How Does GPS Work?

The global positioning system (GPS) is a fleet of 29 satellites that are orbiting our planet approximately 11,000 miles above Earth's surface. A position can be calculated using three satellites (Figure 1), plus a fourth because of clock imprecision. You may already be familiar with handheld GPS units, which people for navigation (for example, some cars now come equipped with GPS units), recreation (for example, hiking and geo-caching), mapmaking, and land planning. There are several important differences between handheld GPS units and the high-precision ("differential") GPS units that Earth scientists use in their research.

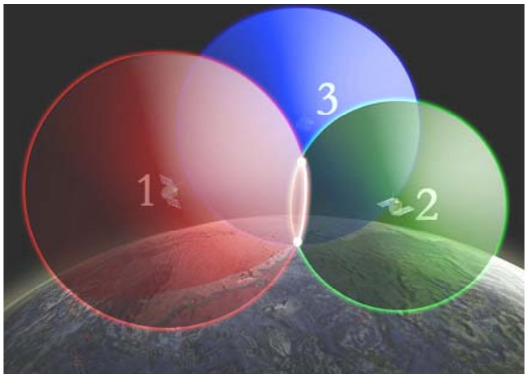


Figure 1. Illustration of calculating a position on Earth's surface using GPS satellites. Figure courtesy of NOAA.

Handheld GPS receivers calculate positions that are known as **autonomous solutions**. In other words, each handheld GPS receiver is independent from all other receivers and uses only satellites to calculate positions. As a result, handheld GPS receivers are unable to correct for many error sources (see table 1). *Differential* GPS uses <u>two</u> GPS receivers to calculate a position: a stationary receiver ("base station") whose location is accurately known from surveying and a roving (moving) receiver (see table 2). Both receivers continuously calculate their positions from the satellites. The base station compares the calculated position with its known location and "**differences**" the two measurements to determine the error in the GPS signal. Then, the base station sends the error corrections to the roving receiver. Using differential GPS allows scientists to minimize the errors associated with measuring positions.

Table 1

Possible Sources of Error in Measuring Positions:

- ✓ Clock: Although the atomic clocks in GPS satellites are extremely precise, they are not perfect.
- ✓ Atmospheric: The ionosphere (the atmospheric layer 30-50 km above Earth's surface) contains particles with electrical charges, which change the speed of radio signals. Water vapor in the troposphere (the atmospheric layer in which weather occurs) may decrease the speed of radio signals.
- ✓ Multipath: When radio signals bounce off objects such as buildings and trees instead of traveling directly from the satellite to the receiver, the signal takes longer to reach the receiver than it should.
- ✓ Ephemeris (orbital): The moon and sun's gravitational pulls influence the orbit of GPS satellites.

Table 2

Why are differential GPS data more accurate than handheld GPS data?

- GPS satellites send out two different signals: L1 and L2. Differential GPS receivers measure both L1 and L2, whereas handheld GPS receivers measure only L1.
- Differential GPS uses antennas specially constructed to reduce multipath error.
- Differential GPS receivers store position data. Handheld GPS receivers do not.
- Differential GPS data are processed at data storage facilities and corrected for errors. Handheld GPS data are not processed.

USING GPS TO STUDY PLATE TECTONICS

The theory of plate tectonics explains that Earth's crust and upper mantle are split into a series of rigid plates (Figure 2). Like moving puzzle pieces, the plates move slowly and interact with one another at plate boundaries. Plates move apart at divergent boundaries, come together at convergent boundaries, and slide past one another at transform boundaries. A variety of geologic phenomena including earthquakes, volcanic eruptions, and mountain building occur at plate boundaries, all of which cause the Earth's surface, the crust, to deform (change).

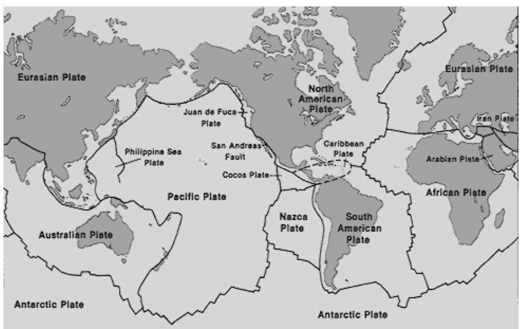
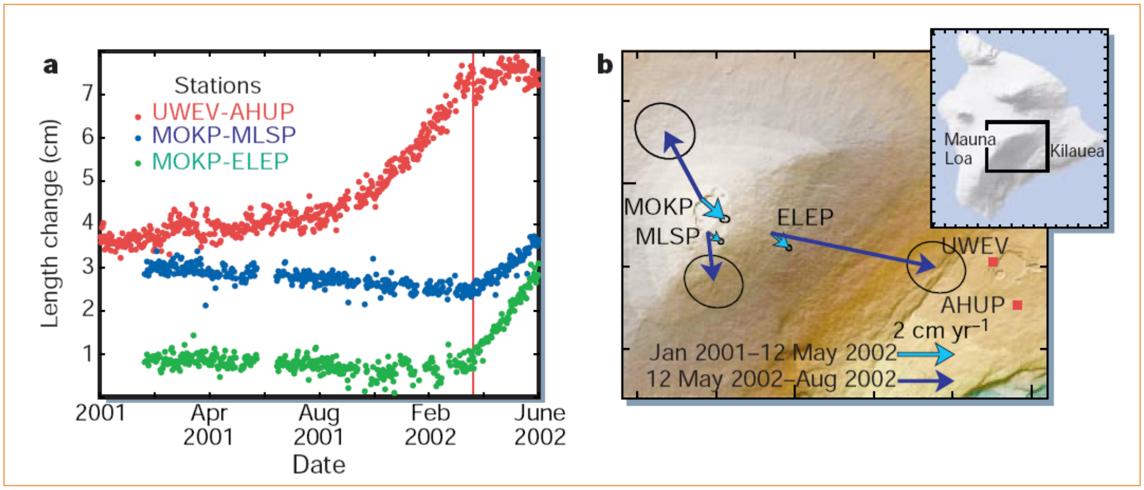


Figure 2. Simplified diagram of plates.
Figure courtesy of USGS.

