

# Water Properties and Seawater Constituents

ES 383

Colby at Bigelow, September 2018



# (Sea)Water is Amazing



## The “Goldilox” Zone



Credit: CBC

# Water has special properties that allow it to:

- Maintain a stable atmospheric climate
- Enable transport of molecules to and within organisms
- Be present in all three physical phases in earth's surface temperature range
- Ultimately produce ocean currents

Location	Percentage of Total $1.4 \times 10^9 \text{ km}^3$
Oceans	97.2
Freshwater	
Ice caps and glaciers	2.38
Surface waters (lakes, rivers, streams)	0.022
Air and soil moisture	0.001
Groundwater	0.40
Total freshwater	2.8



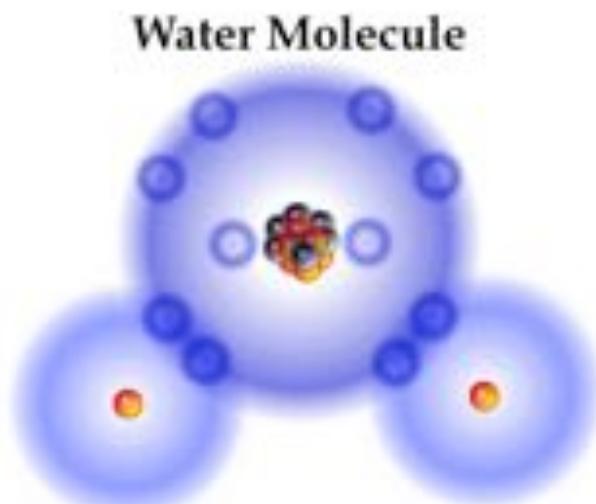
# Properties: structure of the molecule

## Review of atoms:

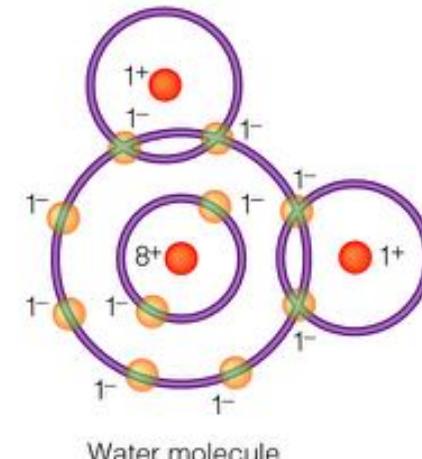
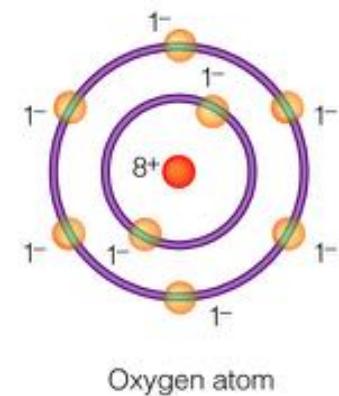
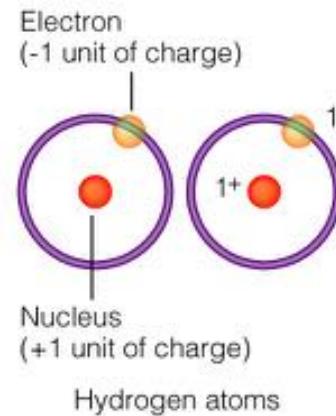
electrons –  
protons +  
neutrons 0

## Covalent Bonds

- strongest bonds
- shared electrons to fill shells
- water has 2 covalent bonds



*Water molecule like a magnet*



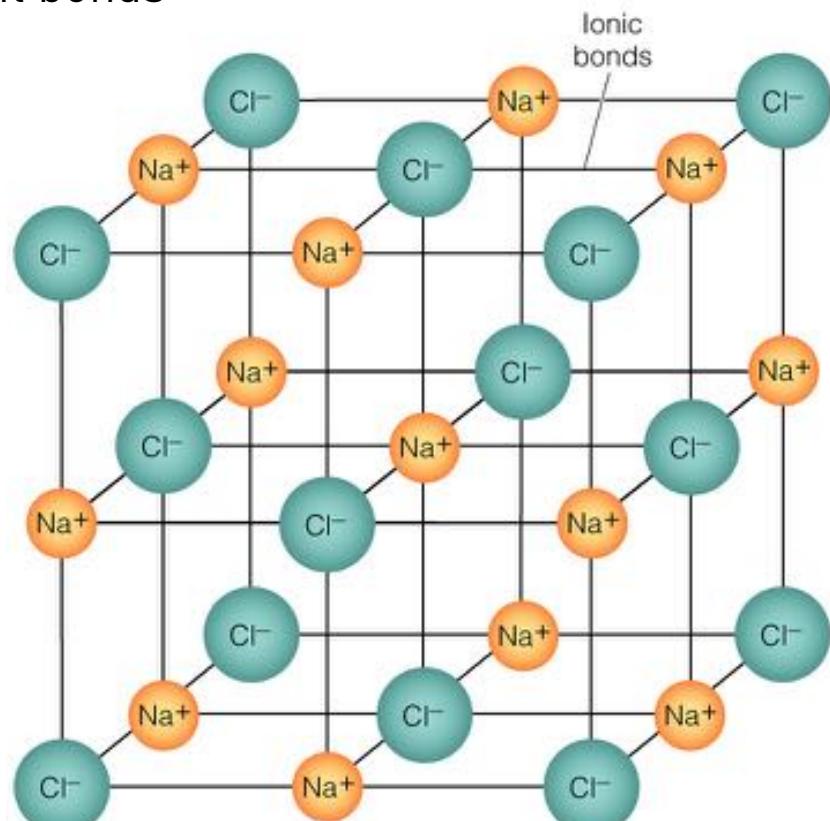
(a)



# Properties: structure of the molecule

## Ionic Bond

- atoms with extra or missing electrons
- electrostatically attracted
- ~10 times weaker than covalent bonds



# Properties: structure of the molecule

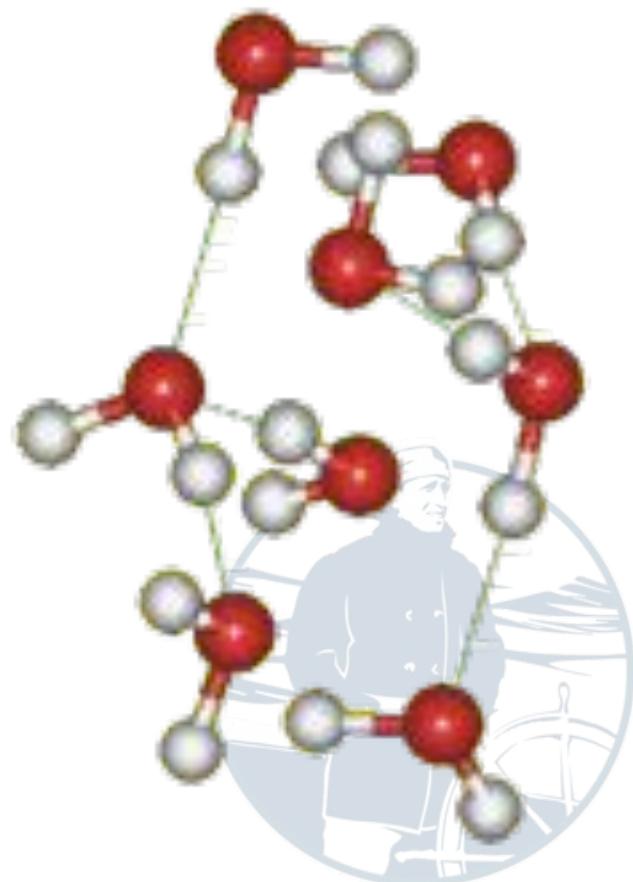
## Hydrogen Bond

- attractive force between the negatively charged side of one water molecule and the positively charged side of another water molecule  
~ 100 times weaker than covalent bonds



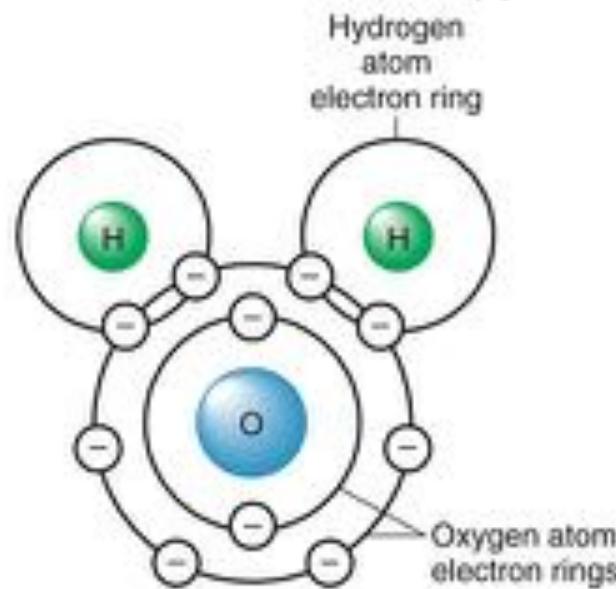
*Water molecule like a magnet:*

- it's polar
- it can join with 4 others

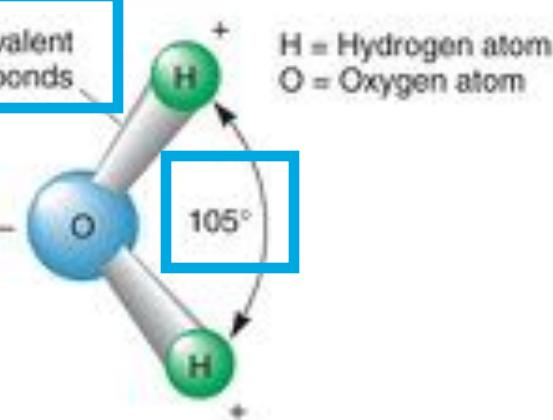


## Neutral but polar

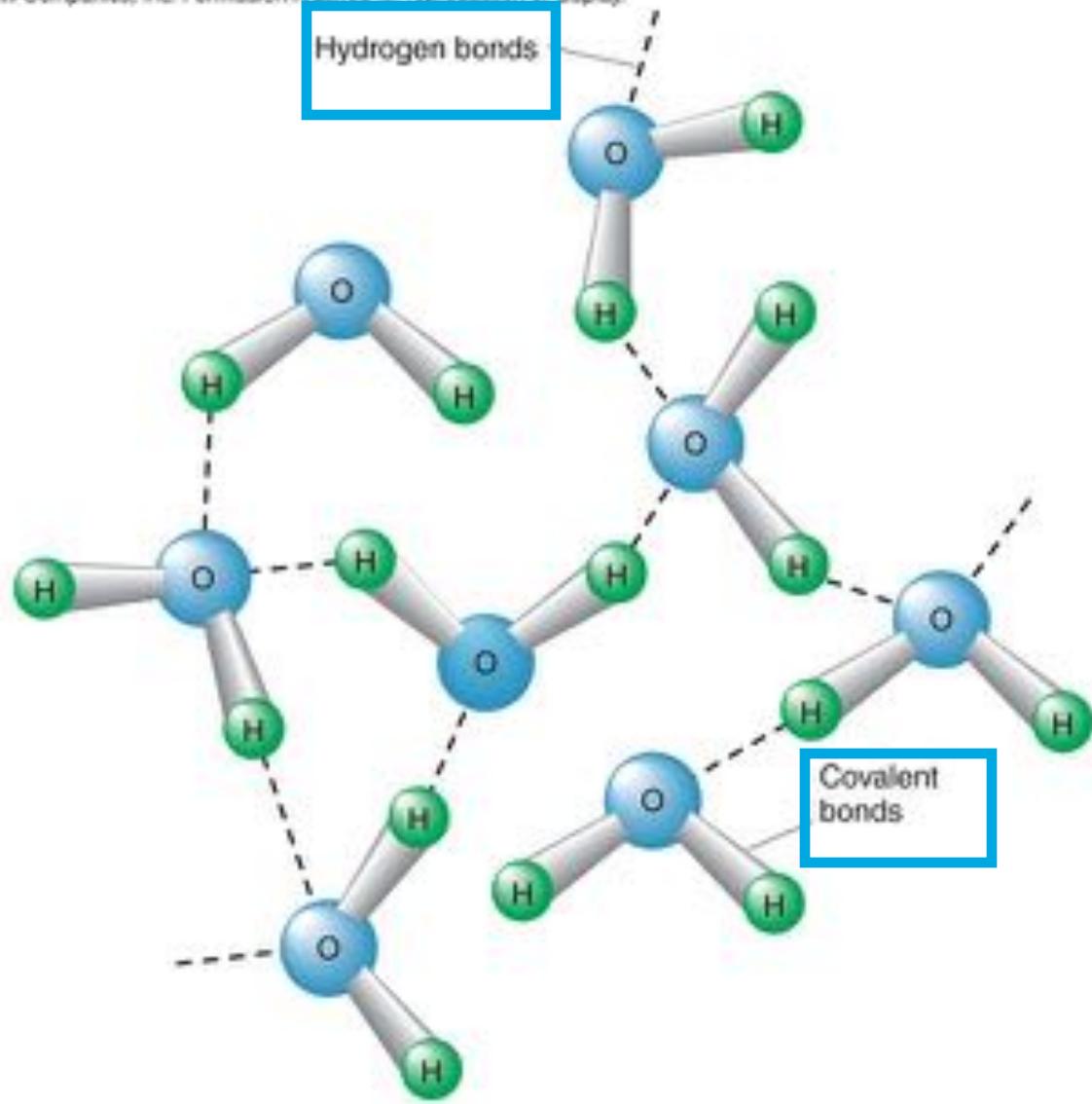
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(a)



(b)



(c)



# Dissolving Power

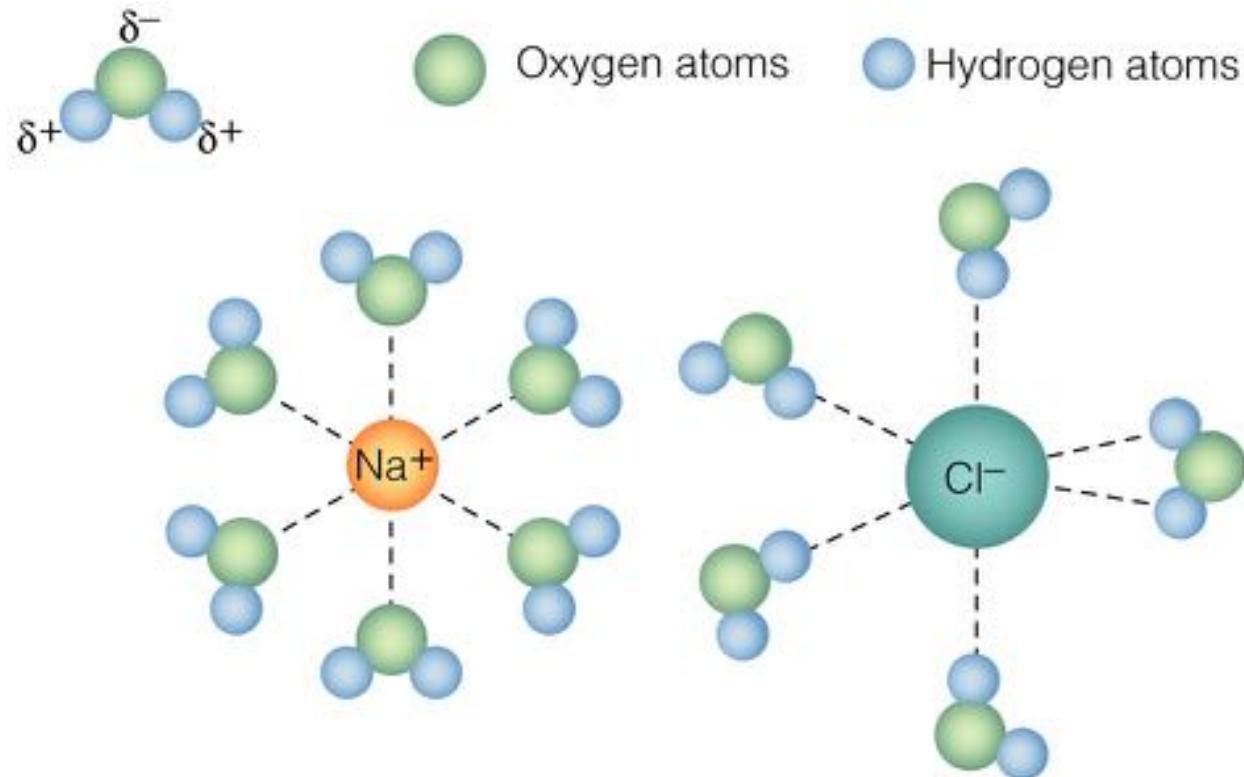
Can dissolve more substances / greater quantities than any other liquid

Hydration – ion surrounded by water molecules

→ Weathering of rocks

    → Sedimentation

→ Facilitates chemical reactions necessary for life



# Thermal expansion

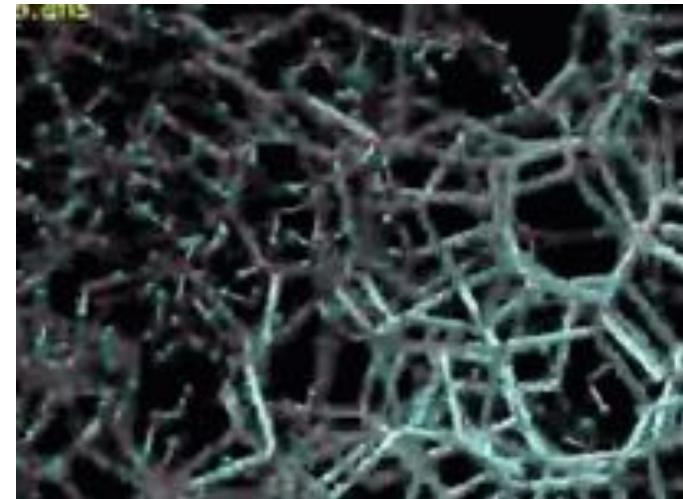
Most substances get denser as they cool  
So does water, down to about 4 °C  
Then it starts to become less dense

<http://www.youtube.com/watch?v=gmjLXrMaFTg>

<http://www.youtube.com/watch?v=RIW65QLWsxE>

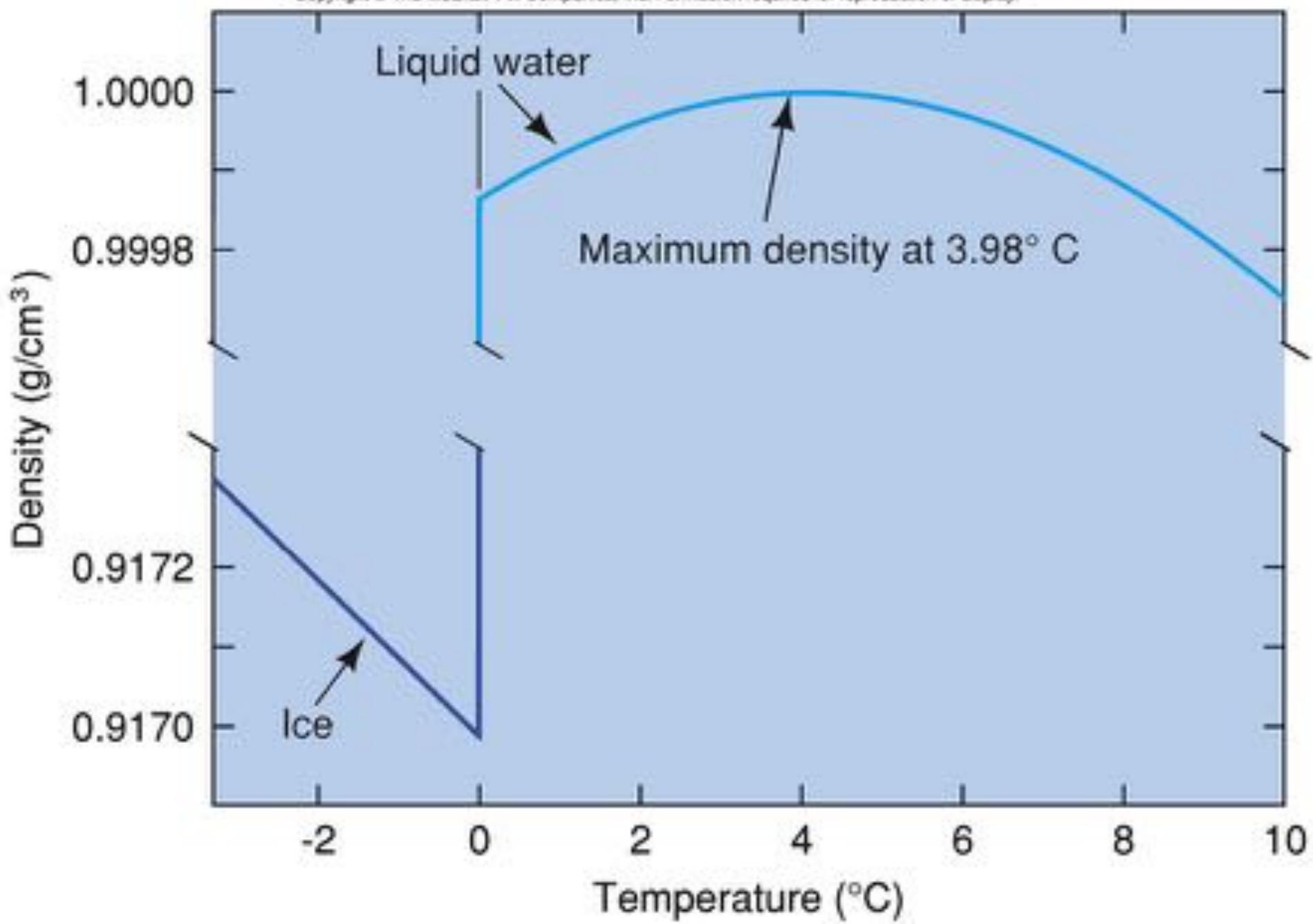
<http://www.youtube.com/watch?v=PcoiLASUvqc>

