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Forest Service

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Comparison of GPS Receivers Under a Forest Canopy



*After Selective Availability
Has Been Turned Off*



OUTSIDE BACK COVER



Comparison of GPS Receivers Under a Forest Canopy



*After Selective Availability
Has Been Turned Off*



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**USDA Forest Service
Technology & Development Program
Missoula, MT**

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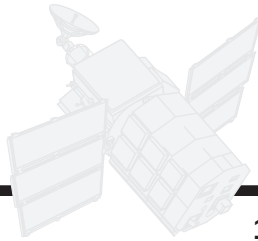
May 2001

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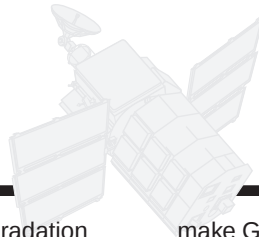
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Introduction



Selective Availability (SA) was the intentional degradation of the Global Positioning System (GPS) satellite signals by the United States. When SA was turned off during early May of 2000, position accuracy for civilian GPS receivers used without correction increased from +/- 100 meters to less than +/- 10 meters (figure 1).

Civilian users of GPS are now able to pinpoint locations up to 10 times more accurately than in the past. The decision to discontinue SA is the latest measure in an ongoing effort to

make GPS more useful for civilian and commercial users worldwide. In addition, two new civilian signals will be added to enhance the civilian and commercial service.

The Missoula Technology and Development Center tested commercially available GPS receivers and compared them to the military receivers now widely used by the Forest Service. This report describes the initial results of those tests conducted during the summer of 2000.

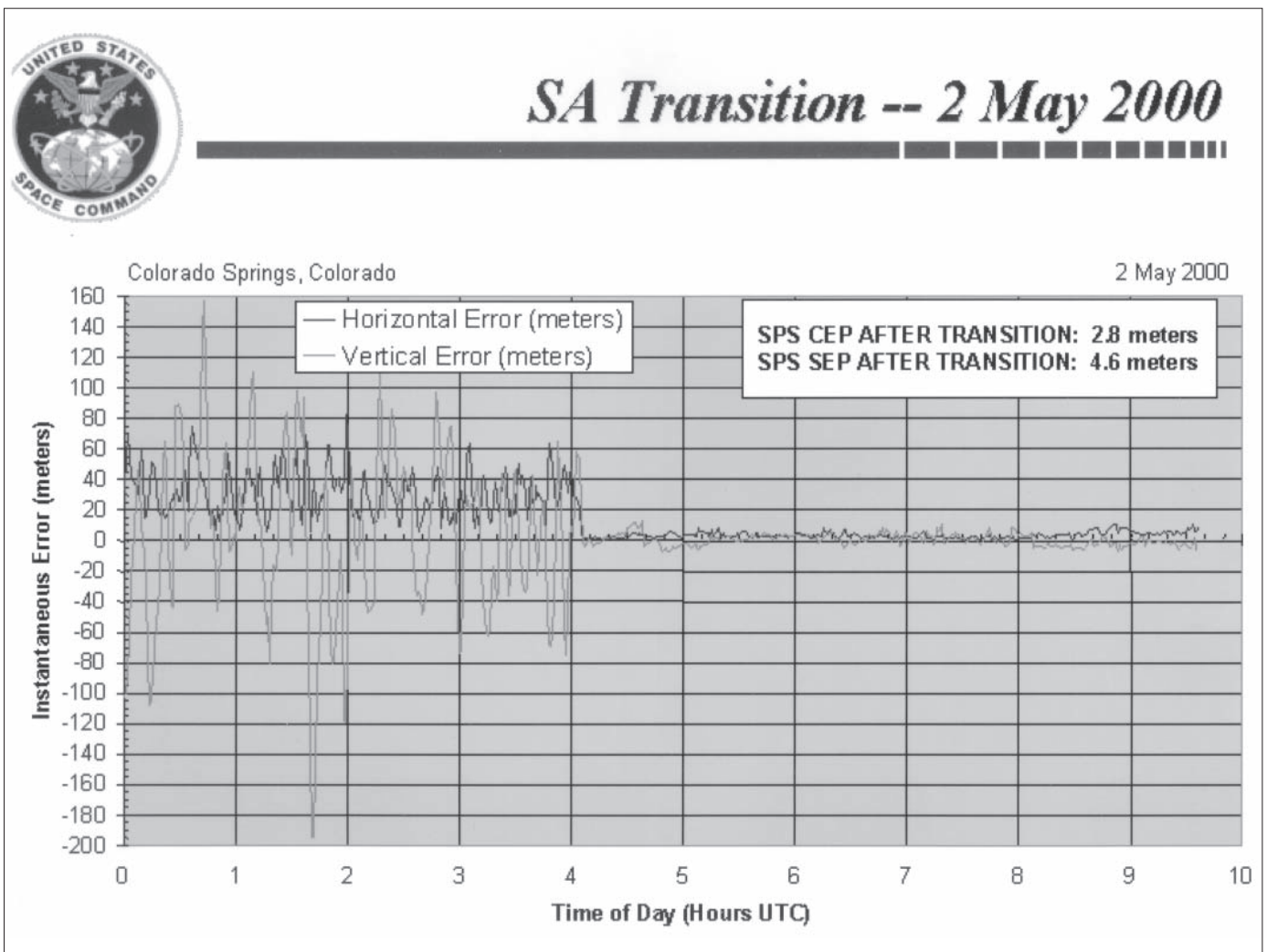


Figure 1—The change in position error when selective availability was turned off.

Test Courses

Powell, ID, Test Course

This GPS test site is located on the Clearwater National Forest's Powell Ranger District. It is on U.S. Highway 12 at the Idaho highway maintenance area about 12 miles west of Lolo Pass and about 55 miles southwest of Missoula, MT. The test site is near the Lochsa River. Mountains on the north and south sides of the course obstruct the view there at an angle of 15 degrees. The canopy consists of large (24-inch d.b.h.) old-growth cedar and spruce trees in a flat valley bottom with only a small amount of understory. At most stations, the canopy would be considered heavy. The course has 11 turning points or stations that outline a 12.019-acre polygon. The polygon can be divided to produce two polygons (figure 2).

