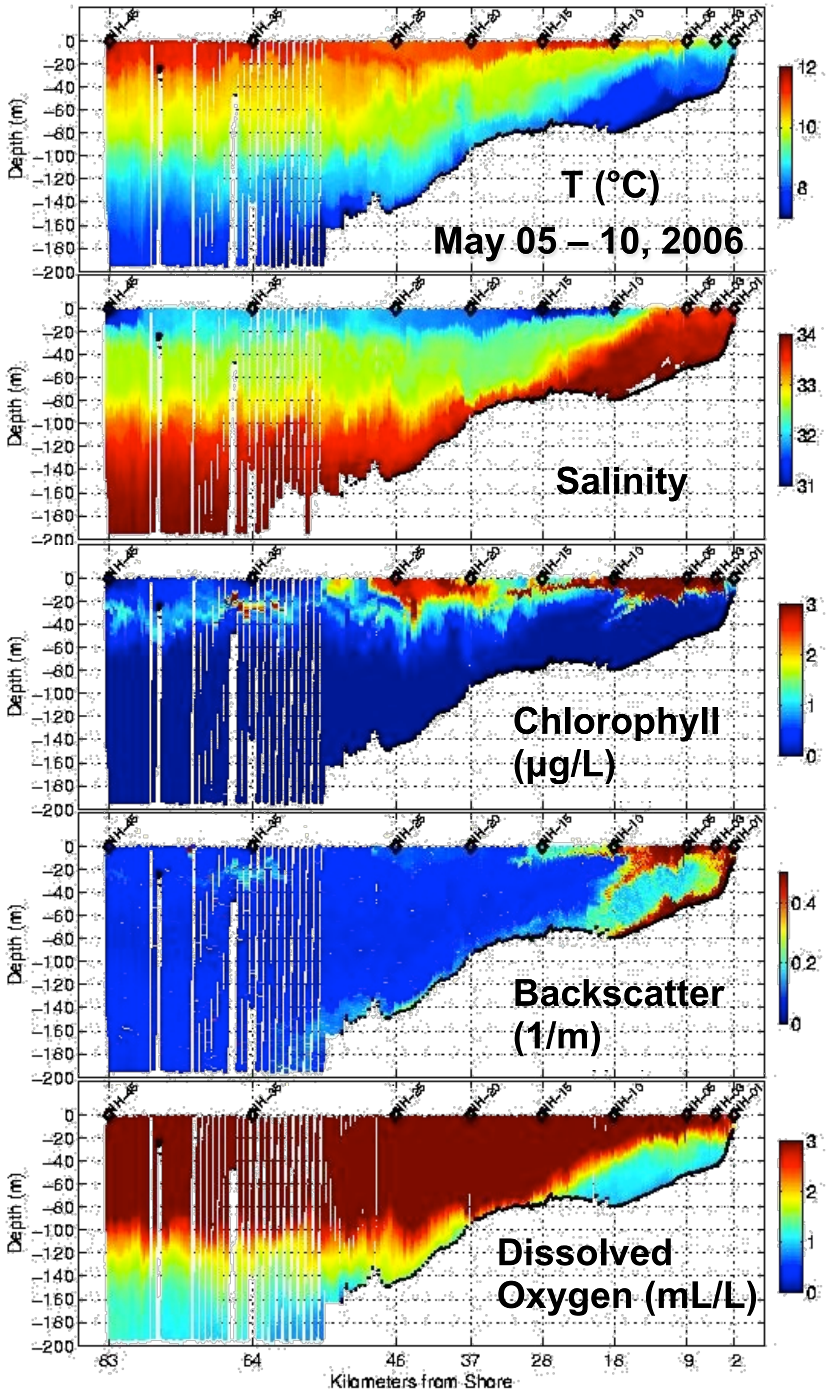
Properties of the Ocean

NOAA Tech Refresh

20 Jan 2012

Kipp Shearman, OSU



Kipp Shearman

Physical Oceanographer

I am interested in all things coastal

Lots of observations: big boats, little boats, no boats.

I think all the best problems in oceanography are interdisciplinary

Why do we need to understand this?

http://www.britishpathe.com/video/gambling-with-gulf-stream-aka-gambling-on-the-gulf

Outline

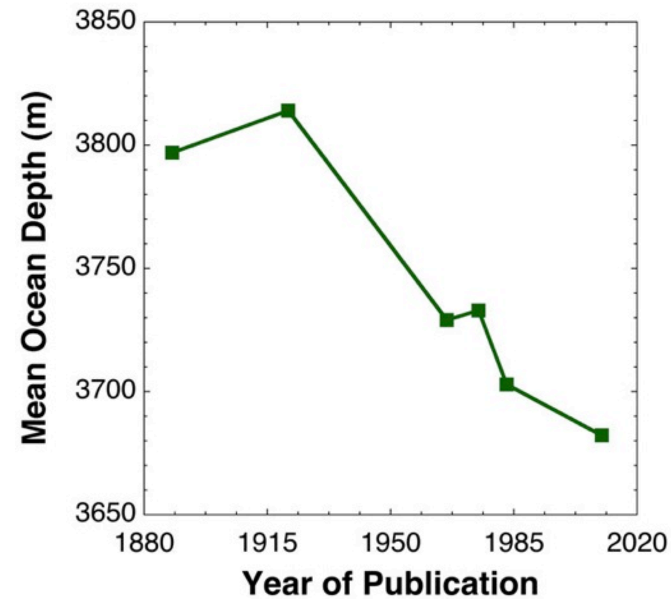
- Characteristics of the Ocean
- T, S, Density, Pressure
- Stratification and Mixing
- Seasonal Cycle

The Global Ocean

TABLE 9.1. Some key ocean numbers.	
Surface area	3.61×10^{14} m^2
Mean depth	3.7 km
Volume	3.2×10^{17} m^3
Mean density	1.035×10^3 kg m^{-3}
Ocean mass	1.3×10^{21} kg

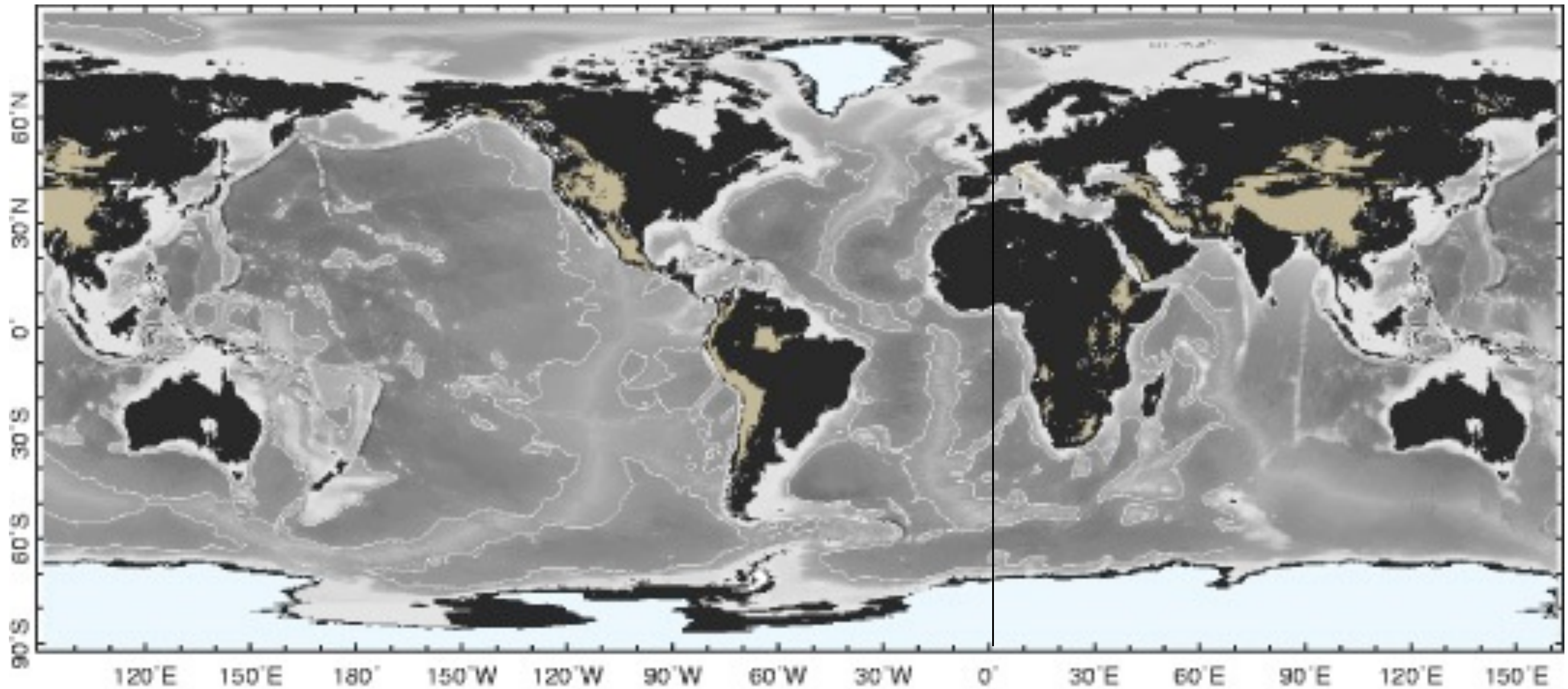
TABLE 9.1. Some key ocean numbers.

Marshall and Plumb, 2008

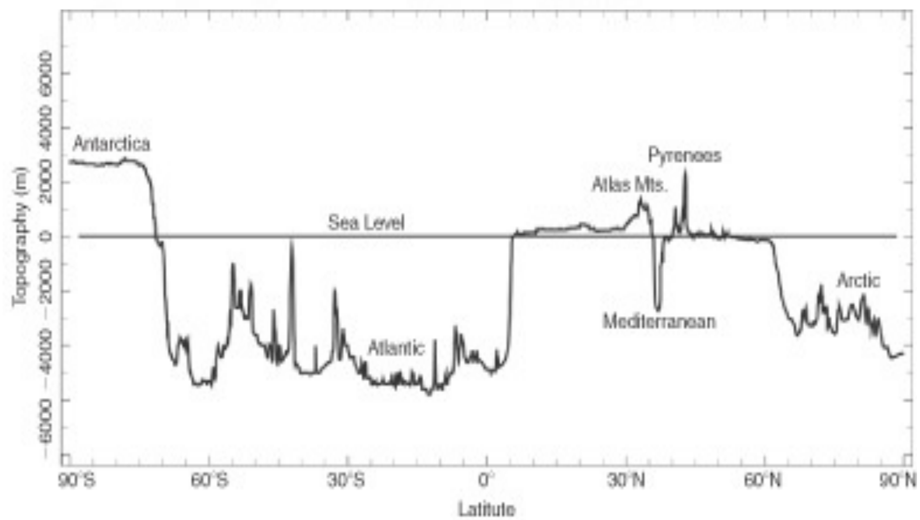


SA x MD = 1.34 x 10^{18} m^3
OM/RHO = 1.23 x 10^{18} m^3

Charette and Smith, 2010: 1.332 x 10^{18} m^3



- The ocean covers 71% of the Earth's surface
- Separated into enclosed basins (except southern ocean)
- Ocean topography (bathymetry) steeper than land topography



