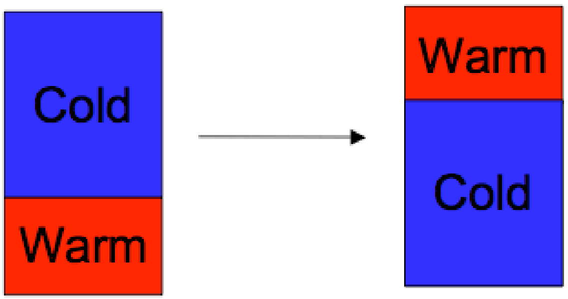
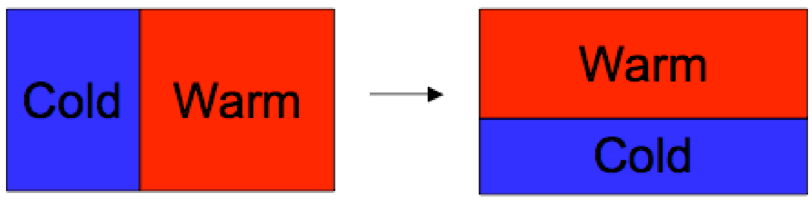
Deep Circulation

Changes in density cause ocean currents



This configuration causes vertical currents. Cold water moves down and warm water moves up.



This configuration causes horizontal and vertical currents. Cold water moves to the right, and warm water moves to the left. Cold water moves down and warm water moves up.

1) This is a review of yesterday's lesson. Differences in density will cause water to move so that warm water is on top. The currents can be horizontal or vertical. In this case, the water would all have the same salinity, so that hot and cold are the same as light and dense.

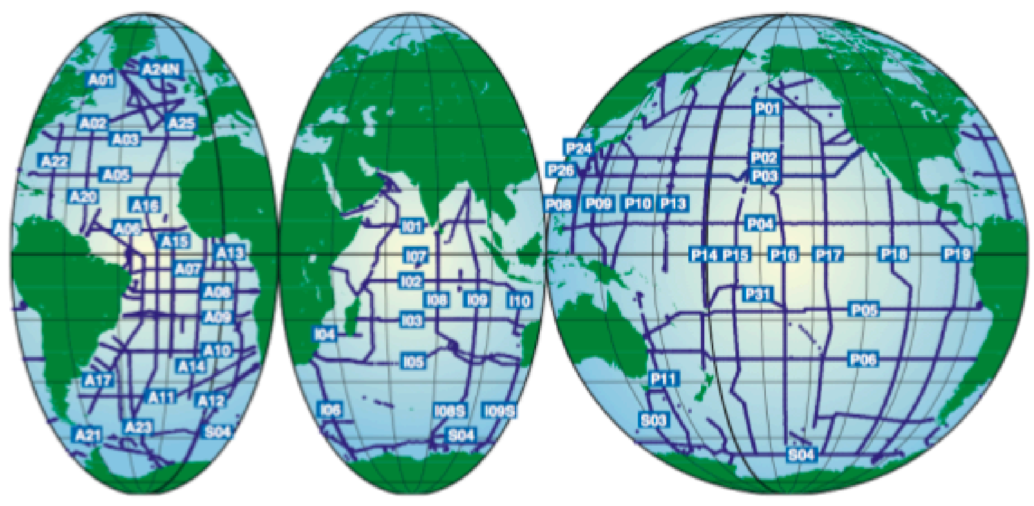
These basic principles happen on many different scales in the ocean, from small bucket sized parcels of water that exchange places in the vertical, to global scale horizontal spreading of dense water under lighter water.

Ocean Layering: Density, Salinity, Temperature, and Circulation
Sylvia Cole, Scripps Institution of Oceanography, San Diego CA
Maureen Quessenberry, University City High School, San Diego CA

How do we know what's near the bottom of the ocean?

World Ocean Circulation Experiment (WOCE)

30 countries working to figure out the ocean circulation



1) The figure shows all of the different slices oceanographers have taken through the ocean from 1990-1998. The labels (P15, P02, etc.) are names for each section. Some of these slices were observed in prior decades as well. Profiles are typically taken every 50 km, with closer spacing where the bottom depth changes quickly, such as near the coasts. The figure is from "WOCE observations 1990-1998: a summary of the WOCE global data resource" published in 2003 by the WOCE International Project Office.

