GPS—Measuring Plate Motion

How fast are the tectonic plates moving?

Background pages to accompany: **IRIS' Animations: GPS–Measuring Plate Motion**

***HOT LINKS*:**

Interactive Flash: **Walk-Run Triangulation**

Interactive Flash: **Plate Boundaries**

Animation: **Plate Boundaries**

What is GPS? How does it work?

Using Real Data:

- **Velocity Viewer: Real-time Plate Rate**
- **Data for Educators**

Triangulating from Satellites

Activity: What is a Rate?

Introduction*

Scientists now have a fairly good understanding of how the plates move (Figure 1) and how such movements relate to earthquakes and volcanic activity. Movement is most pronounced along narrow zones between plates where the results of plate-tectonic forces are most evident (Figure 2).

Current plate movement can be tracked directly by means of space-based geodetic measurements; geodesy is the science of the size and shape of the Earth. Because plate motions are global in scale, they are best measured by satellite-based methods. The late 1970s witnessed the rapid growth of space geodesy, a term applied to space-based techniques for taking precise, repeated measurements of carefully chosen points on the Earth's surface separated by hundreds to thousands of kilometers. The Global Positioning System (GPS) has been the most useful for studying the Earth's crustal movements.

By repeatedly measuring distances between specific points, geologists can determine the movement along faults or between plates. The separations between GPS sites are already being measured regularly around the Pacific basin. By monitoring the interaction between the Pacific Plate and the surrounding mostly continental plates, scientists are learning more about events that build up to earthquakes and volcanic eruptions in the circum-Pacific "Ring of Fire". Space-geodetic data have already confirmed that the rates and directions of plate movements, averaged over several years, compare well with rates and directions of plate movements averaged over millions of years.

