Modeling the Formation of Ocean Currents

Subjects: Science, Writing, Speaking & Listening, Environmental Education, Art

Grades: 5 – 12

Duration: 45 – 60 minutes

Vocabulary
- Density
- “Great conveyor belt”
- Saline solution
- Salinity
- Thermohaline circulation

Overview

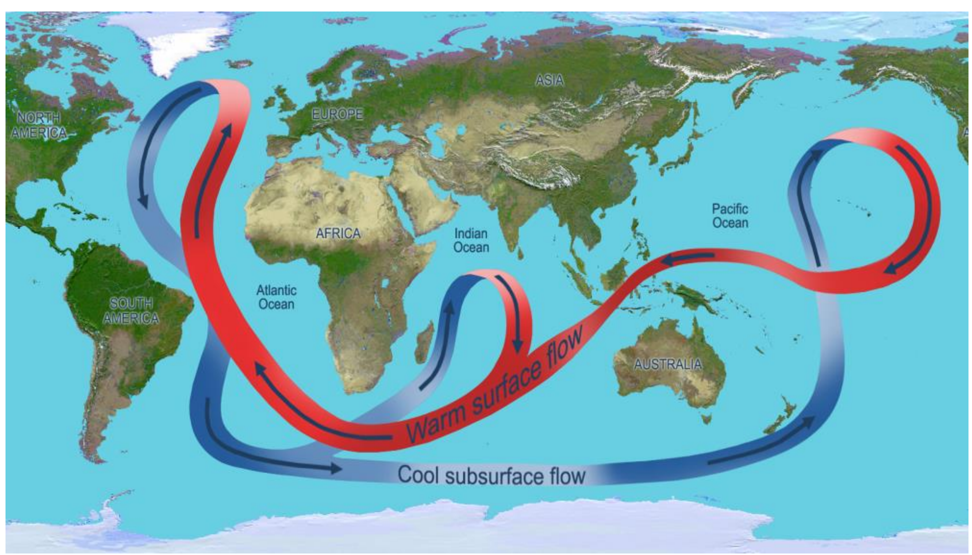
Students do experiments with models of ocean saltwater, cold seawater, and warm water to help them understand how cold water and salty water are denser than warm and less salty water. This prepares them to understand the important process of the “great conveyor belt” of water and energy through Earth’s interconnected global ocean. A variety of Enrich / Extend activities are listed at the end of the lesson to help you meet the needs of all learners.

Guiding Questions

- How and why does ocean water move?
- Why is that process important for life on Earth?
- How might the process be changing due to human activities?
- How can we help restore balance to thermohaline circulation patterns on Earth?

Objectives

- Students will measure salt accurately to create saline solutions to model seawater of different salinity levels.
- Students will experiment with different saline solutions and freshwater and demonstrate understanding that increasing salinity increases water density.
- Students will create models of warm and cold seawater and slowly mix them together, then demonstrate understanding of how decreasing water temperature increases its density.
- Students will form hypotheses to predict the results of their experiments, record their observations, and compare the results with their predictions in writing.

