# Navigating the Ocean

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Photo credit: Daniel Forester, Volvo Ocean Race

**Lesson Objectives:**

- To explain how ocean surface currents affect the path of floating objects.

- To describe how early mariners navigated the ocean based on speed and direction.

- To track Columbus's first voyage to America, and Bligh's mutiny survival.

- To describe the role of ocean explorers in gathering scientific information.


## Introduction: How Did They Do That?
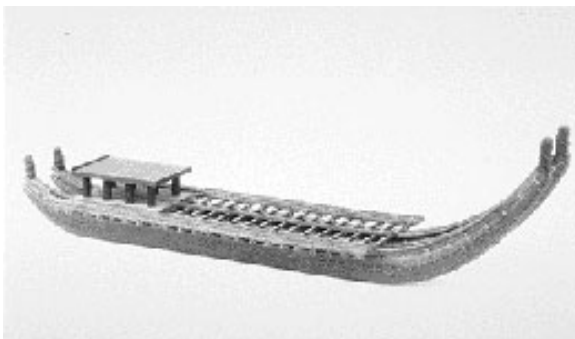
"Historians believe that Pacific Islanders explored the entire South Pacific well before the era of recorded history. Historians speculate around 2500 B.C., Southeast Asians began to migrate throughout the Pacific.[1]" Their 30.5 meter long canoes, shown on the left, were navigated by men who were taught from childhood to decipher nautical information including star positions, ocean currents, wave echoes, prevailing winds, and the habits of migratory birds. "More than 1,300 years ago, Polynesian explorers set out from Havai'i (now Raiatea, in the Society islands) in great double-hulled canoes to cross the vast unknown expanse of the North Pacific Ocean. By chance, they discovered and subsequently colonized, the Hawaiian Islands. A long canoe voyage across the uncharted ocean must have required an exceptional degree of navigational skill. By observing the stars, winds and currents, ancient navigators could approximate their geographic position.[2]"

Ocean surface currents have played an important role in navigation from ancient times, through the exploration of the world by sail to present day shipping. Today, most ships are propeller-driven and less dependent on the winds, but all ships benefit significantly when carried by ocean surface currents.

In Lesson 1, you will experiment with the effects of ocean surface currents on drifting objects. You will use a simple computer model to investigate the movements of objects drifting on the ocean surface. You will also learn how Columbus sailed to the new world using tools such as a compass, an astrolabe, an hourglass, maps, and charts, dead reckoning, winds and currents. You will read Captain William Bligh's journal and find out how he survived after the mutiny on his ship the Bounty, when he was set to sea, in a small boat, near Tahiti without any instruments.

Photo credit: Daniel Forester, Volvo Ocean Race

[1] Adapted with permission from the Mariners Museum
[2] The Blue Planet, An Introduction to Earth System Science",    B. Skinner, S. Porter, D. Botkin

# What Do You Know?

Before beginning this lesson is it helpful to learn how much information you already know about Navigation. A simple preconceptions survey has been created for you to assess your prior knowledge.

1. Click on the blue **Quiz** button below.
2. Take the quiz
3. Submit your responses online and they will be automatically scored.
4. Return to this guide and begin your exploration of the Coriolis Force.

# A Drifter Model
*How do ocean surface currents affect the motion of floating objects?*

Propelled by winds, and steered by Earth's rotation and gravity, the waters in the world's ocean are constantly in motion. Water moves horizontally (east, west, north and south) and vertically (sinking and rising). The following investigation focuses on the horizontal circulation of water at the ocean surface. The waters of the ocean are stratified by gravity so that water found at greater depths is typically denser (colder, saltier) than surface waters. This stratification inhibits mixing of the layers and decouples surface motion from the deeper waters. A simplistic model for surface currents would imagine them as a thin layer of circulating ocean water above more static, deeper layers.

**What is a Drifter Model?**

In order to experiment with drifting objects carried by ocean surface currents, you will use a computer model. The model uses historical monthly, ship drift data, which was gathered about ocean surface current circulation and simple physics equations of motion to predict drifter motion. The OSCAR visualizer, located in this site, contains more recent and accurate sources of ocean surface current data. OSCAR data will be used in lessons 5 & 6.

The drifter database consists of the following values for locations on the ocean surface:
• East-west (zonal) mean velocity component, **u**, and an estimate of its variability.
• North-south (meridional) mean velocity component, **v**, and an estimate of its variability.

For example, a value for **u** in a specific month and location might be 0.3 meters/second with a variability of 0.1 meters/second. In simple terms, the mean or average zonal current moved eastward at 0.3 meters (about 1 foot) in one second, on any given day. The actual current might vary by 0.1 meter per second above and below this value. Commonly observed zonal currents might fall in the range 0.2 to 0.4 meters/second.

Click *Ship Drift Model* to link to the model on your computer. This model accounts for the circulation of currents and does not include effects of wind/waves or the dynamics of the floating object. The drifter is imagined as a small object floating at the surface, with a density near that of seawater. The model does not apply to sailing or motorized ships.

The *Ship Drift Model* page, shown below, displays a map of the world with arrows depicting the mean or average direction of currents at the ocean surface. The current patterns are fairly complex and show the effects of continental landmasses. The arrows indicate the direction of the current and the arrow colors indicate the speed of the current. Below the map, there is a color scale that provides the key for converting each yellow, green, red, or blue arrow to a speed in meters per second.

