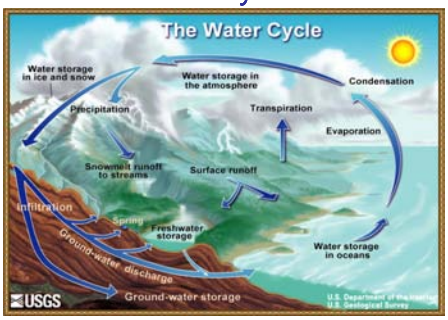
Water Cycle



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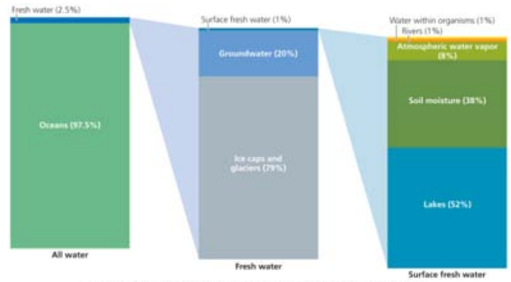

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Residence Time

Reservoir	Approximate Residence Time
Glaciers	40 years
Seasonal Snow Cover	0.4 years
Soil Moisture	0.2 years
Groundwater: Shallow	200 years
Groundwater: Deep	10,000 years
Lakes	100 years
Rivers	0.04 years

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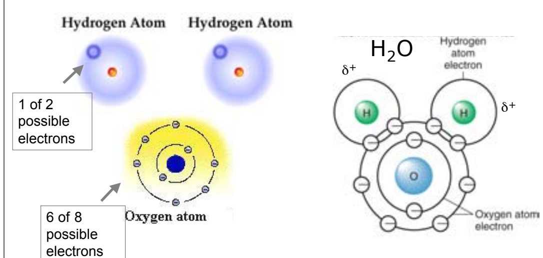
Water Molecule
Covalent Bonds: Shared Electrons



Molecule is a dipole

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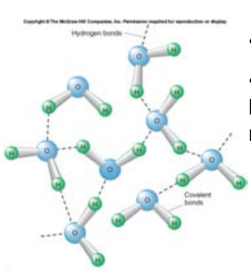
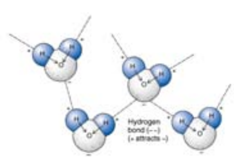
Water Molecules: Hydrogen Bonds



- Hydrogen bonds are weak
- Oxygen is bonded to 2 hydrogens from 2 different molecules



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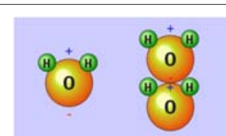
Fresh Water



- States - exists naturally in all 3 states (only substance on Earth)
  - Unusually high melting point
  - Unusually high boiling point - allows for liquid to be prevalent
- Density - Liquid is more dense than solid (only substance on Earth)
  - Shrinks on melting, expands on freezing - Burst pipes!

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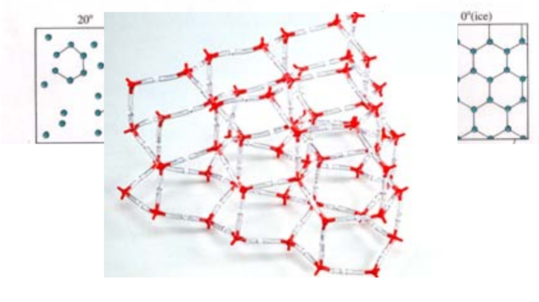
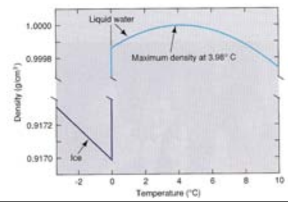
Density - Liquid is more dense than solid (only substance on Earth)



Density = Mass/Vol With warming, density changes, since no mass is created or destroyed the Volume must change with temperature. With warming:

- Ice -10°C to 0°C Expands Lattice most spaced at 0°C
- At 0°C ice to water Contracts Lattice collapses
- Water 0°C to 4°C Contracts Molecules closest at 4°C
- Water 4°C and above Expands Less and less H-bonds