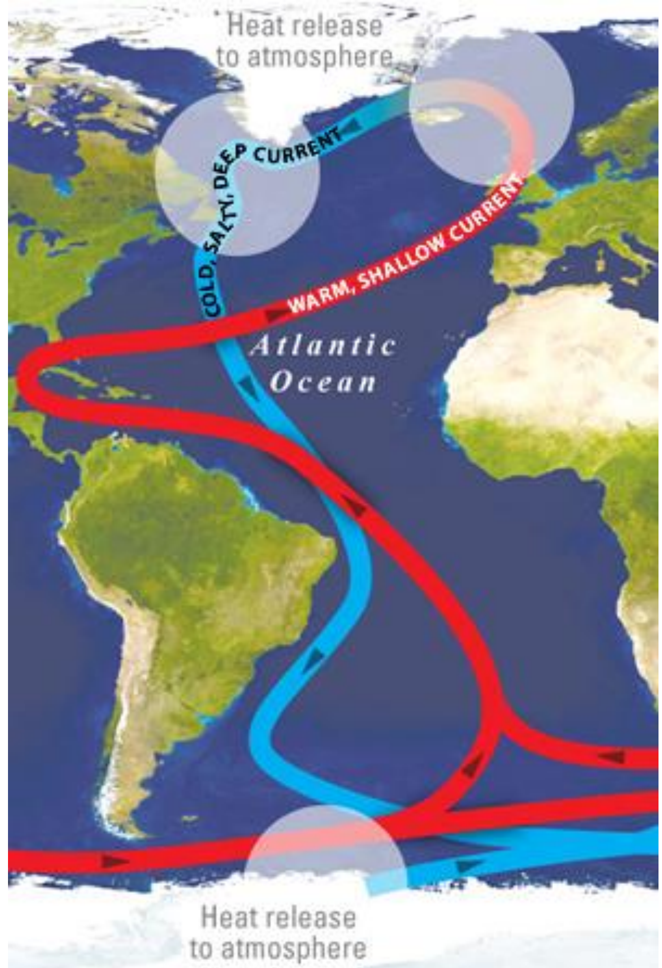


Model showing thermohaline circulation around Earth
jpl.nasa.gov/images/earth/20100325/atlantic20100325-full.jpg

Next Generation Science Standards + Common Core State Standards		
Next Generation Science Standards	Performance Expectations	**5-ESS2-1.** Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact. **MS-PS1-4.** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. **HS-ESS3-6:** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity. **MS-ESS3-5:** Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.
	Crosscutting Concepts	• Cause and Effect • Energy and Matter • Stability and Change • Systems and System Models
	Science & Engineering Practices	• Developing and Using Models • Constructing Explanations and Designing Solutions • Engaging in Argument from Evidence • Obtaining, Evaluating, and Communicating Information
	Disciplinary Core Ideas	**ESS2.A: Earth's Materials and Systems** **ESS2.B: Human Impacts on Earth Systems** **ESS2.C: The Roles of Water in Earth's Surface Processes** **ESS2.D: Weather and Climate** **ESS3.D: Global Climate Change**
ELA	**Writing**	4, 10
	Speaking & Listening	1, 2
	Language Standards	1, 2, 3, 6
	Writing Standards Science & Technical Subjects	4, 7, 10
California's Environmental Principles and Concepts	**Principle II—People Influence Natural Systems** The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human society. **Concept A.** Direct and indirect changes to natural systems due to the growth of human populations and their consumption rates influence the geographic extent, composition, biological diversity, and viability of natural systems.	

Teacher Background

Ocean water is always moving, partly because of winds and tides, but also because of a process called **thermohaline circulation**. These are ocean **currents** caused by water **density differences** resulting from differences in water **temperature** (thermo-) and **salinity** (-haline). For instance, as warm water flows north toward Iceland, it cools, which makes it denser. As some ocean water begins to freeze, the salt precipitates out, and the seawater that remains liquid becomes saltier, which makes it even denser. As a result, the water sinks, while more warm water flows up from the tropics to take its place. This "great ocean conveyor belt" has enormous impacts on climate and life systems around the globe, particularly in places that are close to it, such as Europe, and in areas where layers of nutrients are mixed.



Adapted from "Great Ocean Conveyor Belt." NOAA: pubs.usgs.gov/pp/p1386a/images/gallery-2/full-res/pp1386a2-fig31.jpg

As students conduct hands-on experiments with water of differing densities, they will build the foundation for understanding how these currents form, as well as how the important circulatory system can become weakened.

