

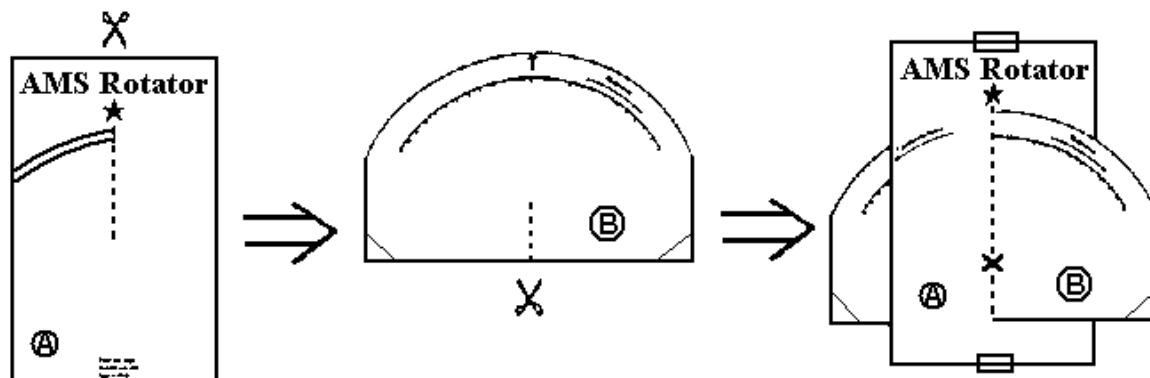
## Activity: Because the Earth Turns

**Introduction:** Almost everywhere on Earth (except at the equator), objects moving horizontally and freely (unconstrained) across Earth's surface travel in curved paths. Planes, boats, bullets, air and water parcels, and other objects turn right or left as seen from our vantage point on Earth. This activity investigates the reason for this turning, a phenomenon known as the *Coriolis effect*.

**Inquiry-Based Approach:** This teacher enhancement activity provides a learning experience on fundamental understandings underlying the Coriolis effect. The goal is to provide teachers with a knowledge base enabling them to guide students in scientifically authentic learning experiences. The teacher is encouraged to employ the *constructivist* model of inquiry by introducing the activity in the classroom after (a) students have been confronted with, discussed, and posed questions relating to some of the effects of the Earth's rotation on moving objects and on the atmosphere and the ocean, and (b) the teacher has determined the appropriateness of the activity in stimulating student thinking, questioning, and scientific inquiry.

**Materials:** Photocopy of *AMS Rotator* sheet, scissors, tape, pencil

**Directions:** First construct the *AMS Rotator*. Cut out the two large pieces, labeled **A** and **B** plus the "straight-edge." Cut along the dashed lines on **A** and **B** only as far as the dots. Fit **A** and **B** together as shown in the drawing, making sure that the dot on **A** coincides with the dot on **B**. Lay the device flat on the desk in front of you with the cut end of **A** positioned away from you. Now tape **A** to your desk at the two places indicated at the midpoints of the far and near edges of **A**, making sure that **B** can rotate freely. Fold up the bottom two corners of **B** as shown. Gripping these tabs, practice rotating **B** so that the two dots always coincide. Note that a *straight scale* is drawn on **A** along the cut-edge and a *curved scale* is drawn on **B**.



