AMERICAN METEOROLOGICAL SOCIETY

The Maury Project

Coastal Upwelling

TEACHER'S GUIDE

The Maury Project

This guide is one of a series produced by The Maury Project, an initiative of the American Meteorological Society and the United States Naval Academy. The Maury Project has created and trained a network of selected master teachers who provide peer training sessions in precollege physical oceanographic education. To support these teachers in their teacher training, The Maury Project develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Forward

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities and in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further reading.

If we except the tides, and ... those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea water at one place and sea water at another; for wherever there is such a difference, whether it be owing to difference of temperature or to difference of saltiness, etc., it is a difference that disturbs equilibrium, and currents are the consequence.

Matthew Fontaine Maury
from The Physical Geography of the Sea. 1855.

Introduction: Coastal Upwelling and Downwelling

In some coastal areas of the ocean, the combination of persistent winds, the Earth's rotation, and shoreline orientation can produce vertical seawater circulations. In regions where the wind transports near-surface water (the surface layer up to about 100 meters thick) away from the coast, it is replaced by water that rises from below. This process is called upwelling. In other regions where the winds move near-surface water toward a coast, water sinks. This process is called downwelling.

The Earth's rotation will deflect water moving horizontally everywhere except at the equator. This deflection is called the Coriolis effect. It results in the net transport of near-surface water in a direction about 90 degrees to the right of the wind flow in the Northern Hemisphere and about 90 degrees to the left of the wind's bearing in the Southern Hemisphere. Persistent winds blowing in directions other than perpendicular to coastlines drive near-surface water away from or toward land, resulting in upwelling or downwelling respectively.

Coastal upwelling and downwelling affect ocean temperature, chemistry, and biology. Upwelling delivers cooler nutrient-rich water from below into sunlight, leading to an increase in biological productivity. Most fisheries are located in areas of upwelling water.

In areas of coastal downwelling, the layer of warm, nutrient-deficient water thickens as water sinks. While this reduces biological productivity, downwelling transports heat, dissolved material, and oxygen-rich surface water downward in the coastal ocean.

Coastal upwelling and downwelling also influence weather and climate. Along the northern and central California coast, upwelling cold water contributes towards the frequent production of summer fogs. Along the west coasts of the African and American continents, upwelling cold water inhibits development of tropical storms and hurricanes. Seasonal upwelling and downwelling moderates the climate along the west coasts of the Americas. Along the coasts of Ecuador and Peru, economically disruptive episodes are associated with the occurrence of the atmospheric-oceanic event called El Niño. During these episodes when upwelling is absent and at times replaced by downwelling, fisheries are drastically reduced.

Upwelling and downwelling areas are of major research interest in search of the global links among wind-driven surface currents, density-driven deep circulation, and the atmosphere. It is possible via this mechanism that small changes in upwelling and downwelling may influence not only the ocean, but weather and climate variability on a planetary scale.

Basic Understandings

The Role of the Wind

1. Unequal heating of the atmosphere by underlying ocean and land surfaces is primarily responsible for atmospheric circulation.

2. The friction between moving air and the ocean surface helps produce the broad-scale horizontal water movements of the ocean's surface, called surface currents. These currents tend to resemble the patterns of the surface winds.

3. If the Earth did not rotate, the friction between moving air and the ocean surface would push a thin layer of water in the same direction as the wind, but at only a fraction of the wind's speed. This layer in turn would drag the layer beneath it and put it into motion. This interaction would continue downward through successive ocean layers, like cards in a deck of cards, each moving forward at a slower speed than that of the layer above.

The Role of Earth's Rotation

1. Since the Earth does rotate, the shallow layer of surface water set in motion by the wind is deflected to the right of the wind's direction in the Northern Hemisphere and to the left of the wind's direction in the Southern Hemisphere. This deflection is called the **Coriolis effect**.