The ground traverse and geodetic control survey of the Powell, ID, GPS test course was done by the Forest Service's Northern Region engineering staff and the Lolo National Forest's cadastral survey group. The conventional survey was conducted with a Topcon total station. The GPS control survey was conducted with four Trimble 4000SSE/SSI geodetic GPS receivers with L1/L2 (the two GPS signal frequencies) compact dome geodetic antennas operating in the static mode. Three data sets were observed from HARN (High Accuracy Reference Network) stations *LOLO GPS* and *W522*. Final results were calculated from a least squares adjustment of the data using fixed integer baselines from the geodetic observations. The GEOID99 model (equations used to define the spherical surface of the Earth) was used to estimate geoid separation. The error estimates for the network observations are in the 2-centimeter range. Coordinates are NAD83 (North American Datum 1983) (1992) Montana HARN latitude, longitude.

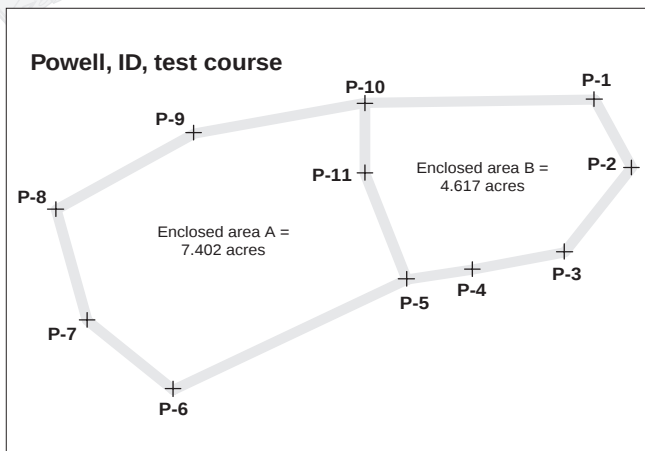


Figure 2—Site diagram for the Powell, ID, GPS test course.

Lubrecht, MT, Test Course

The Lubrecht test course is at the Lubrecht Experimental Forest about 40 miles northeast of Missoula, MT. This course is a polygon with seven turning points (stations) on gentle terrain under a mixed lodgepole and ponderosa pine canopy. The trees are about 19 meters tall with a minimal understory. The canopy could be classified as light to medium. Station B-31 is located in the open with a clear view of the sky down to an angle of 15 degrees (figure 3).

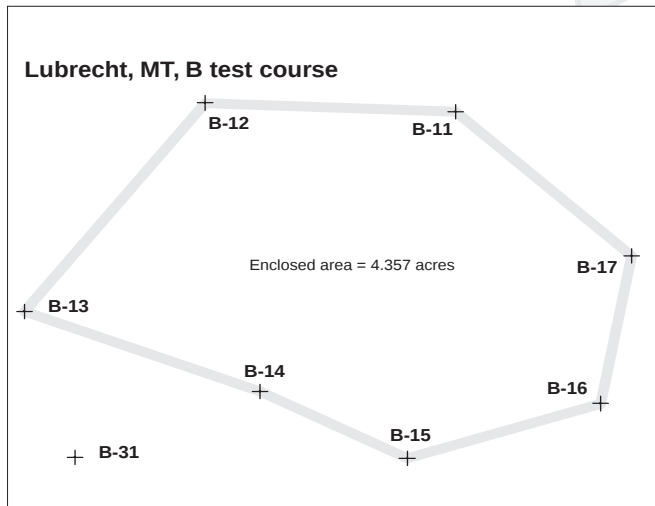


Figure 3—Site diagram for the Lubrecht, MT, GPS test course (under forest canopy).

Clackamas, OR, Test Course

A Pacific Northwest regional surveyor established the Clackamas, OR, test course after the Forest Service's GPS steering group asked him to provide a course in a typical dense West Coast Douglas-fir stand. The course is on gentle terrain in a second-growth Douglas-fir and western hemlock overstory (trees about 24 to 40 inches d.b.h.) with a vine maple and red alder understory. The course has 13 stations, all located within an accuracy of 5 centimeters. The area enclosed by the traverse

can vary from 2.19 to 7.20 acres, depending on the stations chosen (figure 4).

The Clackamas, OR, GPS test network provides a site for testing the performance of P(Y) (military) and C/A (civilian) code GPS receivers under moderate to heavy western Oregon timber canopy. Each point is marked with $\frac{5}{8}$ -inch rebar with plastic caps and an orange Carsonite fence post with a survey monument sticker. All points can be seen from any point. Lines between the survey points are brushed and flagged.

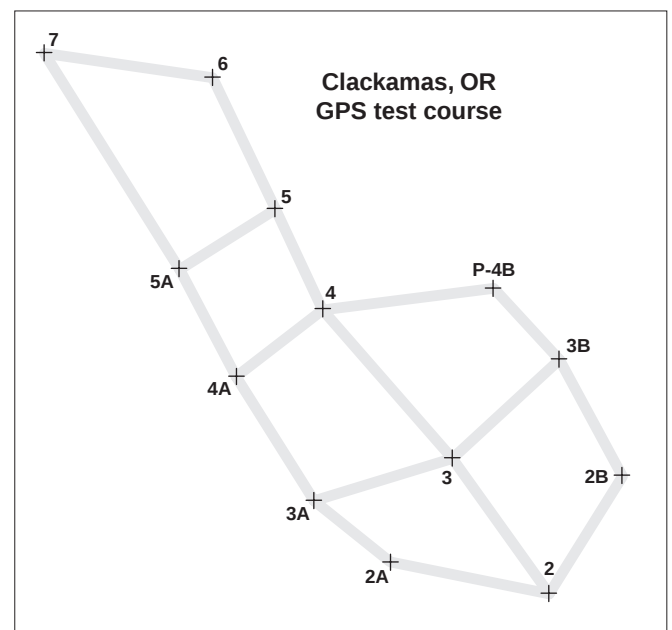
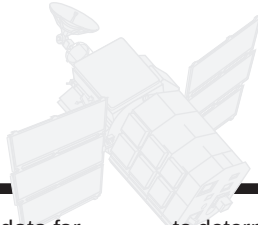


Figure 4—Site plan for the Clackamas, OR, GPS test course.