## Investigations:

1. Orient **B** in the “cross” position as shown in the drawing. If positioned properly, a straight arrow should point towards the ★. Place your pencil point at the center of the *Start Position X*. Carefully draw a line on **B** along the cut-edge and directly towards the ★. The line you drew represents a path that is **[(straight)(curved)]**.
2. Now investigate how rotation affects the path of your pencil lines. Again begin with **B** in the “cross” position with the direction arrow pointing towards the ★. Pulling the lower left tab towards you, rotate **B** counterclockwise through one division of the *curved scale* (on **B**). Make a pencil dot on **B** along the *straight scale* at one scale division above the *Start Position X*. Continue rotating **B** counterclockwise one division at a time along the *curved scale*, stopping each time to mark a pencil dot on **B** at each successive division along the *straight scale*. Repeat these steps until you reach the *curved scale*. Starting at **X**, connect the dots with a smooth curve. Place an arrowhead at the end of the line to show the direction of the motion. The line you drew on **B** is **[(straight)(curved)]**.
3. You actually moved the pencil point along a path that was both straight *and* curved at the same time! This is possible because motion is measured relative to a frame of reference. (A familiar frame of reference is east-west, north-south, up-down.) In this activity, you were using two different frames of reference, one fixed and the other rotating. When the pencil-point motion was observed relative to the fixed **A** and ★, its path was **[(straight)(curved)]**. When the pencil motion was measured relative to **B** which was rotating, the path was **[(straight)(curved)]**.
4. Begin again with **B** in the “cross” position and the arrow pointing towards the ★. Pulling the lower right tab towards you, rotate **B** clockwise one division of the *curved scale* and make a pencil dot on **B** along the *straight scale* at one scale division above the *Start Position X*. Continue in similar fashion as you did in Item 2 above to determine the path of the moving pencil point. The path was straight when the pencil-point motion was observed relative to **[(A)(B)]**. The path was curved when the pencil motion was measured relative to **[(A)(B)]**.
5. Imagine yourself shrunk down in size, located at **X**, and looking towards the ★. You observe all three situations described above (that is, no motion of **B**, counterclockwise rotation, and clockwise rotation). From your perspective at the **X** starting position, in all three cases the pencil point moved towards the ★ along a **[(straight)(curved)]** path.
6. Watching the same motion on **B**, the pencil path was straight in the absence of any rotation. However, the pencil path curved to the **[(right)(left)]** when **B**

rotated counterclockwise. When the rotation was clockwise, the pencil path curved to the **[(right)(left)]**.

This apparent deflection of motion from a straight line in a rotating coordinate system is called the Coriolis effect for Gaspard Gustave de Coriolis (1792-1843) who first explained it mathematically. Because the Earth rotates, objects moving freely across its surface, except at the equator, exhibit curved paths.

7. Imagine yourself far above the North Pole, looking down on the Earth below. Think of **B** in the **AMS Rotator** as representing Earth. As seen against the background stars, the Earth rotates in a counterclockwise direction. From your perspective, an object moving freely across the Earth's surface would move along a **[(straight)(curved)]** path relative to the background stars (depicted by the ★ on the **AMS Rotator**).

Now think of yourself on the Earth's surface at the North Pole at the dot position while watching the same motion. From this perspective, you observe the object's motion relative to the Earth's surface. You see the object moving along a path that **[(is straight)(curves to the right)(curves to the left)]**.

8. Imagine yourself located far above the South Pole. As seen against the background stars, the Earth rotates in a clockwise direction. The sense of rotation is reversed from the North Pole because you are now looking at the Earth from the opposite direction. An object moving freely across the Earth's surface is observed to move along a **[(straight)(curved)]** path relative to the background stars.