2) WOCE is a multinational program that observes slices of the ocean from the surface to the bottom. Each section takes a dedicated ship of about 20 crew, 30 scientists, 1-2 months, and 1 million dollars. Why so expensive? Ship's are expensive and cost $25,000-30,000 per day to operate. One country alone could not complete all of these observations.

Some of the sections are not perfectly straight lines and have detoured to make port at islands, such as Hawaii. Some of the sections detour around the continents to capture all of the ocean basin.

The primary goal is to take a 'snapshot' picture of the ocean from the surface to the bottom. More on what is measured on the next slide.

More information can be found at: http://woce.nodc.noaa.gov/wdiu/index.htm

Sampling the ocean

Sample temperature, salinity, and more from the surface to the bottom every 50 km.

The R/V Melville, one of the ships used in WOCE. Photo by Robert Todd. More information about the Melville, and all of the ships in the research fleet can be found at: http://www.unols.org/images/ships/shipimages.html.

A CTD rosette, the instrument used to profile from the surface to the bottom. The gray tubes are the bottles used to capture the water from different depths. Photo by Robert Todd.

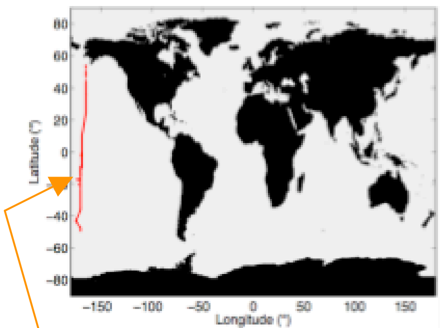
1) To obtain a profile, a rosette with bottles and other instruments is lowered to the bottom. On the way up, the rosette is stopped at certain depths and a bottle is snapped closed using an electronic trigger mechanism. This allows water from different depths to be brought to the surface for analysis. Profiles are taken every 50 km to complete a section through the ocean.

Temperature, salinity, oxygen, fluorescence, and pressure are sampled continuously on the way down and the way up. Water is collected at certain depths, usually about 36 of them. From the sampled water, we can determine: oxygen, salinity, dissolved organic carbon, dissolved organic nitrogen, concentrations of ^{14}C, SF_6, CFC-11, CFC-12, Helium/Tritium ratios, and more.

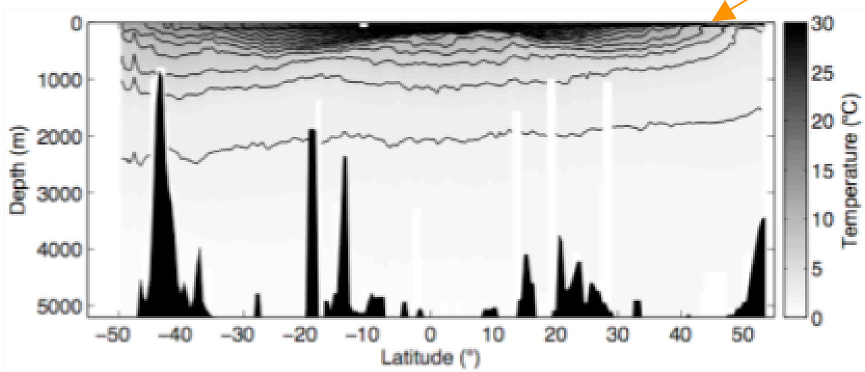
2) The data are publicly available and used by scientists around the world. (see link on previous slide).

Bottom Line: This allows us to sample many properties to the bottom of the ocean, which is something that cannot be currently done any other way.

Vertical slices of the ocean



The red line shows which section we are looking at



2) Temperature observations along the section as a function of depth. The two surface gyres are evident as shallow bowls of warm water. Temperature below 3000 m is very uniform.

Temperature changes quickly as you go down from the surface

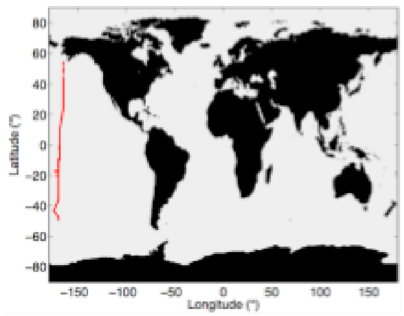
The bottom of the ocean all has about the same temperature

