Comparing GPS Receivers: A Field Study

Kindra Serr, Thomas Windholz, and Keith Weber

Abstract: *This paper compares the precision and accuracy of five current global positioning system (GPS) receivers—Trimble ProXR, Trimble GeoXT without WAAS, Trimble GeoXT with WAAS, Trimble GeoExplorer II, and an HP/Pharos receiver. Each of these receivers, along with other similar units, are frequently used today for data collection and integration within a geographic information system (GIS). To compare receivers, we conducted a field study of 15 established survey markers in the city of Pocatello, Idaho. The points were observed on ten different dates with equivalent settings (e.g., averaging and acceptable point dilution of precision—PDOP) and were differentially corrected using Idaho State University's Community Base Station. Overall, the results indicate that the GeoXT is well suited where submeter accuracy is required, while the Pharos receiver is a viable alternative for applications with accuracy requirements of +/- 10 meters and more.*

Introduction

The use of GPS receivers has become widespread over recent years. Many applications, from hunting to surveying, benefit greatly from these devices. The level of accuracy required from application to application varies greatly. It is important to recognize the grades of GPS receivers, namely consumer, mapping, and survey grade, and their ability to accurately map features with or without differential correction. The accuracies of these receivers range from centimeter to several meters, making it necessary to evaluate how accuracy and precision can affect individual applications.

When using a GPS receiver to collect field data, accuracy can be very important, especially when collecting data for use with high-spatial resolution imagery. Quickbird multispectral imagery, for example, achieves a resolution of 2.4 meters per pixel. To coregister corresponding ground sample locations within the correct pixel(s), an accurate GPS receiver is required. To ensure that each field observation is coregistered with the correct pixel, a GPS receiver must achieve an accuracy < 50 percent of the pixel size (e.g., +/- 1.2 m @ 95 percent CI where Quickbird imagery will be used). The increased availability of less expensive, consumer-grade GPS receivers, such as the HP/Pharos receiver used in this study, that are compatible with common GPS software, such as ESRI's ArcPad or Trimble's TerraSync, has raised concern about data quality. Many such receivers collect data that cannot be differentially corrected, increasing the margin of positional errors in the data collected. Consumer-grade receivers are also unable to control the quality of PDOP during data collection, further increasing positional error. To assess the validity of these concerns a field study was designed to calculate and compare the accuracy and precision of several GPS receivers. The goal of this study was to identify the receivers most appropriate for various research, remote sensing, and GIS applications.

Similar studies have been conducted in which GPS receiver accuracy has been investigated. Some studies compared receivers under various collection protocols. Studies conducted in Ridley State Park in Pennsylvania (McCullough 2002) and the Clackamas Test Network in Oregon (Chamberlain 2002) tested the capability of the Trimble GeoXT receiver in forested and clear areas with similar procedures and yielding comparable results in each study. Using internal and external receivers (antenna located within the receiver—internal, antenna attached externally to receiver—external), the studies experimented with WAAS and postprocess differential correction techniques, but used higher PDOP masks (e.g., PDOP mask = 7.0) than used in this study (PDOP mask = 5.0). Published studies comparing various GPS receivers are limited. One study completed in the summer of 2000 compared the accuracy of five different GPS receivers under forest canopy cover with Selective Availability (SA) off (Karsky et al. 2000). In this study, WAAS was not used because it was not yet available. Differential correction was performed on files that could be corrected and positions were taken at known points in forested areas with 1, 60, and 120 positions averaged for each point. None of the above studies mentions how often points were collected over time or how many times points were collected. Each study concluded the receiver tested was appropriate for its research purposes, whatever those may have been. Overall, previous studies have taken into account some of the aspects related to GPS receiver accuracy, but a comprehensive analysis was not completed.

A study conducted in McDonald Forest, located in western Oregon, investigated the accuracy and reliability of consumer-grade GPS receivers under differing canopy conditions. Six different GPS receivers were evaluated for accuracy under three different canopies: open sky, young forest, and closed canopy. Although the collected data was unable to be differentially corrected, points were averaged and compared relative to the known location, allowing for the receivers' accuracies to be compared to one another (Wing et al. 2005). This evaluation did not include real-time correction, nor was it conducted over an extended period of time.

