Global Positioning System (GPS)

Objectives and Overview

Modern studies of ecology and evolution rely on global positioning system (GPS) technology and geographic information system (GIS) software for analysis of plant and animal distributions in the natural world.

The objective of the next two weeks is to gain experience with both collecting data using a GPS receiver and then analyzing the data you collect.

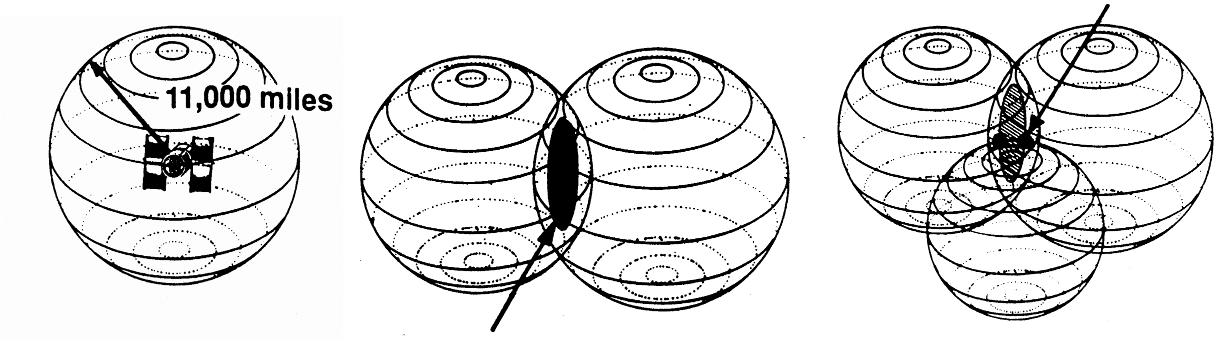
Background I: Global Positioning System (GPS)

This is an abbreviated version of the complete GPS tutorial found at the Trimble (a manufacturer of GPS receivers) website, http://www.trimble.com/gps/ If you are interested in this technology, there are a wealth of resources at this website that explore issues not covered in this manual.

The GPS system originated with the U.S. Department of Defense as a means to provide military personnel with precise location information. The system consists of 24 satellites in high-earth orbit that transmit radio waves to supporting ground stations, and is accessed through the use of a device capable of receiving and interpreting these signals. GPS units are able to recognize the specific signal unique to a satellite and distinguish it from other satellites. When a GPS unit receives a satellite signal, it is able to determine how far it is from the transmitting satellite by deciphering the exact moment the radio waves left the satellite and comparing this to the exact time the signal reached the GPS unit. Since radio waves travel at the speed of light, the distance between a GPS unit and satellite is calculated using the simple formula: speed of light × time = distance.

The GPS unit calculates a position using signals from three different satellites through a process called triangulation. A known distance from a satellite puts the GPS receiver on the surface of a sphere.

With two distances, the location of the GPS receiver can be limited to the circumference of the circle formed by the intersection of the two larger spheres (see figure at right). To visualize this idea, consider two solid balls that have the same area sanded flat on one side. If the sanded sides were put together, the ring around these areas is the same distance from the centers of both balls.



With a signal from a third satellite, the location of the receiver can be pinpointed to the two points on the circumference of the circle that are also the same distance from the third satellite. While a fourth satellite signal is optimum, many times one of the two points delimited by the signals from three satellites can be ruled out because it is off the surface of the earth.

The quality of the estimated position depends on the quality of the estimated distances, which ultimately depends on the estimated times encoded in the radio waves that are transmitted by the satellites. As such, any or all of the following can introduce errors in GPS measurements:

Ionospheric refraction

A layer of electrically charged particles 80–120 miles above the Earth's surface slows the radio signals to a speed slightly below the speed of light.

Atmospheric errors

Water vapor in the atmosphere can affect the speed of satellite signals.

