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Mapping the Watery Hills and Dales

Unless you spend a lot of time at sea—or flying over it—it's hard to keep in mind that far more of our planet is under water than above water. It's also hard to imagine that the deepest parts of the ocean are far deeper than the highest mountains are high. But it's true! That's a lot of salt water.

A Big Energy Transport System

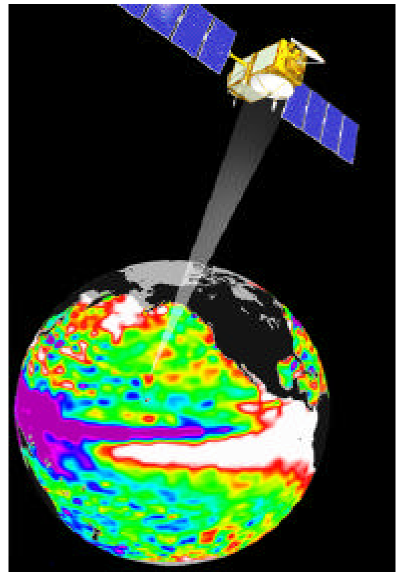
In addition to all the seaweed, fish, and whales that call all this water their home, the oceans also hold a huge amount of heat. The top 3 meters (about 10 feet) of the ocean contains as much heat energy as the whole atmosphere of Earth (which extends up hundreds of miles).

The water in the world's oceans isn't all the same temperature. In some places, like near Earth's equator, the water soaks up a lot of heat energy from the Sun. In other places, like near the North and South Poles, the water cools off, since not much direct sunlight reaches those places.

Since water flows easily, it moves all around the Earth, picking up heat in one place and carrying it someplace else. All this moving heat energy is mostly what causes weather. Thunderstorms, rain, snow, wind, hurricanes, droughts, hot weather, freezing weather—in a very complicated way the oceans are in charge of them all. For example, "El Niño" is what we call the condition when a lot of warm water gathers in one place in the Pacific Ocean and causes unusual weather in many places all over the world.

Global Weather Spies in the Skies

To understand weather, we have to understand the oceans and how they move heat around the Earth. Jason-1 is a new Earth-orbiting spacecraft that will study the oceans. It will be launched in the summer of 2001. It will continue and expand the data that has been collected by the TOPEX/Poseidon spacecraft, which since 1992 has been orbiting Earth at an altitude of over 1300 kilometers (800 miles).



Jason-1 will use an *altimeter* (al-TIM-uh-ter) to measure the height of the ocean surface. As the spacecraft flies over an ocean, the altimeter sends a radio signal down to the surface of the water. The signal bounces off the water and back up to the spacecraft. By measuring how long it takes for the radio signal to bounce back and by precisely measuring the locations of the spacecraft, the altimeter can determine the height of the ocean's surface at that point. Using this information, scientists can create very detailed maps of the ocean surfaces all around the world. The higher the ocean's surface, the warmer the water. Jason-1's altimeter will be even more sensitive than TOPEX/Poseidon's. Like TOPEX/Poseidon, Jason-1 has an instrument called a *radiometer* (ray-dee-AH-muh-ter) that will measure and take into account the amount of water in the air (for example, in clouds), which also affects the speed at which the radio signal travels.

Both these spacecraft make very detailed maps of ocean topography—that is, the hills and valleys on the ocean's surface. Scientists can then study these maps, see how the topography changes from day to day and week to week, and better understand and predict global weather patterns.

Where on Earth Are We?

How can these spacecraft make such exact maps? After all, they not only have to know very accurately the height of the ocean's surface, but they also have to keep track within a few centimeters of exactly where they are in space relative to Earth.

The task of finding out the exact position at any instant of an object traveling at over 25,000 kilometers per hour would be extremely difficult, even on the ground, but with TOPEX/Poseidon and Jason-1, the spacecraft are 1300 kilometers above us in space! How is this feat possible?

There are actually three instruments on board TOPEX/Poseidon and Jason-1 that help to measure their position. One of them, the Global Positioning System Demonstration Receiver (GPSDR), uses signals from a constellation of 24 Global Positioning System (GPS) satellites that were previously launched into space by the United States Department of Defense.