In this paper we describe a field study comparing different GPS receivers to determine optimum applicability for various uses.

$$1.96 \cdot \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}} \qquad 1.96 \cdot \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}{n-1}}$$

Equation 1. Accepted true location based on the mean of observations per sampling site.

$$1.96 \cdot \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \mu_x\right)^2}{n}} \qquad 1.96 \cdot \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \mu_y\right)^2}{n}}$$

Equation 2. Precision of observations at 95 percent confidence.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$$

Equation 3. While the accepted "true" location was based on independent, survey-grade GPS observations of control points, accuracy of tested GPS receivers was calculated as given above at 95.

	Precision		Precision Sum of Squares	Accuracy		Accuracy Sum of Squares
	x	y		x	y	
ProXR	0.38	0.46	0.59	0.46	0.78	0.91
GeoXT	0.43	0.59	0.73	0.53	0.77	0.93
GeoXT with WAAS	0.36	0.66	0.75	0.43	0.96	1.05
GeoExplorer II	1.96	2.90	3.50	2.02	3.25	3.83
Pharos	1.68	2.32	2.86	3.73	4.21	5.62

Table 1. Results of GPS receiver precision and accuracy (in meters) at 95 percent confidence

	Limit	Counts	Limit	Counts
ProXR	>0.5	14%	>1	0%
GeoXT	>0.5	16%	>1	1%
GeoXT with WAAS	>0.5	20%	>1	3%
GeoExplorer II	>0.5	68%	>1	37%
Pharos	>0.5	78%	>1	67%

Table 2. Proportion of extreme positional outliers (>0.5 and >1.0m thresholds) by receiver [0]

Methods

The study area was located in the city of Pocatello and environs (Figure 1). Fifteen points were selected from known locations in Pocatello, Idaho. These points were obtained from the Pocatello ground-control database. Each was referenced in the field with permanent survey markers so the exact location could be relocated easily. Each point was visited ten times over a period of one month at approximately the same time each day (+/- 1 hour). The points were selected for their accessibility and visibility to GPS satellite signals (avoiding vegetation or building interference). These criteria were followed to provide uniformity and the best operating condition for each GPS receiver, thus verifying the precision and accuracy reported by the manufacturer and eliminating as much environmental influence as is possible in a field-based study. Data collection occurred on days where PDOP was within acceptable limits (< 5.0). This was determined using Trimble's QuickPlan software.

The location for each point was observed with the following GPS receivers:

1. Trimble GeoXT receiver with WAAS
2. Trimble GeoXT receiver without WAAS
3. Trimble GeoExplorer II
4. Trimble ProXR
5. HP iPaq with Pharos Navigation software and antenna

Points were collected in latitude/longitude (WGS84), the native reference system for GPS receivers. This was done to avoid any transformation errors that may occur during projection. Receivers did not collect data when the PDOP was > 5.0 to reduce this type of error. Receivers averaged 120 positions per point each time a site was visited. The weather conditions on most collection dates were comparable and skies were relatively cloudfree in all cases.

After collection, each point file was differentially corrected using files from Idaho State University (ISU) GIS Training and Research Center's (GIS TReC) GPS Community Base Station, with the exception of those points collected with the HP/Pharos receiver (the Pharos receiver does not collect the necessary information for differential correction through a base station). The base station was located on the ISU campus in Pocatello. The location of each point ranged from 1.5 km to 12.6 km from the base station. Seven of the 15 original points were then revisited and their location collected using a Leica GPS 530 survey-grade GPS receiver (+/- 0.1m @ 95 percent CI) (Leica 2002), corrected in real time using the ISU College of Technology's GPS CORS station (NGS 2005), also located on the ISU campus. These seven locations were used to assess the accuracy of the GPS receivers, while all 15 locations were used to assess precision.