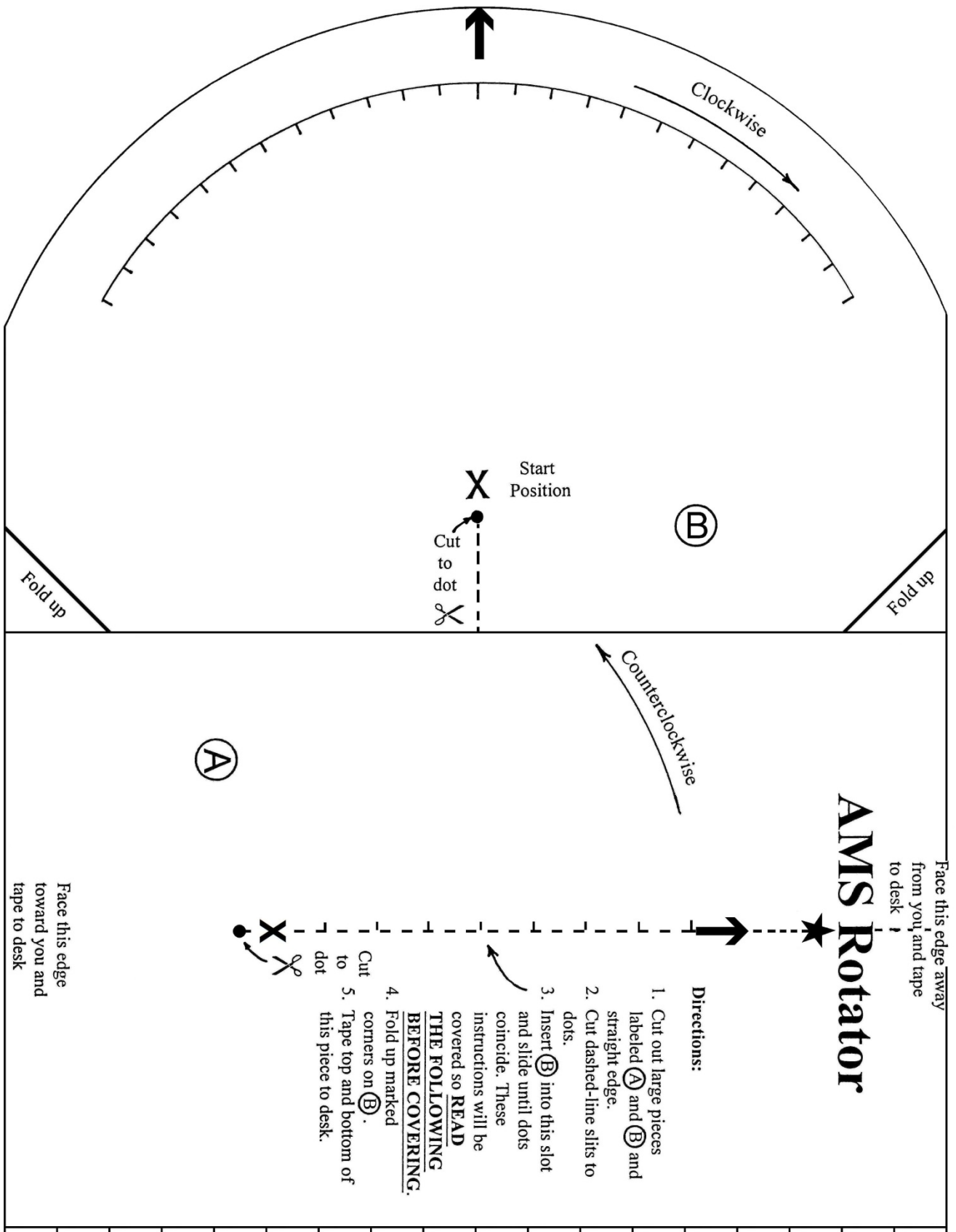
Now think of yourself on the Earth's surface at the South Pole while watching the same motion. From this perspective, you observe the object's motion relative to the Earth's surface. You see the object moving along a path that **[(is straight)(curves to the right)(curves to the left)]**.

9. In summary, the Coriolis effect causes objects freely moving horizontally over Earth's surface to curve to the **[(right)(left)]** in the Northern Hemisphere and to curve to the **[(right)(left)]** in the Southern Hemisphere.

### Further Investigations:

1. Again begin with **B** in the "cross" position. Create paths that originate on the *straight scale* at one division below the *curved scale* and move toward the original *Start Position(X)*. Do this for **B** rotating clockwise and then counterclockwise. Earlier we found that curvature to the right was associated with counterclockwise rotation and curvature to the left was associated with clockwise rotation. In these cases, the same associations between curvature and direction of rotation **[(apply)(do not apply)]**.

2. Try moving across **B** while it rotates by using the “straight edge” as a pencil guide. Orient the “straight edge” at a right angle to the cut edge in **A** about half way between **X** and the ★ and tape its ends so that **B** rotates freely. While rotating **B** counterclockwise, draw a line several scale units long from left to right beginning at the cut-edge. Repeat the process for **B** rotating clockwise. Curvature was to the **[(right)(left)]** with counterclockwise rotation and to the **[(right)(left)]** with clockwise rotation.
  