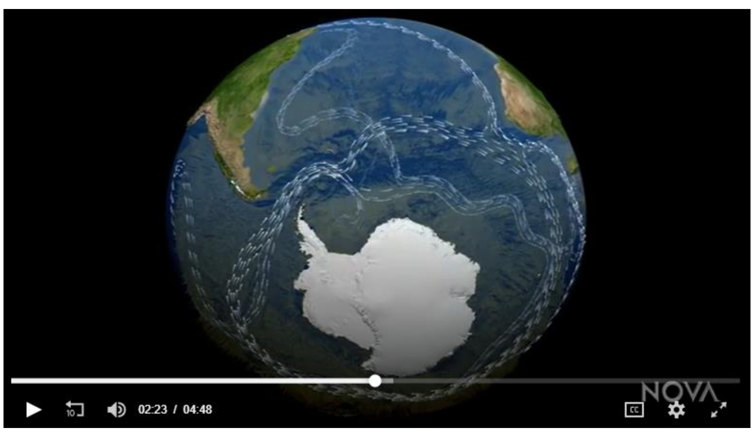
Over the long term, these circulation patterns seem to maintain a balance that moderate climate. However, freshwater ice in places like Greenland is now melting at a rapid rate, accelerating flows of freshwater and ice into the ocean, which is altering thermohaline circulation patterns, including the Gulf Stream, which helps to moderate the climates of places like Europe, that might otherwise become significantly colder, and the Caribbean, which might become much hotter.

Human activities including the burning of fossil fuels are warming the planet, which scientists believe are the cause of the accelerating changes. Rising carbon dioxide and methane concentrations in the atmosphere are already causing the planet to heat up. At the same time that greenhouse gases have been increasing, average global temperatures have risen 0.8 degrees Celsius (1.4 degrees Fahrenheit) since 1880, with the Arctic and Antarctic warming considerably more, leading to more ice melt and more warming.

This rise in temperature isn't all the warming we will see based on current carbon dioxide concentrations. Greenhouse warming doesn't happen right away, because the ocean soaks up heat. This means that Earth's temperature will increase at least another 0.6 degrees Celsius (1 degree Fahrenheit) because of carbon dioxide already in the atmosphere. The degree to which temperatures go up beyond that—and how much ice melts, changing circulation patterns—depends in part on how much more carbon humans release into the atmosphere.

Materials + Preparation

- For each student group (2-4 students):
    - Clear container (plastic or glass) about the size of a shoebox (or an actual shoebox)
    - Tap water
    - 4 paper cups
    - Blue, green, and red food coloring
    - Ice cube
    - 2 clothespins, other clips, or tape (to attach cup to container)
    - Cup of salt
    - 2 one-liter beakers, 2 60-ml cups, or similar-sized containers
    - Stirrers (such as coffee stirrers or teaspoons)
- 4 or more scales or baking tablespoons/teaspoons for student groups to share and measure salt
- ***Optional:*** Make your own experimental setup ahead of time to show students before they make their own setups.
- ***Optional:*** Gain more background knowledge from sources such as the ones listed below and in the "More Resources / References" section at the end of the lesson. You could also share one or more of them with your students and discuss them.
    - "Global Ocean Circulation" video from NOVA, which includes discussion questions and more resources: opb.pbslearningmedia.org/resource/nves.sci.earth.oceancirc/global-ocean-circulation/#.WZyXqlV96xA



    - "The Gulf Stream Explained" video: youtube.com/watch?v=UuGrBhK2c7U
    - "Currents: The Global Conveyor Belt." NOAA: oceanservice.noaa.gov/education/tutorial_currents/05conveyor2.html
    - Osborn, T. and Kleinen, T. "The Thermohaline Circulation": cru.uea.ac.uk/documents/421974/1295957/Info+sheet+%237.pdf/320eba6e-d384-497d-b4fc-2d2c187f805e

Teaching Suggestions in the 5E Model

Engage

1. Ask students an essential question to engage them and prime them for the lesson, such as "How and why does ocean water move, and why is that process important for life on Earth?" Write the question on the board (or do so ahead of time or show it via a data projector) and direct them to do a "Think, Pair, Share" in which they think about the question for a minute, jotting down their ideas on a piece of paper, then discuss the question with a neighbor while you circulate to answer any questions. Then ask for volunteers to share their thoughts.
2. Explain how most ocean water is ALWAYS moving, including at the very bottom of the deepest oceans. Tell students that part of how that happens—and what it means for our planet and us—is what students will be investigating today.
3. Demonstrate the experimental setup to test how the phenomenon begins, and the process explained on the student handout at the end of the lesson. Point out how the liquids should be poured into the shoebox-size container slowly, so that they do not mix as easily.