**1.** Look carefully at the world map below (or on your computer screen), to find the speeds corresponding to colored arrows. Fill in the empty boxes with current speeds.

| Arrow Color | Dark Blue | Light Blue | Green | Yellow | Orange | Red | Dark Red |
|---|---|---|---|---|---|---|---|
| Current Speed (m/s) | | | | | | | |
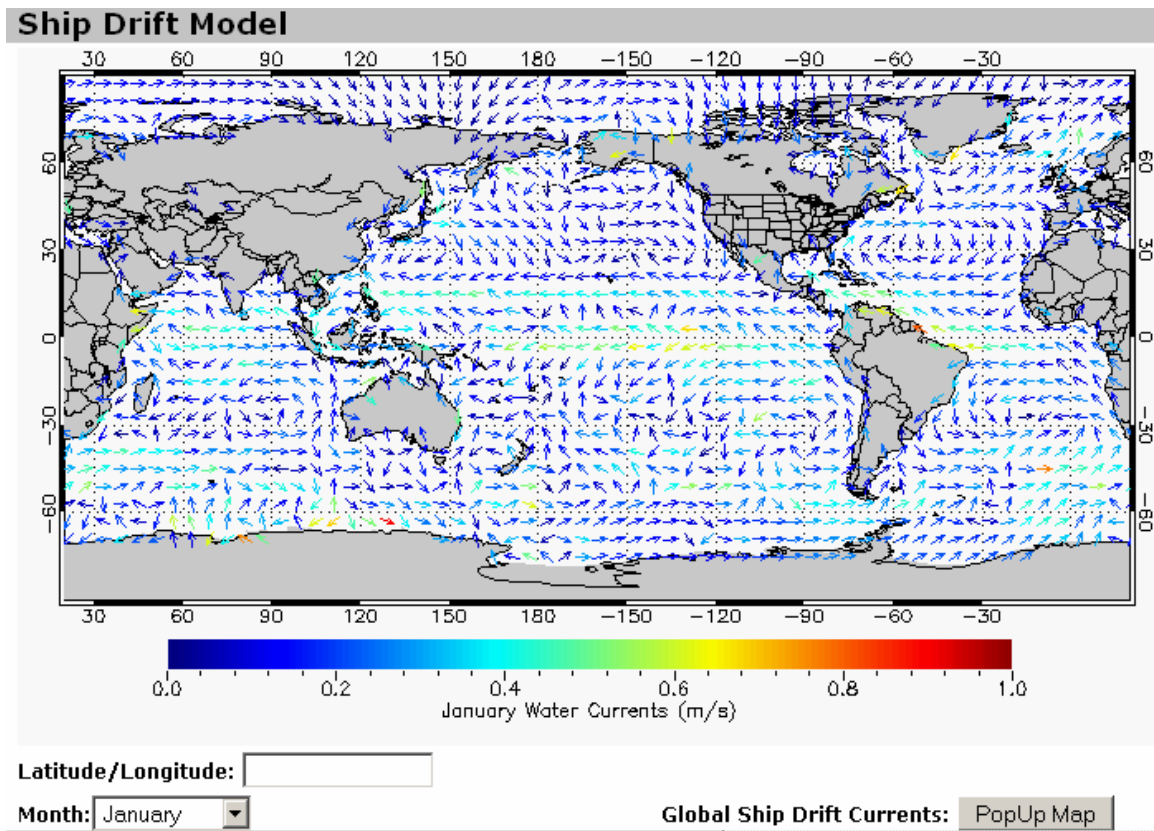


**Using the Ship Drift Model on your computer**

Look at the bottom of the data visualizer. There are three options, 1. Latitude/longitude, 2. The month selection and 3. The Pop-up Map.

• To find the latitude and longitude of a point on the map, roll the mouse over the map. The latitude and longitude for that point will appear in the box at the bottom of the currents map.

• To view currents in greater detail, choose a month from the drop-down menu on the left, and then click the Pop-up Map button on the right and a large, zoomable map will pop up in a separate window. The Pop-up map will be helpful in tracing surface current circulation.

• To start your drifters voyage, move the computer mouse cursor over the ocean and click on the map. A second window with a map showing the tracks of five drifters will pop up.

In the example shown below, the start click was made near the southeast coast of the United States. A square, black, outline box marks the beginning of the drifter's voyage (labeled in the image with the word "Start"). The colored tracks (purple, blue, red, orange, blue) follow five drifters under the influence of variable currents through five years. A color-coded, diamond-shaped, outline box marks the end of each track. The five different tracks show the approximate effects of the ocean surface current variability.

Coordinates on the map below use degrees of longitude (horizontal scale) and degrees of latitude (vertical scale). The starting point has a longitude near -80° and latitude near 31°.
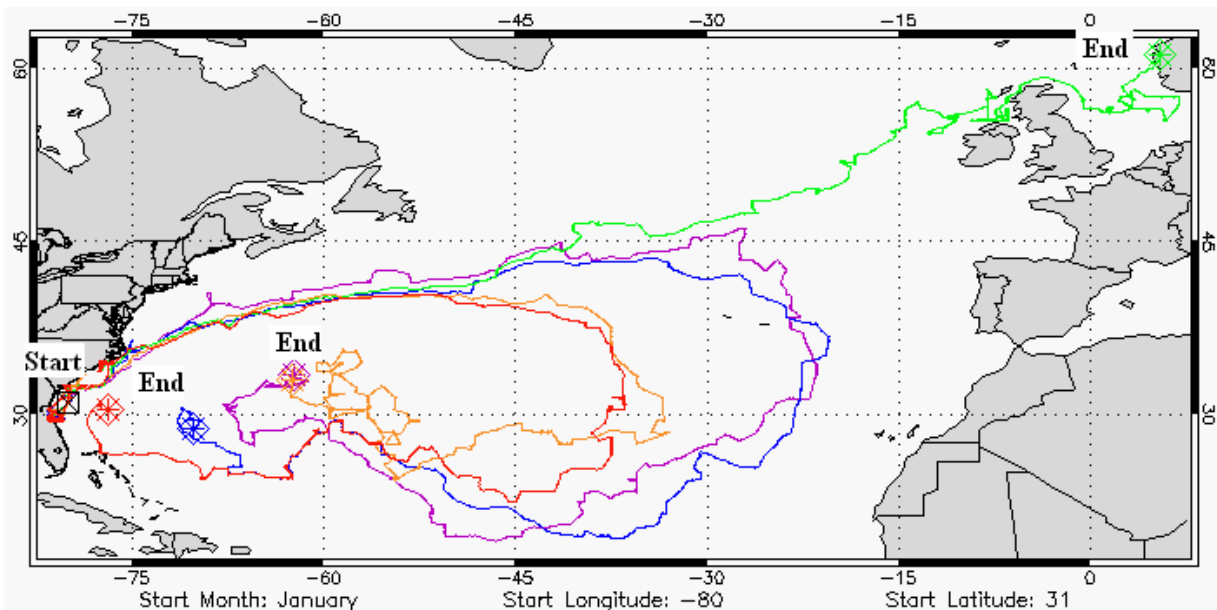


