3 GPS Basics and Mapping Theory

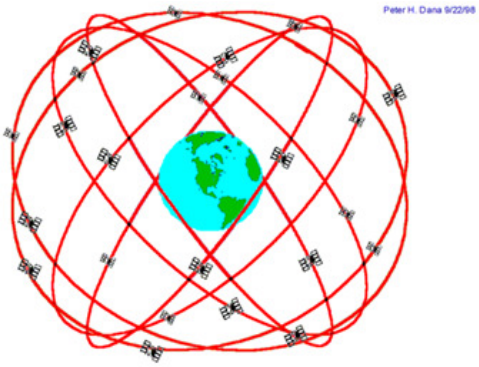
3.1 What is GPS?

- Global Positioning System (GPS) is a satellite based navigation system funded by the US Department of Defense.

- Originally developed for military operations in the 1980's, but later made available for civilian use in the mid 1990's. Since then GPS is available 24/7, works all across the world, works in all weather conditions, and is free.

- The system consists of up to 32 satellites, but only 24 of those needed to be fully active. The extras are spares.

- The satellites are arranged in 6 orbital planes with 4 sats in each plane. Orbit altitude is roughly 20,200 km (12,550 miles) above the earth.



- As of 2000, selective availability has been turned off so the government no longer introduces artificial error in GPS positions.

- There are other satellite navigation systems in place such as the Russian GLONASS system and others in the works such as the European Galileo constellation.

3.2 How GPS Works

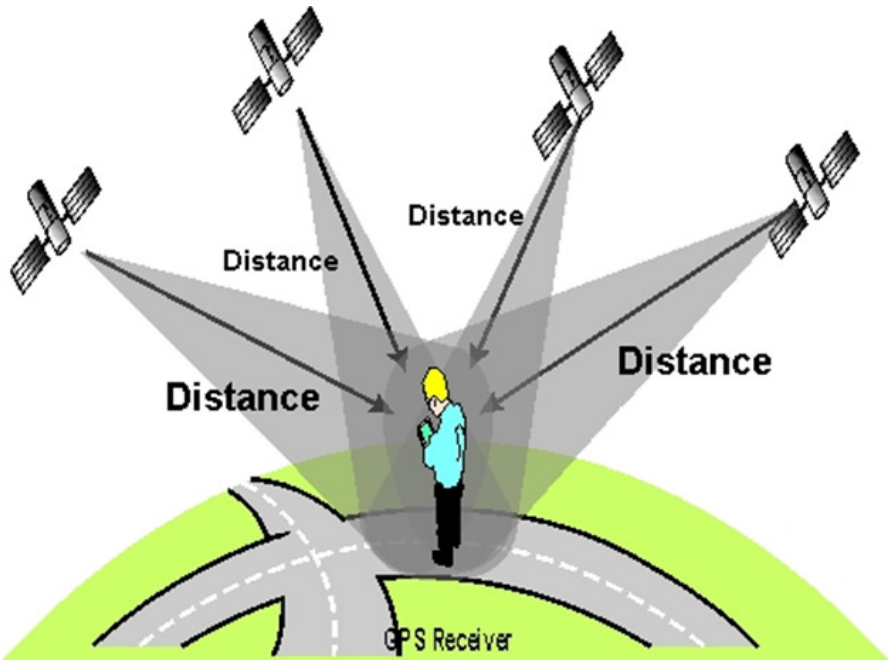
- GPS satellites emit specially coded radio signals much like FM radio signals. Each satellite transmits its exact location along with a timed reference signal.

- These signals travel all the way to earth in about 1/15th of a second.

- GPS receivers decode the signals and use them to calculate the distance (range) from the receiver to each satellite in view.

- A process called trilateration is used to calculate positions on Earth. The GPS receiver needs at least 4 satellites to determine a 3D position (Lat, Long, Elevation).

- Since the signals travel so fast, even tiny delays caused by tree canopy, buildings, or atmospheric conditions can introduce error in the range calculations.