Multipath error

Errors can be caused by the interference of a signal that has reached the receiver antenna by two or more different paths. This is usually caused by one path being bounced or reflected.

Satellite and/or Receiver Errors

Even with these potential sources of error, it is possible to differentially correct your data based on the location of a known base station. This correction can increase your accuracy so that your location data are within sub-meter accuracy. The idea of correction is straightforward; the base station can correct the signals coming in from satellites since it "knows" its true location. This correction is then applied to the signals received at the roving GPS receiver. The Trimble website (www.trimble.com/gps/) provides some nice demonstrations of how this works if you are interested.

During laboratory this week you will collect GPS data, and these data will be corrected before you work with them next week in a GIS program.

Background II: Geographic Information System (GIS)

After you have collected your spatial data with a GPS receiver, you are ready to work with these data in a GIS environment. Geographic Information System is the broad term that describes the computer systems used to view and manipulate the data captured using GPS technology. Often called "mapping software," these applications have the ability to deal with spatial information in a way that links attributes and characteristics to geographic locations. Prior to laboratory you should explore the tutorial on GIS found at https://learn.arcgis.com/en/arcgis-book/chapter5/

GIS data allow for scientists to examine phenomena in a location, and may be used specifically to search for patterns called autocorrelation. **Spatial autocorrelation** is a simple concept whose main principle is that when things exhibit spatial autocorrelation, they tend to be found close together. In essence, spatial autocorrelation asks whether similar objects are found closer together than expected by chance. A more formal definition is that spatial autocorrelation analysis tests whether the observed value of a variable at one locality, say type of tree at location X, is independent of the values at neighboring localities. If a dependence exists, the variable is said to exhibit spatial autocorrelation. To follow the example above, imagine the variable is a type of tree, either oak, mountain laurel, or cedar elm. If an oak is mapped to one location and there is a greater chance that neighboring trees are oaks than the other species, we would say that tree type shows spatial autocorrelation. This would mean that across the landscape, we would tend to see groves of oaks separate from groves of cedar elms, separate from groves of mountain laurel trees. Spatial autocorrelation measures the level of interdependence between the variables, and the nature and strength of that interdependence. Spatial autocorrelation may be classified as either positive or negative: in a positive case all similar values appear together, while in negative spatial autocorrelation dissimilar values appear in close association.

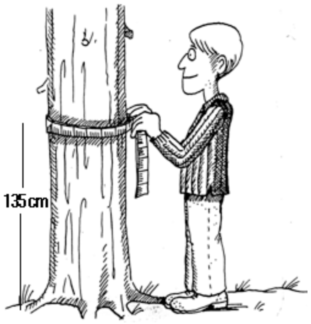
Biological variables are spatially autocorrelated for two reasons: inherent forces such as limited dispersal, gene flow, or clonal growth tend to make neighbors resemble each other, and organisms may be restricted by, or may actively respond to, environmental factors such as temperature or habitat type, which have a spatial dimension.

Background III: Tree Assessments

Recording information such as the number and types of species in an area can allow researchers to make estimates of **species diversity and species richness***, which are valuable measures of ecosystem health. In addition, the species found in a given habitat can tell scientists a story about the conditions there: some species will vary in their utilization of resources, some may be more resistant to harsh environmental conditions, some may prefer areas of disturbance, *etc*. As a broad example, you could probably make some reasonable hypotheses about a habitat that is dominated by pine trees versus one that is primarily dominated by palm trees.

Besides species type, a researcher may also be interested in measures of size or health of the individuals. The **diameter at breast height (DBH)** is a standard measurement used by ecologists and foresters to assess trees. This measurement is the diameter of the tree taken at a height of 135 cm above ground level, and is used to estimate relative tree-size and above ground biomass. This measurement is also an important factor in equations that use species-specific wood density to determine approximate carbon storage for individual trees.