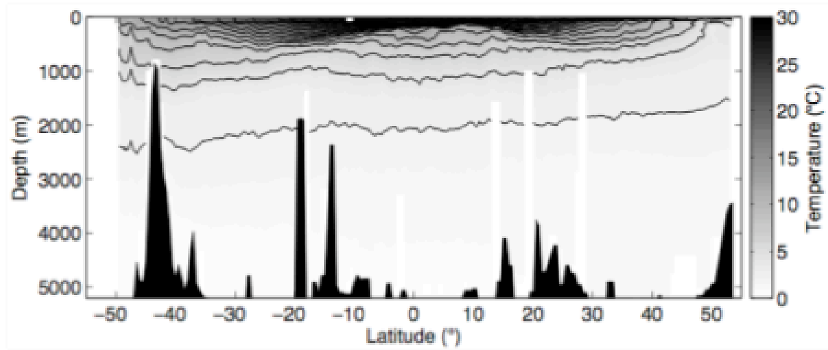
1) This slide shows a slice through the ocean at approximately 160-170°W. It was taken in two segments, from the south Pacific to Hawaii in Jan-Feb 1996, and from the equator to Alaska in Sept-Oct 1994. The section does not start right at Antarctica because the ship used was not equipped to operate near ice.

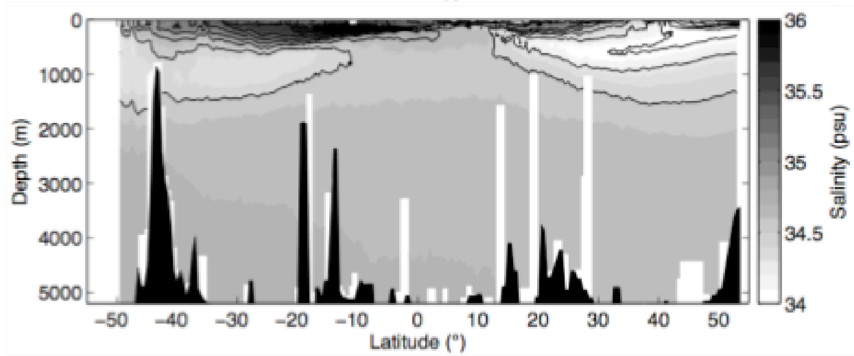
The temperature section clearly shows vertical layering. Students may be confused by the term ‘vertical layers’ because it refers to horizontal layers stacked in the vertical.

The temperature contours are not perfectly straight and wiggle up and down slightly. These are perturbations at 50 km scales and larger and occur all over the ocean. Most of the figures in text books are schematics or long term averages, and so do not have this structure.

Vertical slices of the ocean







How is salinity similar or different from temperature?

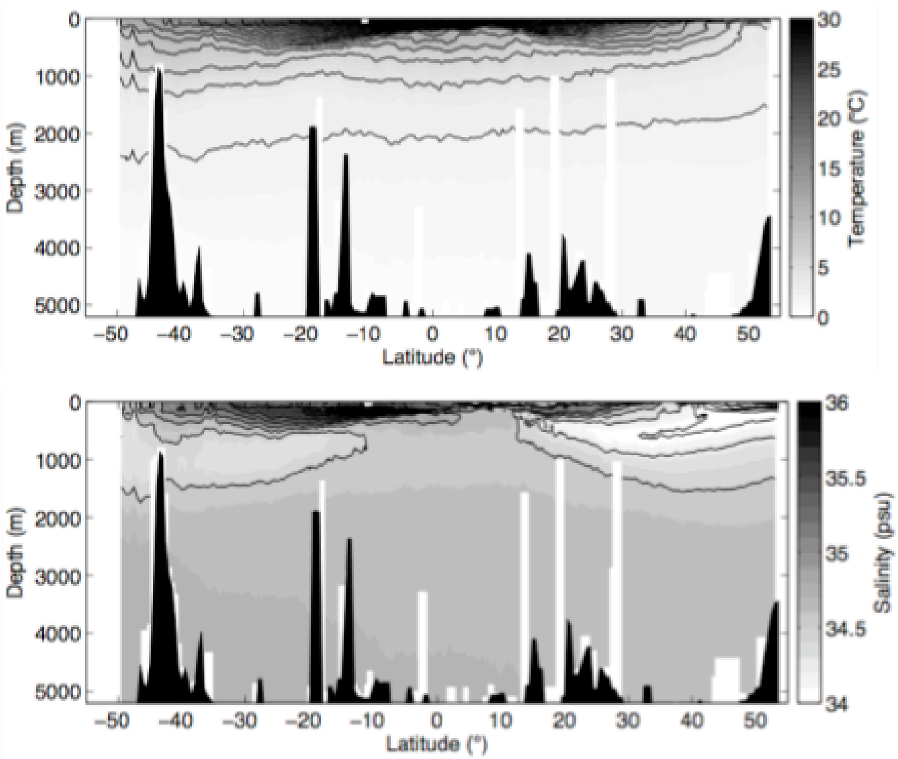
1) Salinity is similar to temperature in that salinity near the surface changes quickly as you go down, and the ocean mostly has the same salinity below 2000 m.

