Lecture 2
Overview of Light in Water

Collin Roesler
Department of Earth and Oceanographic Science
Bowdoin College

http://marketingdeviant.com/wp-content/uploads/2008/01/underwater-light-beams.jpg

19 July 2021

Welcome

- Diverse backgrounds of the instructors
- Diverse teaching styles within and between us
- Diverse backgrounds of the students
- Diverse learning styles within and between you

- Consider your learning style. Which of the following do you find most effective for your learning?
  - Reading
  - Hearing
  - Discussion
  - Graphs
  - Equations
  - Hands on activities

Strategies

- Independent
  - Knowledge Surveys
- Collaborative
  - Think-pair-share
    - Consider a problem on you own, brainstorm
    - Pair with a partner
    - Share ideas, work through questions, articulate consensus
  - Jigsaw
    - Individuals or small group experts work on one aspect of problem
    - Groups get together to share results
    - Problem is solved by synthesis of everyone's contributions
    - The whole is more than the sum of the parts
- Assessments
  - Daily exit sticky notes (give to Guillaume before lab)
    - Something new you learned
    - Nagging question or point of confusion
  - Daily group presentations
    - Accountability for work
    - Assess, revise, resubmit

Let's start with this exercise

- Consider the Radiative Transfer Equation (RTE)
  - Take out a piece of paper and pen/pencil
  - Sketch a diagram
  - Write an expression or equation
- But first, take this knowledge survey:

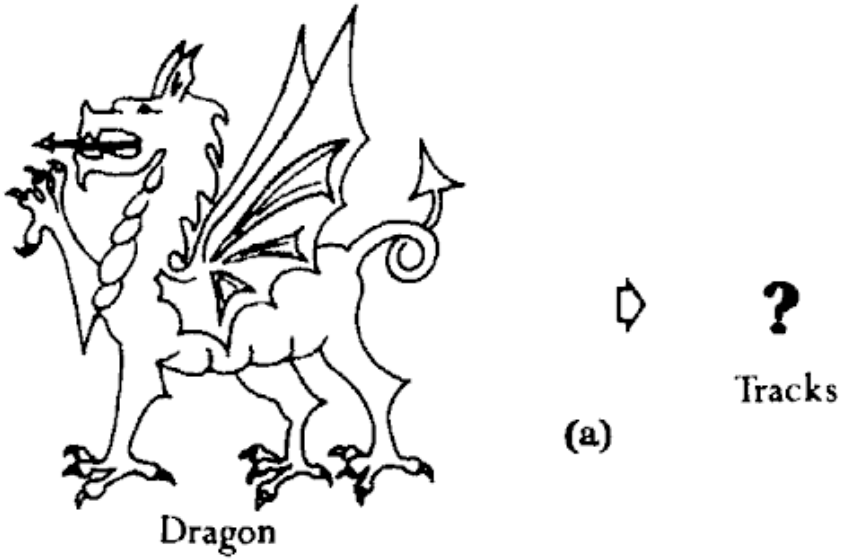
A. Sketch a diagram or write an expression for the radiative transfer equation (RTE)

1. I know just what to do
2. I will get pretty close
3. I can give it a try
4. I can try but it will likely be wrong
5. I have no idea where to start
6. What is the radiative transfer equation?

Consider the light field in the ocean

- Forward approach
- Inverse approach

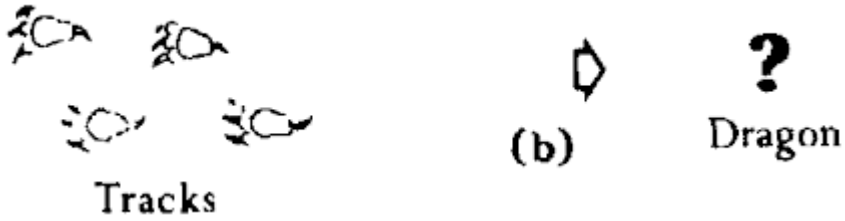
Direct or Forward Model



Bohren and Huffman 1983

- We know there is a dragon
- Thus we can predict the tracks it will leave

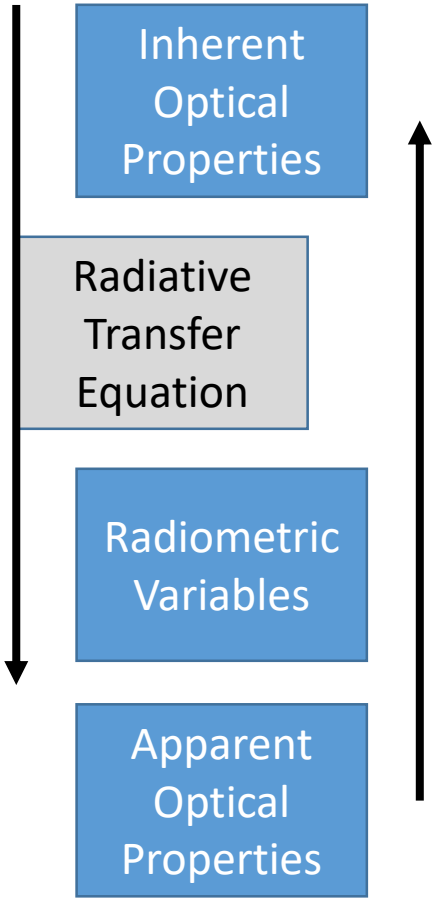
Inverse Model



Bohren and Huffman 1983

- We observe the tracks
- From that observation, we can determine what kind of dragon

Optically



- Forward model
  - We know (have measured) the absorption and scattering properties of the ocean (dragon)
  - Can predict the oceanic light field (imprint on light field)
  - Radiative Transfer Equation
- Inverse model
  - We observe (or measure) the light field in the ocean (or apparent properties derived from it)
  - Can predict the absorption and scattering properties that gave rise to it
  - Various inversion models

The radiative transfer equation is a forward model that describes how sunlight propagates from it source (define the source) into the ocean

The Source

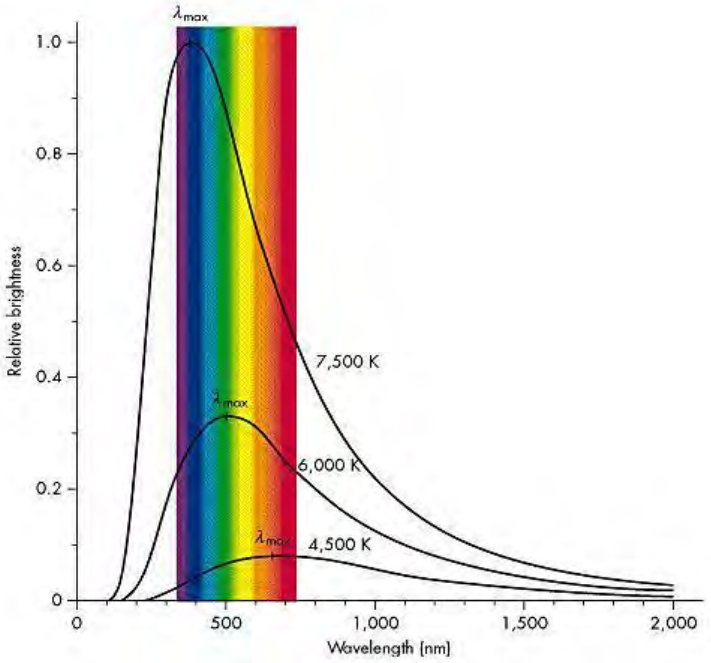
View of the sun and Earth's horizon as seen from the International Space Station.