Surface temperatures through the global ocean

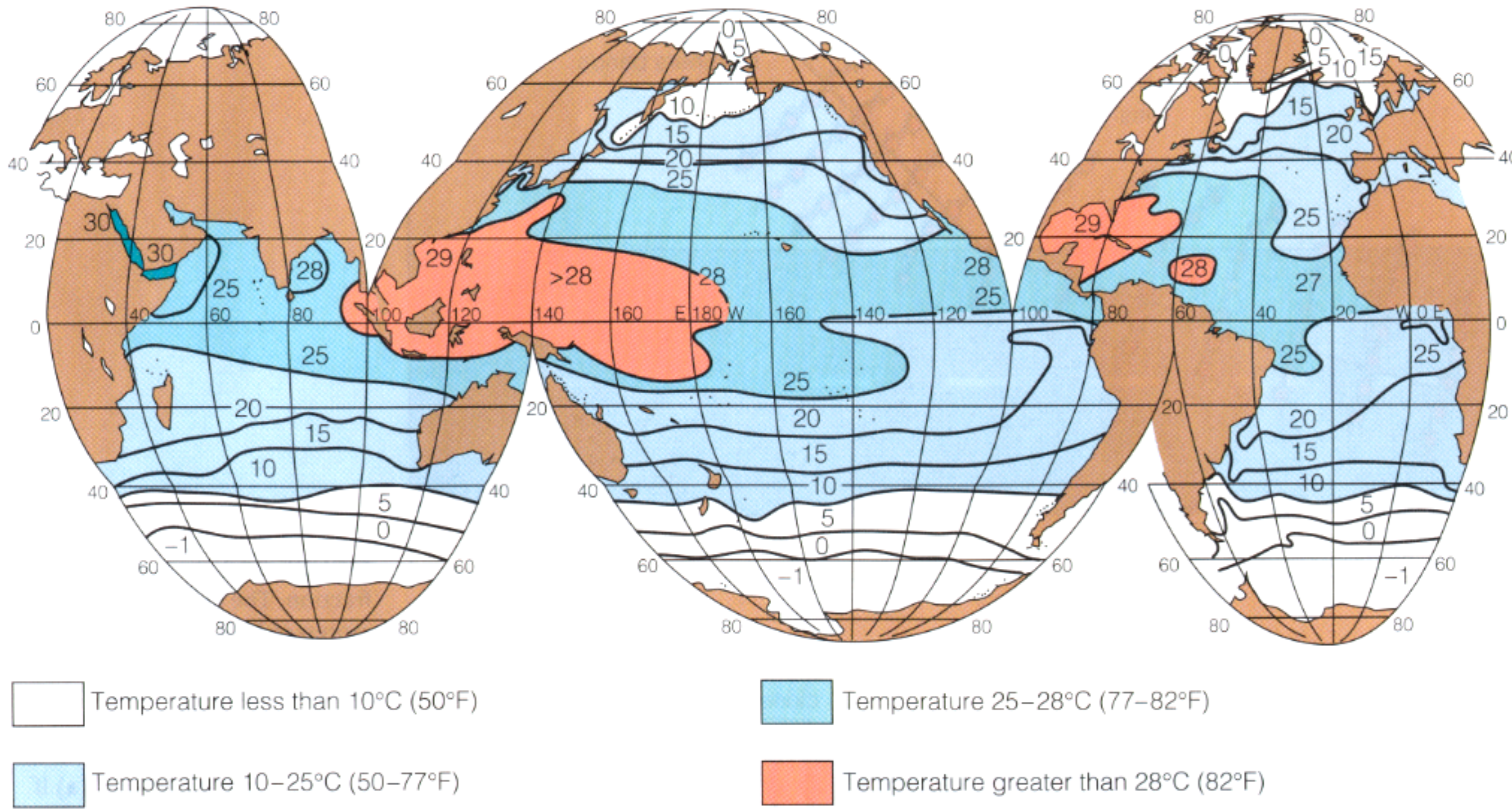


FIGURE 6.16 Sea surface temperatures in degrees Celsius during Northern Hemisphere summer.

Where surface heating is positive, temperature is increased and vice versa.
Note: coastal variations are not evident on this coarse scale map.

Surface salinities through the global ocean

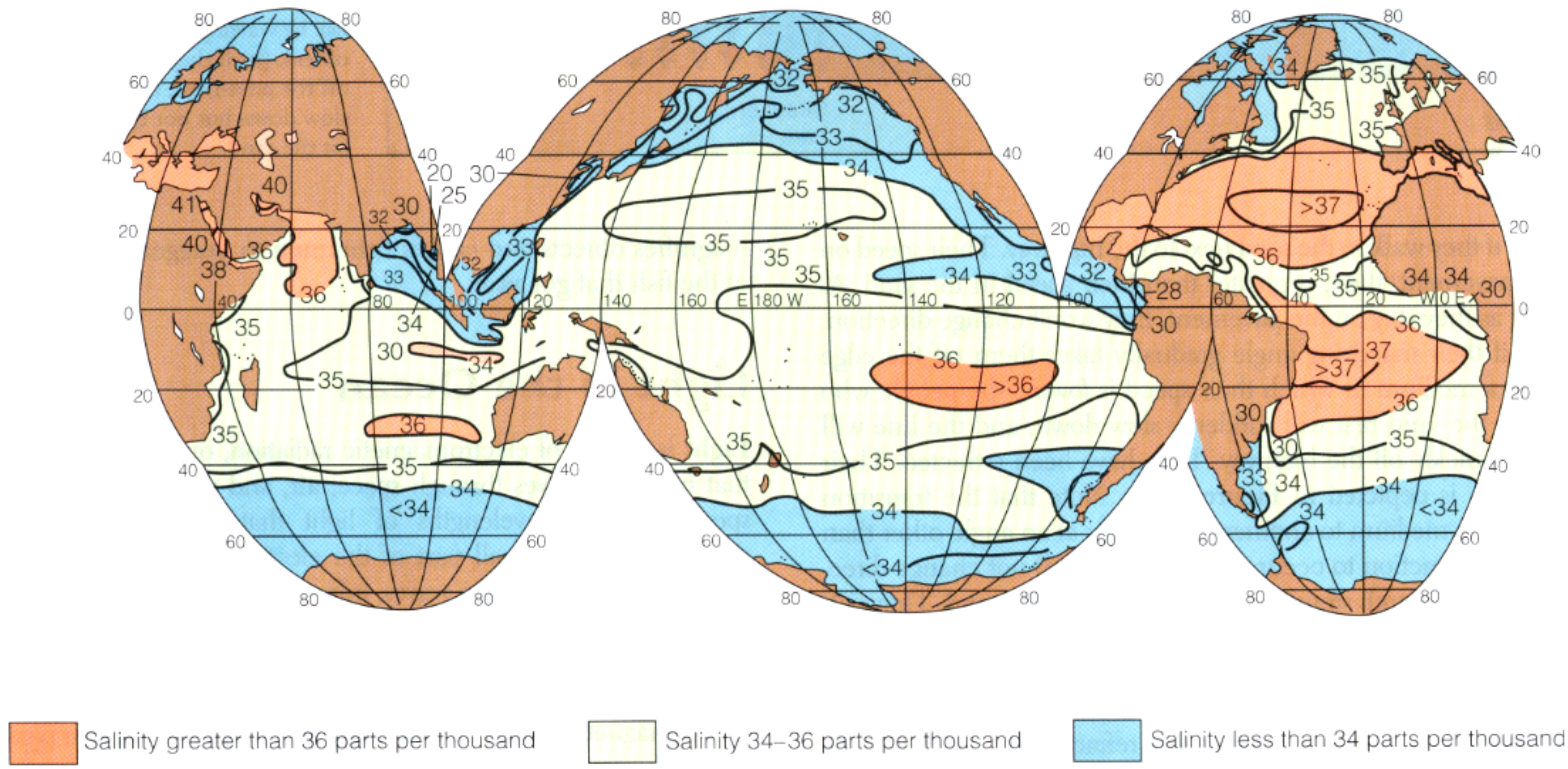
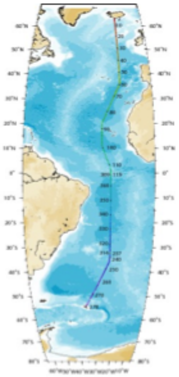
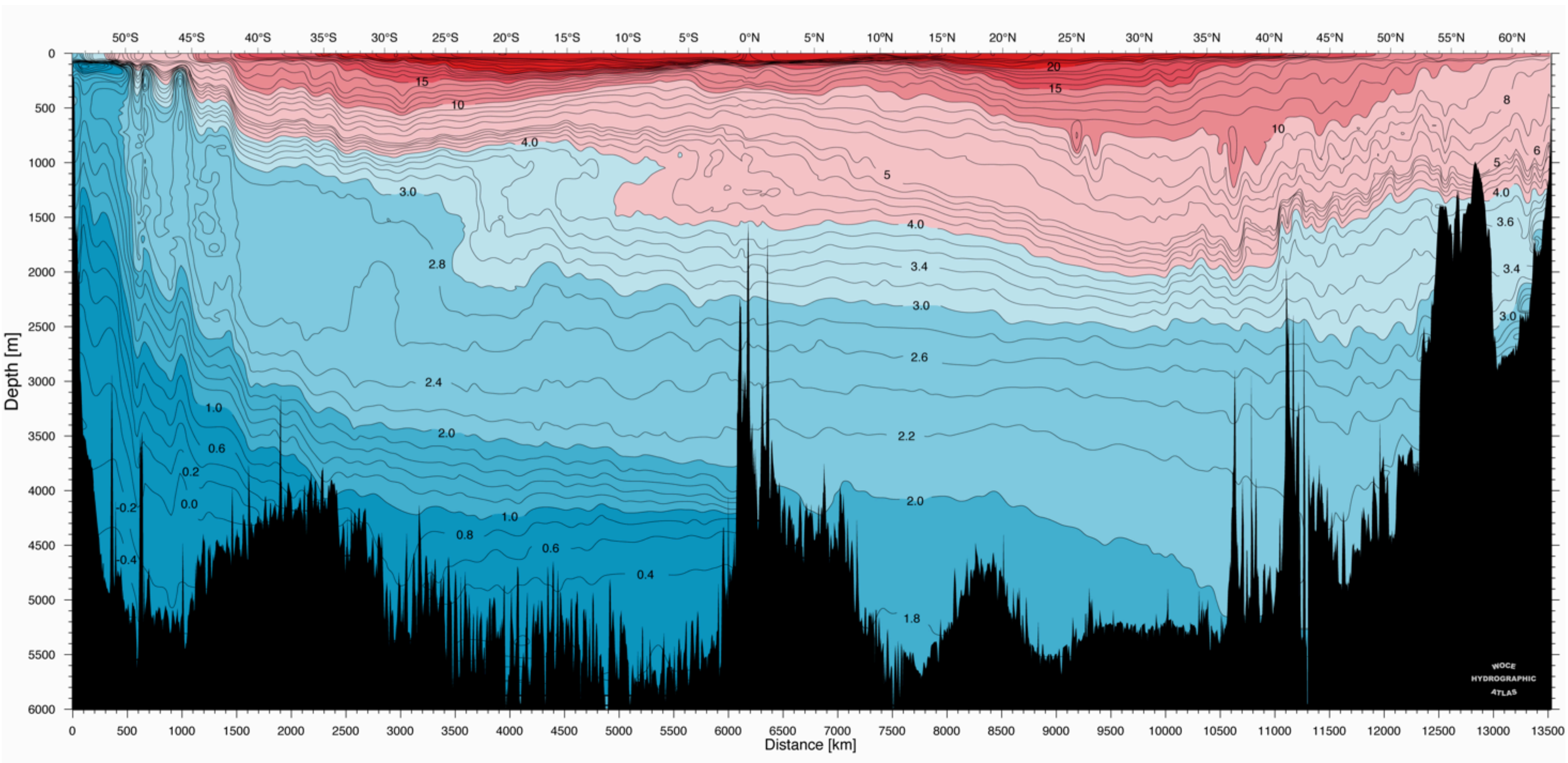


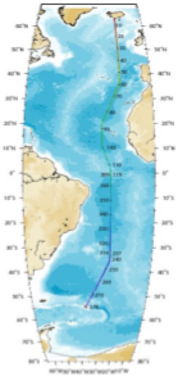
FIGURE 6.17 Sea surface salinities in parts per thousand (‰) during Northern Hemisphere summer.