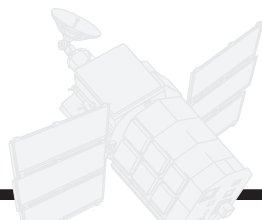
Test Procedure



The receivers were turned on and allowed to collect data for 20 minutes before the tests were run. This procedure ensured that a current almanac was stored in the receiver before testing. External antennas were used on all receivers for most of the tests. Some tests were run with the built-in internal antennas to compare the two types of antennas. Different numbers of positions (1, 60, and 120) were averaged at the different stations

to determine the effect on accuracy. When possible, the position dilution of precision (PDOP) and estimated position error (EPE) values were monitored to determine the type of satellite constellation the receivers were accessing. The position errors obtained at each station were averaged over the complete course to determine the individual receiver's average error.

Receivers Tested



The following receivers were tested on the Lubrecht and Powell courses:

- * Rockwell PLGR +96, PPS, serial number 165268 with sw: 613-9868-015 software
- * Garmin GPS III+ serial number 92113388 with 2.05 firmware
- * Trimble Pro XR, serial number 0220174140 with TSC1 and Asset Surveyor ver. 5.00 software

- * Trimble GeoExplorer 3, serial number 0330040826 with ver. 1.02 firmware

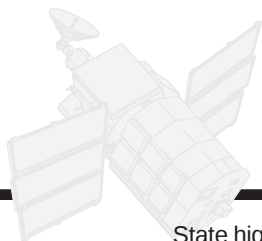
- * Magellan Map 410 receiver with ver. 1.05 firmware

All receivers were used with external antennas.

The Trimble Centurion is a P(Y) code receiver similar to the Rockwell PLGR +96. Although the Centurion was not tested, its features are summarized in the comparison table for GPS receivers (table 1).

Table 1—Comparison of GPS receivers.

Receiver	Advantages	Disadvantages	Accuracy (two distributions root mean square)	Approximate cost (as of December 2000)
Trimble Pro XR	Logs and postprocesses data; exports data to Arc/Info; real-time DGPS; high accuracy	Expensive; bulky	Open canopy: 1 to 4 m; medium canopy: 2 to 6 m	\$10,000
Trimble GeoExplorer 3	Logs and postprocesses data; exports data to Arc/Info; real-time DGPS	Expensive; not as accurate as the Pro XR; should use external antenna	Open canopy: 2 to 8 m; medium canopy, average of 120 positions: 2.4 to 9 m; postprocessed data: 2.5 to 8 m	\$4,500
Rockwell PLGR +96	Acquires GPS signal in difficult canopy and terrain better than receivers using the civilian signal; easy to use	Must record positions manually; does not log data without an external data logging device; cannot postprocess military data; only the CA signal can be real-time processed; accuracy not as good as other receivers when data are postprocessed; accountable military item; must be rekeyed annually	Open canopy: 2 to 7.5 m; medium canopy, average of 120 positions: 2.5 to 13 m	\$2,500 External antenna, \$200+; misc. accessories and software, \$340
Trimble Centurion	Acquires GPS signal in difficult canopy and terrain better than receivers using the civilian signal; easy to use	Can use Asset Surveyor software and TDC1 data logger to collect data; cannot postprocess military code data; only the CA signal can be real-time processed; accuracy of postprocessed data not as good as other receivers; accountable military item; must be rekeyed annually	Open canopy: 2.5 to 8 m; medium canopy, average of 120 positions: 2.5 to 10 m	\$4,900 External antenna, \$300+
Garmin GPS III+	Inexpensive; easy to use; readily available; records waypoints and can download them; collects real-time DGPS data with optional receiver and some work; can average waypoints	Cannot export data into ARC/Info without additional data logger and software; cannot postprocess data; should use external antenna	Open canopy: 2 to 7 m; medium canopy, average of 120 positions: 2.5 to 12 m	\$350 Software and external antenna, \$200+; DGPS receiver, \$300+
Magellan Map 410	Inexpensive; easy to use; readily available; records waypoints and can download them; collects real-time DGPS with optional antenna and some work; can average waypoints	Cannot export data into ARC/Info without additional data logger and software; cannot postprocess data; should use external antenna; waypoint averaging is tricky since averaging starts when the receiver quits moving	Open canopy: 2 to 7 m; medium canopy, average of 60 positions: 3 to 24 m	\$350 Software, \$60; external antenna, \$100+



Rockwell PLGR +96

The PLGR +96 FED (figure 5) is a five-channel, single-frequency, precise positioning system (PPS) P(Y) code receiver with a built-in antenna. It has been evaluated in other Missoula Technology and Development Center (MTDC) reports. The accuracy of the receiver did not change significantly after SA was turned off. The receiver contains a security module that can eliminate the positional error intentionally introduced when SA is enabled. It decodes the encrypted signal called anti-spoof. The receiver is not classified, but it is an accountable property item that should remain in the control of the authorized user. It can store 999 waypoints and has 15 user-definable reversible routes with up to 25 legs each. An external power supply and antenna is optional. It is ready to be used with differential GPS (DGPS).



Figure 5—Rockwell PLGR +96 P(Y) code receiver.