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3.3 GPS System Components

- **GPS receiver**
- **Data collector or field computer**
- **GPS Data Collection Software**
- Configurations vary from handhelds with GPS built-in to systems with modular components.

3.4 How Accurate is GPS?

Good question. All GPS receivers are not created equal. Accuracy really is determined by the quality (or grade) of GPS and the data collection environment. Here are the 4 major grades of GPS devices and their expected accuracy in open sky conditions:

- **Consumer/Recreational Grade** - 3-15 meters
  (E.g.: Garmin eTrex, Magellan, iPhone, etc.)

- **Mapping Grade** - 1-3 meters
  (E.g.: Nautiz X8, Forge, Nomad, T41G, Archer 2)

- **Professional Grade** - Submeter to decimeter. (E.g.: Trimble GeoXT and GeoXH, Geode, PG200)

- **Survey Grade** - Centimeter accuracy
  (E.g.: Trimble 5800, Ashtech ProMark)

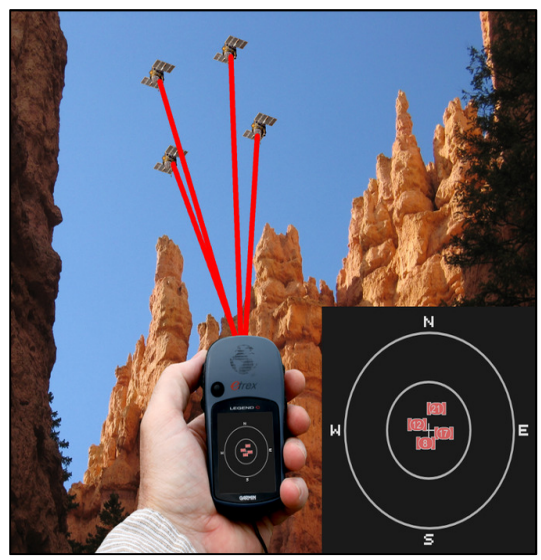
3.5 What about accuracy under tree canopy?

There are several problems brought about by forest canopy.

- **Low SNR – weaken signals**
  The signals transmitted by GPS satellites are low power, and have very little penetrating ability. Materials that have high water content, such as leaves from deciduous trees, cause the GPS signal to be attenuated to the point it becomes unusable. In the field this will be seen as low SNR (signal to noise ratio) for satellites. In contrast, signals with clear line of sight from satellite to GPS will be cleaner and have higher SNR.

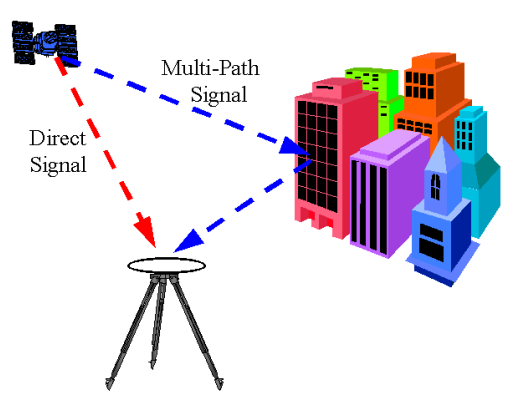
- **High DOP Values – Poor satellite geometry**
  Working under forest canopy will typically limit the view of the sky, causing the GPS receiver to see only satellites that are directly overhead. This results in poor satellite geometry and poor DOP (Dilution of Precision). This has a large detrimental effect on the quality of the positional data. There are several types of DOP including PDOP (positional dilution of precision) that measures both horizontal and vertical error, HDOP which measures horizontal error only, etc. The lower the DOP value the better the expected accuracy. GPS software usually allows users to set max DOP limits to ensure good data quality.