The image was taken using a fish-eye lens attached to an electronic still camera during the STS-134 mission's fourth spacewalk May 2011. *credit: NASA*

http://www.space.com/12934-brightness-sun.html

Black body radiation

- Any object with a temperature >0K emits electromagnetic radiation (EMR)
- **Planck's Law** : The spectrum of that emission depends upon the temperature (in a complex way)
- **Stefan-Boltzman Law**: The hotter the object, the more radiant power it emits, proportional to T^4( )
- **Wien's Displacement Law**: The hotter the object the shorter the wavelength of maximal emission, $\lambda_{max} \sim T^{-1}$ ( )
- **Sun *T*~ 5700 K**
  So it emits a spectrum of EMR that is maximal in the wavelengths

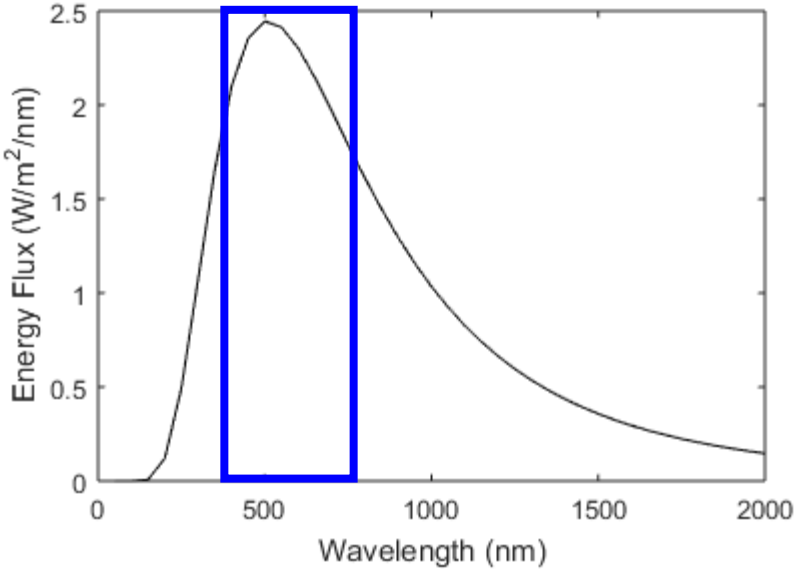


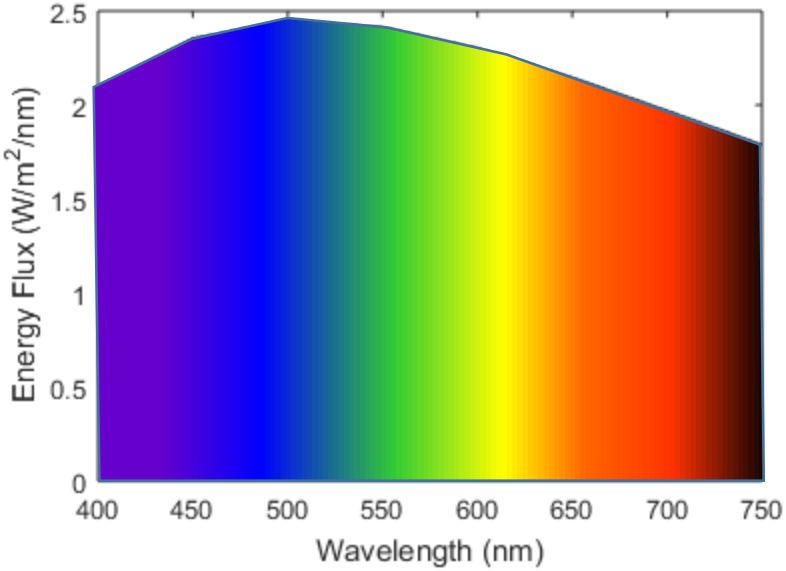
http://aeon.physics.weber.edu/jca/PHSX1030/Images/blackbody.jpg

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5 \left(exp\left[\frac{hc}{\lambda kT}\right] - 1 \right)}$$

Blackbody Radiation –
solar flux density at top of atmosphere

- Is the graph consistent with our observation?





Earth's atmosphere

Let’s make some observations about the atmosphere

Compare the light field at the top of the atmosphere versus Earth's surface

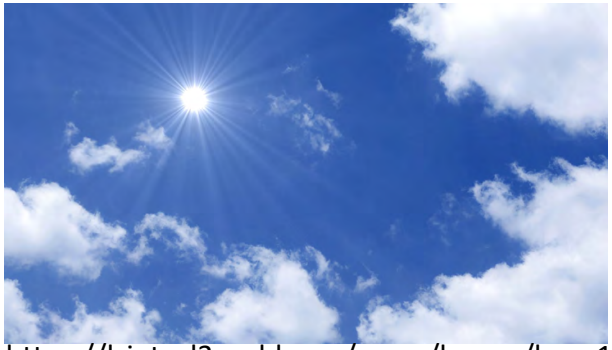
http://www.space.com/12934-brightness-sun.html z

https://lsintspl3.wgbh.org/en-us/lesson/buac18-il-ilchangessky/1

- Similarities
- Differences

Compare the light fields: top of the atmosphere, Earth's surface, below ocean surface

http://www.space.com/12934-brightness-sun.html z

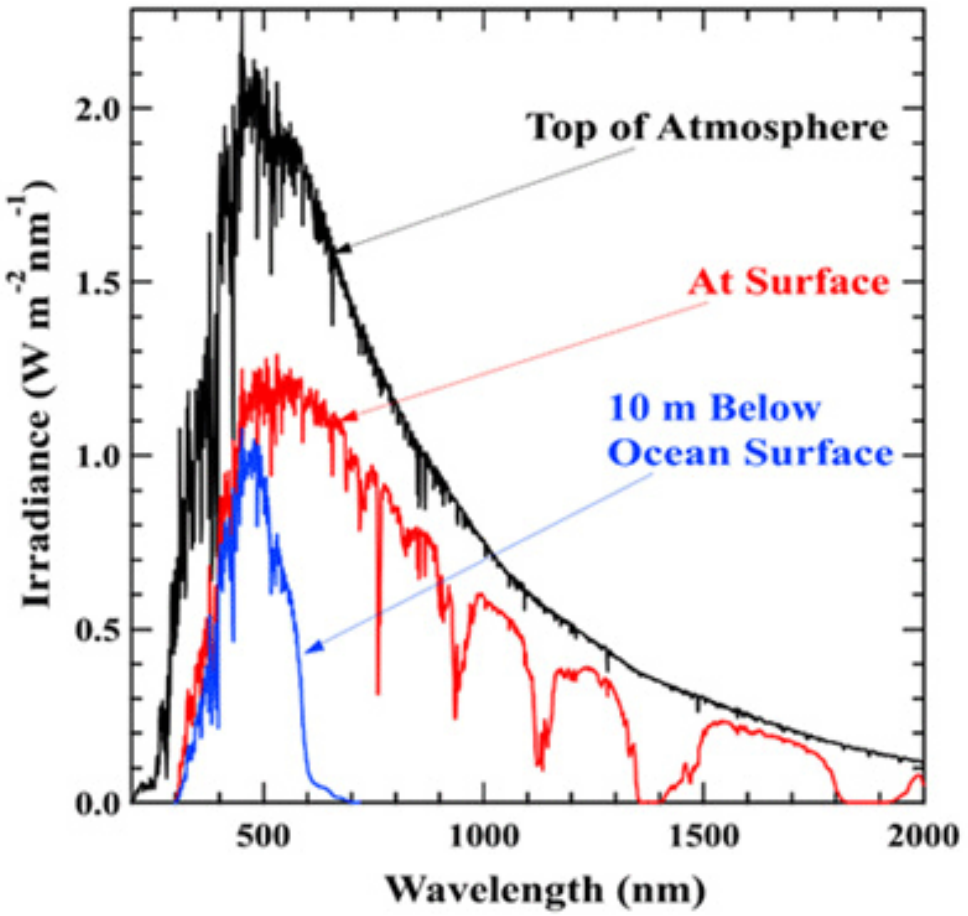


https://lsintspl3.wgbh.org/en-us/lesson/buac18-il-ilchangessky/1

https://www.shutterstock.com/nb/video/clip-1014907747-sun-underwater-sky-scenery

- Similarities
- Differences

Spectrum of energy that we *measure* is different from Planck's Law predictions

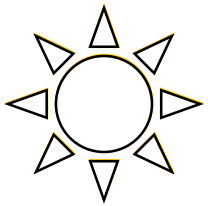


http://lasp.colorado.edu/home/sorce/files/2011/09/fig01.gif

- Top of atmosphere
  - Fraunhofer lines
- Earth surface
  - Atmospheric gases (O_3, O_2, H_2O)
  - Atmospheric aerosols
- beneath Ocean surface
  - Water
  - Particulate and dissolved constituents

