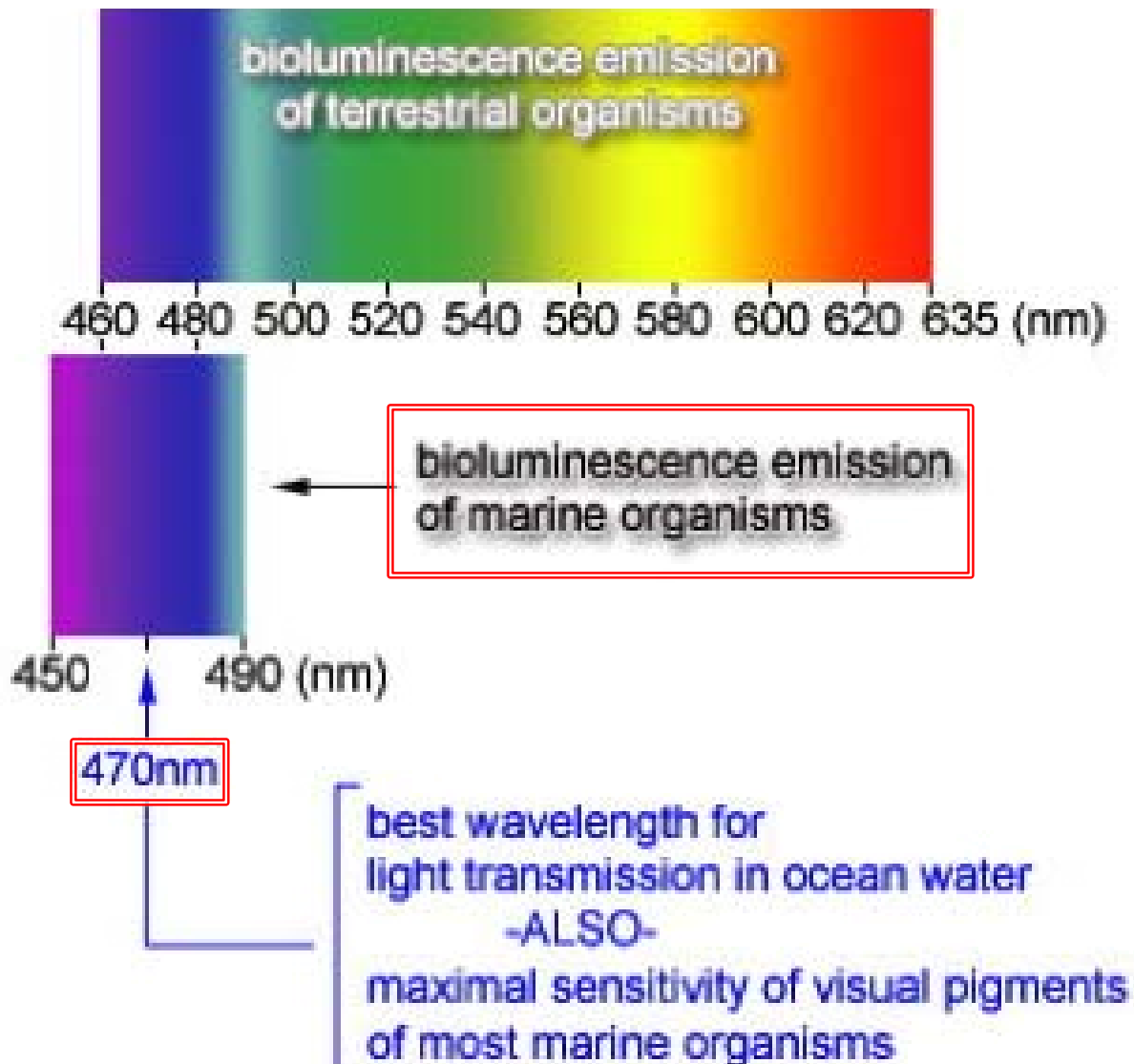
Much larger organisms such as jellyfish emit about  $2 \times 10^{11}$  photons per second for sometimes tens of seconds.



