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Comparing Four Methods of Correcting GPS Data: DGPS, WAAS, L-Band, and Postprocessing

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The global positioning system (GPS) of satellites allows persons with standard GPS receivers to know where they are with an accuracy of 5 meters or so. When more precise locations are needed, errors (table 1) in GPS data must be corrected. A number of ways of correcting GPS data have been developed. Some can correct the data in realtime (differential GPS and the wide area augmentation system). Others apply the corrections after the GPS data has been collected (postprocessing).

In theory, all methods of correction should yield similar results. However, because of the location of different reference stations, and the equipment used at those stations, the different methods do produce different results.

Table 1—The source of GPS position errors after selective availability (intentional error) was turned off (based on DePriest's navigation and GPS articles, see references).

Source of error	Amount of error (meters)
Ionosphere	4
Clock	2.1
Ephemeris	2.1
Troposphere	0.7
GPS receiver	0.5
Multipath	1
Total	***10.4***

For an explanation of these errors, refer to Trimble's excellent tutorial on GPS: *http://www.trimble.com/gps/errors1.html*. The Shockwave player must be installed to view this tutorial. Forest Service employees will need administrative rights to install the free Shockwave player, which can be downloaded from: *http://www.macromedia.com.*

DGPS Beacon Corrections

The U.S. Coast Guard has installed two control centers and more than 60 beacon stations along the coastal waterways and in the interior United States to transmit DGPS correction data that can improve GPS accuracy. The beacon stations use marine radio beacon frequencies to transmit correction data to the remote GPS receiver. The correction data typically provides 1- to 5-meter accuracy in real time.

In principle, this process is quite simple. A GPS receiver normally calculates its position by measuring the time it takes for a signal from a satellite to reach its position. Because the GPS receiver knows exactly where the satellite is, how long the satellite took to send the signal, and the signal's speed, the receiver can compute what is called a pseudorange (distance) to the satellite. This distance must be corrected before the GPS receiver uses it to compute its final position.

A DGPS beacon transmitter site has a reference GPS receiver (or base station) located on a point that's been surveyed very accurately. The reference receiver receives the same GPS signals as other receivers, but because its location is known so precisely, it can attack the equations backwards, using timing signals to calculate its position correction.

The reference receiver figures out how long the GPS signals should have taken to reach it and compares that time with the signals' actual travel time. The difference is an error correction factor. Once the error correction factor has been computed, the beacon station sends it to the field GPS receiver (or rover), which uses it to compute a more accurate location.

Beacon transmitters operate in the 300 kHz frequency band and send data at a rate of either 100 or 200 bits

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per second, depending on the station. Because the station must calculate the corrections and transmit them, the receiver may apply the corrections 2 to 5 seconds after they were made. Most errors change slowly, so this delay usually is not a problem. The accuracy of such systems depends somewhat on how close the receiver is to the beacon, but can be within 1 to 5 meters overall. The *rule of thumb* is that the error will increase 1 meter for every 160 kilometers the receiver is from the beacon station.

Figures 1 and 2 show the beacon coverage areas for the Eastern and Western United States at the beginning of 2004. Plans call for all areas of the United States to be covered by a single beacon station by December 2005. The goal is to have all areas of the United States covered by two beacon stations soon afterward. With double coverage, when a receiver cannot receive a signal from one station, it may be able to receive a signal from another. Budget constraints are delaying installation of new beacon stations.

Even with the use of real-time differential GPS (DGPS) corrections or postprocessing, the locations collected using standard GPS receivers are still not as accurate as those of survey-grade receivers. Such receivers process dual-frequency signals, rely on a DGPS reference station close to the survey site, and also use