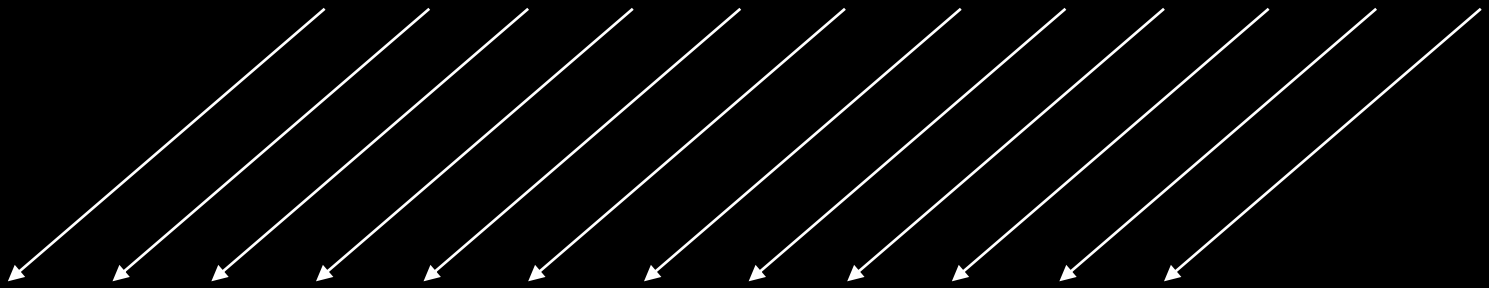
In the **absence** of the atmosphere

- What is the color of the sun?
- What is the color of the sky?
- Sketch the angular distribution of incident light



In the **absence** of the atmosphere

- What is the color of the sun?
  →
- What is the color of the sky?
  →
- Sketch the angular distribution of incident light
  →

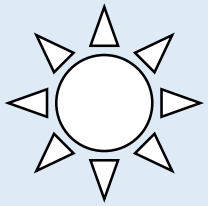


In the **presence** of the atmosphere

- What is the color of the sun?

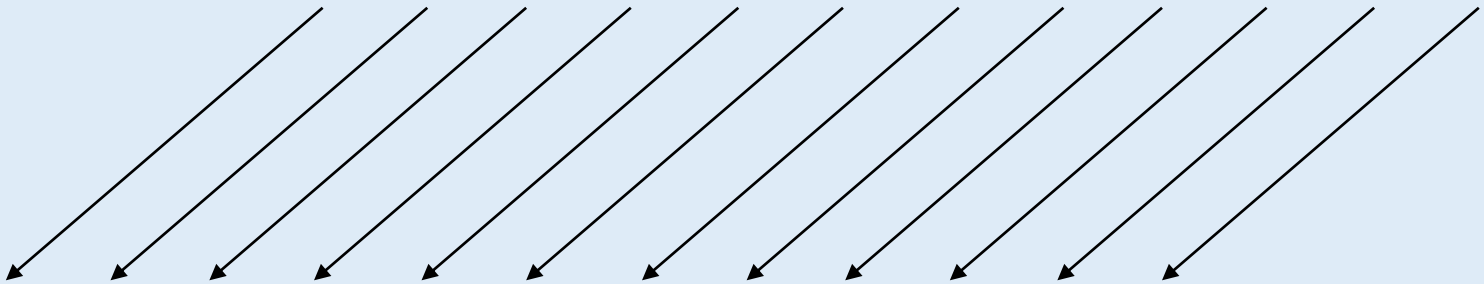
  →

- What is the color of the sky?



- Sketch the angular distribution of incident light

  →

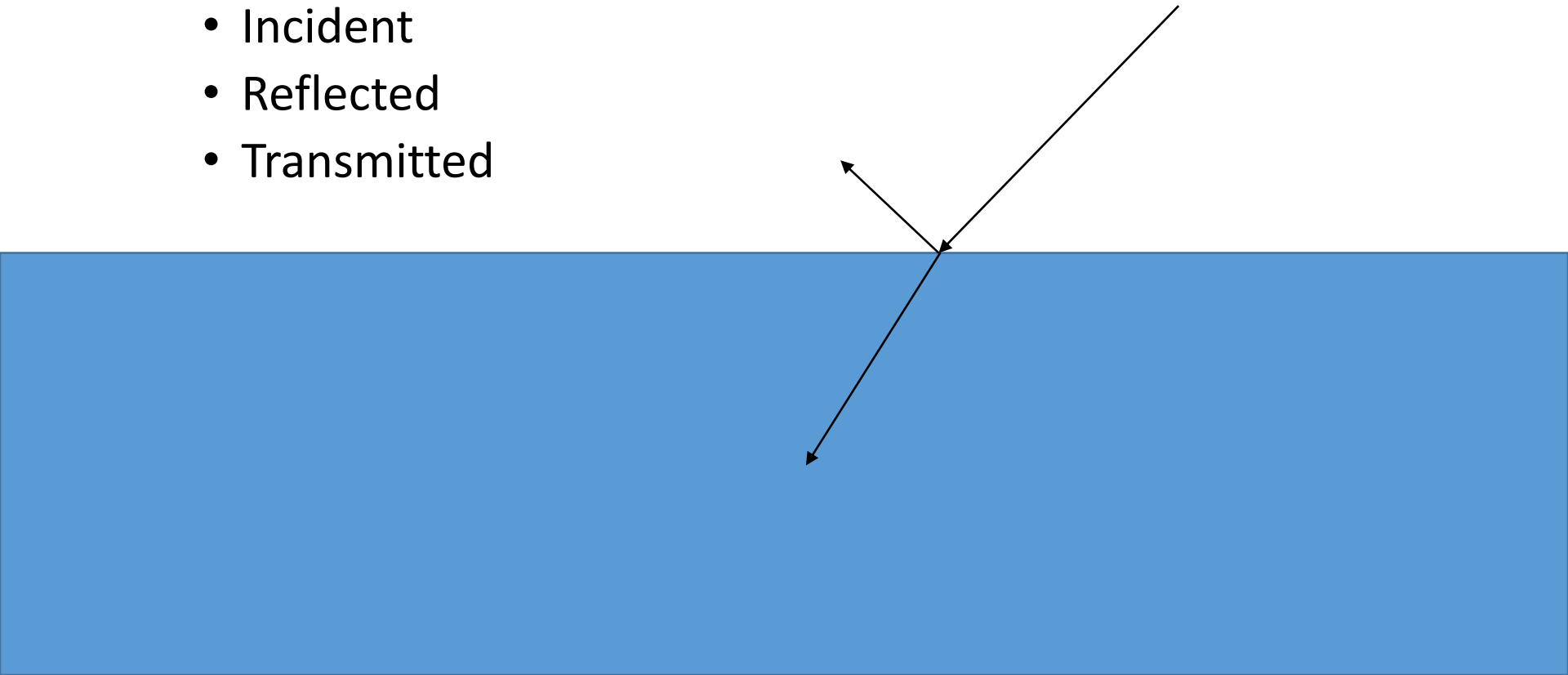


Atmosphere

- Reduces the intensity
- Changes the color
- Changes the angular distribution
- Radiometric properties lab
  - Natural variations in solar radiation
  - Compare radiation from solar beam versus skylight
  - Angular distributions of solar radiation