Salinity is different from temperature because of the fresh tongues of low salinity near 1000 m depth. The lowest values are NOT at the bottom of the ocean. The students will probably be able to trace the fresh salinity back to the surface and tell you that is where it came from. The water is spreading laterally and brining the fresh salinity with it.

2) As you move towards the equator, the fresh salinity tongues slowly get saltier because they mix with the surrounding saltier water. In the southern hemisphere, the tongue is weaker than in the north and the section did not go far enough south to see its surface signature.

3) The main point is that the vertical structure can tell you information about the water, like where it came from. Just like you can trace the colors in clay that has been mixed together to determine what happened to it, you can trace the colors in salinity sections to determine where the water came from and what has happened to it.

Vertical Layering



Vertical layers can show

1) where the water has come from

2) the ocean currents

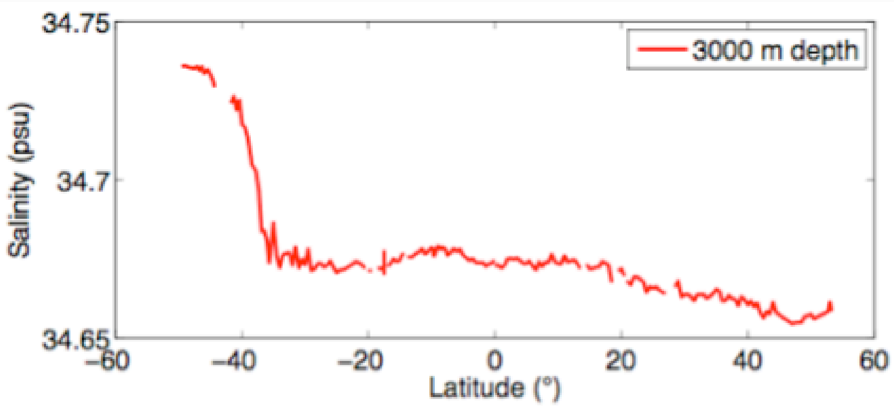
3) how the ocean water is mixed

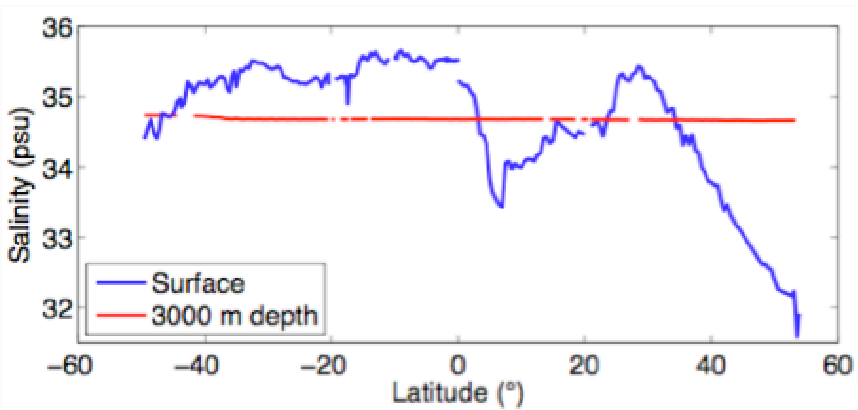
1) The second and third points probably need to be explained.

If the surface currents were different, and there were more gyres for example, it would be apparent in the vertical sections. Properties would change not just at the surface but in the upper 1000 m or so. If currents near the bottom were different, if they were faster, then properties would change near the bottom.

2) If the water mixed more with what was around it, the salinity tongue would be weaker or not even there. If the water mixed less, than the tongues would be stronger. The values at the surface and bottom would also be different. If mixing increased, then more heat would be carried down from the surface, the surface would be cooler, and the bottom would be warmer.