When deformation occurs at a point on Earth's surface, the point's position changes. This position change can be measured using high-precision GPS instruments. Earth scientists use these data to record how much and how quickly Earth's crust is changing because of plate tectonics and to better understand the underlying processes of the deformation.

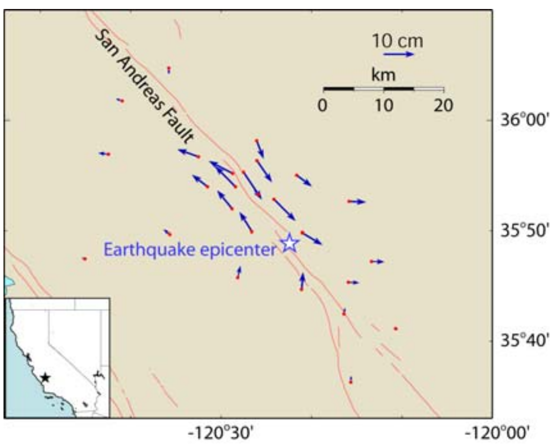
USING GPS TO STUDY EARTHQUAKES AND VOLCANOES

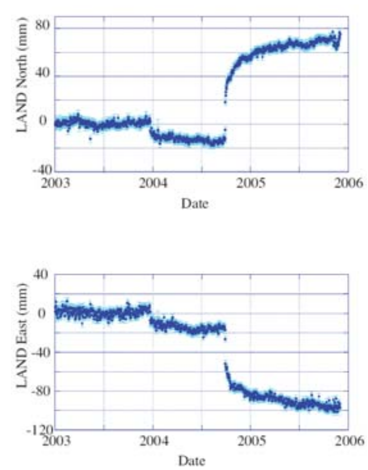
By looking at the position of points on the Earth's surface measured with GPS over time, scientists can see changes in the crust's deformation. For instance, at Mauna Loa volcano in May 2002, GPS stations on opposite sides of the summit started moving away from each other, indicating that the volcano was inflating.



Figures 3 and 4. From Miklius and Cervelli, Nature, 2003, on: monitoring volcanic deformation in Hawai'i..

When an earthquake occurs, the ground on either side of the fault moves instantaneously, sometimes causing strong shaking. GPS measurements enable scientists to map these displacements (Figure 5) and determine how much slip took place on the fault and where slip occurred. Although we cannot feel it, the crust on either side of the fault continues to slip after the strong shaking is over, sometimes for several years. Scientists can record this motion with GPS as well (Figure 6).





Figures 5 and 6. Courtesy of J. Murray.

For more information on GPS please visit http://unavco.org/edu_outreach/edu_outreach.html.

Types of GPS

NAME	HANDHELD GPS	KINEMATIC GPS	FAST-STATIC (RAPID-STATIC) GPS	CAMPAIGN (STATIC) GPS	CONTINUOUS GPS
DIFFERENTIAL GPS?	No	Yes. Consists of one stationary base station at a known location and multiple roving (moving) receivers.	Yes. Receivers must be located less than 10 km from the base station.	Yes. Requires multiple base stations and receivers.	Yes. Requires multiple base stations and receivers.
TYPE OF DATA COLLECTION	Temporary	Temporary	Temporary	Temporary	Permanent and long-term
TYPE OF STATION	Handheld GPS receiver carried by user.	User carries the receiver and antenna. RTK units are in radio contact with the base station. PPK units are not in radio contact with the base station.	Temporary station. Antenna is mounted on a tripod.	Temporary station. Antennas are mounted onto stable posts screwed into the ground, leveled, and oriented to north.	Permanent station. Antennas are mounted onto a stable monument, leveled, and oriented to north.
TIME REQUIRED TO CALCULATE A POSITION	Several seconds	Approximately 15 seconds	8-25 minutes	Several hours	
POSITIONS MEASURED WITHIN	2 meters	1-5 centimeters	1-5 centimeters	0.5-2 centimeters	Less than 1 centimeter
DATA PROCESSING REQUIRED?	No	RTK:no PPK: yes (simple data processing)	Yes. (Simple data processing)	Yes. (Advanced data processing)	Yes. (Advanced data processing.) One year of continuous data are needed to recognize several millimeters of motion.
ERROR CORRECTIONS ?	Cannot correct for multipath or atmospheric errors.	Yes. RTK errors are corrected "on the spot" by the base station. PPK errors are corrected during data processing.	Yes. Errors are corrected "on the spot" by the base station.	Yes. Errors are corrected during data processing.	Yes. Errors are corrected during data processing.
USED FOR	Hiking, navigation	Mapping, marking locations, navigation	Motion, position changes, measuring relatively rapid movement (cm-m per year)	Crustal deformation, relatively slow movement (mm-cm per year)	Crustal deformation, relatively slow movement (mm-cm per year)