Mapping Systems

General Reference

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Corporate Office

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Glossary

CHAPTER

1

Overview

In this chapter:

- Introduction
- Related information
- Your comments

Introduction

Welcome to the *Mapping Systems General Reference* for Trimble Global Positioning System (GPS) products. This manual introduces the basic principles of using GPS for GIS data collection and data maintenance. It provides the background information you need to use Trimble Navigation Limited's mapping products, including GPS receivers, data collectors, and software.

This manual contains the following:

- Chapter 2, GPS Overview, provides an introduction to how GPS works.
- Chapter 3, GIS Overview, answers the question "What is a GIS?" and introduces you to some basic GIS concepts and terms.
- Chapter 4, Collecting GPS Data for a GIS, outlines factors you need to consider when collecting GPS data for a GIS.
- Chapter 5, GPS Data Accuracy, contains advice and techniques for improving GPS accuracy.
- Chapter 6, Datums and Coordinate Systems, explains datums and coordinate systems.
- The Glossary contains definitions of GIS and GPS terms used in this manual.

Related Information

The *GPS Pathfinder Office Getting Started Guide*, which you receive with this manual, describes how to install, set up, and use the GPS Pathfinder Office software. It contains a tutorial that helps you learn how to correct, view, and edit GPS data collected in the field, and then export it in a format suitable for your Geographic Information System (GIS), CAD, or spatial database system.

You may have also received manuals for your GPS receiver and data collector. These manuals will provide the information you need to collect and process GPS data. Where appropriate, this manual refers you to your GPS receiver manual or software manual for more information.

This manual and the *GPS Pathfinder Office Getting Started Guide* are also available in Portable Document Format (PDF). Obtain them from the Trimble website (www.trimble.com/pathfinderoffice.html).

Other sources of related information are:

- www.trimble.com – visit Trimble's website for an interactive look at Trimble and GPS.
- www.trimble.com/support – use the Trimble Product Support website to obtain detailed troubleshooting information, documentation, and the latest files available for download.
- Trimble training courses – consider a training course to help you use your GPS system to its fullest potential. For more information, visit the Trimble website at www.trimble.com.

Your Comments

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- Send an e-mail to ReaderFeedback@trimble.com.
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If the Reader Comment Form is not available, send comments and suggestions to the address in the front of this manual. Please mark it *Attention: Technical Publications Group*.

CHAPTER

2

GPS Overview

In this chapter:

- Introduction
- What GPS is used for
- How GPS works
- GPS Information Center
- GPS Mapping System components
- Differential correction
- Suggested readings in GPS

Introduction

The Global Positioning System (GPS) is a satellite-based navigation system operated by the U.S. Department of Defense (DoD). GPS provides all-weather, worldwide, 24-hour position and time information.

For an interactive tutorial on GPS, visit the Trimble website (www.trimble.com).

What GPS is Used for

Trimble GPS mapping systems are used for a variety of applications. They create and update GIS databases in disciplines as diverse as natural resource sciences, urban development and analysis, agriculture, and social sciences. Position, time, and attribute information is collected by walking, riding, driving, and flying around locations of interest.

Natural Resource Applications

Natural resource specialists, such as foresters, geologists, geographers, and biologists, use GPS mapping systems to record GPS position and attribute information. For example, foresters record attribute information about age, health, quantity, and type of timber. They also survey timber stands for replanting or logging. Biologists locate wildlife habitats, map them, and record animal counts and other attributes.

GPS helps in collecting soil type data which is then combined with 3D terrain models showing slope and aspect, to predict areas requiring special management. Some other natural resource applications include mapping well locations; recording lake size and condition, floodlines, wetland acreage, and stream length; fish and wildlife habitats; changing coastlines; and vegetation and climate zones.

Urban Applications

Urban applications of GPS mapping systems include mapping transportation and utility infrastructure. Streets and highways are digitized by driving along the roads while recording the GPS positions. Road conditions, hazards, and areas that need repairs are entered as attributes for use in inventory and GIS programs.

GPS helps in mapping electrical, telephone, water, gas, and sewer lines. Items like manhole covers and fire hydrants are mapped as points with associated attribute information.

Inspection and maintenance crews use GPS to navigate directly to sites that need attention. Their times of arrival and departure are accurately recorded, along with their comments and the services performed.

Other urban applications include mapping and recording land parcels, zones, public works, street features, and factories.

Agriculture Applications

GPS mapping systems help delineate field characteristics for farming. Microclimates, soil types, crop stress, weed infestations, plant diseases, insect damage, and crop yield are recorded and referenced directly to their location.

Tractor or airplane position and soil data can be correlated so that chemicals are applied only where needed. This lowers chemical costs and reduces ground water contamination from excessive chemical applications.

GPS technology helps agriculturists keep an accurate history of individual field analyses to determine the effects of different types of farming practices.

Social Science Applications

Archaeologists and historians use GPS mapping systems to navigate to and record information about unmarked sites. These locations are recorded using a data collector and are called *waypoints*. Waypoints are useful for navigating to a location. When the desired location is found, comprehensive data can be recorded for entry into a GIS or other database.

One social science application was a study undertaken by anthropologists in the Venezuelan jungle. The anthropologists explored uncharted territory in the jungle and used a GPS mapping system to locate and map previously unknown tribes. The position and cultural data that was collected is helping the Venezuelan government to create preserves to ensure that tribal villages remain undisturbed.

Other Applications

GPS mapping systems can be used for any application that requires accurate time, position, and other feature information. The final output is not limited to plots and maps. Position and time records can also be transferred to software programs that require the information for modeling functions.

The navigation capability of the system helps search and rescue workers, fire and police departments, and surveyors, by helping them to find specific locations quickly.

By mounting a GPS mapping receiver in an airplane or helicopter and flying around burn areas, firefighters can use GPS to rapidly and accurately establish fire boundaries. Fire perimeters are plotted and overlaid with existing maps to assist firefighters. Fire area and perimeter data is also converted to a GIS format for fire damage assessment.

One useful application for GPS mapping systems is to maintain a common reference system for data collection. A frequent concern when using GIS databases is the need for a common reference system between different data sets. Data collected with GPS can be accurately

referenced to control points in a geodetic survey network (that is, a survey network referenced to an ellipsoid). GPS uses WGS-84 (World Geodetic System-1984) as the common reference system.

GPS mapping systems are also helpful in ground-truthing satellite imagery data and for geo-referencing photogrammetric and digital map data.

How GPS Works

There are five basic steps to GPS:

1. Satellite trilateration – the basis of the system
2. Satellite ranging – measuring distance from a satellite
3. Accurate timing – why consistent clocks and a fourth space vehicle (SV) are needed
4. Satellite positioning – knowing where a satellite is in space
5. Correcting errors – correcting for ionospheric and tropospheric delays

Step 1: Satellite Trilateration

Coordinates are calculated for any position on Earth by measuring the distances from a number of satellites to the position—the satellites act as precise reference points. If the distance from one satellite is known, the position can be narrowed down to the surface of a sphere surrounding that satellite. See Figure 2.1.

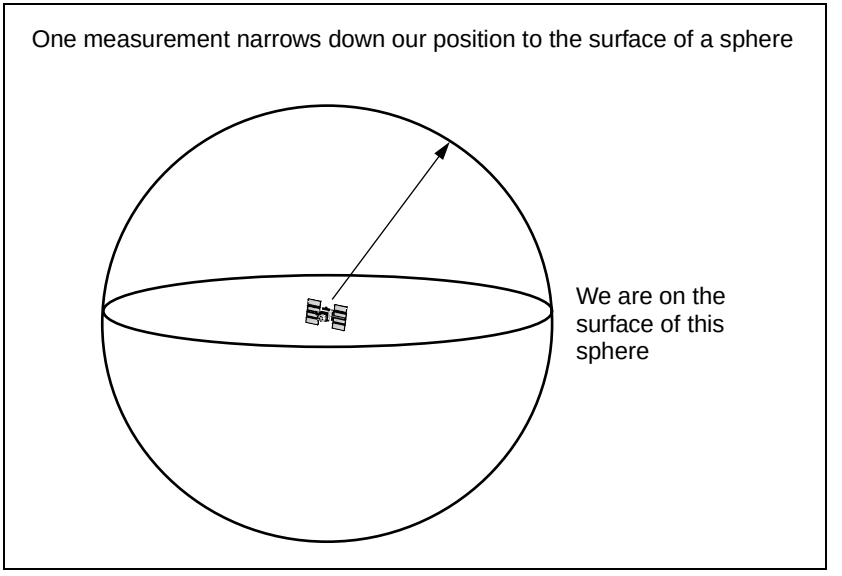

Figure 2.1 One satellite

If the distance from a second satellite is also known, this narrows the position down to the intersection of the two spheres. See Figure 2.2.

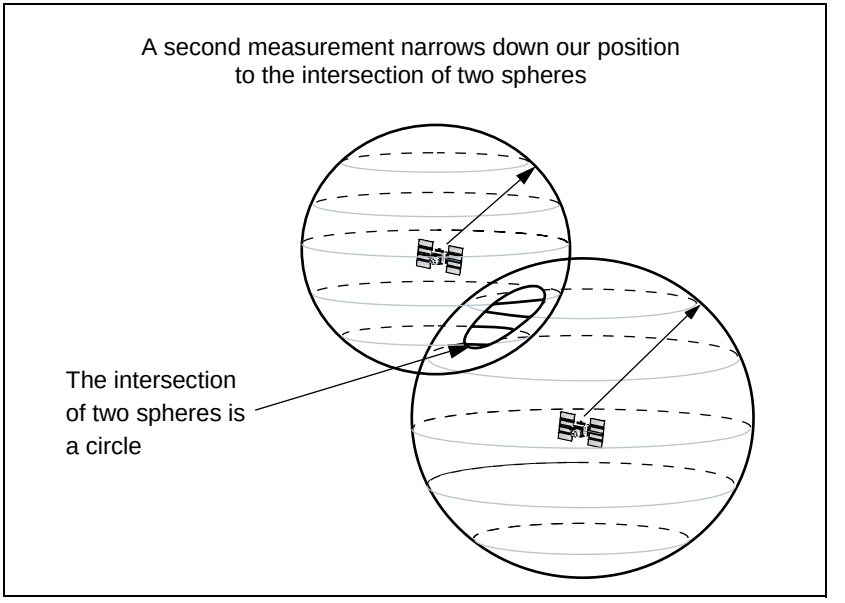

Figure 2.2 Two satellites

Add a third satellite and the position is narrowed down to one of two points. See Figure 2.3.

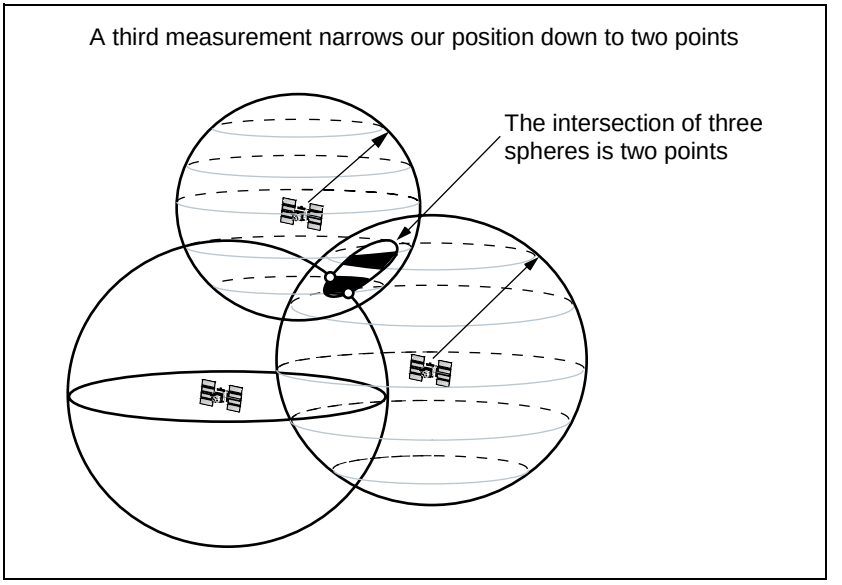

Figure 2.3 Three satellites

One of these positions is disregarded—it will be far out in space or moving at high speed—and so by eliminating this position the correct answer can be found.

Although three satellites can be used to calculate the coordinates for a position, a fourth satellite is needed to solve the four unknowns, *x*, *y*, *z*, and time. See Figure 2.4.

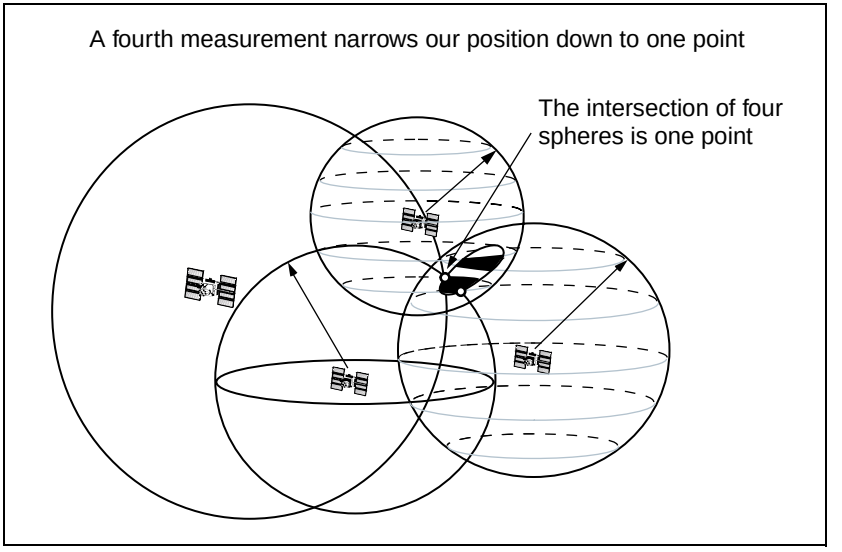

Figure 2.4 Four satellites

Step 2: Satellite Ranging

The distance from a single satellite is established by measuring the travel time of a radio signal from the satellite to the receiver. To measure the travel time of a radio signal, the receiver needs to know when the signal left the satellite.

To establish when a signal left a satellite the same pseudorandom noise code is generated at the same time in both the receiver and satellite. See Figure 2.5.