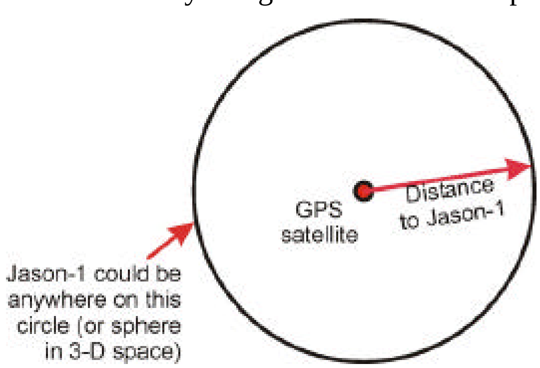
In the following activity, we will explore how Jason-1 will use signals broadcast from the GPS satellites to find out its exact location in space.

From How Fast to How Far

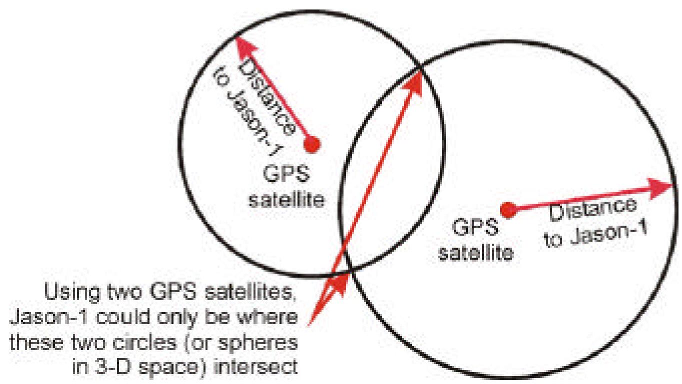
Jason-1 finds its location using two principles: (1) *distance versus time* and (2) *triangulation*.

Each GPS satellite puts out a radio signal with a unique repeating pattern. Radio signals travel at a fixed speed (the speed of light), so in a certain amount of time, the signal travels a certain distance. If the time of travel is doubled, the distance the signal traveled is also doubled. If we know the time it takes for the signal to travel from a GPS satellite to Jason-1, we can calculate the distance from the Jason-1 spacecraft to that particular GPS satellite.

But if we use only one GPS satellite, we know only that the location of Jason-1 is somewhere on the surface of a sphere whose radius is the distance the signal traveled. We can get an idea of how this looks in two dimensions by using circles to show all places that are an equal distance from the point in the center. The point thus represents a GPS satellite and the circle represents all the possible locations of the Jason-1 spacecraft.

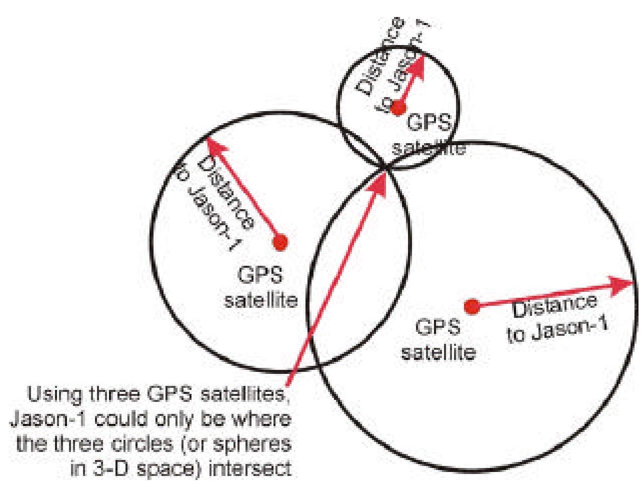


To pinpoint the exact location of Jason-1 on that circle, we must receive signals from more than one GPS satellite. If we use two GPS satellites, we would get two spheres (or circles in our simple approximation), representing Jason-1's possible positions with respect to each of the two GPS satellites. Notice that the two circles overlap in two places. That means that Jason-1 could be at either of the two overlapping points and still be the correct distance from each of the satellites. This is better, but still not good enough.



The Magic Number Three

To find out which of the two intersections is its correct location, Jason-1 must use the signal from a third GPS satellite. Notice that in the third diagram, there is only one point that is intersected by all three



circles. This method of pinpointing a location using the known distance from three different points is called *triangulation*.

Actually, the GPS will use a minimum of four satellites to pinpoint Jason-1's exact position in space. The fourth satellite is used to synchronize the clocks between Jason-1 and the GPS satellites. In order to find the position, you must know the precise time, so the fourth satellite is used for time. Additional satellites (from five to eight all together) enhance the accuracy of the position information.