Where precipitation exceeds evaporation and river input is low, salinity is increased and vice versa. Note: coastal variations are not evident on this coarse scale map.

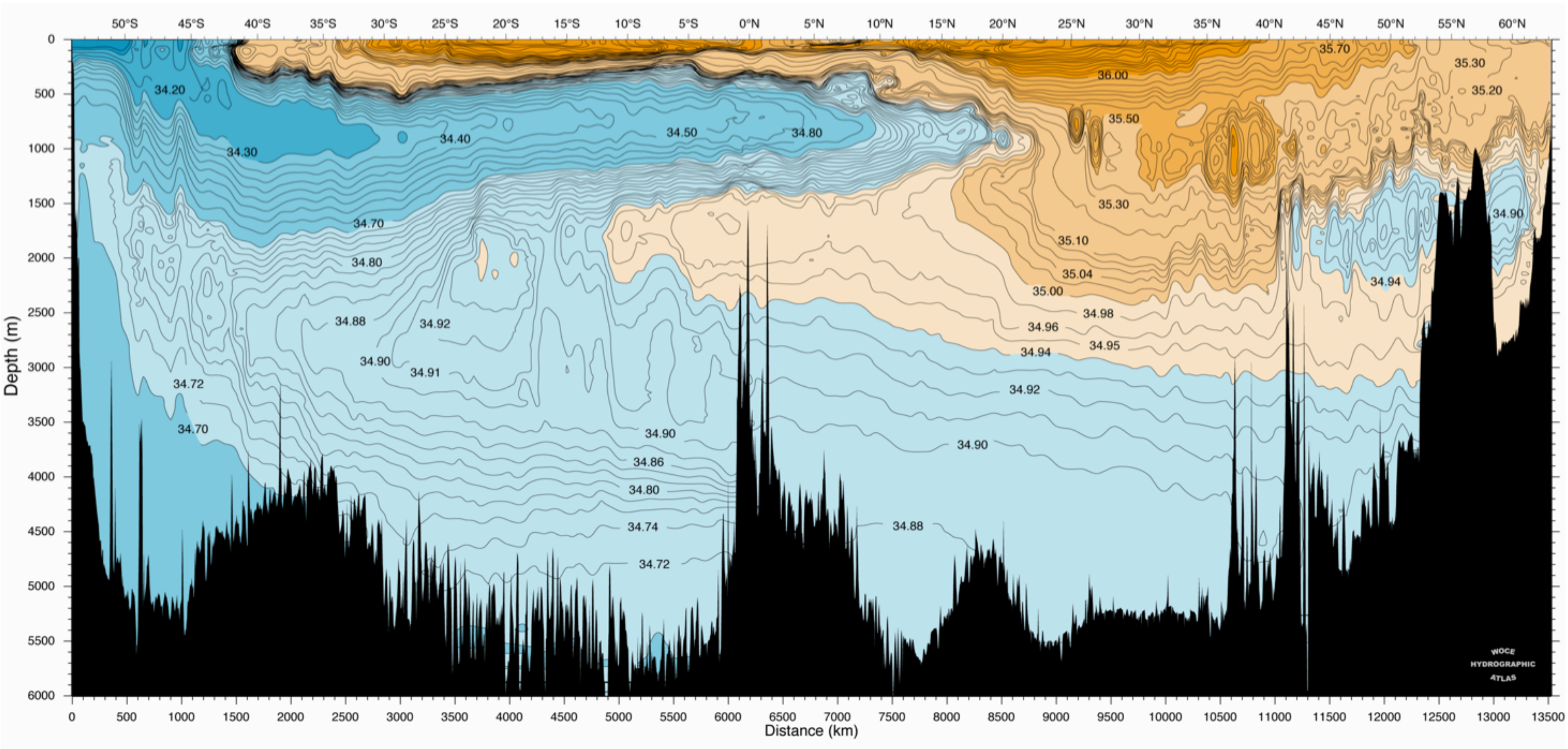


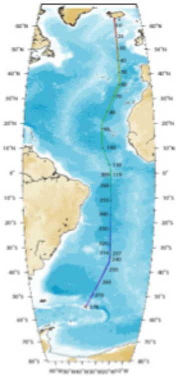
Temperature in the Atlantic



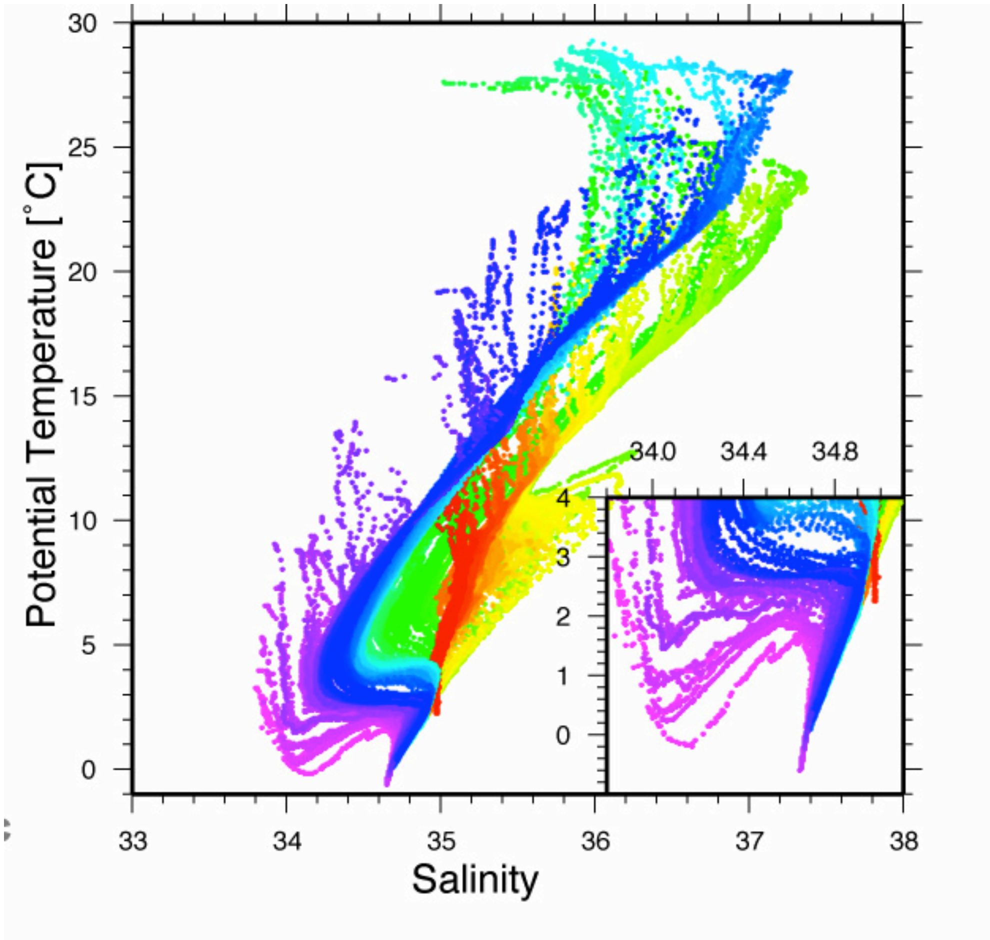


Salinity in the Atlantic





TS diagram in the Atlantic



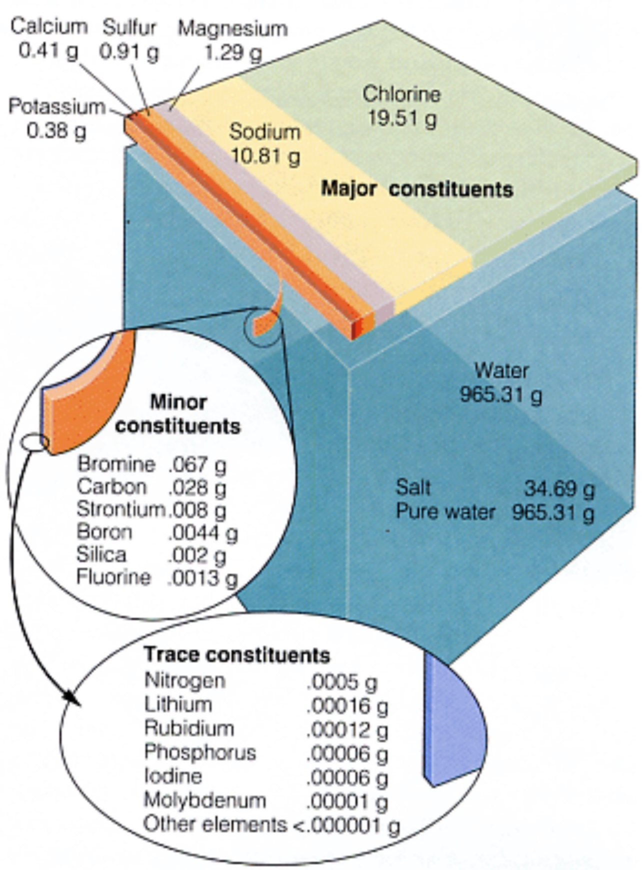
Global average ocean
T = 3.5 C
S = 34.7

Outline

- Characteristics of the Ocean
- T, S, Density, Pressure
- Stratification and Mixing
- Seasonal Cycle

How much salts are in the oceans and what salts are there?

- The average concentration of dissolved salts in ocean water – the salinity – is about 3.5% by weight.
- Older: expressed as parts per thousand, 35‰ or ppt
  Now: no units, S=35. (still is approximately ppt). Also see some use of psu or PSS-78.