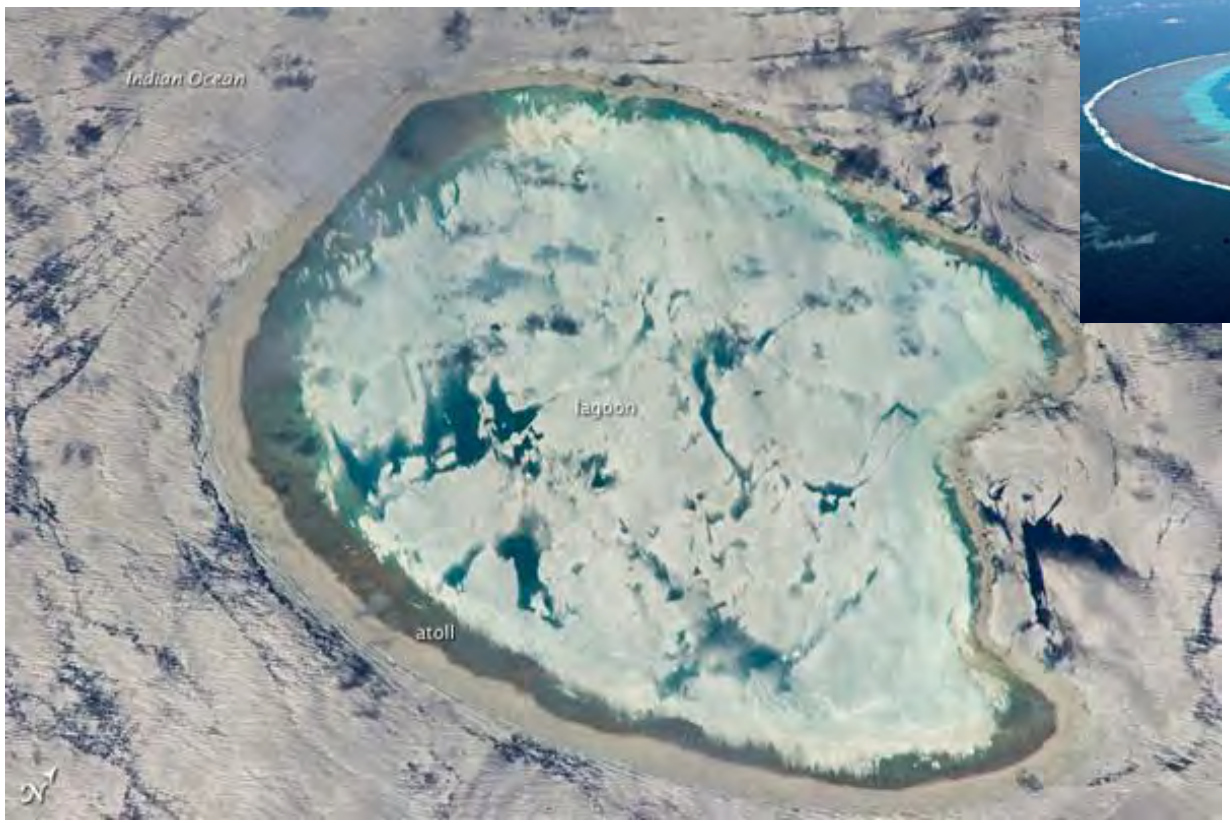
Now we are at the Ocean surface

- Surface effects
  - Incident
  - Reflected
  - Transmitted



Now we are at the Ocean surface

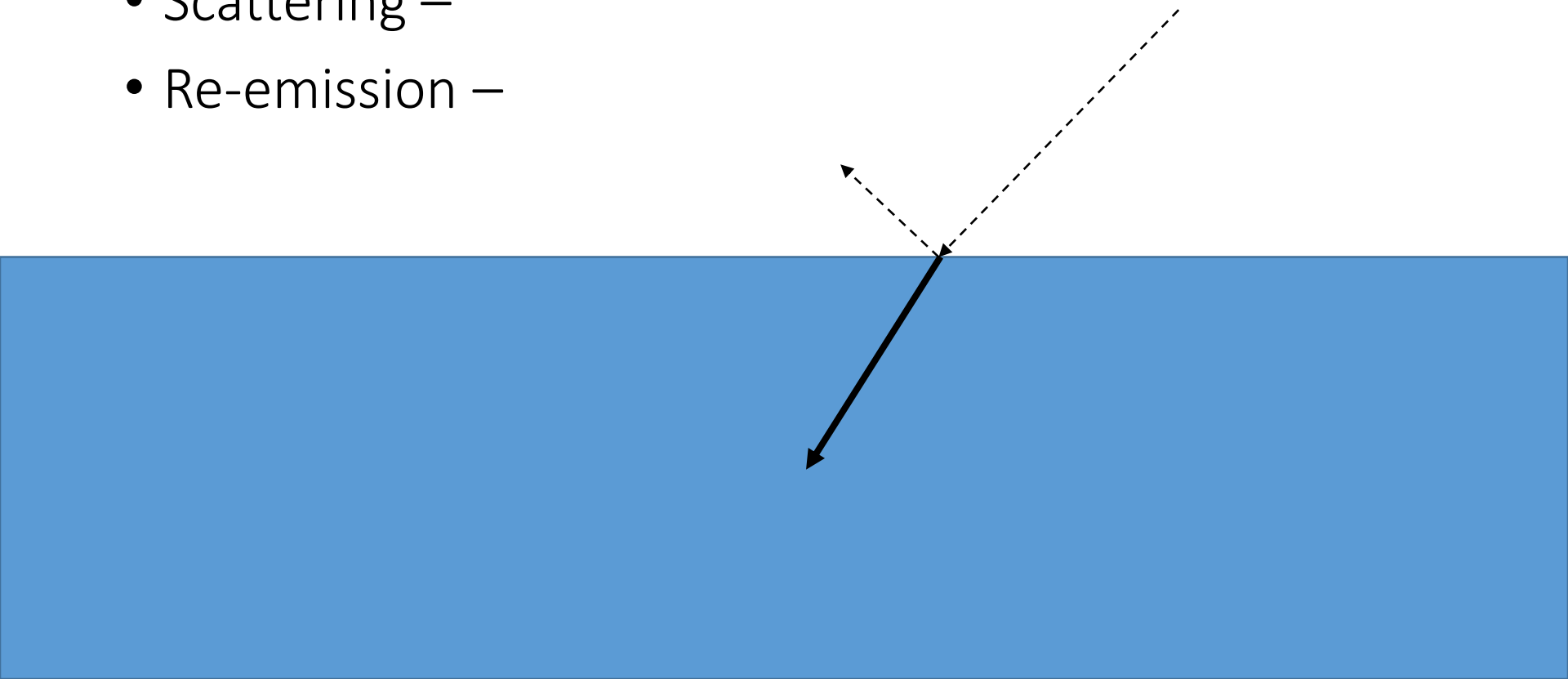
- Surface effects



This photograph of the Bassas da India, an uninhabited atoll in the Indian Ocean, has an almost surreal quality due to varying degrees of sunglint. *credit: NASA/JSC*

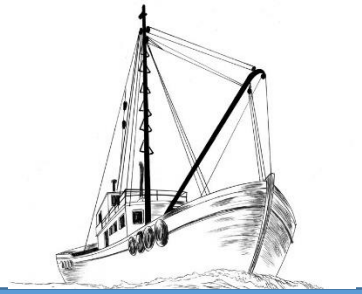
As light penetrates the ocean surface and propagates to depth, what processes affect the light transfer?

- Absorption –
- Scattering –
- Re-emission –

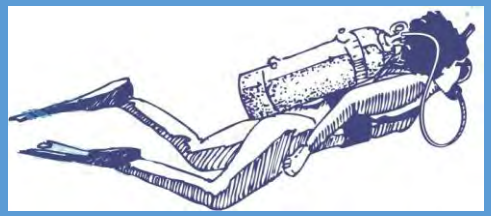


Case study 1:
Consider an ocean that has no particles but does have absorption

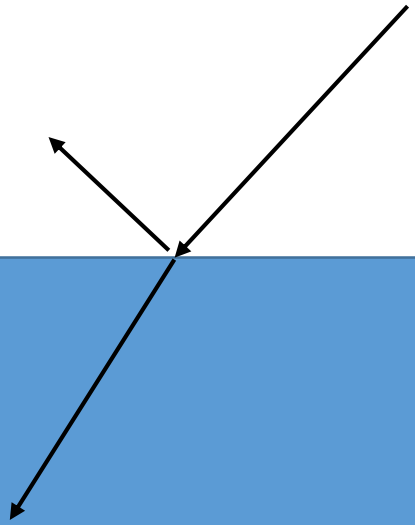
- What do the sailors see from a boat (reflection)?
- What does the diver see (transmission)?



ayoqq.org



uuworld.org



Case study 1:
Consider an ocean that has no particles but does have absorption

- Is there a natural analog?