# At what wavelengths does it occur?



Center wavelengths primarily range from about 470 to 510 nm. Full-width-half maximum (FWHM) values range from around 30 to 100 nm.



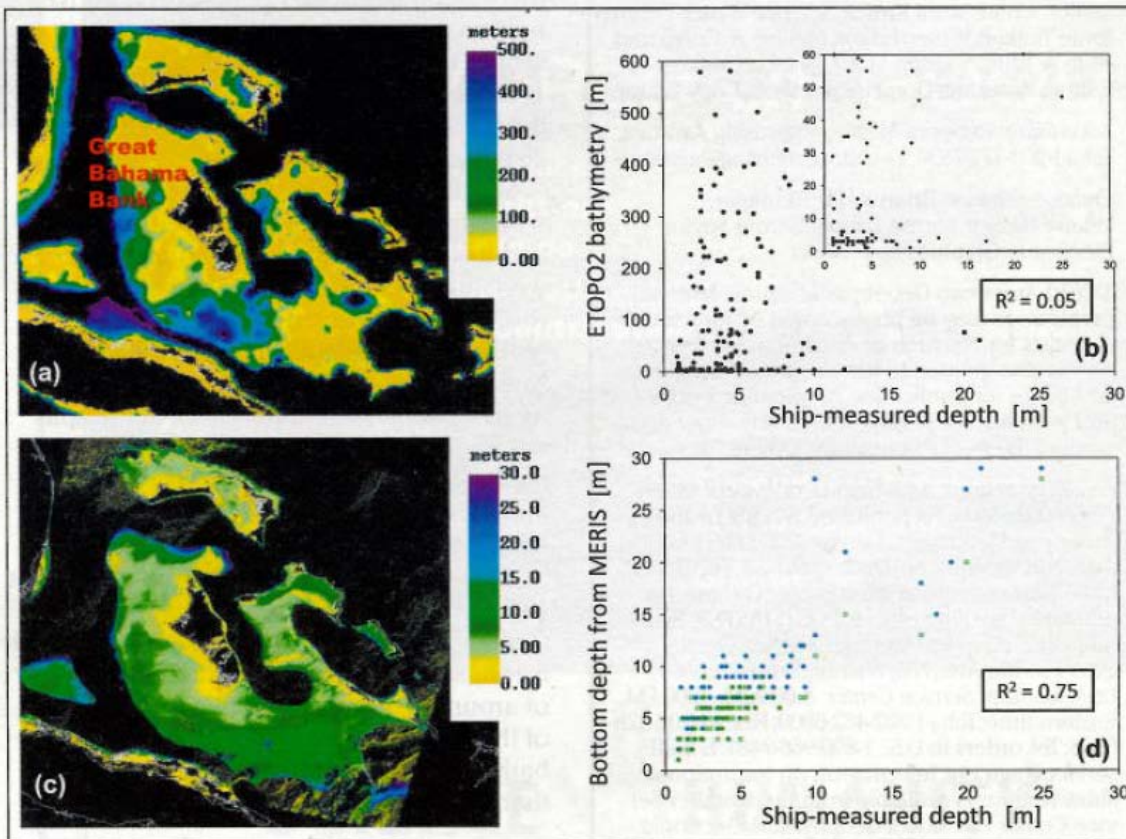
**Figure 6. The end-product of bioluminescence is visible light. The visible part of the spectrum is 400-700 nm, and the emission maxima of most luminous marine organisms falls within the range of 450-490 nm.**

# **Bathymetry Mapping in Shallow Coastal Waters**

# Bathymetry from Ocean Color

- **Knowledge of ocean bathymetry is important for navigation & for scientific studies of the ocean's volume, ecology, and circulation, all of which are related to Earth's climate.**
- **In coastal regions detailed bathymetric maps are critical for storm surge modeling, marine power plant planning, understanding of ecosystem connectivity, coastal management, and change analyses.**
- **Because ocean areas are enormously large and ship surveys have limited coverage, adequate bathymetric data are still lacking throughout the global ocean.**
- **Satellite altimetry can produce reasonable estimates of bathymetry for the deep ocean [*Sandwell et al.*, 2003, 2006], but the spatial resolution is very coarse (~6–9 kilometers) and can be highly inaccurate in shallow waters, where gravitational effects are small.**
- **Depths retrieved from the ETOPO2 bathymetry database for the Great Bahama Bank are seriously in error when compared with ship surveys & no statistical correlation was found between the two**
- **Determining a higher-spatial-resolution (e.g., 300-meter) bathymetry of this region with ship surveys would require ~ 4 years of nonstop effort.**