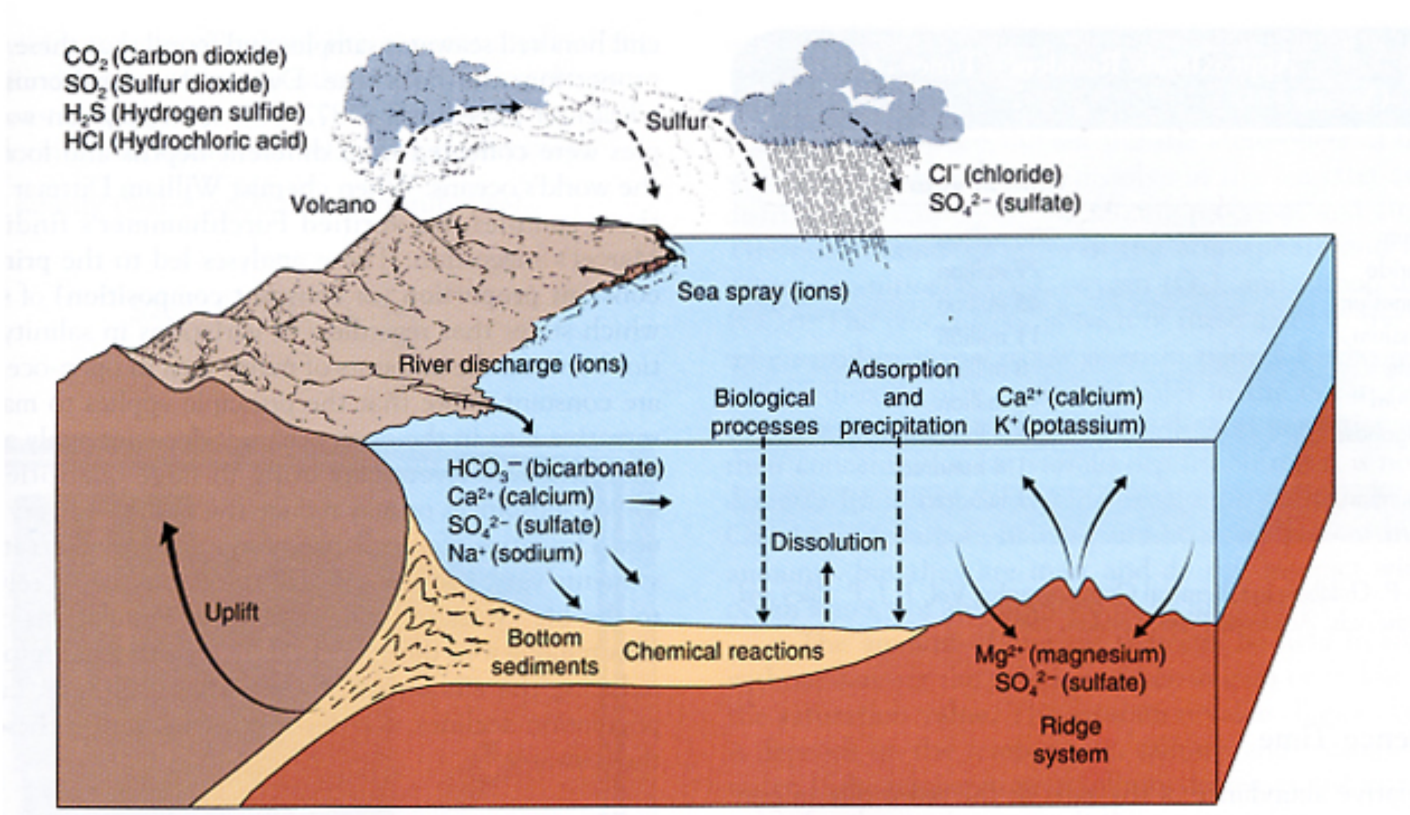


Law of Constant Proportions:

The amount of dissolved salts (g/kg-water) vary from place to place, but the composition of the dissolved salts (ratios of the major constituents) is the same nearly everywhere in the open ocean. So, by measuring one constituent --chlorine, for example -- we can find the total amount of salts.

Major constituents: Cl, Na, Mg, S, Ca, K

Where do the salts come from?



Salt ions added from rivers, volcanos, ridges, and dissolving sediments, particulates.

Salt ions removed by adsorption, ion exchange, spray, chemical precipitation, biological uptake, deposition at ridges

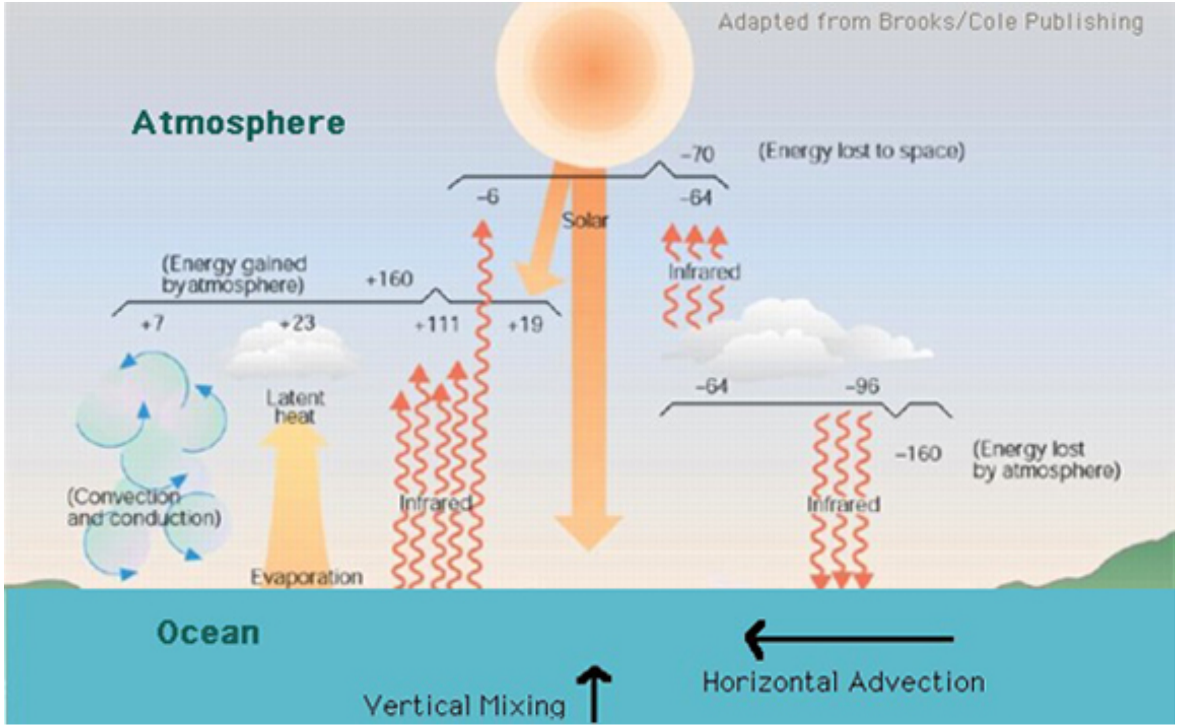
Heat and Temperature

The relationship between the amount of heat added per cubic meter of water) *H* and the corresponding temperature change) T is given by:

$$\Delta H = \rho c \Delta T$$

where ρ is the density and c is the specific heat. The SI unit of heat (energy) is the **joule**, abbreviated as **J** (= kg m^2 / s^2). The specific heat is a weak function of temperature, salinity and pressure, changing by approximately 1% over normal ranges of these variables in the upper 1000 meters of the ocean. The value of c ~ 4000 J /(kg °C) at 0 pressure, S= 35 and 15°C.

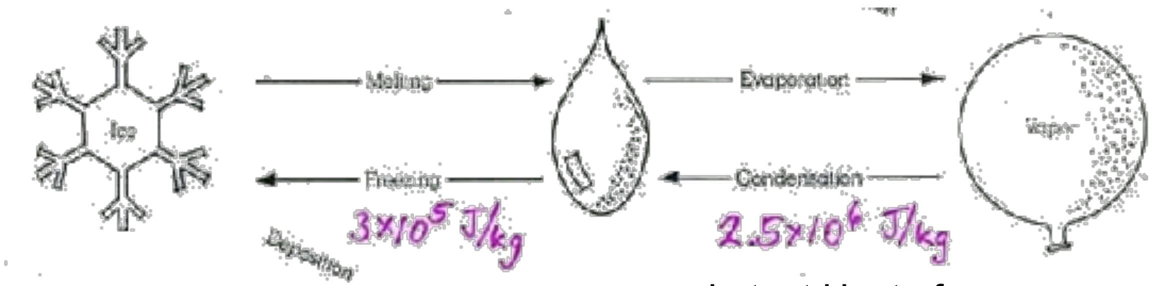
Processes that increase (decrease) temperature



- Solar (infrared) radiation
- Contact with warmer (cooler) air
- Mixing with warmer (cooler) water
- Increasing (decreasing) pressure
- Condensation (evaporation)

Phase Changes

Heat goes in



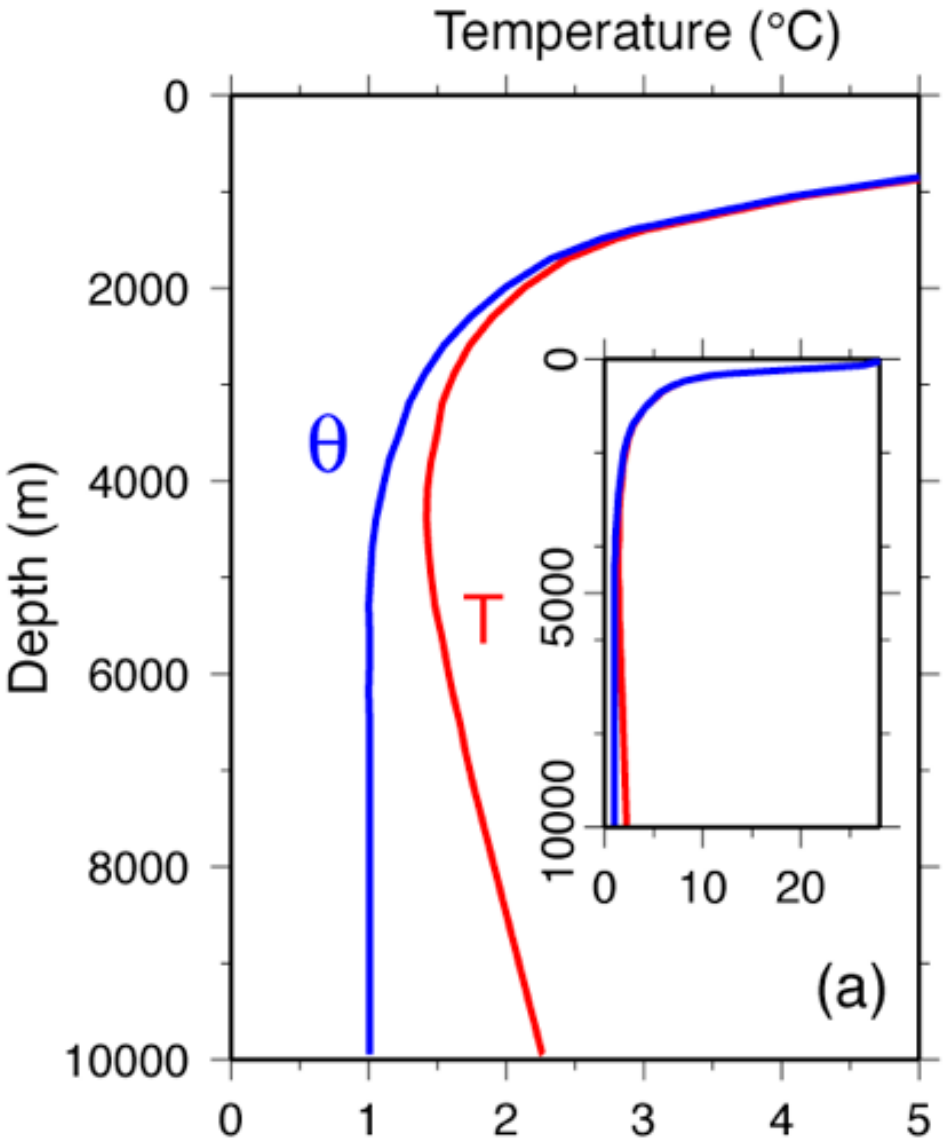
Latent Heat of Fusion

Latent Heat of Evaporation

Heat goes out

The heat (energy) required to evaporate 5 mm of water from the surface of the world's ocean could raise the temperature of the entire atmosphere 1°C!