The Rio Negro in 2010
Credit: MODIS Rapid Response Team
NASA GSFC

Case study 1:
Consider an ocean that has no particles but does have absorption

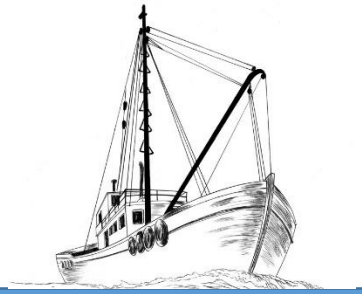
http://2.bp.blogspot.com/-4NPGeVA5zVs/T-iCGJp3GlI/AAAAAAAAEaI/3cTvA31bth4/s1600/encontro-do-negro-e-solimoes.jpg

Case study 1:
Consider an ocean that has no particles but does have absorption

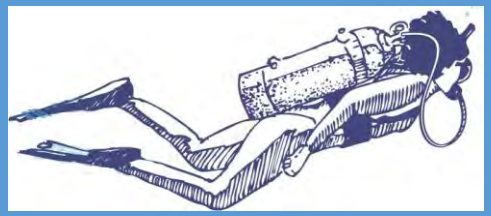
http://www.mongabay.com/images/pictures/brazilrio_negro_beach_close.html

Case study 2:
Consider an ocean that has no absorption but does have particles

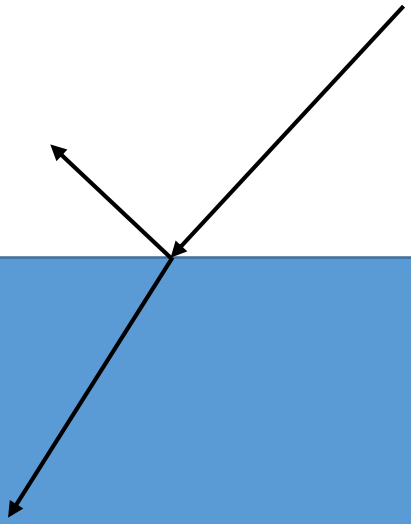
- What do the sailors see from a boat (reflection)?
- What does the diver see (transmission)?



ayoqq.org



uuworld.org

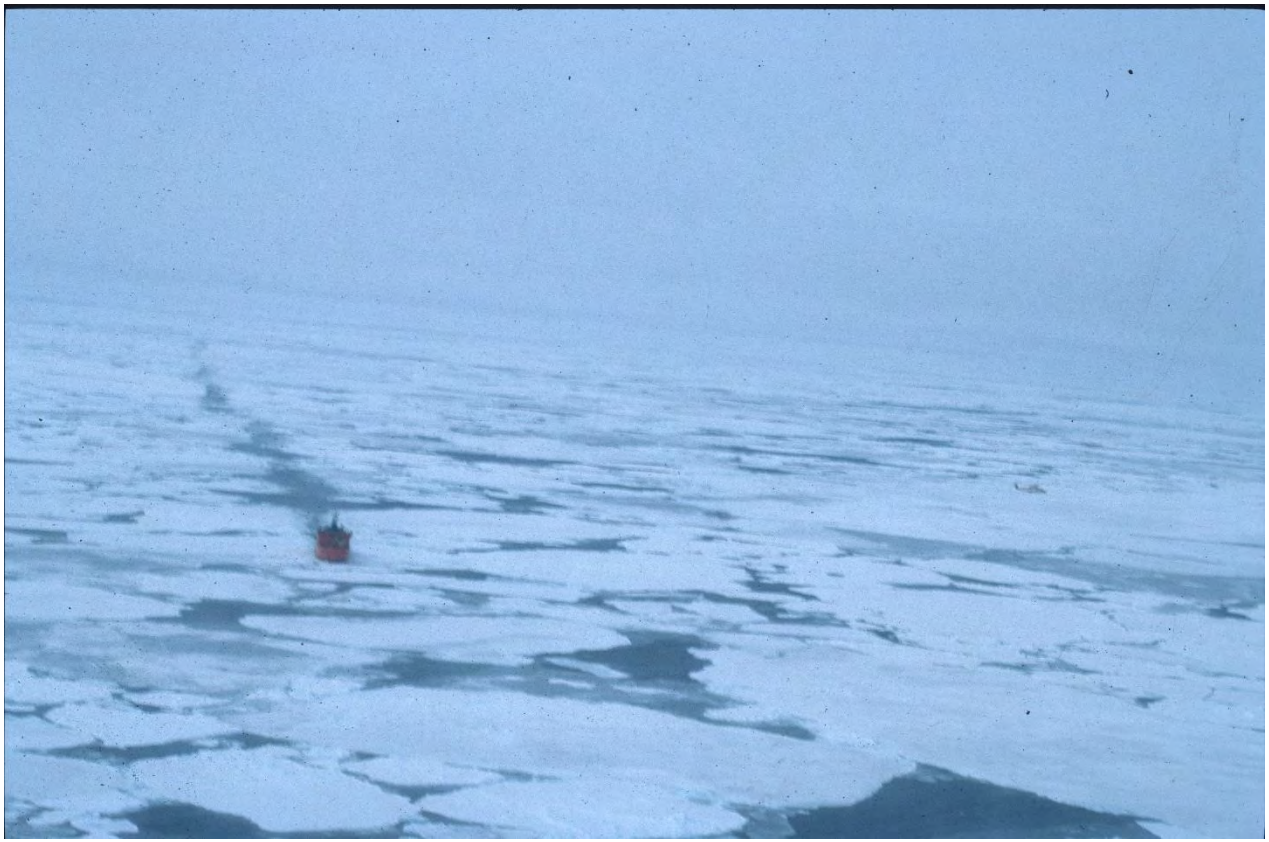


Case study 2:
Consider an ocean that has no absorption but does have particles

- Is there a natural analog?

Case study 2:
Consider an ocean that has no absorption but does have particles

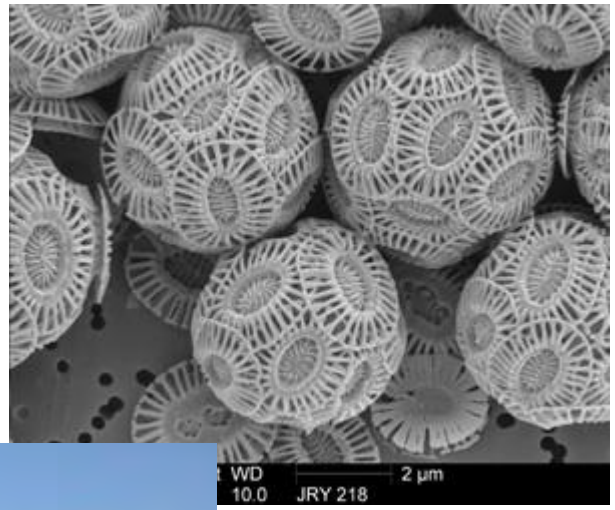
- Is there a natural analog?



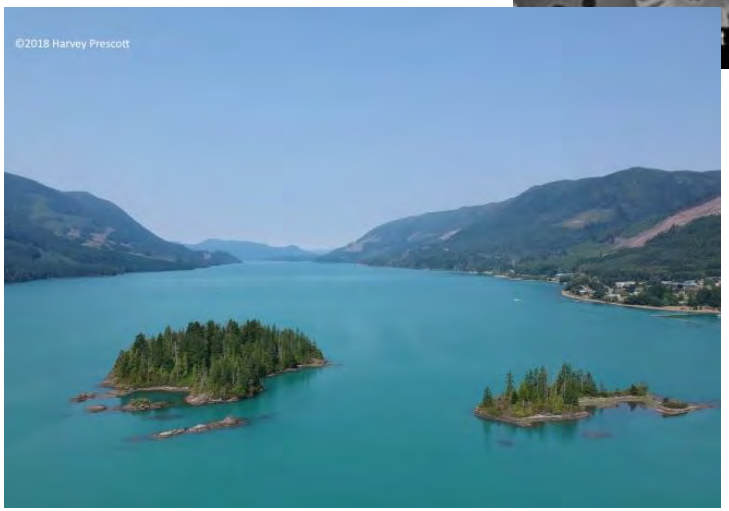
Case study 2: Consider an ocean that has no absorption but does have particles

- Is there a natural analog?

http://www.co2.ulg.ac.be/peace/objects/218-01.JPG



https://www.bigelow.org/enews/English%20Channel%20Bloom.jpg



https://themarinedetective.com/2018/07/29/why-is-our-cold-ocean-suddenly-tropical-blue/

Case study 2: Consider an ocean that has no absorption but does have particles

- Is there a natural analog?