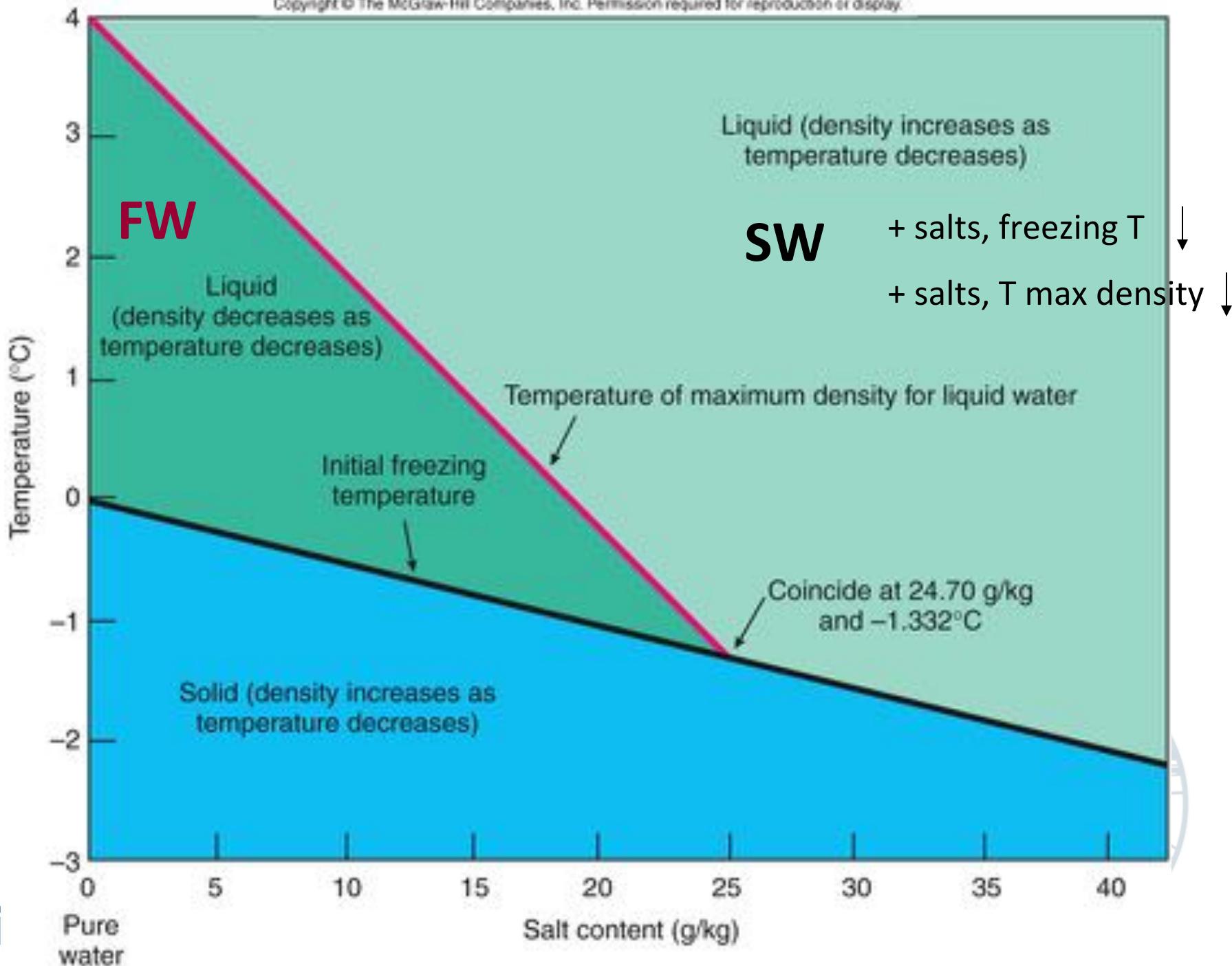
<http://www.youtube.com/watch?v=Vlqgih0Rpag>



- Allows water to stay unfrozen under ice
- Produces global thermo-haline circulation  
(dominant circulation pattern in oceans)





**Bi**

# Heat Capacity

- Amount of heat required to increase temperature
- Very high in water
- It takes roughly 100 times as much heat to warm water 1 degree, as compared to air

→ Oceans absorb and “buffer” atmospheric temperature changes

Note: Specific heat = heat capacity of a material / heat capacity of water

Material	Heat Capacity (calories/g/°C)
Acetone	0.51
Aluminum	0.22
Ammonia	1.13
Copper	0.09
Grain alcohol	0.23
Lead	0.03
Mercury	0.03
Silver	0.06
Water	1.00

# Surface Tension

Very high compared to other liquids

Allows droplets to form in the atmosphere → precipitation

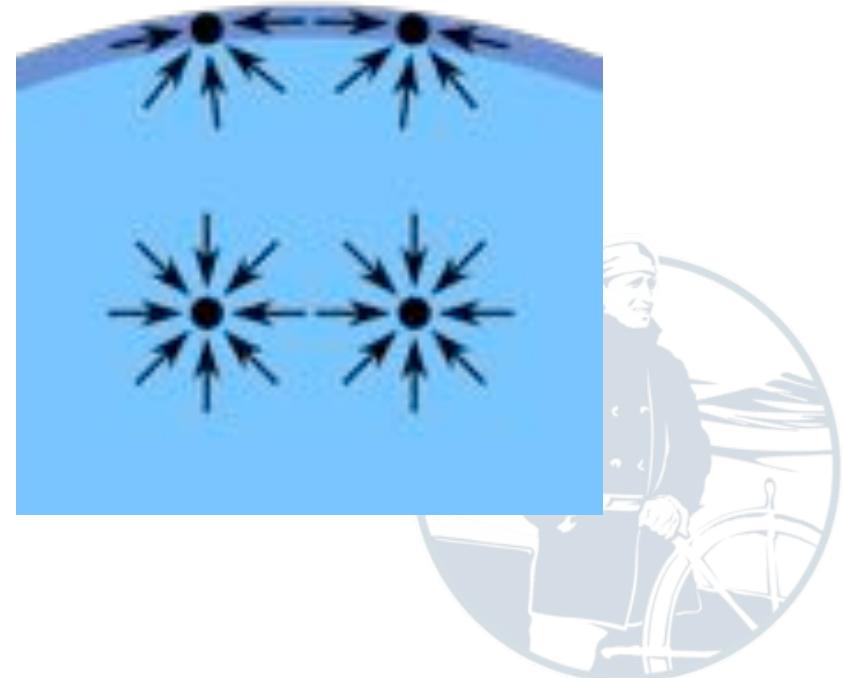
Allows bubbles to form in the water

Determines many wave and surface properties

Water + salt: surface tension up

Water + T : surface tension down

Water - T : surface tension up



# Viscosity

Water has a low viscosity

Water + salt: viscosity up (small amount)

Poles

Water + T : viscosity down

Poles

Water - T : viscosity up

Tropics



# Summary

Properties are a result of its molecular structure:  $\text{H}_2\text{O}$

- Covalent bonds => link 3 atoms; 2 e- are shared
- Polar molecule => unequal spatial distribution of charges
- Hydrogen bonds => ea.  $\text{H}_2\text{O}$  molecule can join w/ 4 others

Changes of physical state:

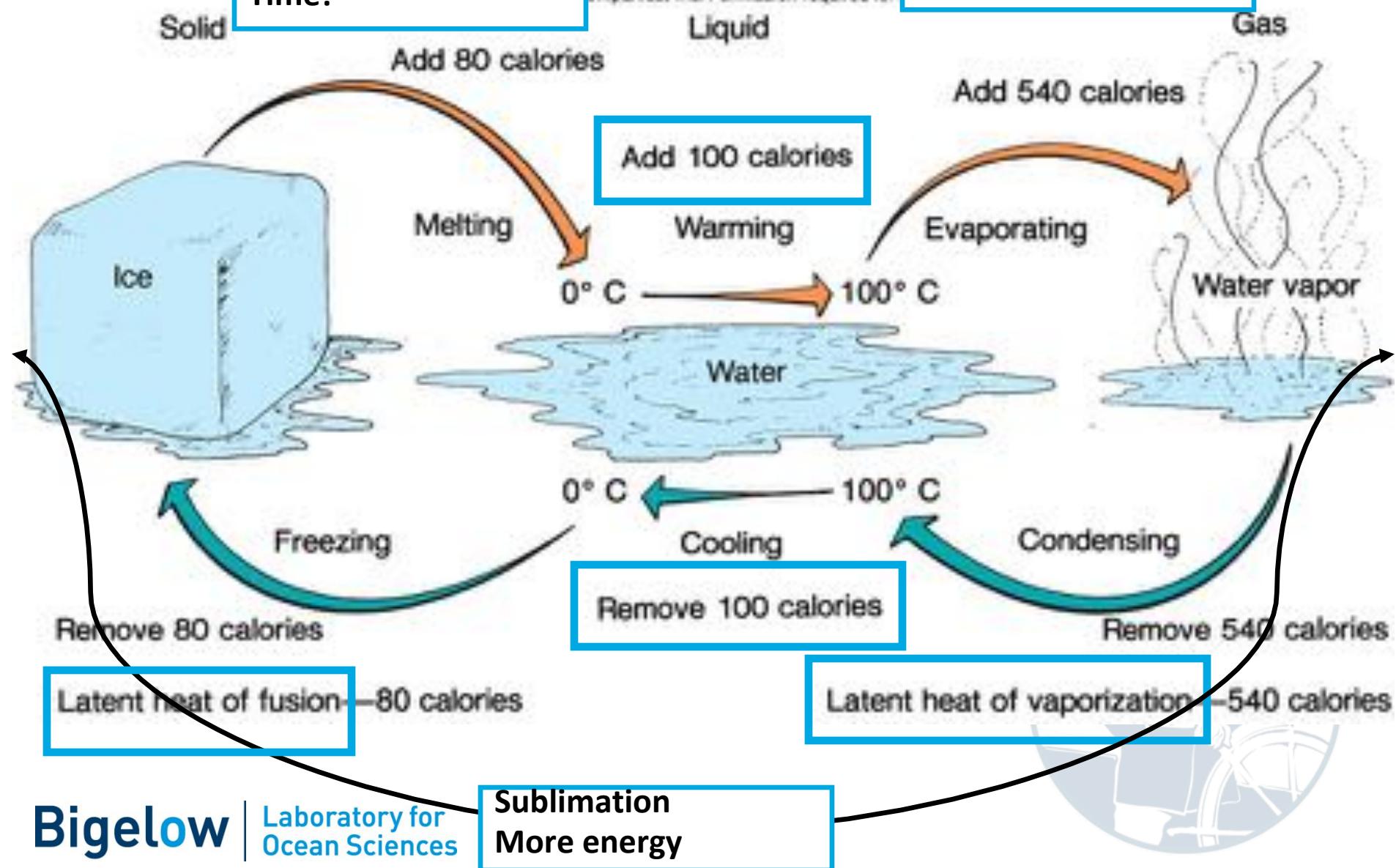
- Solid or ice (less dense); liquid or water; gas or vapor (moisture, humidity)
- pure water = fresh water w/o suspended particles, dissolved substances or gases
- energy required to break H-bonds to form water and vapor => 1 calorie = amount of heat needed to raise temperature of 1g water by 1°C



**0°C**  
**No change in temp.**  
**Time!**

# For 1 g H<sub>2</sub>O

**100°C**  
**No change in temp.**  
**Time!**



## HEAT

Energy in a material  
Depends on mass  
J or cal  
Cannot be measured directly

vs

## TEMPERATURE

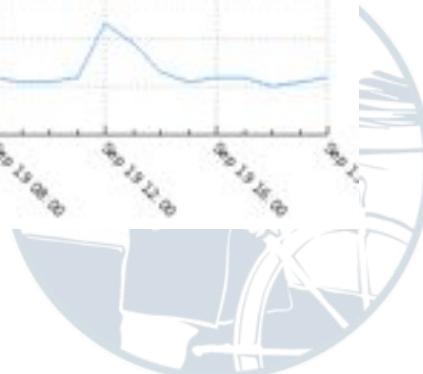
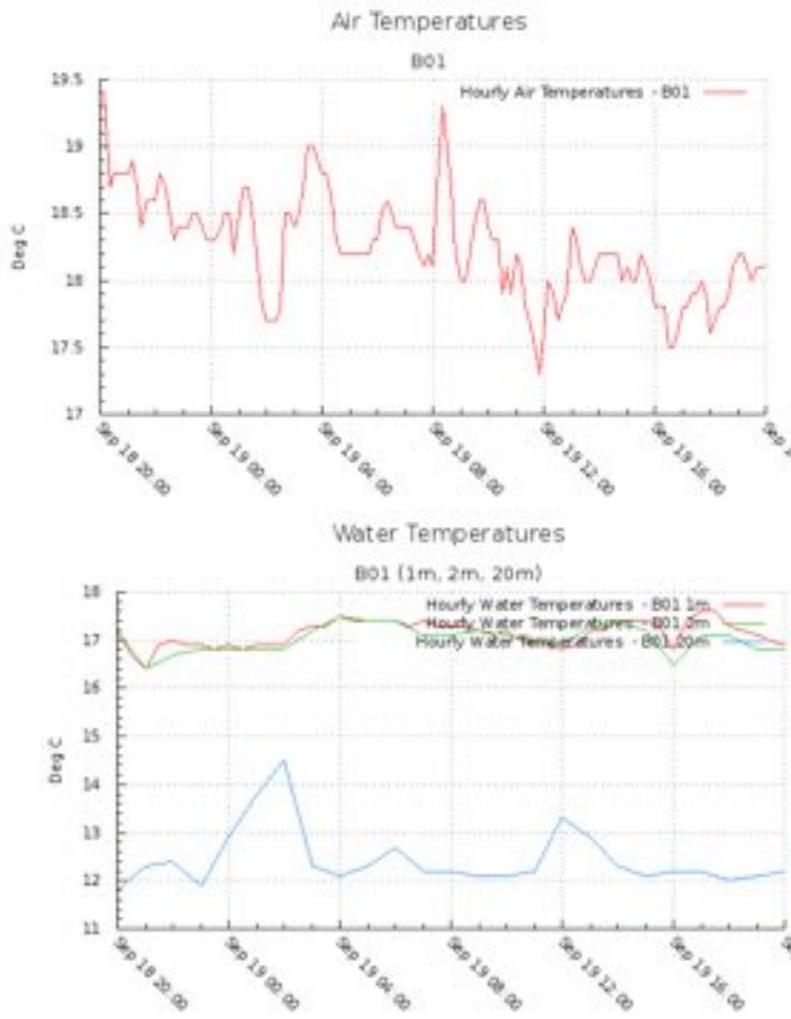
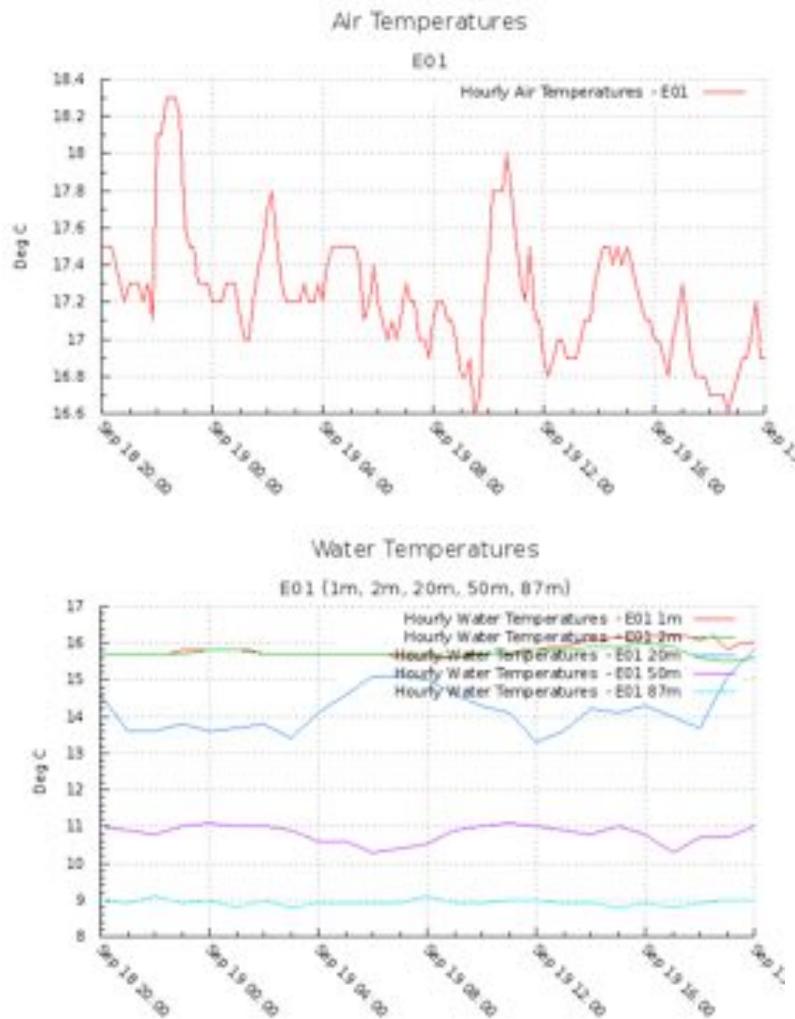
Not a measure of energy  
Does not depend on mass  
Degrees C, K, or F  
Can be measured directly

Heat energy can induce a change in temperature or a phase transformation

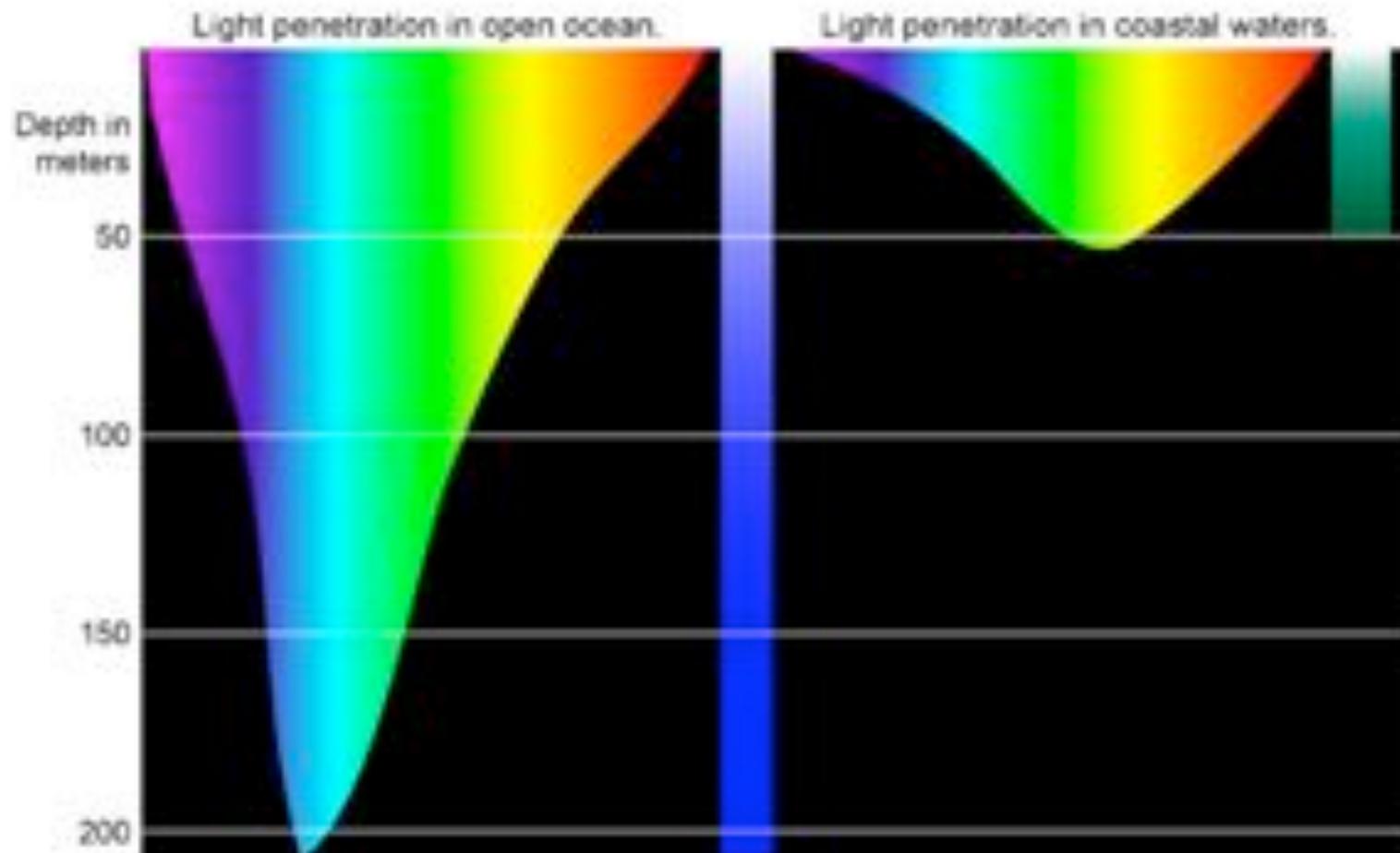
Temperature indicates the direction heat energy will flow.



