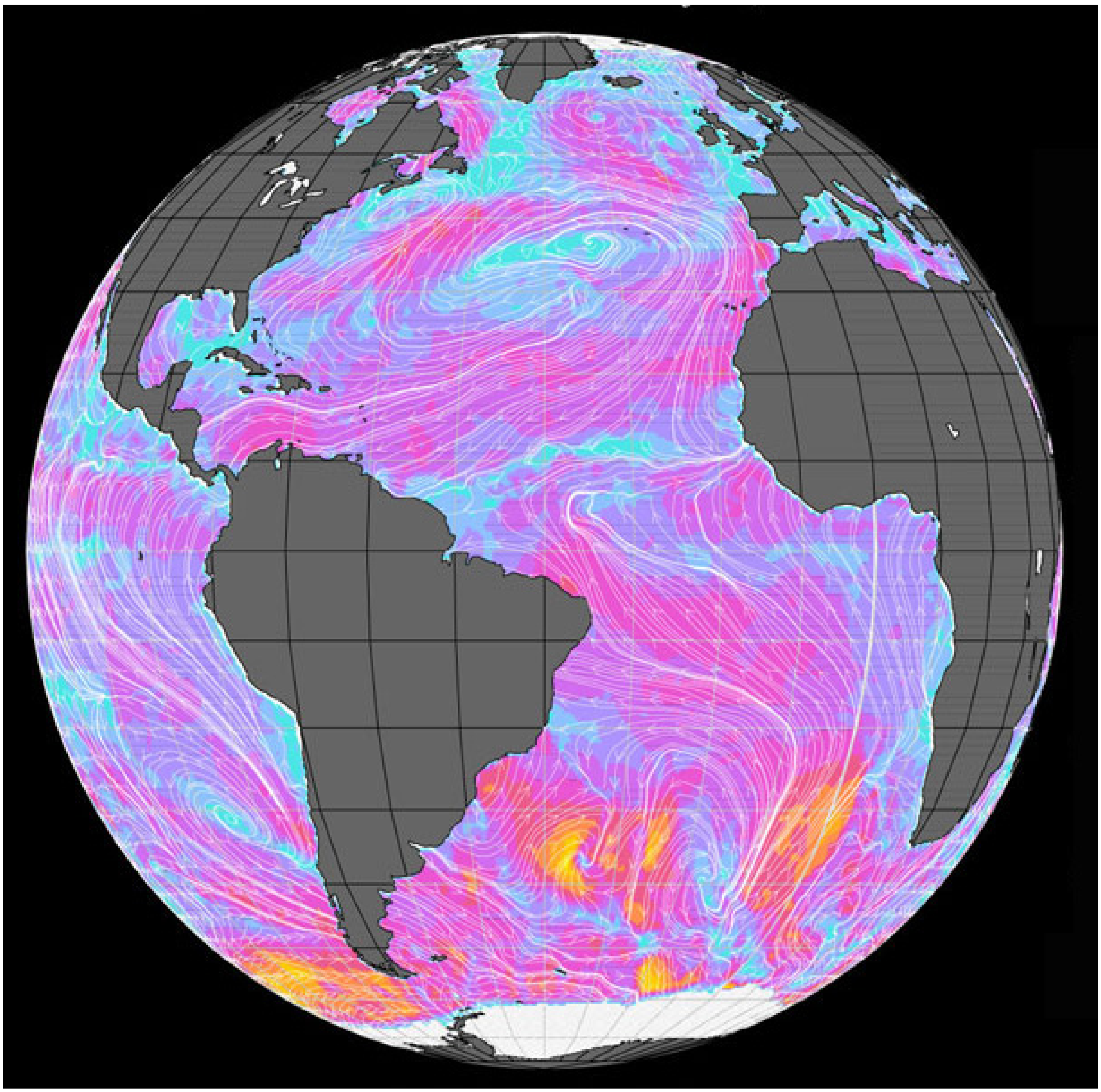
Surfing Ocean Gyres

Cold are the feet and forehead of the earth,
Temperate his bosom and his knees,
But huge and hot the midriff of his girth,
Where heaves the laughter of the belted seas,
Where rolls the heavy thunder of his mirth
Around the still unstirred Hesperides.

The Belted Seas, Arthur Colton



Ocean Surface Wind by QuickSCAT http://winds.jpl.nasa.gov/

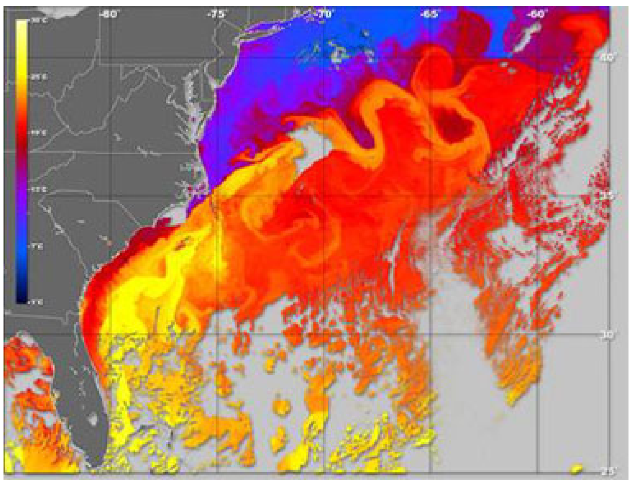
Lesson Objectives	**Performance Tasks**
To describe the primary patterns of ocean surface currents that are observed	Examine ship drift current data to determine the circulation patterns of ocean gyres.
To describe how the Earth's rotation impacts ocean circulation	Describe some consequences of stopping the Earth from rotating.
To describe how ocean gyres would circulate on a non-rotating Earth	Use the Stommel model and predictions to understand the effect of Earth's rotation on ocean surface current flow and water levels.
To describe how ocean gyres would circulate on a rotating Earth with a cylindrical or a spherical shape.	Use the Stommel model and predictions to understand the effect of the Earth's rotation on surface current flow and water levels.

Materials: Student Guide (PDF file)
Internet access
Time: 80 minutes

Grade Level: high school
Courses Supported: Math, Earth Science, Physics

Glossary: controls, data, dead reckoning, fluid dynamics, hypothesis, independent variable, laminar flow, latitude, longitude, magnetic declination, model,

Introduction: Rivers in the Ocean



Okeanos was the name given by the Greeks to a god and to a wide, deep-running river *whose unsleeping tide encircles the whole earth*.[1] With this myth, the Greeks captured, one of the fundamental characteristics about oceans that interests researchers today: these vast, bounded basins of water develop unsleeping patterns of circulation that play an important role in moderating our weather and maintaining Earth's climate. Driven by winds and the pole-equator temperature difference, the oceans are heat engines that store and distribute solar energy more equally over the planet. Ocean currents can flow for thousands of kilometers and are very important in determining the climates of the continents, especially those regions bordering on the ocean.

This lesson explores behaviors of the surface currents in the ocean basins. Classroom explorations will be accomplished by examining the predictions of a mathematical model[2]. This is a model which is not constrained by the walls of your classroom and which will allow us to study the behavior of millions of square miles of water surface on worlds quite different from Earth. Equations that apply to fluids and rotating objects are solved and the solutions are used to make images of the model ocean surface. The scientist who developed the concepts for model, included in this lesson, was Henry Melson Stommel (1920 – 1992). He was driven to understand what caused ocean surface currents to strengthen on the western boundary of major ocean basins. Beginning in the 1940s, he advanced theories about global oceancirculation patterns and the behavior of the Gulf Stream, pictured above, that form the basis of physical oceanography.

[1] Prometheus Bound 139
[2] Stommel H. The Westward Intensification of Wind-Driven Ocean Currents, *Transactions, American Geophysical Union*, 29, 2 (April 1948), 202-206

Engage: Preconceptions Survey, "What do you know?"

Students are asked to take an online Quiz consisting of six questions. When they submit their responses online, a pop-up window appears that shows the correct response to each question and provides additional, clarifying information. All six questions, the correct responses and additional information are provided below

Engagement activities, such as this one, are typically *not graded*. Student responses to this survey will help determine how much accurate information they already know about the ocean models.