http://www.alamy.com Image ID: CX4R4C

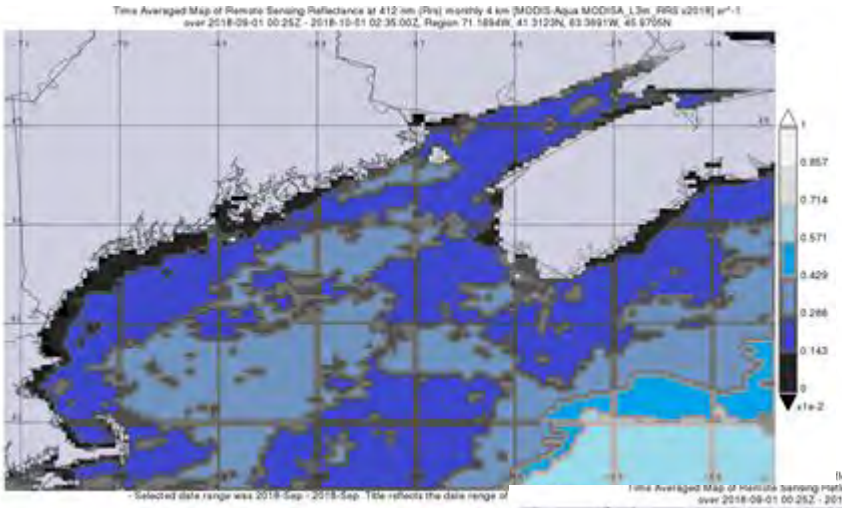
https://www.escapecampervans.com/blog/guide-to-iconic-lakes-in-banff/

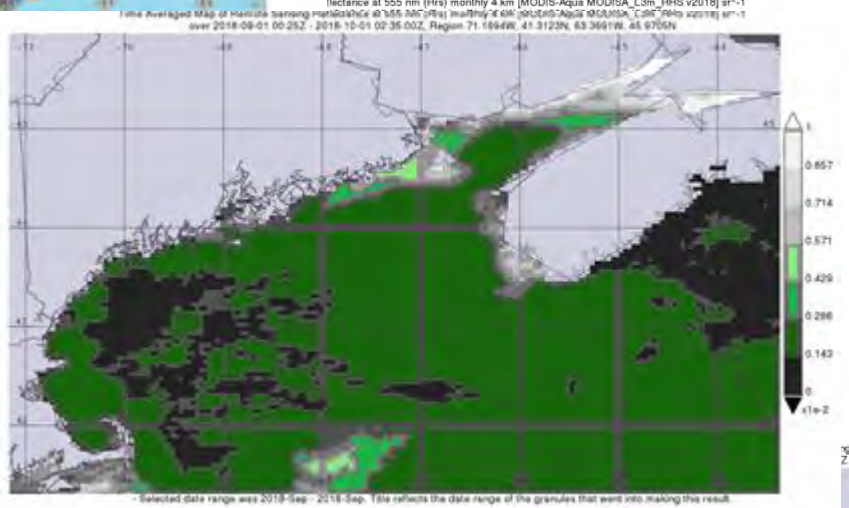
While these examples have generally considered the whole visible spectrum, it is important to realize that within narrow wavebands, the ocean may behave as a pure absorber or pure scatterer and thus appear nearly “black” or “white” in that waveband

- Pure absorber in near infrared (water absorption)
- Close to pure scatterer in the uv/blue (clear water)

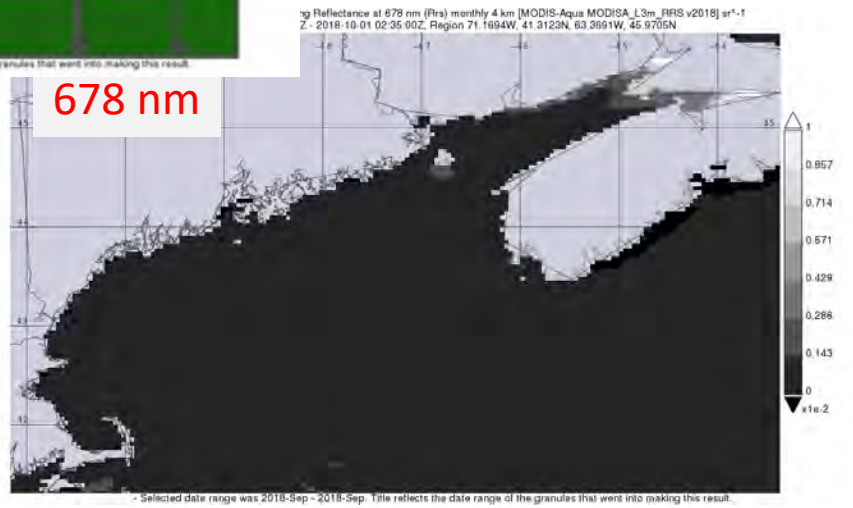
MODIS-AQUA reflectance images

Gulf of Maine September 2018





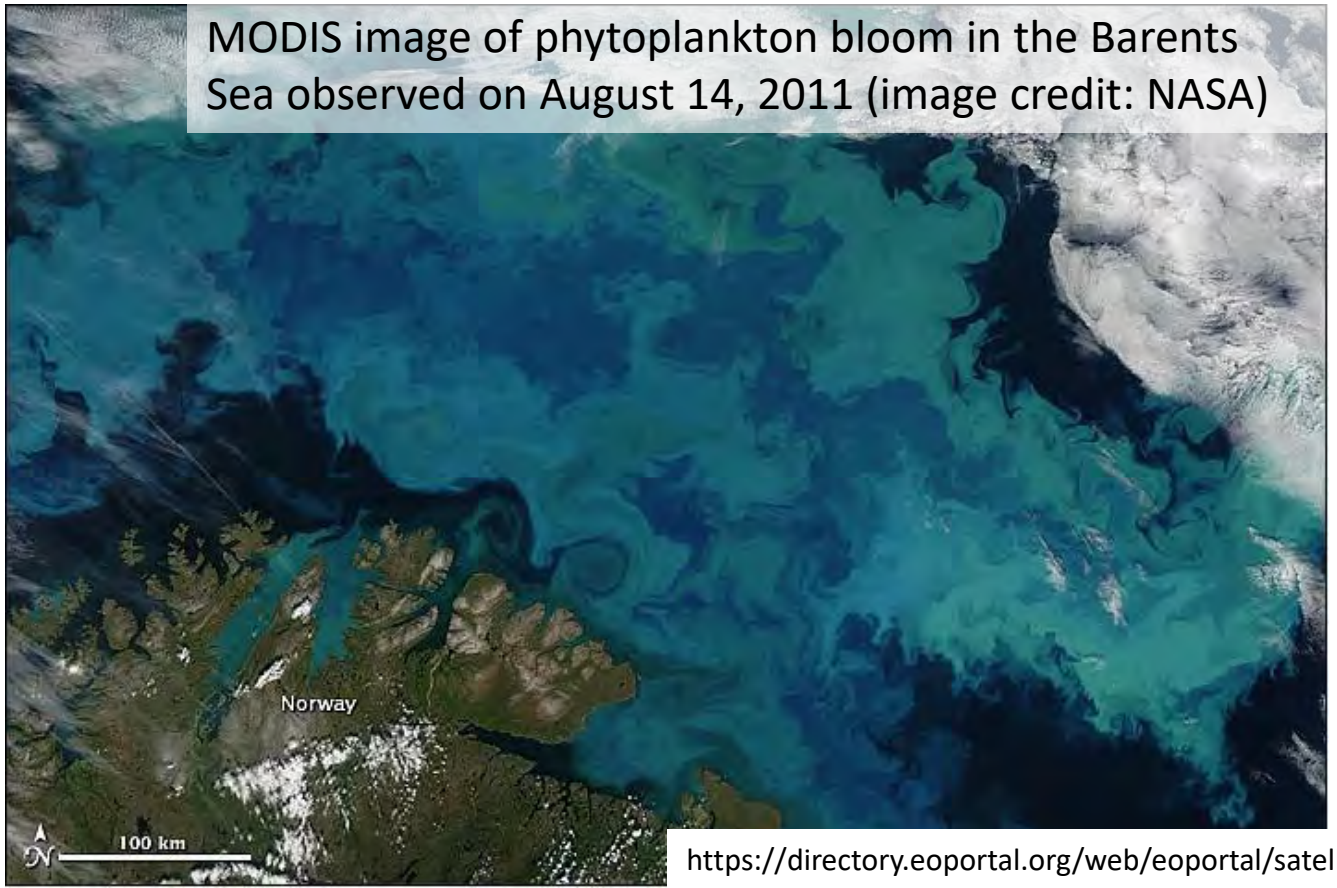
678 nm



https://giovanni.gsfc.nasa.gov/giovanni

From space the ocean color ranges from bright to dark generally in the green to blue hues

