**Real World Globes – Exploring Deep-Ocean Water Masses**

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**Purpose:**

- To discuss the global "thermohaline circulation", the mechanisms by which it operates, and the measures implemented to quantify water mass age.
- To perform basic plotting on a gridded surface, and to recognize patterns inherent within the plotted data.
- To practice basic conversions and calculations when provided a formula and values.

**Target Audience:**

- Non-science Major Undergraduates
- Science Major Undergraduates

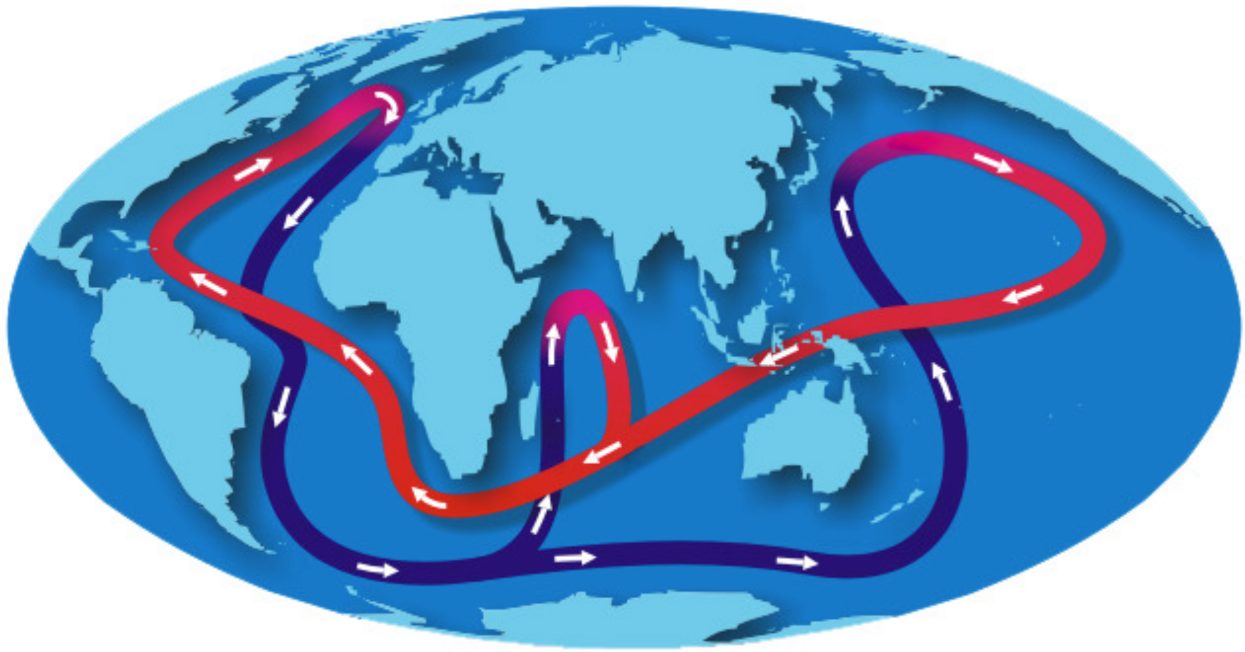
**Materials:**

- Mother Earth Globe™
- Great Circle ruler and grid
- Transparent Atlantic Salinity Overlay
- Dry-erase markers, eraser, and calculator

**Introduction:**

The world's oceans are layered, separated by differences in temperature and salinity. This stratification results in a differentiation of large bodies of the deep ocean into separate *water masses,* specifically defined by their temperature and salinity values. These water masses acquire their distinctive characteristics from their point of origin: either from the North Atlantic within the Norwegian/Greenland Seas, or from the Weddell Sea off the coast of Antarctica. At these two regions of the globe, natural processes increase the density of the ocean water that sits at the surface. In consequence, the surface water sinks into the deep ocean, where it begins its journey around the world's oceans as a part of the interconnected global "conveyor belt" of ocean currents known as the *thermohaline circulation* (see picture below).