2. Except at the equator, where there is no Coriolis effect, each layer of water put into motion by the layer above is turned in direction because of the Earth's rotation.

3. When viewed from above, the changes in current direction and decreased speed with increased depth, form a spiral called the **Ekman spiral**.

4. Although the motion of the surface layer can be up to 45 degrees to the right or left of the wind direction, the Ekman spiral phenomenon results in the direction of net transport of water in the top 100 meters or so of the ocean to be approximately perpendicular to the wind direction.

Upwelling

1. There are regions of the ocean where the winds and surface currents cause surface water to move away from an area and be replaced by the upward movement of colder water from below. This upward movement is called **upwelling**.

2. In coastal regions, upwelling can be caused by the transport of water away from the coast by winds blowing more or less parallel to the shore. The moving of water away from an area is called **divergence**.

3. The Coriolis effect acting on the westward flowing equatorial currents (near, but not at the equator) moves surface water away from the equator, to be replaced by water from below. This process is known as **equatorial upwelling**.

4. Upwelling occurs along west coasts in the Northern Hemisphere when the wind direction is from the north because the net transport of near-surface water is away from shore. Winds from the south cause upwelling along east coasts in the Northern Hemisphere.

5. Upwelling occurs along west coasts in the Southern Hemisphere when the wind direction is from the south because the net transport of near-surface water is away from shore. Winds from the north cause upwelling along east coasts in the Southern Hemisphere.

6. Upwelling delivers cooler nutrient-rich water from below into sunlit surface regions, leading to an increase in biological productivity. Most fisheries are located in areas of upwelling water.

Downwelling

1. There are regions where the winds and surface currents move surface water towards an area, causing the surface water to pile up. In response, near surface waters sink. This downward movement is called **downwelling**.

2. In coastal regions, downwelling can result from the transport of water towards the coast by winds flowing more or less parallel to the shore. The process of water moving towards a barrier, or water masses moving toward each other, is called **convergence**.

3. In regions of convergence, the piling up of the warm surface waters near the coast leads to downwelling. This thickening of the nutrient deficient surface waters leads to a decrease in biological productivity.

4. Downwelling is a mechanism that transports heat, dissolved material, and oxygen- rich surface water downward.

Impacts of Upwelling and Downwelling

1. The prevailing summer winds bring cold upwelling water to the northern and central California coast and help produce frequent summer fogs.

2. Upwelling along much of the west coasts of the African and American continents leads to colder water in the eastern Atlantic and Pacific Oceans inhibiting development of tropical storms and hurricanes because of relatively low sea surface temperatures.

3. Upwelling influences the climate along the west coasts of the Americas. The upwelling cold coastal water is partially responsible for reducing the annual temperature range of coastal localities.

4. Upwelling and downwelling are investigated as part of the global connection among wind-driven surface currents, density-driven deep circulation, and the atmosphere.

5. This research into upwelling and downwelling may help to identify the mechanisms by which changes in weather influence upwelling and downwelling. It may also reveal how changes in upwelling and downwelling can influence not only the weather, but also climate and climate change on local, regional, and global scales.

Activity: Upwelling and Downwelling Experiences

Introduction

In some near-shore areas of the ocean, the coastal orientation, prevailing wind, and rotation of Earth combine to influence vertical ocean circulation. In these regions, the wind sometimes transports water in about the upper 10 to 100 meters, away from a coast, to be replaced by cooler water from below. This process, called coastal upwelling, brings to the sunlit surface nutrient-rich water which can spur biological production. At other times, the wind moves near-surface water towards a coast, causing warm surface waters to pile up and sink. This process, called coastal downwelling, thickens the layer of nutrient deficient water, resulting in reduced biological production.

This activity investigates coastal upwelling and downwelling by looking at the combinations of coastline orientation, persistent wind direction, and Earth rotation that produce them.

Materials

Photocopy of diagram page, scissors, paper brad, red and blue pencils.