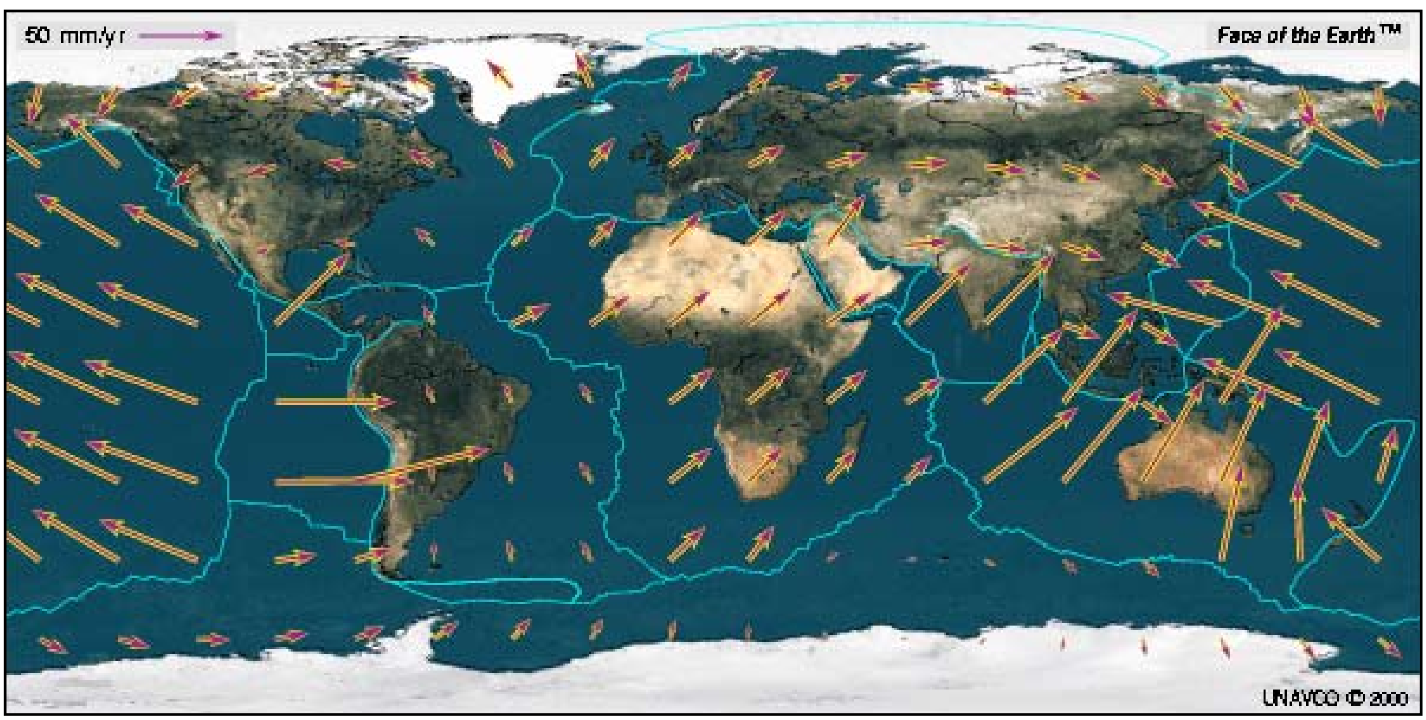


Figure 1: *General plate motions on a global scale. Regional maps show far more complicated motion vectors. Length of arrows indicates rate of movement of that part of the plate.*

Map from From UNAVCO Plate Motion Calculator: **http://sps.unavco.org/crustal_motion/dxdt/model/**

*Text from **www.gps.gov/**, **www.usgs.gov** and **www.faa.gov**

Before GPS how did we know the plates were moving?

Two lines of evidence unlocked the mystery: Seemingly related rock types great distances apart and the magnetic polarity recorded by ocean-floor rocks.

Alfred Wegener (1880-1930) found that large-scale geological features on separated continents often matched very closely when the continents were brought together. For example, the Appalachian Mountains of eastern North America matched with the Scottish Highlands, and the distinctive rock strata of the Karroo system of South Africa were identical to those of the Santa Catarina system in Brazil. He was ostracized for his theory of "continental drift" because the all-important geology of ocean basins that confirm plate tectonics and continental drift was not sufficiently understood until the 1960s and 70s. Evidence of past rates of plate movement on a smaller scale can be obtained from geologic mapping. If a rock formation of known age—with distinctive composition, structure, or fossils—mapped on one side of a plate boundary can be matched with the same formation on the other side of the boundary, then measuring the distance that the formation has been offset can give an estimate of the average rate of plate motion. This simple but effective technique has been used to determine the rates of plate motion at divergent boundaries, for example the Mid-Atlantic Ridge, and transform boundaries, such as the San Andreas Fault.

The oceans floors were a key piece to the puzzle. Because the ocean-floor magnetic striping records the flip-flops in the Earth's magnetic field, scientists, knowing the timings of magnetic reversals, can calculate the average rate of plate movement over time spans of several million years. These average rates of plate separations can range widely. The Arctic Ridge has the slowest rate (less than 2.5 cm/yr), and the East Pacific Rise near Easter Island, in the South Pacific about 3,400 km west of Chile, has the fastest rate (more than 15 cm/yr).