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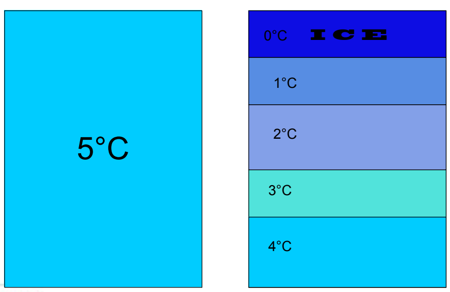
Density and Freezing

- Depth



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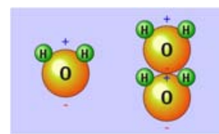
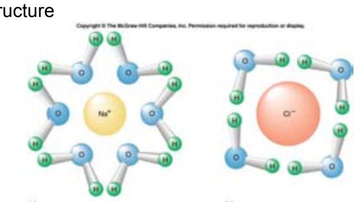
Fresh Water



- Dissolving Power - highest of any liquid. Water is the "Universal Solvent"
- Due to dipole structure

The vast majority of dissolved materials are salts.



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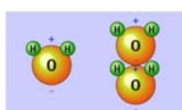
Fresh Water



- Heat Capacity - 2nd highest of any liquid
  - This allows oceans to act as large heat reservoirs moderating global temperature.
  - Liquid water has over twice the specific heat capacity of ice or steam.This explains why the oceans are so much better at moderating temperature than are, say, glaciers.
  - Water: 1cal/gm °C
  - Ice: .5 cal/gm °C
- Heat Conductivity - 2nd highest of any liquid
  - Titanic
  - Ack! My beer is warm!

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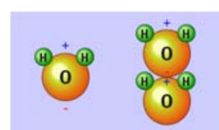
Fresh Water



- Latent Heat of Evap. - highest of any liquid
  - Evaporation: 540 cal/gm
  - As water evaporates, it removes a large amount of heat with it. If it condenses it releases a large amount of heat.
- Latent Heat of Fusion - 2nd highest of any liquid
  - Fusion: 80 cal/gm

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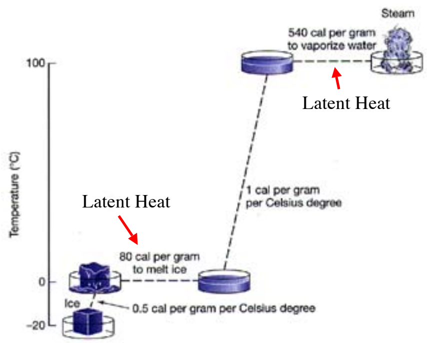

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Salinity

•Total amount of dissolved material in seawater

•35 psu = 35 ppt = 35 o/oo = 35 grams of dissolved material in 1 kg of water

•If S = 35, what % of the sample is dissolved material?

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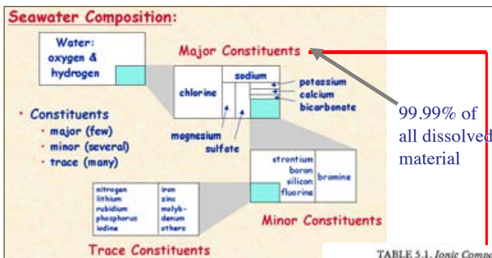

TABLE 5.1. *Ionic Composition (by weight) in Seawater*

Ion	Symbol	Seawater %
Chloride	Cl^-	55.04
Sodium	Na^+	30.62
Sulphate	SO_4^{--}	7.68
Magnesium	Mg^{++}	3.69
Calcium	Ca^{++}	1.15
Potassium	K^+	1.10
Bicarbonate	HCO_3^-	0.41

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Principal of Constant Proportions

- Ocean water is very well mixed with respect to the major constituents
  - Composition of salinity is the same from place to place
  - Means that the relative amount (%, ‰) of each major ion is the same whether salinity is 15 ‰ or 30‰

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Principal of Constant Proportions

- If you know the concentration of one ion, you know the concentration of all the ions, and you know the total salinity
- S (o/oo) = 1.8065 x CL(o/oo)
  - CL = chloride concentration or chlorinity