## Temperature fluctuations very different between land and ocean

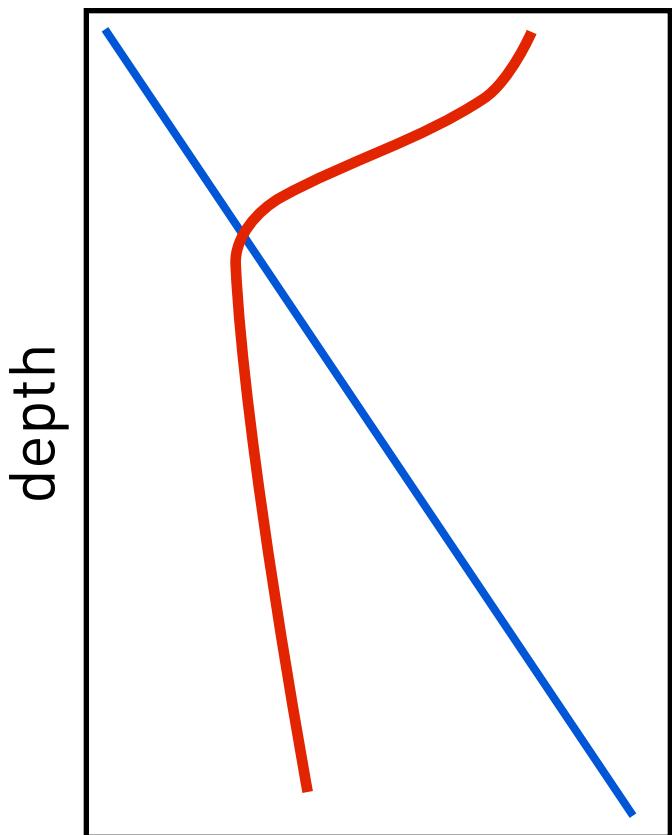


# Other properties of water: light



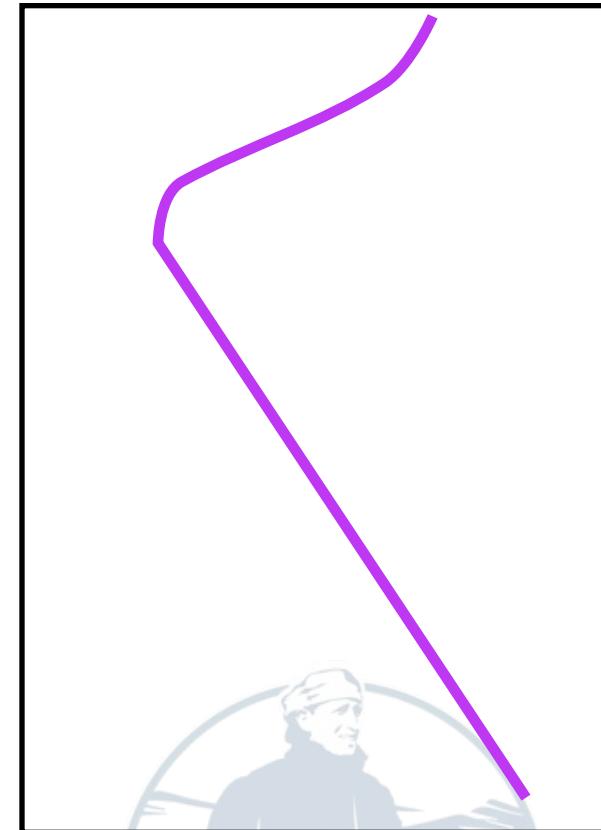
Big

# Other properties of water: sound

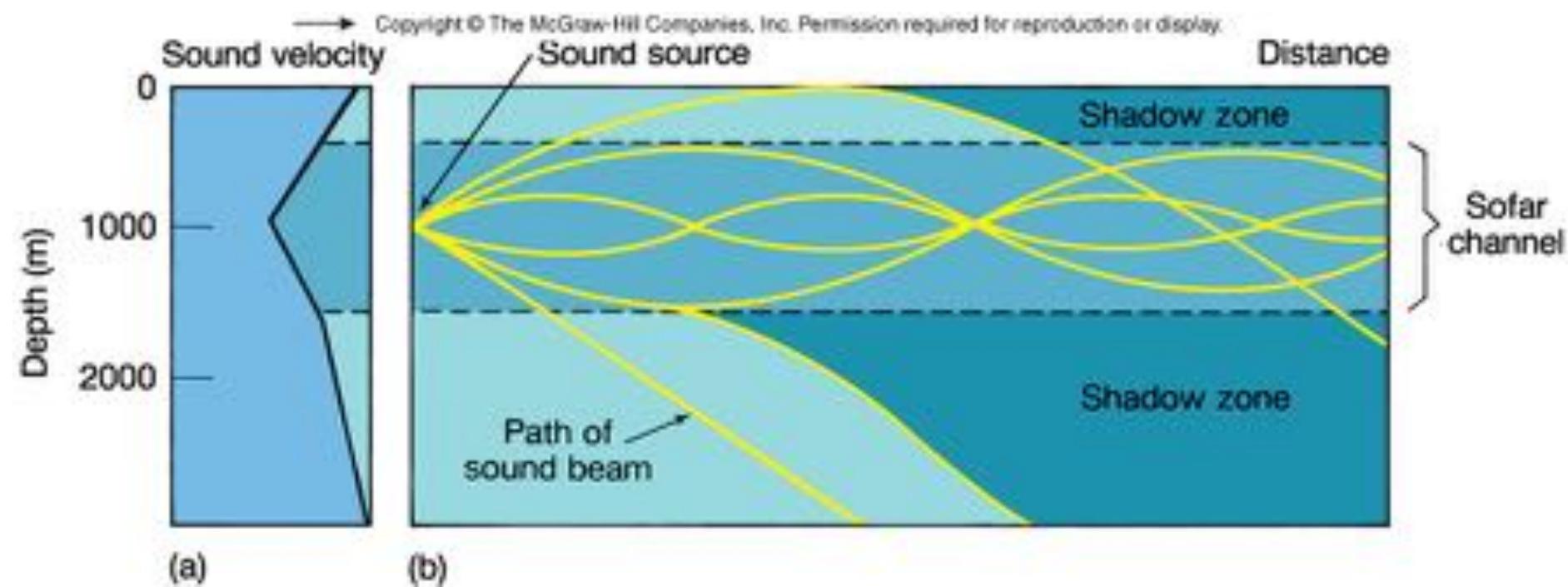


Sound speed  
increases w/ temp

Sound speed  
increases w/  
pressure



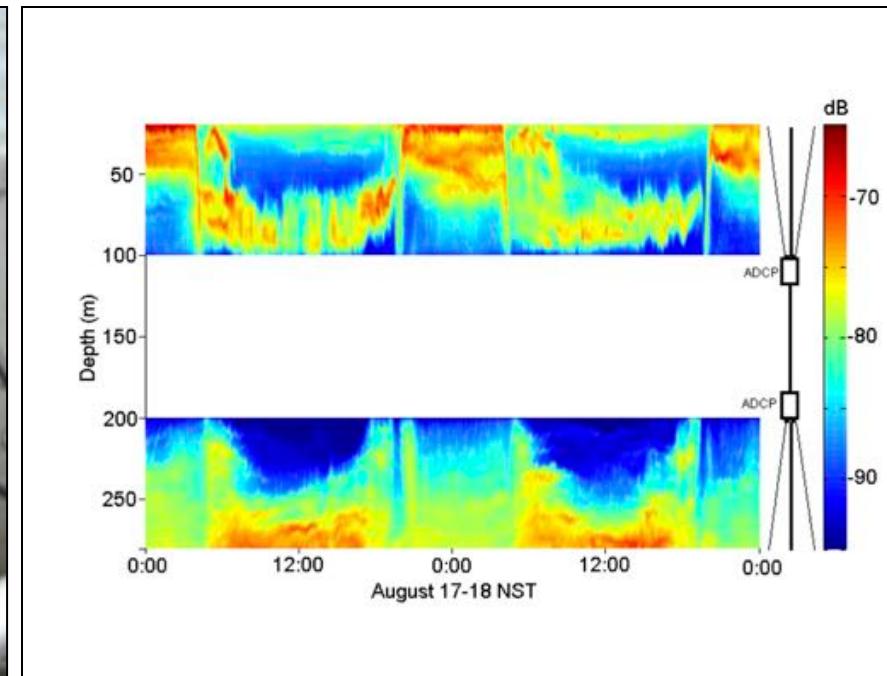
# Other properties of water: sound



# Other properties of water: sound

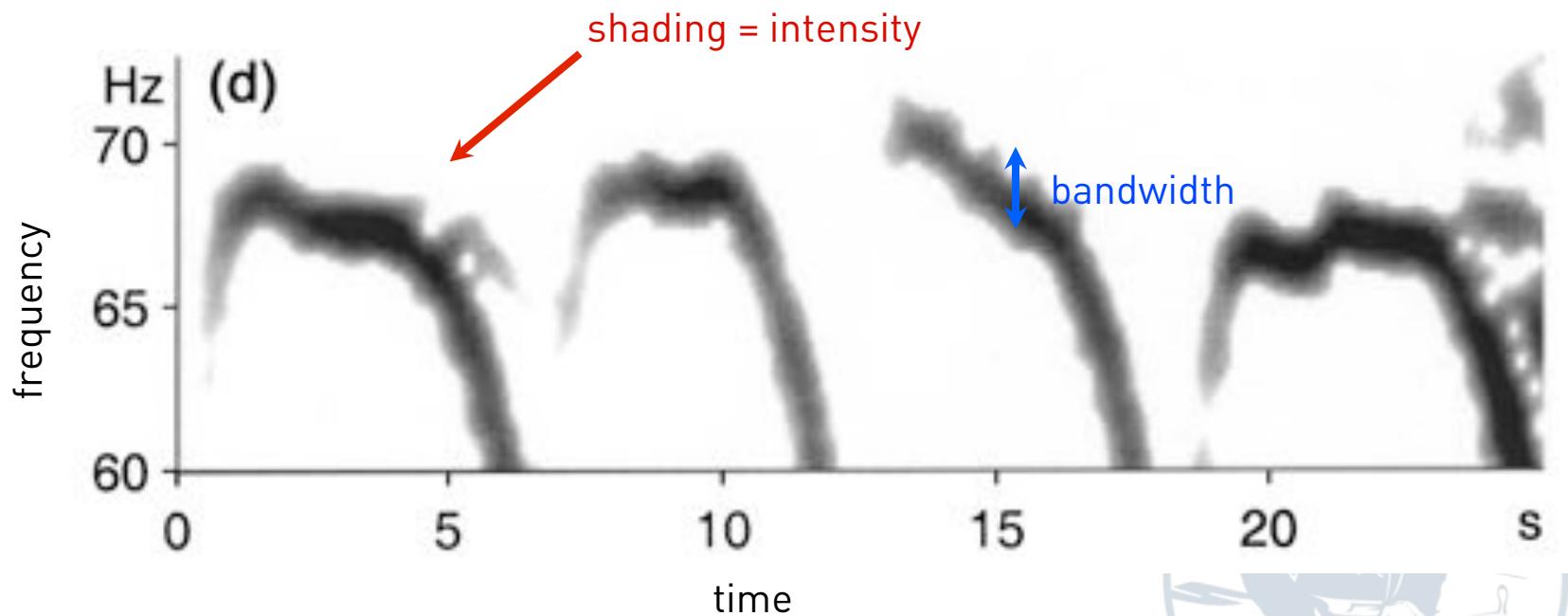


Human Echolocation



# Other properties of water: sound

- Passive acoustics monitor & track whales
- Noise pollution affects whale communication



blue whale from Mellinger & Clark (2003)

**Table 4.1** Properties of Water

Definition	Comparison	Effects
<b>Physical States</b> Gas, liquid, solid Addition or loss of heat breaks or forms bonds between molecules to change from one state to another.	The only substance that occurs naturally in three states on the Earth's surface.	Important for the hydrologic cycle and the transfer of heat between the oceans and atmosphere.
<b>Heat Capacity</b> One calorie per gram of water per °C.	Highest of all common solids and liquids.	Prevents large variations of surface temperature in the oceans and atmosphere.
<b>Surface Tension</b> Elastic property of water surface.	Highest of all common liquids.	Important in cell physiology, water surface processes, and drop formation.
<b>Latent Heat of Fusion</b> Heat required to change a unit mass from a solid to a liquid without changing temperature.	Highest of all common liquids and most solids.	Results in the release of heat during freezing and the absorption of heat during melting. Moderates temperature of polar seas.
<b>Latent Heat of Vaporization</b> Heat required to change a unit mass from a liquid to a gas without changing temperature.	Highest of all common substances.	Results in the release of heat during condensation and the absorption of heat during vaporization. Important in controlling sea surface temperature and the transfer of heat to air.
<b>Compressibility</b> Average pressure on total ocean volume 200 atmospheres; ocean depth decreased by 37 m (121 ft).	Seawater is only slightly compressible, $4-4.6 \times 10^{-9} \text{ cm}^2/\text{g}$ for an increase of 1 atmosphere of pressure.	Density changes only slightly with pressure. Sinking water can warm slightly due to its compressibility.
<b>Density</b> Mass per unit volume: grams per cubic centimeter, g/cm <sup>3</sup> .	Density of seawater is controlled by temperature, salinity, and pressure.	Controls the ocean's vertical circulation and layering. Affects ocean temperature distribution.

<b>Viscosity</b> Liquid property that resists flow; internal friction of a fluid.	Decreases with increasing temperature. Salt and pressure have little effect. Water has a low viscosity.	Some motions of water are considered friction free. Low friction dampens motion; retards sinking rate of single-celled organisms.
<b>Dissolving Ability</b> Dissolves solids, gases, and liquids.	Dissolves more substances than any other solvent.	Determines the physical and chemical properties of seawater and the biological processes of life forms.
<b>Heat Transmission</b> Heat energy transmitted by conduction, convection, and radiation.	Molecular conduction slow; convection effective. Transparency to light allows radiant energy to penetrate seawater.	Affects density; related to vertical circulation and layering.
<b>Light Transparency</b> Transmits light energy.	Relatively transparent for visible wavelength light.	Allows plant life to grow in the upper layer of the sea.
<b>Sound Transmission</b> Transmits sound waves.	Transmits sound very well compared to other fluids and gases.	Used to determine water depth and to locate targets.
<b>Refraction</b> The bending of light and sound waves by density changes that affect the speed of light and sound.	Refraction increases with increasing salt content and decreases with increasing temperature.	Makes objects appear displaced when viewed by light and sound.

From Fundamentals of Oceanography, 4th edition, Duxbury, Duxbury, and Swerdrup. Copyright 2000 The McGraw-Hill Companies. All rights reserved.



# Sea Water Constituents



# Salinity

The amount of dissolved salts in seawater

Mix of types of salts:

90% NaCl

9% MgSO<sub>4</sub>

Ca

K

Traditionally measured in grams-of-salt per kilogram-of-water:

35 g of salt in 1 kg of water = 35‰

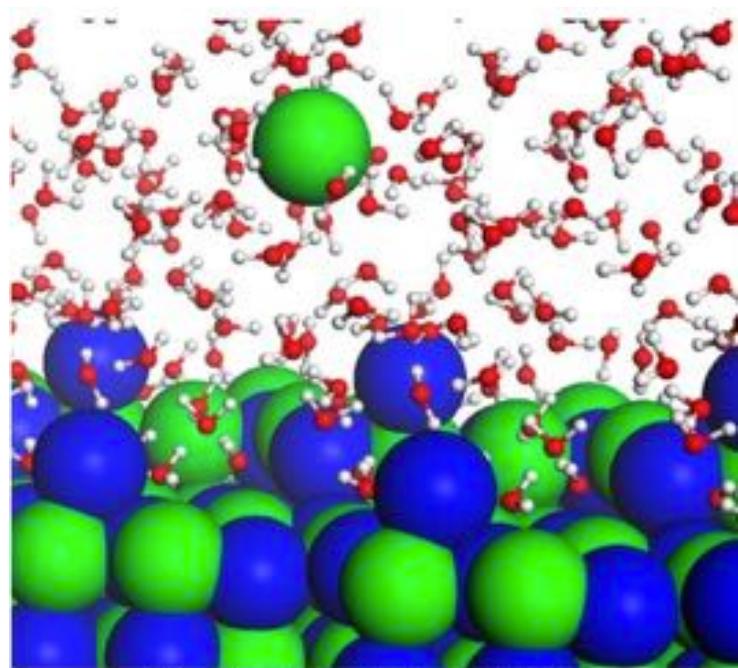
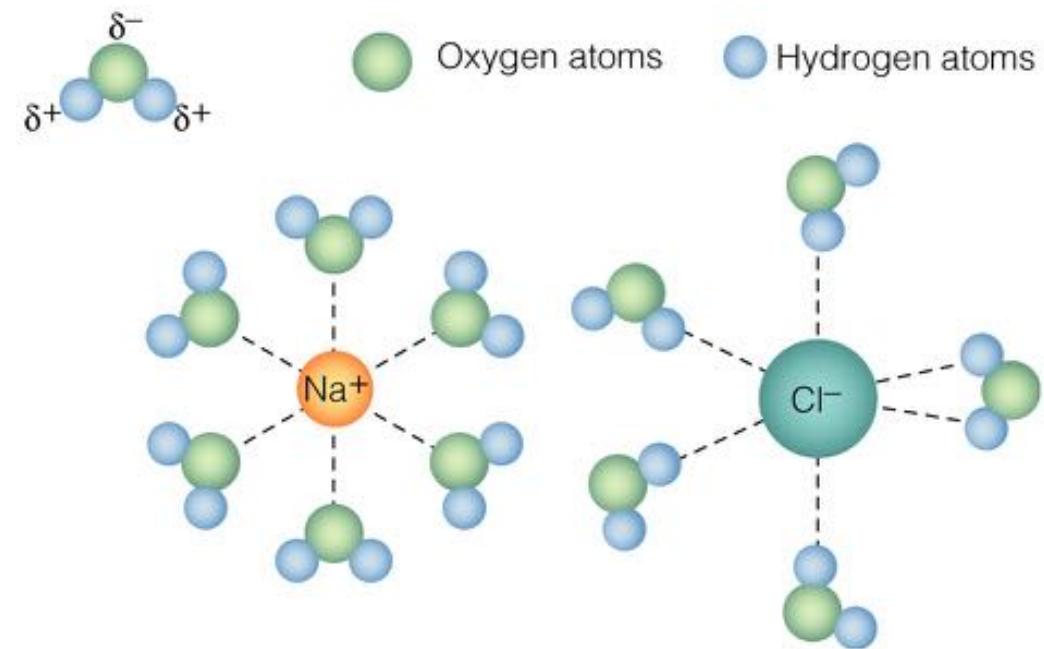
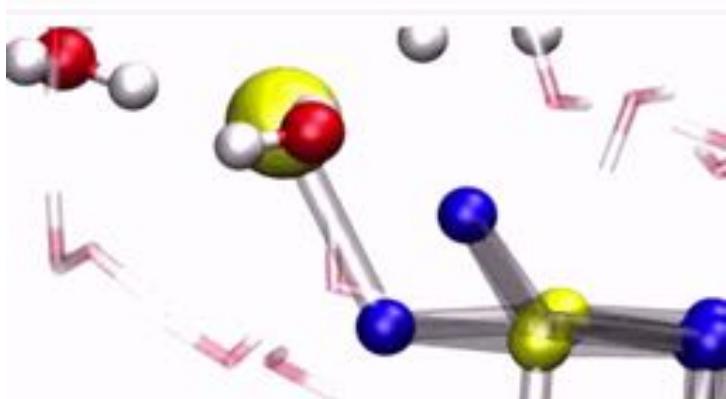
Now measured using electrical conductivity

35 PSU



# Salinity

These elements easily form ions  
→ salt is dissolved



Water dissolving salt, Liu and Michaelides, London  
Centre for Nanotechnology, UCL,  
<http://www.ucl.ac.uk/news/ucl-views/0803/salt500>

# Salinity

Salinity has a major effect on density

Density has a major effect on currents

→ Try to measure salinity to  $\pm 0.001$

Ice less dense  
→ Floats

→ Salinity concentrated



# Seawater: other constituents

## Minor constituents:

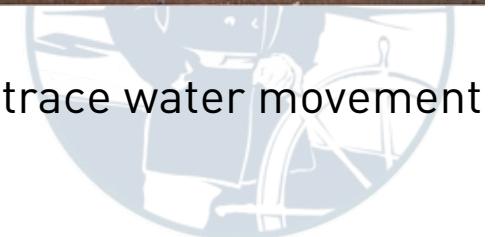
- Bromine
- Carbon
- Strontium
- Boron
- Silicon
- Fluorine
- 1-100 parts per million

## Trace elements:

- All other elements
- less than 1 part per million
- Some are important (Fe = nutrient, Hg = toxin)

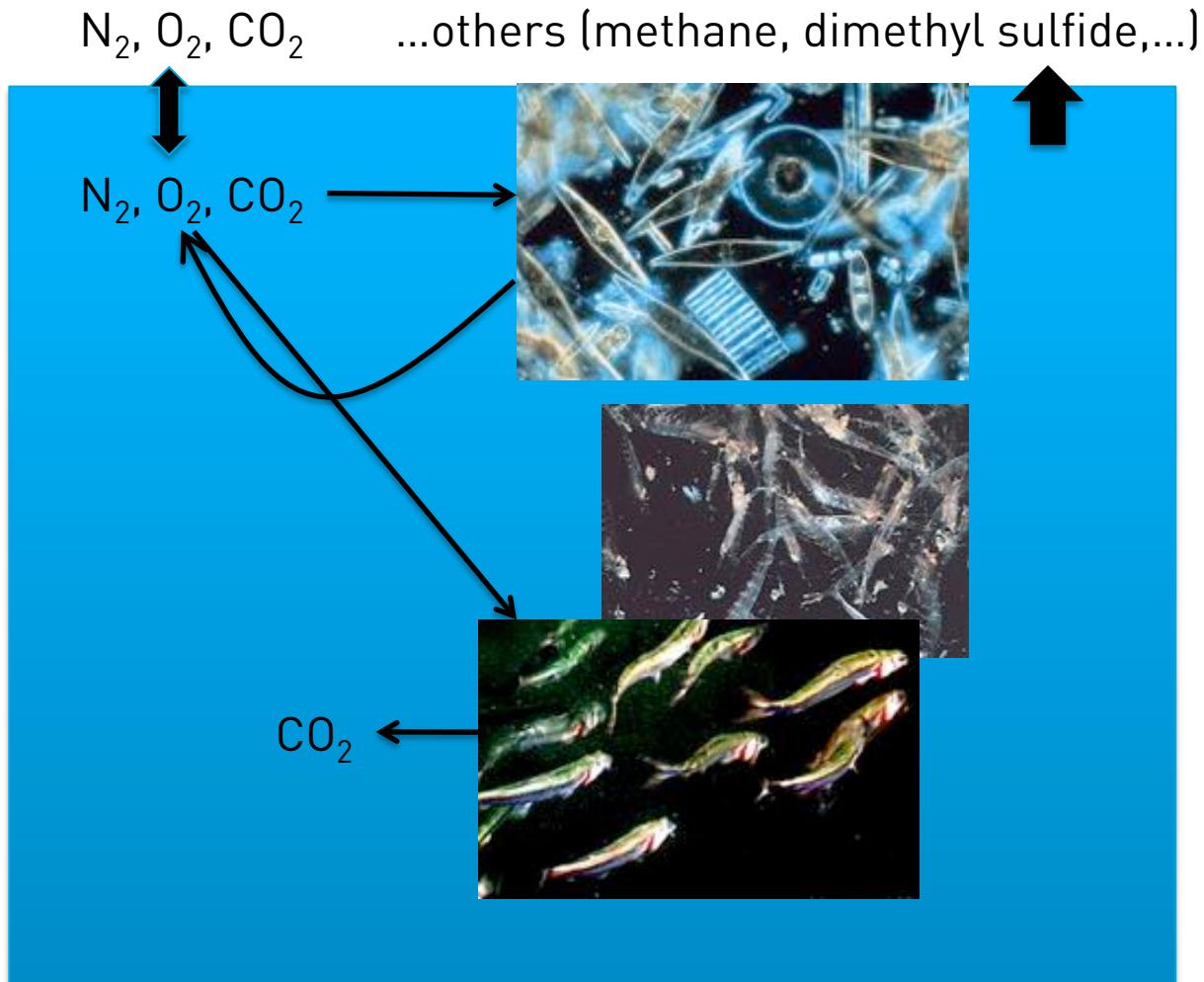
## Radionuclides:

- Most are natural
- Tritium from nuclear testing (1950-1962) can be used to trace water movement



