Advantage

Restricted to FERIC Members and Partners

Vol. 7 No. 15 October 2006

Contents

Introduction.......1
Study description 2
Results...............3
Discussion 7
Implementation..10
Acknowledgements..............10

Effect of GPS hardware and differential correction choices on survey results

Abstract

Test results are presented comparing average cross-track errors obtained in kinematic mode for three GPS receivers of different price ranges using three differential-correction methods under three kinds of forest canopies. Data was collected in all weather over a three-month period and was separated by leaf-on and leaf-off conditions. All receiver/correction configurations provided average cross-track errors suitable for most forestry applications. GPS data collection practices are probably more important than the choice of receiver or correction type.

Authors

Rick Reynolds
and
Pierre Turcotte
Eastern Division

Keywords:

Global positioning systems, Differential global positioning systems, forestry, accuracy, real-time correction services, WAAS, CDGPS, post-processing, GPS receivers, weather, canopy.

Introduction

Forestry workers require a high level of accuracy from GPS receivers to meet regulations and conduct quality operations. The challenging forest environment usually dictates the use of high-price receivers, which may become very expensive if many units are required. To reduce costs, many organizations are using less-expensive GPS receivers, but there is uncertainty that they provide sufficient accuracy.

Differential correction offers more accurate positioning, whether by post-processing or in real-time. Post-processing is generally thought to be more accurate, but requires a base station and office time. Real-time correction is performed immediately as the GPS data is being collected by receiving a correction message usually broadcasted from a satellite. There are two free real-time satellite systems relevant to North America: WAAS, the American system and CDGPS, the Canadian system. Because the CDGPS correction message is customized for Canadian locations, it may be more accurate than WAAS.

The forest represents a very difficult environment for the reception of GPS, WAAS and CDGPS signals. Moreover, efficient use of workers' time means that much GPS data is collected in poor weather conditions which can compound reception problems.

Can forestry workers get the required accuracy with less expensive equipment? What conditions confound accurate positioning, and can equipment choice overcome adverse conditions? Is specific equipment necessary to ensure certain levels of positional accuracy? FERIC conducted a study to answer these questions.

The results obtained in this study are specific to these brands and may not necessarily be representative of the performance of other brands of the same price class. As well, manufacturers regularly upgrade their receivers' firmware, and the results of this study may not reflect the performance of these same brands operating with new firmware made available since this study.

Study description

Three brands of GPS receivers representing three price levels (low, medium and high) were tested with three differential correction methods: real-time WAAS and CDGPS, and post-processing. Brand selection was based on availability and prevalence in eastern Canadian forestry operations. Two receivers of each brand were used and configured as shown in Table 1.

The masks on the ProXRS receivers were set so as not to restrict the receiver from recording any reasonable positions. Subsequent data analysis indicated that the masks used did not result in unacceptable accuracies for a receiver of this type and specifications. It is these unfiltered results that are thus reported here. Since the configuration of the SXBlue requires special expertise and is rarely done by users, factory defaults were used. The GPSMAP 76 is not configurable for these mask values. All units used external antennae recommended by the manufacturer.

The GPSMAP 76 files are not capable of being post-processed. The receivers were thus set up with the two real-time corrections as were the two SXBlue receivers whose files can be difficult to post-process. One ProXRS received WAAS corrections while the other was post-processed with three different base stations as indicated in Table 2. The equipment configuration did not allow for inclusion of a ProXRS with CDGPS corrections. However, it was anticipated that there would be much difference from the results obtained with WAAS for this receiver.

Table 1. Configuration of test receivers

	Trimble ProXRS	Geneq SXBlue	Garmin GPSMAP 76
Price	High	Medium	Low
Logging rate	1 per sec. (1 Hz)	1 per sec. (1 Hz)	1 per 2 sec. (0.5 Hz)
Elevation mask	5	Default	Default
PDOP mask	60	Default	Default
SNR mask	1	Default	Default
Antenna	Dealer supplied	Panasonic VIC-3	GA-27
Correction type performed			
Post-processing	Yes	No	No
WAAS	Yes	Yes	Yes
CDGPS	No	Yes	Yes

Forest Engineering Research Institute of Canada (FERIC)

Find us Online!
www.feric.ca

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
☎ (514) 694–1140
(514) 694–4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
☎ (604) 228–1555
(604) 228–0999
admin@vcr.feric.ca

Publications mail #40008395 ISSN 1493-3381

Disclaimer
This report is published solely to disseminate information to FERIC's members. It is not intended as an endorsement or approval by FERIC of any product or service to the exclusion of others that may be suitable.