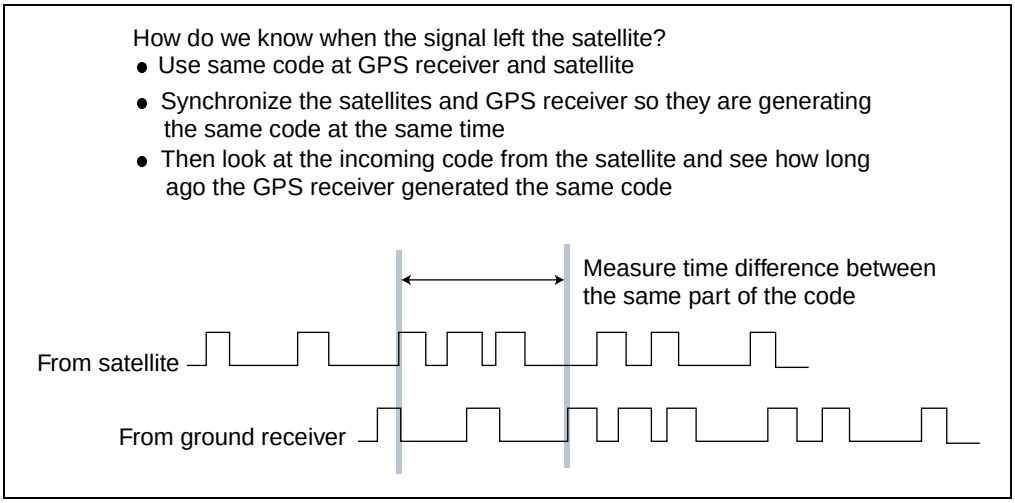

Figure 2.5 Code generation

The receiver examines the incoming code from the satellite and then checks how long ago it generated the same code. This time difference multiplied by the speed of light (186,000 m/s) gives the distance.

The use of a code is important because it allows the receiver to make the comparison at any time. It also means many satellites can operate at the same frequency, because each satellite is identified by its own pseudorandom number (PRN) code.

Step 3: Accurate Timing

The calculations depend on highly accurate clocks. The code has to be generated in both the receiver and the satellite at exactly the same time. Satellites have atomic clocks that are accurate to a nanosecond (one billionth of a second), but these are too expensive to put in every ground receiver. Receivers use a measurement from a fourth satellite to remove any clock errors.

For the sake of simplicity, the illustrations used in this explanation show only two dimensions, and so only three satellites are needed to calculate a position.

If both the satellite and receiver clocks are accurate, an accurate position can be found by measuring the distance from two satellites. See Figure 2.6.

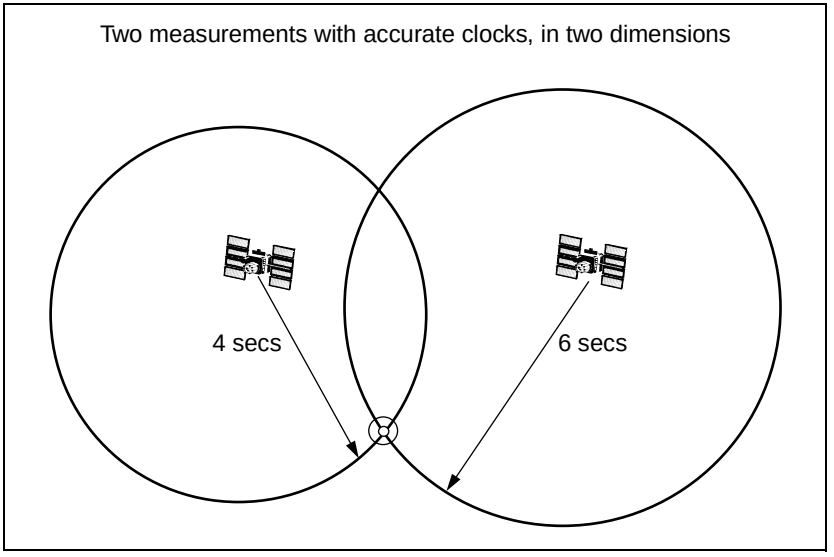

Figure 2.6 Measuring distance from two satellites with accurate clocks

If a measurement is made from a third satellite and all clocks are accurate, the third measurement also intersects. See Figure 2.7.

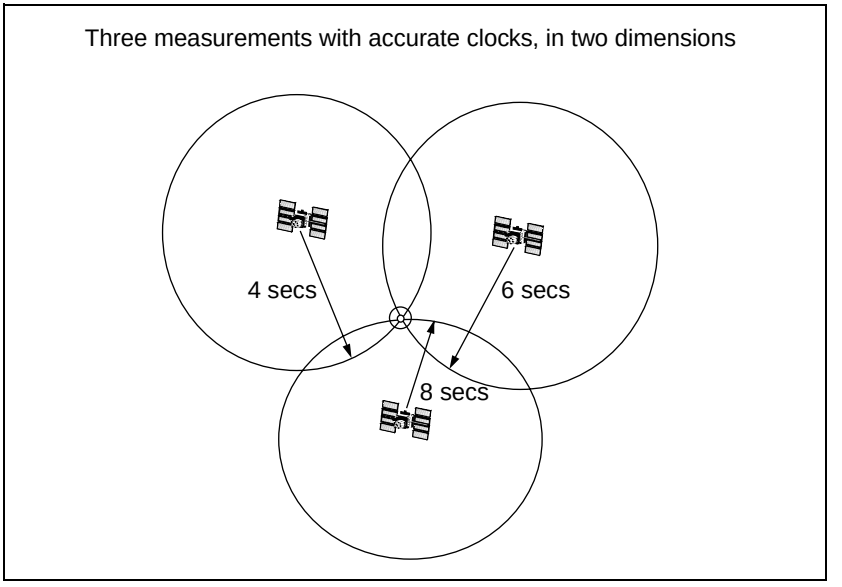

Figure 2.7 Measuring distance from three satellites with accurate clocks

However, if the receiver clock is fast by 1 second, the measurements from two satellites intersect. See Figure 2.8.

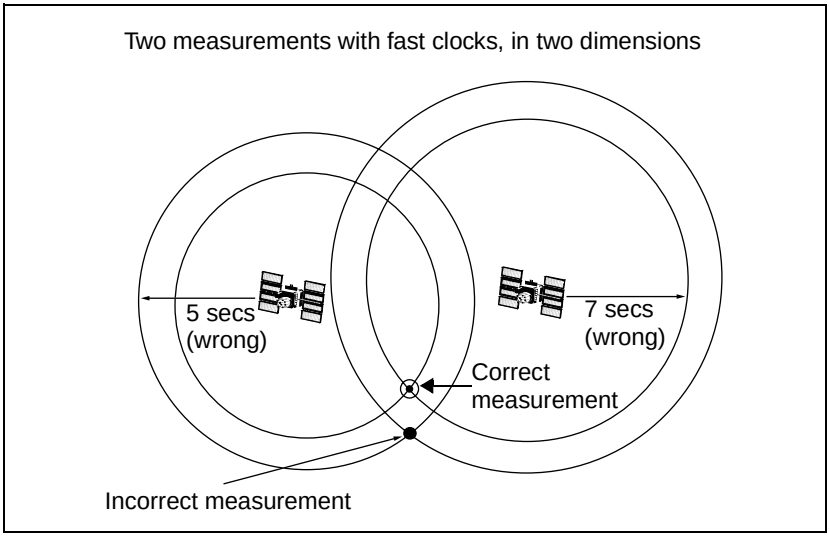

Figure 2.8 Measuring distances from two satellites with fast clocks

If a measurement is made from a third satellite and the receiver clock is fast by 1 second, the third measurement does not intersect with the other two. See Figure 2.9.

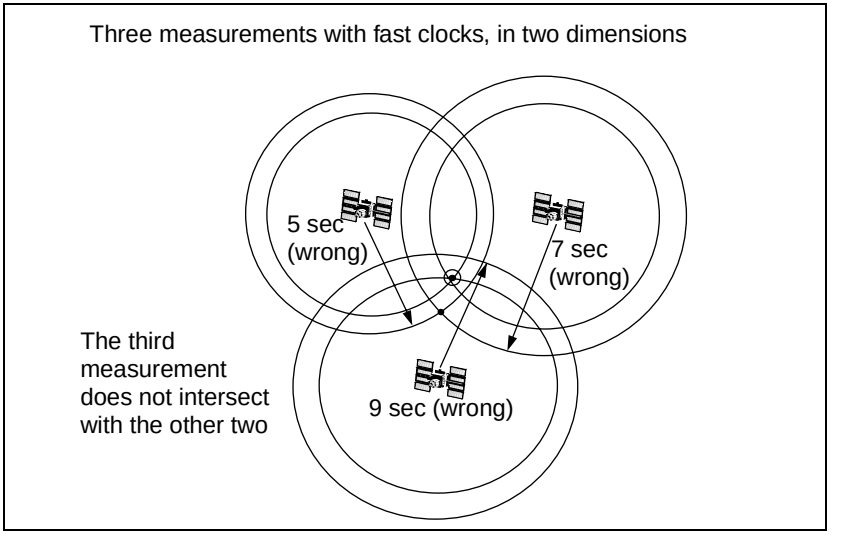

Figure 2.9 Measuring distances from three satellites with fast clocks

When a GPS receiver gets a series of measurements that do not intersect at a single point, the computer in the receiver starts subtracting (or adding) time until it arrives at an answer that lets the ranges from all satellites go through a single point. It then works out what the time offset is and makes the appropriate adjustments.

If you require three dimensions, four satellites are needed to cancel out time errors. So when GPS data is collected in the field, four satellites must be in view and the receiver must have four GPS channels or be able to sequence among four satellites.

Step 4: Satellite Positioning

There are 24 operational NAVSTAR (NAVigation Satellite Timing And Ranging) satellites orbiting the earth every twelve hours at an altitude of about 20,200 km (12,600 nautical miles). There are four satellites in each of six evenly distributed orbits inclined 55° to the equator. Because the satellites are so high there is little atmospheric drag and their orbit is very stable.

There are three segments to GPS:

- The space segment

  The space segment consists of 24 satellites, which are constantly monitored by the U.S. DoD. Each satellite contains several high-precision atomic clocks and constantly transmits radio signals using its own unique identifying code.[1]

- The control segment

  The U.S. DoD has four ground-based monitor stations, three upload stations, and a master control station. The monitor stations track the satellites continuously and provides data to the master control station. The master control station calculates satellite paths and clock corrections, and forwards them to an upload station. The upload stations transmit the data to each satellite at least once a day.

- The user segment

  The user segment consists of the GPS equipment.

[1.] Each GPS satellite transmits two radio signals, L1 at 1575.42 MHz and L2 at 1227.60 MHz. The L1 signal is modulated with two pseudorandom noise (PRN) codes, P-code and C/A code. The Precision or P-code can be encrypted for military use. The Coarse/Acquisition or C/A code is not encrypted. The L2 signal is modulated with the P-code only. Most civilian receivers use the C/A code to obtain GPS system information.

Step 5: Correcting Errors

Some sources of error in GPS are difficult to eliminate. The calculations assume that the GPS signal travels at a constant speed (the speed of light). However, the speed of light is constant only in a vacuum. Once the GPS signal enters the ionosphere (a band of charged particles 80 to 120 miles above the surface of the earth) and the troposphere (our weather), the signal slows down, resulting in incorrect distance calculations. Trimble GPS receivers correct these delays.

Atomic clock and satellite orbit errors can occur, but are usually very minor and are adjusted by the U.S. DoD from the monitor stations.

Multipath interference can introduce error into a GPS position. This occurs when the signal is reflected off other objects at or near the earth's surface. The reflected signal interferes with the straight line signal. Advanced signal processing and well-designed antennas help minimize the effect of multipath. Examples of multipath sources are mountains, trees, buildings, and bodies of water.

GPS Information Center

The U.S. Coast Guard operates the GPS Information Center (GPSIC). The GPSIC provides information on the operational status of the Global Positioning System. (Trimble also lists this information through their support website—www.trimble.com/gpsdataresources.html.) Table 2.1 lists contact details for the GPSIC.

Table 2.1 GPSIC contact details

Contact method	Contact details
Recorded GPS status message (24 hours)	Ph +1-703-313-5907
Live voice (normal working hours)	Ph +1-703-313-5900
Fax	Fax +1-703-313-5920
Website	www.navcen.uscg.gov
FTP site	ftp.navcen.uscg.gov

GPS Mapping System Components

Trimble produces a range of products designed specifically for geographic mapping and GIS applications. They can quickly and accurately collect data to create and maintain geographic databases. The mapping products include GPS receivers, data collectors, and software packages. This section discusses each of these components.

Receivers

GPS receivers calculate positions as often as once per second and provide submeter to five-meter accuracy with differential correction processing. Receivers vary in size, weight, the number of positions they store, and the number of channels they use to track satellites.

While you physically traverse or stand at a site, the receiver receives signals from GPS satellites and then computes a position. The position computations are displayed as coordinates on a data collector screen. GPS receivers also compute velocity and heading, allowing you to navigate between positions.

Data Collectors

Data collectors are handheld computers running data collection software. Some data collectors record attribute data tagged to positions, while some only store positions. The data collection software controls the GPS receiver. Settings control how often and how much GPS data is stored.

Data collectors vary according to size, weight, the type of data they store, the type of physical environment they are suitable for, and the amount of information they store. Some data collectors must be connected to a separate GPS receiver. Some combine the GPS receiver and the data collector in a single piece of hardware.

GPS Processing Software

GPS processing software such as the GPS Pathfinder® Office software enables you to plan your data collection session, transfer the collected GPS data from your data collector to your PC, improve the accuracy of the data (*differential correction*), and review it before transfer to your GIS.

Some programs enable you to manipulate, adjust, delete, and plot the position and attribute data. The software packages vary according to the number of editing features and the range of export options.

GPS helps you to collect geographic feature and attribute information for input into GIS or other databases. GPS processing software exports your data to a GIS package where it can be combined with information from other sources for further mapping and analysis.

Differential Correction

Differential correction is a technique that greatly increases the accuracy of the collected GPS positions. A GPS receiver at a known location (a base station) collects GPS data that is then compared to data collected at unknown locations by other GPS receivers (*rovers* or *remotes*).

Figure 2.10 shows the components of a Differential GPS (DGPS) system.

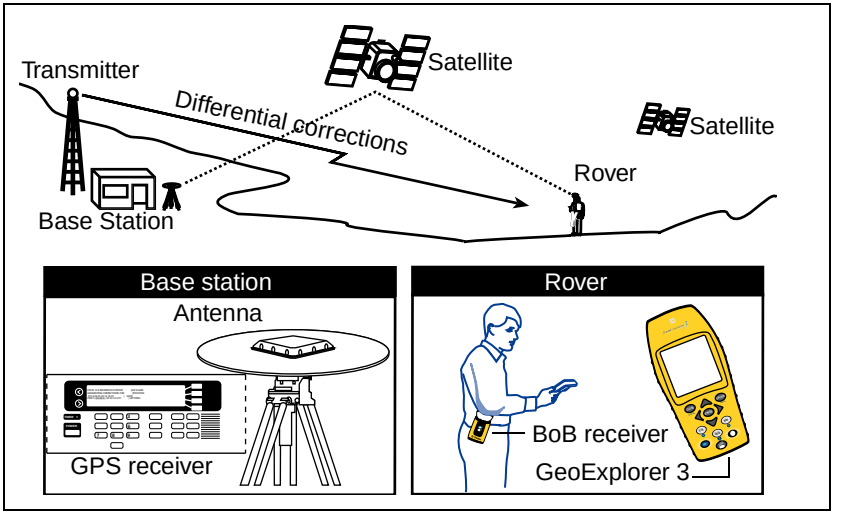

Figure 2.10 Components of a DGPS system

The data collected at the known location is used to determine what errors are contained in the satellite data. The base station data is then applied to the data collected by the rovers, and the offset differences are used to remove errors from the rover positions[2]. You need to know your base station position very accurately as the differential correction position accuracy depends on the accuracy of the coordinates of the base station.