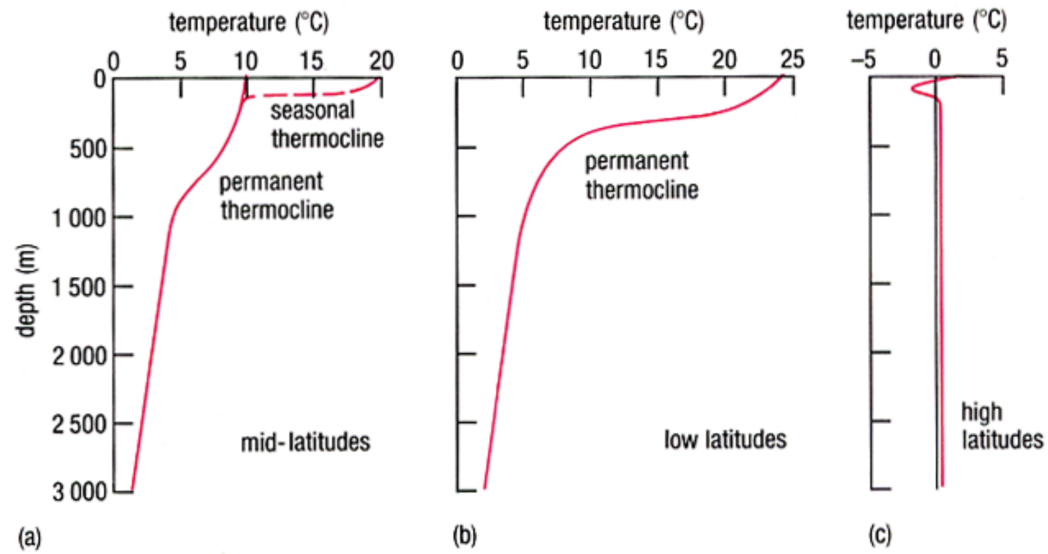
Temperature in the ocean is affected by pressure (slightly).



In-situ temperature, T
Potential temperature, θ

T is the temperature of a parcel of fluid as measured at the location (depth) of the parcel. θ, is the temperature the parcel would have if brought to a reference pressure (usually to p = 0, the surface of the ocean) without adding or subtracting heat. A process that does not add or subtract heat is known as an *adiabatic* process.

Oceans acquire temperature (and salinity) at the surface



- Most solar energy (direct heating) is absorbed within just a few meters of the surface.
- The biggest downward transfer of heat comes from wind-driven surface mixing. Often produces a surface mixed layer with uniform temperature.
- T drops rapidly with depth between about 200m and 1000m. This is the permanent thermocline.
- Above permanent thermocline, can get seasonal warming producing a seasonal thermocline.

Density

ρ = Mass/Vol ➔ units: kg/m^3 or g/cm^3

Freshwater = 1000 kg/m^3; saltwater = 1025 kg/m^3

Too busy to say "one-thousand blah, blah blah?"

Use shorthand for density

$\sigma = \rho - 1000$

so 1025.2 kg/m^3 ➔ 25.2 kg/m^3 (or "sigma units" or no units at all)

Freshwater density

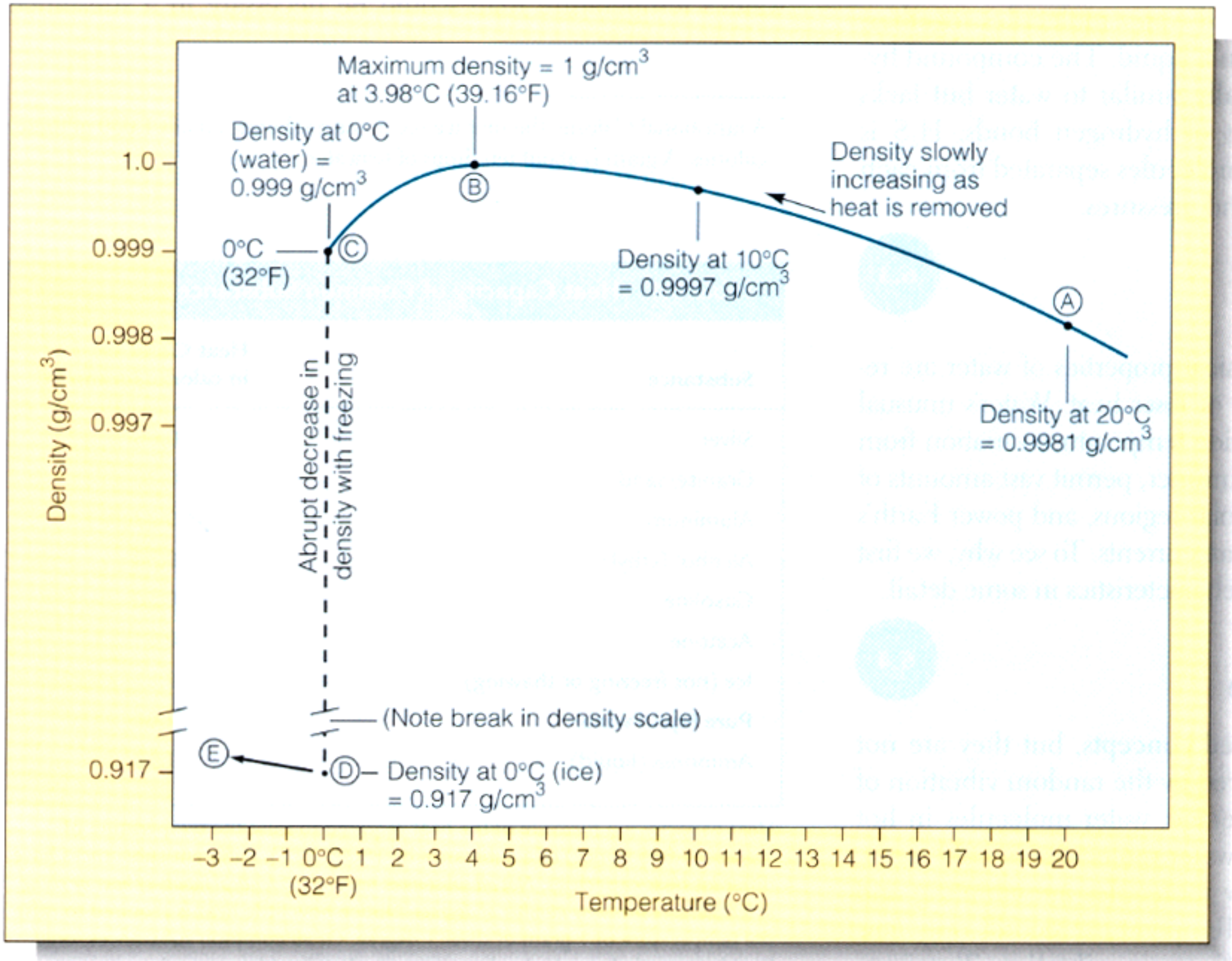
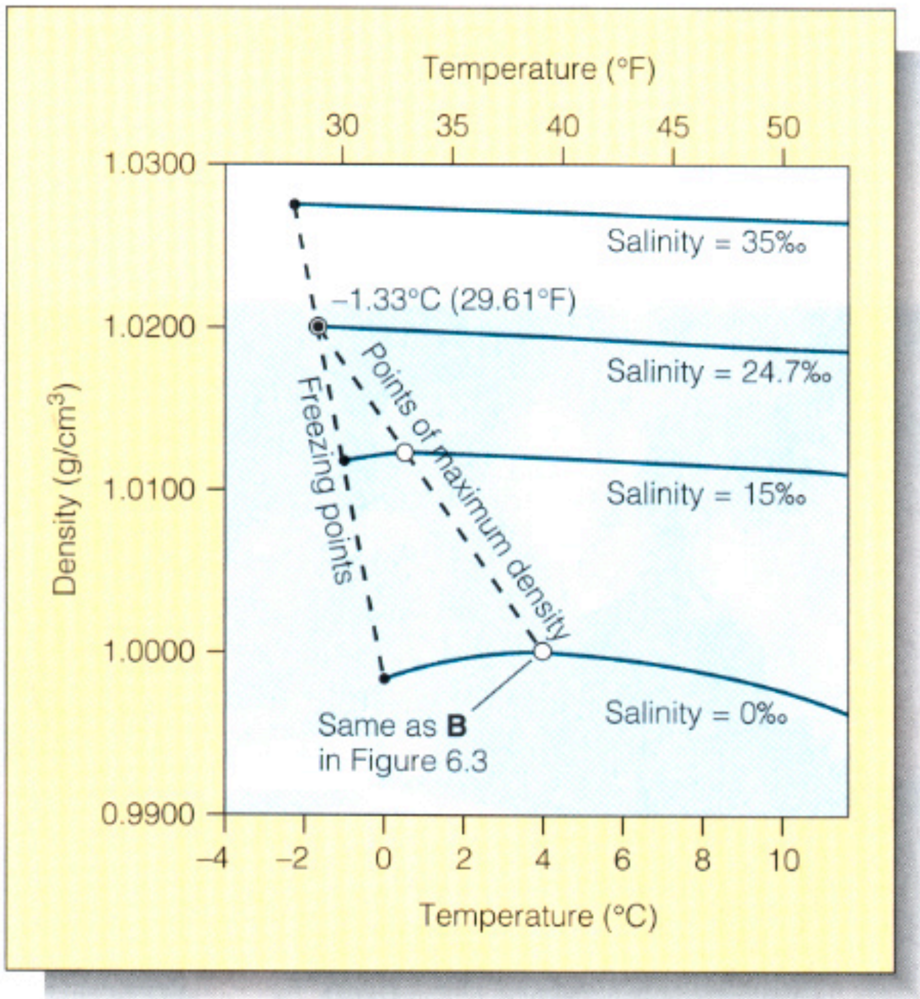
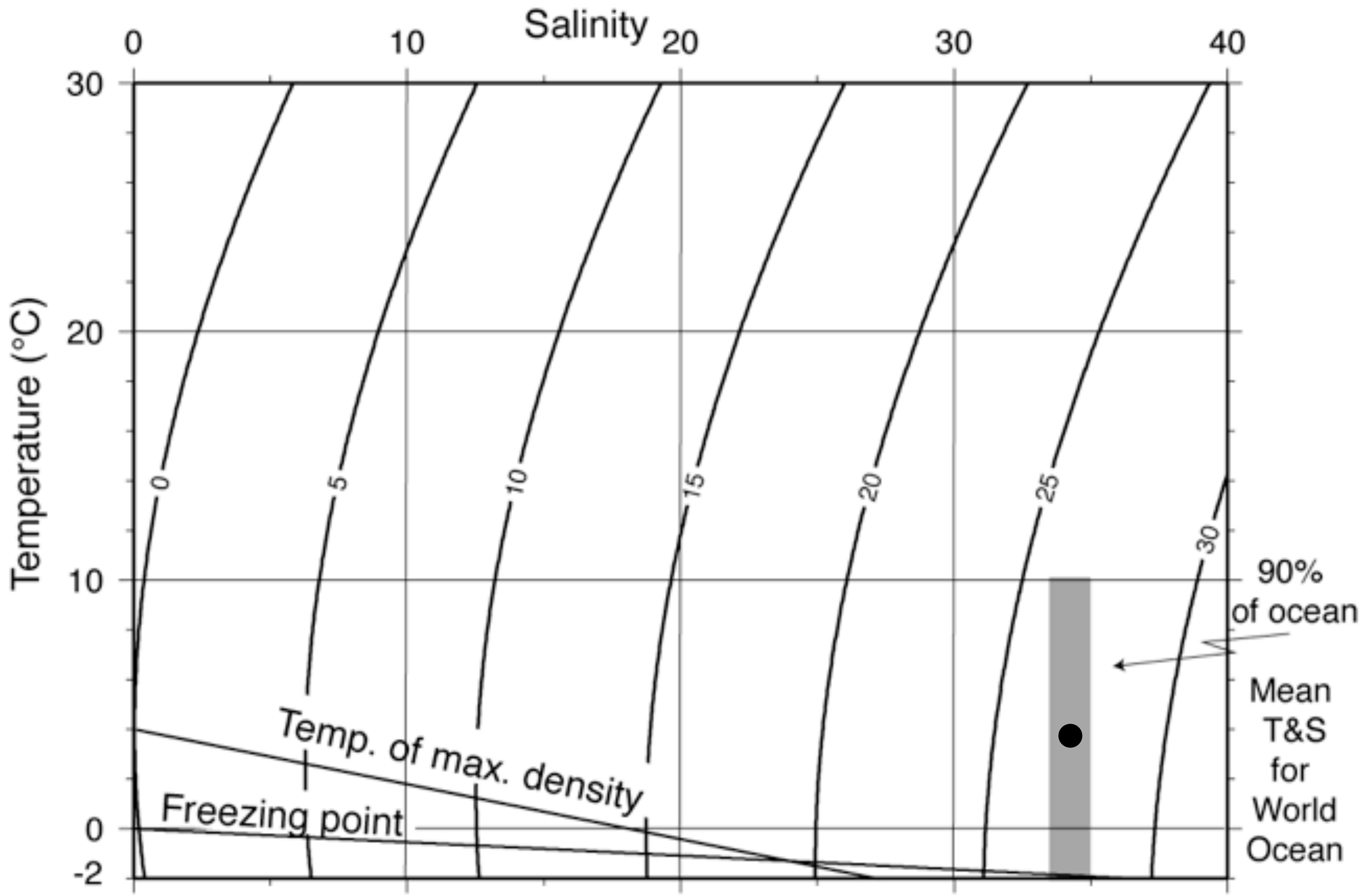