True or False	Statement
1 TRUE	**Oceanography computer models all use the same basic equations.** *The models use the same basic equations that the scientific community has developed. The models are very different in the significance assigned to various processes and how the model deals with processes that are poorly understood.*
2 FALSE	**Ocean surface water is generally still and does not show strong flow movement.** *The ocean surface waters do flow in distinct patterns. The motions are driven by the Sun (including the winds driven by solar heating) and the Earth's rotation. The land masses (continents) affect the flow patterns.*
3 FALSE	**Surface currents and deep currents in the ocean flow generally in the same direction.** *The warmed surface water does not mix readily with the deeper cold water. The two stratified layers slide over each other and do not strongly interact. The surface waters flow in response to the winds and the sinking of dense, cold surface water. The oceans are a closed fluid system: Water In = Water Out. Dense water that sinks (downwelling) has to cause other water to rise to the surface (upwelling).*
4 FALSE	**Computer models of the ocean are very simple and accurate because there is mainly one kind of molecule in the ocean: H_2O.** *The ocean models are very complex because the fluid's molecules are all free to move, and it is difficult to gather enough data on the state of the ocean and do enough computations to determine the future behavior of all molecules. Models of solid objects (like airplanes or buildings) are much easier to develop because the objects are solid: their atoms stay in a fixed position with respect to each other.*
5 TRUE	**Computer models use ocean data measured above, below and on the ocean** *Data measured by ships, satellites, undersea probes, and buoys, are used by many computer models to adjust and tune their predictions. This process is called data assimilation. Models adjust their computations to better match the limited data available.*
6 FALSE	**Modeling the oceans is of very little practical use because we are relatively powerless to change the state of the ocean.** *Modeling the oceans helps us test our understanding of ocean processes in great detail. By better understanding ocean processes we can make better predictions about how changes in the ocean will affect our lives and weather.*
100	**Overall Score (%)**

Explore: Ocean Boundary Currents

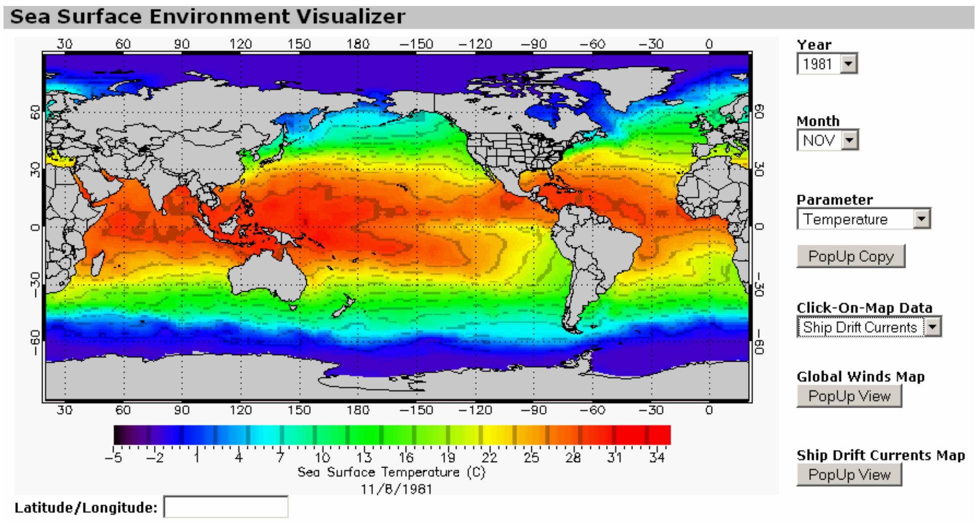
Is there a pattern to the movement of ocean currents?

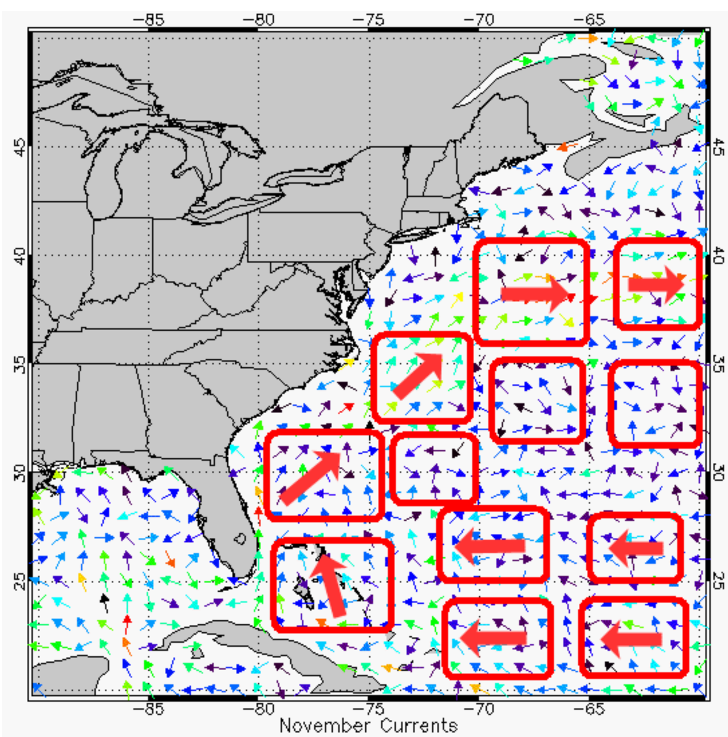
To explore patterns in ocean surface currents, particularly boundary currents—ocean currents with dynamics determined by the presence of a coastline—you will use the Sea Surface Environment visualizer. Go online to the Sea Surface Environment visualizer and click on the following settings.

Set the controls as follows:

- Month - Choose any month, in the following example November was selected
- Ship Drift Currents Map – Click, “Popup View” and a new window will appear with the map.

(Note: The settings of the other controls are not important for this study.)

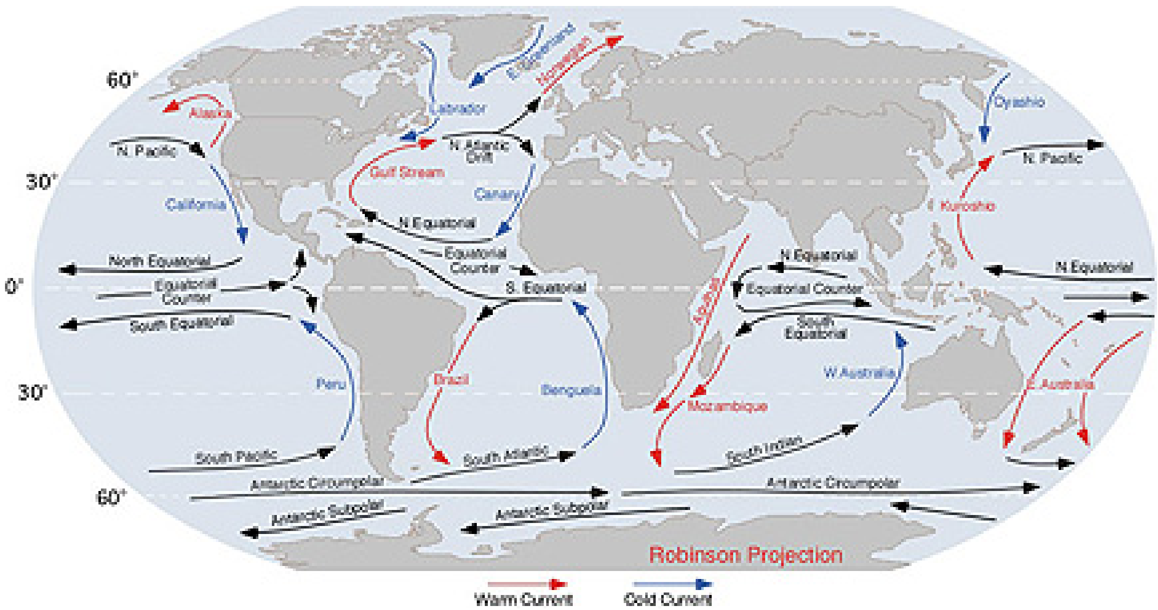




The map images show colored arrows that point in the direction of surface currents; the color of the arrow is keyed to the speed of the current. You can click on ocean regions of the Sea Surface Environment map to see more detailed ocean surface current maps.