Good geometry



Poor geometry

- **Multipath**

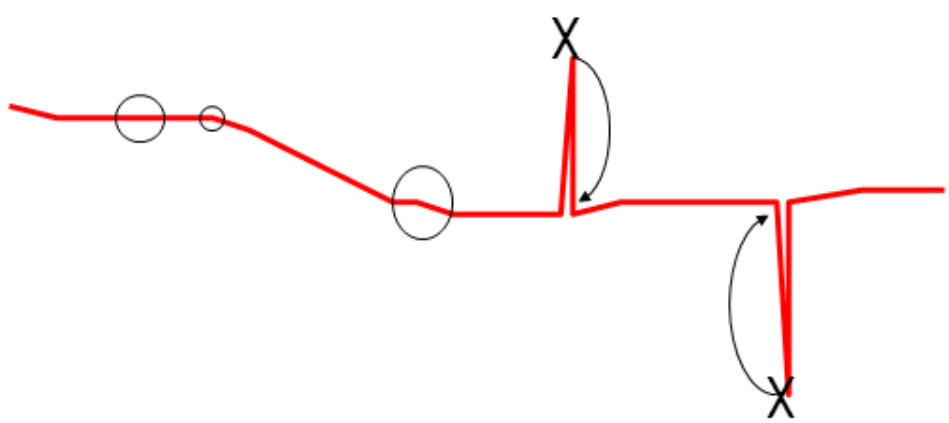


Multi-path occurs when signals are reflected off of objects such as trees or branches and take multiple paths to the GPS. These reflections delay the signal before it reaches the antenna and throw off the range calculations. Since accurate timing is necessary for accurate positioning, this can cause significant error. Multi-path is the greatest source of error in forestry settings and the most difficult to combat.

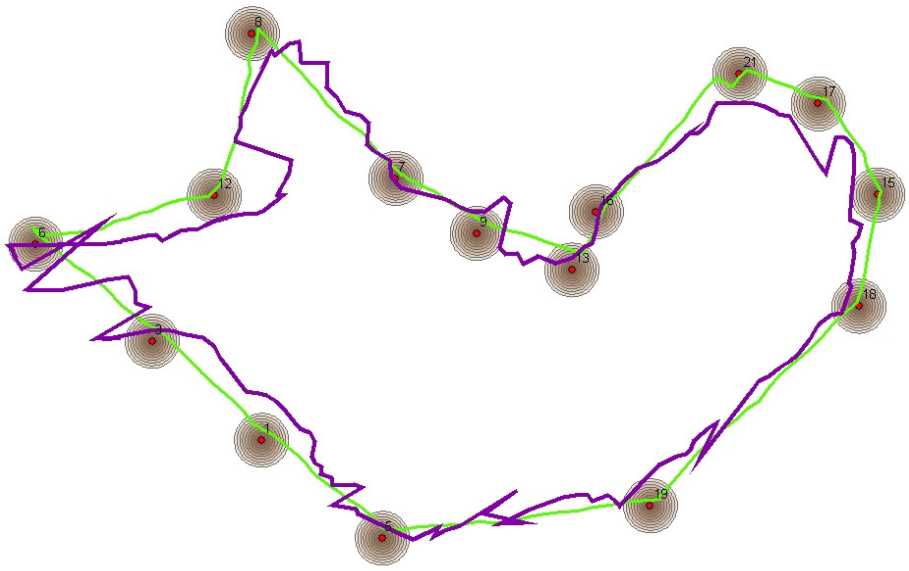
- **Constantly Changing Satellite Constellations**
  In forested environments, especially when the user is moving, the view to the sky can change rapidly and frequently. This causes different satellites to be used in the position computation. Satellite constellation has a large effect on the quality of the data collected, as different satellite constellations cause different bias in the data. Constantly changing constellations result in data that is inconsistent and has poor relative accuracy.

3.6 Techniques for Better Data Collection

- **Reject Multipath**
  The Kalman Filter (Velocity Filter) is an inertial filter that monitors direction and speed. It also detects and corrects erroneous data due to multi-path error by a continuous comparison to past positions. The diagram below is an example of how the Kalman filter builds a "bubble of possibilities" around each GPS position based on the previous monitoring of direction and speed. If a new position falls outside of the "bubble", the filtering moves that position back to its predicted location thus "smoothing" out the dynamic positions.