FIGURE 6.3 The relationship of density and temperature for pure water. Note that points C and D both represent 0°C (32°F) but different densities and thus different states of water. Ice floats because the density of ice is lower than the density of liquid water.

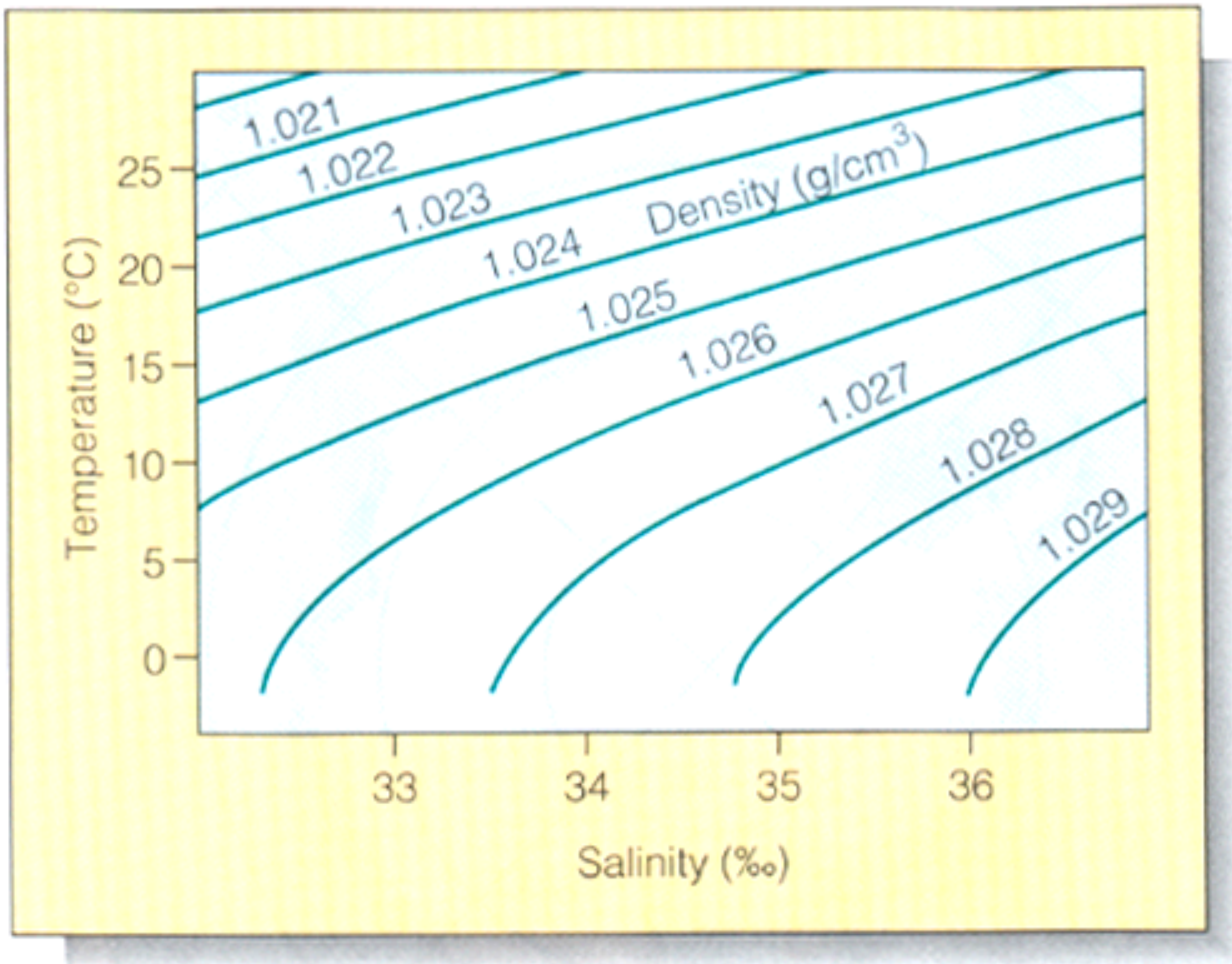
Add salt and the temperature-density relation changes



Salinity in the ocean typically varies from 0 parts per thousand (at river mouths) to 35-36 parts per thousand (in highly evaporative areas).


Salinity
0
10
20
30
40
30
20
10
0
-2
Temperature (°C)
0
5
10
15
20
25
30
Temp. of max. density
Freezing point
90%
of ocean
Mean
T&S
for
World
Ocean

Density is a function temperature, salinity (and pressure)



The colder and saltier the water, the greater the density.

Density is computed from T, S and P using the Equation of State

Different Density Variables (slightly confusing)

1. in situ

$$\rho = \rho(S,T,P)$$

$$\sigma = \rho(S,T,P) - 1000$$

true density

computed from equation of state

2. sigma-t

$$\sigma_t = \rho(S,T,0) - 1000$$

removes effects of high pressure squeezing

3. sigma-theta

$$\sigma_\theta = \rho(S,\theta,0) - 1000$$

removes effects of high pressure squeezing and warming due to ↑ pressure

Definition and units of pressure

Pressure = Force/Area, or $p = W / A$,

where the force is the weight, W, of a column of water. The weight is caused by the mass, M, attracted by the Earth's gravitational field:
$W = Mg$, where g is the acceleration of gravity (~9.8 m/s^2). This is an application of Newton's 2nd law: Force = *mass* x *acceleration*. Hence,

$$p = Mg / A \qquad (1)$$

The SI unit of pressure is the **pascal**, abbreviated as **Pa**: $Pa = N / m^2$,
where **N** is a **newton**, the SI unit of force. In the fundamental SI units of *kg*, *m*, and *s*, a newton is: $N = kg\ m / s^2$.

Pa are inconvenient to oceanography as units for pressure as a function of depth. The decibar (**db or dbar)** = 0.1 bar = 10^4 Pa is preferred by oceanographers, because pressure increases *approximately* 1 db with each meter of depth in the ocean.

The **bar** which is approximately equal to the atmospheric pressure at sea level.
A bar is defined as *1 bar* = 10^5 *Pa*.

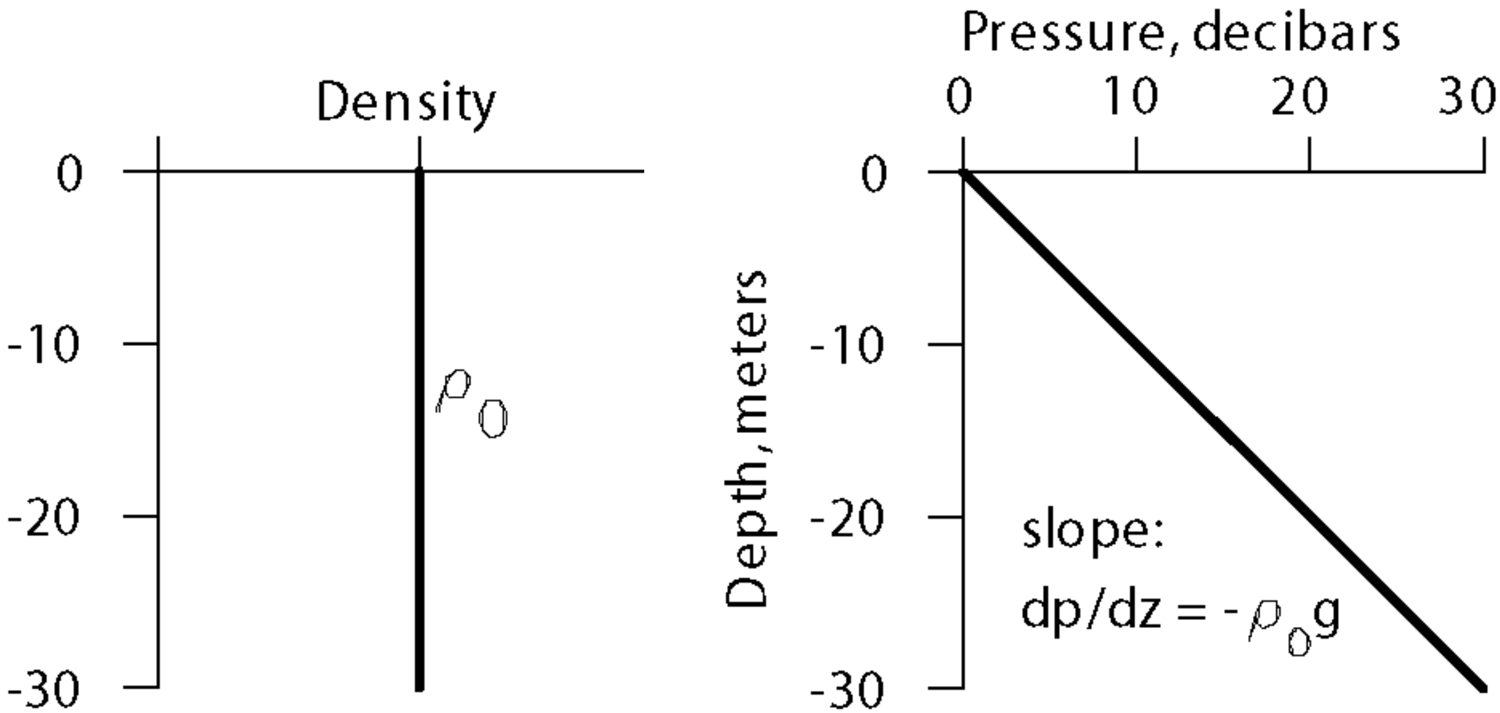
Density and Pressure in the Ocean

- The density and pressure are closely related:

$$\frac{\partial p}{\partial z} = -\rho g$$

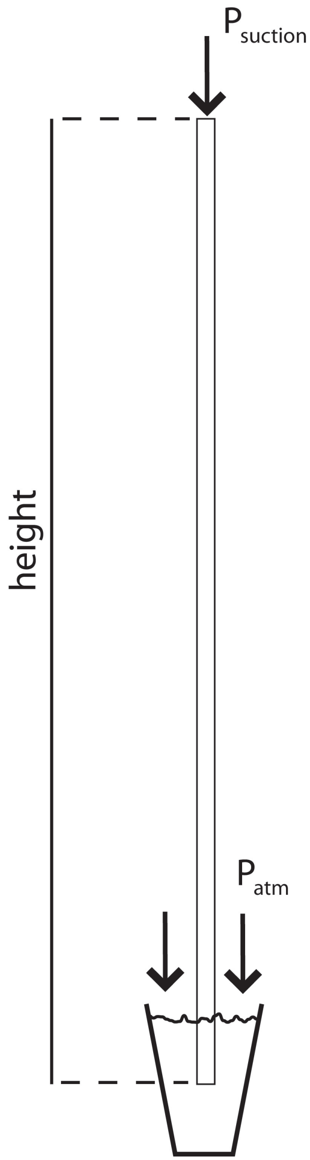
- If density remains constant, pressure P increases proportionally with depth. Ocean density varies by small values (about ±2%) (but these small variations are very important, as we will see later).
- Typical ρ is 1025 kg/m^3, and g is 9.8 m/s^2. Then each 1m depth adds about 10^4 N/m^2, or about 0.1 atmosphere (1 decibar or 1 db) of pressure. So each depth increase of 10m adds as much pressure as the weight of the entire atmosphere.

Pressure as a function of depth for a constant density



Here we have defined a coordinate system with z = 0 at the surface and z increasing upward. Hence z becomes more negative as depth increases.

What's the longest possible straw you can drink from?



$$\frac{\partial P}{\partial z} = -\rho g$$

$$\frac{P_{atm} - P_{suction}}{h} = \rho g$$

$$P_{atm} - P_{suction} = \rho g h$$

$P_{suction}$ = 0

P_{atm} = 1 bar = 10 dbar = ~10 m

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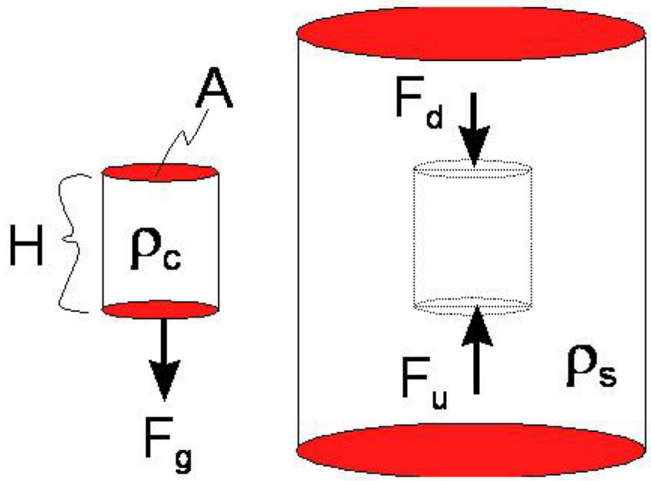
Archimedes' Principle:

The upward buoyant force acting on a submerged or floating object is equal to the weight of the water displaced.



$F_d = p_d A$

$F_b = F_u - F_d$

$= (\rho_s A H)g$

$F_u = p_d A + (\rho_s A H)g$

$F_g = \text{Mass} \times g = (\rho_c A H)\, g$

So, the **net force on the parcel** is:

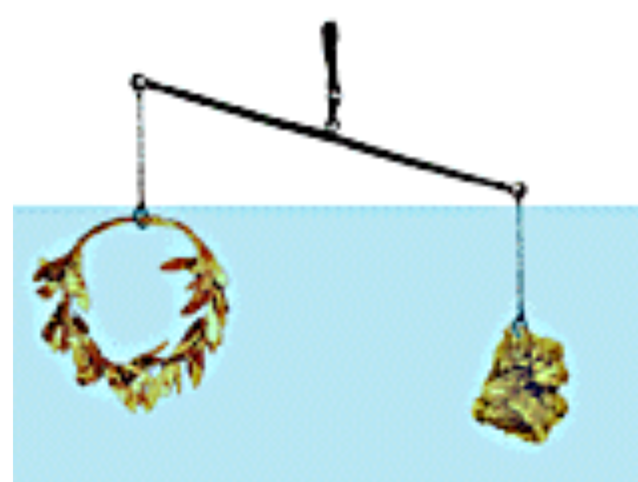
$F_{parcel} = F_b - F_g = (\rho_s - \rho_c) A H g$

What does this mean?
Dense water sinks and light water floats!

Archimedes’ Website

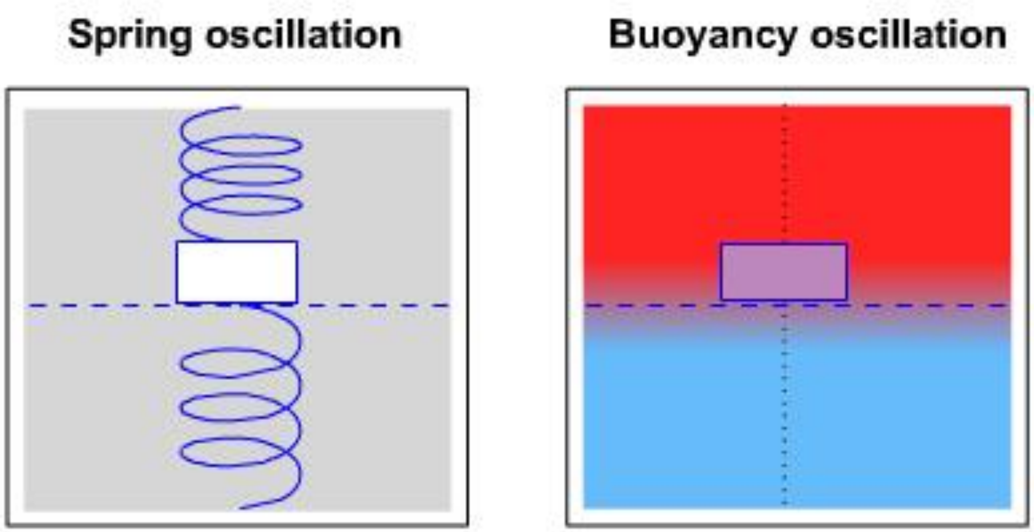
http://www.math.nyu.edu/~crorres/Archimedes/Crown/CrownIntro.html

Balanced in air



Unbalanced in water

Restoring process in stable air



The frequency, *N*, of the oscillator is given by

$$N^2 = \left[-\frac{1}{\rho_0} \frac{\partial \rho}{\partial z} \right] g \quad \left[\text{radians/s} \right]^2$$

Note: N often defined as s^{-1} (Hz) or cycles per hour (cph), linear units of frequency as well

N is known as the buoyancy, Väisälä, or Brünt-Väisälä frequency. The period of oscillation is given by

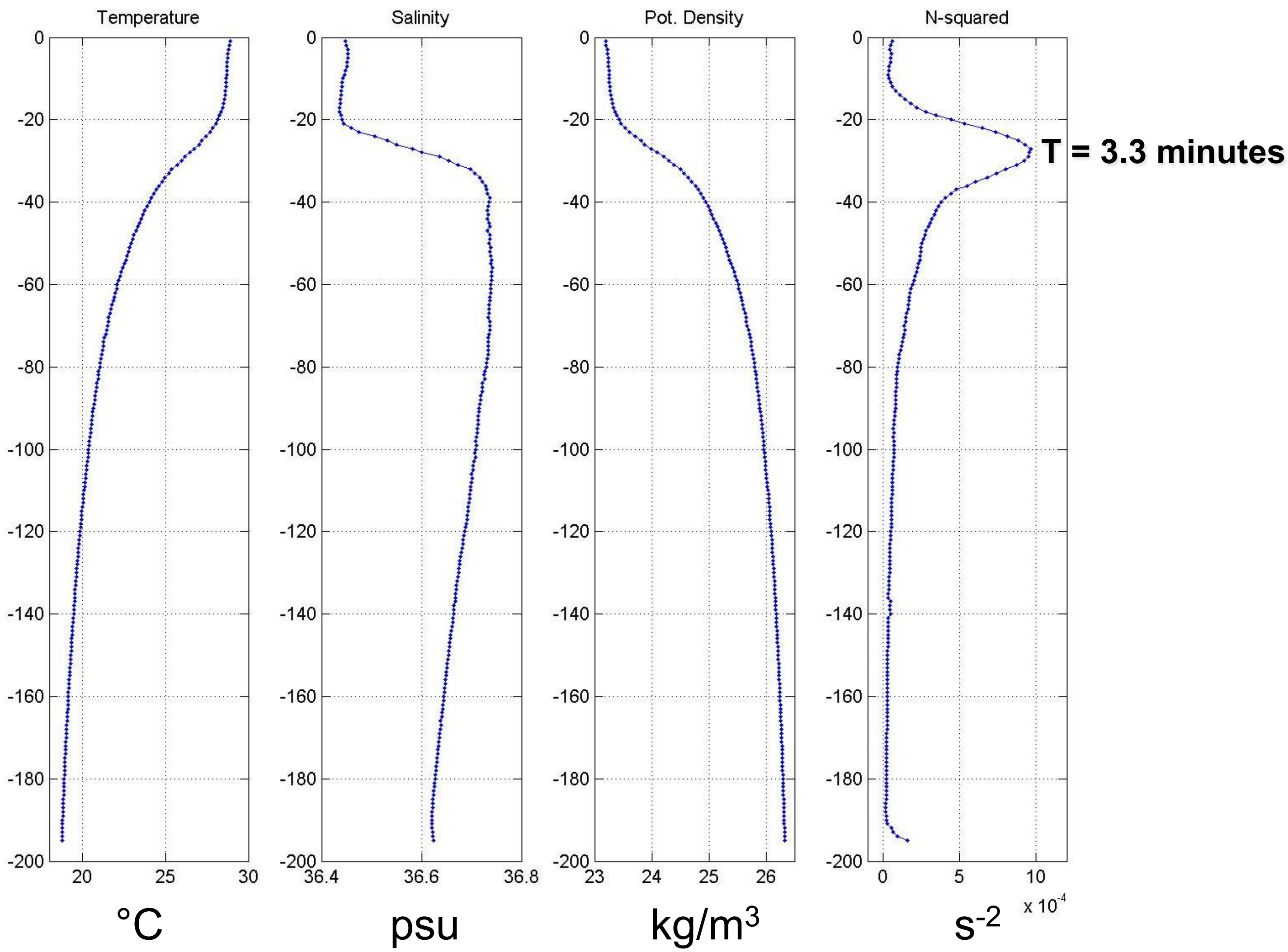
$$\tau = \frac{2\pi}{N} \quad [s]$$

A high *N* (short τ) indicates a strong restoring force and vice versa.