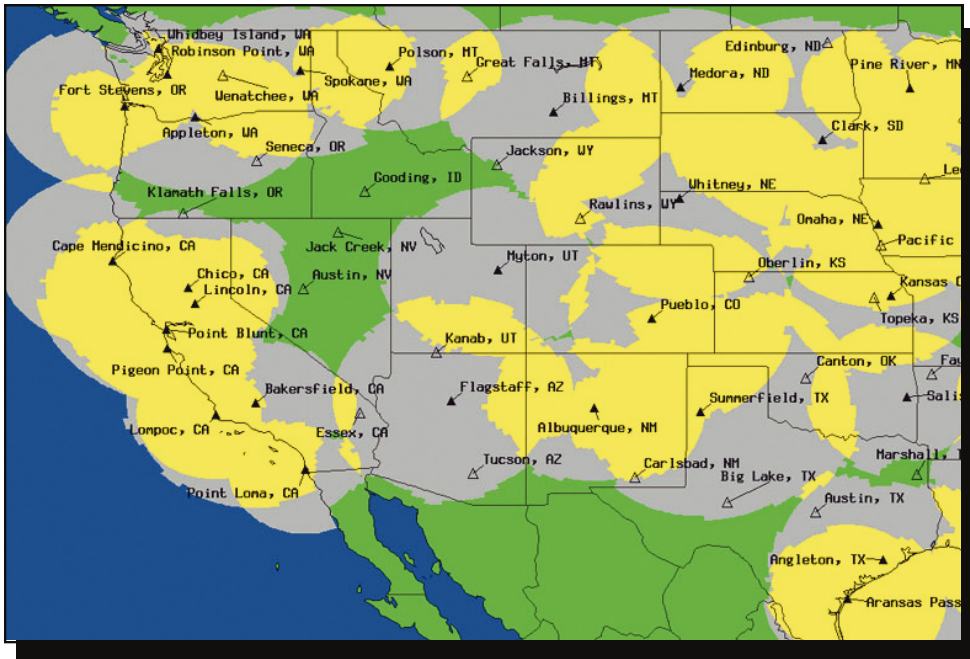

Figure 1—DGPS coverage in the Western United Sates by U.S. Coast Guard beacon stations (Jan. 2004, *http://www.navcen.uscg.gov/dgps/coverage/WestCoast.htm*).

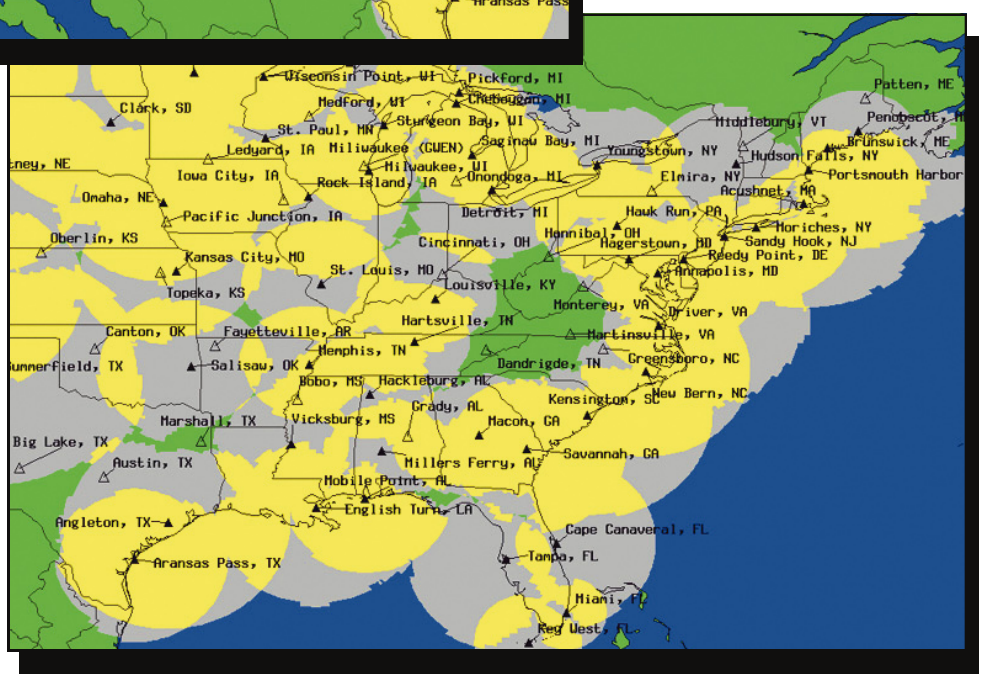

Figure 2—DGPS coverage in the Eastern United States by U.S. Coast Guard beacon stations (Jan. 2004, *http://www.navcen.uscg.gov/dgps/coverage/EastCoast.htm*).

postprocessing techniques. This tech tip discusses the techniques used to reduce errors in locations collected with standard GPS receivers, not survey-grade receivers.

Wide-Area Augmentation System (WAAS)

WAAS was developed by the U.S. Federal Aviation Administration to assist aerial navigation. Unlike traditional ground-based navigational aids, WAAS covers a large service area. Wide-area ground reference stations have been linked to form a nationwide WAAS network. These precisely surveyed ground reference stations receive signals from GPS satellites and identify any errors. Each station relays the data to one of two wide-area master stations, which compute correction information for specific geographical areas. A correction message is prepared and uplinked to a geostationary communications satellite (GEO) by a ground uplink station.