**2.** Estimate the end locations for the five drifters and write the number in the table below.

| Drifter color | Blue | Green | Orange | Red | Purple |
|---|---|---|---|---|---|
| End longitude | | | | | |
| End latitude | | | | | |

**Experiment With Your Own Drifter**
Try creating your own voyager drifter. Use the main map of the Ship Drift Model as well as the higher resolution map to select a starting site and make a prediction of where your drifters will travel.

**3.** Starting Longitude _____ Starting Latitude _____

**4.** Sketch your prediction for the drifter's track on the map on the next page. In case of uncertainty, trace several possible routes.

**5.** Click your selected starting location on the map. Estimate the end locations of each of the five drifters:

| Drifter color | Blue | Green | Orange | Red | Purple |
|---|---|---|---|---|---|
| End longitude | | | | | |
| End latitude | | | | | |

**6.** How well does your estimate of the drifter route agree with the computer model?  Where is there agreement?  Where do predictions disagree the most?
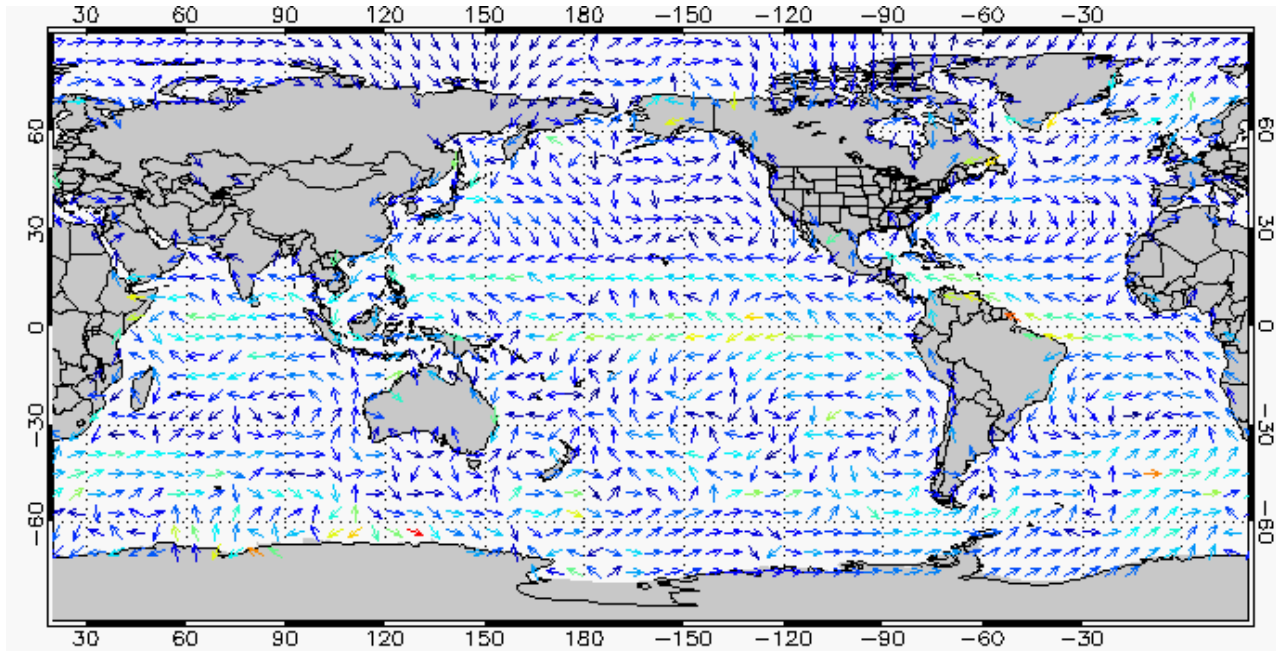


# Rubber Duckies Venture Around The World
*What do you know about the flow of currents around the world?*



Jim Ingraham / NOAA-Fisheries

Many tools are used to study the flow of the ocean. Curt Ebbesmeyer, pictured on the left with tub toys, says that when investigating the paths of ocean surface currents, he uses every tool available. He studies satellite images and data from buoys. He tosses objects into the water to see where they go.

In January 1992, his toolbox grew even larger. A storm washed several containers from a ship bound from Hong Kong to Tacoma, Washington. One container carried 29,000 bathtub toys. Ten months later, plastic ducks, turtles, frogs, and beavers began washing up near Sitka, Alaska. A new experiment had begun and Curt's career as a pioneer in the study of floating debris was in full swing.