# Seawater: other constituents

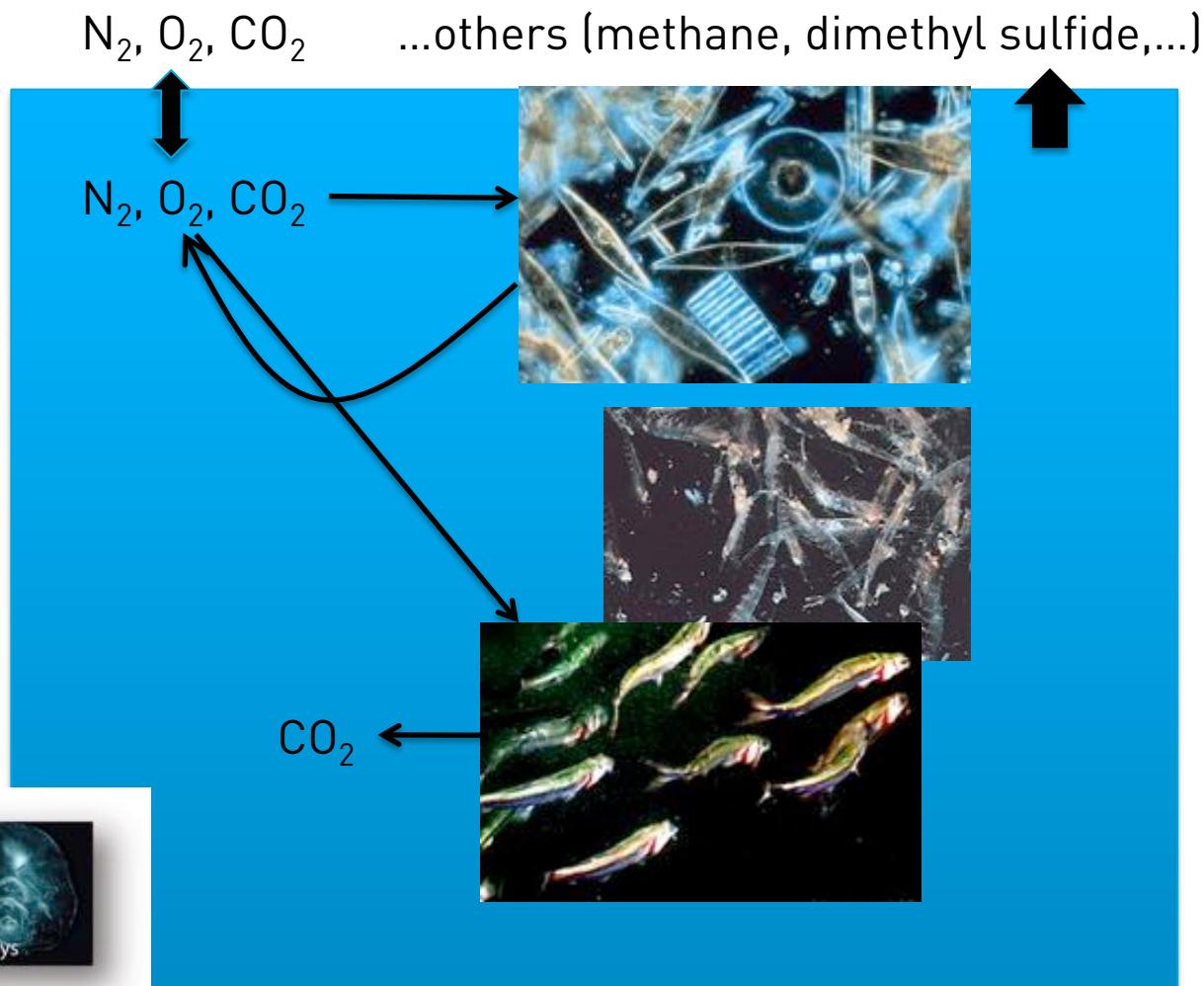
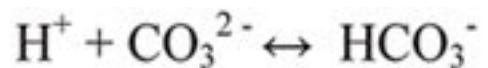
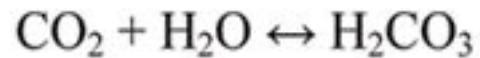
- Dissolved Gasses
- Hydrogen ions ( $H^+$ )  
i.e. pH



# Seawater: other constituents

- Dissolved Gasses
- Hydrogen ions ( $H^+$ )  
i.e. pH

## Acidification Problem



# Seawater: Density

Determines structure/currents in the ocean

Measured in : g / cm<sup>3</sup>  
or g/mL

or, because pure water has a density of 1000 kg/m<sup>3</sup>,  
... measured in (kg/m<sup>3</sup> – 1000 kg/m<sup>3</sup>)  
i.e. 1021.2 kg/m<sup>3</sup> → 21.2

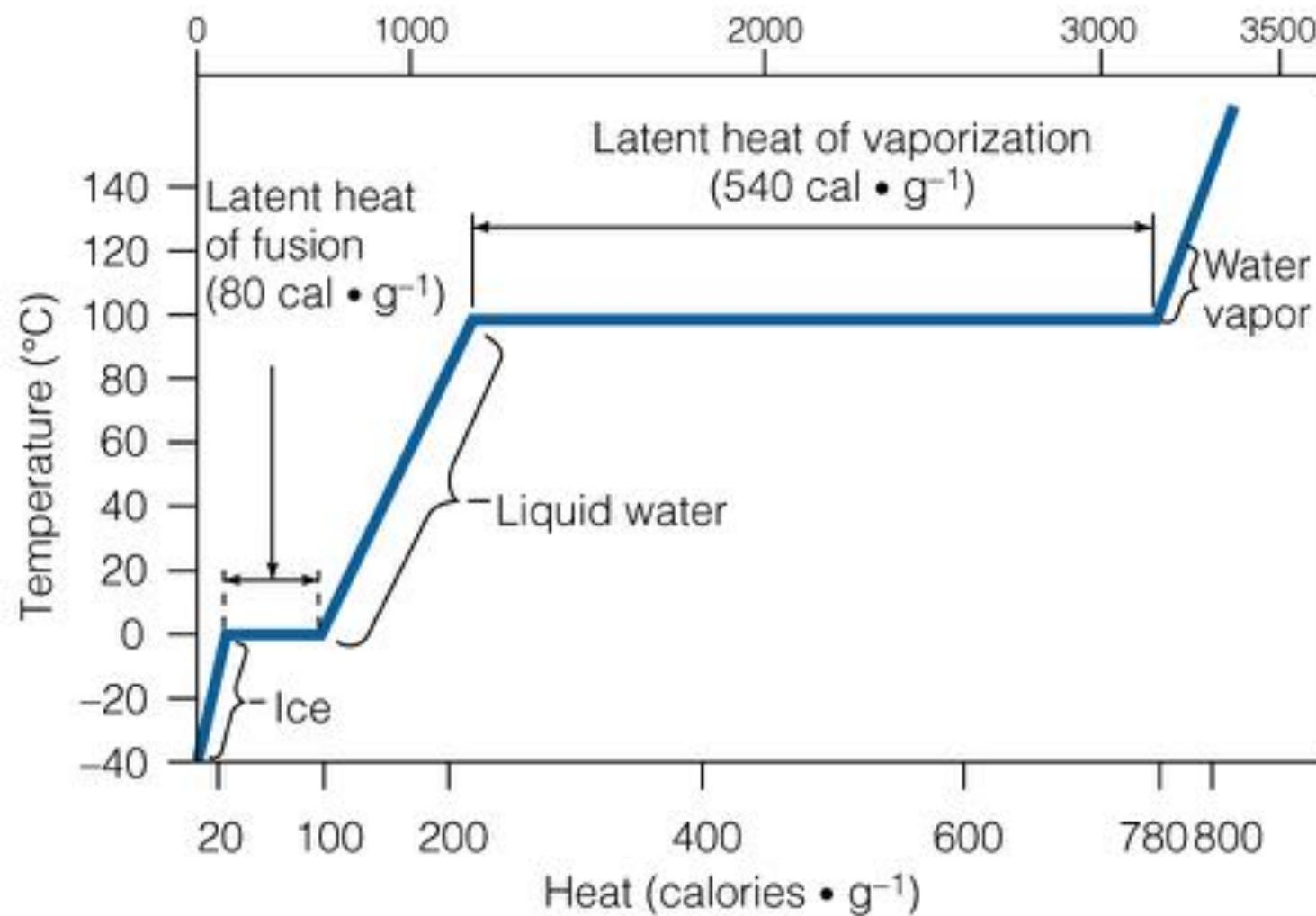
Determined by:

- 1) Temperature
- 2) Salinity
- 3) Pressure



# 1) Temperature

Heat (J)

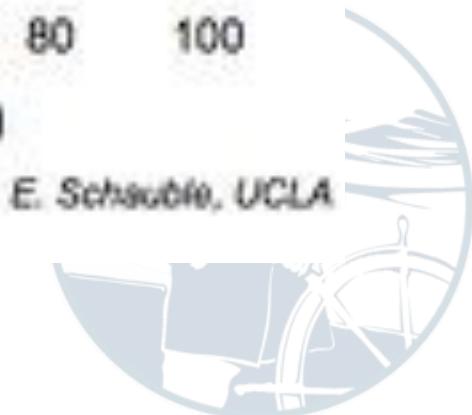
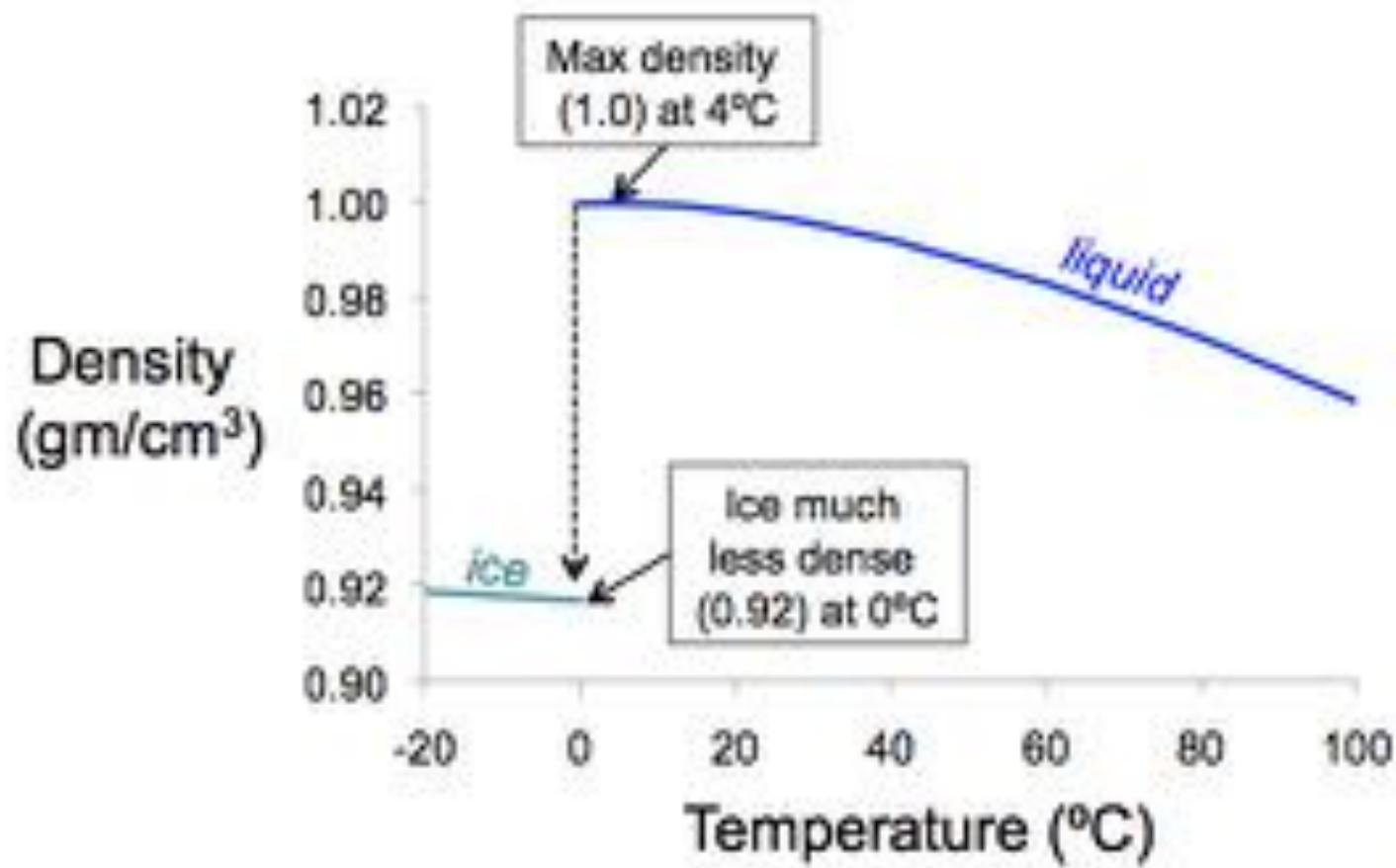


**Sensible Heat:** measurable change in temperature when heat is added or subtracted (sloping lines).

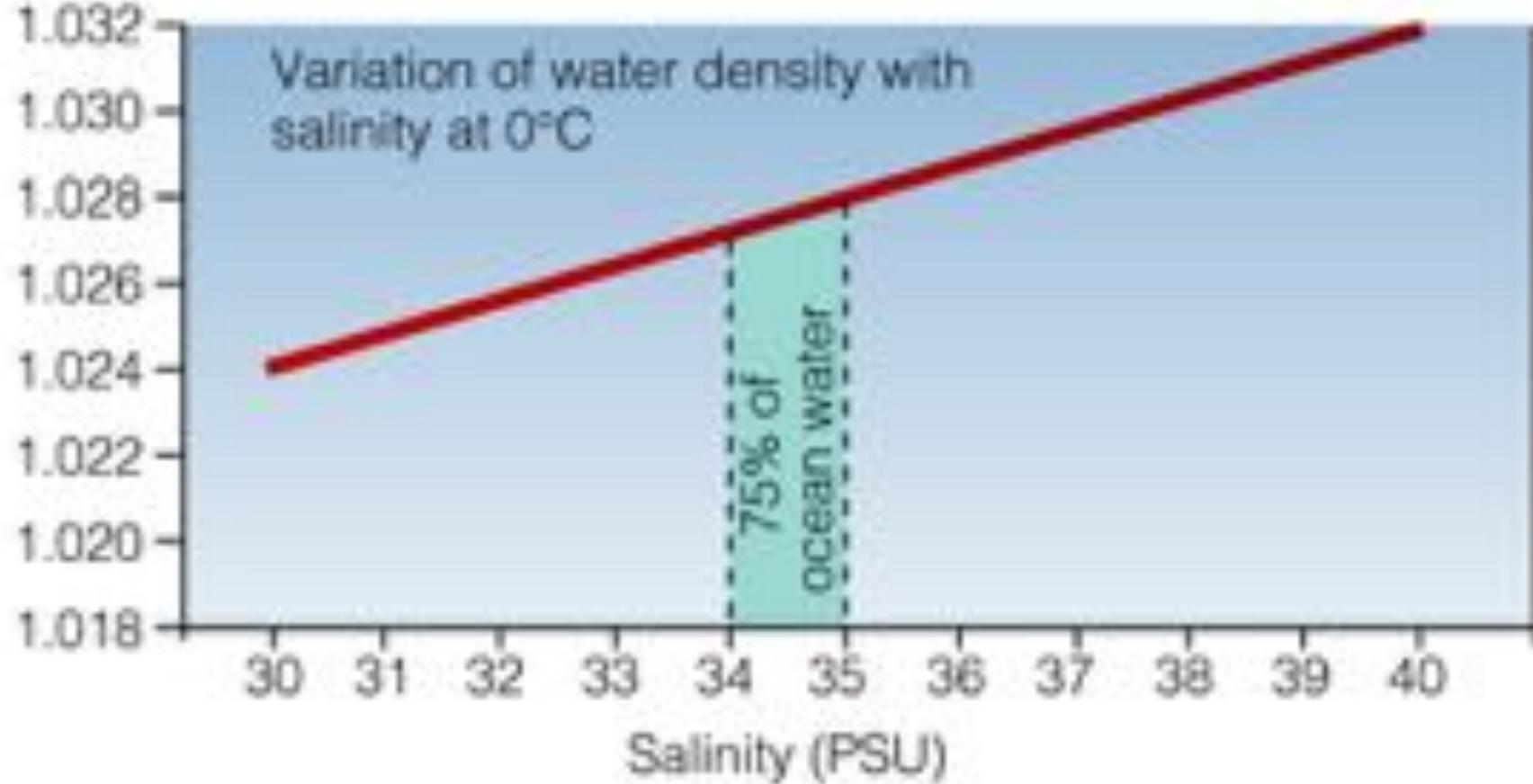
**Latent Heat:** no temperature change with added/subtracted heat (flat lines).



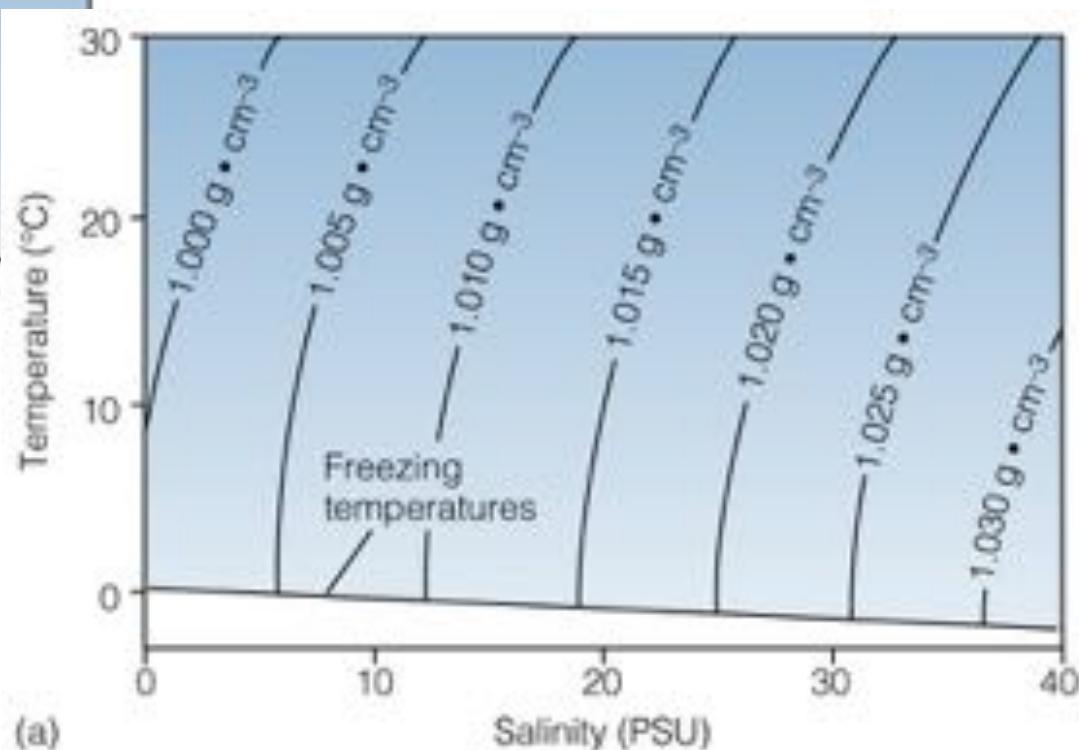
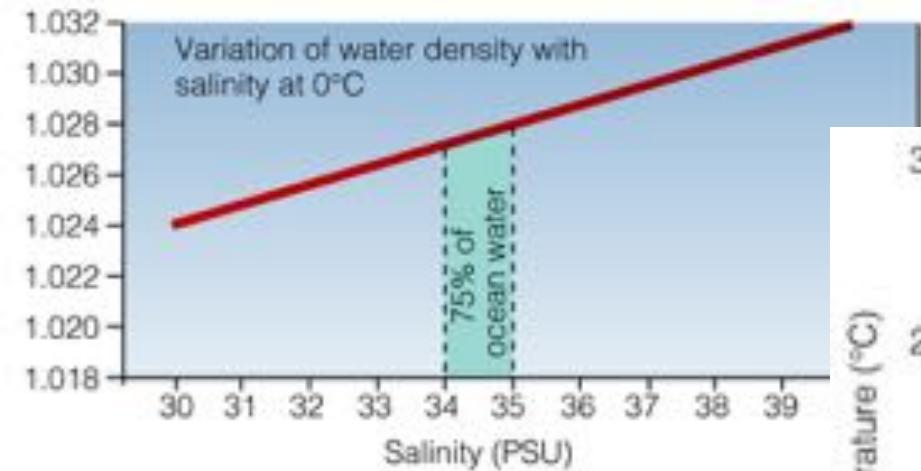
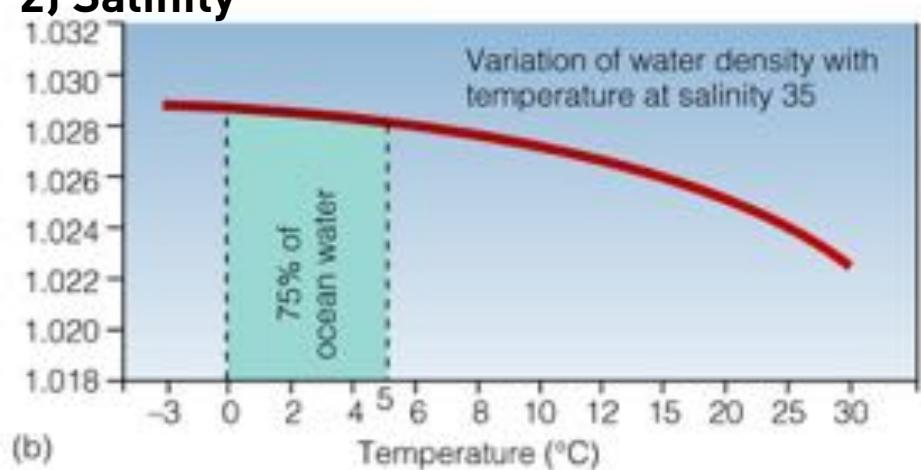
# 1) Temperature