There are two methods for performing differential correction: real-time and postprocessed.

2. Possible sources of error include receiver clocks, satellite clocks, satellite position, and ionospheric or atmospheric delays. For more information, see Step 5: Correcting Errors, page 20.

Real-Time Differential Correction

Real-time differential correction gives you better accuracy as you collect GPS data. In real-time differential GPS, the base station calculates and broadcasts through radio signals the correction for each satellite as it receives the data. This correction is received by the rover and applied to the position it is calculating. As a result, the position displayed by the controlling software and logged to the data file is a differentially corrected position.

These corrected positions can be saved to a file on the data collector. Real-time corrections are usually formatted using the recommendations of RTCM SC-104[3]. All of Trimble's current GPS mapping products can perform real-time differential correction.

Postprocessed Differential Correction

In postprocessed differential GPS, the base station records the correction for each satellite directly to a file. The rover also records its own positions. Once data collection is complete, the two files are processed in the GPS processing software and the output is a differentially corrected rover file. All Trimble's GPS mapping systems include software that can perform postprocessed differential correction.

A unique feature of Trimble's mapping systems is that real-time and postprocessed differential correction techniques can be used together. When you are using real-time, if the radio link is lost or becomes intermittent (for example, because you are out of range), the receiver continues recording uncorrected positions that can be corrected later using postprocessed differential correction.

3. The Radio Technical Commission for Maritime Services Special Committee Paper No. 104. This paper recommends a method of encoding the differential GPS signal for use by remote GPS receivers.

Suggested Readings in GPS

For more information on GPS, consult the following:

- *GPS, A Guide to the Next Utility,* Trimble Navigation Limited, www.trimble.com, part number 16778.
- *Differential GPS Explained*, Trimble Navigation Limited, www.trimble.com, part number 23036.
- *Trimble: The GPS Solution Video,* Trimble Navigation Limited, www.trimble.com.
- D. Wells, *Guide to GPS Positioning*, (1987) Canadian GPS Associates, ISBN 0-920-114-73-3.

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- A. Leick, *GPS Satellite Surveying*, (1995) John Wiley & Sons, ISBN 0-471-30626-6.
- B. Hofmann-Wellenhof, H. Lichteneger, and J. Collins, *Global Positioning System, Theory and Practice*, (2001) Fifth Edition, Springer-Verlag, Wien, New York, ISBN 3-211-83534-2.
- M. Kennedy, *The Global Positioning System and GIS:An Introduction*, (1996) Ann Arbor Press Inc., ISBN 1-57504-0 17-4.
- K. Steede-Terry, *Integrating GIS and the Global Positioning System*, (2000) Environmental Systems Research Institute, Inc., ISBN 1-879102-81-1.
- *GPS World, News and Applications of the Global Positioning System*, Monthly, Advanstar Communications, www.gpsworld.com, ISSN 1048-5104.

CHAPTER

3

GIS Overview

In this chapter:

- Introduction
- Data collection
- Data types
- Data structure
- Data analysis
- Data display
- Data management

Introduction

A Geographic Information System (GIS) is a computer database management system designed for the collection, storage, analysis, and display of spatial data. Other software used for mapping include computer-aided drafting and design (CAD) systems, computer-aided mapping systems, automated mapping and facilities management (AM/FM) systems, or land information systems (LIS). For the purpose of this discussion, all of these will be referred to as Geographic Information Systems.

Due to the geographic nature of the objects, data in a GIS is spatially referenced. Each object found in a GIS relates to some location on the earth and can be mapped. The objects in a GIS are defined by their location and by multiple attributes that describe characteristics of the object. The computer files containing the GIS information can be related to each other in a “spatially-aware” database.

Trimble GPS mapping systems provide a data collection tool for a GIS. Your Trimble mapping system includes processing software that allows you to transfer your GPS data to a GIS easily and efficiently.

Data Collection

A GIS allows you to integrate data that has been collected at different times, at different scales, and using different methods of data collection. Sources of data include maps on paper or transparency, written data, digital files, and information stored in human memory. Without a GIS, integrating data in different formats, from different times, and at different scales, is very time consuming and expensive.

Without GPS, data can be collected for a GIS by digitizing existing maps, manually entering textual data, and scanning information. There are limitations with these methods. Original maps are often out of date, can contain transcription errors, and may not be in a suitable scale. A GIS is only as good as the information it contains. Poor

quality data causes erroneous or meaningless interpretations of the information derived from a GIS. For more information, see GPS Data Collection Benefits, page 36.

GPS provides accurate, up-to-date data when and where you need it. With GPS mapping tools you can define a data dictionary (see Designing a data dictionary, page 38) and collect attributes in the field at the same time as position data. This method is fast, eliminates transcription errors, and ensures that the information in your database is current.

Collection of data for a GIS is an endless task. The ongoing need to collect new spatial data is one of the largest expenses in operating a GIS. GPS speeds up and simplifies the collection of your GIS data and ensures that the information in the GIS is current.

Data Types

There are two main types of data in a GIS: cartographic and non-graphic.

Cartographic Data

Cartographic data is map information stored digitally. It is the geographic features described on a map. These features are classified as points, lines (arcs), and areas (polygons or regions). Every entity on a map can be defined as a point, line, or area. See Table 3.1.

Table 3.1 Types of entities

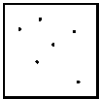
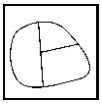
Entity type		Definition	Examples
Point		A point represents a feature for which only one geographic location (such as latitude-longitude) is needed.	Nest sites, well sites, traffic accidents, utility poles.

Table 3.1 Types of entities (Continued)

Entity type		Definition	Examples
Line (arc)		A series of connected points make up a line. It is one-dimensional, having length but no width.	Streams, roads, animal trails.
Area (polygon)		A polygon is an area enclosed by lines. It is two-dimensional; the area enclosed by a polygon has length and width.	Areas of common soil types, regions of timber sales, wetlands.

Non-Graphic Data

The second type of data used in a GIS is non-graphic. This is descriptive information stored in a database about the features (points, lines, and areas) located on a map.

The descriptive information is called an *attribute*. An attribute common to all features is geographic location, which can be given the attribute name Location. Other attributes depend on the type of feature and what characteristics are important for a particular purpose or application. For example:

- A land parcel has an owner, a size, and a use.
- An oil well is of a certain type and has a daily flow rate.
- A road has a name, a surface type, and can have a route or designation number.

Each of these characteristics can be specifically identified in a GIS by giving it an attribute name, such as Owner, Land-use, or Roadname.

Each attribute has a set of possible values called the *domain*. The domain for the attribute Roadname is all road names in the area of interest. Each instance of a feature has specific attribute values associated with it. For example, roads in general have names, but a

particular road has the name Forest Street. The attribute Roadname is an attribute of all roads, and Forest Street is the value of that attribute for a specific road.

Data Structure

There are two types of data structure: topology and layers. Topology provides the logic that connects points, lines, and polygons to each other. The GIS operator does not usually change this information. Layers provide a way for a GIS operator to structure the data.

Topology

Topological information describes how features relate spatially to each other.

When describing where something is, you usually say it is to the left of, next to, or some distance from something else. This definition is not precise enough for a GIS. A GIS requires the precise definitions that topology provides to perform spatial analysis.

Topology defines the positional relationship of features by defining properties of features. It includes information about what labels are connected to which features, how points are connected to each other, and which points and lines make up which polygons. This information is stored within the GIS. The topological information allows the GIS to perform spatial relationship functions like overlaying polygons, buffering polygons, determining if a line is within a polygon, and determining the proximity of one feature to another.

The manipulations and analyses performed by non-topological GIS systems (such as CAD systems) are limited. Make sure that the underlying structure of your GIS meets your requirements.

Layers

Most GISs allow you to separate the information on a map into logical categories called *map layers*. These are also called map themes, levels, or coverages. Layers usually contain information about only one type of feature, like soil type areas, or about a small group of related features, such as public utilities (for example, telephone, gas, and electric lines).

Map layers logically separate data so that you can manipulate and spatially analyze it, either alone or in combination with other layers. For meaningful analytical results, you must register the layers to each other by the common coordinate system of the database.

Layers help create composite maps by overlaying them on a computer display in the same way that clear acetate sheets are overlaid on an overhead projector. During analysis, new overlays are created by mathematically combining existing overlays. New composites help to create alternative scenarios. Logically separating data into layers makes it easier to manage and use the database.

Data Analysis

Data analysis allows you to derive new information from the contents of the GIS database. Analyzing data can include:

- Spatially overlaying features
- Querying
- Reclassifying, merging, and deleting features
- Buffering features
- Performing proximity operations

Figure 3.1 is an example of a simple query. The GIS operator needs to know which houses are built on the fill soil type. Two types of data (soil types and house locations) for a defined geographic area are used to answer this query.

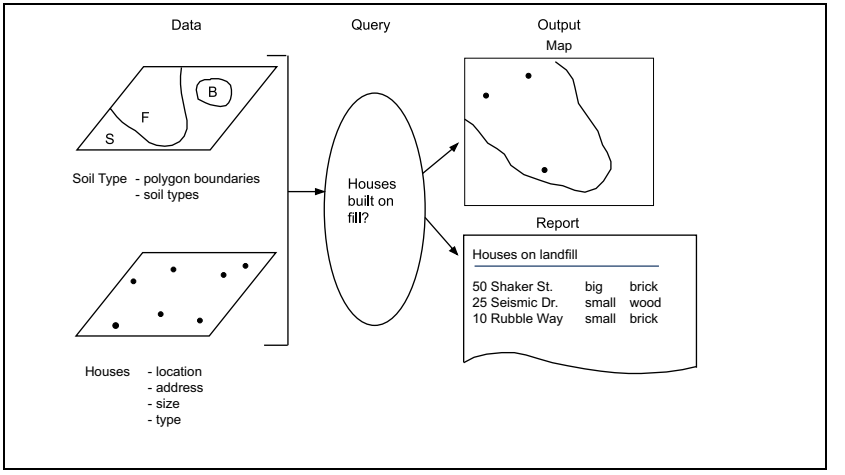


Figure 3.1 Simple query

The GIS uses the data provided by both layers of information and integrates them to form a new source of information. The link between the two layers of data is the geographic location (latitude, longitude) of each entity. Given the simplicity of the example, it is easy for a human to visually select the houses that are built in the fill area. However, if you work with a much larger area, the task would be extremely challenging.

Data Display

Data display includes creating plots, displaying statistics on data, creating cartographic products, and combining these products in reports. Some products created with a GIS are simply screen displays. Other products are hard copies of tabular files or maps, or files for use in other computer programs.

Data Management

In order to provide useful information, GIS data must be collected efficiently and then be well managed.

Good data management comprises the following:

- Creating standard methods for entering, updating, and retrieving data
- Controlling the information stored in the GIS
- Controlling user access to the GIS for reading, modifying, and archiving purposes

You need an organized and flexible GIS to effectively perform these data management tasks.

CHAPTER

4

Collecting GPS Data for a GIS

In this chapter:

- Introduction
- GPS data collection benefits
- Data collection considerations

Introduction

GPS data collection is an excellent way to collect and maintain data for a GIS. However, there are some specific issues to be aware of when you are using GPS to collect GIS data. This chapter looks at reasons for using GPS to collect GIS data. It also covers what you need to consider when preparing to collect GPS data, when collecting GPS data in the field, and when processing the data back in the office.

GPS Data Collection Benefits

There are a number of ways to collect data for a GIS:

- Digitizing or scanning existing maps
- Using aerial photographs and photogrammetry
- Manually typing text into a database
- Transferring files from other sources
- Collecting data using GPS

GPS helps you collect data quickly and accurately.

It is important that the data entered into a GIS is accurate. A GIS enhances decision-making and research, but the value of the information derived from a GIS is only as good as the data entered into it. Poor quality data causes erroneous or meaningless interpretations of the information derived from a GIS. GPS is an excellent tool for collecting accurate geographic data.

A frequent cause of error in a GIS is poor source material, for example, maps that are too old, show only partial detail, are of the wrong scale, or do not accurately portray the required information. GPS data is collected directly from the field, so the GIS accurately portrays the current situation. Using GPS provides you with up-to-date information.

With other data collection methods, errors are introduced during data transcription, text entry, and digitizing. Because GPS data is collected digitally, transferring the data directly into the GIS is quick and easy and transcription errors are eliminated.

One of the most common problems with source materials is geographic inaccuracy. Poor source materials, faulty instruments, or operator errors decrease the accuracy of positions to below the required level. Often there are insufficient funds and time to collect the data to the required level of accuracy.

GPS positions can verify the accuracy of other maps and GIS products by comparing the GPS data to the map or GIS product in question. You can compare data by creating plots at any desired scale, or you can import it into your existing GIS for comparison.

Data Collection Considerations

This section highlights important issues that you need to think about before you use GPS to collect GIS data.

Defining the Data

Deciding what data to collect is a critical part of your data collection operation. Consider the following:

- The amount of data you want to collect
- The structure of the data
- How your GPS data fits in with existing data

Plan your data collection carefully. Create a plan of your project describing the purpose, scope of work, and possible ways that you will use the data.

If your project is very large, you may want to discuss the project with other agencies or local experts. Their advice regarding valuable information and potential uses of the database can affect the project definition. If the database is to be shared among many users, then their feedback is also important.

Designing a data dictionary

If you have a GPS mapping system that lets you collect feature and attribute data, you need to use your GPS software to create a data dictionary. A *data dictionary* is the equivalent of a paper form: it lists the features that you want to collect and, for each feature, the attributes that describe it.

The data dictionary is transferred to your data collector, so that in the field it can prompt you to enter the appropriate features and attributes. It is important to use a data dictionary to ensure that the data you collect in the field provides you with the correct answers once it is in the GIS. You should read your software user guide and become familiar with creating data dictionaries.

When creating a data dictionary, consider the following:

- What is the GIS application?

  This affects what feature and attribute information you want to collect.

- How many features do you want to collect?

  The GPS software has limits and your GIS can also have limits. You may find that by collecting data on one or two additional attributes, you can attract another group of potential users. Collecting more data increases the database's value. However, keep time and memory limitations in mind. More data and redundant data take longer to collect and longer to process.

- How is the data structured?

  Think about how different feature types relate to each other in real life and in your GIS. Consider how the GIS defines the relationship between a feature and its attributes, as this can influence the design of your data dictionary.

- How will you collect data?

  Different types of features can be combined in one file, or they can be collected separately in different files.

- What are the constraints on the data dictionary? Do you need more than one data dictionary?

  There are internal limits on space, character length, and number of features. For more information, refer to your user guide.

- How will you process data?