Garmin GPS III+

The Garmin GPS III+ (figure 6) has 12 parallel channels that can continuously track and use up to 12 satellites to compute and update a position. It is ready to be used with DGPS. Signal acquisition times are about 15 seconds when warm and about 45 seconds when cold with a continuous update rate of 1 second. It can store 500 waypoints with symbols, 20 reversible routes, and a track log of 1,900 points. A built-in detailed base map covers lakes, rivers, interstate highways, Federal and

State highways, secondary roads in metropolitan areas, cities, railroads, and airports. It includes a detailed database of exits on the Federal highway system. More detailed maps are an option. The receiver has 106 different map datums. It has a NMEA 0183 and RTCM 104 DGPS corrections interface and an optional external antenna.



Figure 6—Garmin GPS III+ receiver.

Trimble Pro XR

The Trimble Pro XR (figure 7) is a 12-channel, real-time GPS receiver with an integrated antenna. The antenna receives the GPS signal and the real-time differential corrections broadcast by a radio beacon maintained by the U.S. Coast Guard or the U.S. Army Corps of Engineers. The operator can select whether DGPS will be used and which real-time broadcast station to use. The receiver can output both the real-time differentially corrected position and the raw data for each position.

In this study data were collected using the Trimble System Controller (TSC1) data logger with Asset Surveyor software version 5.00. The data collection interval was set at 1 second, with the PDOP and signal-to-noise ratio (SNR) masks set at 6, and the elevation mask set at 15. Pathfinder Office software version 2.70 was used to differentially postprocess the raw data and to display the postprocessed and the real-time-corrected position data. Data for postprocessing were obtained from the Forest Service base station in Missoula for the Powell and Lubrecht sites (<http://www.fs.fed.us/database/gps/missoula.htm>). That base station, which records data at 5-second intervals, is about 39 miles from the Lubrecht, MT, test course and about 55 miles from the Powell, ID, test course.



Figure 7—Trimble Pro XR GPS receiver.

Trimble GeoExplorer 3

The GeoExplorer 3 receiver (figure 8) is easily portable. Its size and powerful features make the GeoExplorer 3 an ideal tool for creating and maintaining databases for utilities, urban areas, and natural resources. The antenna is integrated with a high-



Figure 8—Trimble GeoExplorer 3 GPS receiver.

performance 12-channel GPS receiver. The receiver firmware provides for easy geographic information system (GIS) data collection, easy maintenance of existing GIS databases, and cable-free, real-time DGPS using the DGPS receiver (that can be worn as a belt). The receiver supports ARC/INFO, AutoCAD, Intergraph, MGE, ERDAS, and GRASS software. The GPS Pathfinder Office software is included for data processing and GIS export.

Magellan Map 410

The Magellan Map 410 receiver (figure 9) has 12 parallel channels and includes a detachable antenna. A built-in worldwide background map and detailed base map for the Americas include cities, lakes, rivers, railroads, coastlines, and interstate, national, and State highways. It has a built-in altimeter. It can store 500 waypoints and 20 routes with 30 legs. When the receiver is not moving, it will automatically average positions. It has nine graphic navigation screens, a trip odometer that can be reset, "Ezstart" initialization, and a built-in simulator for training and education. It can upload and download data, has NMEA output, and is ready to be used with DGPS.



Figure 9—Magellan Map 410 GPS receiver.

Results

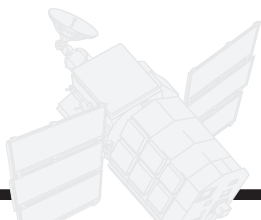


Figure 10 shows the position errors for the four receivers at the Powell, ID, test course. Stations 2 and 9 show larger errors, which could be due to multipath (reflected signals) from the canopy nearby. The Trimble Pro XR and GeoExplorer 3 collected files that were postprocessed. The error over the course with the Pro XR was often less than 2 meters under the forest canopy.

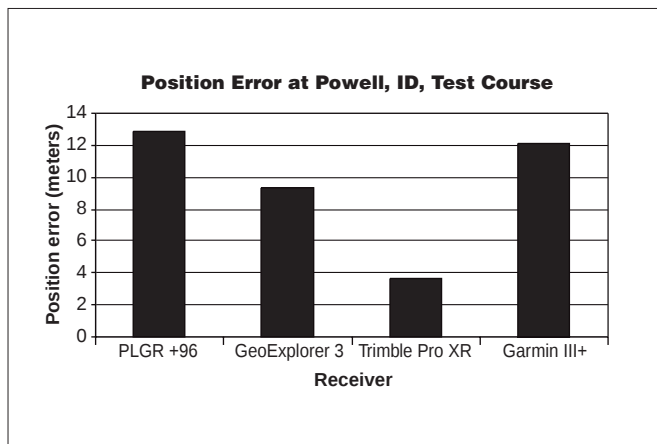


Figure 10—The position error (two-distributed-root-mean-square) for the different receivers on the Powell, ID, GPS test course (120 records averaged). The error will be less than shown 95 percent of the time. Data from the Trimble Pro XR and GeoExplorer 3 receivers were post-processed, reducing the error.