In this study, precision refers to the repeatability of a specific GPS receiver collecting locational estimates. The error value (i.e., precision) was based on a relative comparison among measurements (Equations 1 and 2) of the same unit on different days. Accuracy, however, is not a relative comparison, but an absolute comparison. In this case, the error value (i.e., accuracy) was calculated (Equation 3) by comparing measurements of a single unit on different days to the known true location of the observed point. These points were collected independently (i.e., different observer, different base station, and well-established GPS receiver accuracy) and corrected using the nearby (< 12 km) CORS station in real time. Thus, 150 samples were collected to calculate precision (15 points visited 10 times each) and 70 samples were collected to calculate accuracy (7 points visited 10 times each).

Spatial analysis of these points was conducted within the native WGS84 geographic reference system. Conversion from

	Stated Accuracy (m)	Calculated Accuracy (m)	Cost
ProXR (Trimble 2005a)	0.5	± 0.91	$8,490 (including data logger)
GeoXT (Trimble 2005b)	<1.0	± 0.93	$4,295
GeoExplorer II (Trimble 2005c)	2.0-5.0	± 3.83	$3,995
Pharos iGPS 360 (Pharos 2005)	<10.0	± 5.60	$300

Table 3. Correlation between manufacturer stated accuracy measured accuracy, and cost of receiver

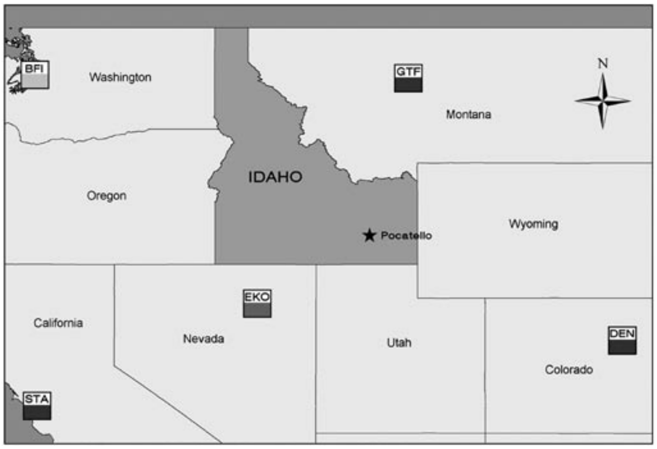

Figure 1. The location of the Pocatello study area and WAAS stations

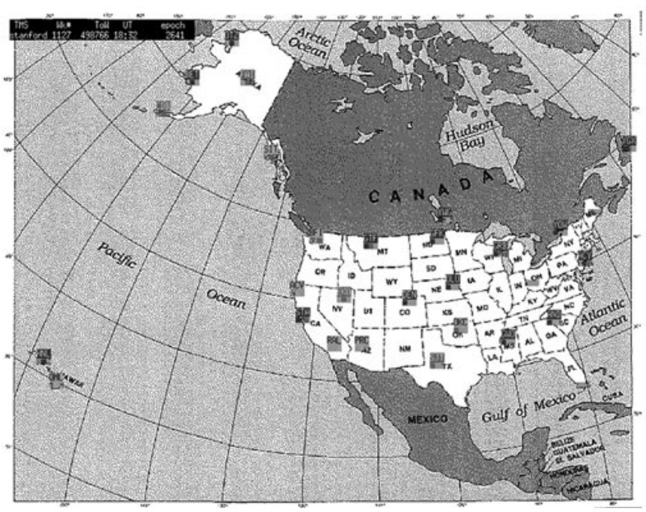

Figure 2. The location of WAAS stations across the United States. Blue indicates active, gold indicates passive, and red indicates communication failure.

decimal degrees (WGS84) to meters was performed using ESRI's ArcGIS software. Resulting units are reported in meters.

Results

The results of precision and accuracy calculations for the tested GPS receivers are given in Table 1. There is a slight difference in the magnitude of errors between x and y coordinates. Sum of squares was used to assess positional accuracy (i.e.,). To assess the utility of each receiver for various applications we used sum of squares.