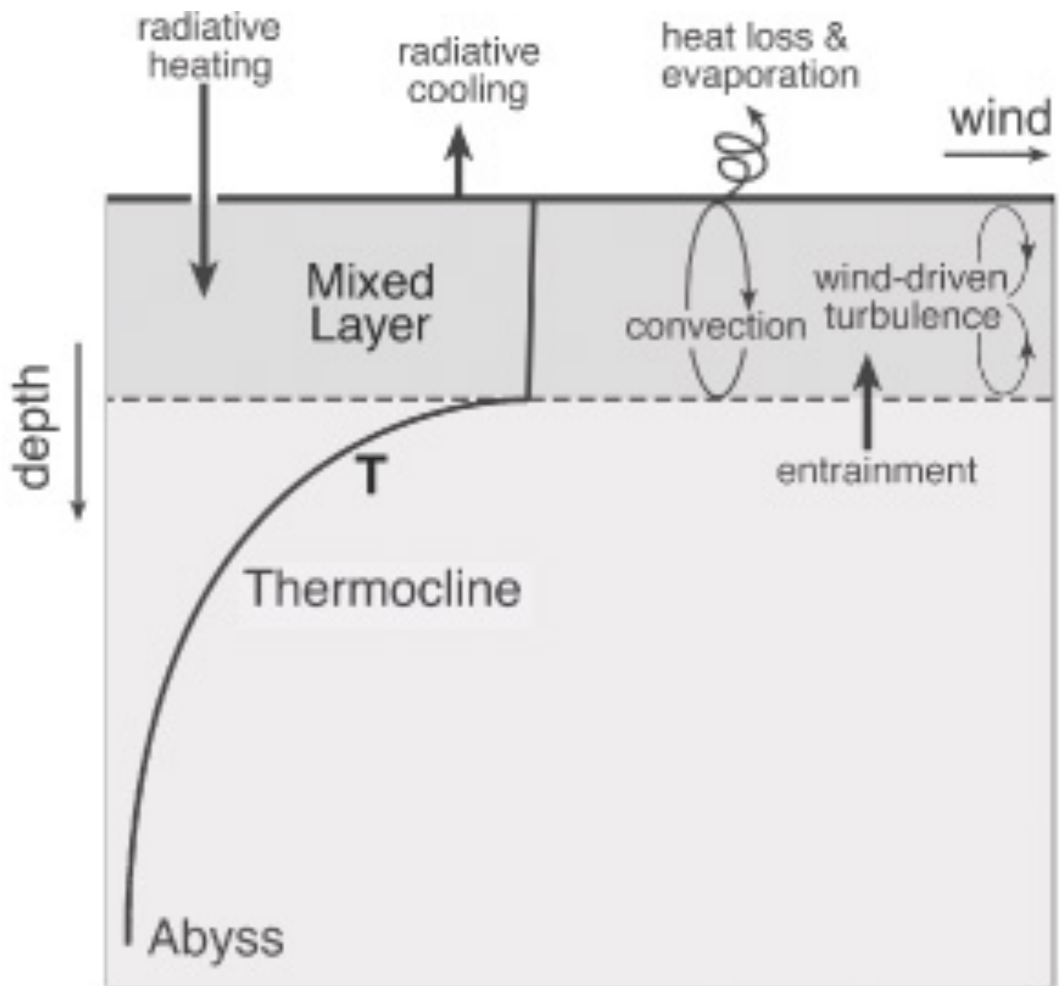
It is often reasonable to replace ρ by σ_t or σ_θ in the above expression, since water is nearly incompressible – not true for atmosphere.

See note on radial (angular) frequency http://en.wikipedia.org/wiki/Angular_frequency

Observed open ocean buoyancy frequency



Mixing is the natural enemy of stratification



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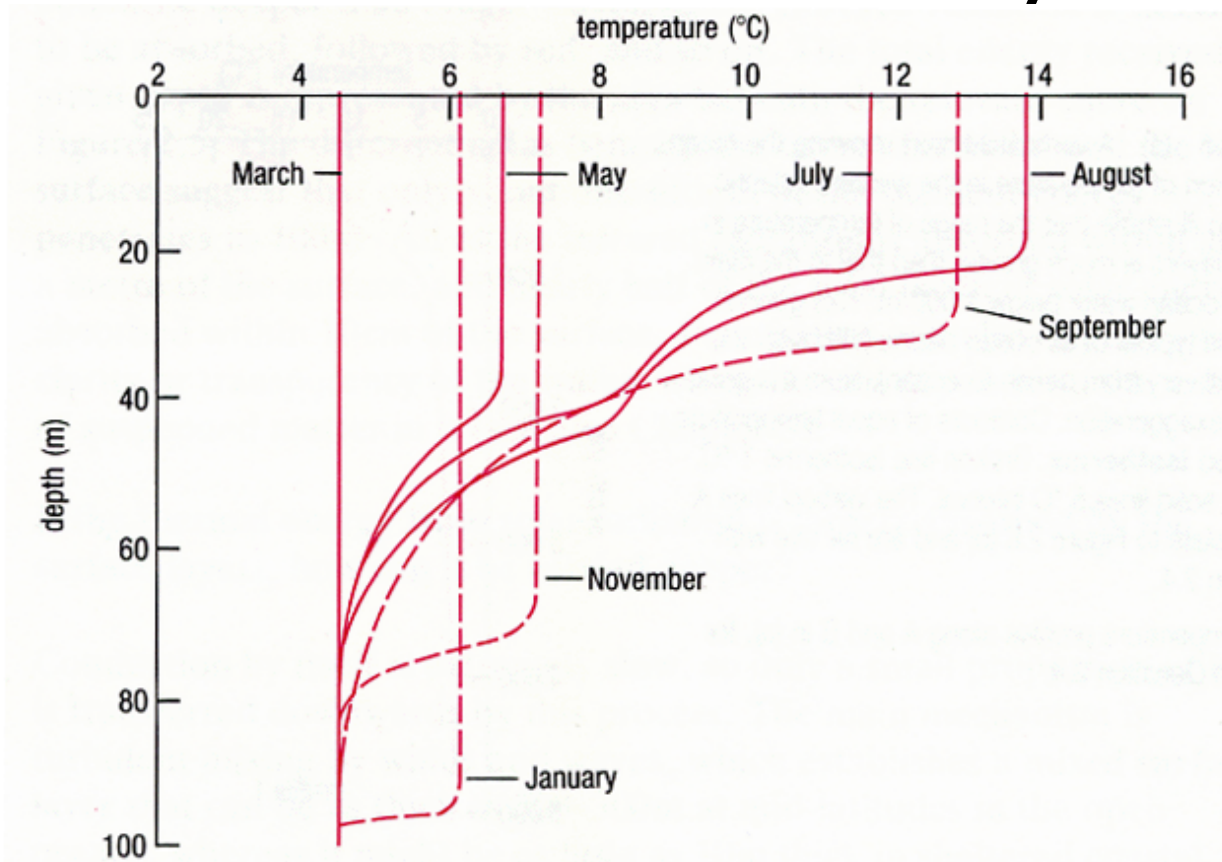
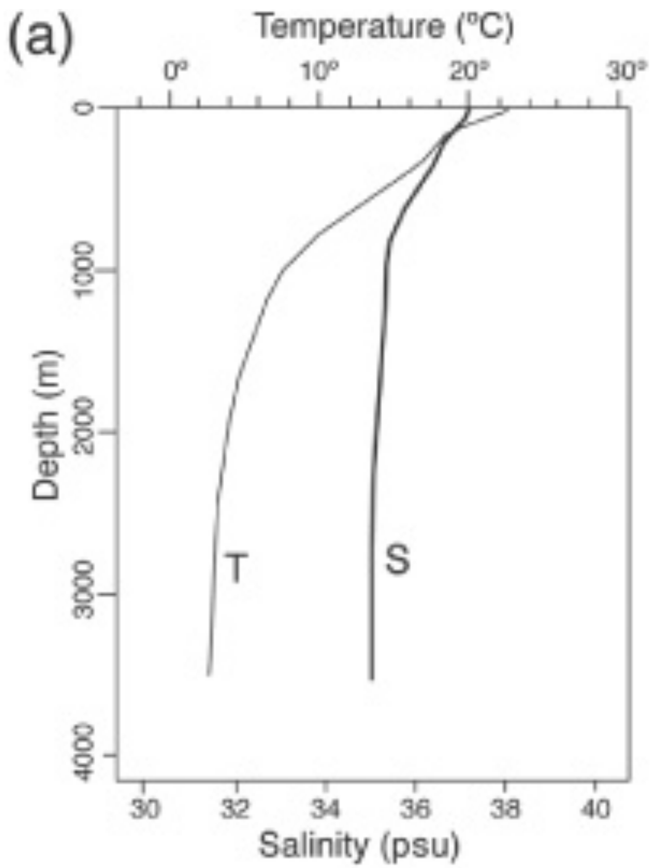
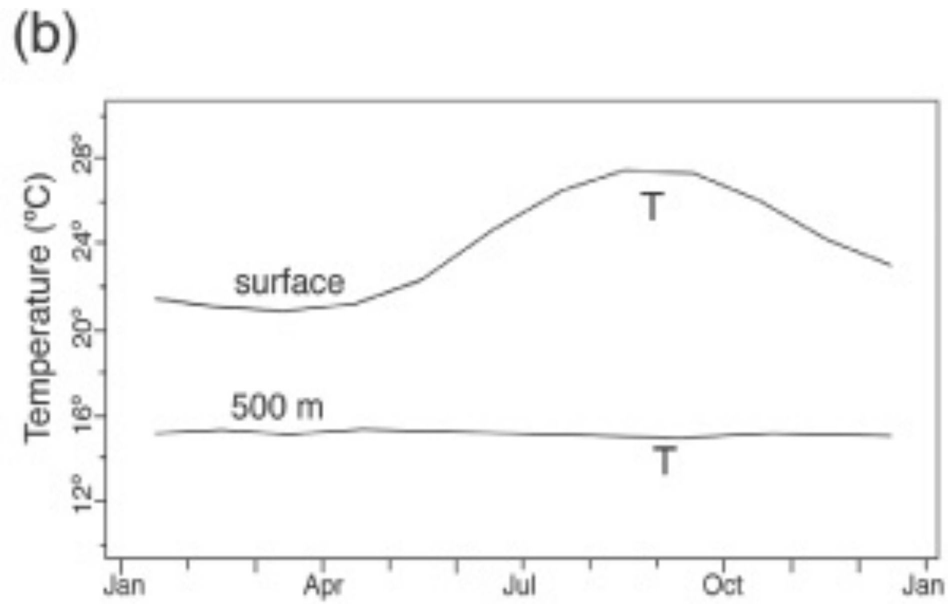
Surface Mixed Layer



Temperature vs. depth profiles at different times of year. Mixed layer is deepest at the end of winter storm season. As sun shines in May, develop warming in surface layer. Layer heats up through summer. New mixing in Sept. cools surface layer, warms deeper layer. Continues through Fall and Winter.



50° W, 30° W



50° W, 30° W

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