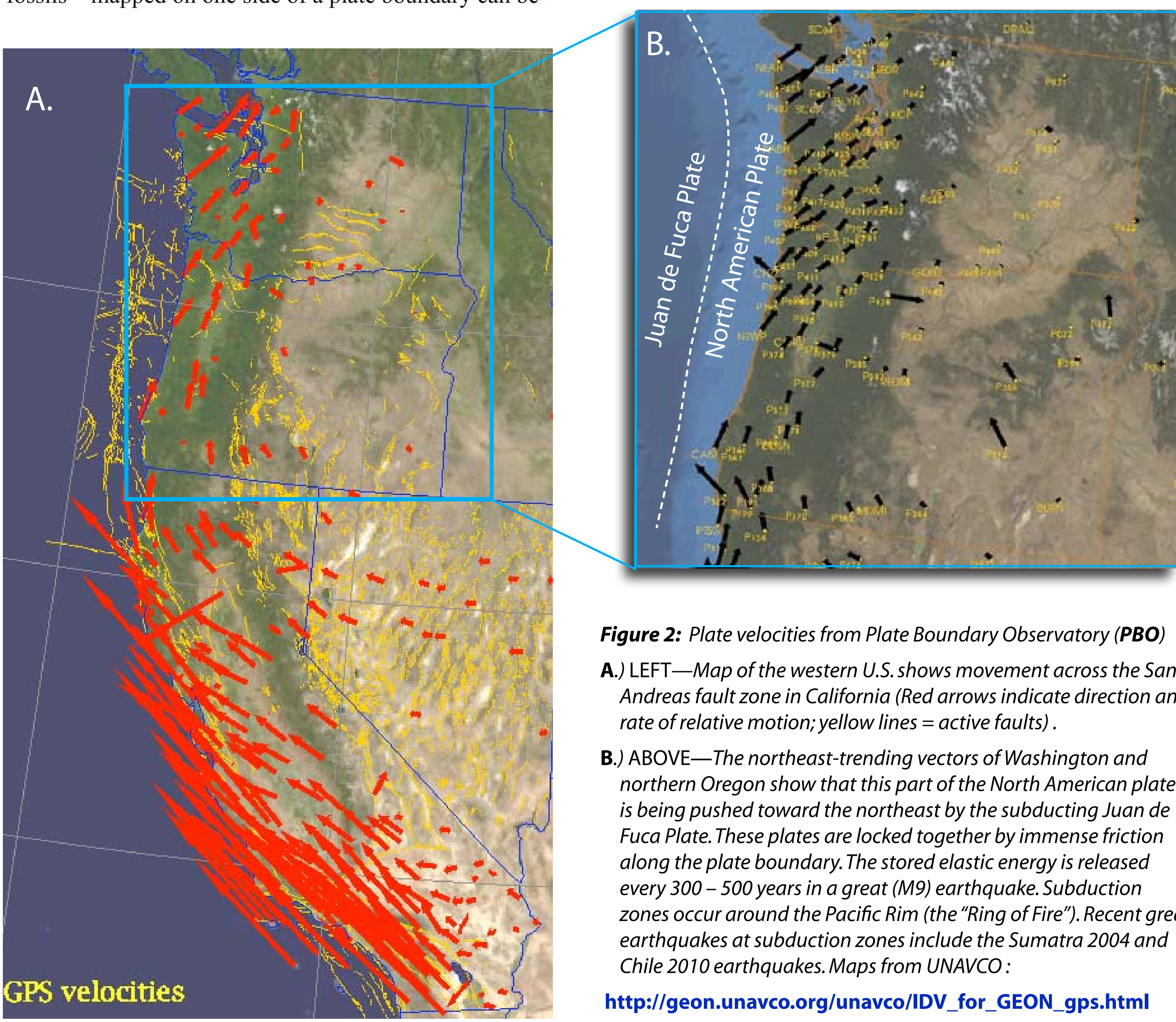


***Figure 2:** Plate velocities from Plate Boundary Observatory (**PBO**)*

A.) LEFT—*Map of the western U.S. shows movement across the San Andreas fault zone in California (Red arrows indicate direction and rate of relative motion; yellow lines = active faults) .*

B.) ABOVE—*The northeast-trending vectors of Washington and northern Oregon show that this part of the North American plate is being pushed toward the northeast by the subducting Juan de Fuca Plate. These plates are locked together by immense friction along the plate boundary. The stored elastic energy is released every 300 – 500 years in a great (M9) earthquake. Subduction zones occur around the Pacific Rim (the "Ring of Fire"). Recent great earthquakes at subduction zones include the Sumatra 2004 and Chile 2010 earthquakes. Maps from UNAVCO :*

http://geon.unavco.org/unavco/IDV_for_GEON_gps.html

Reading GPS time-series plots

GPS measures rate of movement in north, east, and vertical directions that are combined to give information of the location in 3-D space. These motions are recorded onto three separate graphs as illustrated by Figures 3A and 3B.