Although WAAS was designed for aviation users, it is now being used in agriculture, surveying, recreation, and surface transportation. The WAAS signal has been available since 2000 for applications that do not involve safety of life. Now millions of GPS receivers are enabled to use the WAAS signals.

The WAAS signals, like GPS signals, are transmitted in the line of sight. A receiver must have an unobstructed view of a GEO satellite to receive the WAAS signals. The direction to the satellites depends on the receiver's location. The GEO satellite over the Atlantic Ocean Region–West (AOR–W) is identified with a Pseudo Random Noise (PRN) of 122. The GEO satellite over the Pacific Ocean Region (POR) is identified with a PRN of 134.

Both GEO satellites are relatively low on the horizon. If you live in the Northern United States and your view to the south is obstructed to an angle of 20 degrees or more, you probably will not be able to obtain the WAAS correction signals. Signals can be blocked on the north side of mountains and in canyons. Medium to heavy canopy will also block WAAS signals.

In 2004, the Federal Aviation Administration hopes to launch a third GEO satellite, which may alleviate some signal problems. The best location for this new satellite still has not been determined. Whatever the satellite's final location, it will provide additional signals from a different azimuth, reducing (but not necessarily eliminating) the problem of WAAS signal reception. The earliest a new GEO satellite is expected to be in operation is sometime in 2004.

Satellite Service Providers Using L-Band Frequencies

The L-band frequencies can be used to download information from satellites. Before correction data became widely available through beacon stations and WAAS, some areas of the country could only receive correction information from commercial satellite service providers over L-band frequencies. Such providers include Racille, OmniSTAR, and Landstar. A custom receiver (or special software) is needed to assemble data in the form used by GPS receivers (the RTCM-104 standard). Data conforming to this standard can be sent by a cable from the custom receiver to the GPS receiver through the GPS receiver's serial port.

OmniSTAR has satellite coverage over most of the land areas of the globe, with the exception of some areas farther than 60 degrees north and 60 degrees south latitude. However, even within the coverage areas, users must have a clear line of sight to the local OmniSTAR satellite.

The AMSC (American Mobile Satellite Corporation) satellite used by OmniSTAR in North America is located at 101 degrees west longitude. It is over the equator, roughly south of a line through Denver and El Paso.

The altitude of the OmniSTAR satellite is relative to the user's latitude. Along the Southern States, the satellite is 50 to 55 degrees above the horizon. Along the Canadian border, the satellite is 25 to 30 degrees above the horizon. At 60 degrees north, the satellite is less than 20 degrees above the horizon. When the satellite is less than 5 degrees above the horizon, it is very difficult to get a clear line of sight.

Our testing has shown that under a tree canopy the correction signal is difficult to acquire. For aerial spray applications and for use in open fields, the correction signal should be available across most of the continental United States. A 1-year OmniSTAR subscription costs $800 for North America.

Canadian DGPS

For GPS users in the interior of Alaska, Canadian DGPS (CDGPS) is another DGPS correction option. The broadcast CDGPS corrections can be accessed anywhere in Canada and in portions of interior Alaska using a custom-built CDGPS receiver. The correction data—based on algorithms developed by Natural Resources Canada and positioning data from Canadian reference stations—are optimized for Canada. The service is free.

End-users must purchase a CDGPS receiver to access the CDGPS signal. This unit has been developed by Mobile Knowledge, Inc., in Ottawa, Ontario, to complement the CDGPS service and support real-time requirements for field users. It is designed for portable applications. It outputs data in the GPS C, RTCM SC-104, or NMEA formats. The receiver costs $1,500 (Canadian).

Postprocessed GPS Data

While DGPS reference stations transmit GPS error corrections in real time, it's also possible to save the correction information in files that can be used to correct GPS data days, weeks, or months after the data has been collected.

Software designed to use these files can compare the time a GPS location was recorded with the error correction for that time and apply the appropriate corrections to all locations collected with the roving GPS receiver. The corrected locations are more accurate than the locations collected by the roving receiver because much of the error identified in table 1 has been removed.

The National Geodetic Survey, an office of the National Oceanic and Atmospheric Administration's National Ocean Service, coordinates a network of continuously operating reference stations (CORS, figure 3) that provide GPS carrier phase and code range measurements for correcting GPS data throughout the United States and its territories.