Surface vs. Bottom





The water near the bottom of the ocean

1) is NOT all the same

2) shows where the currents are

1) The top picture shows salinity along the same section at 3000 m depth. The change across the whole section is less than 0.1 psu. Salinity does wiggle up and down near the bottom, because there is motion near the bottom of the ocean. There are global scale currents, local currents, and waves.

The bottom picture shows the same salinity at 3000 m depth in red, and salinity at the surface in blue. Salinity at the surface changes by almost 4 psu. In comparison, there is more happening at the surface.

2) How can this tell you where the currents are? Just from salinity at 3000 m depth, you can't really tell. It is the vertical structure near the bottom of the ocean that shows the salty portion near 50°S is moving down and spreading north.

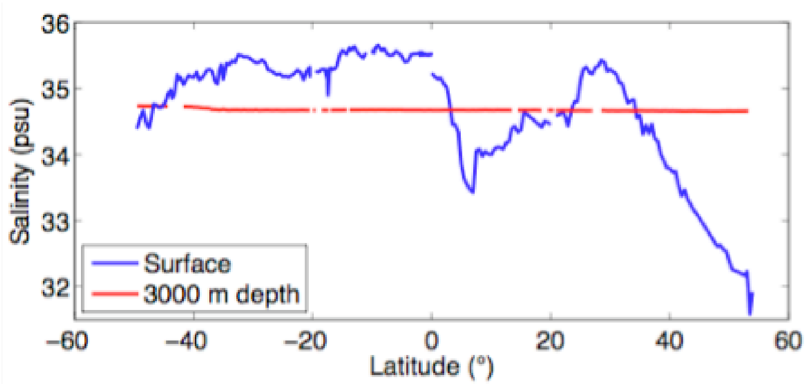
3) The main point here is that while there is more happening at the surface, the deep ocean is interesting, it moves and changes and is not just still water.

Surface vs. Bottom

Why are the largest changes at the surface?

This is where the atmosphere can change the ocean

Salinity from evaporation, precipitation, or river runoff
Temperature from energy from the sun or wind



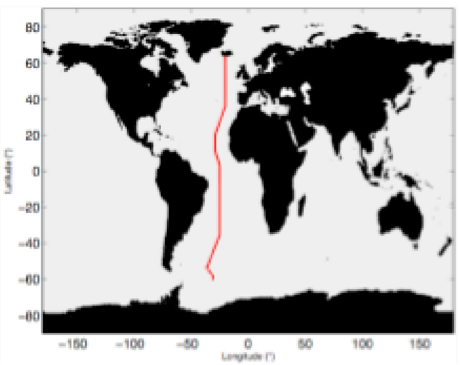
2) Bottom line: The surface of the ocean varies a lot more than the bottom of the ocean because this is where the atmosphere can influence the ocean.

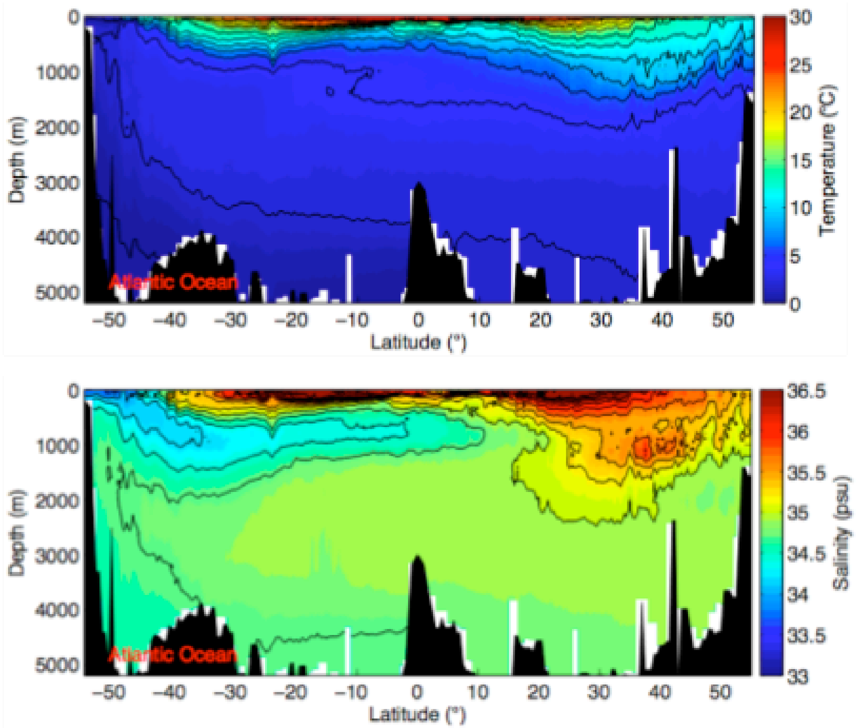
1) Why is the surface so much more active than the bottom? All of the processes that can easily change salinity or temperature happen at the surface.