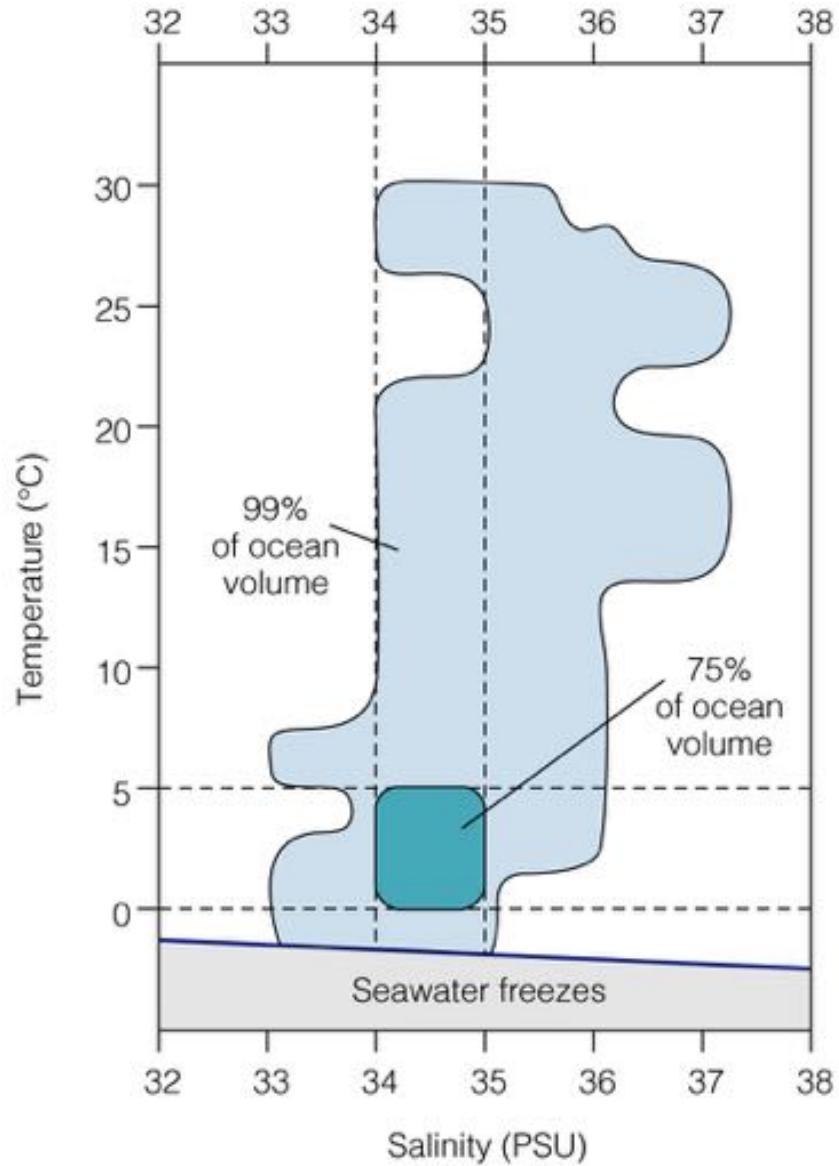


## 2) Salinity



## 2) Salinity





### 3) Pressure

Pressure compresses materials to make them more dense

Water is almost completely incompressible

Only matters in the very deepest part of the ocean

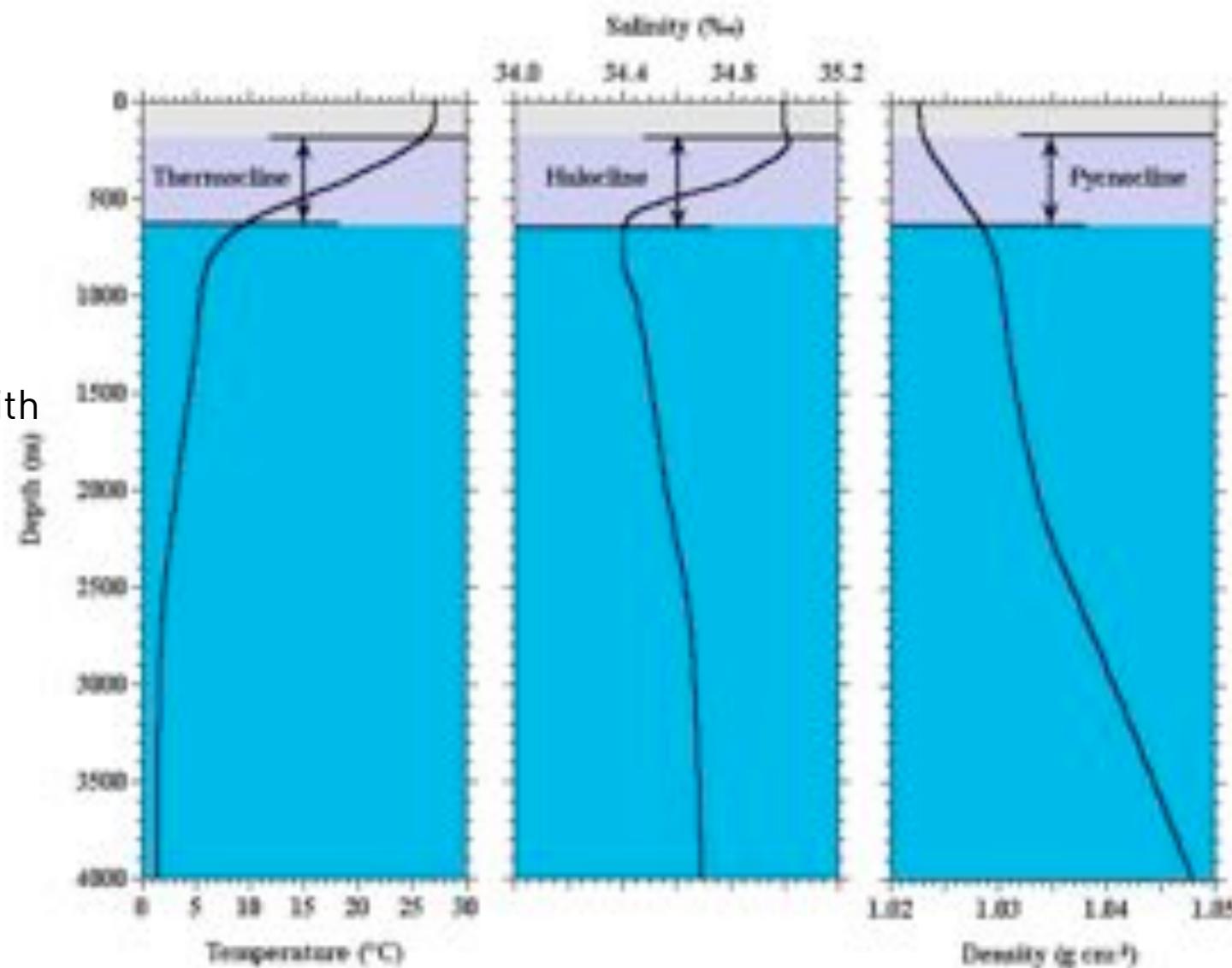
Only increases density by about 2%



## Typical ocean layering

### Mixed layer

- wind-mixed
- nearly uniform
- 100m – 1000m
- ~ 2% of ocean
- Sunlit → photosynthesis
- gas exchange with atmosphere

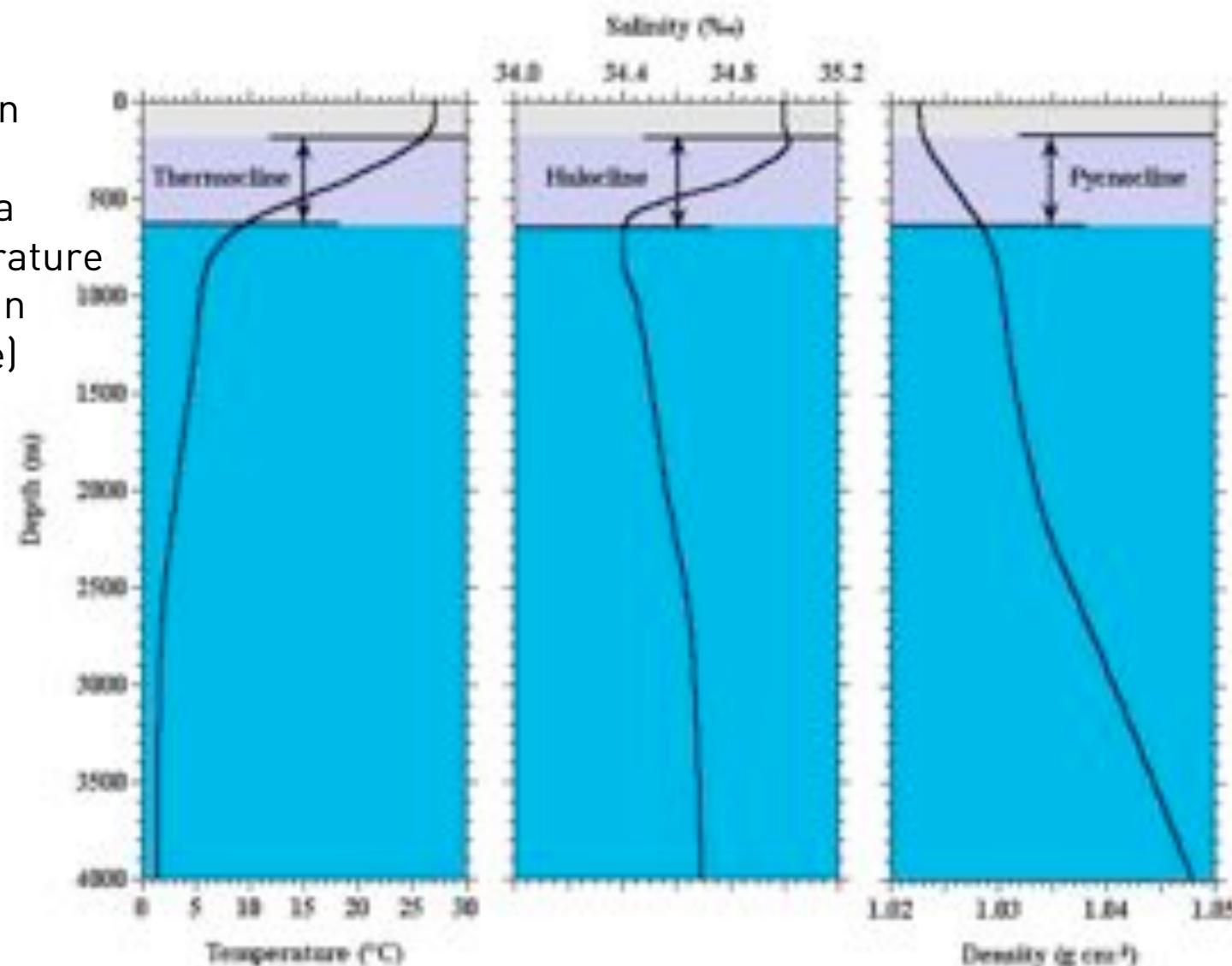


Bigelow

## Typical ocean layering

### Pycnocline

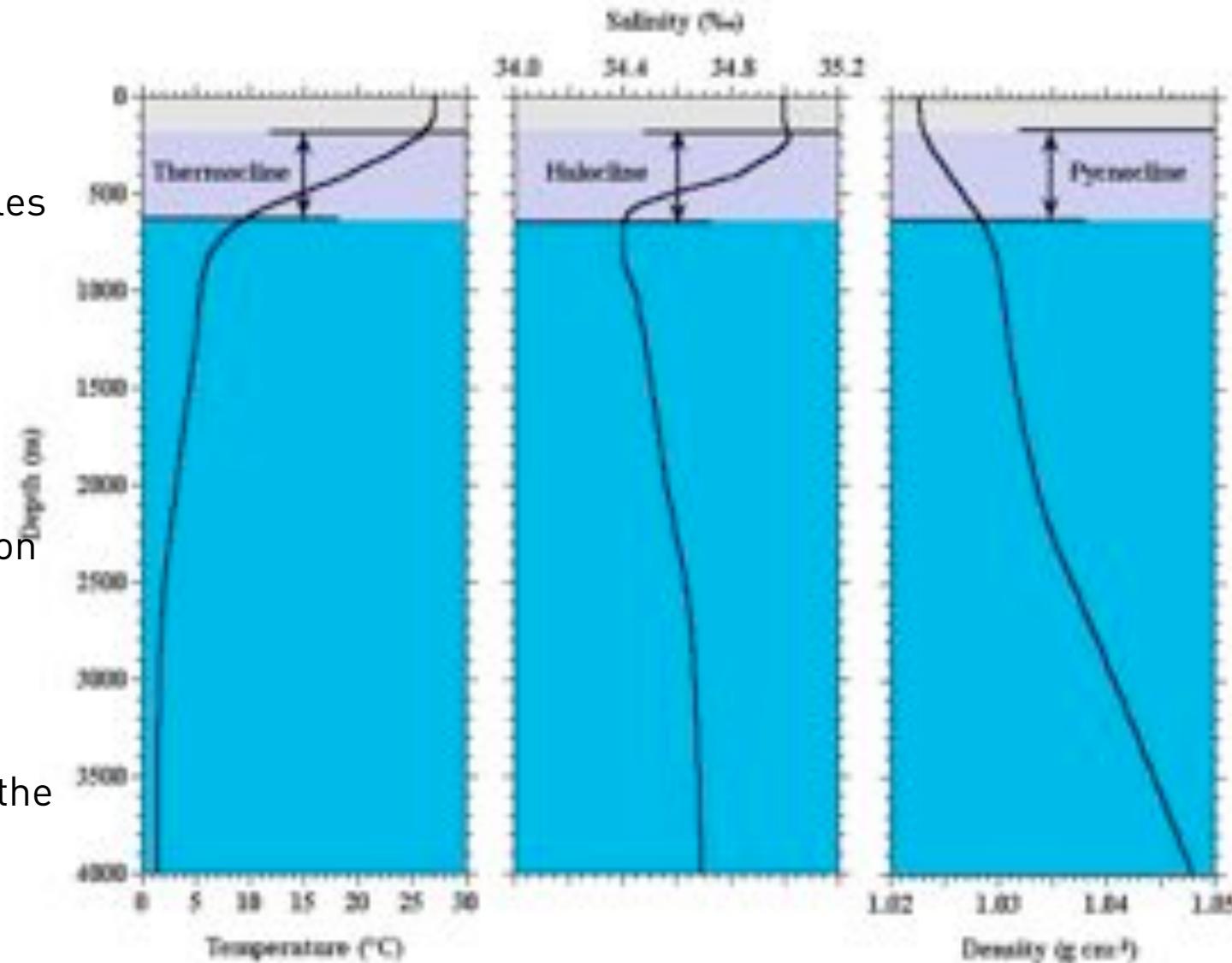
- Sharp gradient in density
- Could be either a change in temperature (thermocline) or in salinity (halocline)
- ~18% of ocean



## Typical ocean layering

### Deep layer

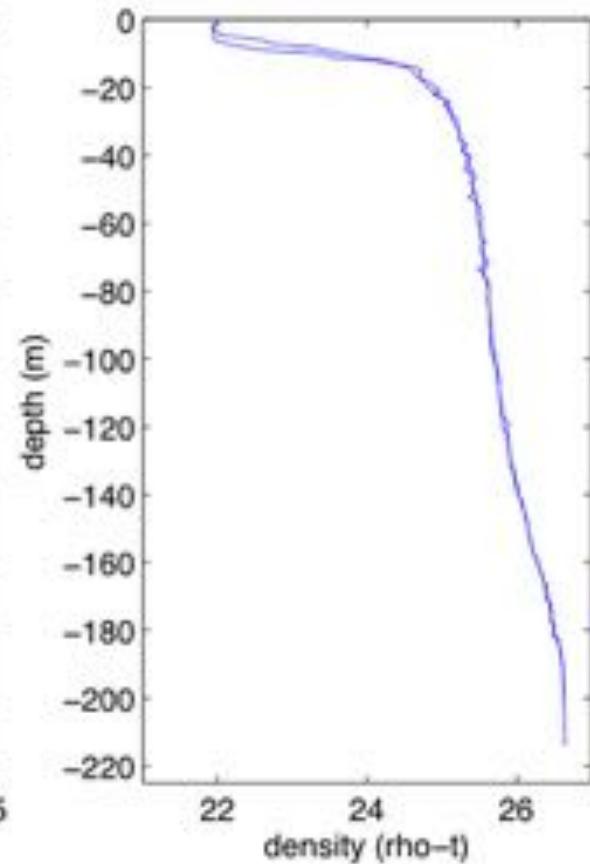
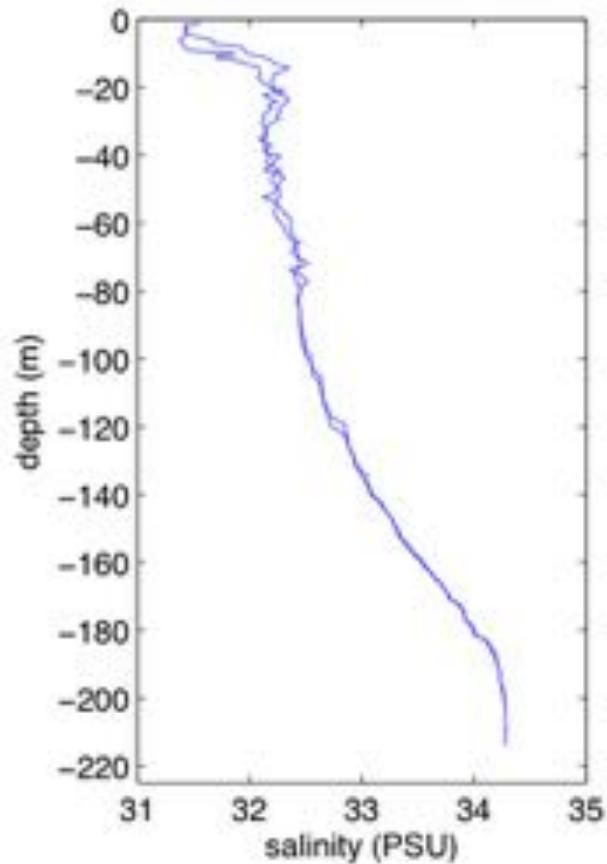
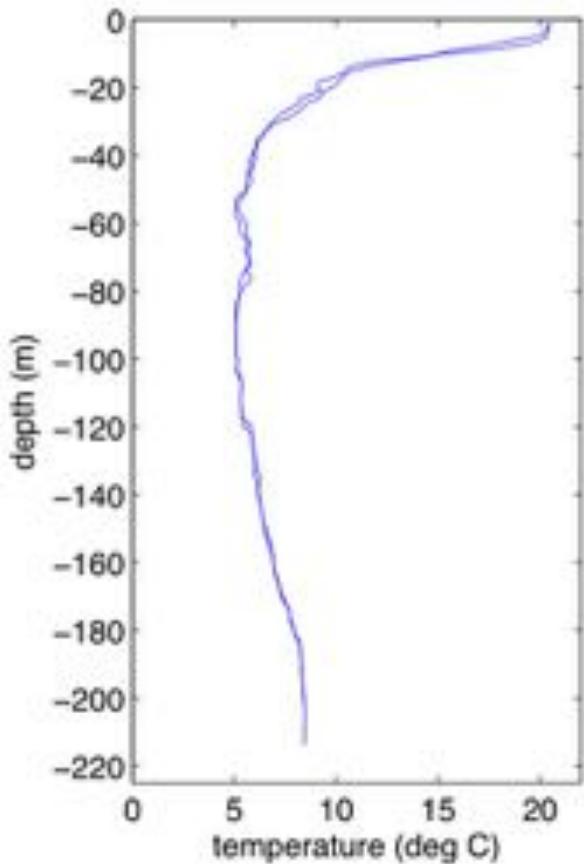
- Cold (<4 deg)
- Originates at poles
- Dark (no photosynthesis)
- Not much effect from surface processes
- ~80% of ocean
- Largest habitat on earth\*

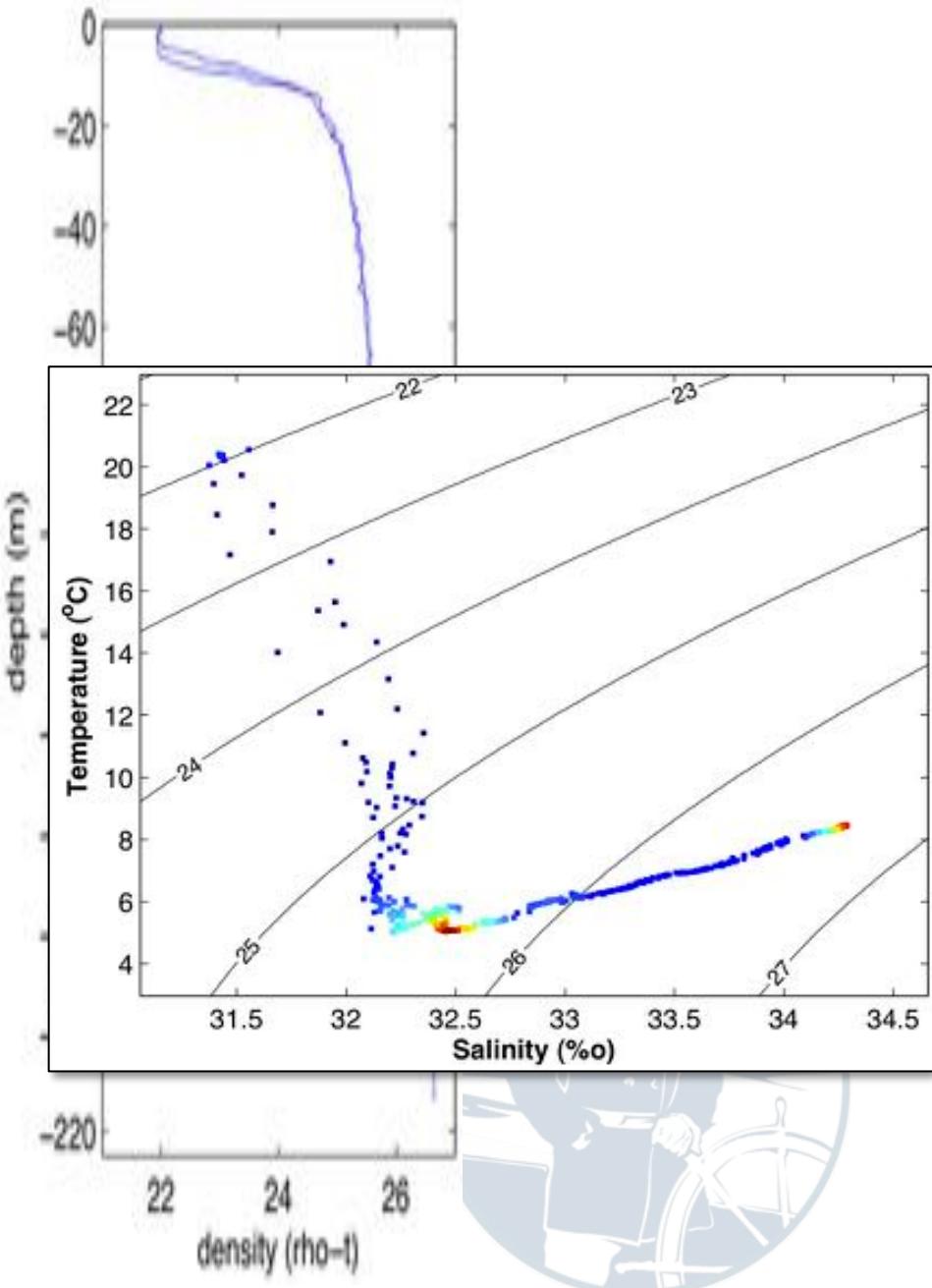
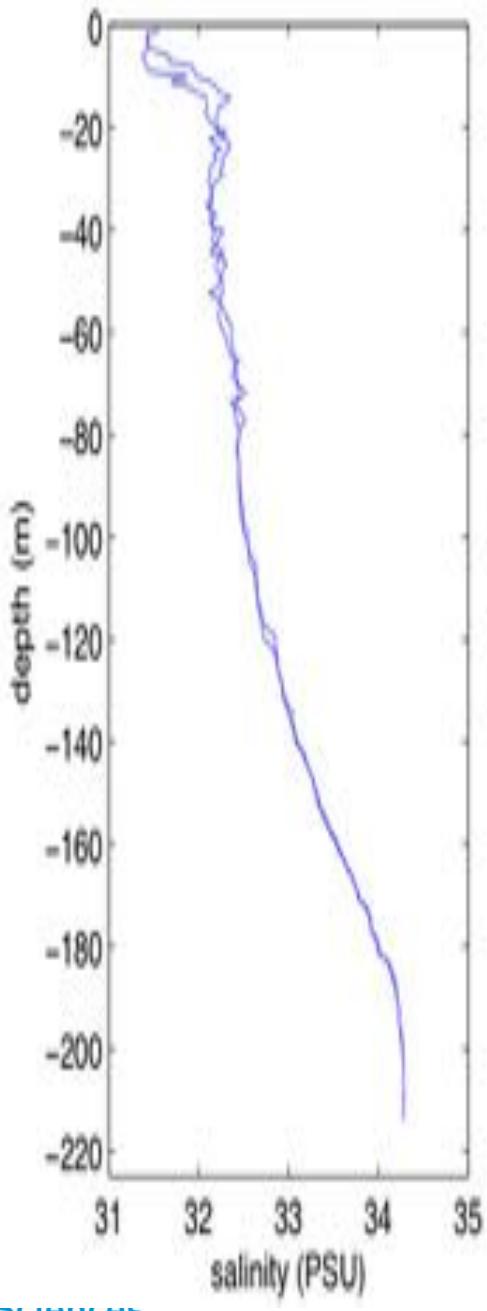
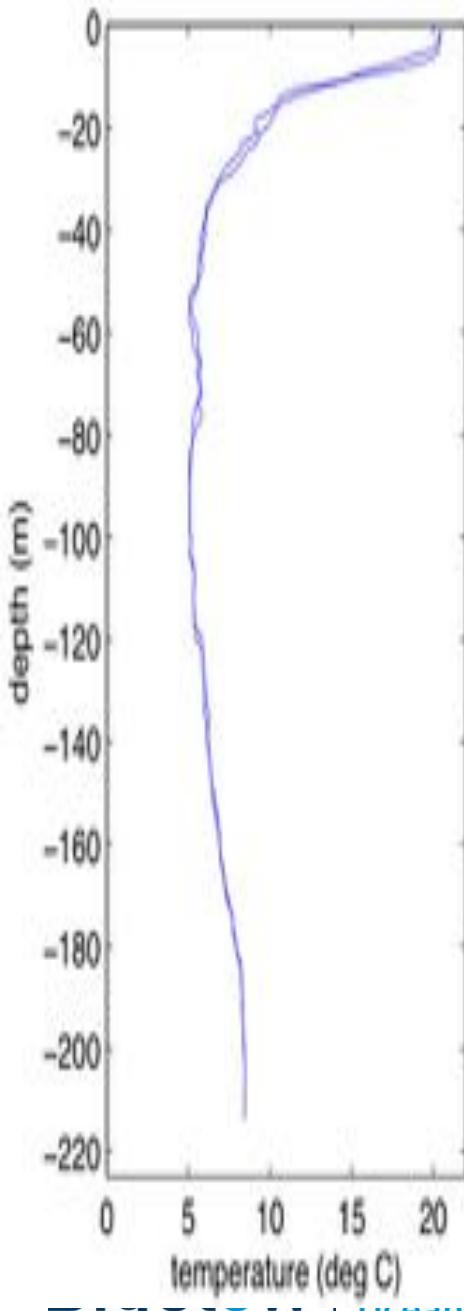


