

# Density in the ocean

Density is primarily determined by **temperature and salinity**

**sinks** → Cold water has a **higher density than** warm water → **floats**  
Salt water has a **higher density than** fresh water → **floats**

Density changes by  $3 \text{ kg m}^{-3}$  if:  
temperature changes by  $15^\circ\text{C}$   
salinity changes by 3 psu

2) Temperature changes of  $15^\circ\text{C}$  are more common than salinity changes 3 psu, so temperature tends to have a bigger effect on density than salinity does. As a general rule, cold water sinks and salt is just carried along with it. More on the next slide.

3) Cold salty water will sink, and warm fresh water will float. But cold fresh water may have the same density as warm salty water. This is part of what makes the ocean interesting.

1) Density is calculated from temperature, salinity, and pressure. Pressure matters because temperature changes with pressure. The full equation to calculate density has many terms, and is called the equation of state for seawater. It can be approximated as:

$$\Delta \text{Density} = \alpha \cdot \Delta T + \beta \cdot \Delta S$$

$\alpha$  and  $\beta$  are coefficients of thermal expansion and saline contraction.

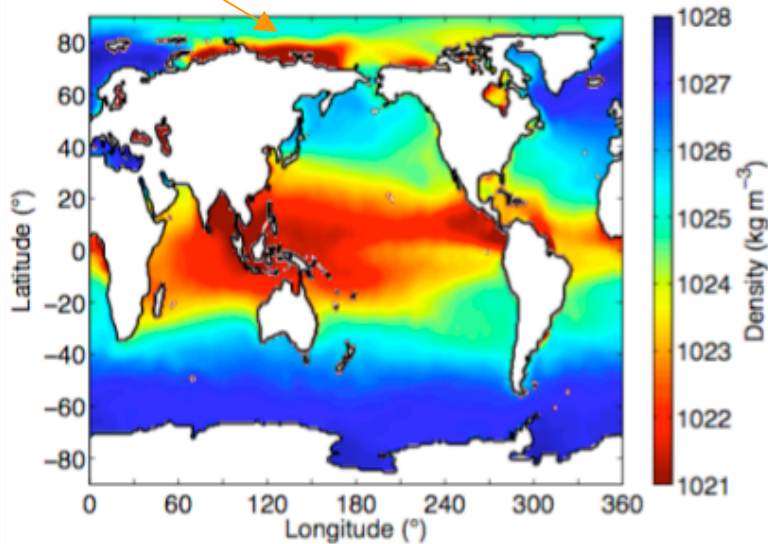
$\alpha$  is roughly  $0.2 \text{ kg m}^{-3} \text{ }^\circ\text{C}^{-1}$

$\beta$  is roughly  $1 \text{ kg m}^{-3} \text{ psu}^{-1}$

These values are where the  $15^\circ\text{C}$  and 3 psu come from. In the ocean,  $\alpha$  and  $\beta$  also depend on salinity, temperature, and pressure.

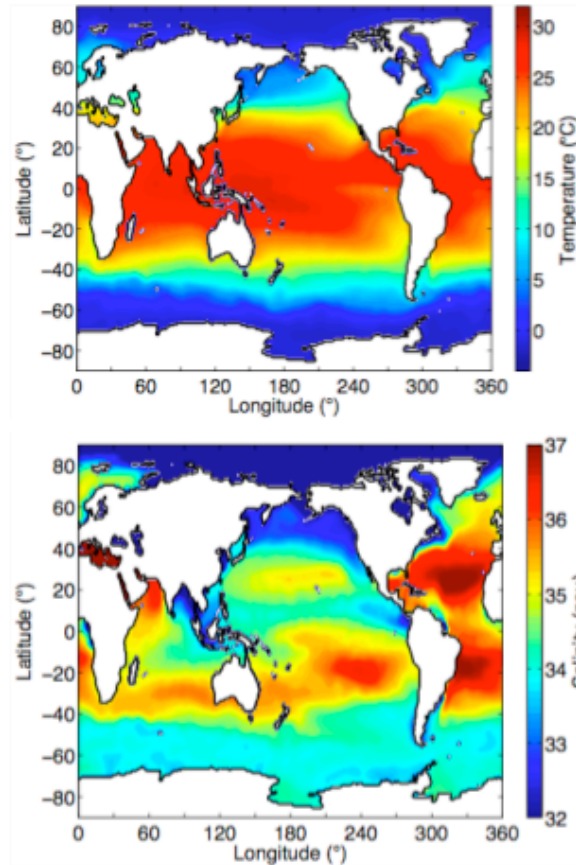
This water is very fresh, and not very dense.