Viewing patterns of ocean surface currents may be confusing. The arrows often seem to point in various directions at random. To simplify your recognition of patterns, you may wish to print out the map and then draw equal-sized boxes around current regions and decide if the data indicates a dominant flow in a certain direction. Mark each region with an arrow that points in this dominant direction. Where there seems to be no dominant pattern, do not draw an arrow. Slow currents (blue arrows) often seem to point in random directions because these measurements are not much different from the errors made the instruments which gathered the data. Another reason for the confused patterns is that the data used for estimating these currents, were measured by instruments on ships over many years.

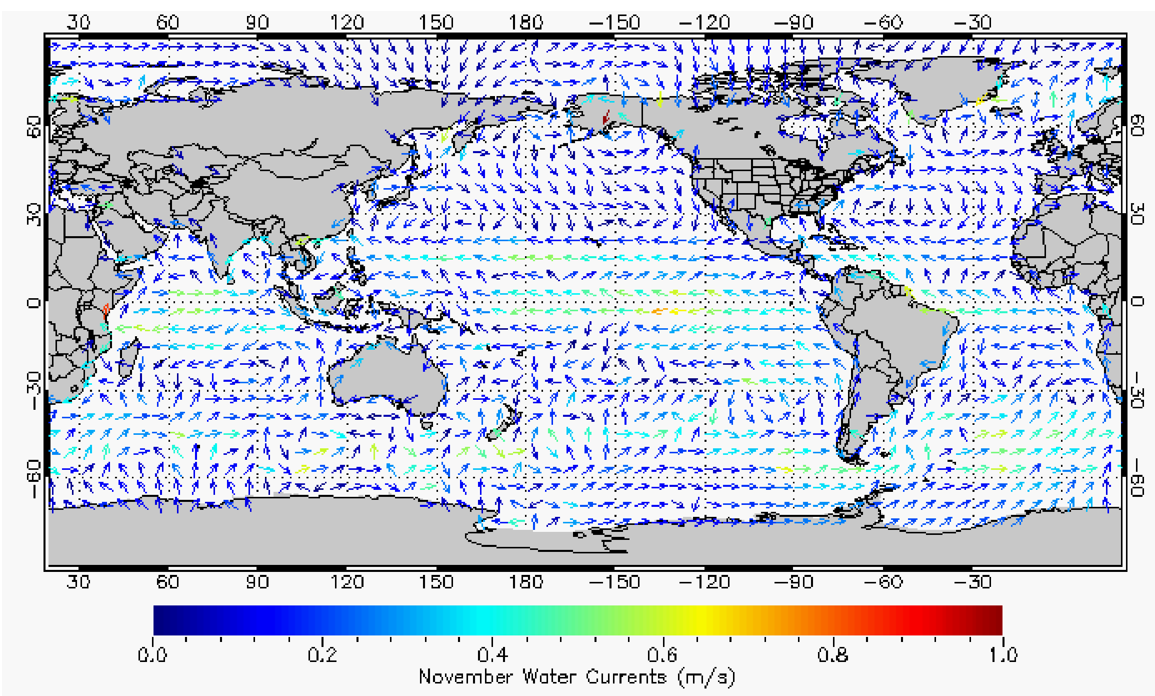
The patterns to identify on the global map are the ocean [gyres](). These are ocean-scale surface currents that circulate water from the Equator toward the poles. These Equatorial currents tend to follow the easterly trade winds.



Go to The Sea Surface Environment [visualizer](), and click the following settings:

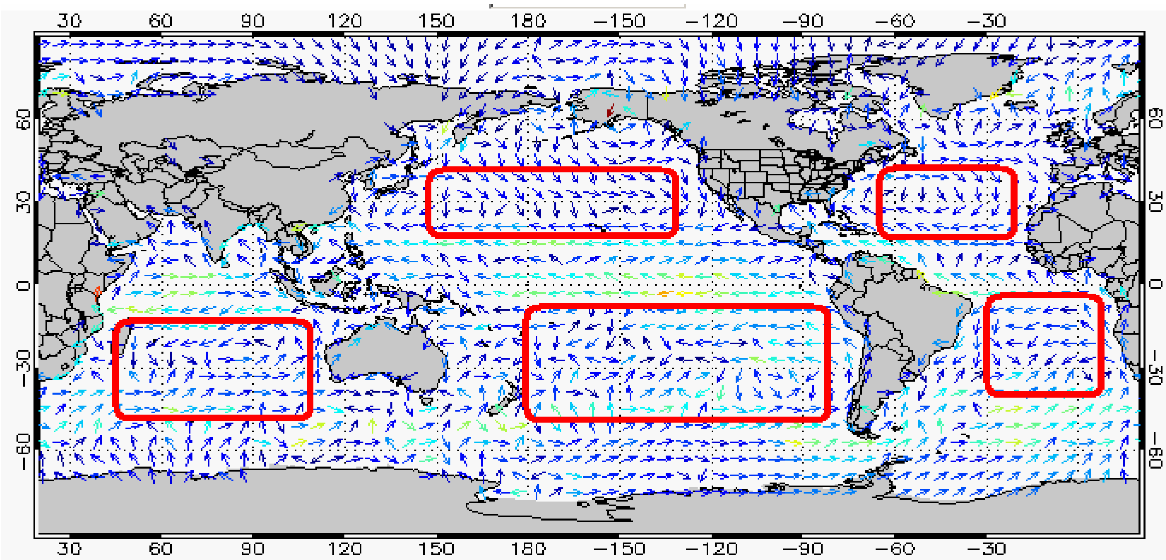
- Month – **Your birth month**
- Click-on-Map Data – **Ship Drift Current**

Click the global map to view ocean currents in different regions of the world. Alternatively, click the PopUp View button for Ship Drift Currents Map to see a large global currents map. The visualizer images indicate the current direction with an arrow and the current speed with colors (e.g., blue=slow, red=fast). Identify significant flow patterns.



1. In the map above, look at both the western and eastern boundary currents in several ocean basins and judge, which show a gyre pattern of currents spanning the full width of the ocean.

Month of Year __*November*___	Gyre Pattern?	
Ocean Basin	Yes	No
North Atlantic Ocean	X	
South Atlantic Ocean	X	
North Pacific Ocean	X	
South Pacific Ocean	X	



These circulating patterns of surface currents are largely driven by winds and both the winds and the water are directed by the Coriolis force. The Coriolis force affects the motion of fluids on a rotating Earth.

Explore: Earth's Rotation and Flow Patterns

How does the rotation of Earth affect the pattern and behavior of ocean currents?

The hemispheric gyre patterns you observed on the global maps are features that stand out in several oceans. There are data to suggest that these patterns of flow have persisted for centuries. This dominant, persistent circulation is found in differently sized and shaped oceans, which suggests that this characteristic circulation is 1) driven by external forces that are essentially the same in all basins and 2) is not dependent on peculiarities of continental boundaries or local wind/weather patterns. Henry Stommel perceived that because the gyre phenomenon seemed to be somewhat independent of all the peculiarities of ocean size, shape, meteorology and undersea topography, the oceans could be modeled as a shallow, rectangular water-filled basin driven by steady winds. In meteorology as well as oceanography, many phenomena and processes seem complex and unpredictable, but some phenomena repeat consistently year after year and so serve as keys for understanding the main processes driving change.

2. What statements can you make about weather patterns or occurrences that repeat year after year the weather in your hometown or school? Examples are; temperature, precipitation/drought, wind, storm, and snow fall.
For the Middle Atlantic region of the U.S., temperatures are coldest in January and February and hottest in July and August. Precipitation is somewhat steady during the year. Winds vary in direction and intensity.

In this exploration, you will focus on learning the effects of a rotating Earth on water flow patterns and behavior in ocean basins. Since it is not possible to perform real-life experiments that speed up or slow down Earth's rotation, discussion will focus on using a computer model to make predictions based on principles and mathematical equations of fluid physics.