  Become familiar with your GPS processing software. There are ways to edit and manipulate the data that can affect your decision on how the data is collected. For example, you can combine features from separate files into one file or separate a combined-feature file into several files. For more information, refer to your user guide.

- What about the existing data?

  If you have already created a GIS database, think about how to design the GPS data dictionary, so that the collected data fits in with the existing data.

- What units, datum, and coordinate system do you need to use?

  These parameters are set up in both the PC software and on the data collector. If you have existing data, use the same settings when you transfer the GPS data to your GIS so that it matches the existing data.

Some GPS mapping products do not support data dictionaries. However, you can still collect point, line, and area features in the field. For more information, see Collecting Data in the Field, page 40.

For more information on data dictionaries and how to create them, refer to your GPS Pathfinder Office documentation.

Deciding When and Where to Collect Data

Usually you need to identify where the data is to be collected. Decide on a start point and a route that makes the data collection as efficient as possible. Some applications require data collection over many days or months. You need to think about field conditions such as weather, the size of the area to be mapped, the accessibility of terrain, and any obstructions that can affect satellite visibility at different locations.

You also need to think about when is the best time to collect your GPS data. The relative positions of the satellites affects accuracy and you should plan carefully to ensure you collect accurate data. Your GPS processing software includes a mission planning option that allows you to plan the best time to collect your data. For more information, refer to your software user guide. For information on how planning can help improve the accuracy of your GPS data, see Planning Data Collection, page 51.

Collecting Data in the Field

Your data collector manual covers the specific steps for collecting data in the field. This section covers a few points you should keep in mind when collecting data.

Using a data dictionary

How data is collected is determined by the capabilities of your mapping system and by your preparation. If you have a data dictionary, you can open a file and select the feature you want to record.

You can collect the locations of features without using a data dictionary by creating a new file for every feature. However, this is time-consuming in the field and inefficient back in the office if you postprocess the data. Also, you cannot store attributes for the features.

For more information about data dictionaries, see Designing a data dictionary, page 38.

Using appropriate filenames

Naming files is an important part of collecting and processing your data. To keep track of data sets, establish a file naming convention for your office. With GPS, you can collect enormous quantities of data quickly. Keeping track of that data can become a problem if you do not properly manage the files. All personnel within a single office should adopt the same conventions and use them consistently.

Filenames should include some indication of when the file was created. By default, Trimble data collectors use the following filename convention:

- RMMDDHHX

Where R is the filename prefix for rover files, DD is the day, MM is the month, YY is the year, and HH is the hour. X increments within this hour, starting at “A” for the first file in that hour, then “B” for the second file, and so on.

Tip – If you need to collect base files, change the filename prefix to “B” to identify the file as a base station file. For more information, refer to your data collector manual.

You can change the suggested name or enter an entirely different name. You could use filenames such as:

- PARK1
- SEAVIEWGIS_260601

The maximum length of the filename depends on your data collector. For example, the TSC1 Asset Surveyor® software accepts filenames of up to 8 characters. The GeoExplorer® 3 handheld can accept filenames of up to 20 characters. For information on filenaming conventions, refer to your data collector manual.

However, unless you are dealing with a small number of data files at a time, Trimble recommends that you consider using the default filename convention, as it helps to identify files by time and date.

Some data collectors record time in UTC time, others use local time for the default filename. For more information, see your data collector manual.

Processing the Data

Once you have collected data, use the GPS software to transfer the data to your PC, differentially correct it if required, display it, manipulate it, and transfer it to the appropriate GIS format. The specific steps are covered in your software user guide.

Some important things to remember are:

- Set up a filenaming convention
- Back up all files before processing
- Make sure the units, datum, and coordinate system are correct when converting data files to GIS files

CHAPTER

5

GPS Data Accuracy

In this chapter:

- Introduction
- Equipment
- Planning data collection
- Data collection parameters
- Data collection procedures
- Processing data

Introduction

With Selective Availability turned off, GPS accuracy can range from less than 1 centimeter to more than 10 meters depending on the equipment, data processing techniques, and other factors. To some extent, the accuracy of your data depends on your knowledge and skill in using GPS technology.

Remember that the horizontal coordinates derived from GPS are typically two to five times more accurate than the vertical coordinates for any given GPS position. When techniques and equipment yield a measurement of 1 centimeter horizontally, the associated vertical accuracy is about 2–5 centimeters. This becomes a significant factor when you are using techniques and equipment that yield only 2–5 meters of horizontal accuracy. The associated vertical accuracy could be as low as tens of meters.

This chapter provides details that will help you to maximize the accuracy of your GPS data.

Equipment

The equipment you choose affects the accuracy of the GPS positions.

GPS Receivers

Trimble mapping-grade GPS receivers are categorized according to how they process the radio signal. There are two categories:

- C/A code receivers use the information contained in the radio signals to calculate positions.
- Carrier phase receivers use the radio signal itself to calculate positions.

The two processing methods are not mutually exclusive: some C/A code receivers can perform limited carrier phase processing techniques, and all carrier phase receivers can compute C/A code

positions. Without differential processing, both types of receivers only compute C/A code positions. With Selective Availability turned off, these positions are accurate to about 10 meters.

C/A code receivers

Trimble's GPS mapping grade products use C/A code receivers. The accuracy of these receivers ranges from 50 centimeters to 5 meters with differential correction. C/A code receivers do not need to maintain a constant lock with the satellites to calculate positions. This allows a C/A code receiver to be used in an unfavorable data collection environment, such as under trees.

Carrier phase receivers

Some of Trimble’s GPS mapping-grade products can use carrier phase capable receivers.

Depending on the specification of the GPS receiver you can log features with accuracies ranging from 1 centimeter to 1 meter. However, certain criteria need to be met in order to achieve these levels of accuracy. For example:

- Check that each feature that you want to log carrier phase data for is set to carrier phase accuracy. (Use the Data Dictionary Editor to check this.)

  When you start a new feature that is set to carrier phase accuracy, the software logs carrier phase data in the foreground so this feature can be processed using carrier phase accuracy. Each feature can benefit from a “span” of useful carrier phase data that might begin before the feature and end after it.

- Check that you have a clear view of the sky

- Check that the elevation mask is set to an appropriate value (carrier phase data is not logged from satellites below the elevation mask).

- Choose a time of the day when you can track a maximum number of satellites with the best possible geometry. You need a minimum of four satellites to calculate the positions. Use the QuickPlan™ utility in the GPS Pathfinder Office software to help you determine this.

  Carrier phase logging stops when fewer than four satellites are available. This is called *loss of lock*. Carrier phase logging only restarts when lock is regained. This means that if you lose lock, the data collected may not provide the precision required when postprocessing your data.

- Check that the distance between the base receiver and the rover receiver is less than 10 km.

- Check that the base and rover logging intervals are the same.

- Log carrier phase data for the minimum time for which you must maintain lock. You are effectively setting a precision warning level, below which you consider the recorded data to be insufficient.

  In GeoExplorer 3 and TerraSync™ this is 10 minutes.

In order to obtain the best carrier phase precision, you should collect enough carrier phase information for the Differential Correction utility in the GPS Pathfinder Office software to compute high accuracy positions. Generally, the longer the block of continuous carrier phase data, the greater the precision of the features collected within it.

For more information on carrier-based logging, refer to your GPS receiver manual.

Note – *Your data files will be larger if you record features using carrier phase rather than code phase.*

Number of channels

A minimum of four GPS satellites is required to compute accurate three-dimensional (3D) GPS positions.

A single-channel GPS receiver can only track signals from one satellite at a time. It must also use the same channel to track satellites and to obtain other important satellite messages. However, a multi-channel GPS receiver uses the multiple channels to track multiple satellites simultaneously.

Multi-channel GPS receivers work more efficiently than single-channel receivers. In a perfect data collection environment with a stationary C/A code receiver, no sky obstructions, and no multipath or other signal degradation, there is little noticeable difference. However, in the real world, where the receiver is probably moving and the signals from satellites can be interrupted, the receiver functions better with more channels. You need at least four channels to use carrier phase processing techniques for high accuracy GPS work. This is because a carrier phase receiver devotes one channel to each satellite that is tracked.

When a GPS receiver is used as a base station, it is important that the GPS receiver track every visible satellite. For this reason, current Trimble receivers designed to be used as base stations have twelve channels. When using recommended elevation masks, there are a few places that have more than nine satellites visible simultaneously and none that have more than twelve visible simultaneously.

Trimble receivers designed for use as rovers can track at least eight satellites. This is more than sufficient for roving applications. In roving applications, four or more satellites are required for the position computation.

Trimble's current mapping-grade receivers are available in models ranging from eight to twelve channels. These receivers track satellites continuously, and simultaneously track as many satellites as they have channels.

C/A or P-code receiver

GPS satellites transmit two codes on the same carrier. Trimble's mapping-grade GPS receivers, like most civilian GPS receivers, use the Coarse/Acquisition (C/A) code. The GPS satellites also transmit a

Precise code (P-code). Most military receivers use the P-code. A few civilian survey-grade receivers can use the P-code in addition to the C/A code.

The P-code is slightly more accurate but is generally restricted to military use. The military reserves the right to encrypt the P-code. When the P-code is encrypted, it is referred to as the Y-code. This encryption is also called *Anti-Spoofing* (AS). For more information, see Anti-Spoofing below.

Data Collectors

There are several different data collectors available for use with Trimble GPS receivers. They vary in terms of capabilities, power requirements, and data capacity. A variety of data collectors are available so that you can efficiently and easily collect the type of data important to your application. You should base your choice of data collector on whether or not you need detailed attribute information, how many positions you want to collect, and what your typical working environment is like.

Satellites

The U.S. Department of Defense (DoD) developed GPS primarily to satisfy a military need for navigation. In the early days of GPS, the U.S. DoD directed that GPS must include the capability to deny unauthorized users access to this utility. Selective Availability (S/A) and Anti-Spoofing (AS) are the results of that directive. On 1 May 2000, the White House announced a decision to discontinue the intentional degradation of the GPS signals to the public by discontinuing the use of S/A.

Anti-Spoofing

AS is the deliberate encryption of the P-code. When the P-code is encrypted, it is referred to as the Y-code. AS accuracy loss in dual frequencies is partly due to the inability to determine ionospheric

delays in real time. Also, since P-code measurements are less noisy and less susceptible to interference, the denial of the P-code creates noisier position solutions. Trimble's mapping receivers do not use P-code, therefore AS is not an issue for people using these receivers. However, some survey-grade receivers use P-code.

Satellite health

Satellites normally broadcast a health message in their signal, and sometimes the message can indicate an unhealthy satellite. GPS receivers will avoid using the satellite signal from an unhealthy satellite. Satellites are typically marked as unhealthy by the control segment for the following reasons:

- Initial on-orbit operations when the satellite is first launched. At that time, tests are conducted with the satellite—and the satellite’s orbit and clock behavior are not yet well modeled.
- Periodic maintenance such as orbit maneuvers and cesium clock maintenance.
- Repair of abnormal performance when the satellite has malfunctioned and must be fixed.

The U.S. DoD usually announces when a satellite is unhealthy. For information on how to obtain this data, see GPS Information Center, page 20. The health status of all satellites is included in the almanacs transmitted by each satellite. Almanac data for the satellites is updated daily by the U.S. DoD and is broadcast from each satellite approximately every 12.5 minutes.

If your GPS receiver collects an almanac while a satellite is unhealthy, that satellite is considered unhealthy by the GPS receiver as long as that almanac is used. The receiver will not track the unhealthy satellite or use it to calculate positions. This is true even if the satellite returns to health. The receiver must collect a new almanac before it will use that satellite signal again. These details are automatically monitored by your GPS receiver and rectified whenever necessary.

Although a GPS receiver typically will not use the signal from an unhealthy satellite, when you are using planning software you can override the health status for the purpose of satellite availability prediction. In this case, you can use the information from an unhealthy satellite or ignore the information from a healthy satellite. If you override an unhealthy message in the planning software, the satellite is included in visibility calculations as if it were healthy. If you override an unhealthy message in the base station software, the unhealthy message is ignored and the satellite data is recorded in the base files.

Antenna location

For best results, a GPS antenna must have a clear view of the sky from horizon to horizon. It can then receive satellites from any direction. The satellite signals do not penetrate metal surfaces, buildings, tree trunks, or similar objects. The signals weaken when they penetrate the leaves of tree canopy, glass, plastic, and other similar obstructions. A few drops of water on the antenna does not affect data collection. Powerful transmitters (especially in the microwave frequency range) can disturb the GPS signal. You should avoid collecting data in the focused path of a microwave transmission or near powerful radar using a frequency close to multiples of the L1 signal (1575 MHz).

The base station antenna must be placed in clear view of the sky. If a base station does not have a clear view of the sky, the rover may pick up satellites that cannot be seen by the base station. If the rover calculates positions from satellites that the base station did not track, these positions cannot be differentially corrected.

It is more difficult to maintain a clear view of the sky when collecting rover data. When recording tree location data, for example, consider using data collection techniques such as offsets to maintain a clear view of the sky. Also try to avoid standing directly next to a building as this is a common cause of multipath. Try to maintain a clear view to the sky as much as possible.

Planning Data Collection

When using GPS, plan your data collection to take advantage of optimal satellite conditions. Most Trimble GPS software includes an option for forecasting satellite availability. The software can predict when the satellites are available and when the best satellite geometry is present.

Date, Time, and Location

Three parameters are required for accurate prediction of satellite availability: the correct date, time, and location for your data collection session.

Date

If the date is entered incorrectly, the calculations will be incorrect by about 4 minutes per day. This is because each satellite rises about 4 minutes earlier every day.

Time

Enter the offset between your local time and Universal Time Coordinated (UTC) correctly. Use the following formula to calculate the correct UTC offset:

Local Time – UTC Time = Local Offset

Note – *Local time offsets from GMT are positive to the east of Greenwich and negative to the west.*

Table 5.1 shows some examples of UTC offsets (in standard time).

Table 5.1 UTC offsets

Location	Offset
London, England	0 hours
New York, USA	–5 hours
San Francisco, USA	–8 hours
Milan, Italy	+1 hour
Bangkok, Thailand	+7 hours
Sydney, Australia	+10 hours

Location

Enter the approximate location where you will be collecting data (not your current location). If the location is entered to within 10 miles (or about 10 minutes of latitude), prediction errors will be negligible. For specific information on entering these parameters, refer to your software user guide.

Using a Valid Almanac

An almanac or an ephemeris file contains orbital information for all of the GPS satellites. The satellites transmit the almanac and the GPS receivers automatically record it. You need to transfer an almanac from your GPS receiver to your PC so that the planning software can predict the location of the satellites. When you receive your software an almanac file is included, but you will probably need to collect a more recent one.

An almanac is valid for about three months from the date of collection. An almanac file can become incomplete or invalid sooner if a new satellite is launched, if an existing satellite is set unhealthy, or if a satellite is moved to a new orbit. You should avoid calculating visibility more than three months in advance, as the calculations may not be very accurate. If a new satellite is launched after the almanac

file was collected, you can still use the visibility calculations but they do not include the new satellite. It is a good policy to transfer a new almanac file to your PC on a regular basis. Weekly or bi-weekly almanac updates are usually sufficient.