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Salt in Water

•Density increases
•Boiling Point increases
•Freezing Point decreases
•Increases viscosity
  –Alters speed of sound in seawater
•Increases Osmotic Pressure
  –Across cell membranes (water moves from low S through membrane to high S)

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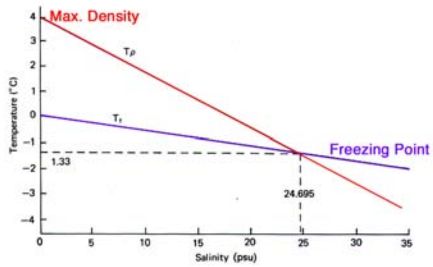
Salt Water & Freezing

S > 24.7 Cooled surface waters sinks to bottom



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Light Penetration in the Ocean

- Absorption by molecules & ions
- Scattering by molecules & ions
- Absorption for photosynthesis
- Decrease in intensity: Attenuation
- Longer wavelengths of light get attenuated faster

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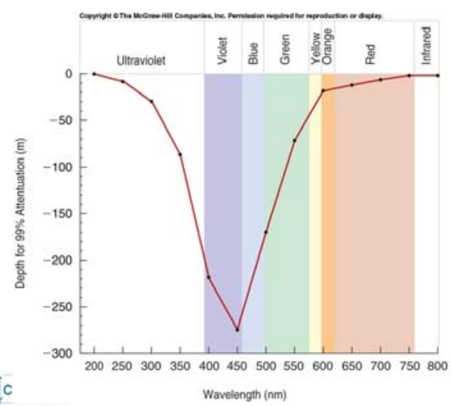

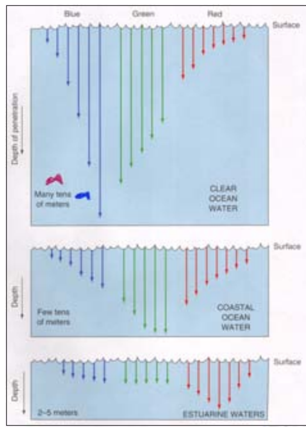

Shorter wavelengths get deeper
50% of light attenuated in top 10 m, blue makes it to ~100m

Coastal waters have high turbidity

Estuarine waters have highest turbidity
96% of light attenuated in top 10 m.

Attenuation

$$I_z = I_o e^{-kz}$$

I_o = light intensity at the surface
I_z = light intensity at depth = z
k = attenuation coefficient (unit m^{-1})
k depends on water clarity (location) and wavelength
The depth for a given light intensity ratio (I_z / I_o) is $z = -\{\ln(I_z/I_o)\}/k$

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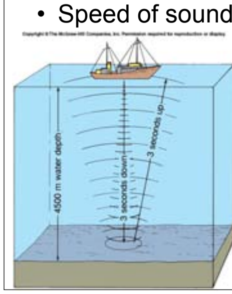
Sound

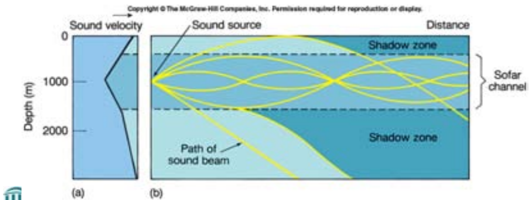
- Sound travels further and faster in seawater (1500 m/s) than in air (334 m/s)
- Speed of sound depends on T, S, P



- Low frequency sounds can travel much faster
- Sound is reflected when it hits an object
- Marine scientists use sound to map the sea floor

Sound - Sofar Channel

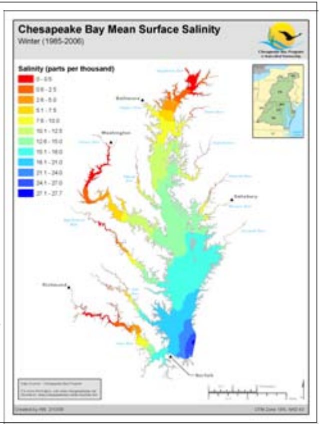
- T, S, P at around 1000m depth creates zone of minimum velocity
- Sound produced in the Sofar Channel does not escape, can travel across entire ocean basin



Acoustic Thermometry

Salinity

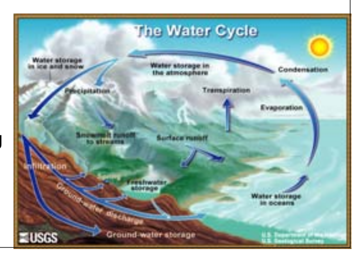
- Average ocean salinity = 35 ppt
- Coastal waters - below or above average?
- Coastal waters also highly variable. Winyah Bay has been observed to range from 0 ppt to 40 ppt.