Here's an example of how bad multipath can be in a forest setting. The purple line is a 5 acre traverse created by an older GPS with no multipath filtering compared to a newer model with filtering in green. Notice the smoothing used in the new model contributes to much better accuracy and fewer "fliers".



- **Use HDOP Filters**
  Most foresters are concerned more with horizontal accuracy for acreage calculations rather than vertical accuracy. If you feel this way too, consider using HDOP as a quality control filter in your GPS settings rather than PDOP. PDOP accounts for horizontal, vertical and temporal component. By ignoring the vertical component, more positions will pass the standard test, resulting in more positions being collected in the field without sacrificing horizontal accuracy.

- **Differential Correction**
  The principal of differential GPS (DGPS) is that a GPS receiver, known as the base station, is set up on a precisely known location. The base station receiver calculates its position based on satellite signals and then compares this location to the known location. The difference or "correction" is applied to the GPS data recorded by a nearby roving GPS receiver, thus improving the rover's accuracy. There are different methods used to apply the correction

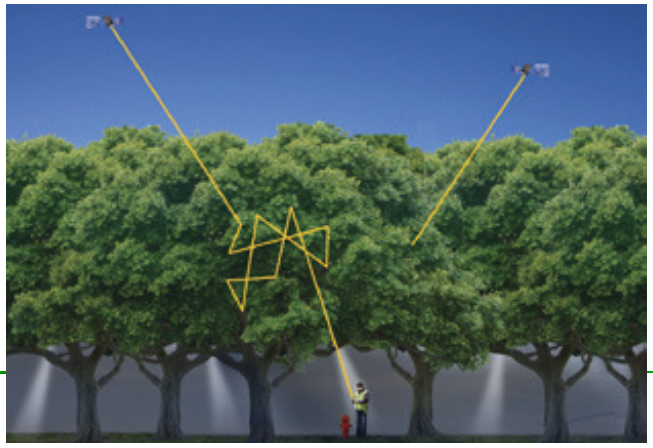
data to rover GPS and the quality associated is usually based on the rover's proximity to the base station. Differential correction is mainly used to attempt to negate error in GPS caused by the signal delay as they travel through the atmosphere.

Currently, most all GPS receivers have the capability to use real time differential correction from free sources such as WAAS. **WAAS (Wide Area Augmentation System)** is a system which uses two geosynchronous telecommunications satellites to rebroadcast differential correction data to rover GPS units over a GPS frequency. The WAAS system has a large base station network that covers most of North and Central America. Corrections from this source can allow mapping grade GPS receivers to achieve 1-3 meter accuracy in open sky conditions and professional grade units to get sub-meter accuracy.

Most professional grade GPS receivers have the ability to take differential correction one step further. They can collect and store raw data that can be corrected after-the-fact by more sophisticated correction algorithms to gain extra accuracy. Post processing is more time consuming and requires additional software, but can achieve better accuracy than real-time SBAS correction from sources such as WAAS. The workflow is generally to collect field GPS data, download it to a PC with post-processing software, import correction data from a base station, and apply the correction to the rover data to produce a new "improved" dataset.

High accuracy real time correction sources are also available for many professional and survey grade GPS receivers. These corrections come from a network of survey grade base stations that are very close in proximity to the rover units (much closer than the WAAS correction stations). They transmit more precise correction data via cell phone signal. Some examples are nTRIP and Trimble VRS.

- **Trimble Floodlight Technology**
  Satellite shadow is the number one obstacle for collecting accurate data in forested conditions. Trimble has recently developed their "Floodlight" technology to reduce shadows by:



- Combining GPS and GLONASS satellites resulting in 60% more satellites available
- Advanced tracking algorithms to speed up signal acquisition and ensure more stable tracking.
- Altitude constrained positioning from an internal barometer that reduces the impact of weak signals.

Newer Trimble units such as the Geo 6000 series make Floodlight available as an option.