Today, Curt presides over a network of thousands of beachcombers. These volunteers and hobbyists walk the beaches of the world, snatching up shoes, hockey equipment, surveyor stakes, bowling balls, Lego's, tobacco jars, fishing gear, survival suits (with and without body parts), and the occasional message in a bottle, and report their findings to Curt. Curt studies the information, thinks about what it all means, and compiles these stories into a newsletter, Beachcombers Alert, which he mails to his subscribers four times a year. If a new cargo spill occurs, Curt alerts his network about what to look for.
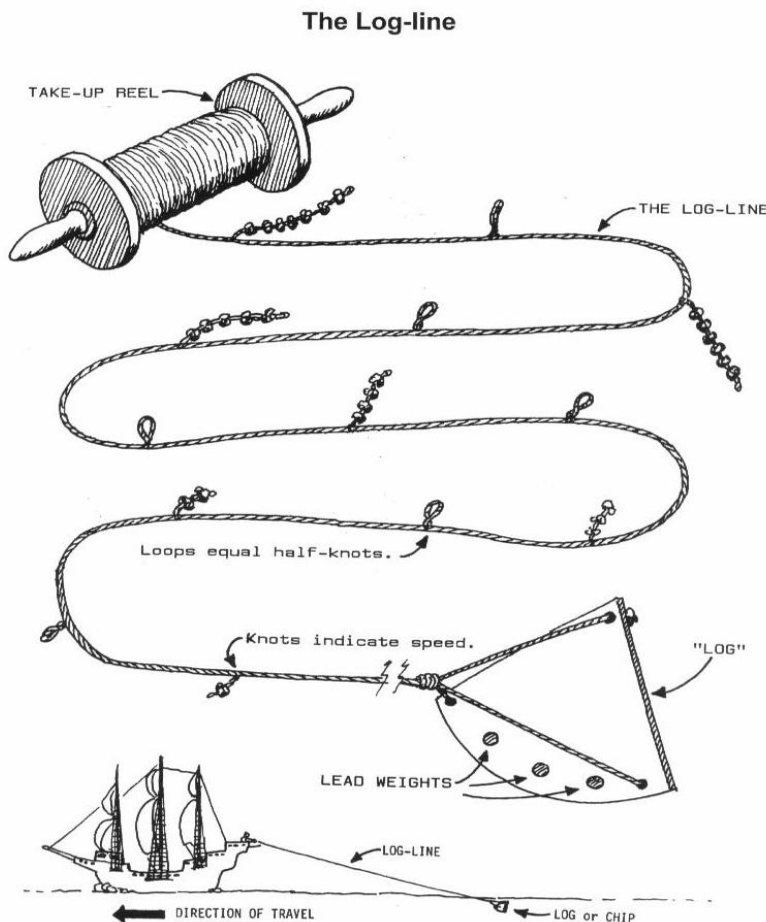
Read more about Curt by clicking on his name in the first paragraph.

# Dead Reckoning

*How can one navigate—determine location—on the open ocean?*

When not using the stars, Sun or moon to determine their location, sailors and explorers navigated by deduced (or dead) reckoning. This was the method used by Columbus and most other sailors of his era. In dead reckoning, the navigator finds his position by measuring the course and distance he has sailed from some known point. Starting from a known point, the navigator measures out his course and distance from that point on a chart, pricking the chart with a pin to mark the new position. Each day's ending position would be the starting point for the next day's course-and-distance measurement. For this method to work the navigator needed a way to measure his course and to measure the distance sailed. Course was measured by a magnetic compass, which had been known in Europe since at least 1183. Distance was determined by a time and speed calculation: the navigator multiplied the speed of the vessel by the time traveled to get the distance.

**7.** To determine speed on old sailing boats, sailors often used a log line. Describe how a log line was used and make a drawing of a log line on the back of this sheet.

## The Log-line



TAKE-UP REEL

THE LOG-LINE

Loops equal half-knots.

Knots indicate speed.

"LOG"

LEAD WEIGHTS

LOG-LINE

DIRECTION OF TRAVEL        LOG or CHIP

The fundamental flaw in using this log line method to determine distance is that it does not account for the effects of surface currents. The log line method measures the speed of the ship relative to the surface water. It provides no means to estimate how fast the water itself flows. If a boat is carried westward by a strong current, the log line method will not reveal the existence of the current. If you travel steadily on a train along a straight track, you will barely be aware that you are in motion relative to the tracks. This fact is related to Newton's First Law of Motion, which states that steady motion in a straight line is "natural" and undetectable without reference to an outside reference object.

**8.** How do you think a speedometer on a car measures speed? Are there any circumstances that might cause this measurement to be incorrect and not reveal the "true" speed of the car?

To determine their direction of travel, sailors used the compass. The compass is a magnet with ends labeled N and S. The N end points to the north magnetic pole of the Earth. This pole is situated in northern Canada and does not coincide with the north geographic pole (the "North Pole"). True north lies along Earth's axis of rotation and points in the direction of Polaris, the North Star.

**9.** Click the link to "Magnetic Declination" and write a definition of it. Include a drawing that shows the difference between geographic north and magnetic north.
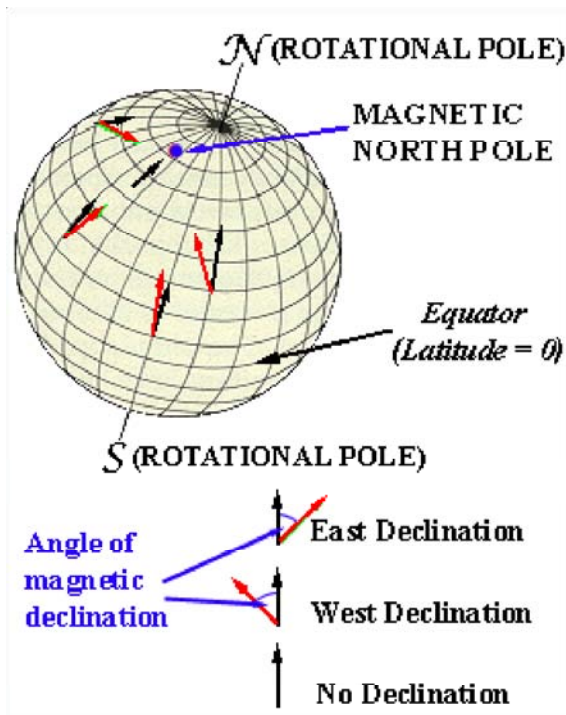


To plot their track on a map, sailors observed the heading or direction their ship traveled. They then compared their heading to the magnetic North direction revealed by a compass. Sailors were aware that the magnetic declination did not represent true north, so to compensate, they tried to map magnetic declinations around the globe. North as measured by the compass typically is off by several degrees; this variation depends on location and changes over decades.