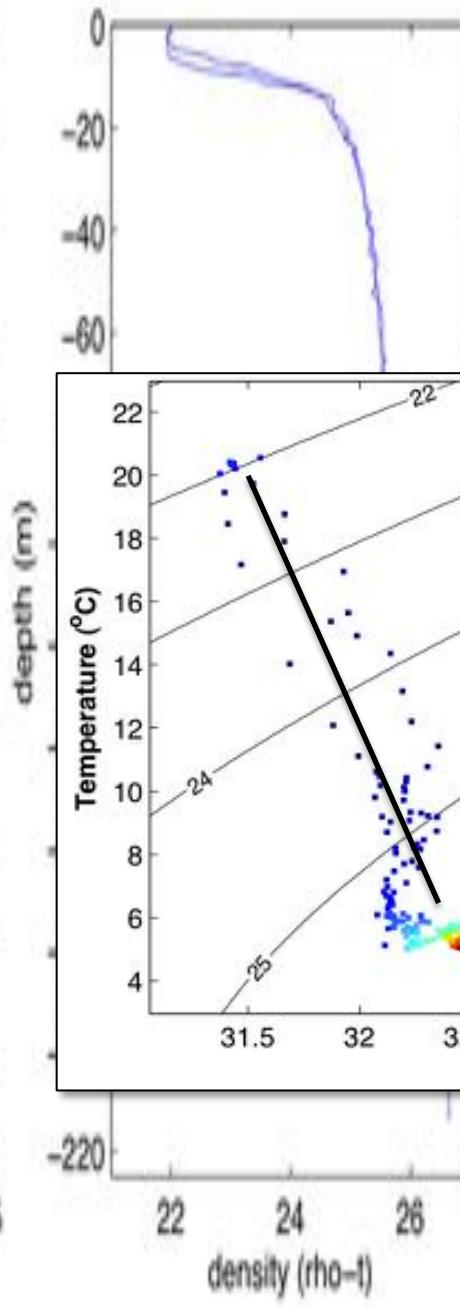
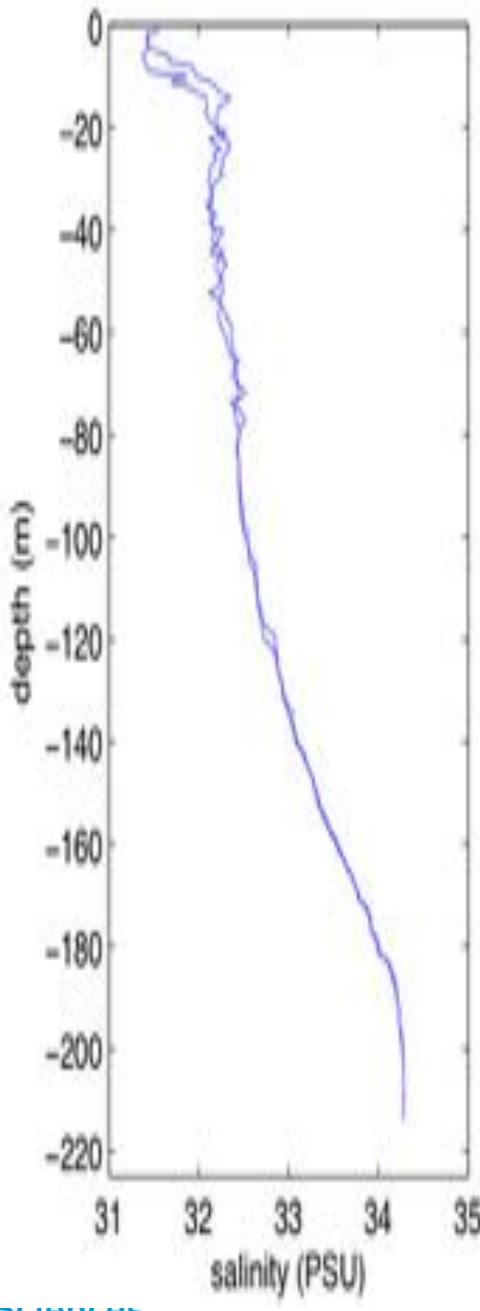
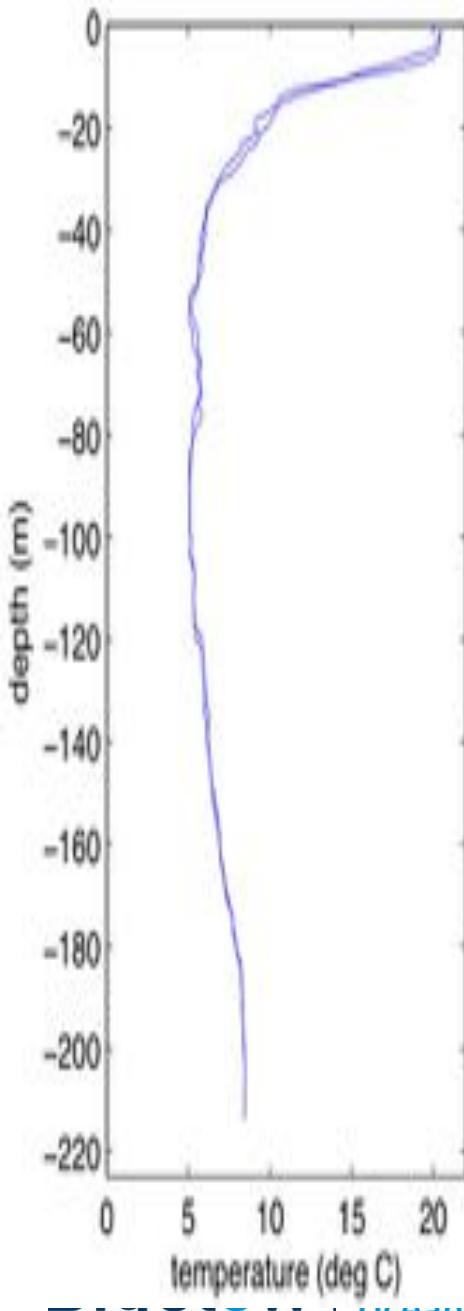
\*except possibly the deep biosphere

## Tracing water masses

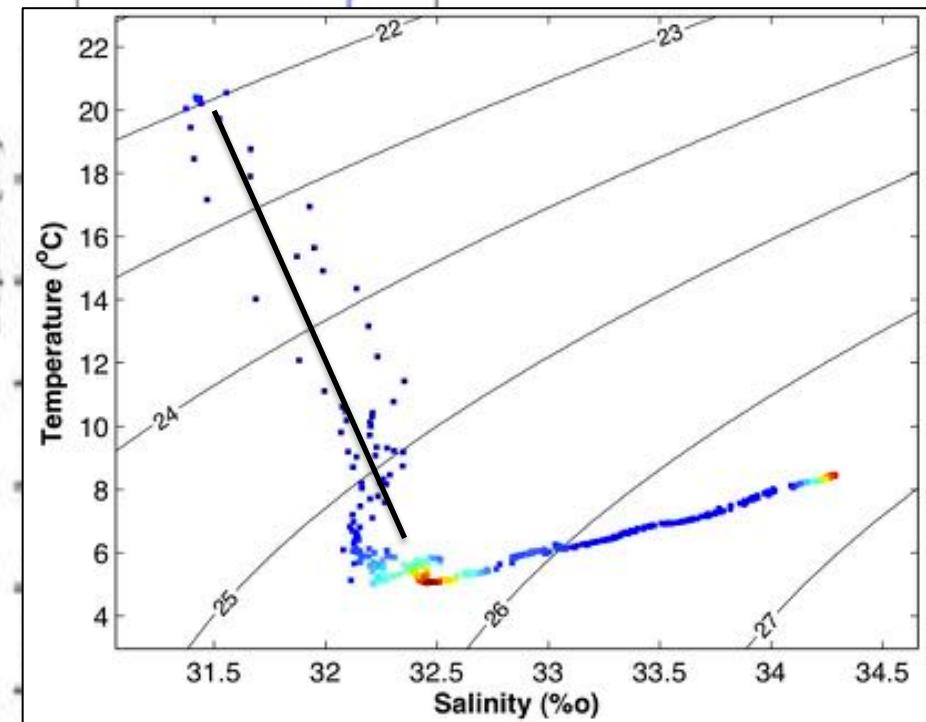
Wilkinson Basin



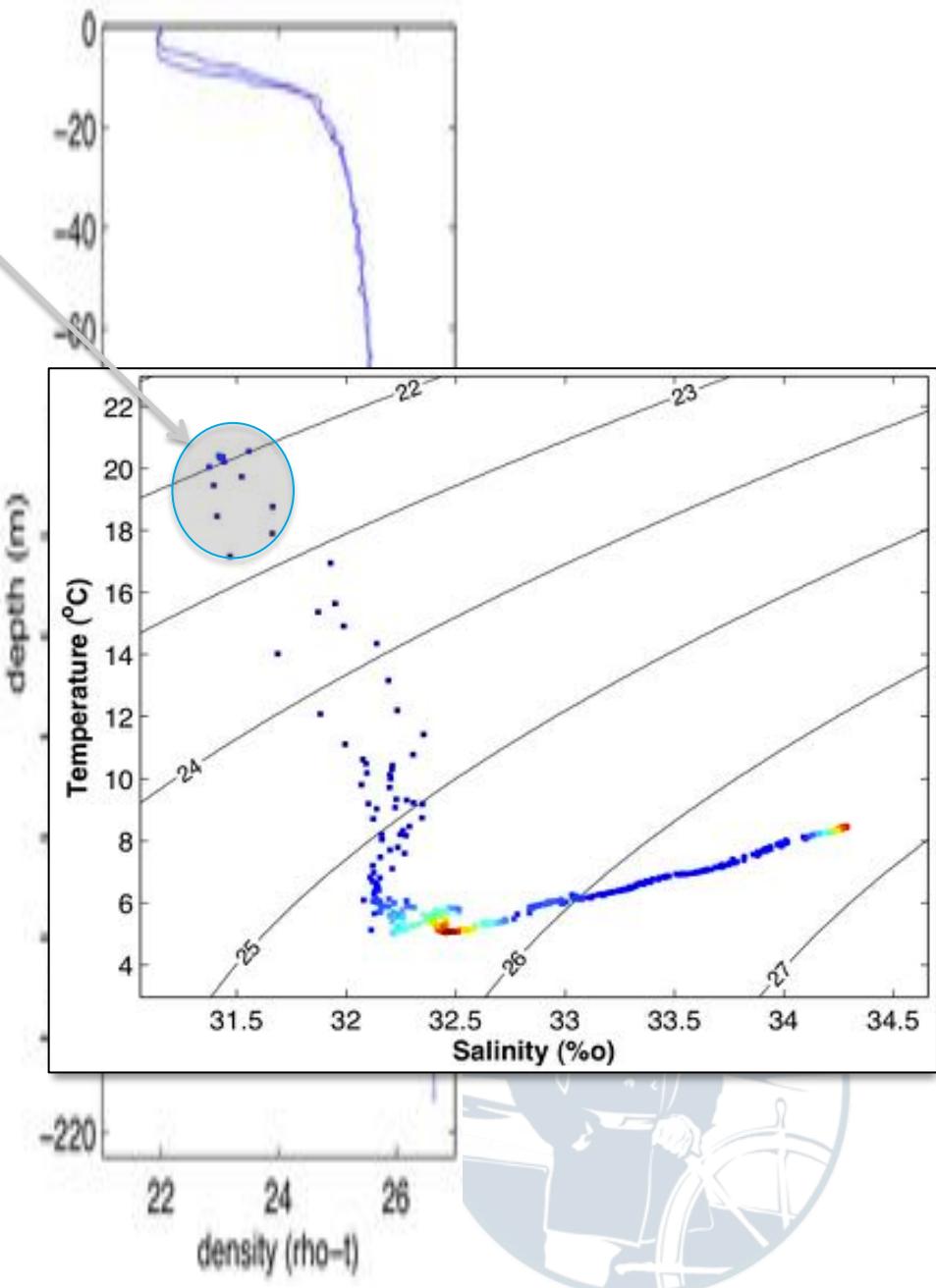
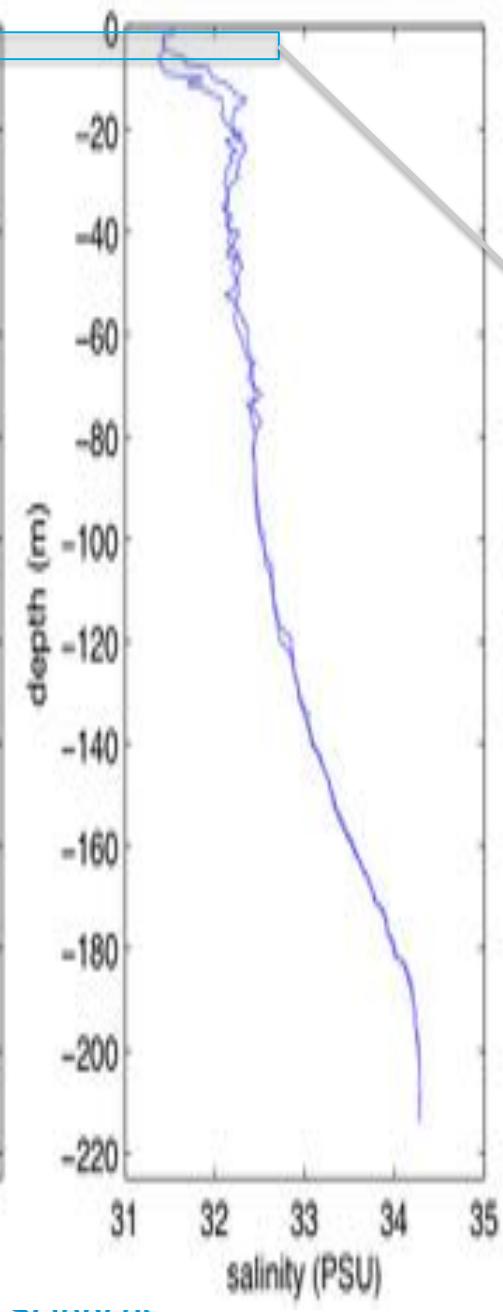
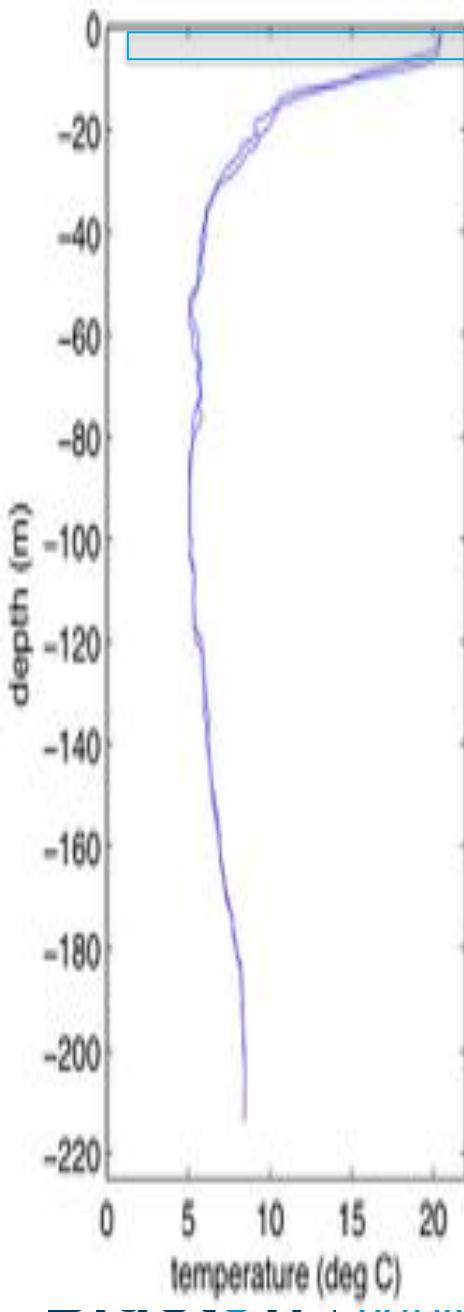