- **Smart Data Collection**
  Many GPS programs today allow you to see estimated error in the field during the collection process. Some will even allow you to offset your collected points a given distance and bearing from the occupied position allowing you to collect data where the receiver has a better, "clearer" view of the sky.

So what kind of accuracy can really be expected under forest Canopy?

A good rule of thumb is to take the manufacturer's stated accuracy and multiply by a factor of 2, sometimes 3.

3.7 Best Practices for Field GPS Data Collection

- Turn on your GPS receiver before you reach the job site.

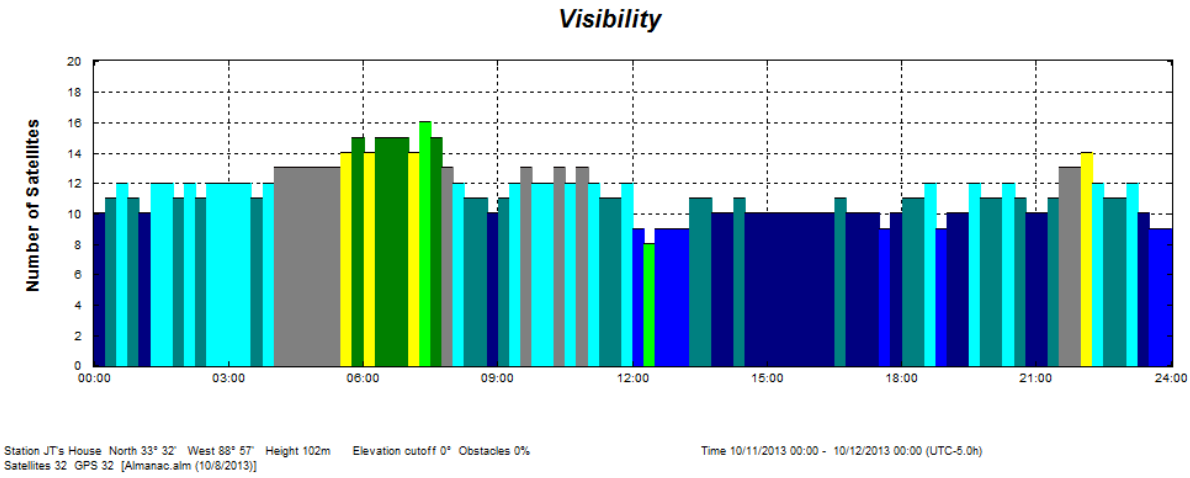
- Your GPS receiver will acquire a position much faster if you give it a clear view of the sky. A clear view of the southern sky will help with WAAS acquisition as those satellites are located on the equator.

- Be aware of the location of the GPS antenna in your system and hold it so that it can work at its best. The Flint and Forge units should be held perpendicular to the ground so their GPS antennas are facing up for best results.

- Be aware of reflective surfaces and potential error from them. Use offsets as a way to work smarter and get better accuracy.

3.8 Frequently asked questions about GPS

- **Mission Planning – Is it really necessary?**
  In today's world of "gotta get it done now", mission planning is used much less frequently. Mission planning can be a useful tool if you have a professional grade GPS which requires high signal strength. There are several free mission plan applications that allow the user to input his home location and time frame and get a chart output like the one below which displays the number of satellites available throughout that time period. The user can pick the time when there is most availability to collect data. Most mapping grade or recreational grade units track well enough under canopy that most foresters don't use mission planning unless they are in unusually difficult environments such as a river bottom or in mountainous terrain.



- **How does my iPhone or Android device compare to other GPS units?**
  Not so well. About 2x the error of Mapping Grade units. Use dynamic data collection method if possible.