Both the log line and the compass provided sailors with the means for deduced reckoning (frequently abbreviated ded or dead reckoning) so they could at least approximately reconstruct their travels. On the ocean, this task is crucial for survival and success since there are few stable landmarks in a fluid environment.

**10.** You may be accustomed to using deduced reckoning when you travel from one place to another. For example, suppose you are in a car or train and judge that you are "30 minutes from downtown." What simple assumptions does this make about your travel? Write your answer in the space below.

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**Closed loop survey**

To practice and test your skills of measurement and deduced reckoning, try conducting a closed loop survey activity. This activity can be done on a small desktop, as well as outside. Making measurements of your travels in a closed loop, where you end up at the point where you started provides a simple check of navigation methods. If you come back to the same point, your measurements should determine a path that draws a closed loop.

Sailors knew that surface currents affected the accuracy of their navigation predictions. They called the difference between their deduced and astronomically determined positions, ship drift. Astronomical determination of positions on Earth using the Sun and the stars is possible because the stars appear fixed and the Sun follows a cyclical, predictable motion. The measured differences between positions determined by dead reckoning and astronomical methods provided the earliest estimates of ocean surface currents.

# The Astronomical Fix
*How can you determine where you are located on planet Earth?*

The stars, moon, and Sun provide reference points necessary to determine one's position accurately. As Earth rotates, the astronomical objects follow a path in the sky. The time they reach determined positions may be used to determine your longitude and latitude.

Our Earth is a sphere, and angles are used to specify the location of sites on the surface of the Earth. In the east-west direction, one measures longitude with $0^o$ set at Greenwich, England. Moving westward (towards America), longitude angles are negative: between $-180^o$ and $0^o$. Moving eastward (towards Europe, the Middle East and Russia), longitude angles are positive: between $0^o$ and $+180^o$.
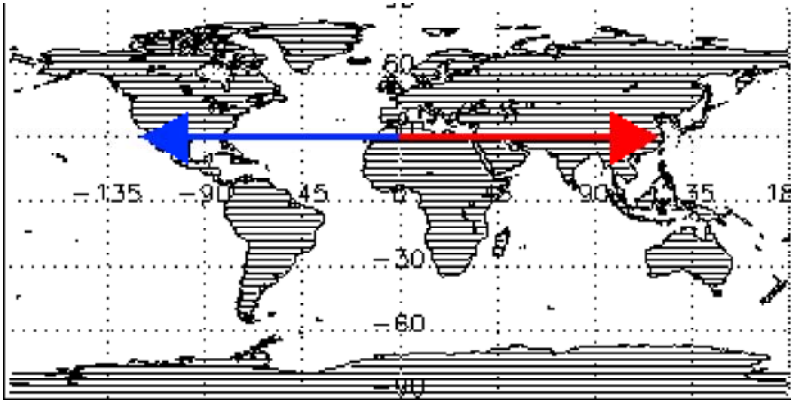


In the north-south direction, one measures latitude with $0^o$ set at the equator of Earth. Northward (towards the North Pole), positive latitude angles are between $0^o$ and $90^o$. Southward (towards the South Pole), negative latitude angles are between $-90^o$ and $0^o$.
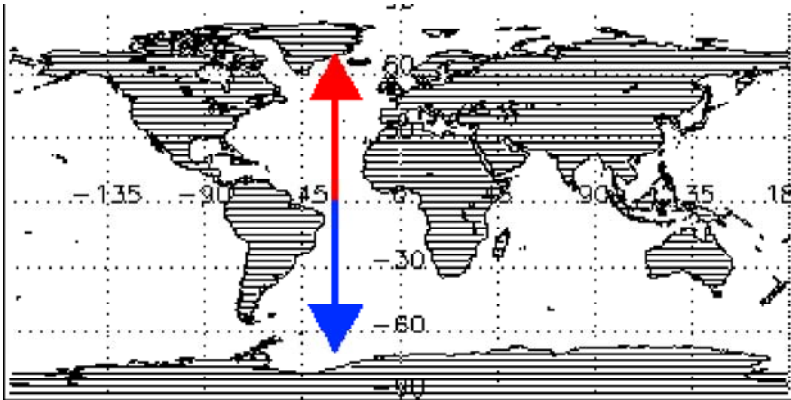


Over the course of 24 hours, Earth rotates through 360 degrees, and the stars appear to rotate in the opposite direction. The positions of the stars, moon and Sun in the sky at any specific time, depends on your location. By carefully measuring both the positions of astronomical object positions and the times, you can find your latitude and longitude. This is called an "astronomical fix".

## Find Your Place In The Sun by measuring your longitude and latitude.

The easiest times to determine one's position are when the astronomical bodies pass overhead or reach their highest elevation above the horizon. Solar noon is when the Sun is highest in the sky. On a clear day, it is easy to determine the time of solar noon. As an investigation, measurements of the Sun around solar noon may be used to determine longitude and latitude.