	Precision	Accuracy	Applicable image resolution	Effective Map Scale
ProXR	±0.59	±0.91	>1.8m	1:1,075
GeoXT	±0.73	±0.93	>1.9m	1:1,100
GeoExplorer II	±3.50	±3.83	>7.7m	1:4,524
Pharos	±2.86	±5.62	>11.2m	1:6,639

Table 4. Suitability of various GPS receivers for use with remote sensing imagery and GIS mapping products

Extreme values of individual point observations (100 percent CI) varied between individual receivers (Table 2). The largest error observed was recorded with the HP/Pharos unit (8.41m).

Discussion

The calculated accuracies were all within manufacturer specified ranges. Table 3 lists manufacturer-stated accuracies with accuracies reported in the results of this paper. Also given is the cost of each receiver provided by the manufacturer. Selecting a GPS receiver that has acceptable accuracy and a reasonable price is important. Generally, increased accuracy comes at higher expense as demonstrated by this study. While purchasing a low-cost receiver, such as the Pharos iGPS 360, may create less expense for an organization, accuracy is compromised. The best accuracy was achieved using the Trimble ProXR (+/- 0.5 m @ 95 percent CI), but this accuracy comes with increased expense. Based on this information, we conclude that accuracy and cost are directly linked. Higher accuracy results in higher receiver costs.

In Table 1, we reported diminished accuracy when the wide area augmentation system (WAAS) was activated on the Trimble GeoXT receiver. We speculate that the cause for this performance decline was the lack of station coverage within our study area. WAAS uses approximately 25 ground reference stations that collect correction data for effects of the atmosphere, clock errors, and slight satellite orbit errors (ephemeris) (Figure 2). The closest ground station to our study area was the Elko, Nevada, station, which is approximately 360 kilometers away (Figure 1). However, the Elko station was offline at the time of this study, making the Great Falls, Montana, station the closest active reference station (523 kilometers away). We assumed that the correction factor applied for the column of atmosphere near Great Falls departed from conditions in and around the study area, therefore, making the WAAS correction less reliable for our application. This was not anticipated, nor is it expected for all applications.

In general, outliers, or extreme values, were within vendor-specified ranges. The Pharos receiver had the greatest extreme values. Thus, where accuracy and precision are concerned, the more expensive receivers outperformed less expensive receivers. It should be noted that Pharos GPS receivers cannot mask for PDOP and do not collect files suitable for differential correction. As indicated in Table 1, the lack of the ability to differentially correct the data is reflected in the relatively large decrease in accuracy compared to its precision. The results reported for the Pharos receiver were effectively best-case scenarios, inferring that accuracy and reliability will quickly deteriorate under more realistic conditions (i.e., poor PDOP, obstruction, etc.).

The achieved accuracy and precision may be attributed—at least in part—to precollection planning. To better ensure field conditions would satisfy the PDOP mask, Trimble's QuickPlan software was used to determine the optimum collection window. This procedure virtually guaranteed that the Pharos receiver, as well as the other receivers tested, would also collect data under ideal conditions. The use of receivers with the ability to implement a PDOP mask allowed us to monitor PDOP, thus assuring the Pharos receiver was collecting data within the same specified PDOP parameters. A more realistic scenario, however, often requires the user to collect data completely independent of other receivers and planning software/tools. For example, if the only available receiver was a Pharos, PDOP could not be observed or masked, which would lead to reduced accuracy. For these reasons, the Pharos receiver cannot be recommended for any tasks requiring < 10 m accuracy, yet it is definitely a viable alternative for other applications, such as data collection for lower resolution imagery (i.e., Landsat).

A limitation of this study was that accuracy calculations were not based on continuously observed data, but rather on field sampling and revisiting a site over a period of time (i.e., one month). This study does, however, offer a comparison between various GPS receivers under similar research conditions. The same level of accuracy detailed in this study may or may not be achieved using similar equipment. These accuracies were based on methods specifically set up to evaluate the equipment available (i.e., long observation times) and may not be similar to typical operating conditions.