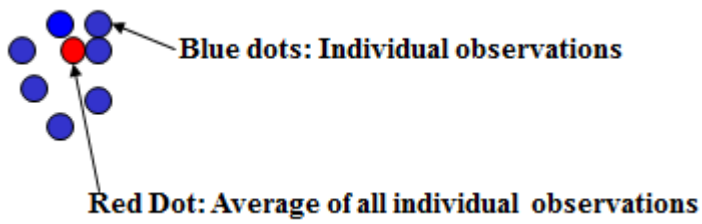
- **Is sub-meter accuracy achievable under canopy? Does post-processing help?**
  Not consistently with Current Pro Grade units. Post Processing does help (0.5 – 1 meter) but may not be worth the additional time and investment to use post-processing software (up to $2K for Pathfinder Office).

- **What kind of accuracy can I expect from the Flint and Forge units as well as Trimble's T41G?**
  Our tests usually result in 2-5meter accuracy under canopy on average.

3.9 Static vs. Dynamic Data Collection Techniques

GPS data collection can be broken down into two methods:

Static Data Collection- the process of collecting GPS positions while keeping the receiver stationary over a feature. This usually entails averaging those GPS positions to increase accuracy by "averaging out" potential error.



This data collection method is most often associated with point features. Some example of instances where static data collection is preferred:

- Property Corners
- Fire hydrants
- Individual trees
- Man hole cover

5-20 positions are usually sufficient to average to get a good position.

Dynamic Data Collection - the process of collecting GPS positions while the GPS antenna is in motion. This collection method is most often associated with line and polygon features where positions "meander" and don't just consist of long straight segments. Some examples are:

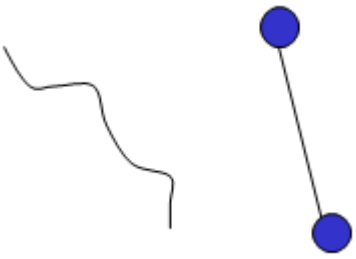
- Creeks and streams
- SMZ's
- Woods roads
- Metes and bounds property boundaries

3.10 Feature Types

A feature is an object which is being mapped. There are three geometry classification types that a feature can fall into: Points, Lines, and Areas (polygons).

Point Features – almost always collected using the static method.

Line Features – Can be collected using static or dynamic methods or a combination of both.



Area Features – Can be collected using static or dynamic methods or a combination of both.

3.11 Feature File

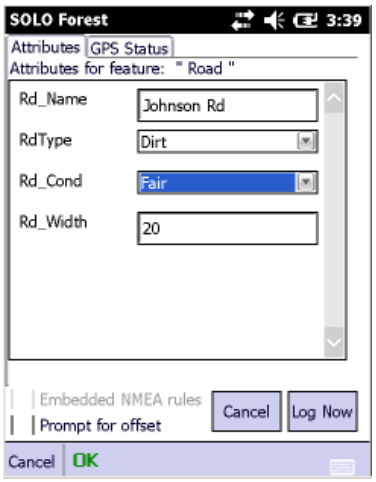
A **Feature File** is a list of available features that GPS position can be applied to. These features are points, lines, and areas that can be given more specific names. An example would be a Line Feature called a **Road**.

Name	Type
Stand	Area
Tract	Area
Road	Line
GIS_Edit_line	Line
Hydro	Line
Plot	Point
Misc_Point	Point
Specimen_Tree	Point
Structure	Point
Utility_Line	Line

Attributes are characteristics which describe the Feature. Attributes can be thought of as questions which are asked about the Feature. Some attributes for a Road feature might be: **Type, Number, Condition, and Name.**

Value: descriptive information about the feature. Values can be thought of as the answers to the questions posed by the Attributes. Values for the previous example feature attributes might be: **Dirt Road, #322, Fair, Johnson Rd.**

Importance of the Feature File



- The feature file helps the user collect and describe GPS features in a quick and effective manner.
- The attribute data collected will be exported out in the shapefile and become the attribute table in your GIS application.
- Attributes in the feature file can be setup as menu, number ranges, text, and dates.
- Good attribute information allows easy querying in your GIS and the ability to symbolize features based on attributes.