# The Columbus Voyages

*How can we track a voyage of Columbus?*



In celestial navigation, the navigator observes celestial bodies (Sun, Moon and stars) to measure latitude. (In Columbus's day, it was usually impossible to measure one's longitude.) Even in ancient times, it was fairly easy to find one's latitude by looking at the Sun and stars, as long as one wasn't too concerned about accuracy. Each star has a



Santa-Maria

celestial latitude or declination. Knowing the declination of a star that is directly overhead enables you to know your latitude on earth. Even if a star isn't directly overhead, by measuring the angle between the star and the overhead point (called the zenith), you can still determine your latitude — provided you measure the star at the time of night when the star is highest in the sky.

Use Table 1 (below) to re-create Columbus's travels with the Voyager model. To make the re-creation as accurate as possible, this model provides three tools: ocean current data, a historical model of Earth's magnetic field, and physics kinematic equations to trace a ship's movements. Because the ocean currents of Columbus's time are unknown, this model uses monthly surface current data based on ship drift observations made mostly in the 20th century. Observed current fluctuations (i.e., the "Variable Current" in the model) are simulated with random numbers. This model does not simulate the effect of winds. Rather, it uses speeds measured by Columbus and his crew. These log-line speeds reflect both the wind conditions and the way the ship was being sailed.

To determine his direction (or heading), Columbus relied on a compass, and his readings were not corrected for the difference between magnetic north and the geographic north. The Voyager model includes a magnetic model that predicts Earth's magnetic field on Earth's surface between 5000 BC and 1950 AD.

Historical records provide navigation details about the voyages of Columbus. Table 1 is based on Columbus's record of his first voyage to the Americas. Values have been adapted, and simplified, with permission, from the website of Keith A. Pickering

**11.** Begin a simulation of Columbus's voyage by manipulating the Voyager model and record the values for longitude and latitude for 34 days in 1492 in table 1. On the left side of the model, you will input the following:

• Year: 1492
• Month: September
• Initial Longitude: -17.0
• Initial Latitude: -28.0
• Compass Heading
• Log Line Speed (meters/second) as indicated in Table I for each of the days.
• After putting in the data for the first day, click the **Start** button.
• For each following day, enter the compass heading and logline speed from the table and click continue.

The columns on the right side of the model control panel show, current, longitude and latitude at the day's end and magnetic field information. The magnetic variation is labeled as the "magnetic field declination". Record the final longitude and latitude values in Table 1.

| Table 1 – Recreating Columbus's First Voyage to America | | | | | | | |
|---|---|---|---|---|---|---|---|
| Starting Longitude and Latitude -17.0, 28.0 | | | | | | | |
| 1st Column Dates | Compass Heading | Speed (m/s) | Final Longitude, Latitude | 2nd Column Dates Continued | Compass Heading | Speed (m/s) | Final Longitude, Latitude |
| Sep 8 | 270 | 0.52 | | Sep 25 | 234.4 | 1.23 | |
| Sep 9 | 277.7 | 3.09 | | Sep 26 | 261.3 | 1.77 | |
| Sep 10 | 270 | 3.43 | | Sep 27 | 270 | 1.37 | |
| Sep 11 | 270 | 2.52 | | Sep 28 | 270 | 0.80 | |
| Sep 12 | 270 | 1.89 | | Sep 29 | 270 | 1.37 | |
| Sep 13 | 270 | 1.89 | | Sep 30 | 270 | 0.80 | |
| Sep 14 | 270 | 1.14 | | Oct 1 | 270 | 1.43 | |
| Sep 15 | 270 | 1.83 | | Oct 2 | 270 | 2.23 | |
| Sep 16 | 270 | 2.23 | | Oct 3 | 270 | 2.69 | |
| Sep 17 | 270 | 2.86 | | Oct 4 | 270 | 3.61 | |
| Sep 18 | 270 | 3.15 | | Oct 5 | 270 | 3.26 | |
| Sep 19 | 270 | 1.43 | | Oct 6 | 270 | 2.29 | |
| Sep 20 | 271 | 0.52 | | Oct 7 | 266 | 1.60 | |
| Sep 21 | 270 | 0.92 | | Oct 8 | 247.5 | 0.66 | |
| Sep 22 | 292.5 | 2.06 | | Oct 9 | 248.2 | 1.80 | |
| Sep 23 | 315 | 1.83 | | Oct 10 | 247.5 | 3.38 | |
| Sep 24 | 270 | 0.83 | | Oct 11 | 257.7 | 2.83 | |
| 2.67 nautical mile = 1 league; 1 nmi = 1852 meters | | | | | | | |
| Final Longitude and Latitude: -73.7, 22.2 | | | | | | | |