- All of these observed variations are due to the infinite combination of absorbers and scatterers



MODIS image of phytoplankton bloom in the Barents Sea observed on August 14, 2011 (image credit: NASA)

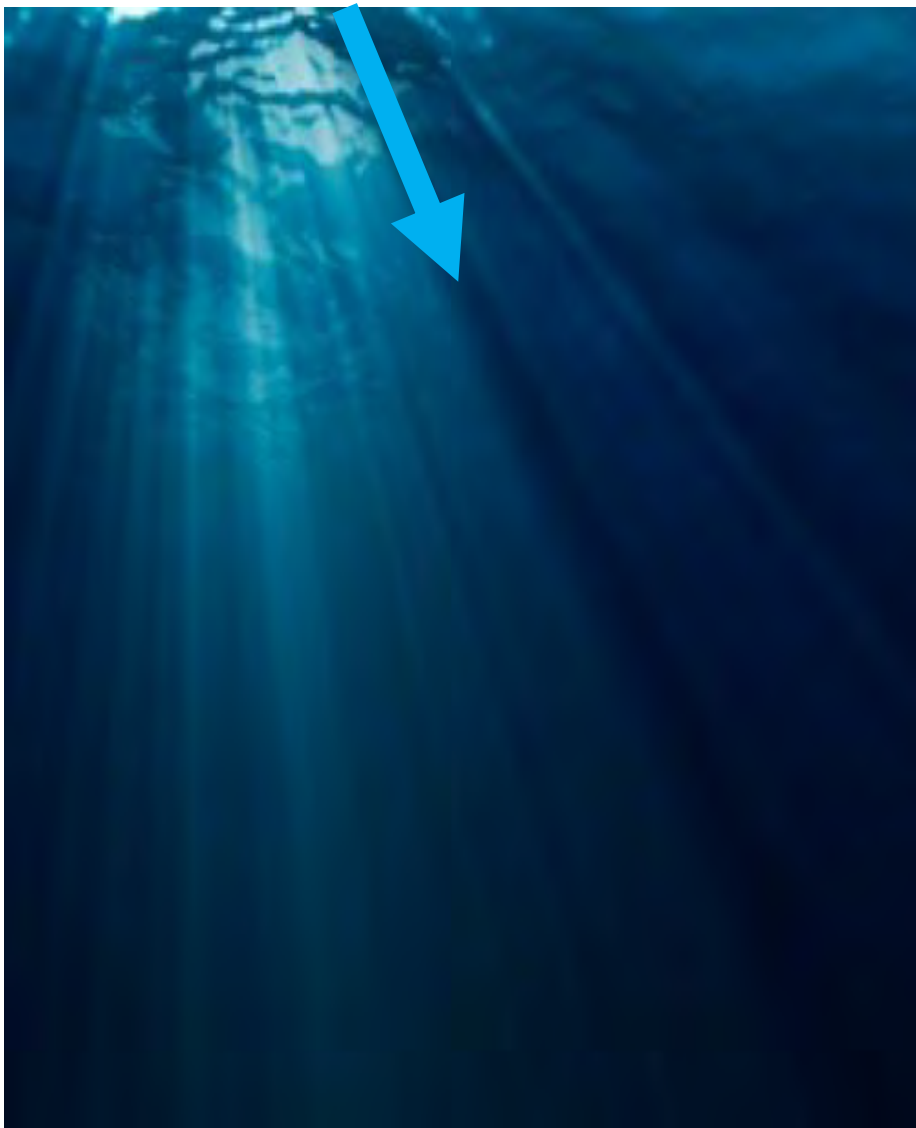
https://directory.eoportal.org/web/eoportal/satellite-missions/a/aqua

Photo credits: Clark Little

http://www.darkroastedblend.com/2010/06/inside-wave-epic-photography-by-clark.html

Now that we have some vocabulary
Trace a beam of sunlight through the ocean

- Imagine you have a sensor that measures the beam of sunlight as a function of depth
- What happens along the path?
  - Describe
  - Sketch
  - Schematic
  - Graph
  - Equation
- Think → Pair → Share

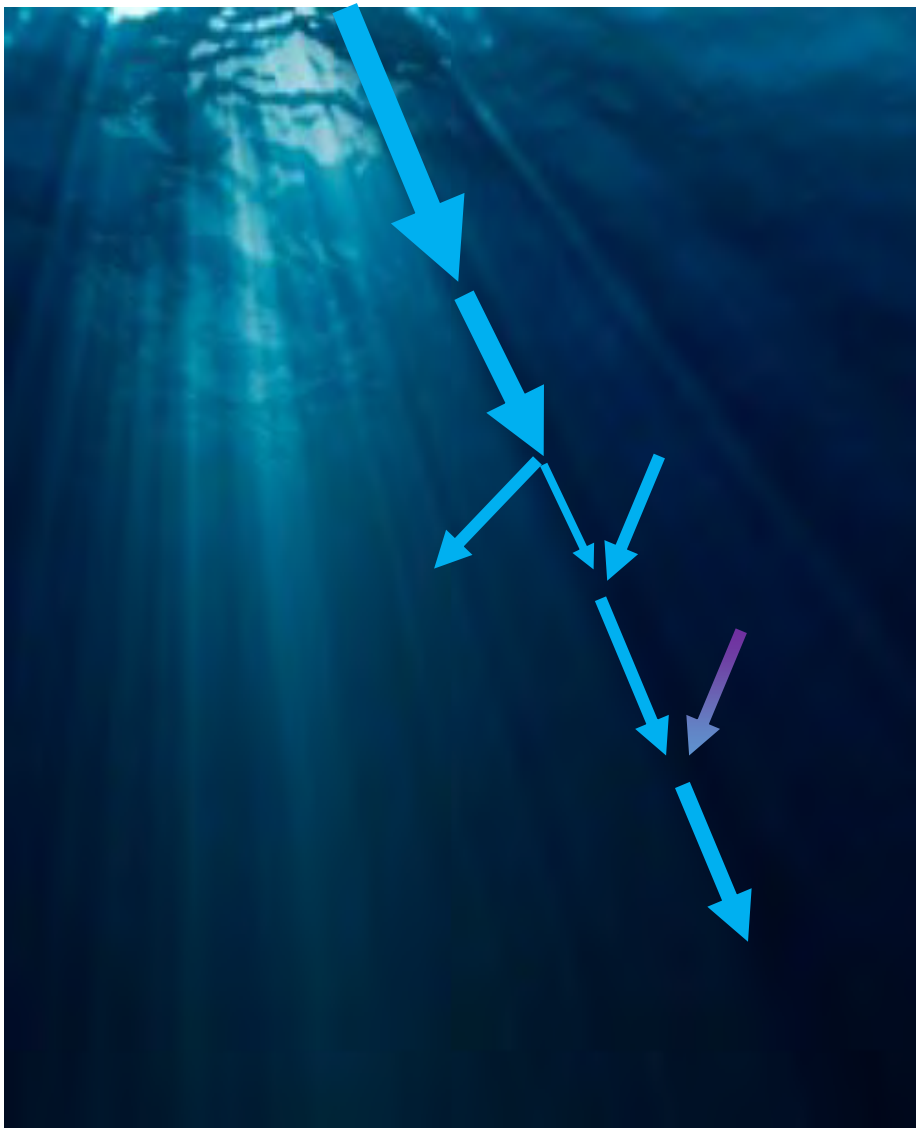


Radiative Transfer Equation

- Sketch a diagram or write an expression for the radiative transfer equation (RTE)
  - 1. I know just what to do
  - 2. I will get pretty close
  - 3. I can give it a try
  - 4. I can try but it will likely be wrong
  - 5. I have no idea where to start
  - 6. What is the radiative transfer equation?