3. Suppose you could slow the Earth's rotation to the point that the western hemisphere of the Earth always faced the Sun (like one hemisphere of the Moon always points at Earth). What would this mean for life on Earth? How are we directly affected by the Earth's 24-hour rotation period?

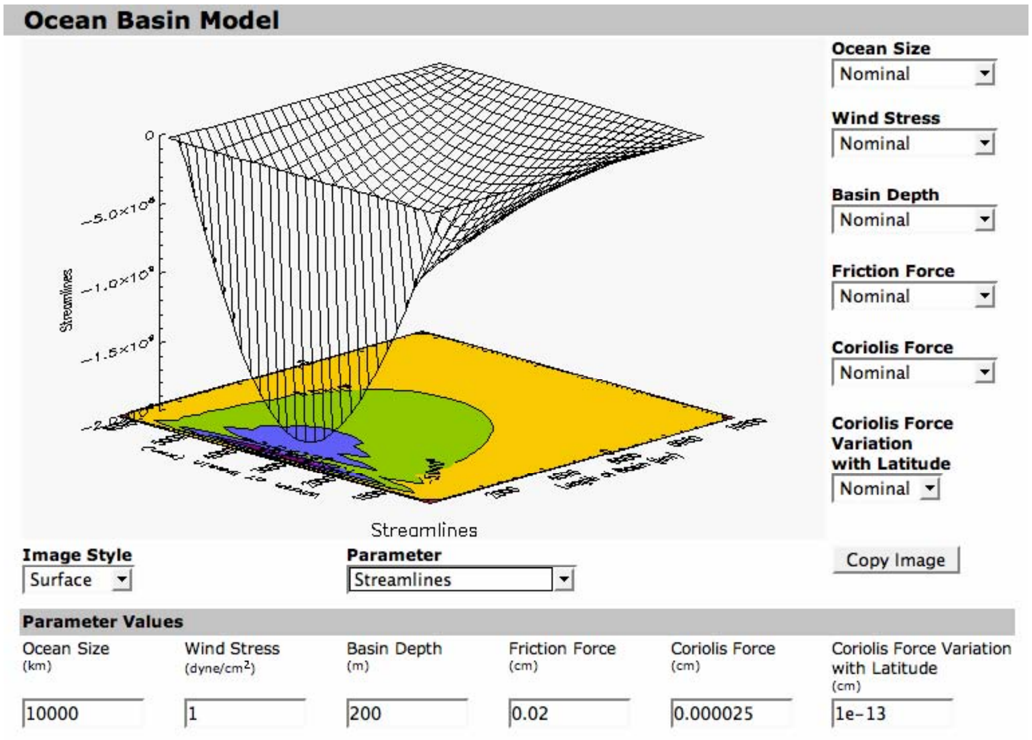
The western hemisphere (facing the sun) would heat up and the eastern hemisphere (facing away from the Sun) would freeze. The 24-hour rotation, the fluid processes of air and water circulation and the tremendous heat storage capacity of the oceans keeps the Earth's surface temperatures moderate. On a non-rotating Earth, much of the surface might be uninhabitable by life as we know it.

Note: One advantage of using mathematical/computer models is that no changes need be made in real-life activities or processes to make scientific predictions. Also modelers can pick and choose the processes they wish to model. The model being used for this exploration does not simulate all the effects of slowing down or speeding up the Earth's rotation. It ignores, in particular, all effects of thermal changes due to changes in the solar cycle (much longer or shorter days).

The Ocean Basin Model that you will use in this investigation is based on concepts from a scientific paper written by Henry Stommel. It is an idealized ocean model of the North Atlantic Ocean. Some of its fundamental assumptions are shown in the following table.

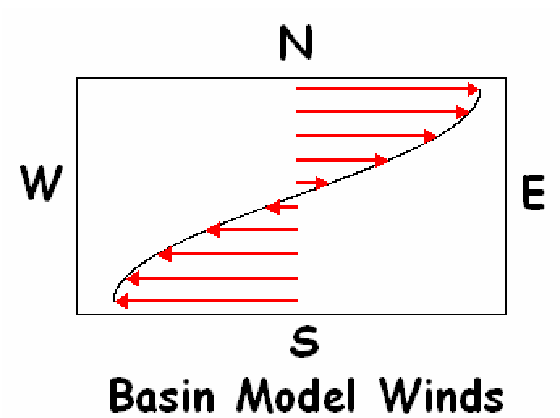
Model	Assumption	Discussion
Simple Geometry	The ocean basin is rectangular with constant width and length.	Neither the irregular continental boundaries nor the uneven ocean floor topography are modeled.
Limited To Surface Waters	The depth of the model basin water is very shallow (~200 m) and uniform.	This assumption seems unrealistic since the average ocean depth is 4-5 miles but is based on the fact that primarily only the ocean surface water contributes to surface currents. This surface water includes the mixed layer where ocean water is well mixed and water temperatures are uniform. There is no interaction with the deeper waters.
Wind-Driven Circulation	The ocean surface currents are wind-driven. The wind stress variation is north to south.	Winds are assumed steady along the E-W direction. The pattern of wind stress represents the Easterlies and Westerlies that drive basin surface circulation.
Steady State	All basin conditions (wind strength, friction effects) are steady and uniform.	No random or changing irregularities (like weather effects, fluid turbulence) are included.

The control panel for the Ocean Basin model is shown below. The operation of the model requires that you set parameter values using the drop-down menus. After you select a new parameter value, the image in the visualizer will change to an image corresponding to the new parameter setting. All the values shown on the right- side of the visualizer start with a value of Nominal. The Nominal values were those used by Henry Stommel in his original model.



You may increase or decrease these nominal values. The values used by the model for computations are shown at the bottom in the Parameter Values panel.

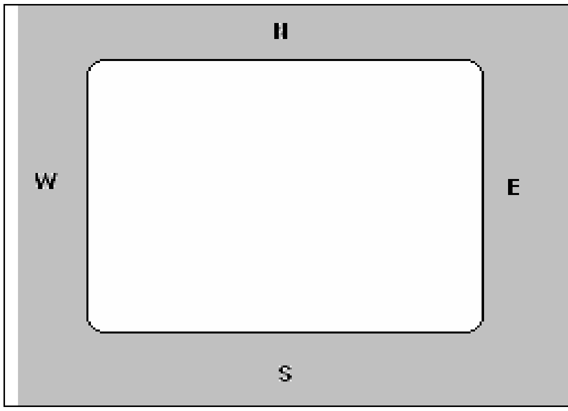
Test the model first by setting the parameters to simulate a situation where you think you know the answers or at least have some basis for judging the correctness of the model predictions. In your first exploration, you will slow the Earth's rotation to a crawl; this will simulate a bathtub basin condition. Water in a bathtub is not measurably affected by Earth's rotation because it is so small. Coriolis-like effects are most easily measured for fluid movements over large distances. Our basin water will be driven by winds—Westerlies in one half, Easterlies in the other half (imagine a bathtub with two fans blowing over the water in opposite directions).



Explore: Changing the Coriolis Force

Case Study 1: Vectors

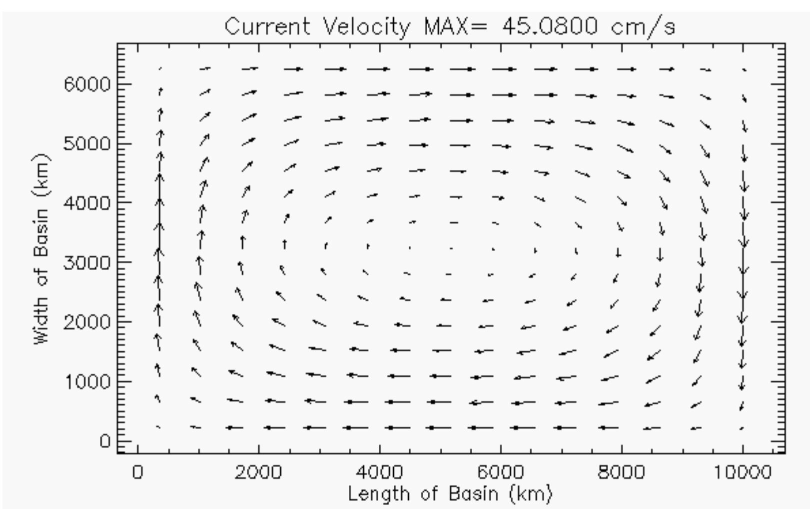
4. Make a hypothesis about the pattern of water flow in the ocean basin due to the effect of the Coriolis force. Indicate in the drawing how the water flows and where you might expect to find the fastest and slowest currents. Explain your reasons for making this hypothesis.