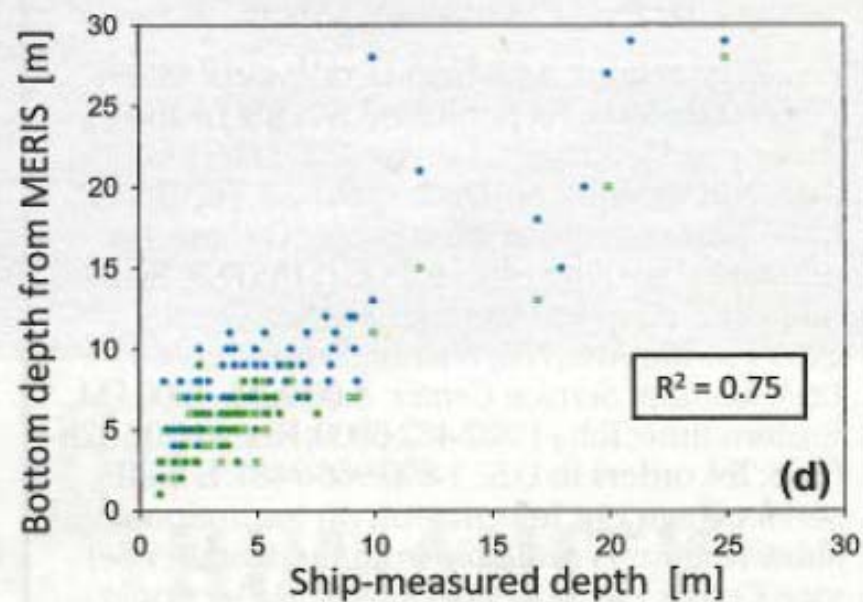
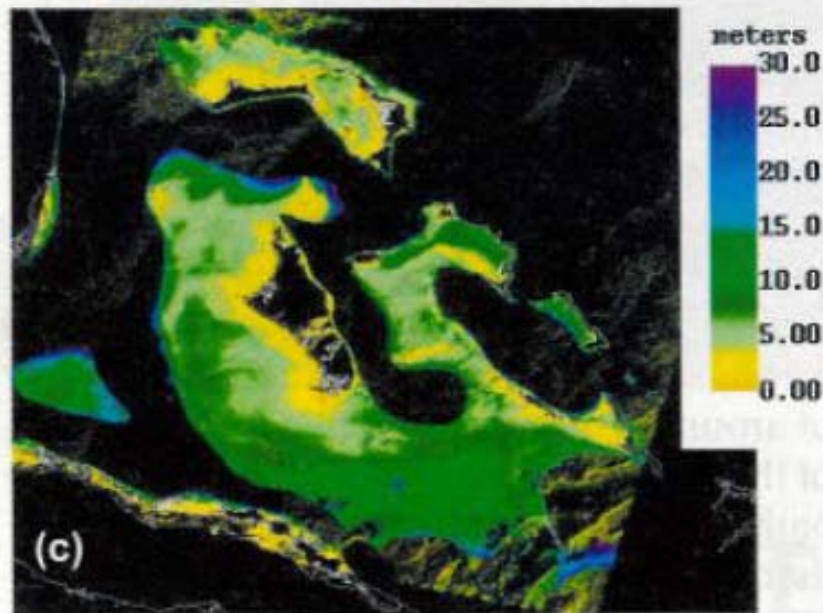
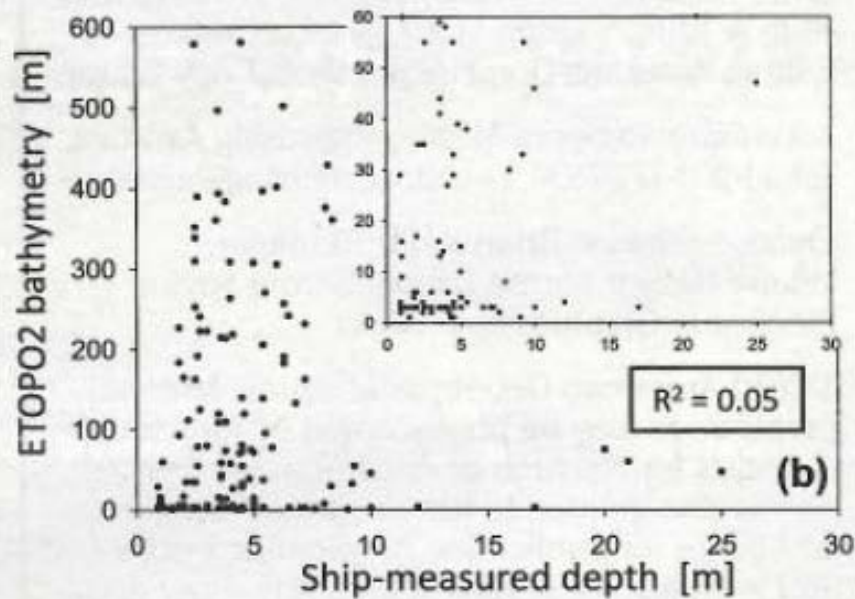
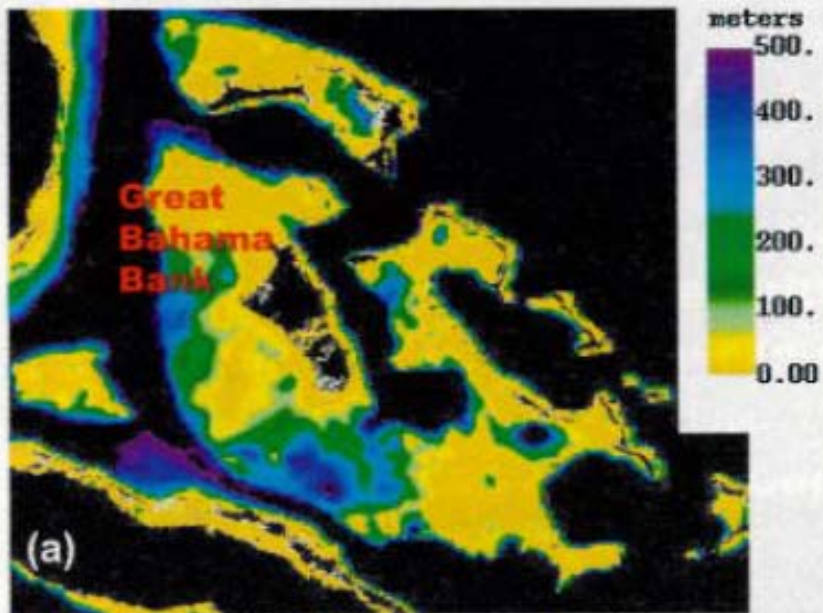
# Bathymetry from Ocean Color



**Fig. 1 (a) Depth of the Great Bahamas Bank retrieved from the E70P02 bathymetry database. (b) Scatter plot between in situ depth and E70P02 bathymetry of matching locations (inset shows ETOPO2 bathymetry under 60 meters). (c) bottom depth derived from Medium Resolution Imaging Spectrometer (MERIS) measurements (14 December 2004) by the hyper-spectral optimization process exemplar (HOPE) approach. (d) like Figure 1 b, a scatter plot between in situ depth and MERIS depths (rounded to nearest integer to match ETOPO2 format; blue indicates 14 December 2004, green indicates 6 September 2008). The coefficient of determination ( $R^2$ ) represents all data points (281) in the plot. Note the color scale difference in Figures 1a and 1c. Black pixels represent land or deep waters.**



# Bathymetry from Ocean Color





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