Satellite launches and health status reports are available from the U.S. Coast Guard GPS Information Center (GPSIC). For more information, see page 20.

Satellite prediction graphs

Mission planning software, such as the QuickPlan utility in GPS Pathfinder Office, lets you create several types of satellite prediction graphs. You can plot information such as the number of satellites available, their elevations or azimuths over time, and the Position Dilution of Precision (PDOP).

Number of visible satellites

Four satellites must be visible to calculate a 3D position (latitude, longitude, and altitude). Three satellites must be visible for 2D positions (latitude, longitude, and time). When collecting 3D positions, it is ideal to have five or more satellites visible. When five or more satellites are available, the GPS receiver can use them all to compute a mathematically stronger solution. These extra satellites also serve as backups to ensure that 3D positions can still be collected if some of the satellites are obscured from the antenna.

DOP

Dilution of Precision (DOP) is an indication of the current satellite geometry. It is the result of a calculation that takes into account each satellite's location relative to the other satellites in the constellation. A low DOP indicates a higher probability of accuracy. A high DOP indicates a lower probability of accuracy. You can select the best data collection time based on reports and graphs showing times of lowest DOP.

Planning software such as the QuickPlan utility in the GPS Pathfinder Office software can predict the position, horizontal, vertical, and temporal (clock offset) dilutions of precision separately (PDOP, HDOP, VDOP, and TDOP respectively):

- Position (PDOP) refers to horizontal and vertical measurements (latitude, longitude, and altitude)
- Horizontal (HDOP) refers to horizontal measurements (latitude and longitude)
- Vertical (VDOP) refers to altitude
- Time (TDOP) refers to clock offset

These predictions do not take into account local obstructions unless you enter these obstructions into the software. Obstructions might block some lower-elevation satellites; if such satellites were included in the DOP computation, the computation would be incorrect.

A PDOP of four or below gives excellent positions. A PDOP between five and eight is acceptable. A PDOP of nine or more is poor. You can set a parameter known as the PDOP mask on your receiver to ignore constellations that have a PDOP higher than the limit you specify. The default PDOP mask in Trimble GPS mapping receivers is usually six.

With some data collection software, you can set a parameter known as the HDOP mask to ignore constellations that have a HDOP higher than the limit you specify. The HDOP mask can be used instead of the PDOP mask and is useful if you are more concerned with the horizontal accuracy of your data than with vertical accuracy. An HDOP of four or below gives excellent horizontal positions. An HDOP between five and eight is acceptable. An HDOP of nine or more is poor. The default HDOP mask in Trimble GPS mapping receivers is usually four.

Figure 5.1 and Figure 5.2 show the impact of relative satellite position on position accuracy.

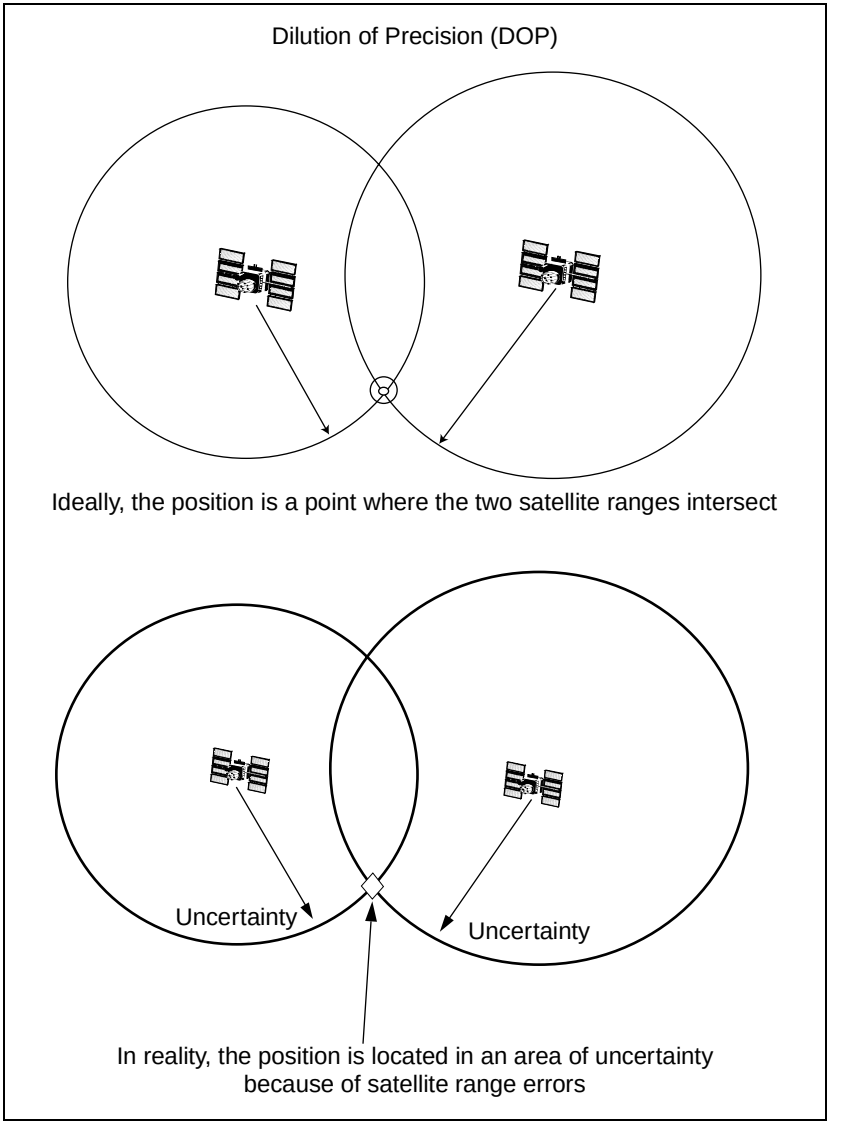


Figure 5.1 A low DOP

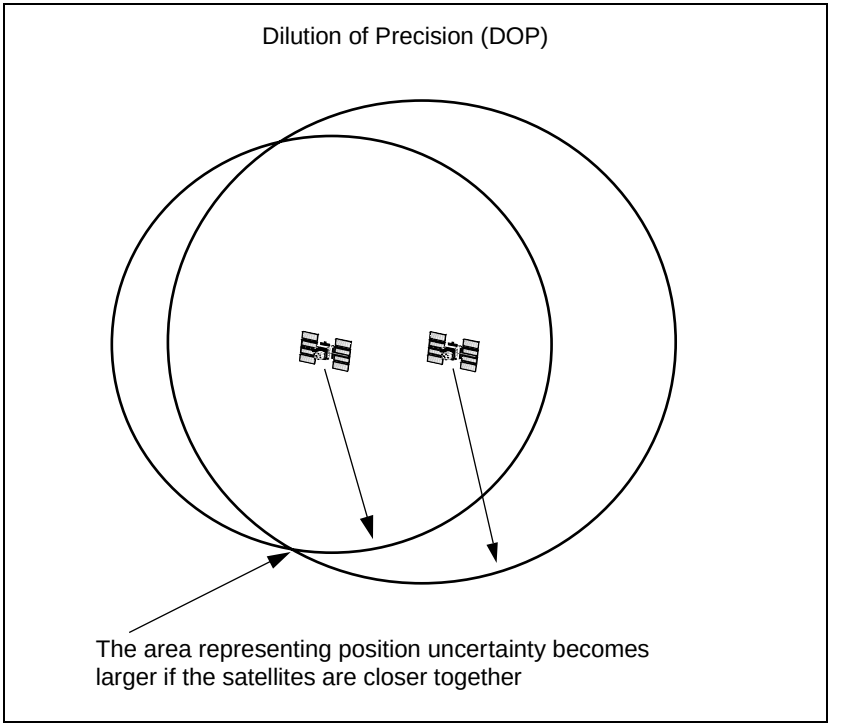


Figure 5.2 A high DOP

Sky plots

The planning software can produce a sky plot for viewing constellation geometry. Sky plots are commonly expressed as a circular graph. A sky plot is a representation of where in the sky you would look to view a particular satellite. Satellites that appear in the center of a sky plot are directly overhead. Satellites that are on the horizon appear at the edge of the sky plot.

Figure 5.3 shows some possible satellite geometries in a sky plot. The ideal constellation has four satellites: three evenly spaced around the horizon and one directly overhead (example 1). This arrangement yields the most accurate 3D positions because any horizontal error

from one direction is checked by the measurement from an opposing direction. The satellite overhead checks the vertical accuracy of the other three.

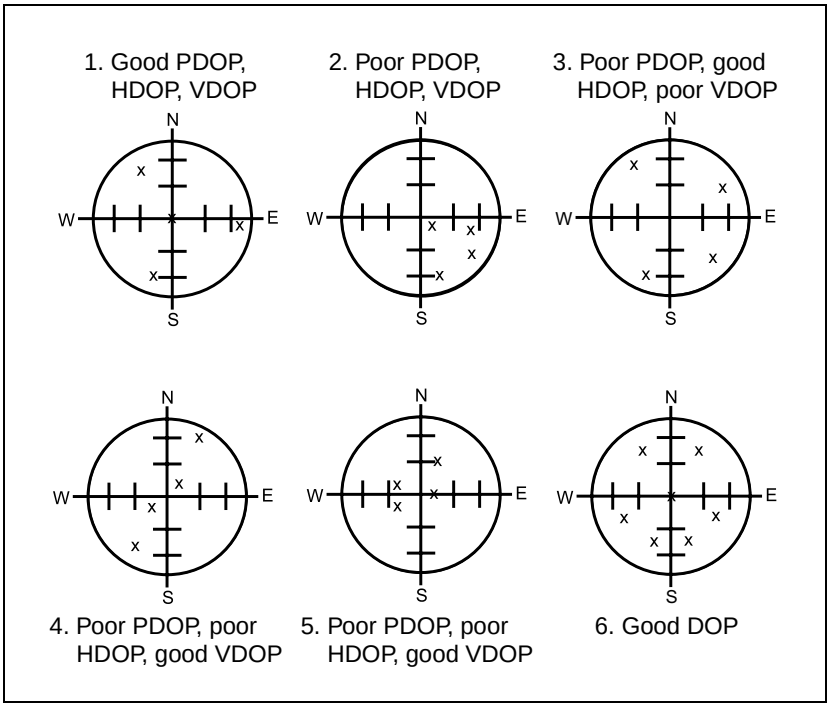


Figure 5.3 PDOP diagram

A poor geometry has all satellites in the same part of the sky (example 2) or all satellites positioned along one line across the sky (example 4). Figure 5.3 also shows other possible geometries.

When a particular geometry is poor for one kind of DOP, it can actually be good for a different kind of DOP. For example, if you need accurate latitude and longitude (horizontal) measurements but do not need accurate vertical measurements, you might be able to collect data when the geometry resembles example 3. Although the constellation has a high PDOP, the horizontal accuracy is good.

Note – *Although you need to be aware of the satellite geometry to obtain good positions, the GPS receiver automatically selects the satellites that provide the lowest PDOP. You can plan the best time to collect your data, but once in the field you do not have to manually select the satellites to be used.*

Data Collection Parameters

Several factors affect the quality of collected data. A number of data collector and GPS receiver settings affect the accuracy of the data you collect. The following sections discuss these settings.

PDOP Mask

The PDOP is perhaps the most important factor in data accuracy. You can set a PDOP limit on the receiver so that positions are not recorded above this limit. The limit is called a *PDOP mask*. You should set it in the data collector before you start to collect data. For most applications and mapping receivers, Trimble recommends a PDOP mask of six. Some receivers may require a PDOP mask less than 4 to achieve submeter accuracies. When a PDOP mask is set, no positions with a PDOP value higher than the setting are recorded. For a more detailed explanation of PDOP, see DOP, page 53.

HDOP Mask

You can set an HDOP limit on the receiver so that positions are not recorded above this limit. This limit is called an *HDOP mask*. You should set it in the data collector before you start to collect data. For most applications and mapping receivers, Trimble recommends an HDOP mask of four. When an HDOP mask is set, no positions with an HDOP value higher than the setting are recorded. For more information, see DOP, page 53.

SNR Mask

The signal-to-noise ratio (SNR) of a satellite (also known as *signal strength* or the *signal level*), measures the information content of a signal relative to the signal's noise. As this proportion decreases, information gets lost in the noise. The typical signal strength of a satellite at 30° elevation is from twelve to twenty. A value above twenty is very good. The quality of a position is lowered if the signal strength of any satellite in the constellation is below six. Low signal strengths give positions that tend to be noisy and erratic.

When the signal strength of a satellite is particularly weak, the positions calculated from those measurements tend to be inaccurate. Weak signals are caused by the following:

- The signal reaches the antenna after penetrating an obstacle such as tree canopy.
- The signal reflects off a surface and does not travel directly to the antenna (multipath).
- The signal from a satellite low on the horizon is weaker than the signal from a satellite more directly overhead, as it must travel further through the ionosphere and atmosphere.
- The signal from satellites in certain parts of the sky can be tracked more effectively than the signal from satellites in other parts of the sky because of the antenna radiation pattern.

To avoid recording weak signals you can set a signal strength level limit on some receivers. This limit is called an *SNR mask*. Trimble recommends a signal strength mask of four. Setting the signal strength mask properly ensures that signals too weak to generate a reliable position are not used.

Position Fix Mode

With some receivers, you can set the receiver to collect positions in one of four position fix modes. The position fix mode affects the operation of your GPS receiver, so only modify it if you fully

understand the consequences. Table 5.2 provides information on how many satellites each mode uses to calculate positions and when to use each mode.

Table 5.2 Position fix modes

In this mode …	the GPS receiver uses …	Use this mode …
Overdetermined 3D (Asset Surveyor) Minimum Satellites (GeoExplorer 3)	as many satellites as it can to compute positions. The GPS positions are logged only if there are at least five satellites available, so that all logged positions are forced to be overdetermined. This yields the most accurate GPS positions.	to achieve a high level of accuracy for logged positions. This is the recommended mode when logging carrier phase data.
Manual 3D (Asset Surveyor) Minimum Satellites (GeoExplorer 3)	as many satellites as it is can (but at least four) to compute positions. This usually yields the most accurate GPS positions and is the most flexible mode in which the receiver can be operated. If your GPS receiver can compute overdetermined GPS positions, it does so in Manual 3D mode when there are more than four satellites available.	to achieve the highest level of accuracy for logged positions.

Table 5.2 Position fix modes (Continued)

In this mode …	the GPS receiver uses …	Use this mode …
Manual 2D(Asset Surveyor) Minimum Satellites (GeoExplorer 3)	the best three satellites available, even if there are four or more that could be used for computing positions. You must supply an accurate altitude above the WGS-84 ellipsoid before using Manual 2D mode.	if you are absolutely sure of your altitude above the WGS-84 ellipsoid. It avoids the inaccuracies experienced in Auto 2D/3D mode when the GPS receiver switches from using a 3D altitude obtained from GPS to using the 2D altitude that you supply. Unless you are operating exclusively at the same altitude, you ***must*** manually enter a new altitude whenever you move up or down. **WARNING** – If you use Manual 2D mode and specify an inaccurate altitude, this has a ***significant*** impact on the position computed by your GPS receiver. As a rule, every meter of error in the altitude you supply will cause ***at least*** 3 meters of error in the position computed by your GPS receiver.

