

## General Introduction to Oceanography

**Note:** We didn't cover all of this material, some of it is more background information for those of you who haven't had a general oceanography course

**Readings (optional):** Lalli and Parsons, Chapter 2  
Valiela, Chapter 2

**OCEANOGRAPHY** The scientific study of the processes and phenomena of the oceans, not considered a 'pure' science in that it is multidisciplinary and draws from the prime sciences.

Can be divided into 4 (5) disciplines:

- Geological Oceanography
- Physical oceanography
- Chemical oceanography
- Biological oceanography  
(Fisheries oceanography)

### ***Ocean / Scientific Study***

1. The container     Geological Oceanography
- locations, shapes of basins & features
  - sedimentary make-up
  - mobility of ocean floor (earthquakes)
  - commercial exploitation

2. The contents

- ABIOTIC                     Chemical Oceanography
- chemical composition of sea salt (salinity)
  - processes/reactions
  - interaction with sediments & atmosphere
  - nutrient cycling - pollutants
  - dating of sediments

- Physical Oceanography
- energy of the sea
  - temperature, pressure
  - currents, wave dynamics, tides
  - climatic & weather modeling (atmospheric

interaction)

- BIOTIC

Biological Oceanography

- plants (macroscopic, microscopic)
- animals (zooplankton to fish to sea birds)
- fisheries (management)

## Classification of the Marine Environment

- Introduction

Can divide the earth into three general regions:

- Atmosphere
- Lithosphere
- Continental Crust (light, thick, granitic)
- Oceanic Crust (dense, thin)
- Mantle (liquid core)
- **Hydrosphere**
- Oceans 98% of H<sub>2</sub>O
- Ice 1.7%
- Groundwater 0.3%
- Lakes and Ponds 0.02%

Hypsographic Curve:

- cumulative frequency curve of elevation vs. area
- earth has 2 nodes, the continents and the ocean basins

## II. Classification by position (National Academy of Sciences, 1950s)

- **Pelagic** environment - "of the sea" - In the water, where the swimmers and floaters live.
- **Benthic** environment - "bottom" - On the bottom, animals that neither float nor swim.

### 1) Pelagic

- Divided into **Neritic** and **Oceanic** provinces
- Neritic: extends seaward from the shore and includes all the water overlying a depth of 200 meters
- Characterized by:
  - 1) Shallow water, so large fluctuations in temperature, salinity
  - 2) Tides expose/submerge the shore
  - 3) Breaking waves disperse a lot of energy
- Oceanic: all parts of the ocean seaward of the neritic province
- Divided into smaller categories based on depth:
  - i. the **epipelagic zone** - surface to 200 meters depth, top of the ocean
  - ii. the **mesopelagic zone** – 200-1000 meters, middle depth of the ocean
  - iii. the **bathypelagic zone** - 1000 to 4000 meters depth, the deep ocean
  - iv. the **abyssopelagic zone** - everything below 4000 meters, "without bottom"

- v. the **hadalpelagic zone** –deeper than 6000 meters, the trenches (“hell sea”)
- It can also be divided based on light availability, into:
    - i. **Euphotic Zone** – depth to 1% light penetration (about 100 m)
    - ii. **Disphotic Zone** – 100-1000 m, very little light
    - iii. **Aphotic Zone** – deeper than 1000 m (no light)
  - The epipelagic zone is the only zone which has sufficient light for photosynthesis.
  - The bottom of this zone (~200 m) is also where oxygen concentrations begin to decline and nutrient concentrations begin to increase.
  - It is also approximately the bottom of the mixed layer, the seasonal thermocline, and the surface water mass.
  - The mesopelagic zone usually includes an oxygen minimum and nutrient maximum between 700 and 1000 meters.
  - Fish and other organisms in this region are adapted to very low light levels and may be bioluminescent, or emit a light of their own.
  - This depth range also includes the deep scattering layer (DSL, see Fig. 14-12)
  - This includes mostly zooplankton and fish which migrate vertically from depths of 100 to 200 m during the night down to as far as 900 m during the day.
  - This migration pattern shows up on sonar, and DSL refers to the fact that they scatter sound.
  - The bathypelagic and abyssopelagic zones include over 75% of the living space in the oceanic province.
  - There is no light and many fish are blind.
  - Animals have unusual adaptations to make them efficient predators in this region, including large mouths and teeth, etc.
  - The oxygen concentration increases due to cold deep polar water masses.
- 2) Benthic
- The benthic environment, or seafloor environment, is divided into two units which correspond to the pelagic environment:
    - i. **Subneritic province** - from the high tide shoreline to a depth of 200 m, including approximately the area of the continental shelf.
    - ii. **Suboceanic province** - all the benthic environment below 200 m.