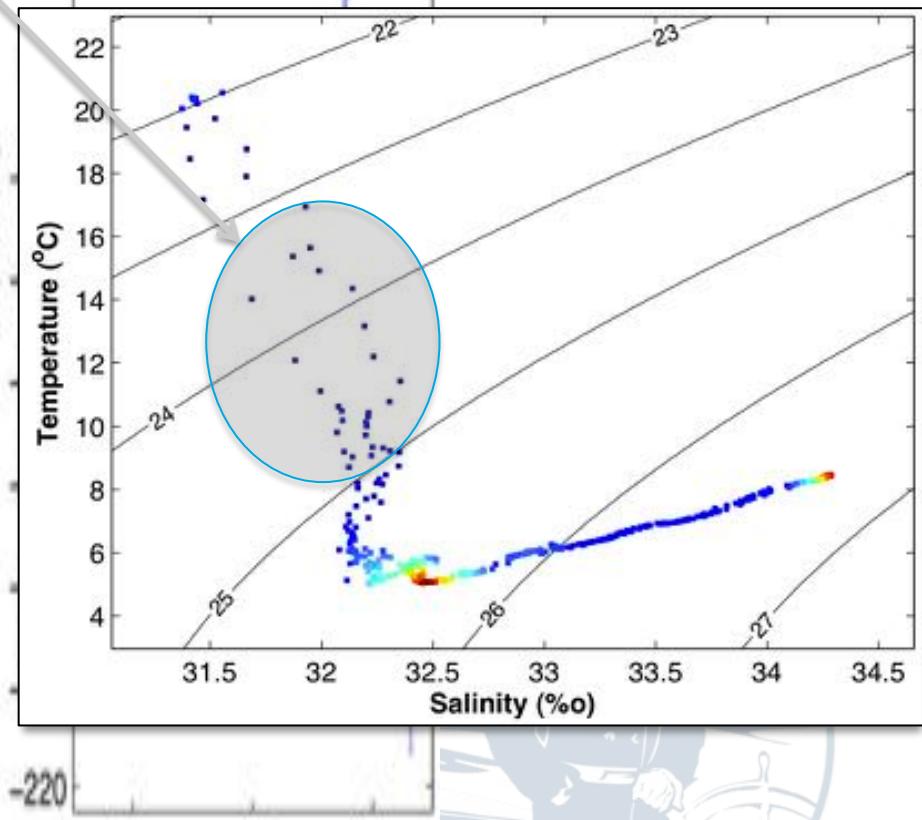
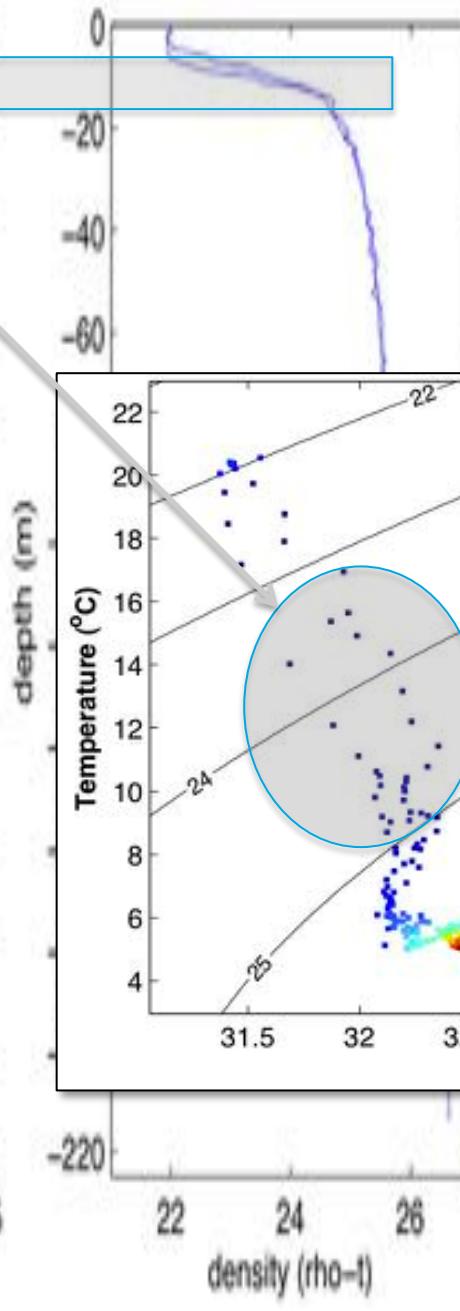
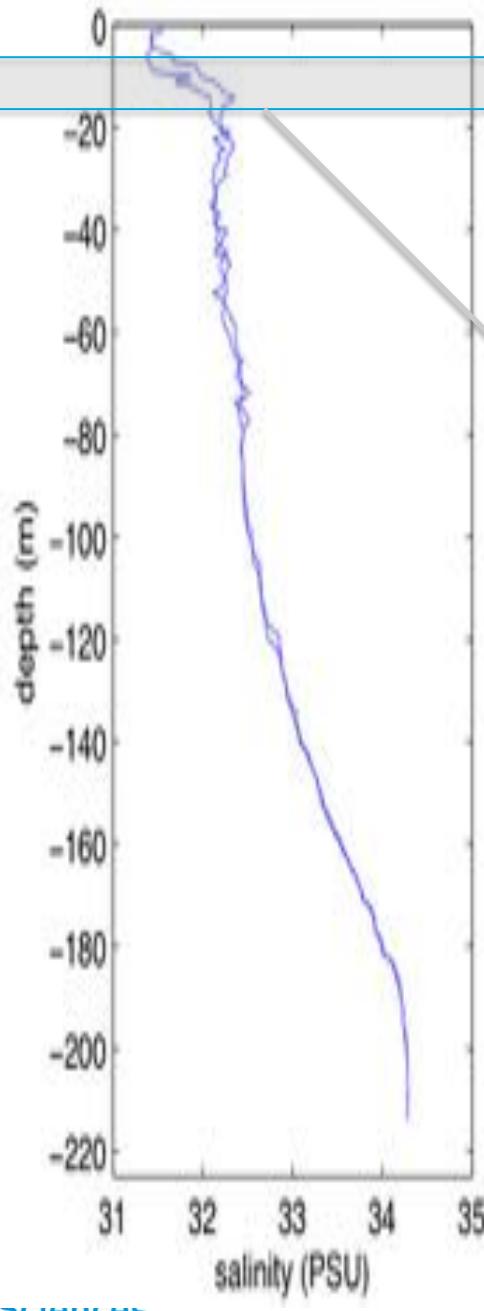
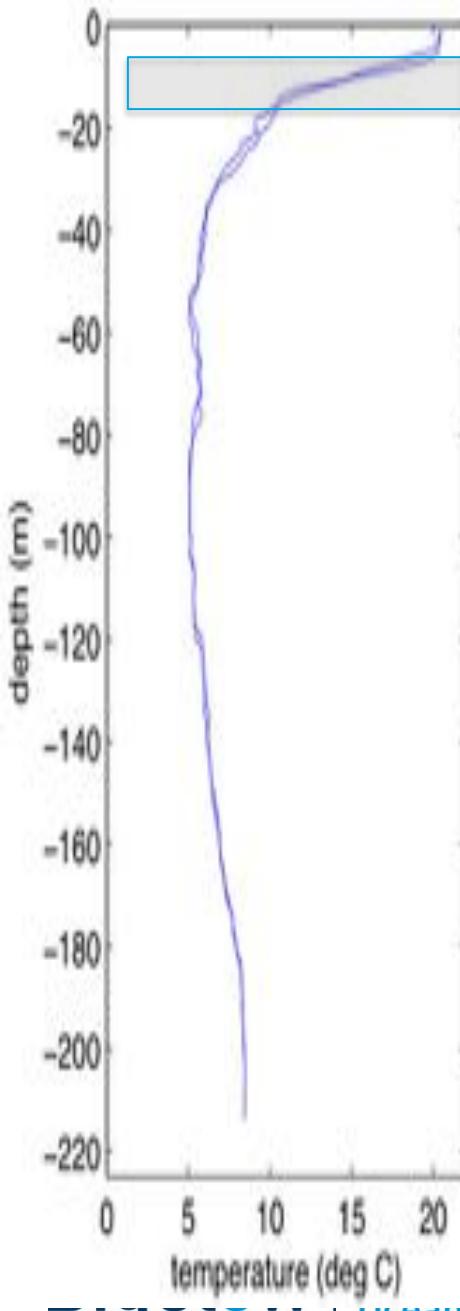


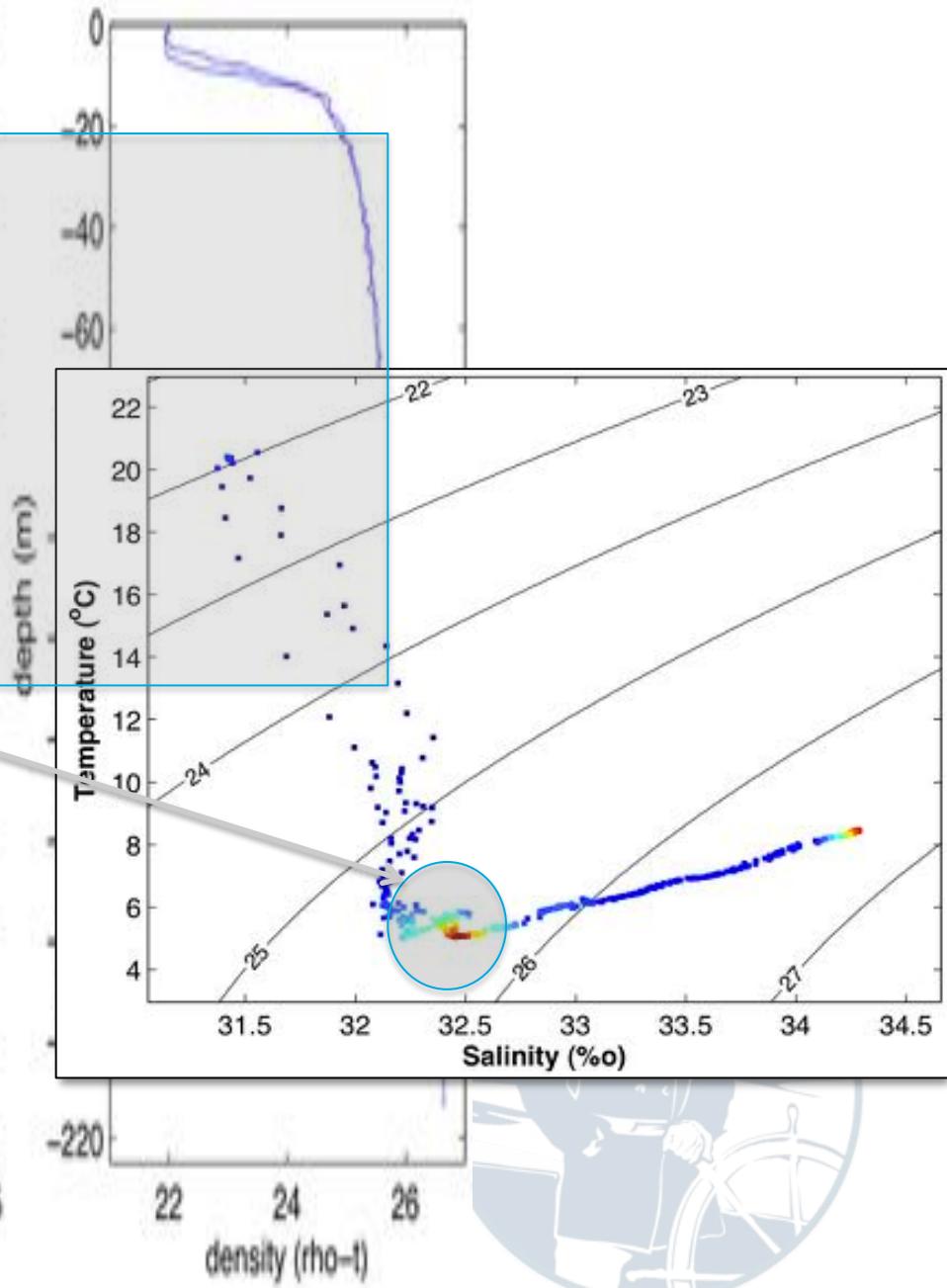
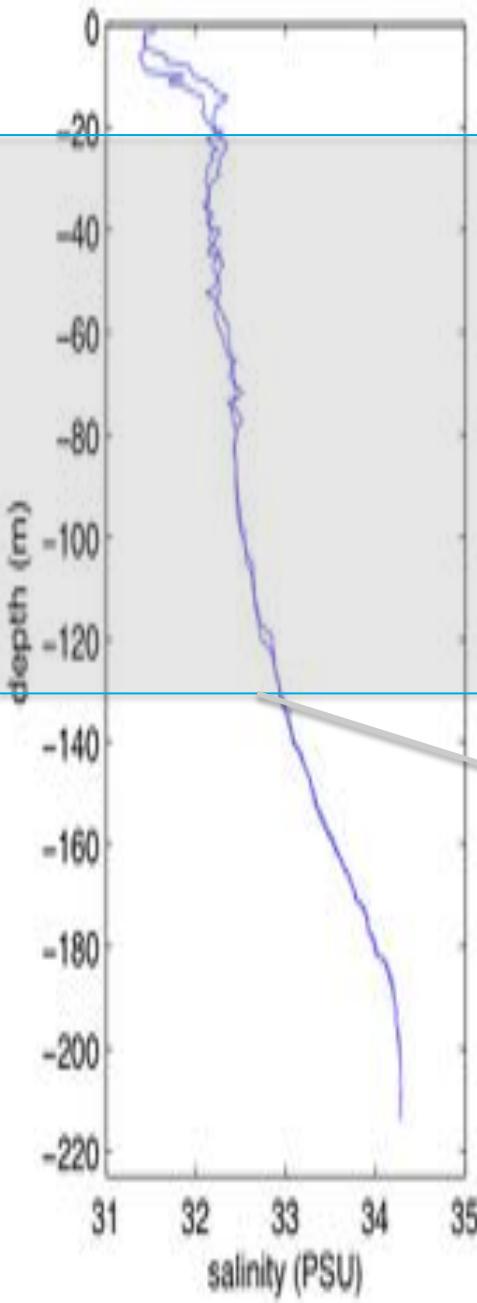
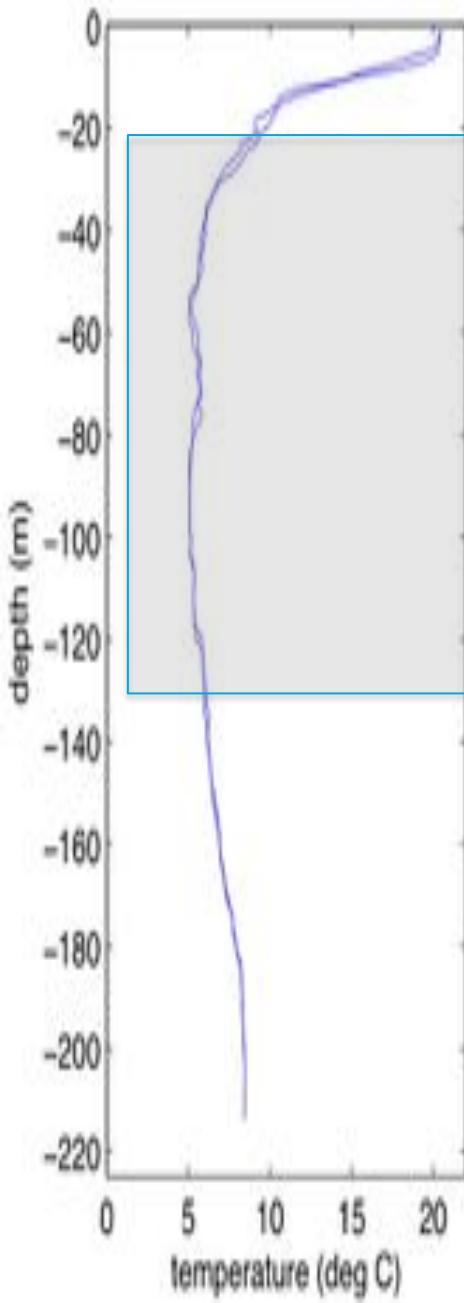
Mixing occurs on a straight line on this plot

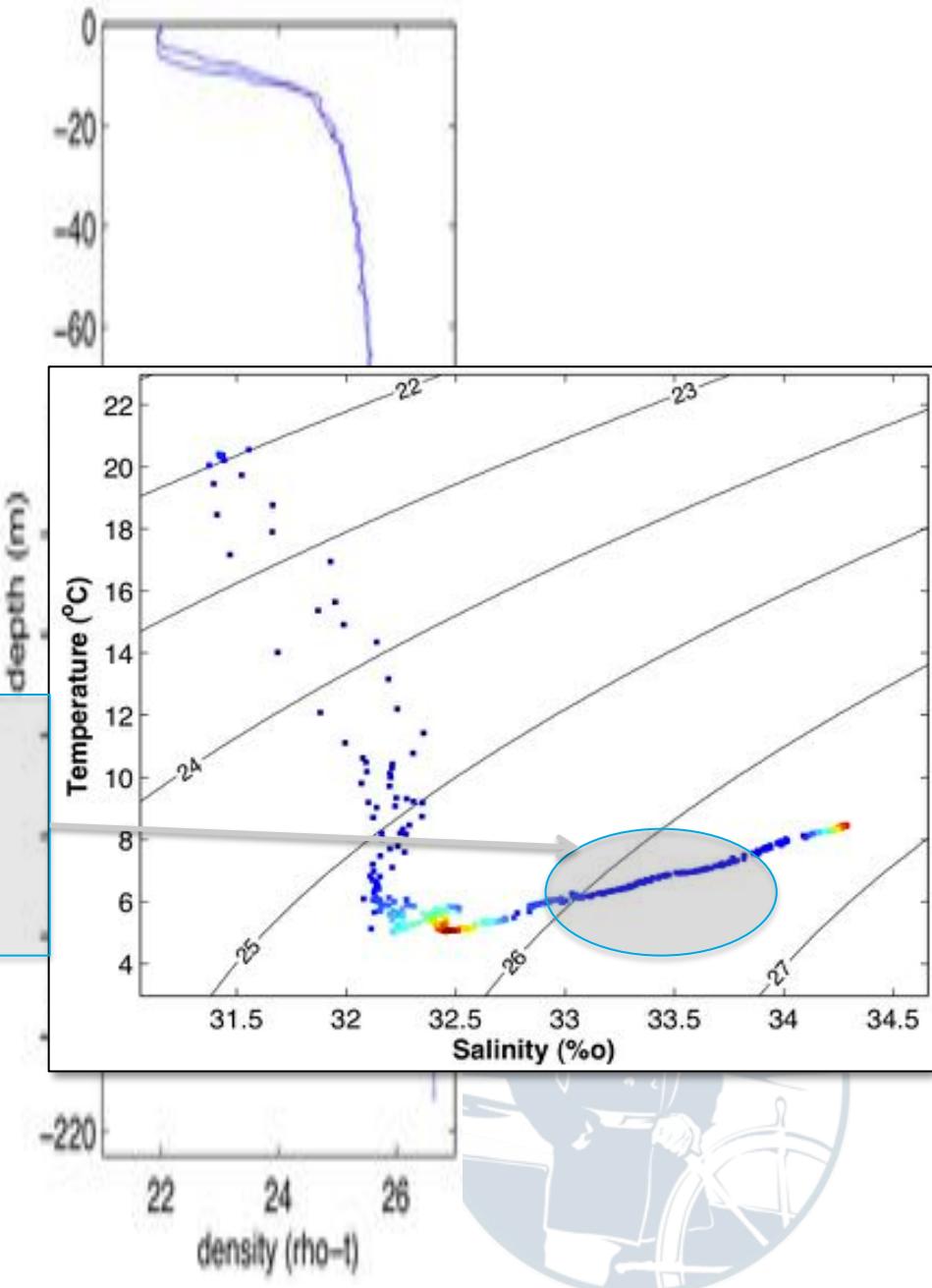
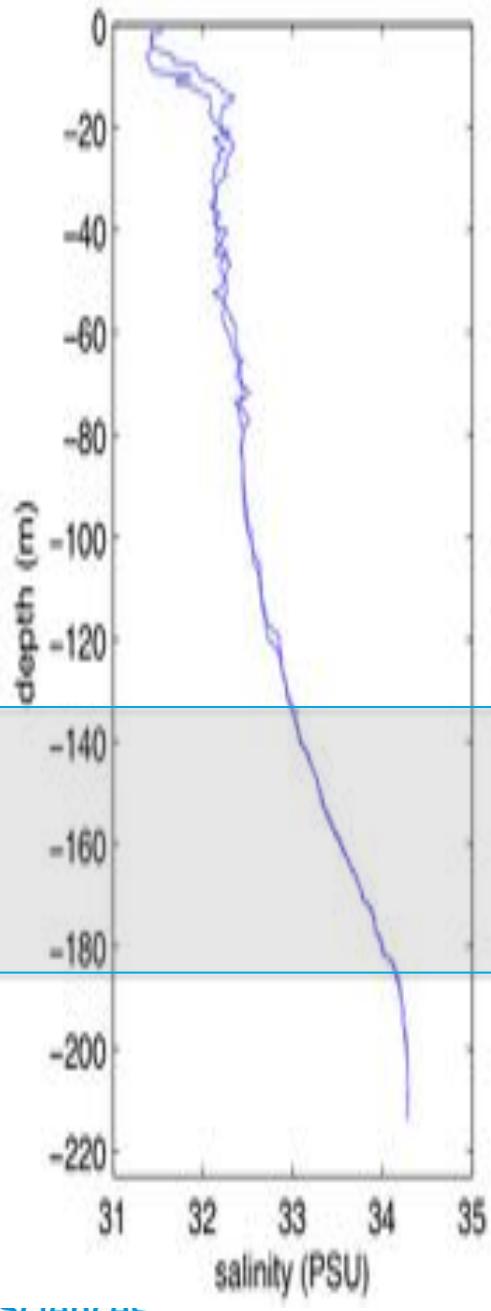
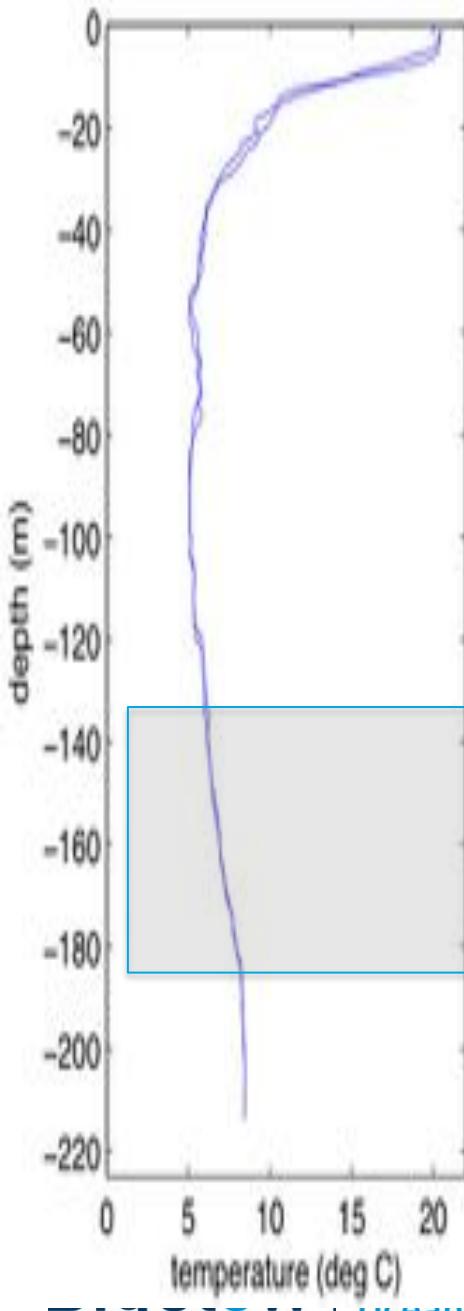