Table 5.2 Position fix modes (Continued)

In this mode …	the GPS receiver uses …	Use this mode …
Auto 2D/3DAuto 2D/3D(Asset Surveyor) (not available on a GeoExplorer 3)	four satellites to compute GPS positions when possible. However, when the number of visible satellites falls to three, it continues to compute positions, using the last known altitude. A position computed when there are only three usable satellites is called a two-dimensional position, and the accuracy of two dimensional positions is crucially affected by the accuracy of the altitude. In Auto 2D/3D mode, when the GPS receiver switches to 2D mode (that is, when there are only three usable satellites), it uses the altitude of the last available 3D position, or any altitude that you have entered manually since the last 3D position was computed.	if you are operating in conditions where satellite visibility is poor and you can determine your altitude above the WGS-84 ellipsoid very accurately at all times. However, be aware that there is a high probability that your data is not always very accurate due to altitude input errors. **WARNING** – If you use Auto 2D/3D mode and specify an inaccurate altitude, this has a ***significant*** impact on the position computed by your GPS receiver. As a rule, every meter of error in the altitude you supply will cause ***at least*** 3 meters of error in the position computed by your GPS receiver.

Avoiding 2D Positions

Trimble recommends that you do not collect 2D positions because of the problem encountered with the altitude measurement. When you set the receiver to calculate 2D positions, you are replacing one satellite measurement (altitude) with a fixed measurement. If this altitude is incorrect, the latitude and longitude will also be incorrect. For example, if the fixed altitude is incorrect by 10 meters, the calculated horizontal measurements can be incorrect by 50 meters or more. For more information, see page 44. Differential correction cannot remove this horizontal error.

You may accurately know the altitude with respect to mean sea level (MSL), but GPS determines altitude by height above the WGS-84 ellipsoid (HAE). The difference between the MSL and HAE can be great. HAE to MSL conversion algorithms can have errors of greater than 5 meters. HAE on the most accurate commercially available

ellipsoid maps is only ± 1 meter. For the best results, contact a surveyor to get the ellipsoid height and the exact separation between the ellipsoid and the geoid for your area of operation.

Elevation Mask

The elevation mask is the elevation angle above the horizon below which satellites are not used. For land-based applications where there are local obstructions (foliage, buildings, etc.), system performance is smoother with an elevation mask of 15° to 20°. The default elevation mask in Trimble GPS receivers is 15°.

When a satellite is low on the horizon, two problems can occur. First, the satellite signals must travel a greater distance through the atmosphere, resulting in lower signal strength and delayed reception by the GPS receiver (propagation delays). Since the distance to the satellite is calculated by the travel time, a slight delay in travel time can result in a large error in calculated distance.

Second, the signals from low elevation satellites tend to reflect off nearby surfaces, so that both the original signal and the reflected signal are received. This multipath effect is a major contributor to error in GPS and is not corrected by differential correction.

You can lessen these effects by using the system default elevation masks (15° for the rover and 10° for the base). Remember that raising your elevation mask limits the number of satellites your receiver tracks and can result in higher PDOP/HDOPs. This is particularly true if the mask is set to values from 20° to 25°.

Always make sure that the rover elevation mask exceeds the base elevation mask by at least 1° for every 60 miles (100 kilometers) between the base and rover. Figure 5.4 shows how coordinating the elevation masks of the rover and the base station can increase the chance of the base station tracking the same satellites as the rover.

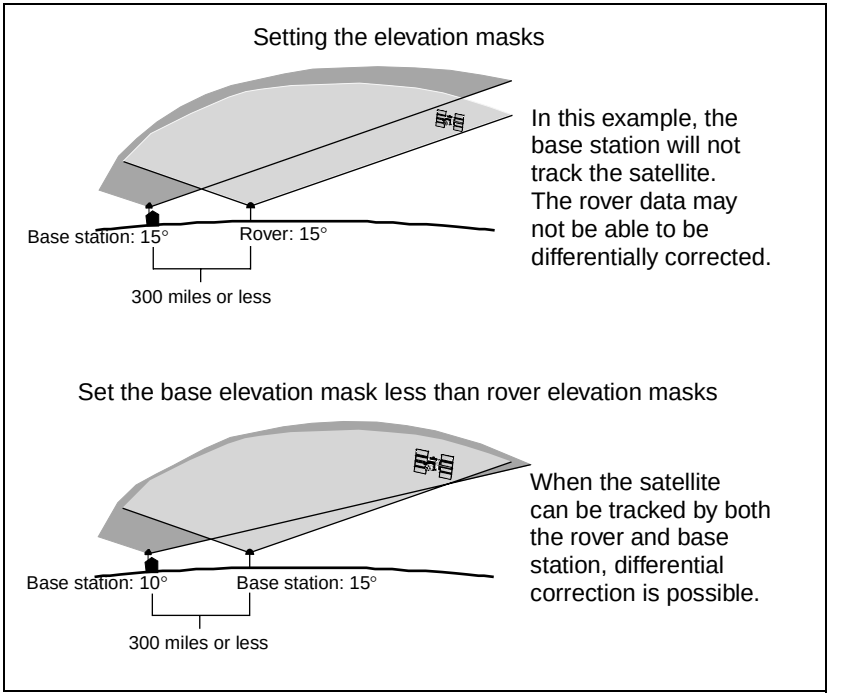


Figure 5.4 Coordinating the elevation mask

Velocity Filtering

All GPS receivers are subject to error caused by multipath. Because the GeoExplorer 3 and GPS Pathfinder Pocket receivers do not use the EVEREST™ multipath rejection technology, and because their antennas are smaller than those of other mapping receivers, they are more susceptible to multipath than the higher-grade mapping receivers, such as the GPS Pathfinder Pro XR receiver.

If you are working in an area of high multipath, such as under and around tree canopy, it may be appropriate to use *velocity filtering*. Velocity filtering is a technique that reduces the effects of hostile GPS environments on position accuracy.

Velocity filtering uses the velocity information from the receiver to smooth the GPS positions. In data sets with multipath error, this tends to reduce the multipath effect and remove spikes and outliers from the data.

Warning – Velocity filtering is not appropriate in all environments, and should only be applied in situations where hostile GPS conditions are expected to degrade position accuracy. When used on predominantly good data, the filtering may decrease accuracy of the data.

If you use or have access to base station data for differential correction, Trimble recommends that you apply velocity filtering during differential correction. This gives you the flexibility to reprocess your data with and without velocity filtering, and then choose the best result.

Data Collection Procedures

Several factors affect the quality of collected data. Some field procedures result in more data, while others ensure that the collected data is highly accurate. The following sections discuss these procedures.

Measurement Type

Some C/A code receivers can perform limited carrier phase processing techniques. The most sophisticated carrier phase processing GPS receivers can compute and display centimeter-level positions in real time. However, when limited carrier phase capabilities are added to a C/A code receiver they can record data for a single point in several minutes.

Carrier phase processing techniques are much more accurate than C/A code techniques. However, they have more elaborate postprocessing requirements and stricter data collection requirements. By recording carrier phase data for approximately 10 or more minutes at a single

location, the coordinates can be determined to within a few centimeters SEP[1]. Although more time consuming than C/A code techniques, both the horizontal and vertical components can be determined to within a few centimeters.

File Type

In the field, one of the first actions performed is to open a file into which your data will be stored. Some Trimble mapping receivers can record two types of data files: rover and base. Data is also stored as waypoints and in an almanac file. Each of these file types is explained in the following sections.

These files are stored in a Trimble proprietary file format known as Standard Storage Format (SSF). After being transferred to a PC these files usually have the extension .ssf. In postprocessing, new files are created. Although these files are named with a variety of other extensions (such as .cor, .adj, .ssx) they are also stored in the SSF format. Files created by the export modules of the postprocessing software are an exception. These files are named with extensions unique to your GIS, CAD ASCII, or database format.

Rover files

Most files recorded with Trimble mapping systems are rover files. Rover data is usually recorded at a wide variety of locations in the field. The primary components of rover files are positions, feature and attribute information, and user's notes. In addition, they may also contain a few other satellite related details such as satellite orbital data, DOP, and receiver settings.

Base files

A stationary GPS receiver at a known location collects base files, which are used to compute differential correction values in postprocessing. These corrections are used to remove systematic

1. SEP means that 50% of the positions are within a sphere with a radius equal to the specified value.

errors from data in the rover files. Base files collect the same type of position data from the satellite signals as rover files. In addition, they collect measurement and other data from each satellite tracked.

One base file can correct any number of rover files as long as the base and rover files contain data collected during the same time period. In order to use a file as a base for differential correction, you must record the data into a base file. A base file that will be used for differential correction must meet the following criteria:

- The base file must be recording during the same time period that the rover file(s) are being collected.
- The base file must collect data from all satellites that the rover(s) used for position computation.

  To ensure that the satellites used by the rover are a subset of the satellites used by the base, the base station must have a clear view of the sky and a lower elevation mask than the rover. The rover should work within 500 kilometers (300 miles) of a base to avoid satellite tracking mismatches between base and rovers.
- The base file logging intervals must be set correctly.

  The satellite measurements in the base file must be continuous and at an interval no greater than one set of measurements every 15 seconds.

Most mapping-grade receivers can be used as a base station. In addition, you can use data files from a Series 4000 receiver as base files. However, the most efficient and convenient method for the collection of base data is to use a GPS Pathfinder Community Base Station or Trimble Reference Station (TRS™). A Community Base Station and Trimble Reference Station automatically records base data in hourly files and can be set up permanently at a site.

Waypoints

Most Trimble GPS data collectors record waypoints. A *waypoint* is a coordinate pair—latitude and longitude or northing and easting—with an assigned name and number. A waypoint usually represents some

geographical point of interest that you would like to navigate to or from. The number of waypoints that can be stored depends on your data collector.

The data collector does not have to be recording data to a file to store a waypoint, but it must be calculating positions. New information can overwrite existing waypoints. Some data collectors allow you to transfer waypoints to your processing software and transfer waypoints to your data collector. However, waypoints are best used for navigation. If you want to transfer your collected data to a GIS, or if you intend to perform differential correction, the data should be collected as rover files.

Almanac file

An almanac file is automatically created from data transmitted by GPS satellites. A complete almanac message takes 12.5 minutes for the satellite to broadcast. This file contains orbit and clock information on all satellites, which the receiver uses to facilitate rapid satellite acquisition and to calculate satellites' azimuths and elevations. The almanac file can be transferred to the PC and is used for planning data collection times.

If a receiver is switched on and gets a position fix on a regular basis, it automatically updates the almanac as needed. You can also force some receivers to collect a new almanac. For instructions, refer to your data collector manual.

Logging Intervals

The logging intervals you select can have an impact on differential correction accuracy. For collecting base data, short intervals yield better differential correction results than long intervals. For rover data, collecting data at the point location for a longer time, then averaging positions after differential correction, yields better results than collecting data at the point location for a shorter time. Specific details are provided below.

Base

The satellite measurement data recorded in a base file is the primary information that affects differential correction accuracy. This measurement information can be recorded in two forms: as satellite pseudoranges, or as carrier phase information for each satellite.

The satellite pseudorange measurement logging interval must be set between 1 and 15 seconds. However, there is little benefit to logging base data more frequently than 3 seconds. The more often measurement data is recorded, the larger the size of the base file. The recommended interval for recording satellite measurement data in a base file is 5 seconds.

Carrier phase information can be used for a more accurate form of differential processing than pseudorange information. Some Trimble data collection systems refer to carrier phase information as synchronized measurements. When carrier phase measurements are recorded in a base file, the differential processing software will process them differently compared to pseudorange measurements. For information about the differences in processing and accuracy, see Submeter Accuracy, page 70.

The satellite carrier phase logging interval must be set between 1 and 15 seconds. The more often carrier phase data is recorded, the larger the size of the base file. The recommended interval for recording satellite carrier phase data in a base file is 5 seconds.

Rover

The Trimble mapping product range encompasses two very different receiver architectures: C/A code and carrier phase. The techniques used to achieve maximum accuracy differ depending on the type of receiver used to collect the rover data.

Differentially corrected C/A code positions recorded by a roving GPS receiver are more accurate if they are recorded at the same time as measurement data is recorded in the base file. For example, if the base station records measurements and rover receivers record positions at the same interval, say 5 seconds, the positions will differentially

correct with the highest accuracy possible. If the rover records positions at a 1-second interval and the base records measurements at a 5-second interval, then only 20% of the data (one position in five) is synchronous. As a result, 20% of the data has the highest possible accuracy and the remaining 80% is slightly less accurate because of imperfections in the interpolation of satellite range errors. Trimble recommends that the rover position interval be a direct multiple of the measurement interval at the base station.

Alternatively, a roving GPS receiver can record carrier phase information in a manner similar to a base station. When both the base and the rover record carrier phase information, the data can be processed to obtain results in the centimeter to decimeter range. Carrier phase processing is only possible if the base and rover record synchronous data. To obtain centimeter results with carrier phase processing techniques requires high quality antennas. Synchronous carrier phase information in both base and rover files is required as well.

Submeter Accuracy

Some Trimble GPS receivers can compute submeter positions on a second-by-second basis from the GPS C/A code. Accuracy can be further improved by collecting more position data over a longer period, then averaging these positions after differential correction. Submeter C/A code receivers are used to collect accurate position data quickly in a high production environment.

To obtain submeter positions on a second-by-second basis, the measurement recording interval at the base station and the position recording interval at the roving receiver must be identical. The rover interval must be a direct multiple of the base interval. For more information, see Logging Intervals, page 68.

It is also possible to record at the base and rover with non-synchronized intervals. In this case, there is usually a small degree of synchronization depending upon the intervals selected. For instance, if the base station is recording at the recommended interval

of 5 seconds, and the rover is recording positions at a rate of 1 per second, then approximately 20% of the positions (one position in five) will be synchronized, and thus submeter. The remaining 80% of the position data will have an accuracy in the 1–5 meter range.

1 to 5 Meter Accuracy

Some Trimble GPS receivers can compute positions from the GPS C/A code with an accuracy of 1–5 meters.

Note – *When data is collected at a point feature using feature and attribute capabilities, the software automatically performs averaging. It outputs or displays a single optimal position value. When data is collected as individual position records, you must initiate the averaging process. The processing software includes modules that can be used to average the positions in data files.*

Distance between Base and Rover

The distance between the base and rover receivers has an impact on accuracy. Accuracy degrades as the distance between base and rover increases. The magnitude of the degradation varies based on the receiver type, but is generally in the range of 1–5 ppm (parts per million). For example, 1 ppm = 1 mm of degradation for every kilometer between the base and rover receivers.