Figure 11 shows position errors for the different receivers on the Lubrecht, MT, test course. The position errors for the Trimble Pro XR and GeoExplorer 3 receivers are similar to those for the

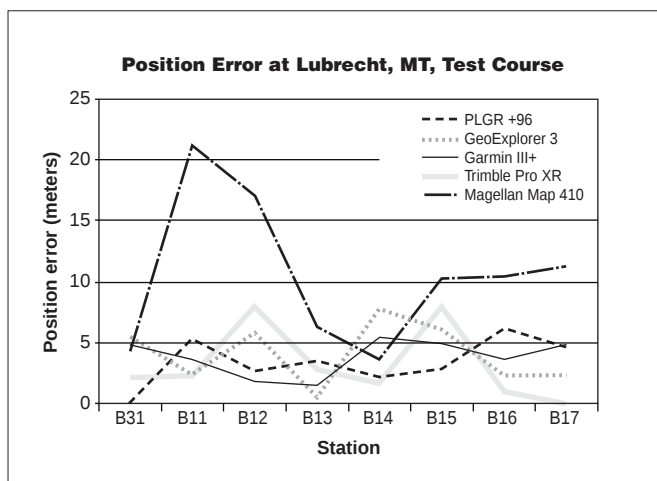


Figure 11—This graph shows the position errors at the different stations on the Lubrecht, MT, GPS test course. Data from the Trimble Pro XR and GeoExplorer 3 receivers were not postprocessed (60-record average).

other receivers because the data were not corrected or post-processed. Position errors for most receivers were less than 7 meters, except for the Magellan receiver, which had errors ranging to 20 meters. Station 31 is in the open. All receivers had position errors of less than 5 meters there. If all the position records are averaged for all the stations on the course, an overall position error can be determined for each receiver (figure 12). Figure 13 shows position errors for the different receivers in an open field near MTDC.

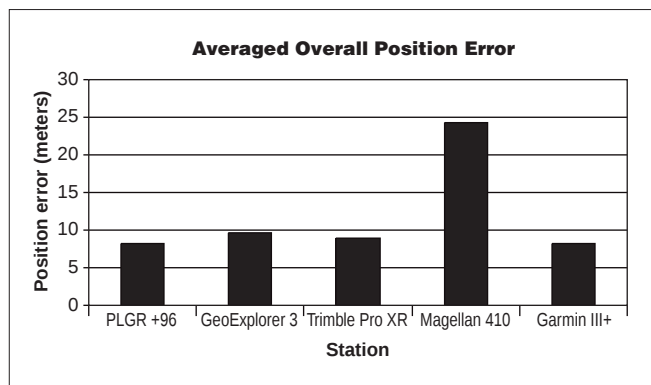


Figure 12—The position error for each of the receivers on the Lubrecht, MT, GPS test course. All position error records for each receiver shown in figure 11 were averaged for each station and then averaged over the whole course to obtain an overall position error for each receiver. The two-distributed-root-mean-square value was calculated from those averages.

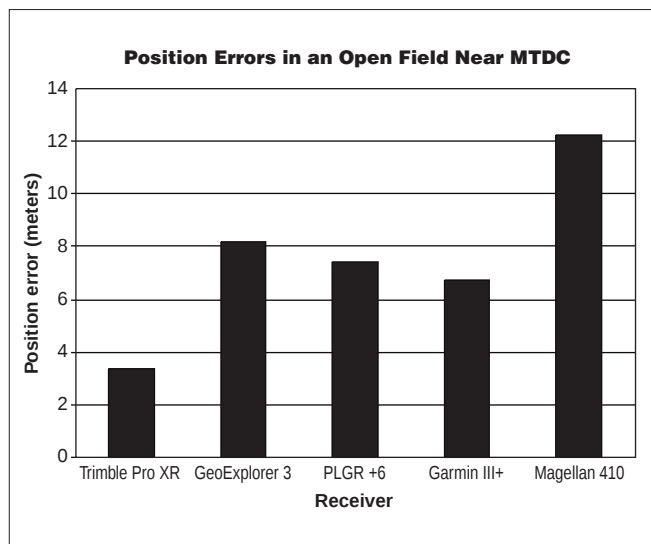


Figure 13—The position error for each of the receivers in the open (no canopy) near the MTDC building. In this graph, the position error was obtained by calculating an average position error for each of the different record sizes (1, 60, and 120 positions). The two-distributed-root-mean-square value was calculated from those averages.

Postprocessing

The only receivers collecting data that could be postprocessed were the GeoExplorer 3 and the Trimble Pro XR. Figures 14 and 15 show the results of postprocessing data from those receivers when 1, 60, or 120 records were averaged.

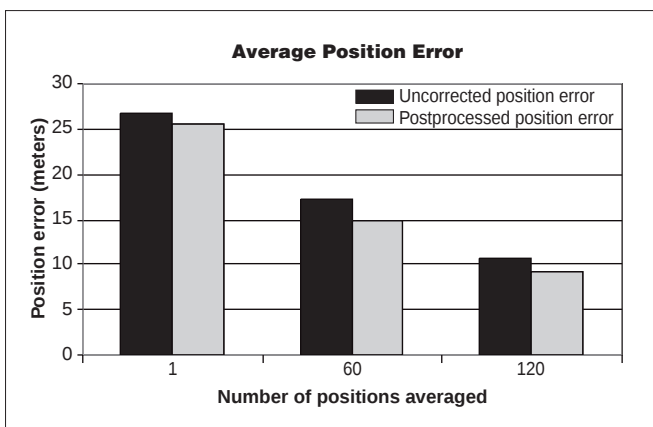


Figure 14—The two-distributed-root-mean-square position error for the Trimble GeoExplorer 3 receiver when 1, 60, and 120 positions were averaged. The files were postprocessed. The potential for large errors exists when only a few positions are averaged.

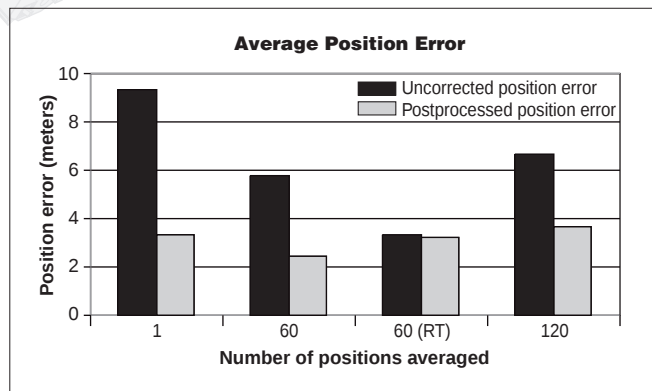


Figure 15—The two-distributed-root-mean-square position error for the Trimble Pro XR receiver when 1, 60, and 120 positions were averaged. The abbreviation *RT* indicates real-time corrected positions. All files were postprocessed. The large error for the 120-record average of uncorrected positions cannot be explained, but much of the error was removed by postprocessing.