3.12 Map Projections and Coordinate Systems

When using SoloForest for GPS data collection the features are initially stored in a Latitude-Longitude WGS84 and when the data is exported in shapefile format it is re-projected to the supported coordinate system the user desires. These include:

- Latitude Longitude WGS84
- UTM
- State Plane
- Others as defined by a custom zone file

SoloForest can also use raster images and vector basemaps such as shapefiles if they too are projected in one of the supported coordinate systems.

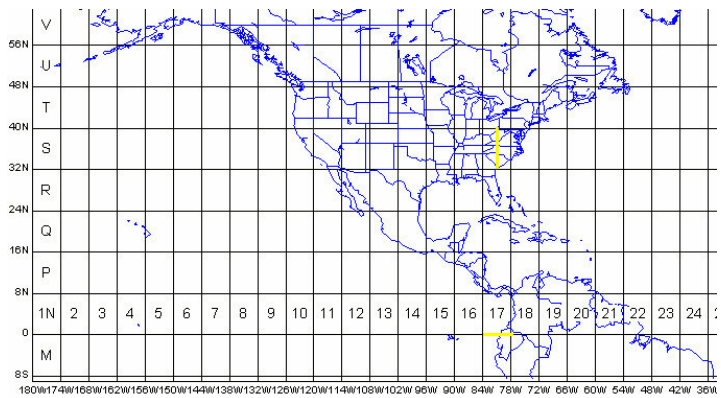
What are Map Projections?

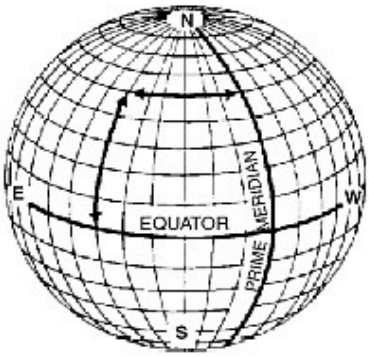
A map projection is simply a way of representing the 3D surface of the Earth onto a 2D map. Often the Earth's surface, which is an ellipsoid, is re-projected onto another surface such as a plane so that distance and azimuth computations are much simpler. As a result, all map projections have some distortion that has to be corrected. SoloForest requires the user to choose between a U.S.-based National Geodetic System (NGS) or an International System.

What are Coordinate Systems?

A coordinate system is simply a means for identifying a point on the earth on a 2 dimensional map. The coordinate system is typically defined using an x- and y-ordinate or northing and easting. The most commonly used are UTM and State Plane Coordinates. Latitude longitude is actually a special kind of coordinate system, using spherical coordinates where coordinates are angles from the center of the sphere.

Here are examples of the UTM Coordinate System on the left which is a projected Planar coordinate system. On the right is an example of Latitude Longitude which is a geographic coordinate system which is not projected.

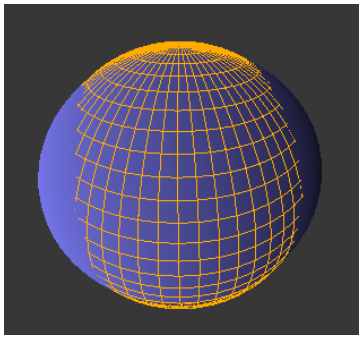


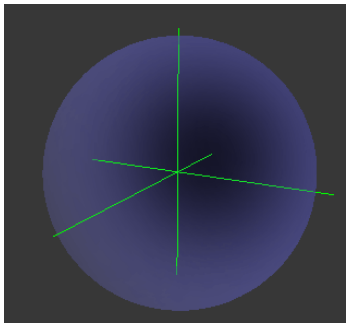


What are Datums?

A datum defines an ellipsoid (a three-dimensional ellipse), which is the currently accepted `best fit' for the overall shape of the Earth. When an ellipsoid is fixed at a particular orientation and position with respect to the Earth, it constitutes a so-called `Geodetic Datum'. In other words, a datum describes the model (including the size and shape of the earth as well as the origin and orientation of the coordinate system) that was used to match the location of features on the ground to coordinates and locations on the map.

WGS 84, NAD27, and NAD83 are examples of Horizontal Datum. NAV88 is an example of Vertical Datum.