Subneritic: The **littoral zone** means the shore.

- i. The **supralittoral zone** is above the high tide line or the spray zone.

## Productivity in the Sea

## General Oceanography &amp; Optics

- ii. The ***littoral zone*** is the intertidal zone between high and low tides.
- iii. The ***sublittoral zone*** is the shallow subtidal zone, essentially the continental shelf. It includes the inner sublittoral zone to a depth of 50 m, the deepest zone for attached plants and algae, and the outer sublittoral zone from the inner zone out to a depth of 200 m or the shelf break.

Suboceanic:

- i. The ***bathyl zone*** is from a depth of 200 to 4000 m. It generally corresponds to the continental slope.
  - ii. The ***abyssal zone*** is from 4000 to 6000 m. It is mostly covered by abyssal clay and represents 60% of the benthic environment.
  - iii. The ***hadal zone*** is below 6000 m and is limited to deep trenches along continental margins.
- By LATITUDE (or temperature):
    - **Tropical** 25°, approximately 0-20 degrees Latitude
    - **Subtropical** 15-25°, approximately 20-40 degrees
    - **Temperate** 2-5°, approximately 40-60 degrees
    - **High-Latitude** <2-5°, approximately 60-90 degrees
  - By BASIN:
    - 1) Indian
    - 2) Atlantic
    - 3) Pacific (accounts for 1/2 of total ocean volume)
    - 4) Southern—this may be considered sub-components of the other basins, also
  - BIOLOGICAL classification
    - 3) Oligotrophic, mesotrophic, eutrophic
      - “trophic” refers to nutritional status
  - Classifying the Marine Environment--Biological
  - **Plankton** (floaters) are all organisms that drift with the current.
  - An individual organism is called a plankter.

## Productivity in the Sea

## General Oceanography &amp; Optics

- Plankton may swim but not strongly enough to determine their horizontal position (e.g. dinoflagellates)
- They make up much of the Earth's biomass.
  - i. Plant plankton are called phytoplankton.
  - ii. Animal plankton are called zooplankton.
  - iii. Bacterial plankton are called bacterioplankton
  - iv. Large plankton (2-20 cm) are known as macroplankton.
  - v. Very small plankton (0.2-2  $\mu\text{m}$ ) are called picoplankton.
- **Holoplankton** are planktonic for their entire life.
- **Meroplankton** are nektonic or benthic organisms which have planktonic larvae.
- **Nekton** (swimmers) include all animals capable of moving independently of the ocean currents, by swimming or other propulsion.
- Many nekton are capable of long migrations, including most adult fish and squid, marine mammals and marine reptiles.
- Most nekton are limited in their distribution by changes in temperature, salinity, nutrients, etc.
  - **Benthos** (bottom dwellers) includes all animals that live on the ocean bottom.
    - i. Epifauna live on the surface attached to rocks or roving over the bottom.
    - ii. Infauna live buried in the sand, shells, or mud.
    - iii. Nektobenthos live on the bottom but move with ease through the water above the ocean floor.
- The littoral and inner sublittoral zones have a great diversity of habitats and consequently animal species.
- Also, these are the only zones where large attached seaweeds are found because there is sufficient light.
- As you move offshore the number of benthic animal species may remain about the same, but the individual numbers and biomass decline.
- Deep sea species tend to be widely distributed because conditions vary little over long distances.
- The major limiting factor in the deep sea is food. This is not a problem for hydrothermal vent communities.
- POLITICAL classification
- Until 1970s, the border of a country was flexible...depended on how big your navy was...generally (post WWII) had exclusive rights to 200 m depth
- In the 1960s, Iceland extended it's fishing rights from 4-12-50-200 miles

- Chile and Peru followed their example
- In 1977, US extended it's Exclusive Economic Zone to 200 miles from its coast, primarily to control fishing (although mineral rights were also an issue).