As well as temperature and salinity, defining chemical characteristics, such as radiocarbon ($^{14}C$) concentrations, create noticeable distinctions between different water masses. $^{14}C$, a radioactive variant of carbon with a half-life approximately 5,700 years, is used to *carbon date* the age of these water masses, which tells us how long it takes to make one trip around the "conveyor belt". $^{14}C$ is produced in the atmosphere, transformed from elemental nitrogen by cosmic radiation. When surface waters are in contact with the atmosphere, the amount of $^{14}C$ in the ocean equilibrates with the atmosphere. Once those surface waters sink into the deep ocean, that water mass stops acquiring new $^{14}C$, and the $^{14}C$ already in the water mass begins to decay. This is analogous to starting a stopwatch the minute the water ceases contact with the atmosphere; from that point onward, the time since the water was at the surface of the ocean can be calculated. This is what we refer to when we speak of the water's "age".



*The global thermohaline circulation begins with the sinking of cold, salty water in the North Atlantic. From there, the water travels south, around Antarctica, and eventually into the Indian and North Pacific Oceans, where it rises to the surface and begins the journey back to the Atlantic.*

**Activity:**

An oceanographic vessel has just returned from two months at sea. The research team traveled down the center of the Atlantic Ocean from Rekjavík, Iceland to South Georgia Island near the Antarctic Peninsula. Along their transect of the Atlantic Ocean, they stopped at a number of stations and took vertical measurements of the $^{14}C$ concentration.

**1** – Assemble the globe. Place the grid atop the Great Circle and orient the circle so that it travels through the Atlantic Ocean.

**2** – Label the x-axis of the Great Circle grid "Latitude (°)" and label each vertical line with latitude values. (The center of the grid should be labeled 0° due to its position on the equator – one box on the grid is equivalent to 2°). **Remember:** Positive latitude values are to the north of the equator, where negative latitude values are to the south. Also, label the y-axis "Depth (m)" and label each horizontal line from the outside of the circle inward (beginning with 0 at the surface – each box is equal to 300 m).

**3** – Orient the Great Circle with superimposed grid so that it aligns down the center of the Atlantic Ocean.

**4** – Plot the points listed in Table 1 on the grid and label the $^{14}C$ age next to each point.

If waters receive their $^{14}C$ signature from the atmosphere, one would expect the waters closer to the surface to be “younger” than the waters deep within the ocean (where most $^{14}C$ has already decayed away). Do you see this pattern in the plotted data? Are there any exceptions? Circle them.

Using what you know about thermohaline circulation, what might be causing these reversals in $^{14}C$ age? Make an educated guess.

**5** – Let’s see if all waters at the same depth have the same $^{14}C$ age. Look at the $^{14}C$ age at 52°N and 1800 m depth (82 years). Draw a line from that point to the next point at 1800 m. Connect each point at 1800 m until you reach the equator. Label this line ‘A’. Look at the ages of each point. How does the $^{14}C$ age vary from the North Atlantic to the equator?

**6** – Let’s do the same exercise but starting in the South Atlantic. Look at the $^{14}C$ age plotted at -72°N and 900 m depth (52 years). Draw a line from the point to the next point at 900 m. Connect each point at 900 m until you reach the equator. Label this line ‘B’. Look at the ages of each point. How does the $^{14}C$ age vary from the North Atlantic to the equator?

Not only do the ages seem to get older as we move from the surface to the ocean floor, but it seems like ages get older from the poles to the equator. Is this true for *all* depths? What might be the cause of this?

**7** – Once everyone has completed the above assignments, I will pass out a transparent ring to lay overtop of your plotted data. Make sure that the figure lines up with 66°N and -72°N latitudes (your data will otherwise not match the patterns in the figure).

The transparent overlay illustrates the different water masses that flow in the Atlantic Ocean. The large body to the North, North Atlantic Deep Water (**NADW**), originates from the Norwegian/Greenland Seas (as mentioned in the introduction) and flows south towards Antarctica. Look again at line 'A' that you drew earlier. Knowing what you know about **NADW**, why do you think the $^{14}C$ ages got older from the North Atlantic to the equator? Explain.