**12.** When you have completed recording all longitudes and latitudes, use these values and trace the simulated voyage on the map below.
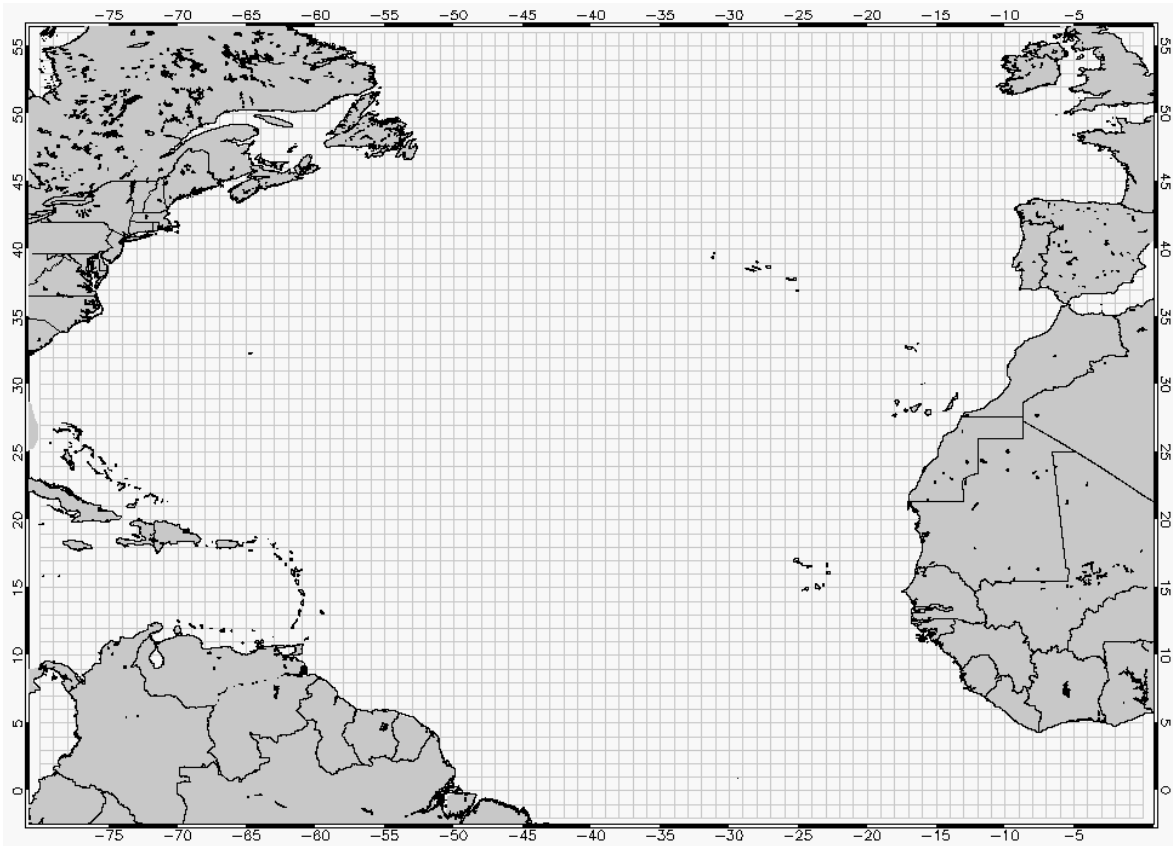


*Note: If you repeat the voyage or have several teams of students use the model; you will notice that the final predicted location (longitude and latitude) of the ship on October 11 varies. This variation is due to the measured uncertainty in the current data. The model deliberately simulates current fluctuations unless you turn off this feature by setting Variable Current to "No."*



*You may use the same model to simulate a voyage that begins from a location anywhere else on the globe. With no knowledge of the wind conditions at another site, you might set the "log line" speed to Columbus's mean speed.*

**Voyage Speeds**
*What can we learn from Columbus's recorded speeds?*

The mean speed of Columbus's voyage was 1.91 m/s. This speed was measured with a log line device and does not include ocean surface currents. Unlike today's self-powered boats, which burn coal, gas or oil, Columbus's boats relied on wind power. Wind power has the disadvantage that it is variable, but has the advantage that it is freely available. The figure, on the right, shows a histogram of the voyage speeds: the horizontal axis shows speed and the vertical axis the number of days at each speed. Note that Columbus's speed varied greatly, perhaps largely a reflection of the varying wind and sailing conditions.
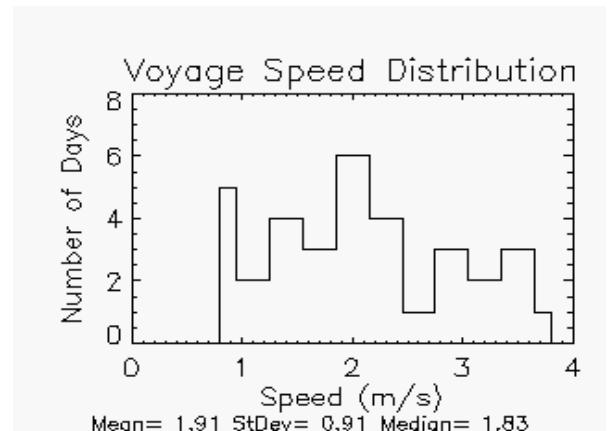


**13.** Measure your walking speed. How does your walking speed compare to Columbus's mean speed?

# The Voyage Of The Bounty—Tracking Captain Bligh
*What kind of information did explorers collect during their voyages?*

The famous voyage of Captain William Bligh, left, on the HMS Bounty to Tahiti provides an example in which astronomical fixes and dead reckoning played an important role in navigation. After having sailed halfway around the world, some of Bligh's crew mutinied, putting the captain and his loyal crewmembers to sea, in a small boat near Tahiti.

While on the Bounty, Captain Bligh had access to an accurate clock that kept Greenwich, England, time so that as he sailed, he could compute his longitude based on the time difference between solar noon and Greenwich time. Because Earth rotates once (360°) in 24 hours, every degree in longitude is equivalent to a time shift of solar noon relative to Greenwich of 24 hr/360° or 4 minutes of time per degree of longitude. Bligh had to bring a clock along on his voyage to keep in time with Greenwich. Today, Greenwich time has been replaced by Universal time and we can find the current Universal time over the Internet (http://aa.usno.navy.mil/faq/docs/UT.html).

After the mutiny, Bligh and the loyal members of his crew, deprived of access to a clock, used estimates of his small sailboat's speed and direction to estimate degrees of longitude and latitude referenced to a nearby islands and landmarks.

Use Captain Bligh's diary from his voyage to reproduce a portion of his travels. The text of his diary is available in an interactive Bounty Log form, pictured below. Using Bligh's words, we track a portion of his voyage and learn about his magnetic variation measurements.



Select one of the following date links. The links will produce a map on which you may plot Bligh's voyage.