Cette publication est aussi disponible en français.

© Copyright FERIC 2006.
Printed in Canada on recycled paper produced by a FERIC member company.

Table 2. Base stations used for post-processing

	Location	km from study	Details
1	Ottawa	133	National Research Council
2	Paul Smith College, NY	112	CORS network
3	Montreal	27	Ministère des ressources naturelles et de la faune

NMEA data were logged using a Panasonic CF-P1 Toughbook while a Trimble TSC1 data logger using TerraSync recorded uncorrected ProXRS data. All the equipment was mounted in a custom-built backpack frame for transport during the study (Figure 1). A test was conducted to confirm that the signal-to-noise ratio (SNR), and thus operating performance of each receiver, was not affected by the proximity of the other operating equipment.

Data collection took place at FERIC's test area near Montreal over a three-month period that represented both leaf-on and leaf-off periods. Three polygons of about 4 ha each were selected to represent three forest conditions: open canopy with surrounding trees, partial canopy and full canopy. Data was collected in all weather conditions for 39 days – 24 with leaf-on and 15 with leaf-off. Each day, the equipment was carried in the backpack 3 times around each polygon, resulting in 81 separate tests per day (3 polygons, 3 repetitions and 9 equipment/correction combinations), creating a theoretical 3159 separate tests or circuits. Only 2926 circuits were recorded due to various access and technical problems. To eliminate the effect of a changing satellite constellation, the schedule called for each circuit to start and end exactly 4 minutes earlier each day. Before each polygon was started, all receivers were calculating 3D positions and corrections in the case of real-time units. Once walking started, no stops were made to reacquire lost signals or ensure positions at strategic locations. Weather conditions were recorded and hourly weather data was obtained from the local Environment Canada station for each circuit.

Figure 1. Equipment assembled in backpack.

Results

Data analysis focused on determining the extent to which various factors affected cross-track error. Cross-track error is the perpendicular distance from the traveled path to recorded points. For each circuit, all recorded data was summarized and an average cross-track error was calculated. Figure 2 indicates the overall means of the circuit averages of cross-track errors for each equipment/correction combination in each canopy type. About 66% of the individual circuit averages lie within the standard deviation indicated by the vertical green bars.