	*My hypothesis is that the water flow will be fastest near the middle of the left (western) boundary and slowest in the basin corners.*

Set the [Ocean Basin Model] controls as follows:

- Keep the "*Nomina*l" setting for; Ocean Size, Wind Stress, Basin Depth, and Friction Force
- Set the Coriolis force to *1/100*
- Set the Coriolis force variation with latitude to *None*
- Set the Parameter to *Surface Current*
- Set the Image Style to *Vectors*

The Coriolis effect is caused by the rotation of Earth; reducing this effect allows you to experiment with the behavior of water in an ocean basin on a planet that is not rotating or very slowly rotating. The arrows, or **vectors**, represent the current velocity at different locations in the North Atlantic Ocean basin. Long arrows, represent high velocity and short arrows represent low velocity. On the display, top=North, bottom=South, right=East, left=West. In the North Atlantic gyre, top=Polar North Atlantic, bottom=Equator, right=European coast, left=U.S. East Coast. Westward blowing winds (Easterlies, winds coming from the east) act on water in the lower half of the basin. Eastward blowing winds (Westerlies) act on the upper half.



5. Describe the pattern of water flow shown by the arrows. Is this the kind of motion that you might expect with the winds blowing over the basin surface? What is the highest speed of water in the basin? Where are the speeds greatest? Where are the speeds smallest?
The water swirls in oval paths around the center of the basin. This is to be expected with west to east winds in the North and east to west winds in the South. The highest speed is 45 cm/sec. The speeds are greatest along the edges of the basin near the center of each site. Speeds are slowest in the center.

Case Study 2: Streamlines

Another way to represent fluid flow is with **streamlines**. Each streamline shows the path of a massless particle moving freely with the fluid. If you put a battleship on the fluid, it would not follow the streamlines precisely because its mass (inertia) would cause it to maintain its state of motion and not always follow the fluid.

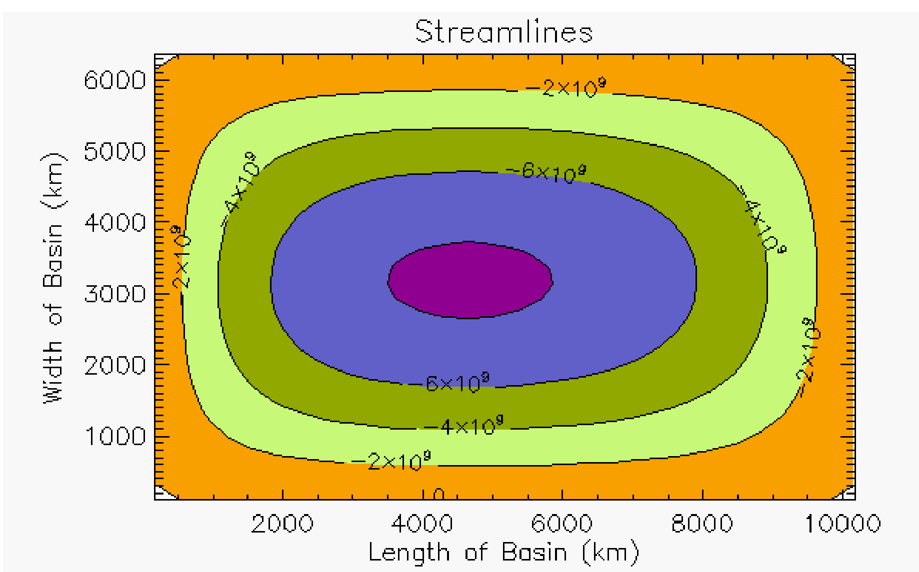
You will view the streamlines with a contour plot. A contour plot displays a surface as seen from directly overhead using lines and colors that follow the surface along the same height. Contour plots are use most commonly to make weather and topographical maps. The weather maps may show lines of constant temperature or pressure. The topographical maps show lines connecting ground points of equal height.

Set the Ocean Basin Model controls as follows:

- Keep the "*Nomina*l" setting for; Ocean Size, Wind Stress, Basin Depth, and Friction Force
- Set the Coriolis Force to *1/100*
- Set the Coriolis Force Variation with Latitude to *None*
- Set the Parameter to *Streamlines*
- Set the Image Style to *Contours*

6. Describe the shape of the paths that light objects would follow in the moving water. Do these paths agree with what you would expect?

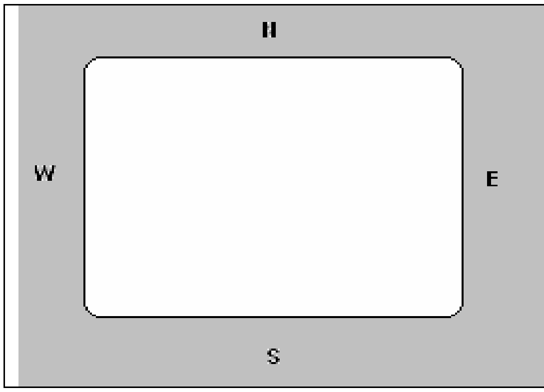
The paths are oval-shaped and symmetric in the basin. This agrees with what I would expect for water with a swirling pattern of currents.



Case Study 3a and 3b: Surface Water Level

Next you will look at the surface water level. With no winds and no rotation the basin water level should be flat. Given the manner in which the winds blow over the model ocean basin, you might expect that the shape of the water surface to change in response to the winds.

7. Make a hypothesis about how the water surface of the basin might change in response to the wind stress pattern of the model (east to west in the South, west to east in the north). Indicate in the following drawing how the winds blow and where you might expect to find the deepest (D) and shallowest (S) water. Explain your reasons for making this hypothesis.



Winds blowing west to east in the North should reduce the water level in the northwest and increase it in the northeast. Winds blowing east to west in the South (near the Equator) should reduce the water level in the southeast and increase the level in the southwest.

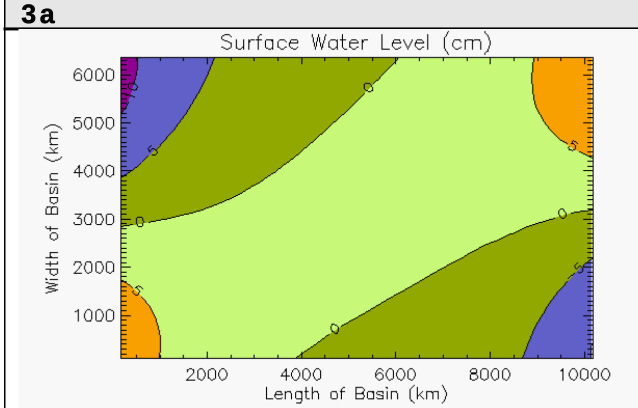
You may use two different displays to view the water surface: 3a) a contour plot and 3b) a surface plot. The surface plot provides a three dimensional representation of the surface water level: x=E/W distance, y=N/S distance, z=Surface Water Level. Look at both representations of the ocean basin level. Both pictures represent the same information. The level of 0 cm corresponds to a flat water surface 200 meters deep.