Objectives

After completing this investigation, you should be able to:

- Demonstrate the causes of coastal upwelling and downwelling.
- Describe the influence of the prevailing wind and the Coriolis effect on upwelling and downwelling.
- Describe the influence of coastal orientation on upwelling and downwelling.

Investigations

1. Use the scissors to separate the top and bottom diagrams along the dashed line and cut out the blocks from the top diagram as indicated. Use the pencils to color the arrows in the bottom diagram marked “W” (for warm) red, and those marked “C” (for cool) blue.

2. The top block diagram represents the ocean surface with a vertical cross-section through a model ocean basin. If desired, this can be better seen by folding the diagram along the intersection of the ocean surface and the vertical cross-section and placing it so the vertical cross-section is hanging off the edge of a table.

3. According to the cardinal direction arrows in the upper left hand corner of the top block diagram, the west boundary of any ocean basin is the land's (***eastern***) (***western***) coast and the east boundary of any ocean basin is the land's (***eastern***) (***western***) coast.

4. Use a pencil point to poke a small hole through the centers (each marked with a ⌖) of the two diagrams. Lay the top diagram (Model Ocean Basin) directly over the bottom diagram (arrows) so the center points of the two coincide. To hold the two together, place a paper brad pin down through the holes at the center of the diagrams.

5. While holding the top diagram stationary, twist the bottom diagram through all 4 positions to determine that since there are 2 different hemispheres, each with 2 different wind directions and 2 different coasts possible, the total number of different combinations of hemispheres, wind directions, and coasts possible in our model is (***2***) (***6***) (***8***).

6. On Earth, away from the equator, surface water set in motion by the wind will be deflected by Earth's rotation. This deflection is called the Coriolis effect. Turn the bottom diagram until a Northern Hemisphere combination appears, that is, an "N" appears in the upper right window. Compare the wind direction and the direction of the near-surface flow. If desired, this can be better seen by orienting yourself so that you are on the tail of the wind arrow facing its head. The near-surface flow is about 90 degrees to the (***right***) (***left***) of the wind direction.

7. Predict the direction of the near-surface flow produced by wind blowing from the opposite direction in the same hemisphere. Your prediction is that the near-surface flow will be about 90 degrees to the (***right***) (***left***) of the wind direction.

8. Now rotate the bottom diagram until the other "N" appears in the window, to check your prediction. From what you have learned so far in this activity, wind-driven near-surface flow in the Northern Hemisphere is about 90 degrees to the (***right***) (***left***) of the wind direction.

9. Repeat the last three steps, but this time for the Southern Hemisphere. Again predict and note the direction of the near-surface flow deflection from the wind direction. The wind-driven near-surface flow in the Southern Hemisphere is about 90 degrees to the (***right***) (***left***) of the wind direction.

10. When wind transports near-surface water away from a coast, it tends to be replaced by cooler water from below in a process called upwelling. Rotate the bottom diagram to a position showing the wind blowing from south to north in the Southern Hemisphere. This combination will produce upwelling along the land's (***eastern***) (***western***) coast.