The positions of each of the 24 GPS satellites is known with a great deal of precision. (Find out how at the end of this article.) The reason for having 24 GPS satellites in space is to ensure that at least four of them are within the line of site of any point on Earth or in space at all times. Often there will be many more than the minimum four GPS satellites visible at any given time.

Make Your Own RPS (Room Positioning System)

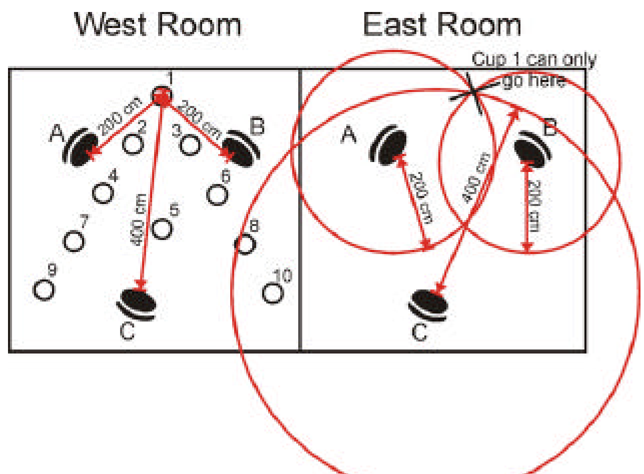
We can demonstrate in the classroom how the GPS works to precisely locate objects with respect to Earth. We will divide the class into two groups. One group will use triangulation to record the positions of several objects placed in a room. Using measurements from this first group, the second group will try to determine the exact placement of the objects in the first room and recreate the pattern in the second room.

Facilities and Equipment Needed:

Two rooms with three chairs each
6 balls of string
20 paper cups
1 or 2 meter sticks

Procedure:

1. In the middle of the first room (the "West Room" in the illustration), arrange three chairs in a triangle, each chair about 15 feet from the others. These chairs represent the known location of three GPS satellites.
2. Place some cups (numbered 1-10) around the room, in a pattern, if you wish. (Make sure some of the cups are inside the triangle formed by the three chairs, and some are outside.) These cups represent the exact location of the Jason-1 spacecraft at different times.
3. Draw the locations of the chairs and the cups on a piece of paper for reference.
4. Place a student on each chair in the triangle (labeled A, B, and C) and have them hold a ball of string.
5. For each cup, pull the string from each of the chairs (GPS satellite) to a cup (a Jason-1 spacecraft location), and measure the length of the string using the meter stick. Record this distance on a data chart as Cup#1: A= _cm, B=_cm, and C=_cm and so on for each cup.
6. Once the locations of all 10 cups have been obtained, pass the data chart to the next room (the "East Room" in the illustration), which also has three chairs placed in the center of it in a similar triangular fashion.



In the "West Room," measure distance from each cup (representing various locations of Jason-1) to each of the three chairs (representing GPS satellites), and record these measurements in a data table. In the "East Room," using the data table only, to find each cup position, use strings to define circles representing the measured distance from cup to each chair, then place the cup at precisely the point where the three circles intercept.

From Cup #	Distance to Chair (cm)		
	A	B	C
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

7. Using the three measurements of distance (A, B, C) for each cup, have the students in the second room try to recreate the exact locations of the 10 cups from the first room.
8. Once all 10 cups are placed, compare the placement with the reference diagram that was drawn from the first room.

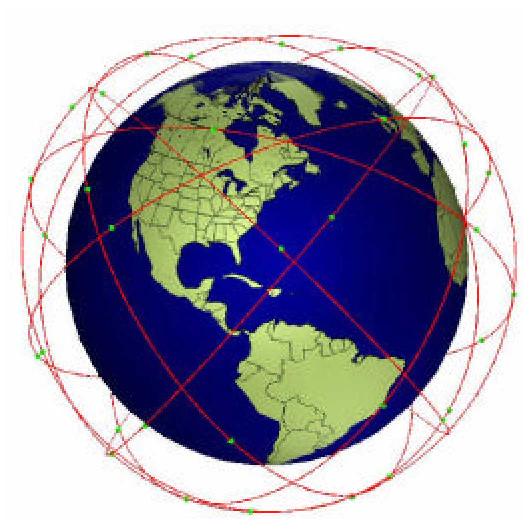
Questions to Consider:

1. In the demonstration, what did the three chairs represent?
2. What did the cups represent?
3. What did the lengths of string A, B, and C for each cup represent?
4. How is real life GPS triangulation different from our model in the classroom?