The correction files can be found at the Web site: *http://www.ngs.noaa.gov/CORS/.*

The USDA Forest Service also has a site with these files: *http://www.fs.fed.us/database/gps/clickmap/cbsmap.htm.*

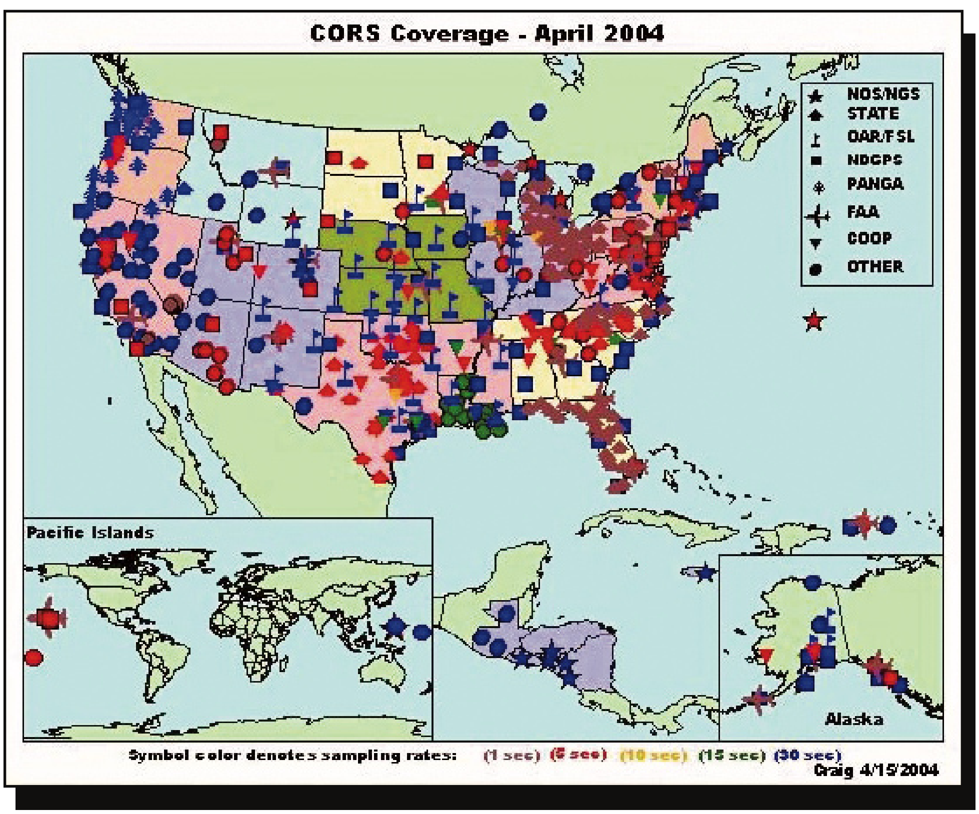

Figure 3—Location of National Geodetic Survey continuously operating reference stations (CORS) across the United States.

Test Results

DGPS Beacon Corrections—The U.S. Coast Guard beacon signal can usually be obtained through canopy even when the station is as far as 350 miles away. Accuracy does depend on the distance from the GPS receiver to the beacon station. A good rule of thumb is that there is 1 meter of additional error for each 160 kilometers the receiver is from the beacon station. Typically, that error will be opposite the beacon station's direction from the receiver. Figure 4 shows the approximate magnitude and direction of errors for positions acquired using different beacon reference stations under an open canopy at the MTDC GPS test course in Missoula. Figure 5 shows the locations of the beacon stations with respect to the MTDC GPS test course.

WAAS—WAAS works well if the sky is unobstructed. In the northern United States, an obstruction to the south at an elevation more than 15 degrees above the horizon can degrade the WAAS signal reception. It can take up to 20 minutes to obtain a lock on WAAS satellites.

L-Band Corrections—Satellite-based L-band corrections may have the same problems as WAAS corrections, depending on their source. If an L-band service provider uses satellites in low-Earth orbits, reception may be better than from WAAS satellites orbiting at higher altitudes.

Postprocessing—Postprocessing provides the best accuracy if real-time information is not needed.