*Species richness is simply the number of species in a community. Species diversity is more complex, and includes a measure of the number of species in a community, and **a measure of the abundance of each species**. We will cover this in more depth next week



Background IV: Carbon sequestration

All plants and animals contain and use carbon to sustain life. During photosynthesis, trees use sunlight, water, and carbon dioxide to produce oxygen and glucose—a carbon-based sugar molecule. While some of the glucose is used during plant respiration, the remainder is stored in the trunk, branches, roots, and leaves as the tree grows. Stored carbon is removed from the atmosphere. A tree's stored carbon can remain in the living tree or in cut wood for many years. Eventually, the stored carbon returns to the atmosphere when the wood decomposes, but this process can take a long time due to the tree's durable woody cells and tissues. For these reasons, forests store more carbon for longer time periods than other plants.

What is the difference between carbon storage and carbon sequestration?

Stored carbon is the amount of carbon that exists in a tree (leaves, wood, stem, roots, and bark) at a particular point in time. Because older trees are larger than younger trees, they are able to store more carbon (see C storage axis, fig1).

Carbon sequestration represents the net intake of carbon over a period of time. For example, net intake of carbon can be measured over the course of a tree's lifespan. Because young, growing trees add biomass at a faster rate than older trees, they are sequestering carbon at a faster rate than older trees (see C sequestration axis, fig1). Although the age at which maximum C sequestration occurs will vary with tree species, the general shape of the graph of this relationship is similar for all species.

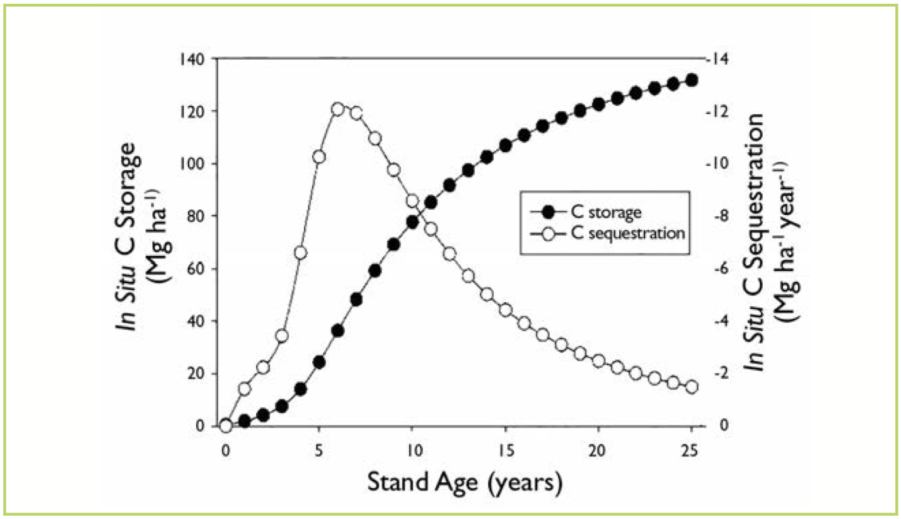


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Fig1.

You can calculate the amount of carbon sequestered in a tree using an estimate of its size using a tree’s DBH using the below formula: where ***C* is the kg carbon sequestered** and ***D* is the DBH**

$$C = 0.45 \times 10^{(-1.43+2.76\log_{10} D)}$$

General Procedures for today's lab

In lab you will use a GPS unit to record assessments of a subset of trees and shrubs on campus. This will include each tree's geographic location, as well as the tree species, diameter at breast height, canopy height, and major axis of canopy orientation.

Next week in lab, GIS will be used to examine ecological trends in community structure. You will calculate carbon sequestration of your trees, and you will use GIS tools to evaluate relationships, including species distribution, spatial autocorrelation of traits, average nearest neighbor distances and species richness. Keep these variables in mind as you complete this lab and consider how they might influence one another.

Because it is difficult to explain much of the activity for this lab without the GPS unit in hand, you will be given a copy of the instructions for the GPS unit in class.