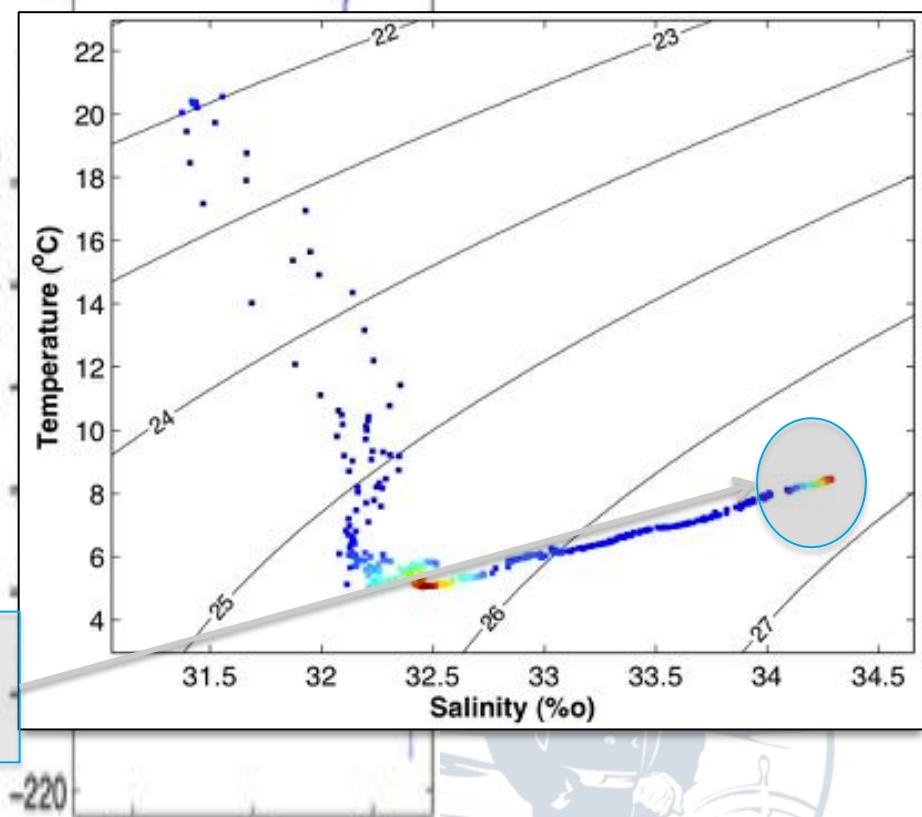
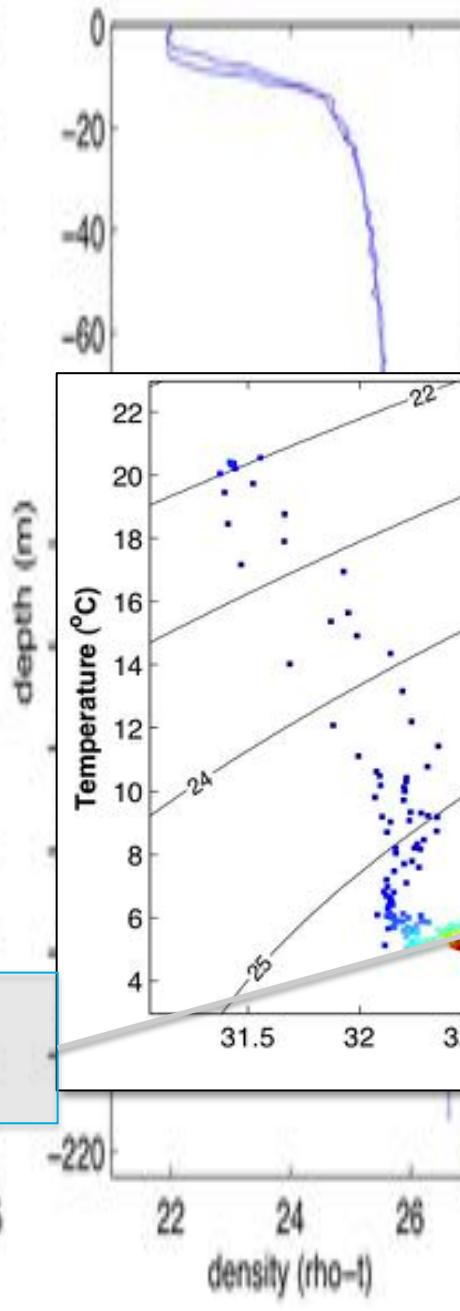
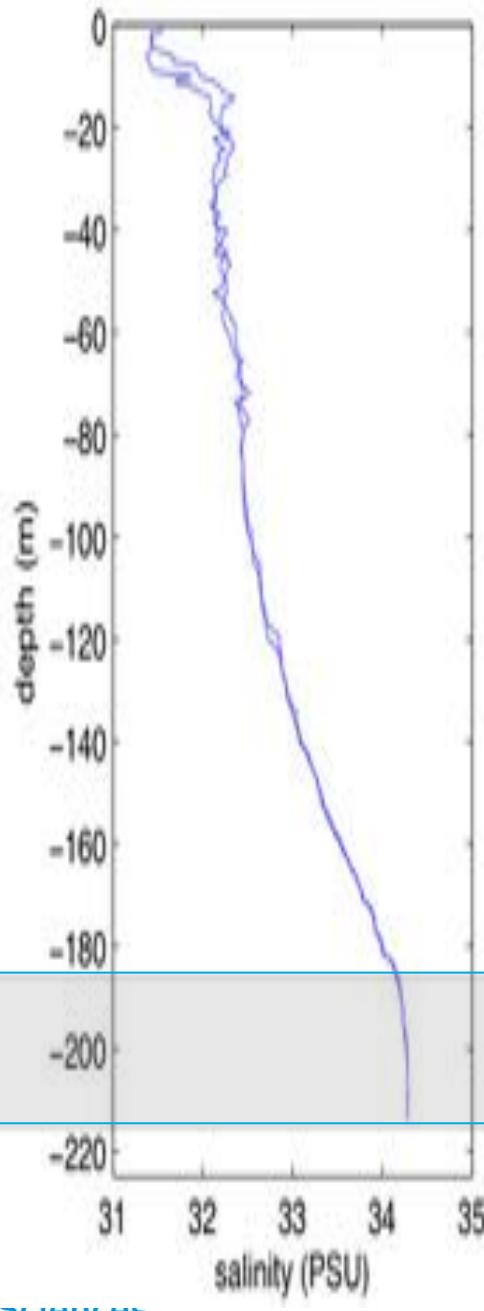
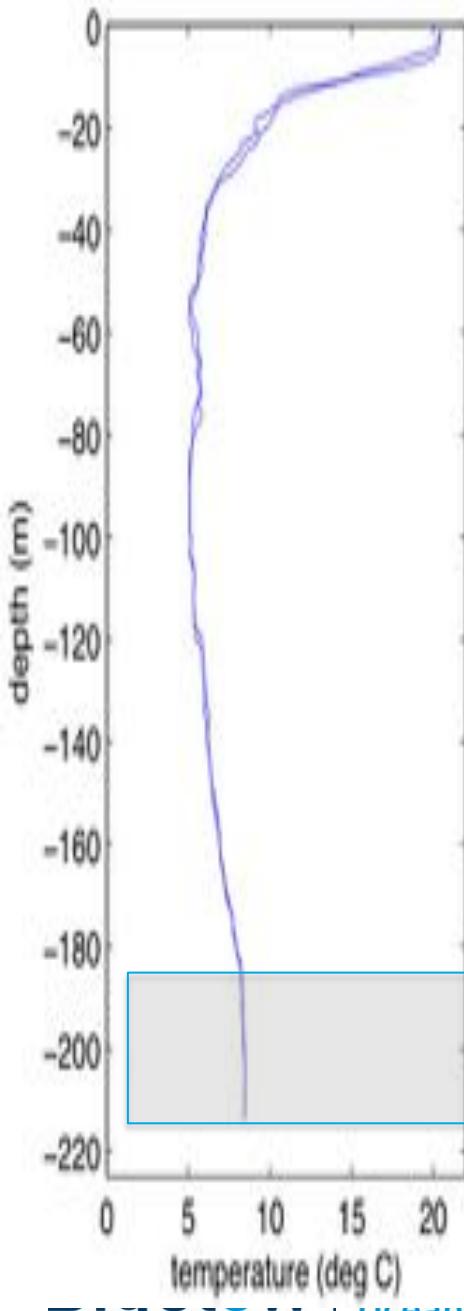
Note:  $T$ ,  $S$  are  
**conservative**  
(only changed  
through mixing)

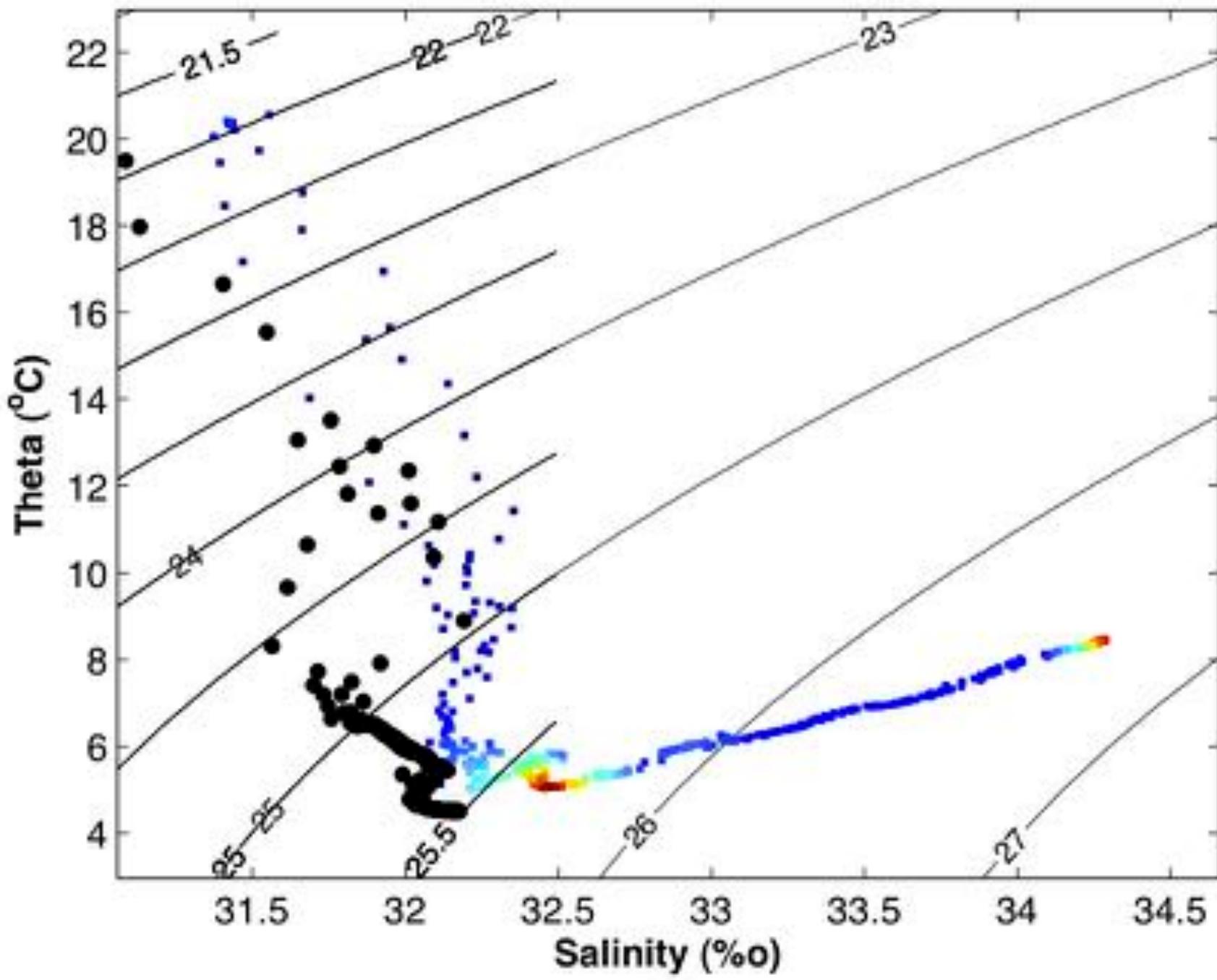




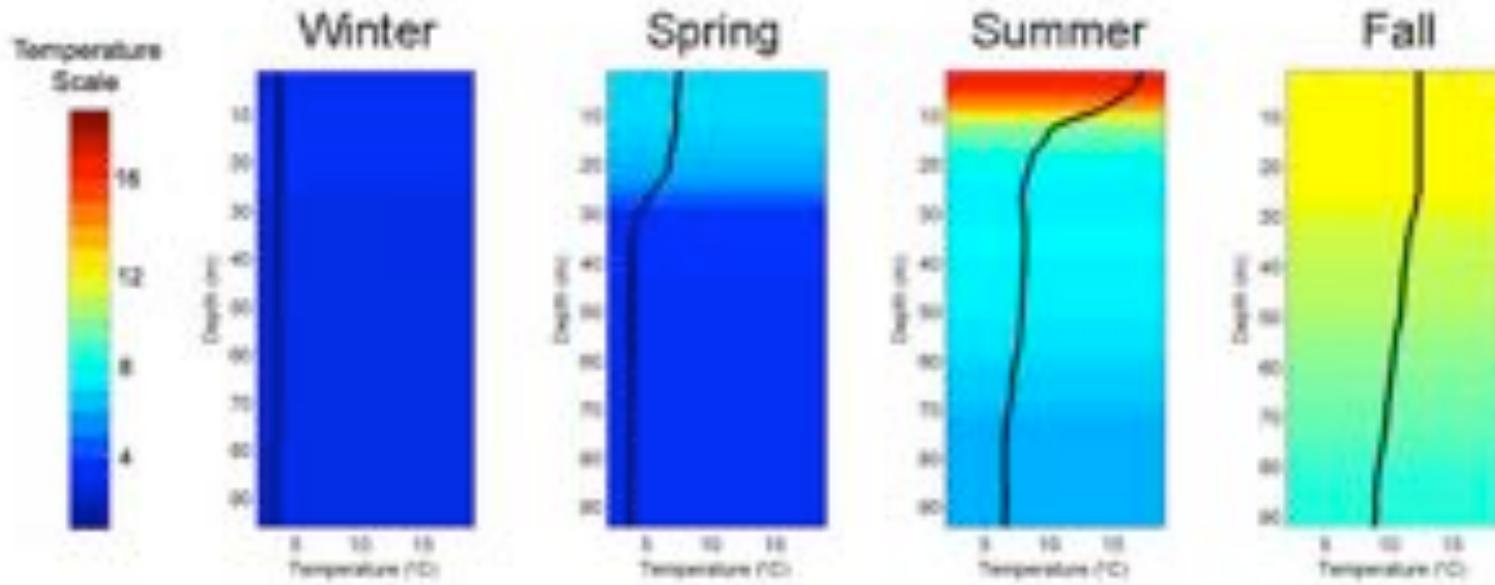




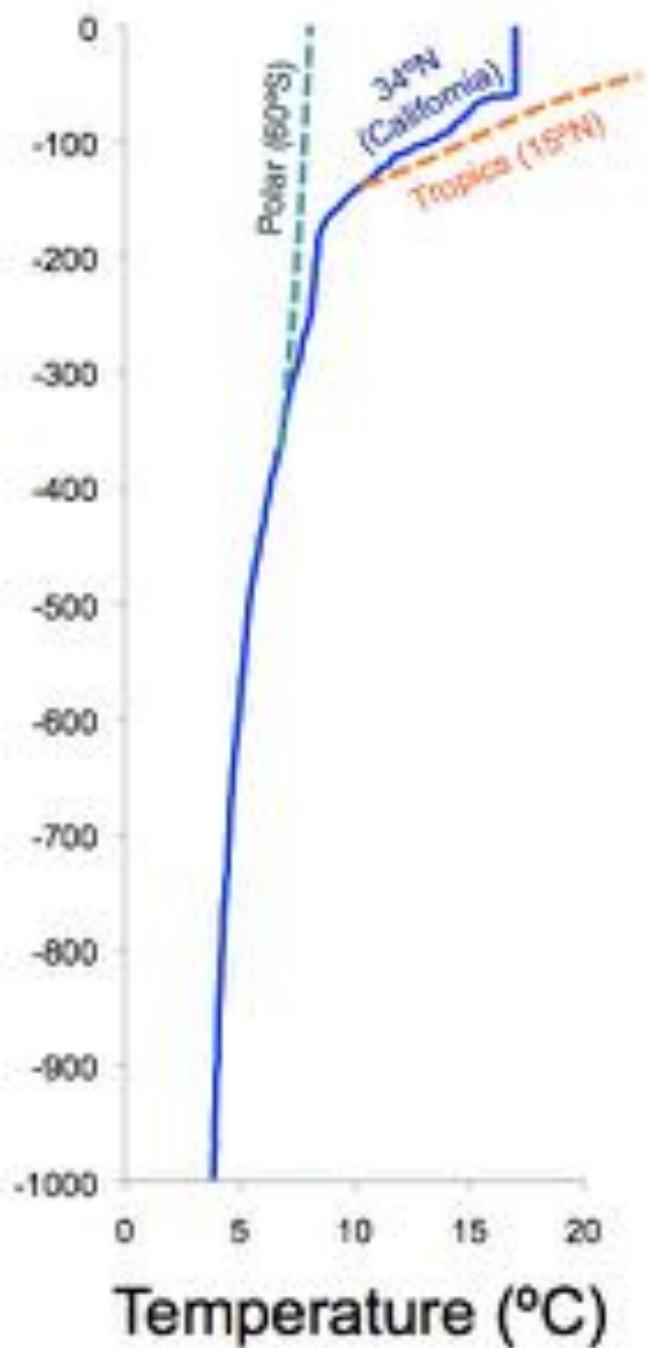




Bi

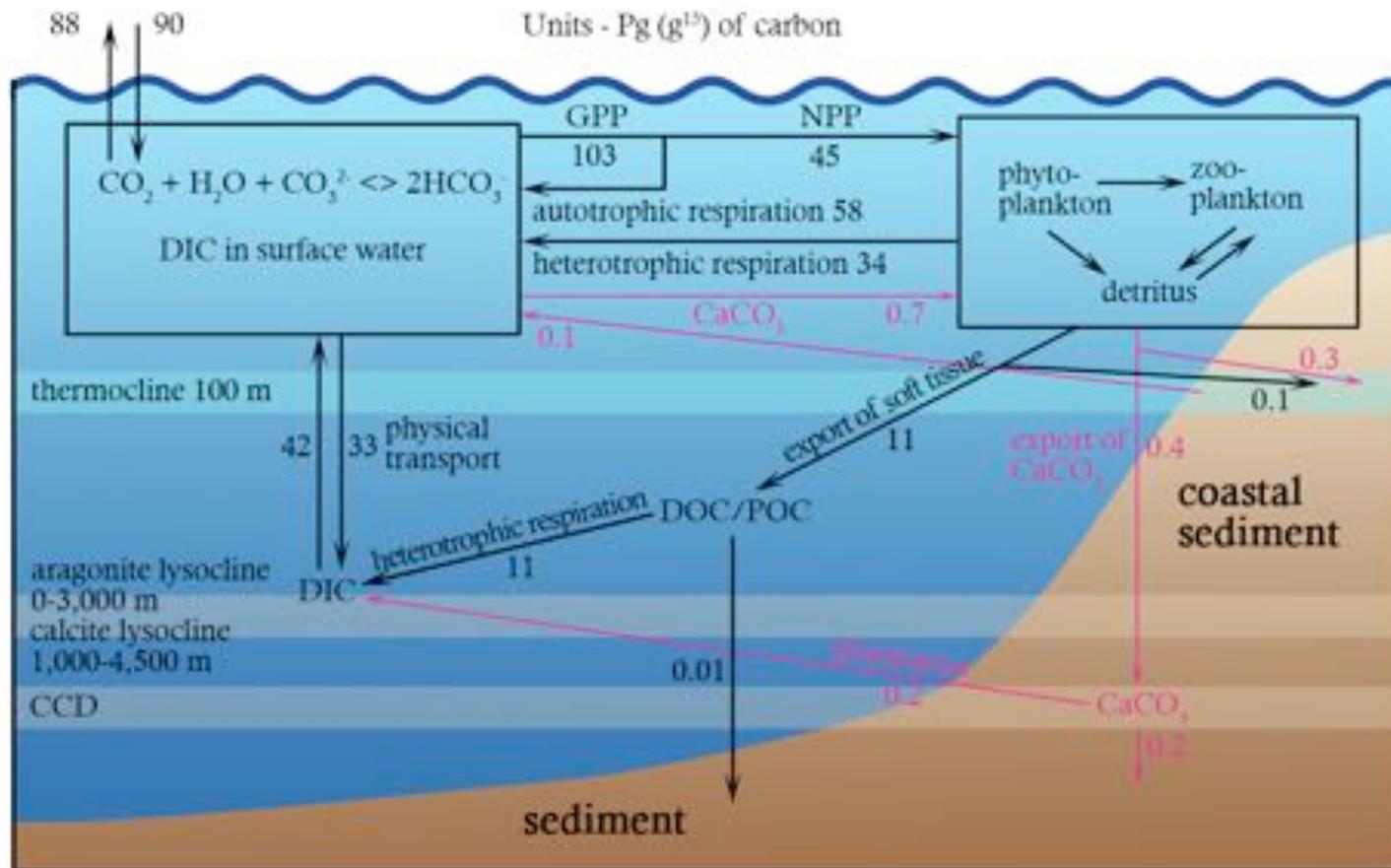


Plot E. Schauble, UCLA  
from NOAA CTD data.



# Element cycles

## Carbon cycling in the ocean

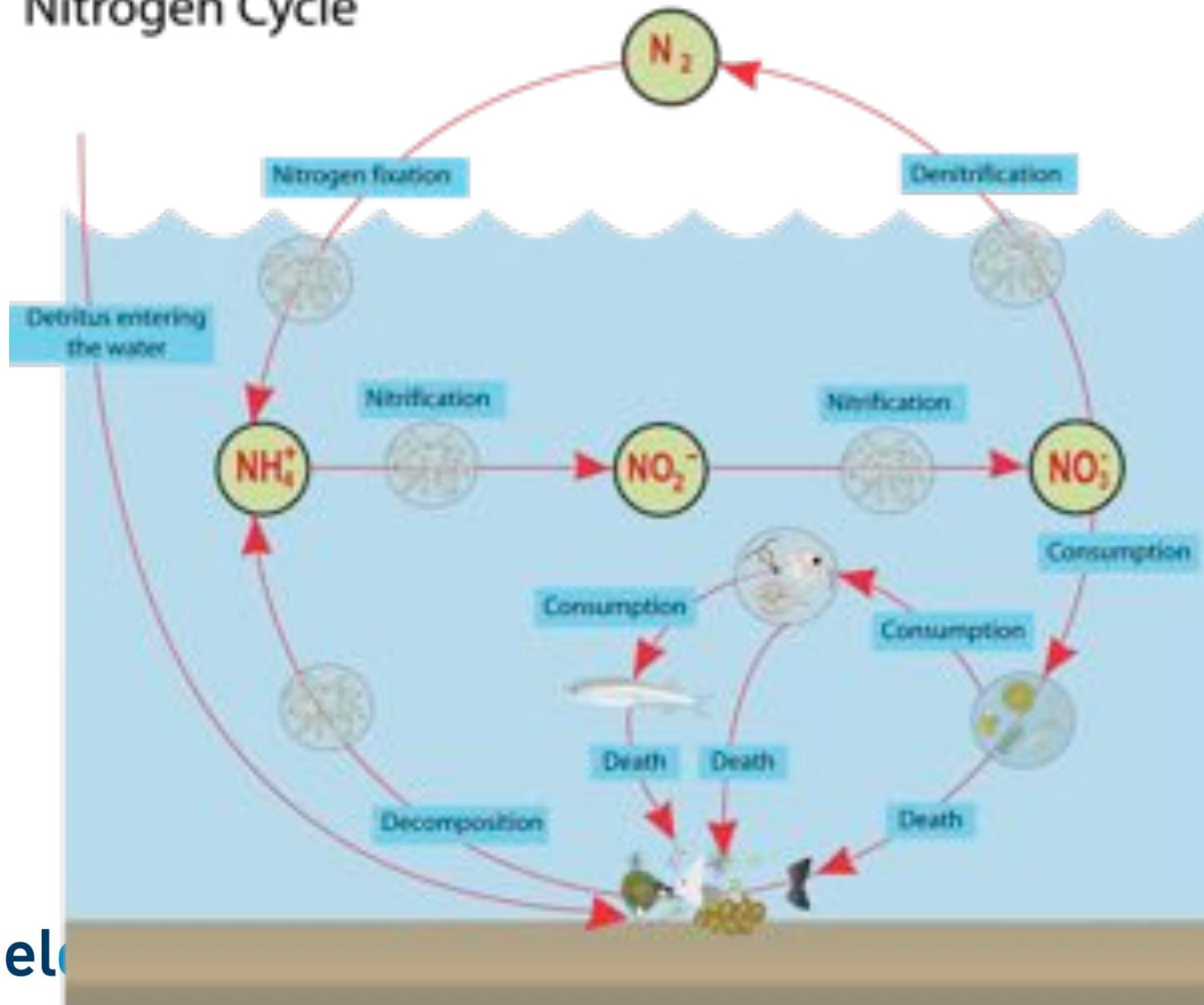


DIC - Dissolved Inorganic Carbon  
DOC - Dissolved Organic Carbon  
POC - Particulate Organic Carbon

GPP - Gross Primary Productivity  
NPP - Net Primary Productivity  
CCD - Carbonate Compensation Depth (a sediment property, where carbonate rain is balanced by carbonate dissolution)

# Element cycles

## Nitrogen Cycle



Bigelo