## ABIOTIC PROPERTIES

'ABIOTIC' means non-biological...these are physical effects that impact the biological properties of the oceans.

### 1) Solar Radiation

- About 30% of solar radiation is reflected by the atmosphere (the percent reflected light is called **albedo**)
- Of the remaining 70%:
  - 17% is absorbed by the atmosphere (especially the ozone layer)
  - 23% is diffuse skylight (scattered)
  - 30% hits the surface as direct sunlight

During summer, the sun is at a high zenith angle, which means it doesn't go through much atmosphere. During winter, the sun is at a low angle, and goes through a lot of atmosphere

Because of this, there are large gradients in absorbed heat depending on latitude and time of year.

This sets up wind patterns, because the atmosphere can react much more quickly than the oceans can.

Because of the high specific heat of water, the combination of evaporation and winds allows a "heat pump" to be set up, from equator to poles. Winds alone can't do it (low specific heat), and water (oceans) is too slow.

### 2) Salinity

salts change their **concentration**, but not their **relative ratio**

we measure salt as mass per unit kilogram

- this used to be referred to as ppt (parts per thousand)
- this was changed to Presumed Salinity Units (PSU) for conductivity
- now it's Practical Salinity Scale (PSS) because there are no units

Major ions in seawater include:

- chlorine

## Productivity in the Sea

## General Oceanography &amp; Optics

- sodium
- magnesium
- sulfur
- calcium
- potassium

## 3) Density (=\_\_\_pronounced'ho')

Density is mass per unit volume, and is controlled by the salinity and temperature

Densest seawater is cold and salty...added salts lower the freezing point of seawater, so that it can get even more dense without freezing.

**Adiabatic** changes in density: changes without a transfer of heat

- this is caused by increasing pressure (=depth)
- as pressure increases, water is essentially incompressible, but pressure add potential energy...this results in heating.

Because density is a function of temperature and salinity, we can make **T-S Diagrams**

- Plot T vs. S, defines a watermass
- Because S is in units of  $\text{kg/m}^3$ , it's convenient to shorten the number:  $\sigma_t = (\sigma - 1000)$
- To correct for adiabatic changes, we use  $\sigma_{\theta}$  **potential density** (theta = temperature corrected for 1 atm. pressure)

and S can only change by mixing two water masses, once those waters leave the surface of the ocean, so  $\sigma$ -S plots are a **conservative property** of a watermass.

**Thermocline:** rapid change in temperature with depth

**Halocline:** rapid change in salinity with depth

**Pycnocline:** Rapid change in density with depth

## 4) Physical Processes

Large-Scale (basin-scale) circulation is controlled by:

- Thermohaline Circulation (deep currents)
- Winds and Coriolis Force (surface-midwater currents)

**Coriolis:**  $f=2 \sin \phi$ , where  $\phi$  =latitude. At  $0^\circ$ ,  $f=0$ .

**Ekman Spiral:** combination of coriolis and *friction* cause water to move 45° to wind direction...summation of all the friction layers results in water transport 90° to wind direction.

**Sverdrup Transport:** Convergence of two Ekman pumps causes north-to-south transport...this is constant from east to west, so there must be an increase in the east-to-west flow to maintain balance.

Because of thermohaline circulation, North Pacific waters are oldest, least salty. Youngest waters are Antarctic, North Atlantic.

Deep-Water is formed in North Atlantic (NADW), Antarctic (AABW). This flows from the Atlantic, through the Indian, into Pacific.

To conserve mass, there must be equal amounts of **surface** water flow from Pacific to Atlantic. In the surface, nutrients are depleted, so Atlantic ends up with fairly low nutrient water.

Pacific also has lots of freshwater input, so it is “capped” and doesn’t ever mix as deeply as the Atlantic. Similarly, the Indian Ocean has lots of major rivers (e.g. Ganges) which pumps in lots of organic matter, enriching the Indian and Pacific Basins relative to the Atlantic.