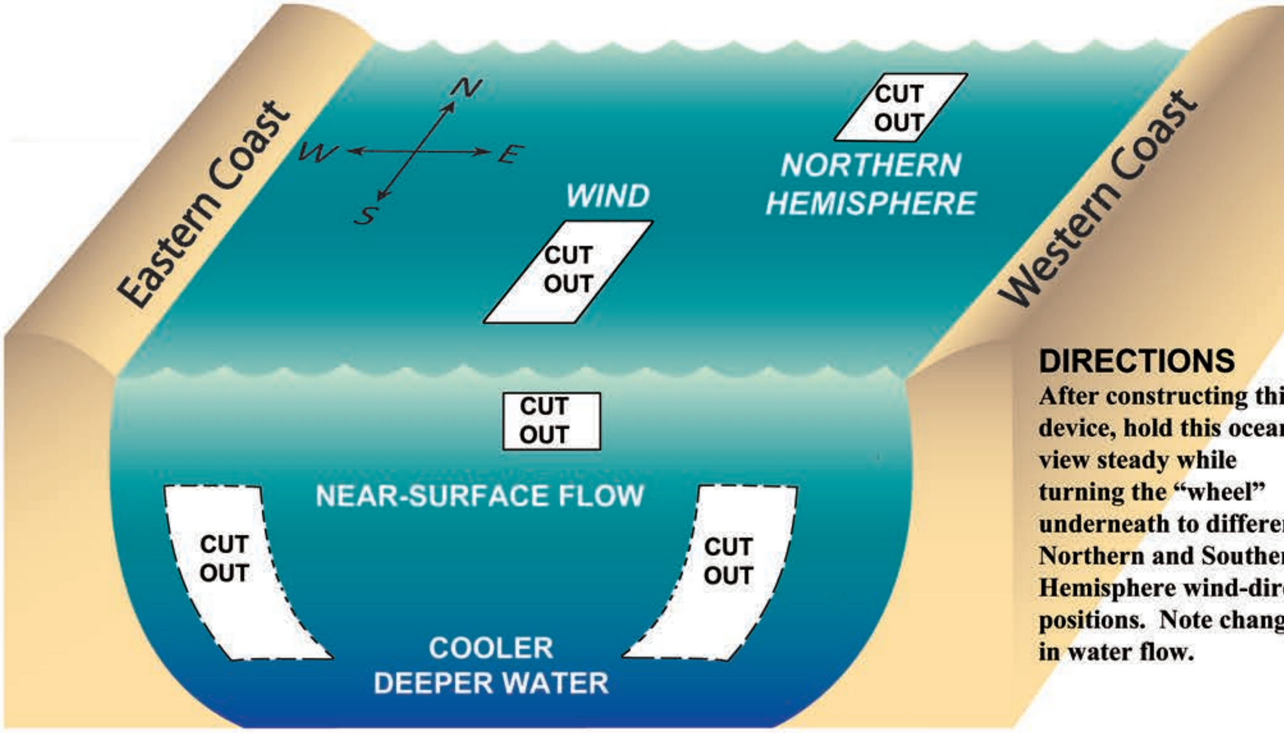
11. The coastal upwelling of nutrient-rich water stimulates the growth of marine plants which support fisheries. Now rotate the underlay to determine that in the Northern Hemisphere on the west coast of Africa, upwelling and increased productivity will be generated by a wind blowing (***south to north***) (***north to south***).

12. When wind transports near-surface water towards a coast, the warm surface layer thickens, decreasing biological activity. This process is called downwelling. Rotate the underlay to a position showing the wind blowing from south to north in the Northern Hemisphere. This combination will produce downwelling along the land's (***eastern***) (***western***) coast.

13. Along the coast of central and northern California, surface winds blow from north to south in the summer and from south to north in the winter. The season of warm water movement towards the coast and downwelling for this region is (***summer***) (***winter***). The season for cold coastal upwelling water producing frequent fog is (***summer***) (***winter***) .

14. The Southern Hemisphere's trade winds have a strong component blowing from south to north. This brings upwelling, high productivity, and productive fisheries to the (***western***) (***eastern***) coasts of Africa and South America.