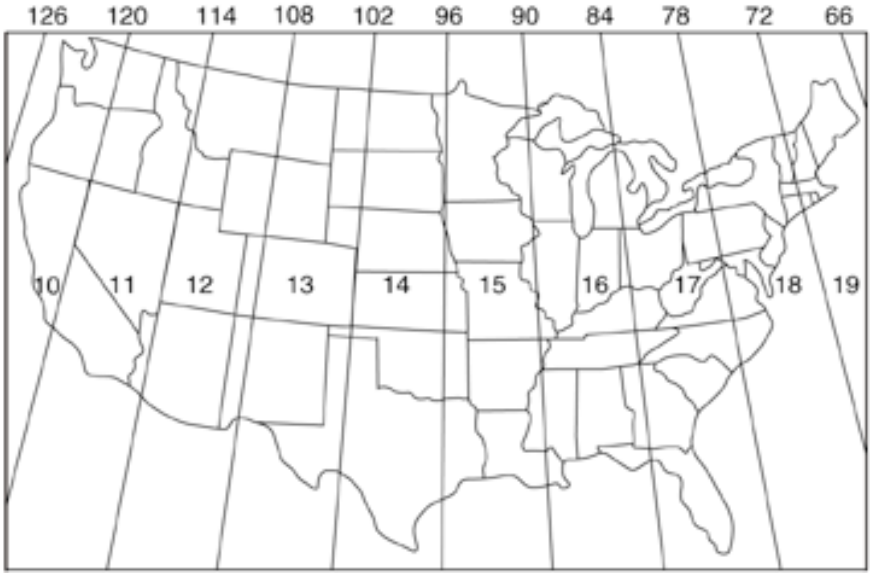




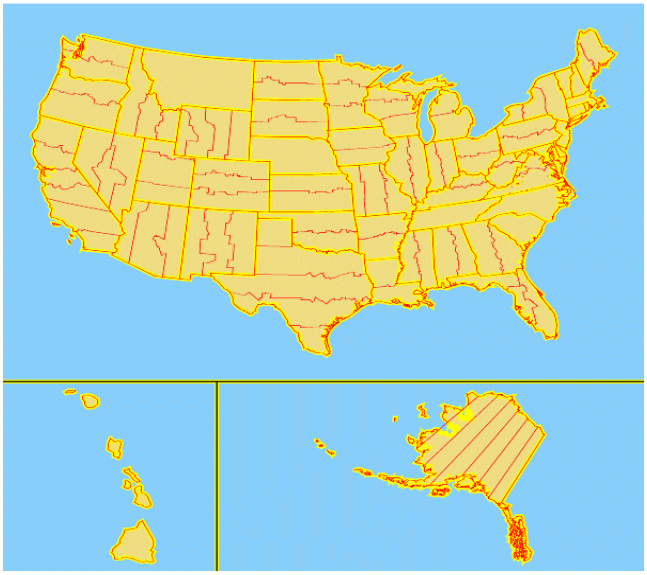
What are Zones and why are they used on Projected Coordinate Systems?

Because coordinate systems were designed for detailed calculations and positioning, they are usually divided into different zones to preserve accuracy. The boundaries of UTM zones follow lines of latitude and longitude while State Plane zones generally follow political boundaries.

The Earth is divided into 60 UTM Zones following lines of Longitude. The continental US is covered by Zones 10 – 19 with each zone representing 6 degrees of longitude.



Boundaries between state plane zones follow county lines as shown below. Depending on its size each state is represented by anywhere from one to ten zones.



Why should all this coordinate system stuff be important to me?

For your GPS data and your basemaps to align correctly, they must share the same coordinate information:

- Coordinate System
- Horizontal Datum
- Zone
- Distance Units (ie. Feet, meters)

SoloForest can change coordinate displays easily, even if you've already collected the GPS data. Images on the other hand are more difficult to reproject; therefore you should adjust your GPS settings to match your image and basemap data.