3. Investigate changes in the relative speed of rotation and the curvature by moving one division along the *straight scale* for every two divisions of the *curved scale* or two divisions of the *straight scale* for every one of the *curved scale*. Does the direction of curvature change? Does the amount of curvature change?



Face this edge away from you and tape to desk

# AMMS Rotator

**Directions:**

1. Cut out large pieces labeled **(A)** and **(B)** and straight edge.
2. Cut dashed-line slits to dots.
3. Insert **(B)** into this slot and slide until dots coincide. These instructions will be covered so **READ THE FOLLOWING BEFORE COVERING.**
4. Fold up marked corners on **(B)**.
5. Tape top and bottom of this piece to desk.

Face this edge toward you and tape to desk

(Save for straight-edge use)

## Optional Activity: Coriolis Deflection and Earth Latitude

**Introduction:** The Coriolis deflection is greatest at the North and South Poles and is absent at the equator. What happens to the Coriolis deflection at latitudes in between? The purpose of this activity is to investigate how the Coriolis effect changes with latitude. In this activity, you will construct generalizations concerning the influence of the Coriolis effect on objects moving horizontally and freely over different latitudes.

**Materials:** Transparent plastic **hemispheric shape** 10 to 15 cm (4 to 6 inches) in diameter, scissors, tape, washable overhead-projection pen or other washable-ink pen that writes on plastic, **AMS Rotator**.

**Directions:** The plastic hemisphere represents the Earth's Northern Hemisphere surface. Place the hemisphere on the **AMS Rotator** (taped flat on your desk) so that the pole position of the hemisphere is directly above the rotational axis (dot location) of the **AMS Rotator**.

1. With your eyes about two feet directly above the hemisphere, look down at the curved line you drew on **B** in Item 2 of the **Because the Earth Turns** activity in this module. Using the overhead-projection pen, draw on the hemisphere surface the path of the curved line as viewed from your perspective. Examine the curve that you drew on the hemisphere's surface. The curvature of the path **[(decreases)(increases)]** as the latitude decreases. This happens because the effect of the Earth's rotation on freely-moving objects is greatest in a plane (flat surface) oriented perpendicular to Earth's rotational axis, that is, at one of the poles. As the plane representing the surface of the Earth tilts more and more from this perpendicular position, the effects of the rotation on motion along that plane decreases. This activity visually depicts this change.
2. Consequently, the effect of the Earth's rotation on horizontally moving objects becomes less and less with decreasing latitude. At the equator, an object moving freely across the Earth's surface would exhibit no deflection due to the Earth's rotation. Stating it another way, the Coriolis deflection increases with increasing latitude. The change in deflection varies as the sine of the latitude. The sine of 0 degrees (equator) is 0, no Coriolis deflection; the sine of 90 degrees (poles) is 1, the maximum Coriolis deflection. The sine of 45 degrees is 0.707, so at 45 degrees latitude the Coriolis deflection is 0.707 of what it is at 90 degrees latitude.

# Real World Applications

Fluids moving over Earth's surface are subject to forces that drive them as well as the rotational effect of Earth (Coriolis). In the atmosphere, horizontal pressure gradients put air into motion. It is subsequently influenced by Earth's rotation (Coriolis effect), to the right in the Northern Hemisphere. The flow from high toward low pressure, deflecting to the right, is evidenced in clockwise and outward flows around high-pressure centers and counterclockwise and inward flow around low-pressure centers. **Figure 1** is a regional weather map for the North Pacific at 06Z (2 a.m. EDT) 3 April 2012 from the Honolulu National Weather Service Forecast Office.