## OCEAN OPTICS

### I. INTRODUCTION

Nature of Light: Both a particle and a wave, so depending on what we are interested in, we need to pay attention to its energy or the number of quanta.

$$E=hc/\lambda, \lambda = h/c \quad \text{where } h \text{ is Planck's constant and } c \text{ is speed of light}$$

$$h=6.625 \times 10^{-34} \text{ Js}$$

$$c=3 \times 10^8 \text{ ms}^{-1}$$

In photosynthesis, we usually don't care how much energy each photon has, only how many photons are collected. Therefore, we are measuring quanta:

$$1 \text{ Einstein} = 6.02 \times 10^{23} \text{ quanta}$$

**NOTE:** This was recently changed to use Systeme Internationale (SI) units, so we now refer to light quanta as mols photons per area per time, where 1 mol photons is equal to 1 Einstein.

When we look at other processes, such as the effect of UV-A and UV-B, it's the energy, and not the number of photons that we are interested in.

When we measure light, we can measure the number of quanta (a quanta meter), or the energy (a pyrroheliometer), or both.

There are two types of light we are interested in measuring:

**Irradiance** denoted as  $E$  (as in the PvsE curve). Radiant power incident per unit area on a surface ( $W\ m^{-2}$ , photons  $m^{-2}\ s^{-1}$ ).

**Radiance** denoted as  $L$ . Radiant power in a given direction per unit solid angle per unit of projected area of the source, as viewed from the given direction. ( $W\ str^{-1}\ m^{-2}\ nm^{-1}$ )

We can also note the direction as upward (upwelling) irradiance or radiance, downward (downwelling) irradiance/radiance, and total radiance/irradiance, by adding the subscripts  $u$ ,  $d$ ,  $0$  to the  $E$  or  $L$  symbols...so  $E_d$  is the amount of irradiance which is moving downward over the  $180^\circ$  of a sphere.

We also talk about light that can be used by plants to grow, which is called **PAR**, or photosynthetically active radiation. This is essentially visible light (400-700 nm)

PAR meters are a special subset of radiometers, because they measure the flux of photons (the number of light particles) between 400 and 700 nm (blue to red light), not the wavelength-specific radiance or irradiance.

There are two types of PAR meters commonly used, also:

**Cosine Detector:** flat detector, responds to the cosine angle of the incident light

**Scalar (or 4-Pi) Detector:** spherical, measures light from all directions.

## II. Light Sources

We generally think of sunlight (or moonlight) as the primary sources of light in the oceans. There are three other sources though:

- iv. Bioluminescence. This is a chemical reaction that oxidizes one compound to produce another compound, and give off light.



This reaction produces light in the blue-green wavelengths, which is where maximum transmission in water occurs. Therefore, it's unlikely that it was an accident that it developed. It also developed independently in many different organisms.

- bacteria
- jellyfish
- often times, bacteria are "harvested" by other organisms (fishes, etc.)
- dinoflagellates
  
- bright first flash in dinoflagellates scares away zooplankton
- counter-illumination (requires that it's the right color, but also the right angle)
- lure (triggerfish, some bacteria that want to be eaten so that they are associated with particles)

- v. Cherenkov radiation—in the deep sea where there should be no light sources, some fishes and other organisms have developed eyes that can perceive the extremely weak photons produced by cosmic radiation interacting with water molecules
  
- vi. Infrared radiation—some shrimps and possibly other organisms have developed the ability to sense IR light given off by hydrothermal vents in the deep sea.

### III. Fate of Light in the Marine Environment

Light is either absorbed or scattered as it moves through a medium.

#### The ABCs of ocean optics:

$c=a+b$ , Where  $c$ =total attenuation,  $a$  is absorption,  $b$  is scattering.

$a, b$ , can be divided into additive components: water, particles, phytoplankton, CDOM, etc.

As an example, in the open ocean, total absorption is equal to absorption by water, absorption by phytoplankton, and absorption by materials that covary with phytoplankton (detritus, exudates, etc):

$$a = a_{H_2O} + a_{phyto} + a_{other}$$

These properties are called **Inherent Optical Properties** (IOPs) because they are totally independent of how much light or where the light is coming from. Other IOPs include index of refraction, etc.

There are also **Apparent Optical Properties** (AOPs), such as the extinction coefficient (measured with a secchi disk for example). This depends on how much light, what color light, etc. This is what we typically measure.

In oceanography, we want to measure the IOPs because they are constants...from the IOPs we can derive the AOPs. However, it is extremely difficult to measure IOPs, and very easy to measure AOPs.

- the only IOP we routinely measure is beam-attenuation or beam- $c$ . This is measured with a beam transmissometer, typically at 660 nm (red light), and is used to estimate particle concentration in ocean waters. We use red light because there is very little in the ocean (most is absorbed).