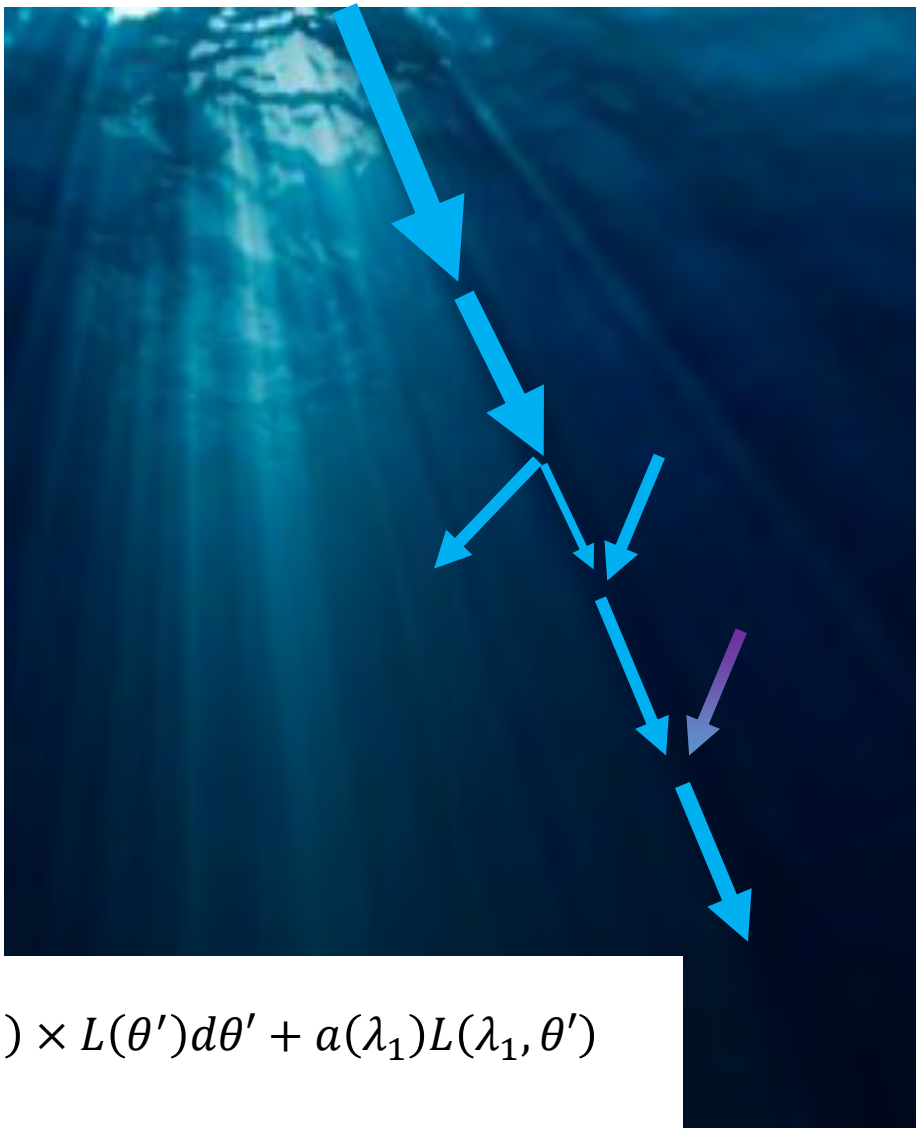
Now that we have some vocabulary
Trace a beam of sunlight through the ocean

- Describe the beam of sunlight as radiance, **L**
- Traveling along a path at a defined angle
- What processes impact the beam?
  - Absorption
  - Scattering out of the beam
  - Scattering into the beam
  - Inelastic scattering



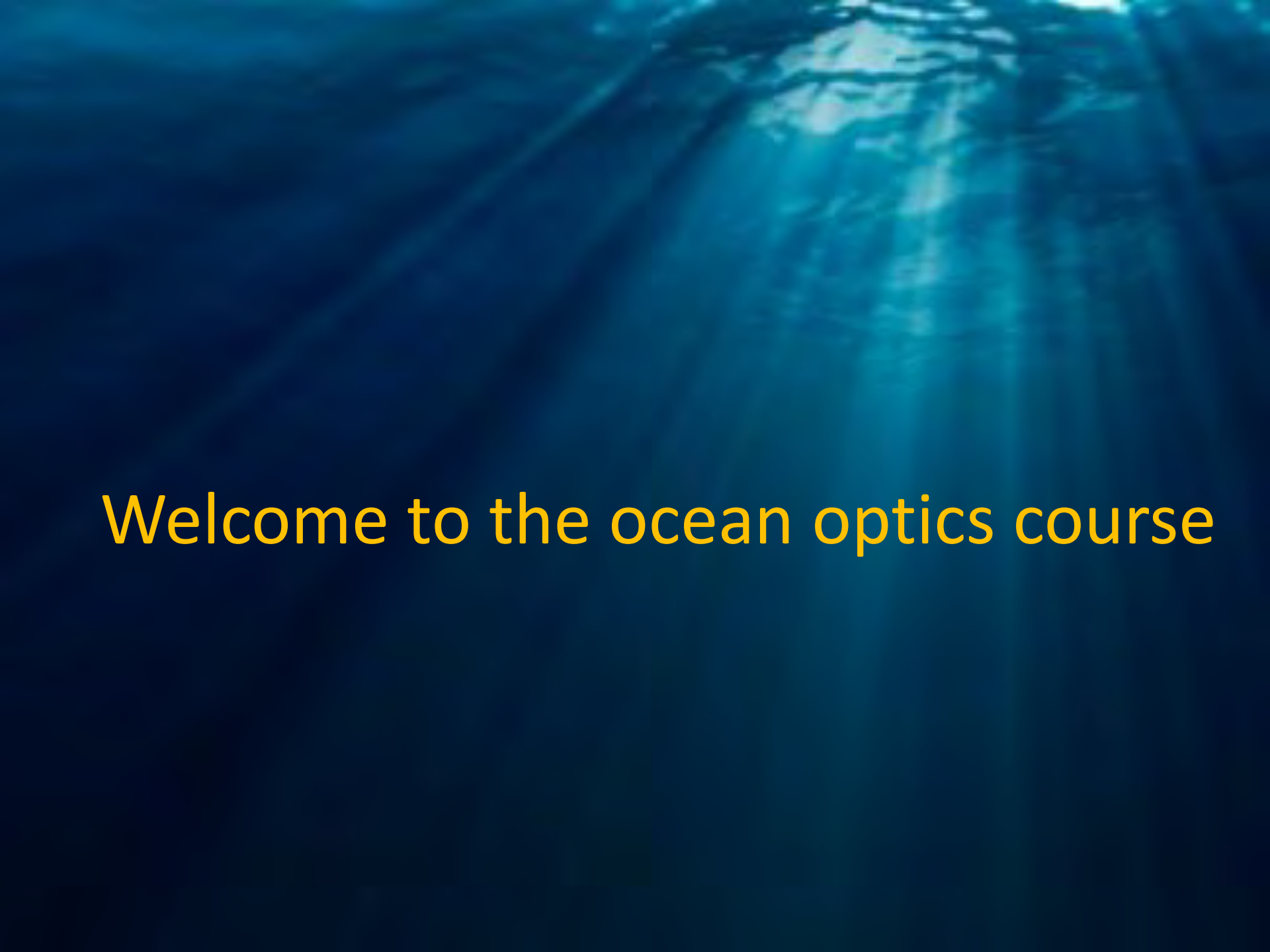
Now that we have some vocabulary
Trace a beam of sunlight through the ocean

- Describe the beam of sunlight as radiance, **L**
- Traveling along a path described by the zenith and azimuth angles
- What processes impact the beam?
  - Absorption
  - Scattering out of the beam
  - Scattering into the beam
  - Inelastic scattering



Radiative Transfer Equation

$$\frac{\cos\theta \, d\, L(\theta)}{dz} = -(a+b)L(z,\theta) + \int \beta(z,\theta;\theta') \times L(\theta')d\theta' + a(\lambda_1)L(\lambda_1,\theta')$$


Welcome to the ocean optics course