Effect of Signal-to-Noise Ratio

Figure 16 shows the effect on position accuracy when collecting data with different signal-to-noise ratio (SNR) values. As SNR increases, so does the accuracy. However, when the minimum SNR value is set to a larger value, the receiver will take more time to acquire positions. Data collection will take longer. Man- cebo and Chamberlain have a more detailed discussion of the effect of SNR on the efficiency of data collection in an MTDC report to be printed in 2001.

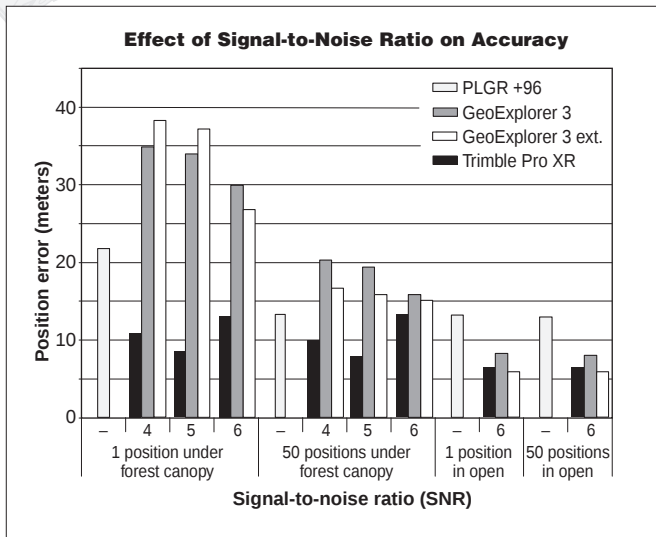


Figure 16—The effect of signal-to-noise ratio (4, 5, or 6) on position accuracy under forest canopy and in the open for 1- and 50-position records. The GeoExplorer 3 was tested with and without its external (ext.) antenna. The two-distributed-root-mean-square value was calculated from those averages.

Effect of Position Dilution of Precision (PDOP) on Accuracy

Figure 17 shows that accuracy decreases as PDOP increases. The data were collected on the Clackamas test course with the GeoExplorer 3 receiver. Postprocessing also affects accuracy. Postprocessed data collected with a PDOP of 12 was more accurate than uncorrected data with a PDOP of 4.

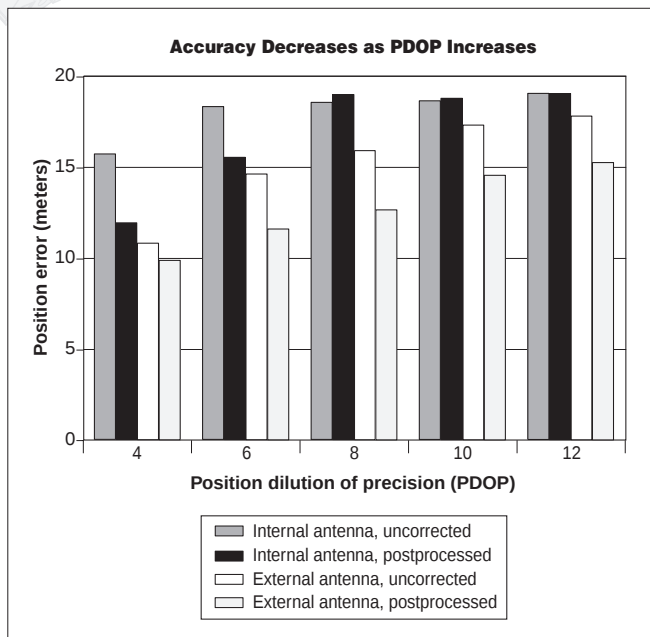


Figure 17—The accuracy of various receiver configurations at the forested Clackamas, OR, test course when acquiring 50 seconds of data at position dilution of precision settings of 4, 6, 8, 10, and 12. The two-distributed-root-mean-square value was calculated from those averages.

Effect of Using External Antennas on the Receivers

All of the receivers tested except the Trimble Pro XR have internal antennas in addition to external antennas. In the open, the internal antennas are usually adequate. Under the forest canopy, however, external antennas can give better accuracy. Figure 18 shows the improvement in accuracy for the Garmin GPS III+ with an external antenna. Results will differ for the different receivers, but the external antennas are more sensitive and help mitigate errors from multipath (reflected) signals.

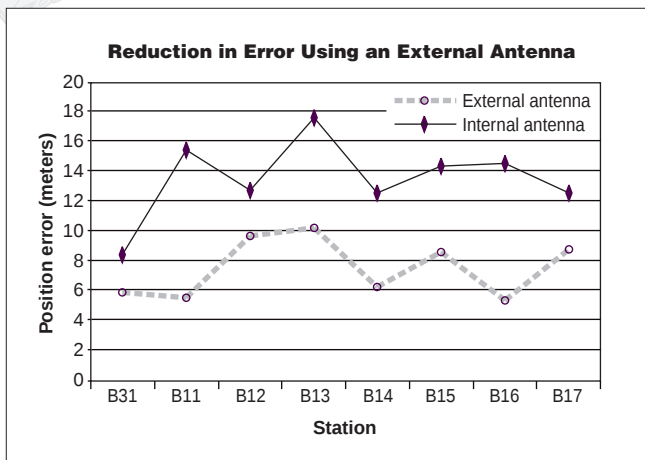


Figure 18—The effect of using an internal or external antenna on two-distributed-root-mean-square position accuracy. These values obtained for the different stations are calculated from the average of 1-, 50-, and 120-position averages.