December 1787,  January 1788,  February 1788,  March1788,  May1788,  July 1788,

August 1788,  September 1788,  October 1788,  May1789

Access Bligh's diary for the month by using **Select Date** on the form and pressing the GO button. The diary text for the month will appear in the **Text Selection** area. Search through the diary text for Captain Bligh's longitude, latitude and magnetic variation (magnetic variation is the same as magnetic declination) values. Each should be converted to decimal degrees using the **Degree, Minutes, Seconds,** and **Converter**.

For the locations where the magnetic variation is available, compare its value to the predictions of the magnetic model in Voyager Model.

**14.** Fill in Table 2 with your data.

| Table 2 - Tracking Captain Bligh | | | | | | |
|---|---|---|---|---|---|---|
| Date | Longitude | | Latitude | | Magnetic Variation | |
| | Degrees (°) Minutes (') | Decimal | Degrees (°) Minutes (') | Decimal | Degrees (o) Minutes (') | Decimal |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**15.** During your selected month, trace Captain Bligh's voyage on the map. Draw arrows to show his direction of travel on the map below.



April 1788
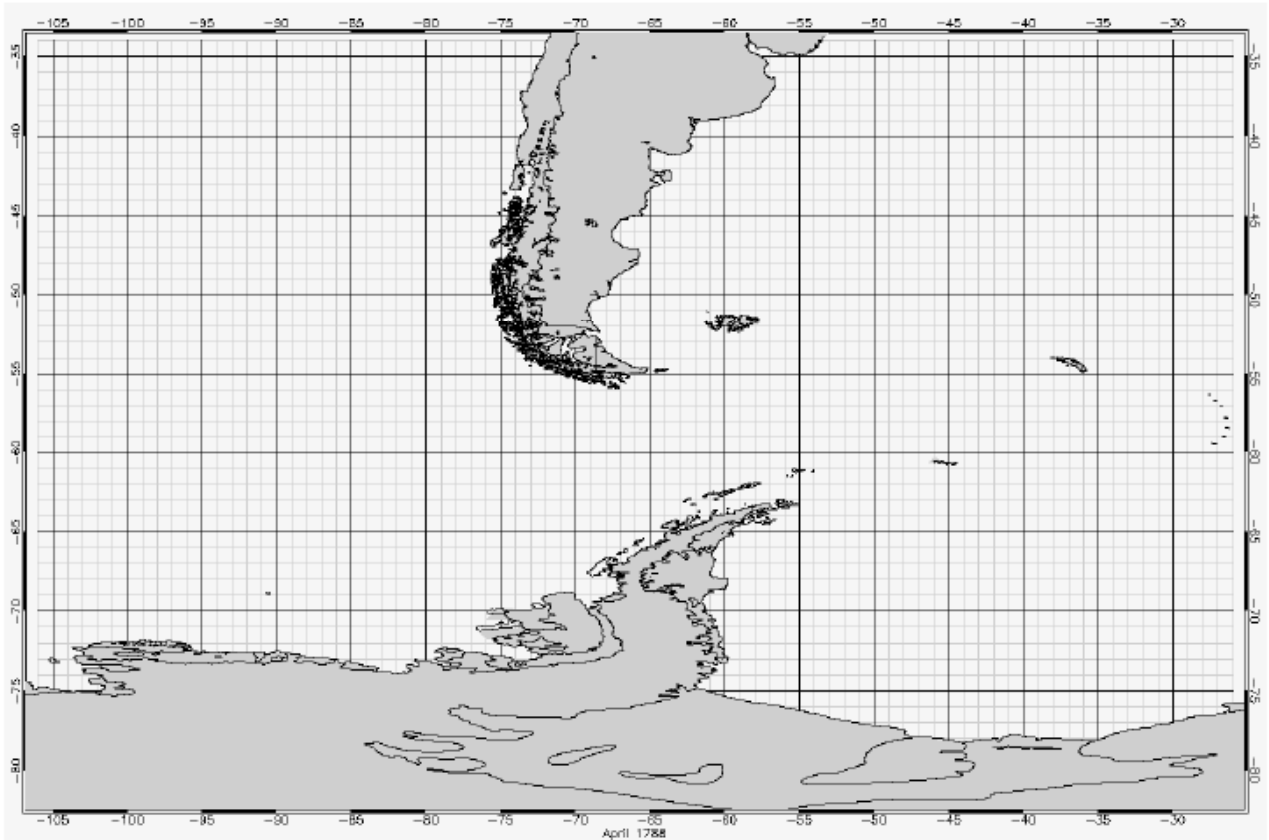
**16.** How well do the predictions of magnetic variation match Captain Bligh's observations? Write your answer below.

### Pathways of the World Ocean

Create your own investigations with the Ship Drift Model.

1. Imagine floating objects on the ocean surface, such as a bottle thrown in the water. Test where it might travel based on the movement of currents.

2. Learn about ship cargo that has been lost at sea. Read examples of newsletters by Curt Ebbesmeyer for the latest flotsam stories. Check the possible flotsam route with the ship drift model.

**Matrix for Grading Lesson 1**
Questions 7 - 22

| | |
|---|---|
| **4**<br>**Expert** | Responses show an in-depth understanding of the models and explorations used to explain the scientific concepts and processes used in the lesson. Data collection and analyses are complete and accurate. Predictions and follow through with accuracy of predictions are explained and fully supported with relevant data and examples. |
| **3**<br>**Proficient** | Responses show a solid understanding of the models and explorations used to explain scientific concepts and processes in the lesson. Data collection and analyses are mostly complete and accurate. Predictions and follow through with accuracy of predictions are explained and mostly supported with relevant data and examples. |
| **2**<br>**Emergent** | Responses show a partial understanding of the models and explorations used to explain the scientific concepts and processes in the lesson. Data collection and analyses 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**<br>**Novice** | Responses show a very limited understanding of the models and analogies used to explain scientific concepts and processes in the lesson Data collection and analyses 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. |