## Density at the Surface



Density is similar to temperature

1) Density is mostly determined by temperature. The densest water is found near the poles, and the lightest water is found near the equator.



2) The coldest water is found near the poles and the warmest water near the equator.

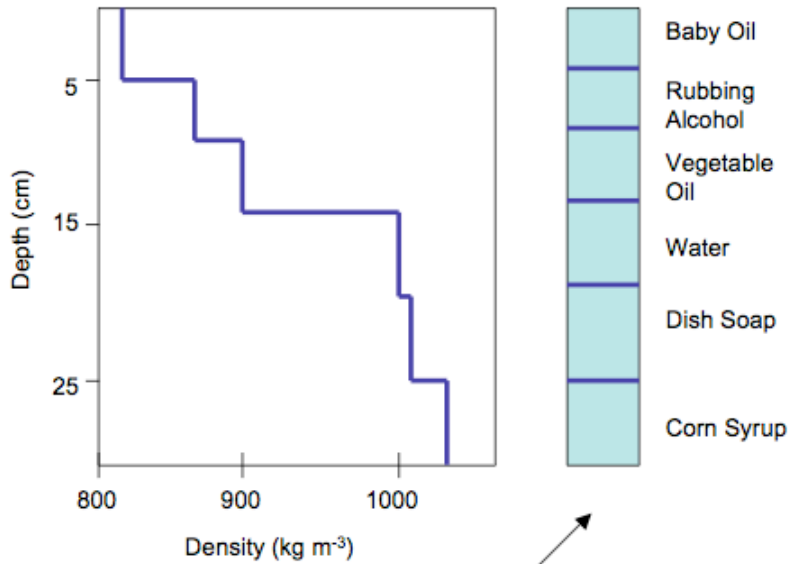
3) The saltiest water is found near the center of the gyres, but this is NOT where the densest water is found.

4) The main point is that temperature will primarily determine where water sinks. There are exceptions to this, and one will be mentioned later (the salty Mediterranean Sea).

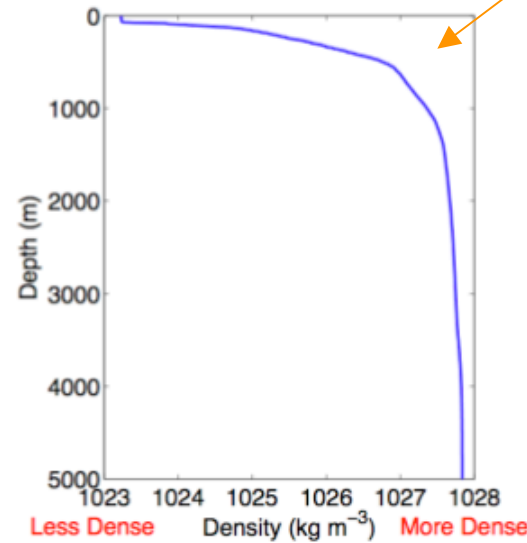
The figures are average temperature, salinity, and density at the surface from the World Ocean Atlas 2005. They are an average of all observations in the last several decades. See [http://www.nodc.noaa.gov/OC5/WOA05/pr\\_woa05.html](http://www.nodc.noaa.gov/OC5/WOA05/pr_woa05.html) for more information.

# Density and Depth

## Water in the ocean has different densities



Liquids Column



Ocean

2) The ocean is a big density column with more layers, and smoother changes between layers. The lightest water is on top, and the heaviest on the bottom.

3) The density profile is smooth because water at any depth mixes a little with water above and below. In most places, most of the water is very dense, with a thin layer of light water near the surface. The profile shown here is from the South Pacific Ocean ( $20^{\circ}\text{S}$ ,  $170^{\circ}\text{W}$ ). It was taken as part of a section from near Antarctica to Hawaii for the World Ocean Circulation Experiment. See '02t.slides.globallayers' (<http://earthref.org/cgi-bin/erda.cgi?n=1014>) for more information.