Set the Ocean Basin Model controls as follows:

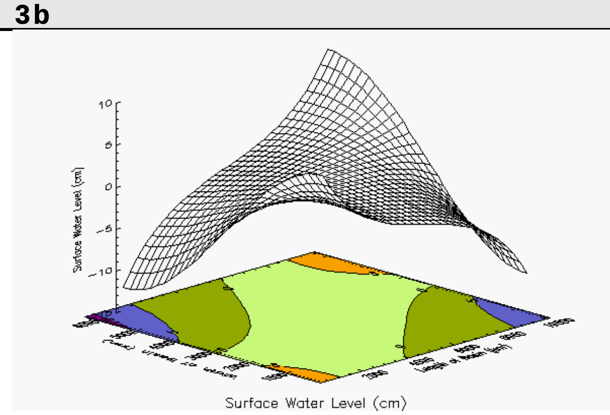
3a
- Keep the "*Nominal*" setting for; Ocean Size, Wind Stress, Basin Depth, and Friction Force
- Set the Coriolis force to *1/100*
- Set the Coriolis Force Variation with Latitude to *None*
- Set the Parameter to *Water Level*
- Set the Image Style to ***Contours***

3b (same as 3a except for the change below)
- Set the Image Style to ***Surface***

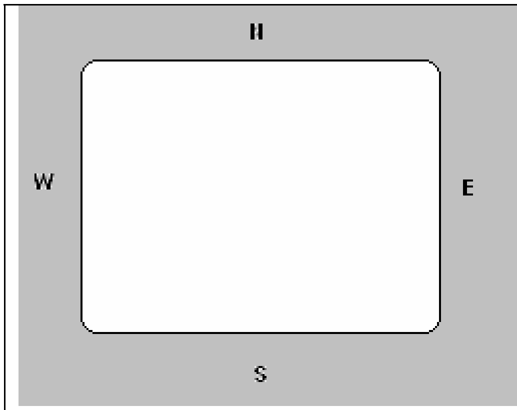
3a



3b



8. Sketch the wind arrows in the following box and indicate where the basin is deepest (D), where it is most shallow (S). How high does the water surface rise above 0 cm? How low does the water surface go below 0 cm? Do the deepest and shallowest regions agree with your hypothesis? Discuss any similarities or differences.



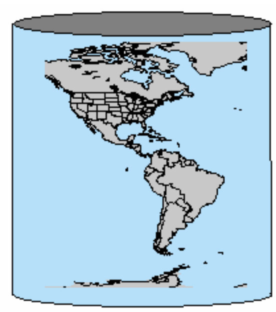
The shape of the water surface agrees with my expectations:

NW corner water level -10 cm
NE corner water level +5 cm
SW corner water level +5 cm
SE corner water level -5 cm

The water level in the middle of the basin is zero (no change in the water depth of 200 m).

9. Suppose you have a bowl of water and you stir the water with a spoon. What shape would the surface take in this case? Why would it be different from the shape of the water surface in our wind-driven basin model?
For a bowl of water stirred rapidly by a spoon, I would expect the water to rise up near the boundaries and be lowest in the center. This is not the principal surface deformation that occurs in the model wind-blown basin. In the spoon-stirred case, the water rises on the edges of the bowl due to inertial forces that are similar to the forces that you feel when driving around a corner in a car. Following Newton's First La, the car turns but your body mass (inertia) want to continue moving straight. The wind-blown water currents in the model are probably travelling too slowly for inertial effects to be measureable.

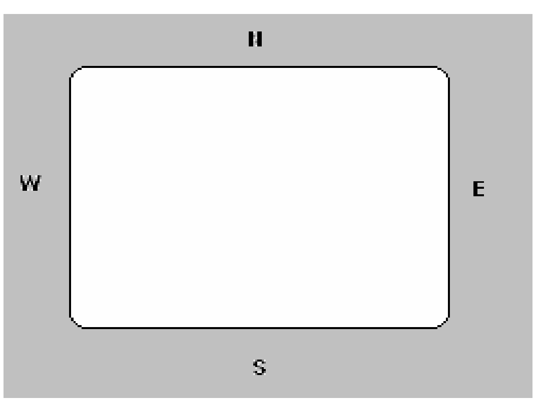
Explore: Cylindrical-Shaped Earth



To move your investigations to the next level of complexity, turn your attention to study of the ocean basin conditions when the Earth is a cylinder rotating in its normal direction. The rotating cylinder will cause a Coriolis force that is constant over the surface of the ocean basin.

Case Study 4: Vectors

10. Make a hypothesis about the pattern of wind flow in the basin and how its speed might change in response to a cylindrical Earth. Indicate in the following drawing how the wind would flow. Explain your reasons for making this hypothesis.



My hypothesis is that the water flow will be fastest near the middle of the left (western) boundary and slowest in the basin corners.

Set the Ocean Basin Model controls as follows:

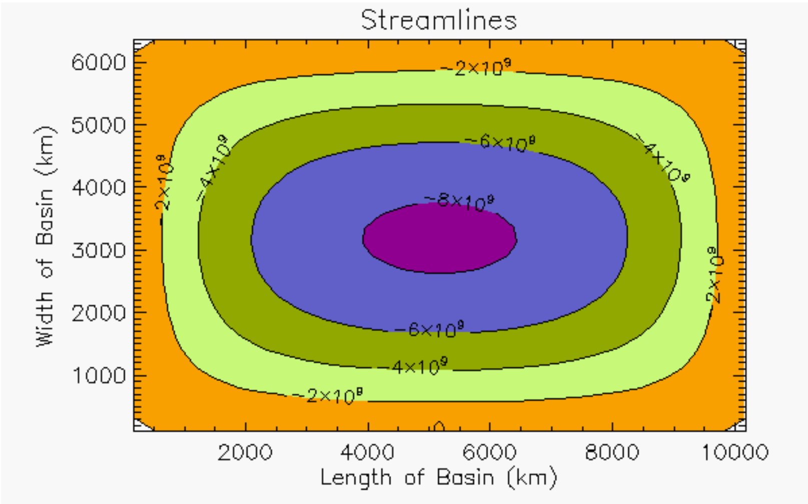
- Keep the "*Nominal*" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and Coriolis Force
- Set the Coriolis Force variation with latitude to *None*
- Set the Parameter to *Surface Current*
- Set the Image Style to *Vectors*

11. Describe the pattern of water flow. Is this the kind of speed that you might expect with the winds blowing over the basin surface? What is the highest velocity of water in the basin?
The pattern looks identical to Case 1 (no or slow rotation). The highest velocity is 45 cm/s.

Case Study 5: Streamlines

Set the Ocean Basin Model controls as follows:

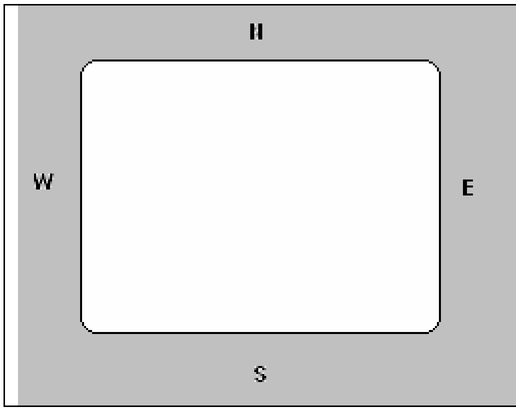
- Keep the "*Nominal*" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and the Coriolis force
- Set the Coriolis Force Variation With Latitude to None
- Set the Parameter to Streamlines
- Set the Image Style to Contours



12. Describe the shape of the streamline paths. Do these paths agree with what you would expect?
The streamlines appear identical to Case 2. The oval paths seem reasonable for the wind-driven water confined to a rectangular basin.