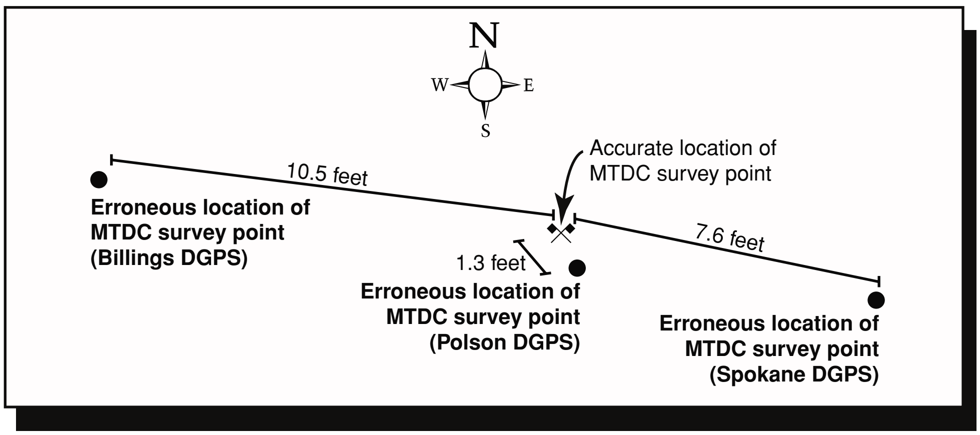

Figure 4—The approximate magnitude and direction of position errors when using different beacon stations to correct a position collected in Missoula at the MTDC survey point. The most accurate corrections will usually be from the closest beacon station.

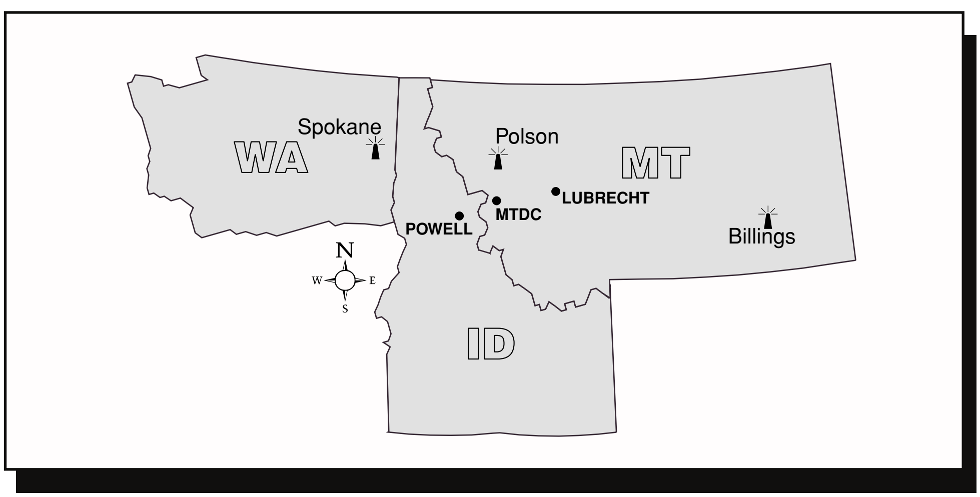

Figure 5—The location of DGPS beacon stations that are closest to the Forest Service's GPS test courses in Montana and Idaho.

Conclusions

The most accurate results, in order, are:
- Postprocessed position data
- Beacon data
- L-band data
- WAAS
- Autonomous GPS receiver data

Additional Information Available Over the Internet

Canadian DGPS (*http://www.cdgps.com/e/desc.htm*)

National Geodetic Survey CORS (*http://www.ngs.noaa.gov/CORS*)

OmniSTAR (*http://www.omnistar.com/home.html*)

Dale DePriest's Navigation and GPS Articles (*http://www.gpsinformation.org/dale/dgps.htm*)

U.S. Coast Guard (*http://www.navcen.uscg.gov/ndgps/default.htm*)

WAAS (Raytheon) (*http://www.waasperformance.raytheon.com/sis/sisqa.html*)

WAAS (General questions) (*http://www.gpsinformation.net/waasgps.htm*)

David L. Wilson's GPS Accuracy Web page (*http://users.erols.com/dlwilson/gps.htm*)

About the Author

Dick Karsky has been program leader of forest health protection, GPS, and the air portion of the watershed, soil, and air program since the fall of 1999. Dick has been a project leader at MTDC in the resource areas of GPS, range, cooperative forestry, engineering, fire, reforestation and nurseries, residues, recreation, and forest health protection. He received a bachelor's degree in agricultural engineering from North Dakota State University and a master's degree in agricultural engineering from the University of Minnesota. He worked for private industry before coming to the Missoula Technology and Development Center in 1977.

Library Card

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Describes four methods used to correct global positioning system (GPS) data and compares their relative accuracies. The correction methods include three that operate in real time—differential GPS (DGPS), the wide area augmentation system (WAAS), and satellite service providers transmitting corrections on L-band frequencies—and one that requires correcting the GPS data after it has been collected (postprocessing). The best methods, from the most to the least accurate, are: postprocessing GPS data, using DGPS beacons to correct GPS data in real time, using satellite service providers transmitting corrections over L-band frequencies to correct GPS data in real time, and using the wide area augmentation system to correct GPS data in real time.

Keywords: accuracy, beacon stations, CORS, differential GPS, global positioning system, L-band, OmniSTAR, wide area augmentation system

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