Explore

4. *Optional:* Before or after the students conduct the experiments, ask them to view (or show the whole class) one or more visuals or videos to help explain the concepts presented in the lesson, such as:
    - The "Great Ocean Conveyor Belt" from NOAA: pubs.usgs.gov/pp/p1386a/images/gallery-2/full-res/pp1386a2-fig31.jpg
    - "Surface currents in the North Atlantic" (Gulf Stream map): en.wikipedia.org/wiki/Norwegian_Sea#/media/File:Golfstream.jpg
5. Have students form groups of 2 – 4 students while you pass out copies of the "Modeling the Formation of Ocean Currents" handout found at the end of the lesson. Have students read the introduction to it and explain how they should get the other materials listed above they need to complete the experiments. Circulate through the room, answering questions—and asking them—to help students complete the experiments and handout.
6. Give students a warning five minutes before they will have to stop working. At that time, direct them to finish cleaning up and answering the questions on the handout.

Explain

7. Close by having students do a "Think, Pair, Share" and/or class discussion about what they learned about how water temperature and salinity differences help drive ocean currents. They should demonstrate verbally and in their written work and illustration of the North Atlantic how differences in water density drive the "great conveyor belt."
8. Include in your discussion how ocean water is always moving, partly because of winds and tides, but also because of a process called **thermohaline circulation**. Be sure that students understand that these are ocean **currents** caused by water **density differences** resulting from differences in water **temperature** (thermo-) and **salinity** (-haline).
9. Encourage students to explain the process on Earth. This could include:
    - As warm water flows north toward Iceland, it cools, which makes it denser.
    - As some ocean water begins to freeze, the salt precipitates out, and the seawater that remains liquid becomes saltier, which makes it even denser.

- As a result, the water sinks, while more warm water flows up from the tropics to take its place.
- Students should understand and be able to explain that this "great ocean conveyor belt" has enormous impacts on climate and life systems around the globe, particularly in places that are close to it, such as Europe, and in areas where layers of nutrients are mixed.
- Students should also be able to explain that freshwater ice in places like Greenland is melting at an alarming rate due to the climate crisis, changing flows of freshwater and ice into the ocean, which is altering thermohaline circulation patterns, including the Gulf Stream, which helps to moderate the climates of both Europe and the Caribbean, which otherwise might become significantly colder or hotter.

Extend / Enrich

- Pass out one or more readings (or direct students to websites) which more thoroughly explain thermohaline circulation. They can discuss the readings in groups and/or as a class. Good readings from the authoritative National Oceanic and Atmospheric Administration (NOAA) include:
    - "Thermohaline Circulation": oceanservice.noaa.gov/education/tutorial_currents/05conveyor1.html
    - "Currents: The Global Conveyor Belt": oceanservice.noaa.gov/education/kits/currents/06conveyor.html
- Ask the students to predict which is more important to layering: temperature or salinity. Then they can design an experiment that might answer the question. For example, students could do separate tests which combine both the warm and cold temperature solutions with the solutions of different salinity. Ask them to report their results in a summary of the lab.
- Show one or more videos which help explain the concepts in the lesson, such as:
    - "Global Ocean Circulation" from NOVA: opb.pbslearningmedia.org/resource/nves.sci.earth.oceancirc/global-ocean-circulation/#.WZyXqlV96xA
    - "The Gulf Stream Explained": youtube.com/watch?v=UuGrBhK2c7U
    - NASA's "The Thermohaline Circulation" (The Great Ocean Conveyor Belt; no audio, but with a good written description): pmm.nasa.gov/education/videos/thermohaline-circulation-great-ocean-conveyor-belt
- Students can create a visual model of the Earth's thermohaline circulation partners, adding:
    - Labeled arrows of varying thicknesses to indicate the flow of ocean currents, as well as their importance to Earth's temperature regulation and living systems.
    - Illustrations of Earth's continents and oceans
    - Color, using color pencils, markers, and/or crayons, etc.