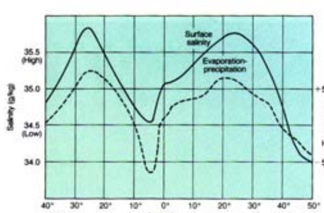
Salinity of Coastal Waters

- No (short term) input/output of dissolved material. Why does salinity vary?

- Runoff
- Precipitation
- Evaporation
- Ice formation/melting



Coastal waters - Salinity

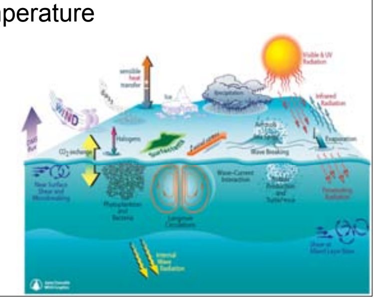


Coasts:

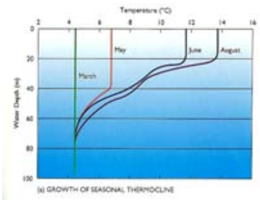
- Runoff
- Local Climate (E - P) over the whole watershed

Mixed Layer

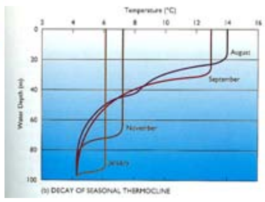
- Layer that is influenced by the wind
- Uniform temperature
- 0 -100 m



Seasonal Thermocline



- Mixed layer - homogeneous layer influenced by the wind



Thermocline - rapid change in temperature with depth

Temperature mainly controlled by difference in energy entering the water and energy leaving the water

Incoming Radiation (Qs)
Heat Gain

- Insolation from the sun
- Primarily visible energy
- Measured by a radiometer at the surface
- 1 cal = 4.18 Joule
- Units are J /s•m^2 or Watts/m^2
- Typical values = 200 - 400 W/m^2

Outgoing Back Radiation (Qb)
Heat Loss

- Infrared Radiation leaving the surface
- = c_{sb} T(°K)^4 $c_{sb} = 5.67 \times 10^{-8}\ W/m^2K^4$
- °K = °C + 273

How much energy is radiated from an average m^2 of the ocean surface?(T = 19°C)

$$= c_{sb}\, T(K)^4$$

$$= \left(5.67 \times 10^{-8}\ W/m^2K^4\right)(292\ K)^4$$

$$= 412\ W/m^2$$

•So the average m^2 of ocean loses about 400 J of heat energy every second from radiation.

•But this IS NOT the heat loss (Qb) of the surface waters

Greenhouse Effect

- Most of the heat that is radiated from the surface never escapes into space. It is absorbed by clouds and gases and re-radiated back to the ocean as infrared radiation.
- The part that does escape is usually only about 20-40% of what leaves the surface.
- Based on cloud cover, the % that escapes to space can be estimated. This is the *net or effective* back radiation.
- This represents the heat loss (Qb) from the surface waters.

Net Heat Loss

Back to our previous example:

$$= c_{sb}\, T(K)^4$$

$$= \left(5.67 \times 10^{-8}\ W/m^2K^4\right)(292\ K)^4$$

$$= 412\ W/m^2$$

•If cloud cover is trapping three-fourths of the outgoing radiation what is the net heat loss?