Processing Data

If good field techniques are observed, the data processing procedure is fast and easy. Detailed instructions for processing the data are in your software user guide. The following sections deal with aspects of data processing that can affect position accuracy.

Setting the Reference Position

When recording a base file, the base receiver is placed at a known location or reference position. If the reference position is not recorded in the base file, it must be entered later during postprocessing. Make sure that you accurately enter the reference position. The most common error is to enter the reference position with respect to the incorrect datum.

You should check and, if necessary, change the reference position once your base data has been transferred to the PC. If the reference position is wrong, differential correction results will be incorrect by the same direction and magnitude. You must enter the correct altitude, latitude, and longitude in the correct datum, coordinate system, altitude reference system, and units for the base reference position.

Using Differential Correction

When using differential correction, the base station and the rover must record data during the same time period, and the rover must use the same satellite signals that are being recorded by the base station.

If you are using the TerraSync software as your data collection software, you can use the SuperCorrect functionality. This functionality is found in both TerraSync and the Differential Correction utility in the GPS Pathfinder Office software. SuperCorrect allows you to postprocess rover positions based on different PDOP, HDOP, SNR, and elevation masks to those used in the field. It also allows positions recorded when the rover and base did not share identical satellite constellations to be postprocessed.

Sometimes differential correction may not adequately correct your rover data. If this occurs, there are options built into the postprocessing software that allow you to create a log file of the differential correction. Differential log files report whether a specific position record was corrected, the magnitude of the correction for every satellite, and the reason for any failures. For detailed instructions, refer to your software user guide.

CHAPTER

6

Datums and Coordinate Systems

In this chapter:

- Introduction
- Datums
- Coordinate systems

Introduction

This chapter explains datums and coordinate systems. You must have some knowledge of coordinates and datums before starting your GPS fieldwork. When comparing geographic data obtained from different sources, you must reference the data to the same datum and coordinate system, since the various datums and coordinate systems provide different coordinate values for each geographic location.

In addition, you can introduce significant errors if you mix different datums or coordinate systems. For example, inaccuracies are introduced into your GPS-derived data if you have reference coordinates for your base station in one datum (such as NAD-27), but you accidentally enter those values as your base reference position with respect to a different datum (such as WGS-84). This is critical for both accurate real-time differential operation and postprocessed differential correction of data.

NAD stands for North American Datum. WGS is World Geodetic System, and 27, 83, or 84 refers to the years 1927, 1983, or 1984, respectively.

Datums

The earth's size and shape can be physically described in two ways. One way is to view the actual terrain of the earth, complete with water surfaces, flat plains, rolling hills, and mountains. The second way is to measure gravity. The two concepts are combined when we say that Pikes Peak is 14,110 feet above mean sea level.

A *geoid* is a representation of the surface of the earth over which the earth's gravity is constant. If the value of the earth's gravity on the geoid is approximately the value of gravity on the average ocean level, then the geoid represents mean sea level. The vertical location of a feature on the surface of the earth has been identified by measuring gravity and comparing to mean sea level gravity.

Unfortunately, because a geoid is an extremely complex surface, mathematical models can only provide a best fit to the surface, not an exact representation. However, over limited areas and depending on the accuracy required, geodesists have found that a simple ellipsoidal (or spheroidal) model of the earth's gravity fits quite well. An *ellipsoid* can be described as an ellipse rotated about its short axis. See Figure 6.1.

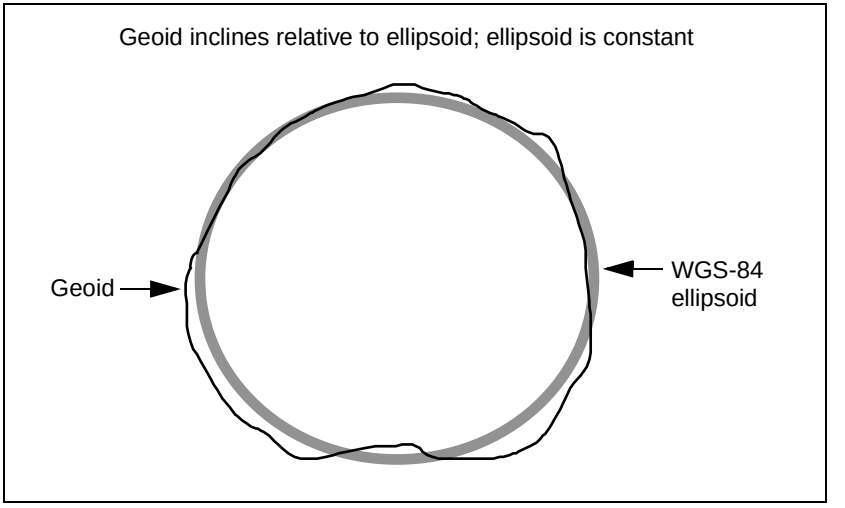


Figure 6.1 Ellipsoidal model with geoid

The size and shape of the best fitted ellipsoid, as well as its location relative to the center of mass of the earth, differs from place to place. As a result, many ellipsoids have been created to fit the geoid in different parts of the world. See Figure 6.2.

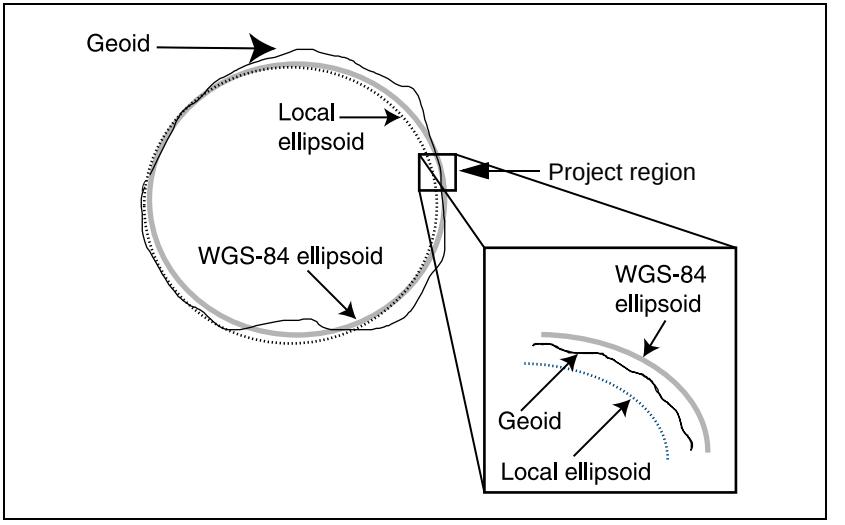


Figure 6.2 Local ellipsoid provides best fit for project region

If the earth was completely liquid, then the natural shape of the spinning Earth would be an ellipsoid, and gravity over the surface of the ellipsoid would be equal. This represents the balance between the gravitational force of the liquid Earth's mass and the centrifugal force of its rotation. An ellipsoid is a good fit to the earth's geoid in a global sense as well as in a local sense.

The ellipsoid chosen for the Global Positioning System is the GRS-80 ellipsoid. The datum incorporating this ellipsoid and used by GPS is called the World Geodetic System 1984 (WGS-84). The semi-major axis of the GRS-80 ellipsoid is 6,378,137.0 meters and the semi-minor axis is 6,356,752.3 meters. That means that the distance from the center of the earth to the equator is only 21 kilometers longer than the distance from the center of the earth to the North (or South) Pole.

Coordinate Systems

A *datum* represents a reference model of the earth, but does not specify how a particular place on the earth is identified. Once you select a datum, you must decide how to represent a point on the earth with respect to the datum. Geographic coordinates (coordinates expressed as latitude and longitude) are commonly used.

Cartographers need to represent the spheroidal Earth on a flat piece of paper without minimal distortion. The formulas that take longitude and latitude and convert to easting and northing (or X and Y) are called *map projections*. The ideal map would correctly represent areas, distances, directions, and shapes, but this cannot be done. One or more of these parameters are always distorted. You have to choose the map projection that best suits your purposes.

Many local coordinate systems, specifying both datum and map projection, have been defined. Examples are the U.S. State Plane system, the Australian Map Grid, the New Zealand Map Grid, and the Ordinance Survey of Great Britain. U.S. State Plane coordinates use either the older NAD-27 datum or the newer NAD-83 datum. Projections used include the Lambert Conformal, Transverse Mercator and, in the case of the panhandle of Alaska, Oblique Mercator.

Since existing data in a GIS can use positions expressed in a local coordinate system, it is important to understand the difference between the WGS-84 system in which GPS computes positions and the local datum and coordinate system in which the GPS position must be expressed. The mapping software lets you convert from WGS-84 to many local coordinate systems, including converting from height above the WGS-84 ellipsoid to height above mean sea level (sometimes referred to as height above geoid).

Postprocessing software can display values from custom (user-defined) local coordinate systems and output the values in ASCII or GIS conversion file formats.

Glossary

almanac

A file that contains orbit information on all satellites, clock corrections, and atmospheric delay parameters. It is transmitted by a GPS satellite to a GPS receiver, where it facilitates rapid SV acquisition. It can be transferred from the receiver to the GPS processing software on your PC where it is then used to predict the best time to collect GPS data. The orbit information is a subset of the ephemeris data, with reduced precision. *See also* **ephemeris**.

altitude (alt)

Vertical distance above the ellipsoid or geoid. It is always stored as height above ellipsoid in the GPS receiver but can be displayed as height above ellipsoid (HAE) or height above mean sea level (MSL).

Anti-Spoofing (AS)

P-code transmitted by satellites that has been encrypted by the U.S. Department of Defense. This encrypted P-code is known as Y-code. It is meant to be useful only to authorized (primarily military) users. Anti-Spoofing is used with Selective Availability to deny the full precision of GPS to civilian users.

attribute

Characteristics of features in a Geographic Information System (GIS) or Coordinate Geometry (COGO) package. Every identifiable feature has attributes. One common attribute of all survey features is geographic position. Other attributes depend on the type of feature. For example, a road has a name or designation number, surface type, width, number of lanes, and so on. Each attribute has a range of possible values, called a domain.

attribute value A particular value for a feature, chosen from the domain of an attribute. For example: surface type is an attribute; bitumen, gravel, and concrete are domains; and gravel is an attribute value.

availability The number of hours per day that a particular location has sufficient satellites (above the specified elevation angle and less than the specified PDOP value) to make a GPS position fix.

azimuth (azm) A horizontal angle reckoned clockwise from the meridian (north) to the object.

base station *Also called a reference station.* An antenna and receiver set up at a known location specifically to collect data for differentially correcting rover files. The base station calculates the error for each satellite and, through differential correction, improves the accuracy of GPS positions collected at unknown locations by a roving GPS receiver. You can use a Trimble GPS Community Base Station, a Trimble Reference Station (TRS), or a Trimble GPS receiver in Base Station mode.

baseline The position of a point relative to another point. In GPS surveying, this is the position of one receiver relative to another. When the data from these two receivers is collected and computed using carrier-phase processing, the result is a baseline comprising a three-dimensional vector between the two stations.

carrier A radio wave having at least one characteristic (such as frequency, amplitude, phase) that can be varied from a known reference value by modulation.

carrier frequency The frequency of the unmodulated fundamental output of a radio transmitter. The GPS L1 carrier frequency is 1575.42 MHz.

carrier phase The difference between the carrier signal generated by the internal oscillator of a receiver and the carrier signal coming in from the satellite.

channel (of a GPS receiver) The circuitry necessary to receive the signal for a single GPS satellite.

Circular Error Probable (CEP) A statistical measure of horizontal precision. The CEP value is defined as a circle of a specific radius that encloses 50% of the data points. Thus, half the data points are within a 2D CEP circle and half are outside the circle.

clock offset / clock error The constant difference in the time reading between two clocks. In GPS, this usually refers to offset between SV clocks and the clock in a receiver.

Coarse / Acquisition (C/A) code The code modulated onto the GPS L1 signal. This code provides a sequence of 1023 pseudorandom binary biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. It has a a code repetition period of 1 millisecond. This code was selected to provide good acquisition properties. It is also known as the civilian code.

constellation A specific set of satellites used for calculating positions: three satellites for 2D fixes, and four satellites for 3D fixes. Alternatively, all the satellites visible to a GPS receiver at one time. The optimum constellation is the constellation with the lowest PDOP.

control point / control station A monumented point to which coordinates have been, or are being, assigned by the use of surveying observations.

control segment A worldwide network of GPS monitor and control stations that ensure the accuracy of satellite positions and their clocks.

coordinate system Any 3D reference frame that locates objects in space.

data dictionary Information that describes features that will be located in the field. This description includes feature names, data type classification (point, line, or area), attribute names, attribute types, and attribute values. After being created on a PC, a data dictionary is transferred to a data collector for use in the field.

data collector *Also called a datalogger or data controller.* A handheld computer running data collection software such as Asset Surveyor or TerraSync.

datum A datum or geodetic datum is a geodetic coordinate system that is used for surveying and mapping purposes.

Before satellites were used for positioning on a global scale, different geodetic datums were developed for different regions. Each of these datums is a mathematical model based on the ellipsoid that most resembles the shape of the earth in a particular region. Each model is designed to fit part or all of the geoid. As a result, there are many distinct datums, each of which best fits some part of the earth's surface.

A geodetic datum is defined by the relationship between an ellipsoid shape and the center of the earth. It takes into account the size and shape of the ellipsoid, and the location of the center of the ellipsoid with respect to the center of the earth (a point on the topographic surface established as the origin of the datum).

Various datums have been established that best suit particular regions. The datum chosen for use in a particular region is referred to as the *local datum*. For example, maps in Europe are often based on the European datum of 1950 (ED-50). Maps in the United States are often based on the North American Datum of 1927 or 1983 (NAD-27, NAD-83). All GPS coordinates are based on the WGS-84 datum surface.

datum

The system supports several datum transformation methods: Seven Parameter, Three Parameter (also referred to as Molodenski), Datum Grid, and Multiple Regression. Typically, datum transformations convert data collected in the WGS-84 datum by GPS methods onto datums used for surveying and mapping purposes in individual regions and countries.

differential correction (Differential GPS, DGPS)

The process of correcting GPS positions at an unknown location with data collected simultaneously at a known location, that is, at a base station. Differential correction usually applies to receivers that use C/A code positioning techniques. The process of differentially correcting one receiver's location relative to another's can be done during postprocessing or in real time if radios are used.

In postprocessed DGPS, the base station logs the measurements in a computer file so rover users can differentially correct their data on return to the base station. In real-time DGPS, the base station calculates and broadcasts the error for each satellite as each measurement is received, permitting rover users to immediately see differentially corrected data.

digitizing

Collecting data in a digital form.