Now look at line 'B' to the south. Within which water mass is this line located? Do you think the same process you mentioned above accounts for the increase in age from the South Atlantic to the equator?

Now look at the data points you circled where there was an age reversal. Do these points both exist within a water mass or do they exist at the boundary between two water masses? Why would one water mass be older than the other?

**Additional Activity for Science Major Undergraduates:**

Knowing the age of two parcels of water at two given locations allows us to calculate the velocity at which the water is flowing. Knowing how fast water masses are flowing tells us something about how fast the larger thermohaline circulation is moving (which is important for calculating ocean mixing times, heat transport, and a bunch of other pieces of important oceanographic information that we're not focused on here). We will be calculating the velocity of **NADW** along line 'A' and Antarctic Intermediate Water (**AAIW**) along line 'B'. **Remember:** Velocity is *distance* divided by *time*, often reported as meters per second (m/s).

**Make sure to show ALL of your work on the attached page!!!**

**8** – First, we need to convert our latitude coordinates in degrees to distance measurements in meters. Find the distance in degrees between the first and last points of line 'A'. Using the conversion that 1° = 111,000 m, how far apart are the two points?

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**9** – Now, we must compute the difference in age between the last point and the first point and convert that into seconds. Using the conversion that 1 year = 31,536,000 s, what is the time difference between the two points?

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**10** – Finally, take the answer from question 8 and divide it by the answer from question 9. What is the velocity of **NADW**?

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**11** – Now let's do the same steps for line 'B'. Compute the distance between the first and last points, calculate the time difference, and divide them just as outlined above. What is the velocity of **AAIW**?

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Is **NADW** or **AAIW** faster? Circle the correct answer.

**SHOW ALL OF YOUR CALCULATIONS! DO NOT FORGET TO INCLUDE UNITS!**

*Table 1 – Radiocarbon Ages from Atlantic Ocean cruise*

| Latitude (°N) | Depth (m) | $^{14}C$ Age (Years) |
|---|---|---|
| 52 | 0 | 16 |
| 52 | 900 | 57 |
| 52 | 1800 | 82 |
| 52 | 2700 | 98 |
| 40 | 0 | 23 |
| 40 | 900 | 92 |
| 40 | 1800 | 121 |
| 40 | 2700 | 141 |
| 40 | 3600 | 168 |
| 34 | 0 | 21 |
| 34 | 900 | 114 |
| 34 | 1800 | 207 |
| 34 | 2700 | 225 |
| 34 | 3600 | 229 |
| 34 | 4500 | 316 |
| 24 | 0 | 42 |
| 24 | 900 | 215 |
| 24 | 1800 | 398 |
| 24 | 2700 | 401 |
| 24 | 3600 | 418 |
| 8 | 0 | 11 |
| 8 | 900 | 451 |
| 8 | 1800 | 462 |
| 8 | 2700 | 471 |

| Latitude (°N) | Depth (m) | $^{14}C$ Age (Years) |
|---|---|---|
| 8 | 3600 | 478 |
| -11 | 0 | 7 |
| -11 | 900 | 253 |
| -11 | 1800 | 573 |
| -11 | 2700 | 599 |
| -11 | 3600 | 362 |
| -26 | 0 | 27 |
| -26 | 900 | 196 |
| -26 | 1800 | 622 |
| -26 | 2700 | 234 |
| -26 | 3600 | 301 |
| -46 | 0 | 9 |
| -46 | 900 | 122 |
| -46 | 1800 | 715 |
| -46 | 2700 | 284 |
| -46 | 3600 | 392 |
| -60 | 0 | 16 |
| -60 | 900 | 69 |
| -60 | 1800 | 111 |
| -60 | 2700 | 197 |
| -60 | 3600 | 219 |
| -72 | 0 | 10 |
| -72 | 900 | 52 |