WHAT IS A RATE?* *(click for details and activity)*

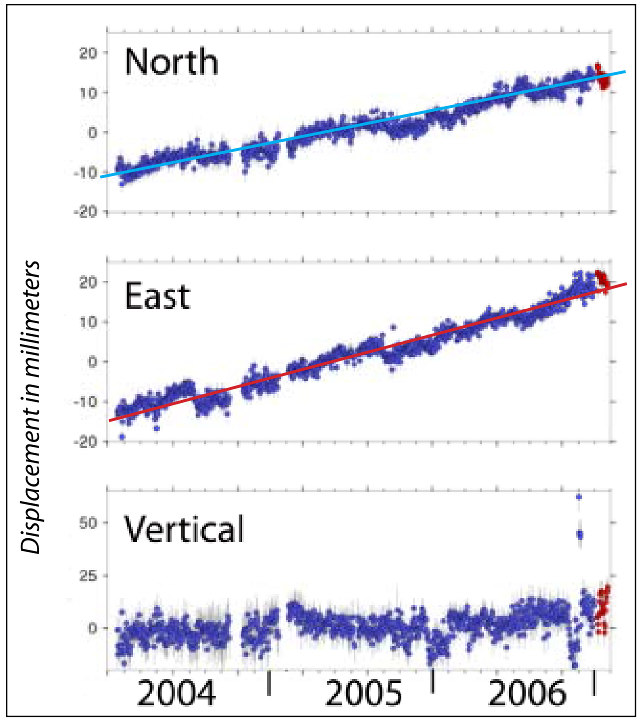
- A rate is a speed of motion
- Velocity has both magnitude (rate = speed) and direction of motion
- Velocities are represented by vectors
- Vectors can be mathematically manipulated
- Vectors can be used to describe properties of motion

Every day we use rates to describe events that happen over a period of time. Perhaps you drove 65 miles per hour to school this morning because you were running late, or you rode on an amusement park ride last weekend that went 80 miles per hour. Each time you describe a change in position with respect to time, you have used a rate to do it. Rates can be described mathematically as: rate = distance / time. Velocity can be represented an arrow, whose length equals the rate (speed) of motion and whose orientation represents the direction of motion. These arrows are called vectors that describe rates and directions of motion.

So why do people use vectors instead of just mathematical expressions? Actually people use both. A perfect example is the velocity maps used to describe how fast and in what direction GPS sites on the Earth's plates are moving. Scientists first calculate velocities for each GPS site in centimeters per year, using mathematical equations. Then, they place the velocities, in the form of vectors, on a map of the Earth. This allows them to get a better mental picture of what is happening to the plates world wide. Velocity maps can be made for any area where the displacements of a sets of points been determined over an interval of time. A displacement is an overall change in position from the start to the end of a measurement interval. For maps of plate velocity, the rates are often given in cm/year.

* **http://scign.jpl.nasa.gov/learn/gpsact2.htm**

A.



Figures 3A: *Graph of GPS movement shows a station in Washington that is being pushed back toward the northeast by the subducting Juan de Fuca Plate (Figure 2B).*
Between 2004 and 2007 this station moved:
North: from -11 mm to +12 mm = 23 mm
East: from -15 mm to +18 mm = 33 mm
The larger error bars, data gaps, and "glitches" in the graph of vertical position show the larger errors involved in determining vertical location. For a classroom activity, we concentrate on the horizontal motions.

B.