PLGR +96 Receiver Maintains Higher Accuracy Under the Forest Canopy



The PLGR +96 receiver acquires positions better under the forest canopy than do the C/A code receivers. This is due to the strength of the P(Y) signal, and the chipping rate (the frequency with which the P(Y) code is transmitted). Under an open canopy, the accuracy of the PLGR +96 may not be as good as some

of the newer C/A code receivers. The receiver's major advantage is that it is simple to use, making data acquisition much more efficient. If a poor satellite constellation is used to calculate a position, position errors may be larger.

Real-Time and Postprocessed Positions

Real-time positions or DGPS positions are positions that are corrected in real time. Correction signals are sent to the receiver from a beacon DGPS station or from a network of ground stations to satellites that retransmit them. The DGPS receivers use these signals to correct the data. Real-time data remove most of the position error due to the effects of the ionosphere and some of the multipath error. Postprocessing real-time data

can improve its accuracy, but the improvement is usually not significant. Sometimes the real-time correction signal is interrupted or “shaded out” by terrain or the canopy. It is usually quicker to collect uncorrected data in the field and postprocess the data at the office. Figures 19 and 20 show the position errors of real-time (DGPS) and postprocessed data.

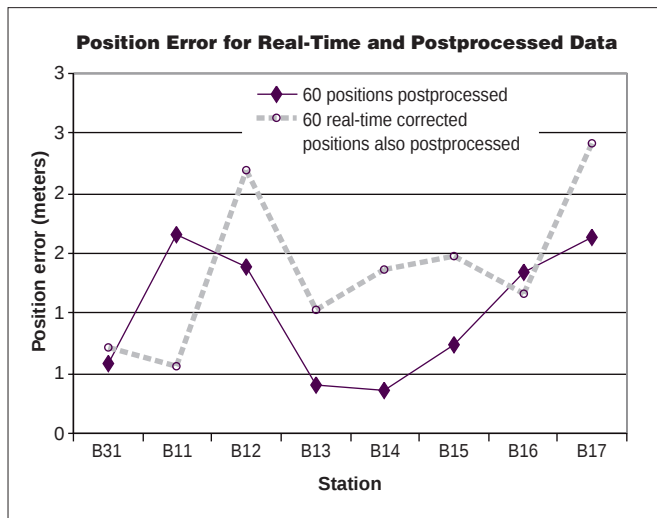


Figure 19—The effect of postprocessing uncorrected data (ssf files) and postprocessing real-time corrected data.

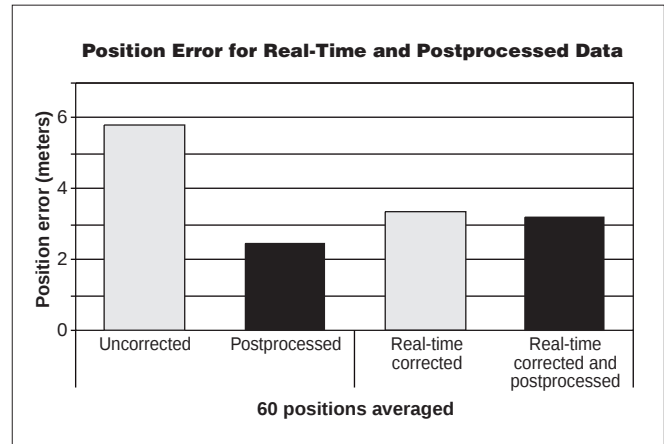
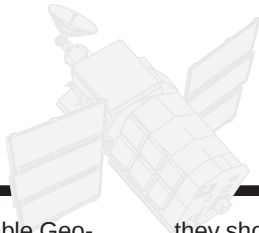


Figure 20—Postprocessing increases accuracy. This increase is significant for uncorrected data, but is very small when real-time-corrected (RT) data are postprocessed. The two-distributed-root-mean-square value was calculated from those averages. The two-distributed-root-mean-square value was calculated from those averages.

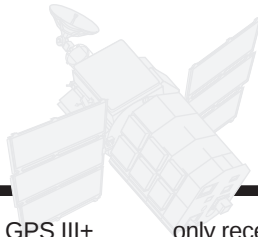
Effect of Battery Voltage



Battery voltage has an effect on PLGR +96 and Trimble Geo-Explorer 3 receivers. Receivers with weak batteries will have difficulty acquiring a signal or GPS position under canopy. When batteries are replaced, the signal is more easily acquired. The Garmin GPS III+ and Magellan Map 410 were operated until

they showed "battery low" on the display panel. A position in open canopy was recorded with low voltage. The batteries were replaced and the same positions were retaken. These two receivers showed little difference in position error whether the batteries were low or not.

Discussion



In some of our tests, smaller units such as the Garmin GPS III+ were used as a guide. The trend seemed to be that if six or seven satellites with high signal strength bars (indicating good PDOP) were displayed on the receiver's skyview screen, the position accuracy was usually good. The Garmin GPS III+ receivers usually produced good accuracy. They are typically on par with the Trimble GeoExplorer 3 receivers.

The Garmin does not have a PDOP or SNR switch, and it does not have a minimum mask angle (which would reduce the potential for multipath signals to be received by the GPS receiver). If the Garmin receiver can see a satellite, it will use it. If the receiver is tracking five to seven satellites with good SNR values (indicated by signal strength bars on the receiver's skyview screen) you will probably get accurate results. If you have only four or five weak satellites, the results won't be very good. Receivers without PDOP and SNR switches, such as the Garmin GPS III+, display poor data rather than indicating that conditions are not favorable for data collection.

The switches on a Trimble GeoExplorer 3 were set to PDOP = 16, SNR = 2, and mask = 3 degrees. The receiver was run with the PLGR +96 and Garmin GPS III+ receivers on the Powell, ID, test course when the satellite constellation was poor. The mission plan indicated the PDOP would be higher than 16 during that period. We got similar position errors (figure 21) from the PLGR +96, Garmin GPS III+, and Trimble GeoExplorer 3 (errors were greater than 20 meters). The Trimble Pro XR was not recording anything because its switches were set so it would

only receive good data. The Garmin will also record two-dimensional fixes using only three satellites when averaging waypoints. The two-dimensional fixes do not include elevation. They are generally not as accurate as three-dimensional fixes. The Garmin was recording two-dimensional fixes during these tests. The Garmin was used with its external antenna, which improved its accuracy (figure 18).