Total Energy Change:

$$\Delta Q = Qs - Qb$$

=Heat Gain - Net Heat Loss

Temperature Change:

$$\Delta Q = m\, c_{water}\, \Delta T$$

- Q in Joules
- c_{water} = 4186 J/kg°C
- m = mass. Per unit volume m equals the density (ρ) of the water

$$\frac{\Delta Q}{vol} = \rho\, c_{water}\, \Delta T$$

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Density (ρ)

- Freshwater = 1000 kg/m^3
- Ocean Density between 1020 - 1030 kg/m^3
- Estuarine waters can be less than 1020 kg/m^3
- Average ocean density ρ = 1027 kg/m^3

Density (σ)

Easier way of labeling density

- **σ = (ρ - 1000)** when ρ in kg/m^3
- Average density σ = 27
- Theoretically σ has units of kg/m^3, but **DO NOT** use σ in formulas, problems, etc.

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Density

- Density is not measured, it is calculated
- Temperature, salinity and pressure (or depth) are measured, used to calculate density

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Equation of State

$$\rho = 1027\, {}^{kg}\!/_{m^3} + \left[\bar{a}(T - 10^\circ C) + \bar{b}(S - 35psu) + \bar{k}p\right]$$

$\bar{a} = 0.15$ kg/m^3 per degree Celsius   a is negative

$\bar{b} = 0.78$ kg/m^3 per part per thousand salinity

$\bar{k} = 4.5 \times 10^{-3}$ kg/m^3 per decibar

- 1 m = 1 db

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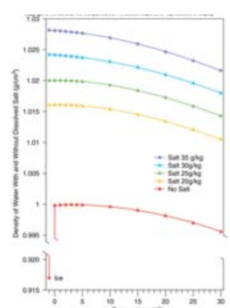
Types of Density

- In-situ $\sigma = (\rho_{s,t,p} - 1000)$
  - Rarely used by marine scientists
  - Pressure changes volume, thus pressure changes density
- Sigma –t $\sigma_t = (\rho_{s,t,0} - 1000)$
  - Is density parcel would have if raised to the surface
  - Removes Pressure's **LARGE** effect on compressibility

$$\rho = 1027\, {}^{kg}\!/_{m^3} + \left[\bar{a}(T - 10^\circ C) + \bar{b}(S - 35psu)\right]$$

Effect of Salt & Temp on Density

- Salt: Linear
- Temp: Non-linear
  - Depends on the initial temperature of the water



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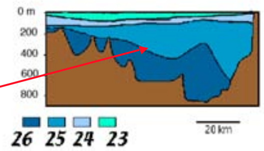
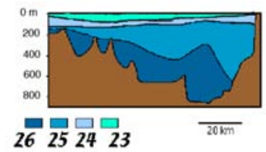
Stability



isopycnal

- Stability = change in density/change in depth
- Measures the ease/difficulty of having vertical motion in the water column
- Thus, it measures the likelihood of mixing (tides/winds) in the water column
- $= -(1/\bar{\rho})\ d\rho/dz$

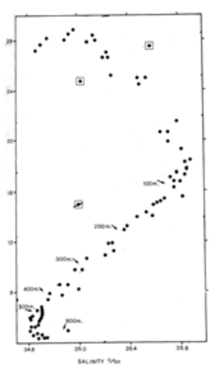
Stability



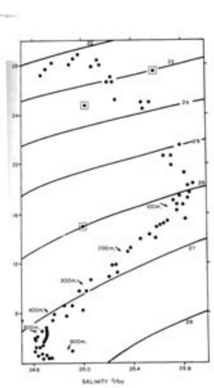
$$= -(1/\bar{\rho})\ d\rho/dz = \frac{1}{\bar{\rho}}\ \frac{\rho_2 - \rho_1}{z_2 - z_1}$$

- Why negative sign?
- + is stable, larger # is more stable
- Open ocean E ~ 10^{-6} m^{-1} to 10^{-8} m^{-1}

T - S Diagram



T - S - σ Diagram



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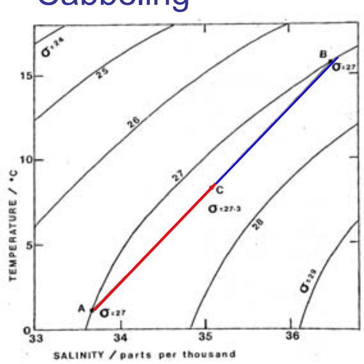

T -S - Time Diagrams