Case Study 6a and 6b: Water Surface Level

13. Make a hypothesis about how the water surface of the basin might change in response to the wind stress pattern of the model. Indicate in the drawing how the winds blow and where you might expect to find the deepest (D) and shallowest (S) water. Explain your reasons for making this hypothesis. *Note: In the Northern Hemisphere, the Coriolis acceleration causes moving water to curve to the right.*

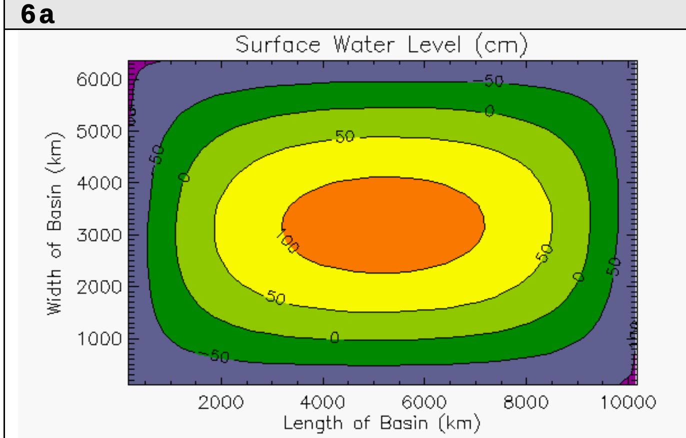
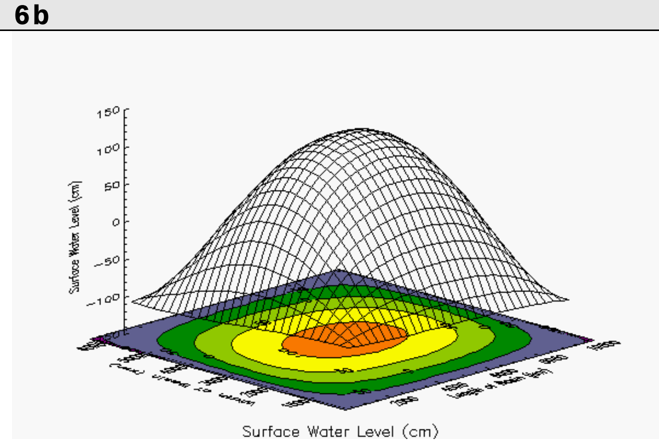
	*I expect it to be the same as in the "no rotation" case.* *Winds blowing west to east in the North should reduce the water level in the northwest and increase it in the northeast. Winds blowing east to west in the South (near the Equator) should reduce the water level in the southeast and increase the level in the southwest.*

Case Study 6a
Set the [Ocean Basin Model](#) controls as follows:

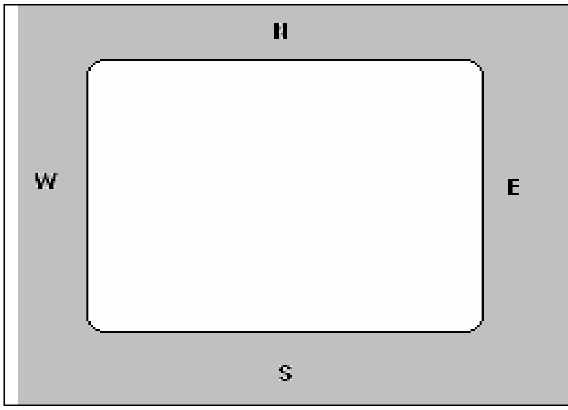
- Keep the "*Nomina*l" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and the Coriolis Force
- Set the Coriolis Force Variation With Latitude to *None*
- Set the Parameter to *Water Level*
- Set the Image Style to ***Contours***

Case Study 6b
Set the [Ocean Basin Model](#) controls as follows:

- Keep the "*Nomina*l" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and the Coriolis Force
- Set the Coriolis Force Variation With Latitude to *None*
- Set the Parameter to *Water Level*
- Set the Image Style to ***Surface***

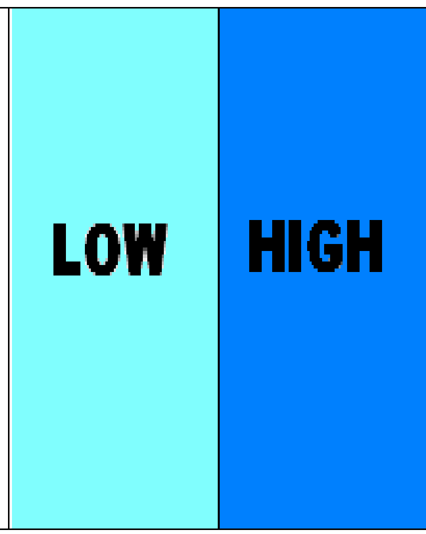
6a	**6b**
	

14. Sketch the wind arrows and indicate where the basin is deepest (D), where it is most shallow (S). How high does the water surface rise above 0 cm? How low does the water surface go below 0 cm? Do the deepest and shallowest regions agree with your hypothesis? Discuss any similarities or differences.

	*The basin is deepest in the middle and shallowest in the corners. The water level ranges between -100 cm (corners) and + 100 cm (center). This disagrees with my hypothesis and is opposite to what occurs in a bowl stirred with a spoon.*

Explain: Pressure Gradient Force

In this exploration, you saw that when the Coriolis acceleration was turned on, the water surface rose in the middle of the ocean basin. This rise of the water is caused by a balancing between a pressure gradient force (fluids at high pressure tend to move towards low pressure) and effects of the Coriolis acceleration.

To understand the pressure-gradient force, imagine a basin of water has a water-tight divider in the middle and a high water level (high pressure) on the right and a low level (low pressure) on the left. The difference in pressure across the basin is the cause of a pressure-gradient force in this case.		If the water tight barrier that separates the right and left sides is removed, gravity will cause the high-level water on the right to flow towards the low level water on the left. Now imagine what water levels will develop in an ocean Northern Hemisphere basin when the Coriolis acceleration is activated (our cylindrical earth rotates at a steady rate of one revolution every 24 hours).

In the Northern Hemisphere, the rule for determining the direction of the Coriolis force is that it will pull moving objects and currents to the right (perpendicular or at 90^{o} to the motion). In the Southern Hemisphere, the pull is always to the left. So when the watertight barrier is removed, the water on the high side starts to flow to the left. This current of water will curve rightwards. The current will curve more and more rightwards until the pressure gradient force to the left in the figure is balanced by a Coriolis acceleration to the right. When this occurs, the current flows north, from the bottom to the top, there will be a dynamic balance of a pressure force and the Coriolis force that appears in the rotating system. The type of current that results from a balance of these two effects is a called a geostrophic current. Geostrophic currents are marked by a difference in water level across the flow of the current.

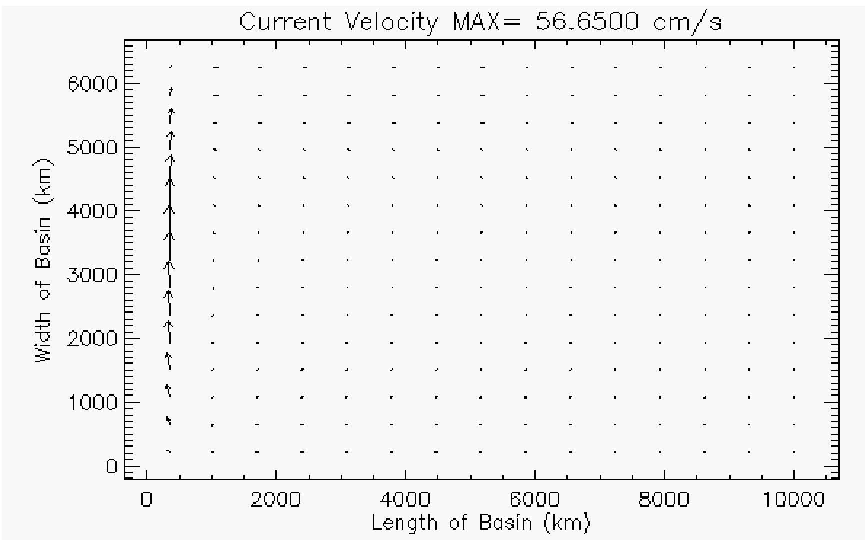
In this last exploration, you saw an example of the effects of a geostrophic current. The water is driven around in a gyre and a balance of pressure forces and the Coriolis acceleration forms a lens of water in the middle of the gyre. The lens-like shape of the water surface is maintained by a balance between pressure gradient and Coriolis forces.

Explore: Spherical Earth Turning on Coriolis Variation with Latitude

You will now turn your attention to studying ocean basin conditions when the Earth is spherical and rotating in its normal fashion. Repeat the same investigations as above but with both “Coriolis Force” and “Coriolis Force Variation With Latitude” now set to Nominal.