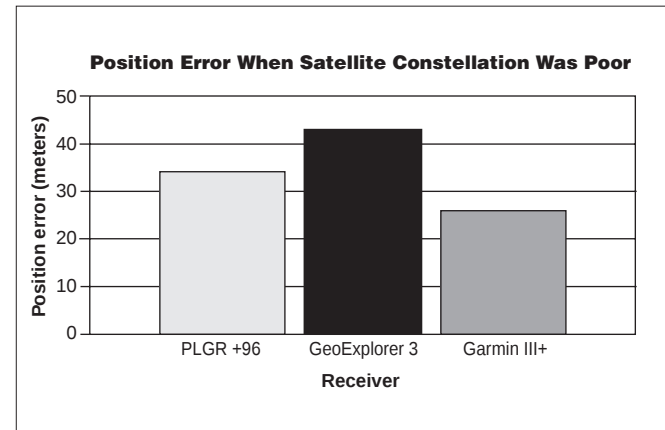


Figure 21—This chart shows position error for three GPS receivers when the satellite constellation was poor. The mission-planning software indicated that the maximum position dilution of precision at the time was 16 or higher. The GeoExplorer 3 mask settings were changed to allow it to record data. The two-distributed-root-mean-square value was calculated from those averages.



Observations About the Receivers Tested

★ The Garmin GPS III+ is a user-friendly receiver that acquires satellite signals quickly. It was easy to average a waypoint. The factory DGPS antenna was not as sensitive as the Trimble antenna and was not able to receive a weak beacon signal when the Trimble Pro XR could acquire one. The receiver provides no way to limit the maximum PDOP setting, the minimum SNR setting, or the minimum mask angle.

★ The Magellan Map 410 is also a user-friendly receiver. Averaging a waypoint is tricky because averaging starts as soon as the receiver quits moving. Some positions a few feet away might be included in the average. The factory DGPS antenna is not as sensitive as the Trimble Pro XR antenna.

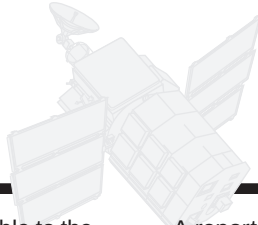
★ The Trimble Pro XR is very easy to use and informs users if a beacon station is available for real-time DGPS. It provides information about the beacon signal: its signal strength, bit rate, frequency, and more. Under a dense canopy, the receiver seems to take a long time to acquire a satellite signal and a position. This is probably due to the receiver switch settings for

PDOP, SNR, and mask angle. The other receivers seem to be more sensitive and more efficient, but they are not receiving good data. The Pro XR provides better accuracy.

★ The Trimble GeoExplorer 3, with its internal antenna, obtains positions that are less accurate than those obtained by the Pro XR and sometimes less accurate than the other receivers. Using an external antenna will provide a big improvement in accuracy for this receiver.

★ The PLGR +96 receiver uses older technology. In the open, it may not be as accurate as the newer receivers. It will acquire a signal under a dense canopy easier than most of the C/A code receivers. It is easy to use, but it must be keyed annually by a P(Y) code custodian or it will not receive the P(Y) code. Two PLGR receivers were compared on the Lubrecht, MT, test course. One receiver was keyed with the P(Y) code. The other had the P(Y) code removed so the receiver could only receive the C/A civilian code. The receiver using the P(Y) code version was more accurate.

Summary



A good satellite constellation (the satellites that are visible to the GPS receiver) is needed to get good data. When the satellite constellation is good, the inexpensive hand-held receivers will provide accurate positions in the open and under a medium canopy. When the satellite constellation is poor or under a heavy canopy, the handheld receivers are not as accurate.

Postprocessing data increases position accuracy, typically by 2 to 4 meters. If data are not needed immediately, it is more efficient to collect uncorrected data and postprocess the information rather than to collect real-time or DGPS positions. This may change in the future when more DGPS stations come online and all areas can receive a DGPS signal from two different beacon stations.

A report of a test of GPS receivers at the Clackamas, OR, test course will be printed in early summer of 2001. That report will evaluate the effects SNR and PDOP have on position accuracy.

Further studies that are needed include:

- ★ Determining the correlation (if any) between the estimated position error indicated on the GPS receiver's skyview screen and the real error.
- ★ Testing real-time accuracy of different DGPS receivers and the efficiency of collecting DGPS data.
- ★ Testing to determine how much postprocessing improves the accuracy of DGPS real-time positions.
- ★ Evaluating the newer PLGR II dual-frequency receiver.

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Library Card

Karsky, Dick. 2001. Comparison of GPS receivers under a forest canopy: after selective availability has been turned off. Tech. Rep. 0171-2809-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 18 p.

Describes tests of various GPS receivers (Rockwell PLGR +96, Garmin GPS III+, Trimble Pro XR, Trimble GeoExplorer 3, Magellan Map 410) at several locations (Powell, ID, Lubrecht, MT, Clackamas, OR). A good satellite constellation (satellites with strong signals within the GPS receiver's view) is needed to get good data. When the satellite constellation is good, the

inexpensive handheld receivers will provide accurate positions in the open or under a medium canopy. The handheld receivers are not as accurate under a heavy canopy, especially when the satellite constellation is poor. Postprocessing data increases position accuracy, typically by 2 to 4 meters. If data are not needed immediately, it is more efficient to collect uncorrected data and postprocess the information rather than to collect real-time or DGPS positions. This may change in the future when more DGPS stations come online and all areas can receive a DGPS signal from two beacon stations.

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