Answers:

1. *The known positions of three GPS satellites.*
2. *Different possible locations of the Jason-1 spacecraft in time.*
3. *The distance from the GPS satellite to the Jason-1 spacecraft, based on the time it took for the GPS signal to travel to Jason-1.*
4. *Only three reference points are needed to locate a stationary object by the triangulation method. However, when the objects are moving very fast with respect to each other, the precise time of each measurement is very important. Thus, the need for the fourth satellite.*

How the Global Positioning System Works



The picture shows the distribution of multiple satellites in orbit around the earth. However, the GPS satellites are *much farther out* than the ones shown in this picture. If you measure the width (diameter) of the Earth in the picture, the GPS satellites orbit about one and one-half times that distance above Earth.

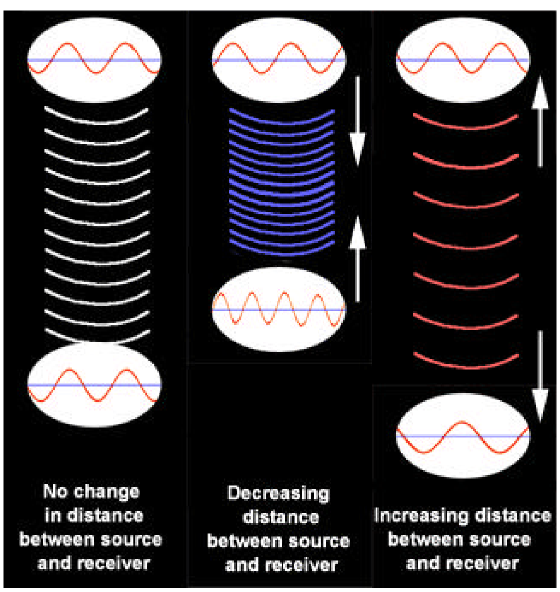
The 24 GPS satellites travel in six different circular orbits (four satellites sharing the same orbit), all inclined 55 degrees from the equator. This way, at any given time, any spot on earth or in space can be in the direct line of site of at least six nearby GPS satellites. Triangulation can be performed as long as the location in question can draw a straight unobstructed line to at least four GPS satellites.

Each satellite orbits at an altitude of nearly 11,000 miles. This altitude was chosen so that each satellite would orbit once every 12 hours, or twice a day. The GPS consists of three parts:

1. The satellites.
2. The ground control stations.
3. The end-user GPS receivers.

The Nuts and Bolts

1. Twenty-four GPS satellites in medium Earth orbit each have onboard atomic clocks to provide extremely accurate time.
2. Ground stations track the exact locations of each satellite and keep the clocks synchronized with each other.
3. Each GPS satellite transmits an accurate position and time signal. GPS receivers on other satellites, such as Jason-1, not only receive the position and time information from the signal, but also take into account the *Doppler effect* on the signal itself. That is, when two satellites (for example, a GPS satellite and Jason-1) are moving closer to each other, the radio signal at the receiving satellite appears a bit squished. If the two satellites are moving farther apart, the received radio signal appears a bit stretched out. The receiving satellite "knows" how the signal should look (that is, its wavelength when it was transmitted), so the Doppler shift tells how fast and in what direction the two satellites are moving with respect to each other.



The receiver (such as the one on Jason-1) measures the time delay for the signal to reach it (as well as the Doppler shift). This delay is the direct measure of the distance to the satellite. Measurements collected simultaneously from four (or more) satellites are processed to solve for the three dimensions of position, velocity, and time.

What Else Can GPS Do?

You can go to the internet site http://gpshome.ssc.nasa.gov and learn about ways GPS is used all over the world. Try to come up with a list of 5 to 10 different uses. Break them into the following categories and describe them:

Location:	Determining a basic position
Navigation:	Getting from one location to another
Tracking:	Monitoring the movement of people and things.
Mapping:	Creating maps of the world.
Timing:	Bringing precise timing to the world.

You can also find very good interactive tutorials about GPS on the Web.

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For more about the oceans and El Niño and a recipe for delicious and educational "Blame El Niño Pudding," go to http://spaceplace.jpl.nasa.gov/topex_make1.htm. For more information about the Jason-1 mission, see http://topex-www.jpl.nasa.gov/jason1/.