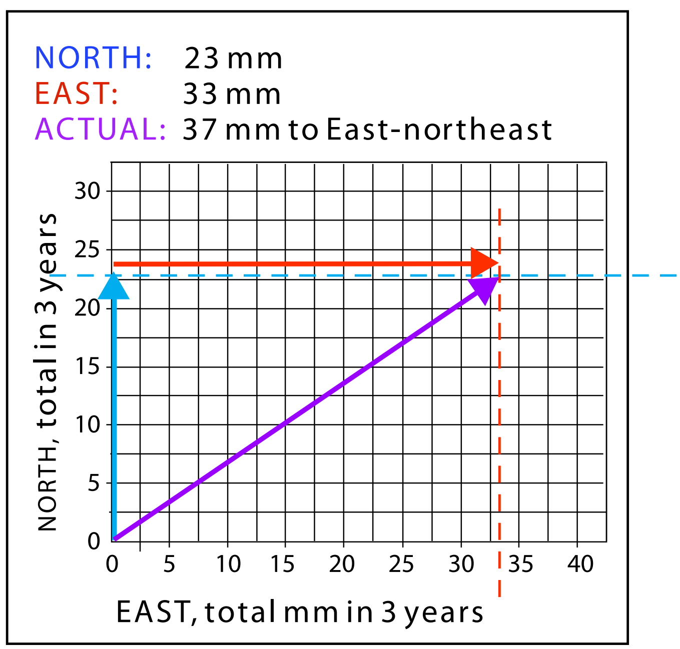
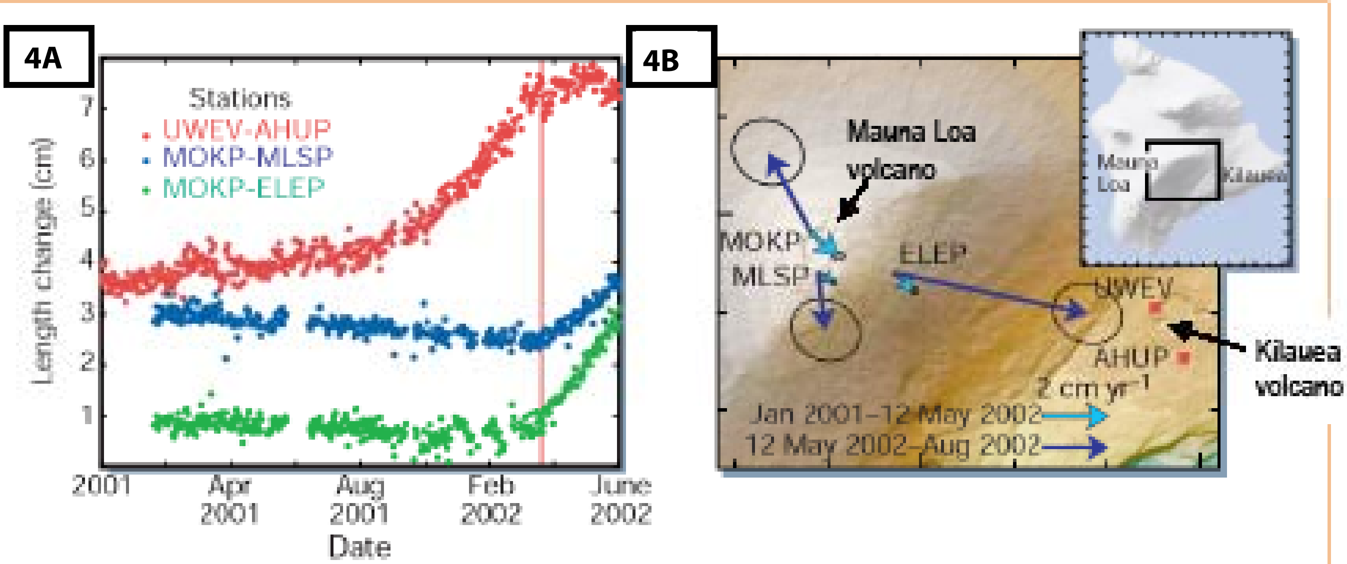


Figure 3B:: How far did it really move?? *Plot the north and east vectors on the grid below and you determine that the movement was 37 mm toward the northeast.*
NOTE: *Watch Roger Groom's video demonstration of this (*"**GPS_Activity_Parts3-5.mov**"*) on our web site.*