Case Study 7: Vectors
Set the Ocean Basin Model controls as follows:

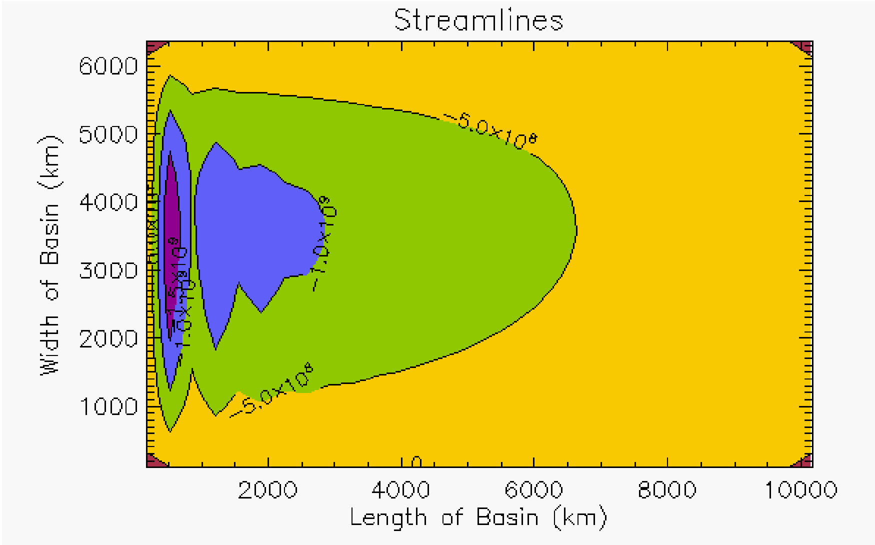
• Keep the “*Nominal*” setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force the Coriolis Force and the Coriolis Force Variation With Latitude
• Set the Parameter to *Surface Current*
• Set the Image Style to *Vectors*



15. Describe the pattern of water flow. Is this the kind of motion that you might expect with the winds blowing over the basin surface? What is the highest speed of water in the basin?
The flow pattern is very different. There is almost no current except along the left (Western shore) boundary. This current is very strong. It has a maximum value of 56.6 cm/s.

Case Study 8: Streamlines
Set the Ocean Basin Model controls as follows:

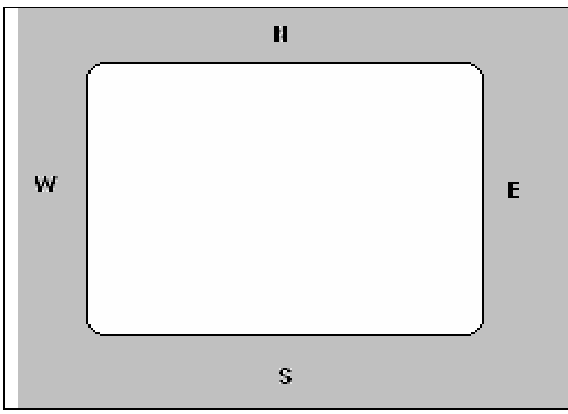
• Keep the “*Nominal*” setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force the Coriolis Force and the Coriolis Force Variation With Latitude
• Set the Parameter to *Streamline*
• Set the Image Style to *Contour*



16. Describe the shape of the paths. Do these paths agree with what you would expect?
The streamlines are very crowded on the left (west) indicating most intense patterns of circulation very close to the western boundary of the basin.

Case Study 9: Water Surface Level

17. Make a hypothesis about how the water surface level of the basin might change in response to the wind stress pattern of the model. Indicate in the drawing how the winds blow and where you might expect to find the deepest (D) and shallowest (S) water. Explain your reasons for making this hypothesis.



My hypothesis is that the water level will be highest near the middle of the left (western) boundary and lowest in the basin corners.

Case Study 9a

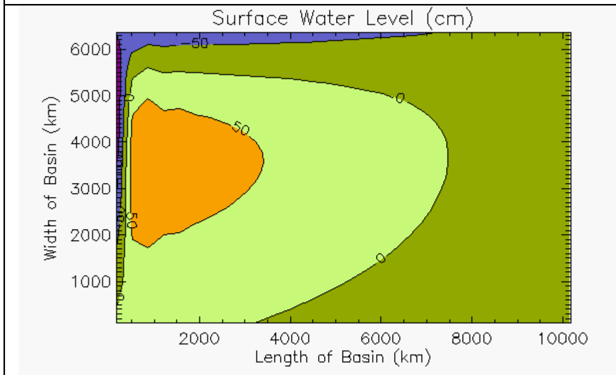
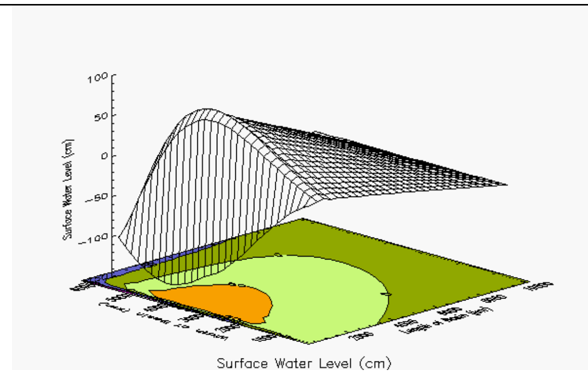
Set the Ocean Basin Model controls as follows:

- Keep the "*Nomina*l" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and the Coriolis Force
- Set the Coriolis Force Variation With Latitude to *None*
- Set the Parameter to *Water Level*
- Set the Image Style to ***Contours***

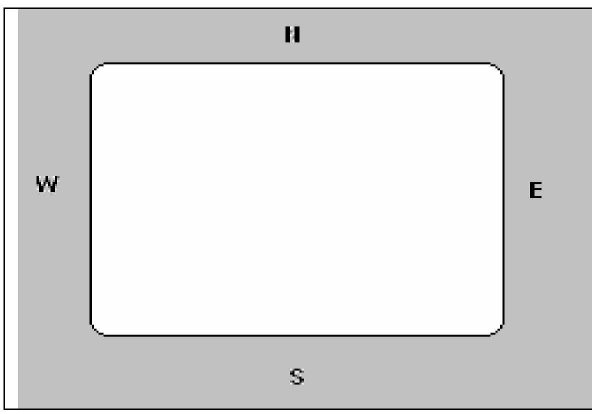
Case Study 9b

Set the Ocean Basin Model controls as follows:

- Keep the "*Nominal*" setting for; Ocean Size, Wind Stress, Basin Depth, Friction Force and the Coriolis Force
- Set the Coriolis Force Variation With Latitude to *None*
- Set the Parameter to *Water Level*
- Set the Image Style to ***Surface***

9a	9b
	

18. Sketch the wind arrows and indicate where the basin is deepest (D), where it is most shallow (S). How high does the water surface rise above 0 cm? How low does the water surface go below 0 cm? Do the deepest and shallowest regions agree with your hypothesis? Discuss any similarities or differences.

	*The water surface level is shallowest in the NW and deepest just off the western boundary. The water level goes down -50 cm and rises to +50 cm.*

The results of this last exploration indicate that the phenomenon of strong boundary currents flowing along the western edge of an ocean gyre is due to the variation in the Coriolis force with latitude. Moving polewards, one's speed of rotation on the surface of the Earth slows at an increasing rate.

Evaluation: Matrix for Grading Lesson 3

4 **Expert**	Responses show an in-depth understanding of Stommel's model used to explain scientific concepts and processes used in the lesson. Proficient manipulation of computer model, data collection, and analysis of data are complete and accurate. Predictions and follow through with accuracy of predictions are explained and fully supported with relevant data and examples.
3 **Proficient**	Responses show a solid understanding of Stommel's model used to explain scientific concepts and processes used in the lesson. Mostly proficient manipulation of computer model, data collection, and analysis of data are mostly complete and accurate. Predictions and follow through with accuracy of predictions are explained and mostly supported with relevant data and examples.
2 **Emergent**	Responses show a partial understanding of Stommel's model used to explain scientific concepts and processes used in the lesson. Some proficiency in manipulation of computer model, data collection, and analysis of data are partially complete and sometimes accurate. Predictions and follow through with accuracy of predictions are sometimes explained and supported with relevant data and examples.
1 **Novice**	Responses show a very limited understanding of Stommel's model used to explain scientific concepts and processes used in the lesson. Little or no ability shown to manipulate computer model, data collection and analysis of data are partially complete and sometimes accurate. Predictions and follow through with accuracy of predictions are not well explained and are not supported with relevant data and examples.