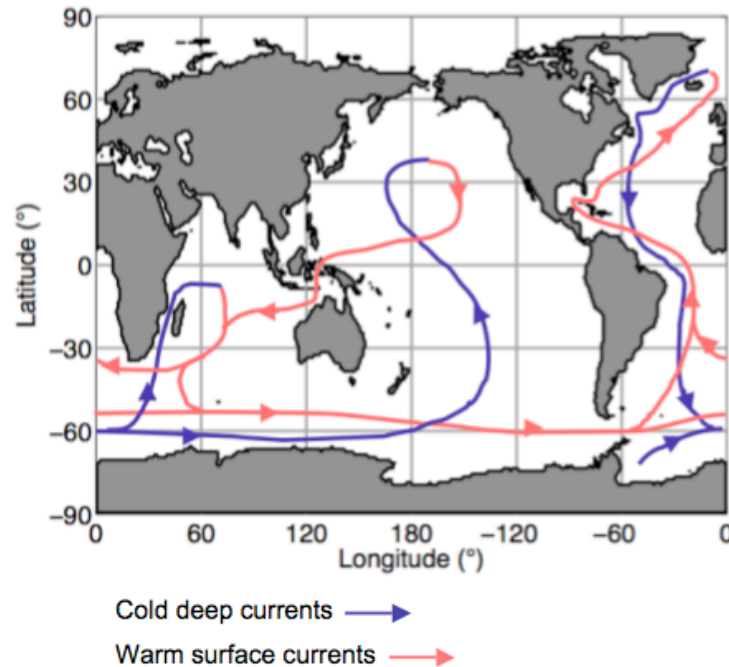
1) This is the approximate density profile for the density column demonstrated at the beginning of class. Some of the layers have a big change in density, and some of them only change a little. It only takes a small change in density for one liquid to float on top of another. The numeric values for each liquid are given in '01t.activity.densitycolumn' (<http://earthref.org/cgi-bin/erda.cgi?n=1001>).

# Density and ocean currents

Changes in ocean density cause deep currents in the ocean.

Dense water sinks quickly, then slowly moves horizontally and rises.

Equal amounts of water sink and rise.



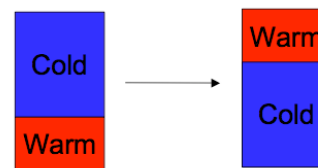
3) For a ninth grader, the important points are that there is a circulation that is global and connects all of the oceans, and the circulation involves the vertical movement of water. This circulation is very different from what happens at the surface. The global conveyor belt is NOT driven by the wind, or organized into gyres. Students should understand that these global currents near the bottom of the ocean are caused by differences in ocean density. Density causes water to sink in some places, which means it will rise in other places and there will be horizontal currents connecting where water sinks and rises.

1) The figure is a schematic of the global conveyor belt circulation after the popular one by W. S. Broecker\*. The conveyor belt circulation is also known as the meridional overturning circulation, or the thermohaline circulation.

2) Scientists are still working on many details of this circulation. It is not even clear what causes the circulation. It may be partially driven by dense water sinking, or by the energy available for water to rise. Lifting cold water from the bottom to the surface takes energy, and that has to come from somewhere. It primarily comes from energy put into the ocean by the tides and winds.

\*Broecker, W S, 1987. The biggest chill. Natural History Magazine, Vol. 97, pp. 74-82.

4) You may want to draw this on the board:



Causes vertical currents. Cold water moves down and warm water moves up.



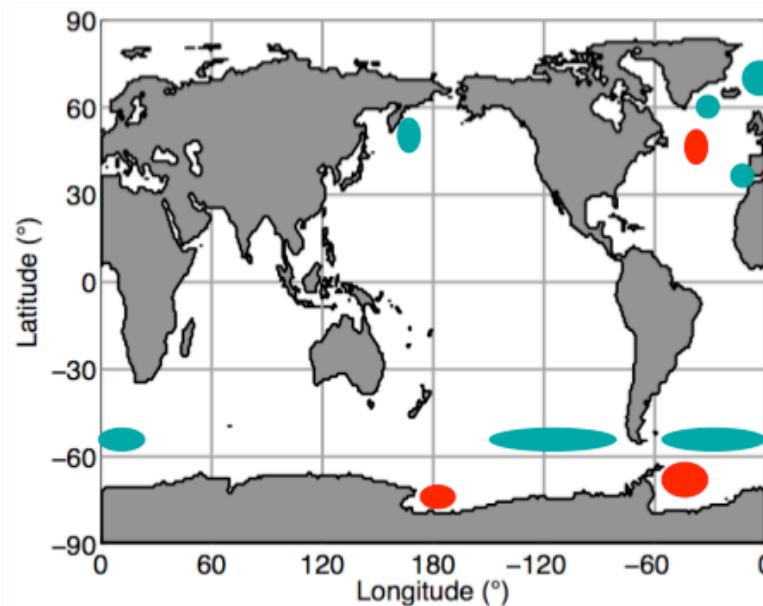
Causes horizontal currents. Cold water moves right and warm water moves left.