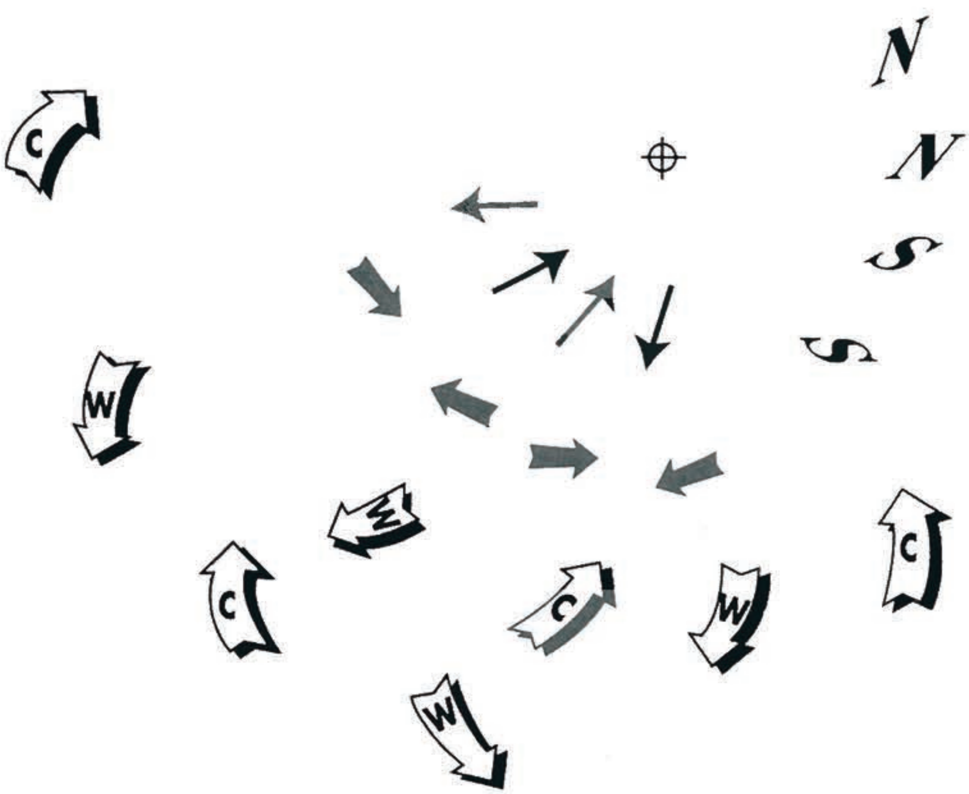
MODEL OCEAN BASIN



DIRECTIONS

After constructing this device, hold this ocean view steady while turning the "wheel" underneath to different Northern and Southern Hemisphere wind-direction positions. Note changes in water flow.

CUT HERE



Information Sources

Ahrens, C.D., 1994. Meteorology Today, *An Introduction to Weather, Climate, and the Environment*, 5th. ed. West Publishing Co., St Paul, MN.

Cullen, V. (ed.), 1993, Coastal Science & Policy I, *Oceanus* Vol. 36(1), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1993, Coastal Science & Policy II, *Oceanus* Vol. 36(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1991, Naval Oceanography, *Oceanus* Vol. 33(4), Woods Hole Oceanographic Institute, Woods Hole, MA

Cullen, V. (ed.), 1992, Physical Oceanography, *Oceanus* Vol. 35(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Duxbury, A.C. and Duxbury, A.B., 1994. *An Introduction to the World's Oceans*, 4th. ed. Wm. C. Brown Publishers, Dubuque, IA.

Golden, F. (ed.), 1989, The Oceans and Global Warming, *Oceanus* Vol. 32(2), Woods Hole Oceanographic Institute, Woods Hole, MA

Gross, M. Grant, 1992. *Oceanography, A View of the Earth*, 6th. ed. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Open University, 1991, *Case Studies in Oceanography and Marine Affairs*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Ocean Circulation*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Seawater: Its Composition, Properties and Behavior*, Pergamon Press, Tarrytown, NY.

Open University, 1991, *Waves, Tides and Shallow-Water Processes,* Pergamon Press, Tarrytown, NY.

Ryan, P.R. (ed.), 1990, Marine Education, *Oceanus* Vol. 33(3), Woods Hole Oceanographic Institute, Woods Hole, MA

Thurman, H.V., 1992, *Essentials of Oceanography*, 4th. ed. Merrill Publishing Co., Columbus, OH