  Completed artwork can be displayed around the classroom or in the hallway to help educate other students and the rest of the school community about this important system and how scientists believe humans are playing a significant role in it.
- Have students play the "A Jason-1 Oceanic Adventure: Voyage on the High Seas" game to help them better understand the role of ocean currents in Earth's system:

  - Resources on the NASA Jet Propulsion Laboratory website: sealevel.jpl.nasa.gov/education/posters/jason1game
  - For more of any explanation of the game and contact information for free printed board games, see the "Currents" lesson plan from NOAA: st.nmfs.noaa.gov/Assets/Nemo/documents/lessons/Lesson_8/Lesson_8-Teacher's_Guide.pdf
- Integrate a unit on ocean currents with biology by having students research one or more organisms which benefit from ocean currents, such as sea turtles, plankton, krill, whales, penguins, seals, and various species of seabirds. Learn more from NOAA: oceanexplorer.noaa.gov/edu/learning/8_ocean_currents/activities/currents.html
- Have students do an experiment in which they attempt to freeze solutions of differently salinity levels, such as 3.5% (average ocean salinity) and 6.0% salinity. This will help them to understand that ocean water only freezes at lower temperatures, and also how it becomes denser in Earth's Polar Regions. See the "More Resources/References" for additional labs which address salinity.
- Share one or more stories which incorporate the concept of ocean currents, such as:
  - *Currents* historical fiction novel by Jane Smolik: penguinrandomhouse.com/books/247678/currents-by-jane-smolik-author/9781580896481
  - *Marco the Molecule: Water Adventure and Activity Book* by Rick Reynolds: engagingeverystudent.com/product/marco-the-molecule
- Take students on a field study to explore an area being impacted by changing ocean currents. For example, you might meet with people who harvest fish or shellfish about how they are being impacted by changing ocean temperatures, oxygen levels, ocean acidification, etc. You might also meet with coastal community leaders about how they are preparing for rising seas and stronger storms due to climate change. Have students reflect on their experiences and how they might take action to help address the challenges in science notebooks or field journals.

Visiting an area being impacted directly by changes in ocean currents and other aspects of climate change will help students make personal connections to the issues.

Evaluate

16. Ask students to explain what their hands-on experiments with water of differing densities showed (in writing in their science notebooks and/or orally), and how the experiments relate to the formations of ocean currents. They should also be encouraged to address how this important circulatory system can become weakened, including how and why scientists believe the Gulf Stream is already weakening.
17. Review completed student reflections and/or any other projects, such as student illustrations of thermohaline circulation and ocean currents on Earth.
18. Lead a discussion about the guiding questions of the lesson and record student participation:
    - How and why does ocean water move?
    - Why is that process important for life on Earth?
    - How might the process be changing due to human activities?
    - How can we help restore balance to thermohaline circulation patterns on Earth?

    Students can also reflect on these questions in writing.

Expand Knowledge + Skills

Thermohaline Circulation

- NOAA Ocean Service Education. "Currents" Tutorial:
    - Complete tutorial: oceanservice.noaa.gov/education/tutorial_currents/welcome.html
    - "The Global Conveyor Belt": oceanservice.noaa.gov/education/kits/currents/06conveyor.html
    - "Thermohaline Circulation": oceanservice.noaa.gov/education/tutorial_currents/05conveyor1.html
    - "Effects of Climate Change": oceanservice.noaa.gov/education/tutorial_currents/05conveyor3.html
- "What Causes Ocean Currents?" Story Map from ESRI: apl.maps.arcgis.com/apps/MapJournal/index.html?appid=d629dd5cc3fe48ea9fc744dada861da0
- "The Ocean's Role in Weather and Climate." Information and teaching resources from NOAA. aamboceanservice.blob.core.windows.net/oceanservice-prod/education/yos/resource/ocean_weather_climate.pdfEncyclopædia Britannica article about the Carbon Cycle with excellent visuals: britannica.com/science/carbon-cycle
- Osborn, T. and Kleinen, T. "The Thermohaline Circulation." cru.uea.ac.uk/documents/421974/1295957/Info+sheet+%237.pdf
- Videos for background knowledge or to share with students:
    - "Global Ocean Circulation" from NOVA, which includes discussion questions and more resources: opb.pbslearningmedia.org/resource/nves.sci.earth.oceancirc/global-ocean-circulation/#.WZyXqlV96xA
    - "The Gulf Stream Explained": youtube.com/watch?v=UuGrBhK2c7U