Using GPS to Study Earthquakes & Volcanoes**

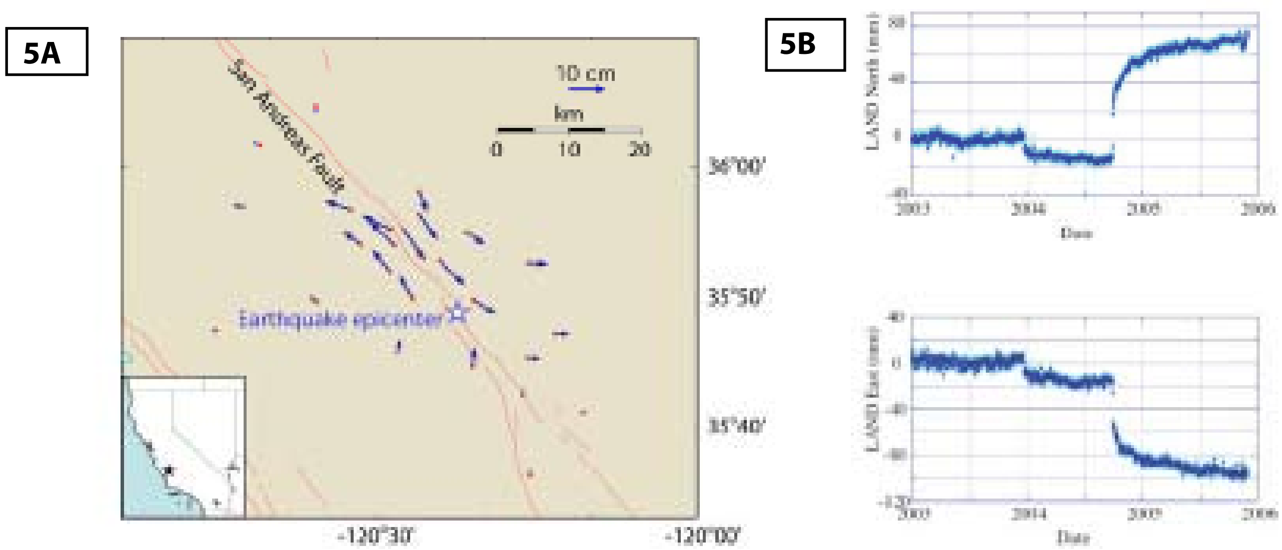
Monitoring volcanic deformation in Hawai`i

Changes to the surface of a volcano (volcano deformation) can provide clues about what is happening deep below the surface and provide telltale information of a forthcoming eruption. Deformation can be measured with GPS.



Figures 4a and 4b: *By looking at the position of points on the Earth's surface measured with GPS, scientists can detect the onset of deformation of the crust. For instance, at Mauna Loa volcano in May 2002, GPS stations on opposite sides of the summit started moving away from each other, indicating that the volcano was inflating. From Miklius and Cervelli, Nature, 2003.*
For narrated animation of extension across a volcano visit:
Measuring Deformation with Tilt and GPS :http://www.iris.edu/hq/programs/education_and_outreach/animations/16

_Measuring displacement due to a recent earthquake in Parkfield, CA



Figures 5A and 5B): *When an earthquake occurs, the ground on either side of the fault moves instantaneously, sometimes causing strong ground shaking. GPS measurements enable scientists to determine the length of these displacements (Figure 5A) and determine how much slip took place on the fault and where slip occurred. Although we cannot feel it, GPS measurements shows that the crust on either side of the fault continues to slip slowly for months to years after an earthquake (Figure 5B).*