Evaporation, precipitation, river runoff, ice formation, or ice melt all occur at or near the surface.

With temperature, energy from the sun or lack thereof will make the surface warmer or cooler. How far down the sun can heat the ocean depends on how clear the water is. For most of the ocean, some light reaches the upper 100 m, or the upper 2-3% of the ocean. Energy from the wind also changes the temperature near the surface. Strong winds will mix the upper portion of the ocean, frequently mixing the warm water near the surface with cooler water below. Again, this is a surface process.

Atlantic Sections



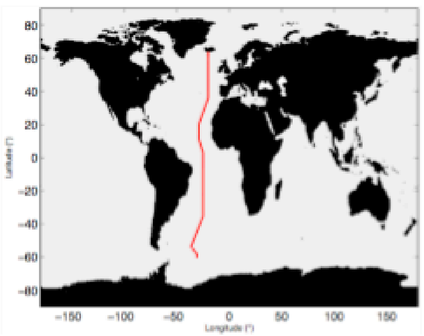


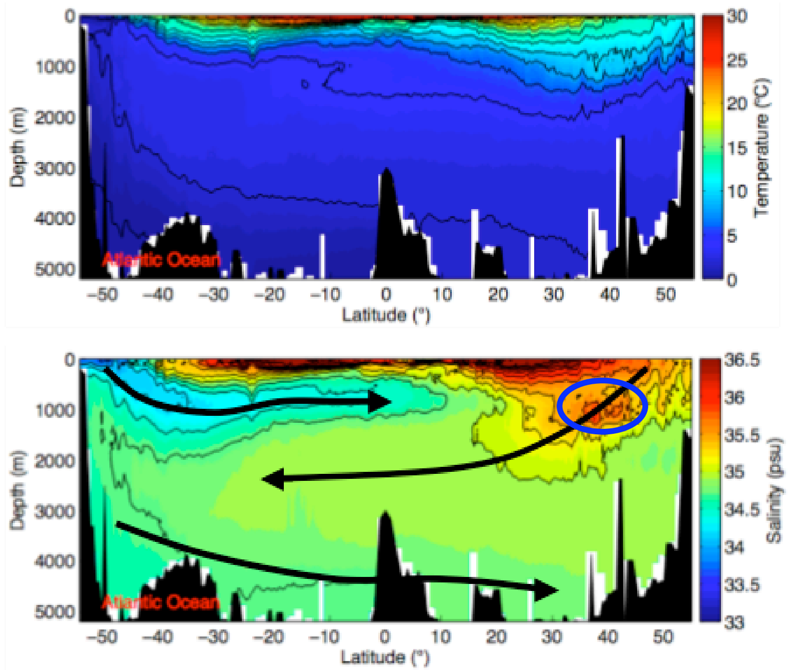
1) This introduces students to the activity ‘02t.activity.globallayers’ (http://earthref.org/cgi-bin/erda.cgi?n=1010). Students will look at a section through the Atlantic ocean. The section was taken in two pieces, from the South Atlantic to 5°S in Jan-Feb 2005, and from 5°S to Iceland in June-July 2003.

2) Introduce the students to the sections, point out what blue means in the top figure and what blue means in the bottom figure. Point out where the section is on the map.

See ‘02t.activity.globallayers’ (http://earthref.org/cgi-bin/erda.cgi?n=1010) for more information.

Atlantic Sections





1) The salinity section here is one example of how you might guess the water is flowing based on salinity (question #5 from the handout).

Just like when you mix two different colors of clay, tracing the different colors can help you decide where the water came from.

The circulation represents the long-term average north-south circulation.

See ‘02t.activity.globallayers’ (http://earthref.org/cgi-bin/erda.cgi?n=1010) for more information.

2) A note about the high salinity patch that is circled in blue: This is water that comes from the Mediterranean Sea, sinks, and spreads west. Because there is excess evaporation in the Mediterranean Sea, the water is very salty, more dense than the surrounding water, and sinks.