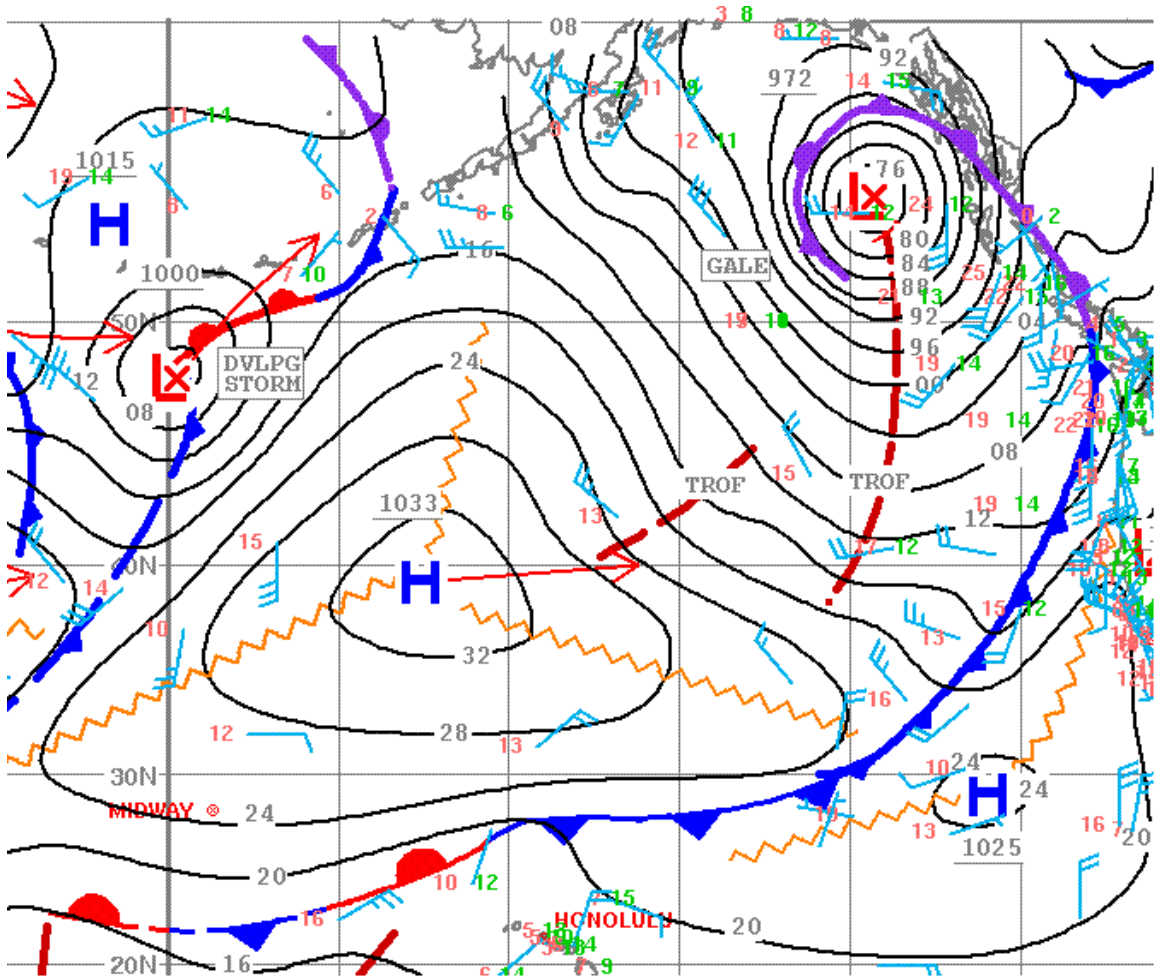


Figure 1. North Pacific regional weather map for 06Z 3 APR 2012. [NOAA]

Light blue wind arrows show observations where the air is moving toward the direction of the arrow head and the speed is shown by the combination of feathers on the tail, long for 10 knots, short for 5 knots.

Imagine yourself at the center of the high pressure (**H** within the “32” line, 1032 mb isobar) near the map center. The horizontal pressure gradient force would begin your motion toward the center of low pressure (**L** within the “76” line, 976 mb isobar) in the upper right. As you travel, you would turn toward your right (Northern Hemisphere).

1. Does your direction of motion match the light blue wind arrows a few centimeters out from the center of the High? **[(Yes)(No)]**.

Next, imagine yourself between the high pressure **H** and the **L**. The horizontal pressure gradient force would begin your motion toward the center of low pressure to the upper right. As you travel, you would turn toward your right.