- There are now commercially available IOP meters, such as the ac-9 or the Hydrosat-6, which can measure these properties directly, but they are expensive, specialized pieces of equipment that we have to be careful in using.

- Typical light measurements by oceanographers are light extinction (secchi depth), PAR, or light color (spectral radiance and irradiance). Less frequently, we measure particulate absorption.

To get light into the ocean, it has to move from the atmosphere into the water. This becomes less likely as the angle gets shallower (the light will reflect off the water surface instead).

Once the light is in the ocean, it is **very difficult** to get back out, because it has a high probability of reflecting back down at the air-sea interface. Only light from a 60° cone (or about 1/3 of all upwelling light) will move through the sea-air interface, due to the index of refraction of water. The rest bounces (reflects) back down into the ocean again.

Because of that, **light typically moves in one direction (downward) in the water**. Light is not a very good reflector of light, and water usually appears much “darker” than land from above.

#### IV. Classification

We can classify water in the ocean based on what properties influence the color of the light:

Case I waters—water that is dominated by the optical properties of water and chlorophyll, and things that covary with the chlorophyll concentration.

Case II waters – water that is dominated by water, phytoplankton, and non-covarying properties such as CDOM

Case III waters – water that is dominated by backscattering of particles (sediments)

Jerlov water types (1976):

Defined the various types of water based on their color—you look at the color of the water, and find a color in the Jerlov scale that matches it.

## V. Constituents of Water

Water appears blue because it has a lot of scattering in the blue, and a lot of absorption in the red:

- scattering obeys a  $\lambda^{-4}$  power law, so scatters most at blue wavelengths
- absorption is low in the blue, very high in the red.
- small particles tend to scatter light in the forward direction, large particles tend to scatter light in the backward direction.
- water is well described by models of molecular scattering and absorption

Case I waters....in addition to water, we have phytoplankton:

like water, phytoplankton generally obey a power-law function with respect to backscatter, so they tend to scatter in the forward direction (or downward), which is why water doesn't usually look red.

When we look at water from above, we are looking at the **Reflectance**, which is the upwelling light ( $L_u$ ) divided by the downwelling light ( $E_d$ ). Satellites see what we call **Remote Sensing Reflectance**.

$$R_{rs} = K \cdot bb / (a + bb)$$

Therefore, the **color** of the water is directly proportional to the amount of scattering, and inversely proportional to the amount of absorption. Waters with lots of phytoplankton appear green because phytoplankton absorb in the blue and red, leaving the green light.

## VI. Measuring Light in the Oceans

- When we talk about ocean optics and phytoplankton, we are usually only interested in the color of the light, the amount of the light, and how much is absorbed by phytoplankton. Phytoplankton don't really care what direction it's

coming from (In other biological studies, such as vision, other aspects, such as the polarization of the light, are very important)

- We also don't usually care about anything other than PAR, with the exception of UV damage in the near surface
- Therefore, as phytoplankton biologists, we can use very simple instruments, because all we really care about is how much light there is, or more often, how deep the light penetrates.

**Euphotic Zone Depth:** the depth (in meters) that PAR penetrates until 1% of the surface light is left—this is approximately how deep phytoplankton can photosynthesize

- If we use the Beer-Lambert equation, we can calculate this depth by knowing how fast light **attenuates** (denoted **k**, or the attenuation coefficient in  $\text{m}^{-1}$  units) in the water:

$$E = E_0 e^{-kz}$$

- The simplest instrument for measuring this is the **Secchi Disk** which uses your eye to estimate the attenuation depth
- Modern instruments (radiometers) do the same thing, but use electronic sensors.
- We can also measure other properties of water, including:
  - Absorption ( $a$ ,  $\text{m}^{-1}$ )
  - Attenuation ( $c$ ,  $\text{m}^{-1}$ )
  - Backscatter ( $b_b$ )
  - Radiance, Irradiance
- These require more sophisticated instruments, though, and are less commonly measured
- Even if we have all of these numbers, it is **very difficult** to accurately model everything that happens to light in the ocean!

Pro

General Oceanography & Optics

- Therefore, we are mostly interested in simple properties that we can measure, such as the attenuation depth, and we make assumptions about everything else.