Lessons / Units

- "Currents" lesson plan with a game from NOAA and the JASON project. https://www.st.nmfs.noaa.gov/Assets/Nemo/documents/lessons/Lesson_8/Lesson_8-Teacher's_Guide.pdf
- Roth, Jerry D. "Hot, Cold, Fresh, Salty." Lesson plan for grades 9-12. https://oceanservice.noaa.gov/education/lessons/hot_cold_lesson.html
- Oceanography 101, a free online textbook with excellent visuals from MiraCosta College: http://gotbooks.miracosta.edu/oceans/index.html
  - Ocean Circulation: http://gotbooks.miracosta.edu/oceans/chapter9.html
  - Properties of Seawater: http://gotbooks.miracosta.edu/oceans/chapter7.html
  - Much of the site's content provided by "Geology Café," an excellent natural resources website: http://geologycafe.com
- "Water and Ice" lesson from the American Association for the Advancement of Science: http://sciencenetlinks.com/lessons/water-1-water-and-ice/
- "Why Does Water Dissolve Salt?" Chemistry lesson plan with video from the American Chemical Society. http://www.middleschoolchemistry.com/lessonplans/chapter5/lesson3
- California Education and the Environment Initiative curriculum: californiaeei.org/curriculum

Standards

- More examples of what NGSS looks like for high school students can be found in Chapter 7 of the *2016 Science Framework for California Public Schools:* cde.ca.gov/ci/sc/cf/documents/scifwchapter7.pdf
- More information about the Next Generation Science Standards, including a link to the *Framework for K-12 Science Education* to which this lesson was aligned, can be found at nextgenscience.org/framework-k%E2%80%9312-science-education.
- More information about the Common Core State Standards and links to the complete documents: corestandards.org

Appreciation + Thanks

Thank you for using Bay Area E-STEM Institute resources and
helping to inspire the next generation of thinkers and scientists!
We also greatly appreciate the support of the National Science
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We welcome your questions or comments.

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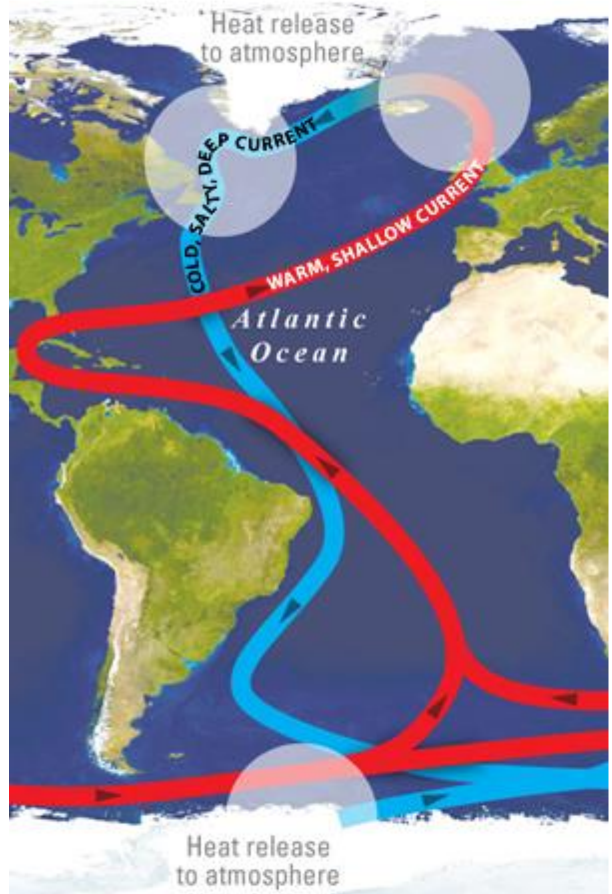
Bay Area E-STEM Institute (BAESI)