# Sinking water

Water that sinks:

- 1) Is dense
- 2) Is found in a few small places near the poles
- 3) Moves quickly

Water will sink in a few days or weeks.



- Sinks to the bottom
- Sinks to the middle

2) The main points are that 1) only dense water sinks, 2) dense water is found in only a few places, usually where water is cold near the polar regions, and 3) sinking happens rapidly compared to rising. Sinking is not a continuous process. If you go to one of these locations, you may or may not observe sinking water. It happens in fits and spurts, and involves interactions with the water, ice, and the atmosphere around it. In some places, water will only sink for a short time in winter.

\*Garrison, *Oceanography: An Introduction to Marine Science*. USA: Thomson Learning, 2002.

1) The figure is adapted from Fig 9.20 of Garrison\*. This shows where water sinks in the ocean, and roughly how deep it sinks.

Red dots: All of the water that sits on the bottom of the ocean sank near these locations. As water sinks it entrains nearby water and is modified as it travels around the globe. Most of the ocean has water that originated near Antarctica.

Green dots: These water masses sink to the middle of the ocean and then spread horizontally. The one by the Mediterranean Sea sinks because it is very salty. The Mediterranean Sea is very salty because there is more evaporation than precipitation there.

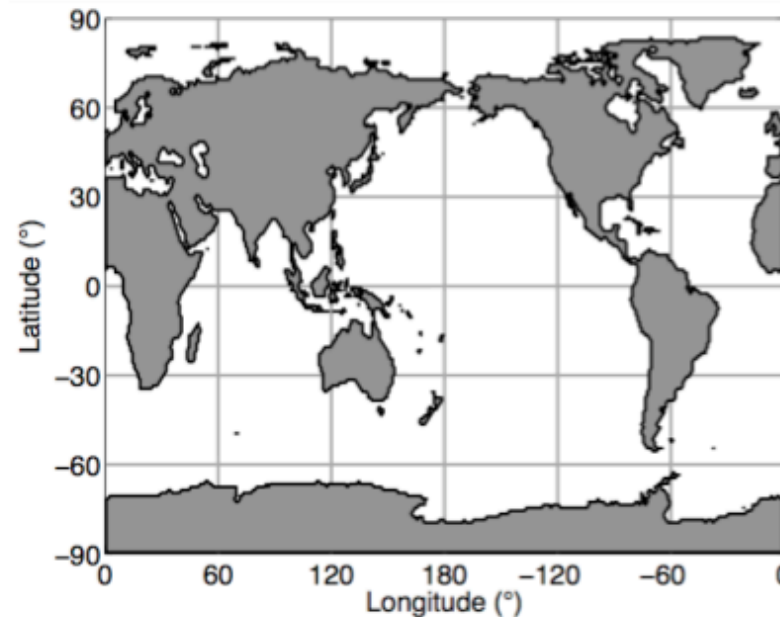
In some places, near Antarctica and Russia, ice is involved in making water denser. When sea ice freezes, it leaves most of the salt behind. This helps to increase the density of nearby and already cold water.

What about the Arctic? Water does sink there, but the bottom topography (underwater hills and mountains) prevents it from spreading around the rest of the ocean. It is trapped in the Arctic.

# Rising water

Water that rises:

- 1) Rises over the whole ocean
- 2) Rises very slowly
- 3) Gradually becomes less dense

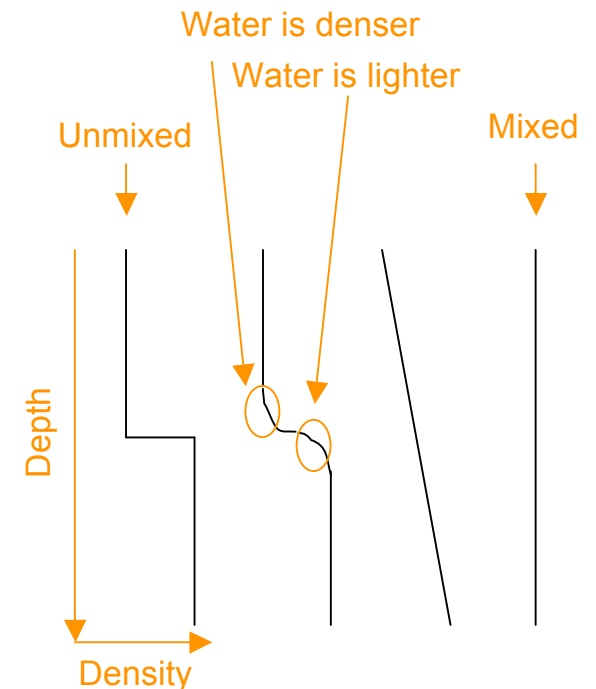


It takes **about 1000 years** for water to rise from the bottom of the ocean to the surface