2. Does your direction of motion match the light blue wind arrows a few centimeters out from the center of the Low? **[(Yes)(No)]**.
3. The overall pattern of wind arrows surrounding the center of the High is **[(clockwise)(counterclockwise)]** as would be result of the combination of horizontal pressure gradient force and Coriolis effect on air motion.
4. The overall pattern of wind arrows surrounding the center of the Low is **[(clockwise)(counterclockwise)]** as would be result of the combination of horizontal pressure gradient force and Coriolis effect on air motion..

Note the winds to the lower right of the map area. The persistent Pacific (or Hawaiian) High with its clockwise flow would often drive winds along the U.S. West Coast from north toward south such as those shown. A generally north-to-south wind flow would drive ocean waters southward. In turn, the waters would also turn to the right (Coriolis effect) to move them offshore. In the ocean this is called *Ekman transport*. In the California coastal region this offshore movement would draw water upward from greater depths in replacement. This deeper water is cooler and contains nutrients feeding biological growth.

**Figure 2** is a composite of three images of the southern California coastal region. Fig 2(a) is a visible view of water, clouds and land areas. Fig 2(b) is an image of chlorophyll amounts where yellows and reds represent the highest chlorophyll levels and greatest biological productivity (brown is land). Fig 2(c) is a map of ocean surface temperatures where the blue and lightest green shades are coolest temperatures (gray is land surfaces while black is cloud cover).

5. Imagine yourself moving in the direction of the winds (northwest to southeast) along the California coast driving the waters to the right by Ekman transport. The general direction of water transport in the coast California region is **[(toward)(away from)]** shore.



6. Water movement away from the shore is replaced by water coming up from depth in a process called *upwelling*. This cooler water **[(is)(is not)]** consistent with the blue and lighter green shadings of temperature seen in Figure 2c.
7. Upwelling brings nutrients that had sunk in the waters back into the sunlit surface regions to spur productivity. The increased amounts of chlorophyll **[(is)(is not)]** consistent with the yellow and red shadings of chlorophyll seen in Figure 2b.

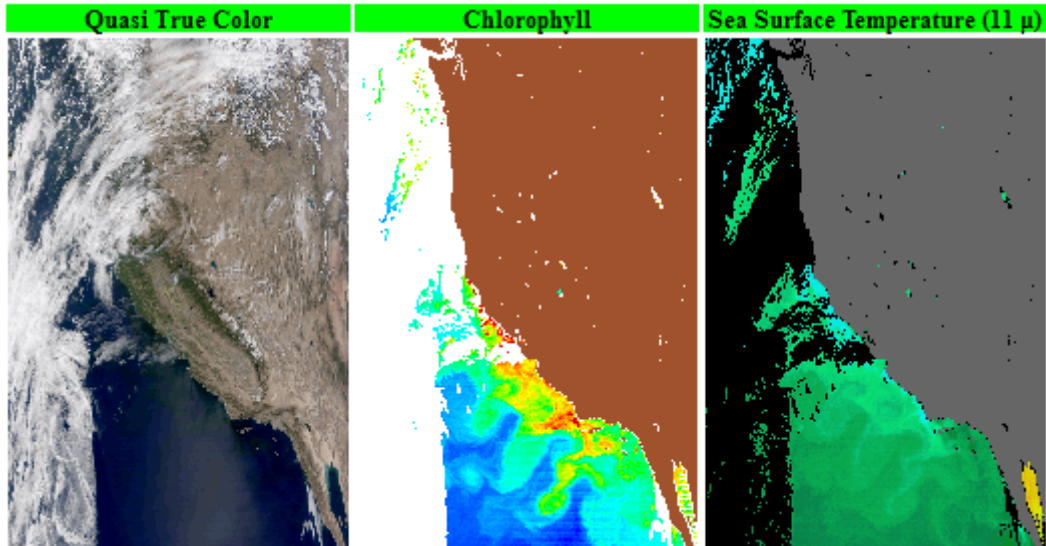


Figure 2. Composite views of (a) visible coastal features, (b) chlorophyll levels, and (c) sea surface temperatures. [SeaWiFS]