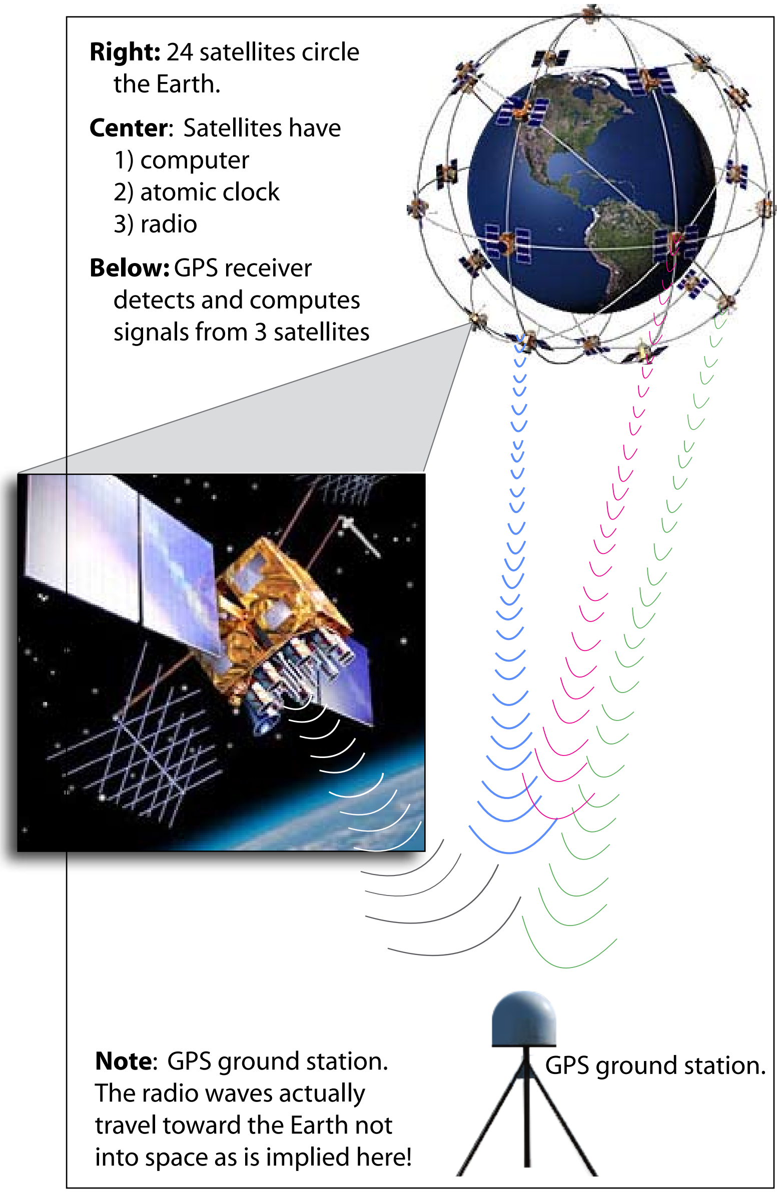
This page from "Using GPS to Study Plate Tectonics: **www.unavco.org/edu_outreach/docs/gps_tev.pdf
Figure credits. 4a and 4b: Miklius and Cervelli, 2003. 5 and 6: J. Murray.

What is GPS?

GPS is a relatively new technology that uses signals sent from satellites orbiting the Earth to very accurately determine the location on receivers on the surface. GPS is based on technologies developed for military and aerospace research, notably radio astronomy and satellite tracking. These satellites continuously transmit radio signals back to Earth. To determine its precise position on Earth (longitude, latitude, elevation), each GPS receiver must simultaneously obtain signals from at least four satellites.

Satellites: GPS relies on two dozen navigational satellites that orbit our planet at 20,000 km (12,500 mi) above the surface every 12 hours, as part of the NavStar system of the U.S. Department of Defense. Spacing was determined so that from any point on Earth, at least 4 satellites will be above the horizon and detectable. Each satellite has:
1) a computer, 2) an atomic clock (Universal Time Coordinated, UTC), and 3) a radio.
With a computerized understanding of its own orbit, it continually broadcasts its changing position and time via radio signals. Once a day, each satellite checks its own time and position with a ground station to make any needed corrections. This makes the GPS receiver the most accurate time piece available to you.

GPS Receiver: The GPS receiver on the ground detects the radio signals from the satellites and the computer "triangulates" its own position by getting bearings from a minimum of 3 satellites. If 4 or more satellites can be received, the receiver/computer can figure out the altitude as well as the geographic position.
Triangulation is a geometric calculation of the distance from, and the angle to, each satellite. The more satellites the GPS receiver "sees" the more accurate the location determination will be. The result is provided in longitude and latitude and can be accurate to within a range of 10–20 meters for hand held GPS, and to within millimeters for anchored GPS stations. The most advanced GPS receivers used for the Plate Boundary Observatory can determine their location to a precision equal to the size of a grain of rice!
If the GPS receiver is also equipped with a display screen that shows a map, the position can be shown on the map. If you are moving, most GPS receivers can calculate your speed and direction of travel and possibly give you estimated times of arrival to specified destinations.



Right: 24 satellites circle the Earth.

Center: Satellites have
1) computer
2) atomic clock
3) radio

Below: GPS receiver detects and computes signals from 3 satellites

Note: GPS ground station. The radio waves actually travel toward the Earth not into space as is implied here!

GPS can answer 5 questions simultaneously:

1. "Where am I?"
2. "Where am I going?"
3. "Where in my destination?"
4. "What's the best way to get there?
5. "When will I get there?"

GPS is the only system today that can show your exact position on the Earth anytime, no matter where you are as long as you have contact with several satellites!