2) What causes water to rise? Water “rises” or becomes warmer and less dense when the ocean is mixed in the vertical (see the diagram to the right). Vertical mixing happens at smaller scales, parcels 10’s of meters high are mixed together. The mixing occurs when waves break. Just like there are surface waves that break on the surface and mix air into the water and water into the air, there are waves below the surface that mix slightly denser water with slightly lighter water when they break. These are called internal waves and are caused by winds blowing on the surface and tidal currents that run into continental shelves, ridges, or other underwater obstructions.

1) There is no real diagram for where water rises, water rises everywhere very slowly.

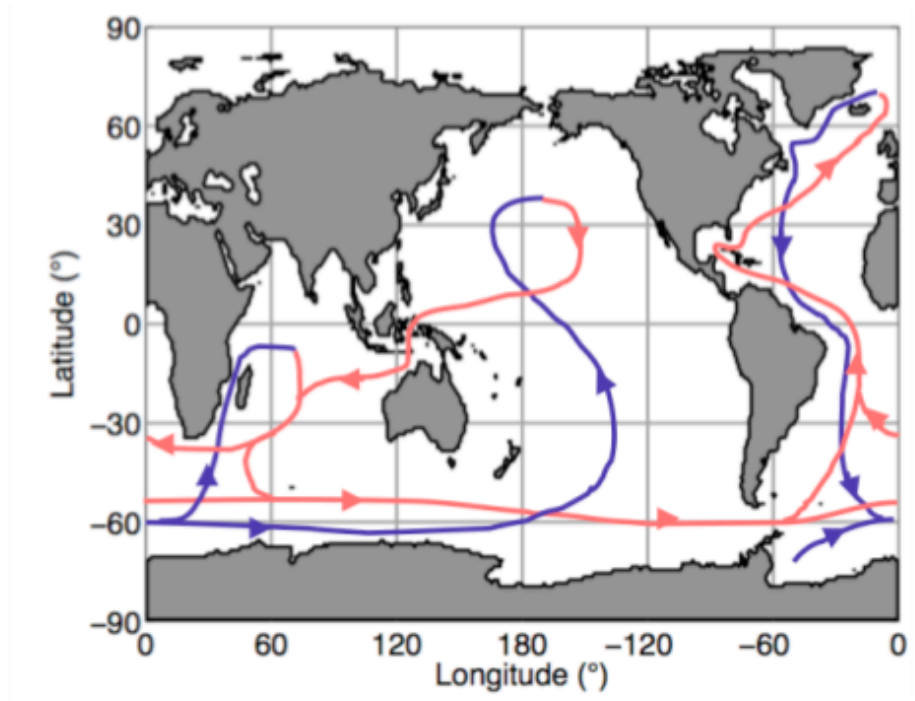
The average speed of water rising is roughly 1cm per day (from Garrison, citation on previous slide). This means that it would take 1095 years to rise 4000 m. This is an average, it may take a few hundred years, or a few thousand years.



# Deep currents

After the water sinks, and while it is rising, it moves around the ocean.

The movement is caused by **changes in ocean density**



This is just a reminder of what the big picture is. The timescale for spreading horizontally around this circuit is about the same as rising, about 1000 years.

Rising water in this diagram is a simplification, it happens everywhere in the ocean. Sinking water really does occur in just a few places.

The figure mainly shows the circulations involved with water that sinks to the bottom. Water that sinks to the middle of the ocean can have similar patterns, with flow between the different ocean basins.

# Why do we care?

1) Just like surface currents, deep currents transport many things. They can transport heat, salt, nutrients, sediment, gasses, pollution, whatever is in the water.

One of the most important things the ocean transports is heat, because this affects our climate on land.

Our climate is also affected by how fast the ocean mixes in the vertical. If the mixing were increased or decreased, our climate would change. Weaker mixing means a greater temperature difference between the surface and the bottom, so the surface would probably be warmer.

Deep currents transport heat around the globe

Deep currents affect our climate: If water took longer to rise, the surface could be **WARMER**

Deep currents bring nutrients from the bottom of the ocean to the surface

2) The third point has to do with nutrients, which is what biology needs to grow. The rising part of this circulation is important for bringing nutrients up from the bottom. If water did not rise, not as much life could grow in the ocean. The global conveyor belt circulation is not the only way for water to rise in the ocean, but it is still important.