Dilution of Precision (DOP)

An indicator of the accuracy of a GPS position, which takes account of each satellite's location relative to the other satellites in the constellation and their geometry. A low DOP value indicates a higher probability of accuracy. *See also* **GDOP**; **HDOP**; **PDOP**; **RDOP**; **TDOP**; **VDOP**.

distance

The (changing) amount of separation between any two points. For example, as someone moves toward a point, the distance changes.

domain

In a GIS, the possible values of an attribute. Domains are usually a set of numbers, characters, or strings. For example, the domain of the attribute surface type can be bitumen, gravel, and concrete.

earth-centered, earth-fixed (ECEF) Cartesian coordinates

This is the 3D coordinate system used for satellite positioning. The origin of this system is the center of the mass of the earth. The X direction is the Greenwich meridian (0° longitude), the Y direction is 90° east longitude, and the Z direction is the northerly rotational axis of the earth. The current GPS version of this system is called WGS-84, while prior to 1978 the version used was WGS-72.

easting

The grid coordinate of a point eastward (positive) or westward (negative) from a reference meridian. Left to right on a grid (*x*-axis).

elevation (elev, elv)

Vertical distance above (or below) the geoid or mean sea level.

elevation angle

The angle of the satellite above the horizon, measured 0 to 90º.

elevation mask

The lowest elevation, in degrees, at which a receiver can track a satellite. Measured from the horizon, 0º to 90º. Normally set to 15º to avoid interference problems caused by buildings, trees, and multipath errors.

ellipsoid

A mathematical model of the earth formed by rotating an ellipse around its minor axis. For ellipsoids that model the earth, the minor axis is the polar axis, and the major axis is the equatorial axis. An ellipsoid is completely defined by specifying the lengths of both axes, or by specifying the length of the major axis and the flattening.

Two quantities define an ellipsoid. These are usually given as the length of the semimajor axis, a, and, the flattening, $f = (a - b)/a$ where b is the length of the semiminor axis.

ellipsoid distance The length of the normal section between two points. Not the same as the geodesic distance.

ellipsoid height The distance, measured along the normal, between a point and the surface of the ellipsoid. Not the same as elevation above a physical, vertical datum. GPS receivers output position-fix height in the WGS-84 coordinate system.

ephemeris A list of predicted (accurate) positions or locations of satellites as a function of time. A set of numerical parameters that can be used to determine a satellite's position. Available as broadcast ephemeris or as postprocessed precise ephemeris.

feature A physical object or location of an event. A feature can be a point (a tree or a traffic accident), a line (a road or a river), or an area (a forest or a parking lot).

flattening A measure of the flattening of an ellipse. A circle has a flattening of 0. Flattening of the WGS-84 ellipsoid is approximately 1/298.257223563 = .00335281066474.

geodetic datum *See* **datum**.

geographic (geodetic) coordinates Latitude, longitude, and ellipsoid height.

Geographic Information System (GIS) A computerized system used to input, manage, manipulate, analyze, and display geographic data in digital form.

geoid

The surface of gravitational equipotential that closely approximates mean sea level. It is not a uniform mathematical shape but an irregular figure with an overall shape similar to an ellipsoid. Typically the elevations of points are measured with reference to the geoid. However, points fixed by GPS methods have heights established in the WGS-84 datum (a mathematical figure).

The relationship between the WGS-84 datum and the geoid must be determined by observation since there is no single mathematical definition that can describe the relationship. This requires observing the elevation above the geoid (using terrestrial survey methods such as spirit leveling), and the height above the WGS-84 ellipsoid, at the same point for comparison purposes. By gathering a large number of observations of the separation between the geoid and the WGS-84 datum (geoidal separation), grid files of the separation values can be established allowing the interpolation of the geoidal separation at intermediate positions. Files containing these grids of geoidal separations are referred to as geoid models. Given a WGS-84 position that falls within the extents of a geoid model, the model can return the interpolated geoidal separation at this position.

geoid height

Also known as geoid separation or geoidal undulation. The distance of the geoid (MSL) above or below the reference ellipsoid.

Geometric Dilution of Precision (GDOP)

An indicator of the accuracy of a GPS position that takes account of each satellite's location relative to the other satellites in the constellation and their geometry in relation to the GPS receiver. $GDOP^2 = PDOP^2 + TDOP^2$. A low DOP value indicates a higher probability of accuracy. *See also* **DOP**.

Global Positioning System (GPS)

A GPS system consists of:

- a space segment (up to 24 NAVSTAR satellites in 6 different orbits)
- the control segment (5 monitor stations, 1 master control station and 3 upload stations)
- the user segment (GPS receivers)

NAVSTAR satellites carry extremely accurate atomic clocks and broadcast coherent simultaneous signals.

GPS time

A measure of time used internally by the NAVSTAR system. GPS time is based on UTC, but does not add periodic “leap seconds” to correct for changes in the earth’s period of rotation. As of 1 July 1999, GPS time was 13 seconds ahead of UTC.

Greenwich Mean Time (GMT)

The local time the of 0° meridian passing through Greenwich, England. A traditional term often used in reference to GPS and UTC.

grid

A 2D horizontal rectangular coordinate system, such as a map projection.

HAE

Height Above Ellipsoid.

heading

The current direction in which one is moving.

HDOP (Horizontal Dilution of Precision)

A measure of the magnitude of DOP errors in latitude and longitude. *See also* **DOP**.

ionosphere

The band of charged particles 80 to 120 miles above the earth’s surface.

ionospheric delay A wave propagating through the ionosphere experiences delay. The delay depends on electron content and affects carrier signals. Group delay depends on dispersion in the ionosphere as well, and affects signal modulation (codes). The phase and group delay are of the same magnitude but opposite sign.

kinematic surveying A form of continuous differential carrier phase surveying requiring only short periods of data observation. Operational constraints include starting from or determining a baseline, and tracking a minimum of four satellites. One receiver is located at a control point for each baseline observation, while others are moved among the points to be measured.

latitude (lat) The north/south component of a location on the surface of the earth. Latitude is an angular measurement north or south of the equator. Traditionally north is considered positive, and south is considered negative.

local datum *See* **datum**.

lock To track a satellite.

log To store data in a receiver or on a computer disk.

longitude (lon, long) The east/west component of the coordinate of a point on the surface of the earth; expressed as an angular measurement from the plane that passes through the earth's axis of rotation and the 0° meridian and the plane that passes through the axis of rotation and the point of interest. Traditionally, east is considered positive, and west is considered negative.

map projection A rigorous mathematical expression of the curved surface of the ellipsoid on a rectangular coordinate grid.

master control station Part of the GPS control segment. The master control station calculates satellite paths and clock corrections and forwards them to an upload station.

mean sea level (MSL) The mean height of the surface of the ocean for all stages of the tide. Used as a reference for elevations.

monitor stations A worldwide group of stations used in the GPS control segment to monitor satellite clock and orbital parameters. Data collected here is linked to a master station where corrections are calculated and controlled. This data is transferred to each satellite at least once per day from an upload station.

multipath error Errors caused by the interference of a signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected off the ground or structures near the antenna.

NAD-27 *North American Datum of 1927*. A horizontal datum employing the Clarke 1866 ellipsoid. Height values of this era are expressed in NGVD (National Geodetic Vertical Datum) of 1929.

NAD-83 *North American Datum of 1983*. A horizontal datum employing the GRS-80 ellipsoid. Its geometric definition is almost identical to that of the WGS-84. For GPS purposes, the NAD-83 and WGS-84 datums are identical.

NAVSTAR The name given to GPS satellites. NAVSTAR is an acronym formed from NAVigation Satellite Timing And Ranging.

northing A linear distance in the coordinate system of a map grid. The northing points northwards from the east-west line through the origin.

observing session The period of time over which GPS data is collected simultaneously by two or more receivers. *See also* **relative positioning**.

origin The intersection of axes in a coordinate system. The point of beginning.

overdetermined A network for which more measurements have been made than are necessary to compute the coordinates of a point.

P-code The protected or precise code used on Ll and L2 GPS bands. This code is only made available by the U.S. DoD to authorized users. P-code is a long (about 1014 bits) sequence of pseudorandom binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which does not repeat for about 38 weeks. Each satellite uses a one-week segment of this code that is unique to that GPS satellite. This unique code is modulated onto both the L1 and L2 carrier waves. The P-code is replaced by a Y-code when Anti-Spoofing is active.

PDOP mask The highest PDOP value at which a receiver will compute positions. *See also* **Position Dilution of Precision (PDOP)**.

position The latitude, longitude, and altitude of a point. An estimate of error is often associated with a position.

Position Dilution of Precision (PDOP) A unitless figure that expresses the relationship between the error in user position and the error in satellite position. It indicates when the satellite geometry can provide the most accurate results. The best data collection time can be selected based on reports and graphs showing PDOP.

Geometrically, PDOP is proportional to one divided by the volume of the pyramid formed by lines running from the receiver to four satellites observed. It is the result of a calculation that considers each satellite's location relative to the other satellites in the constellation.

Good values are small, less than three. Values greater than seven are poor. Thus, small PDOP is associated with widely separated satellites. A low DOP indicates a higher probability of accuracy. A high DOP indicates a lower probability of accuracy. PDOP is related to horizontal and vertical DOP by PDOP2 = HDOP2 + VDOP2. *See also* **Dilution of Precision (DOP)**.

precision

A measure of how closely random variables cluster around a computed value. High precision implies small residuals. Usually expressed as one part in, or alternatively, as parts per million (ppm).

propagation delay

When a satellite is at a low elevation and its signal must travel a great distance through the atmosphere, the signal has delayed reception by the GPS receiver. Since the distance to the satellite is calculated by the travel time, this slight delay in travel time can result in a large error in calculated distance. Signals are delayed at all elevation angles, but more so at lower elevation angles.

pseudorandom noise / pseudorandom number (PRN)

A sequence of digital 1s and 0s that appears to be randomly distributed like noise, but can be exactly reproduced. PRN codes have a low autocorrelation value for all delays or lags, except when they are exactly coincident. Each NAVSTAR satellite has its own unique PRN (pseudorandom number) code.

pseudorange

A measure of the apparent propagation time from the satellite to the receiver antenna expressed as a distance. Pseudorange is obtained by multiplying the apparent signal-propagation time by the speed of light. Pseudorange differs from the actual range by the amount that the satellite and user clocks are offset, by propagation delays, and by other errors.

The apparent propagation time is determined from the time shift required to align (correlate) a replica of the GPS code generated in the receiver with the received GPS code. The time shift is the difference between the time of signal reception (measured in the receiver time frame) and the time of emission (measured in the satellite time frame).

Pseudorange is the distance from the satellite to the antenna plus the distance calculated from the clock offset. When the satellite sends the PRN code, the receiver aligns the received code with an internal replica of the code. The clock offset is the

difference between the two codes.

reference station

See **base station**.

relative positioning

The process of determining the relative difference in position between two points with greater precision than the position of a single point can be determined. A receiver (antenna) is placed over each point and measurements are made by observing the same satellite at the same time. This technique allows cancellation (during computations) of all errors common to both observers, such as satellite clock errors, propagation delays, and so on. This technique does not use carrier phase differencing computations.

RDOP (Relative Dilution of Precision)

A unitless value, normalized to 60 seconds. *See also* **Dilution of Precision (DOP)**.

RMS (root mean square)

Expresses the accuracy of point measurement. It is the radius of the error circle within which approximately 70% of position fixes are to be found. It can be expressed in distance units or in wavelength cycles.

rover

Any mobile GPS receiver collecting data in the field. A receiver's position can be differentially corrected relative to a stationary base GPS receiver.

RTCM (Radio Technical Commission for Maritime Services)

A commission established to define a differential data link for the real-time differential correction of roving GPS receivers. It is also the body responsible for defining and updating RTCM SC-104. There are two types of RTCM differential correction messages, but all Trimble GPS receivers use the newer Type 2 RTCM protocol.

satellite geometry

Position and movement of GPS satellites during a GPS survey.

scale
A multiplier used on coordinate and other linear variables, such as for map projections and transformations.

scale factor
A map projection parameter used to convert ellipsoid distances to projection (grid) distances, and vice versa.

Selective Availability (SA)
Artificial degradation of the satellite signal by the U.S. Department of Defense (U.S. DoD). SA controls the accuracy of pseudorange measurements. It causes the user to receive a false pseudorange that is in error by a controlled amount. The error in position caused by SA can be up to 100 meters. Differential GPS techniques can reduce these effects for local applications. Since 1st May 2000, SA has been turned off.

semimajor axis
One-half of the major axis of an ellipse.

signal-to-noise ratio (SNR)
Also called signal level or signal strength. Arbitrary strength units used to determine the strength of a satellite signal. SNR ranges from 0 (no signal) to around 35. Higher-elevation satellites have SNRs in the high teens to low 20s. An SNR lower than 5 is considered unusable.

SNR mask
The lowest signal strength at which a receiver will use a satellite for positioning.

spatial data
Information about the location and shape of geographic features, and the relationships between the features.

Spherical Error Probable (SEP)
A statistical measure of precision defined as the 50th percentile value of the 3D position error statistics. Thus, half of the results are within a 3D SEP value.

SSF file
The Trimble Standard Storage Format data file for GPS data from a mapping receiver.

State Plane Coordinates

Special definitions of Transverse Mercator and Lambert Conformal mapping projections adopted by statute in the U.S. There is one set of such zones for NAD-27 and another for NAD-83.

SV

Abbreviation for satellite vehicle.

TDOP

Refers to clock offset. *See also* **Dilution of Precision (DOP)**.

tracking

To make a pseudorange measurement with a GPS receiver.

Universal Time Coordinated (UTC)

Local solar mean time at Greenwich Meridian. A uniform atomic time system maintained by the U.S. Naval Observatory and kept very close to UT2 by offsets. GPS time directly relates to UTC:

UTC – GPS = seconds (changing constant = 5 seconds in 1988, 8 seconds in 1993).

Some commonly used versions of UTC are:

UT0 –	Universal Time as deduced directly from observations of stars and the fixed numerical relationship between Universal and Sidereal Time, 3 minutes 56.555 seconds.
UTl – UT0	Corrected for polar motion.
UT2 – UTl	Corrected for seasonal variations in the earth's rotation rate.

VDOP (Vertical Dilution of Precision)

Refers to altitude. *See also* **Dilution of Precision (DOP)**.

WGS-72 (World Geodetic System 1972)

The mathematical reference ellipsoid used by GPS until 1987, which has a semimajor axis of 6378.135 km and a flattening of 1/298.26.

WGS-84 (World Geodetic System 1984)

The mathematical ellipsoid used by GPS since January 1987, which has a semimajor axis of 6378.137 km and a flattening of 1/298.257223563.

The shift from WGS-72 to WGS-84 at 37° latitude is about 13.6 m east, 45 m north, and 2.7 m up.

x*, *y*, or *z

An expression for coordinates with separate meanings for EC Cartesian and rectangular coordinates. In the EC Cartesian system, *x* refers to the (direction of the) coordinate axis running from the system origin to the Greenwich Meridian, *y* to the axis running from the origin through the 90-degree east longitude meridian, and *z* to the polar ice cap. In rectangular coordinate systems, *x* refers to the east-west axis, *y* to the north-south axis, and *z* to the height axis.

Y-code

An encrypted form of the information contained in the P-code. Satellites transmit Y-code in place of P-code when Anti-Spoofing is in effect.

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