Name: _______________________________ Period: ____ Date: _______________________

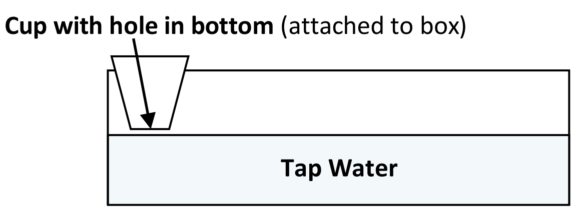
Modeling the Formation of Ocean Currents



Imagine you are a microscopic water molecule flowing in the warm Gulf Stream from the Caribbean toward Europe. At first you enjoy the adventure, with sea turtles swimming in your fast-moving **current**. But as you flow toward Iceland, getting colder and colder, you ask yourself, "How did this happen?" You get even more confused when you start plunging toward the ocean bottom off the coast of Greenland. "WHY IS THIS HAPPENING??!!" you ask yourself. "Will I ever warm up again???!!!" In these experiments you will create seawater models which will help you answer these questions.

A. Effect of Salinity Experiment

1. Create a **saline** (salty water) **solution** to model ocean **saltwater**:
   - Add 35 grams (2 tablespoons + 1 teaspoon) of salt to
   - 1 liter of tap water.
   - Stir the mixture to create a 3.5% saline solution (35 parts per thousand), the average salinity of ocean water.
   - Add **blue** food coloring.
2. Fill a clear container about the size of a shoebox halfway with tap water. This represents **freshwater** (without salt).
3. Use a pencil to poke a hole in the bottom of a paper cup and clip or tape the cup to the box so that the bottom of the cup is just above the level of the water in the box.



4. What do you predict will happen if you pour the saline solution into the paper cup?

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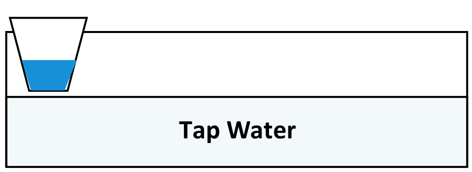
5. Pour a small amount of the saline solution into the paper cup attached to the box.



6. Record your observations of what happens in the space below.

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7. Which do you think is more dense, saltwater or freshwater? Why?

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8. Create a **6% saline solution**:
   - Add 60 grams (4 tablespoons) of salt to 1 liter of tap water.
   - Stir the mixture to create a 6% saline solution (60 parts per thousand).
   - Add **green** food coloring.

9. **Predict** what will happen if you pour the 6% saline solution into the paper cup attached to the container:

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10. Pour some of the 6% saline solution (green) into the paper cup and record your observations.

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11. How does increasing salinity affect density?

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B. Effect of Temperature Experiment

1. Empty out your shoebox-size container and refill it about halfway with tap water.
2. Create a model of **cold ocean water**:
   a. Pour some of your **blue** 3.5% saline solution into a cup or beaker.
   b. Create an ice bath: add ice and water to a bowl or insulated container that is larger than your cup of saline solution. Then set your cup of saline solution in the cold water bath.
   c. Wait 10 – 15 minutes, or until the saline solution has chilled to a temperature of about 5˚ Celsius (41˚ F).
3. While you wait for the saltwater to chill, create a **warm ocean water** model:
   a. Pour some of your **blue** 3.5% saline solution into a heat-resistant beaker.
   b. Warm the water on a hot plate to a temperature of about 43˚ Celsius (110˚ F). If you do not have a hot plate, you can use hot tap water and/or a microwave or hot pot.
   c. Add **red** food coloring.

4. **Predict** what will happen if you combine the models of cold and warm ocean water in the shoebox-size container. Record your hypothesis in the space at the top of the next page.

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5. At the same time:
    - Slowly pour your model of cold seawater (**blue**) into the paper cup taped to the side of the container.
    - Slowly pour your model of warm seawater (**red**) into the other side of the container.

6. Describe your observations:

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7. What might happen when warm and cold ocean water meet? Why? How might that process be important for Earth's system and maintaining a stable climate?

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8. Where do you think ocean water that is more salty than average seawater may exist?

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9. Use the map of the North Atlantic Ocean on the next page to:
    - Illustrate the "great ocean conveyor belt."
    - Label what happens when cold seawater that is saltier meets warm, less-salty seawater.