Reliable accuracy and precision of GPS receivers has become increasingly important concomitant with advances in high-spatial resolution imagery. GPS receivers with accuracies of 2 to 5 meters, such as the Trimble GeoExplorer II, are unable to collect data that will reliably coregister within the correct 2.4-meter pixel of Quickbird imagery (Table 4) or other similar imagery. Depending on these types of project-dependent considerations, it may be necessary to use a GPS receiver capable of achieving superior accuracy and precision. The Trimble GeoXT tested in this study is a viable receiver for applications requiring high accuracy. Although the Trimble ProXR achieved better results, the GeoXT offers a user-friendly interface and compatibility with common GPS software, such as ESRI's ArcPad or Trimble TerraSync, effectively lowering the total cost of ownership by decreasing the time it would take to learn to use the receiver.

Conclusions

This study assessed four GPS receivers and determined both precision and accuracy at 95 percent confidence. While selection of the optimal GPS receiver is a project-dependent consideration, the data we present is important for GIS managers to help them: (1) understand the differences in horizontal positional accuracy obtained from various GPS receiver types; (2) ensure coregistration of GPS-acquired features and satellite or aerial imagery; and (3) determine the appropriate GPS receiver to use to satisfy mapping scale requirements.

About The Authors

Kindra Serr is the GIS Center Technician at Idaho State University's GIS Training and Research Center. She has a BS in history and a minor in geotechnologies.

Corresponding Address:
ISU GIS Training and Research Center
Campus Box 8130
Pocatello, ID 83209-8130
giscenter@isu.edu

Thomas Windholz is a scientist with Milcord, LLC, and previously the Associate GIS Director at Idaho State University.

Corresponding Address:
Thomas Windholz
Milcord, LLC
20 Godfrey Drive
Orono, ME 04473
twindholz@milcord.com

Keith T. Weber is the GIS Director at Idaho State University. He is a certified GIS professional and past-president of the Northern Rockies Chapter of URISA.

Corresponding Address:
ISU GIS Training and Research Center
Campus Box 8130
Pocatello, ID 83209-8130
webekeit@isu.edu

References

Chamberlain, K. 2002. Performance testing of the Trimble GeoXT global positioning system receiver. Draft report—global positioning system. U.S. Department of Agriculture Forest Service, October 2002, http://www.fs.fed.us/database/gps/mtdc/ geo_xt/trimble_geoxt.pdf.

Karsky, D., K. Chamberlain, S. Mancebo, D. Patterson, and T. Jasumback. 2000. Comparison of GPS receivers under a forest canopy with selective availability off. Project report—technology and development program. U.S. Department of Agriculture Forest Service, December 2000, http://www.fs.fed.us/database/gps/mtdc/gps2000/gps_comparison.htm.

Leica. 2002. GPS System 500: GPS equipment user manual, version 4.0, 59.

McCullough, M. 2002. Performance testing of the Trimble GeoXT global positioning system receiver. Draft report—global positioning system. U.S. Department of Agriculture Forest Service, November 2002, http://www.fs.fed.us/database/gps/mtdc/geo_xt/ridley_ck_geoxt_rich_mccollough.pdf.

NGS. 2005. National Geodetic Survey Continuously Operating Reference Stations (CORS), http://www.ngs.noaa.gov/cgi-cors/corsage.prl?site=idpo.

Pharos. 2005. Pharos science and applications—Bluetooth

navigation, http://www.pharosgps.com/products/bluetooth/PT200.htm.
Trimble. 2005a. GPS Pathfinder Pro XR, http://trl.trimble.com/docushare/dsweb/Get/Document-128930/.
Trimble. 2005b. Datasheet—GeoXT Handheld, http://trl.trimble.com/docushare/dsweb/Get/Document-128927/.
Trimble. 2005c. Trimble GeoExplorer II specifications, http://trl.trimble.com/docushare/dsweb/Get/Document-10404/geo2_specs.pdf.
Wing, M. G., A. Eklund, and L. D. Kellogg. 2005. Consumer grade global positioning system (GPS) accuracy and reliability. Journal of Forestry 103(4): 169-73.