10. What might happen if a lot more ice melts in Earth's Polar Regions, adding a lot more freshwater to the oceans in the regions? Why might this cause changes everywhere on Earth, not only at sea?

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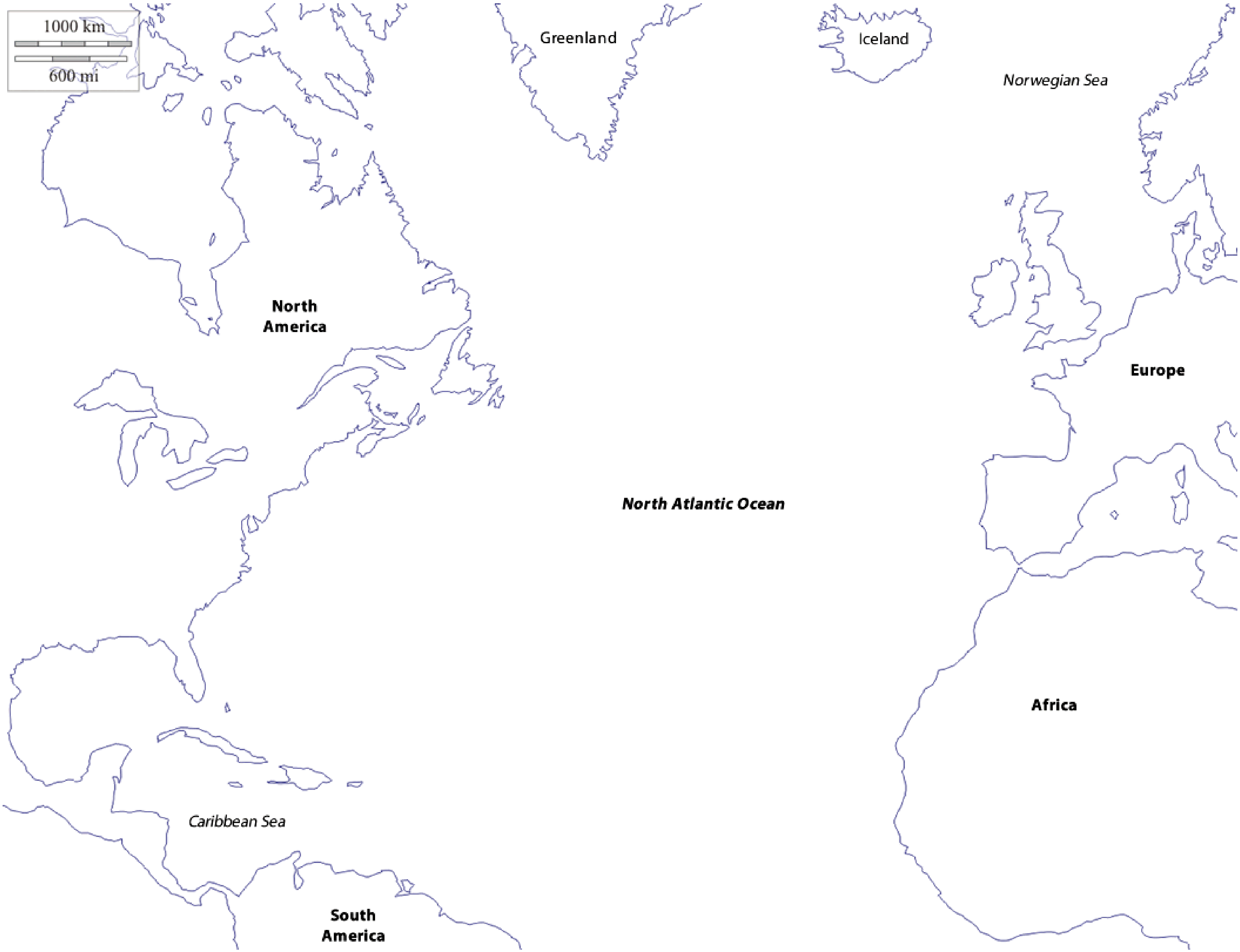
1000 km
600 mi
Greenland
Iceland
Norwegian Sea
North America
Europe
North Atlantic Ocean
Africa
Caribbean Sea
South America