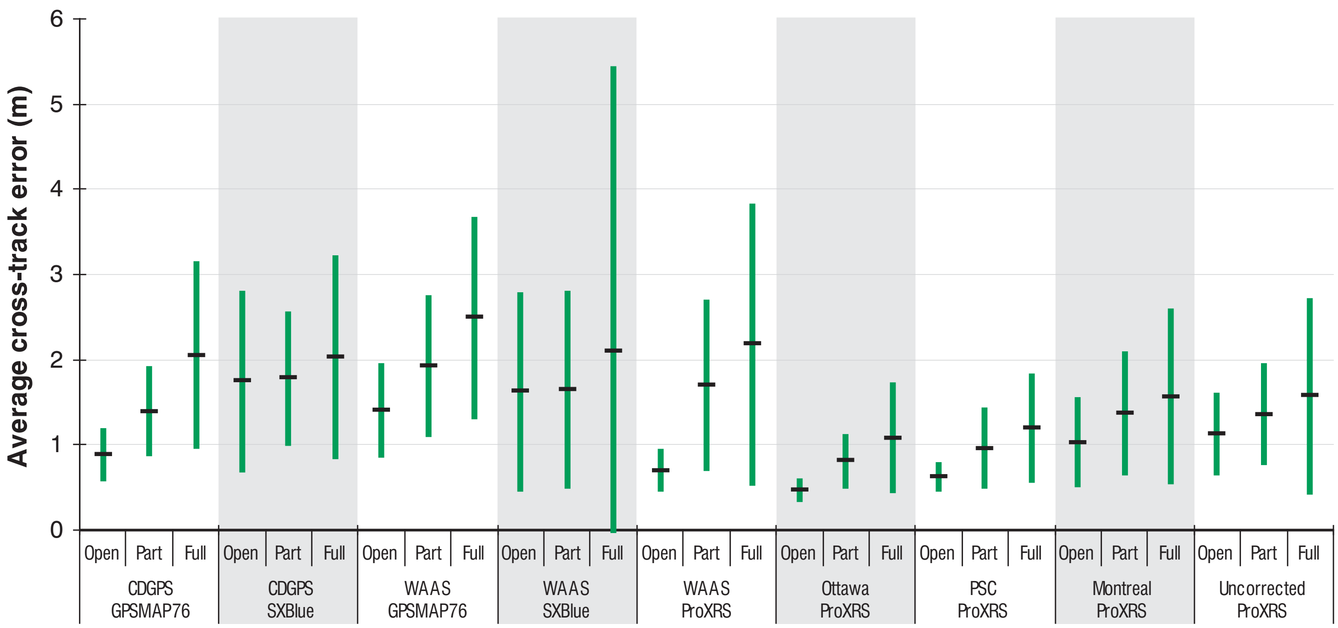

Figure 2. Means and standard deviations of average cross-track errors.

The means of the circuit average cross-track error for all equipment/correction combinations were less than 2.5 m. Standard deviations varied widely from 0.1 m for Ottawa post-processed ProXRS data under an open canopy to 3.3 m for the WAAS-corrected SXBlue under full canopy. In the open canopy, all equipment combinations provided circuit averages of less than 1 m at least some of the time. Means for all corrected ProXRS data in the open canopy were less than 1 m and about 1.5 m for the real-time-corrected SXBlue and GPSMAP 76. Under partial canopy, all equipment/correction combinations had average cross-track errors of less than 2 m for the majority of their circuits. In full canopy conditions, real-time corrected data of all receiver types had mean circuit averages near 2 m, while for the post-processed ProXRS it was generally less than 1.5 m.

An increase in the means and standard deviations of circuit average cross-track error with denser canopies was a common pattern to all equipment/correction combinations. Because of the considerable overlapping of the standard deviations, particularly under full canopy, a generalized analysis of variance (95% confidence level) was conducted on the data to examine whether the results from one equipment/correction combination are statistically different from another combination. All possible two-way comparisons (36) were made within each canopy type. This analysis showed that with an open canopy there was a significant performance difference between most of the equipment/correction combinations (31 of the 36 comparisons). Less performance difference was noted under partial canopy (28 of 36), and especially under full canopy (only 14 of 36). Figure 3 summarizes the relative performance of the equipment/correction combinations and indicates where there is no statistical difference between the performances of the equipment/correction combinations. In the figure, the arrows point to the receiver/correction combination that provided the lower cross-track errors of the pair compared, whereas the green shading indicates no statistical difference in performance. For example, the WAAS-corrected ProXRS did not perform any differently (better or worse) than the SXBlue or GPS-MAP 76 (WAAS or CDGPS-corrected) under full canopy. However, it did perform differently than all the post-processed and uncorrected ProXRS combinations.

OPEN CANOPY		CDGPS SX-Blue	CDGPS GPSMAP76	WAAS SX-Blue	WAAS GPSMAP76	WAAS ProXRS	Uncorrected ProXRS	Montreal ProXRS	Ottawa ProXRS
P. Smith College	ProXRS	←	←	←	←	■	←	←	■
Ottawa	ProXRS	←	←	←	←	←	←	←	
Montreal	ProXRS	←	■	←	←	←	■		
Uncorrected	ProXRS	←	↑	←	←	↑			
WAAS	ProXRS	←	←	←	←				
WAAS	GPSMAP76	←	↑	←					
WAAS	SX-Blue	■	↑						
CDGPS	GPSMAP76	←							

PARTIAL CANOPY		CDGPS SX-Blue	CDGPS GPSMAP76	WAAS SX-Blue	WAAS GPSMAP76	WAAS ProXRS	Uncorrected ProXRS	Montreal ProXRS	Ottawa ProXRS
P. Smith College	ProXRS	←	←	←	←	←	←	←	■
Ottawa	ProXRS	←	←	←	←	←	←	←	
Montreal	ProXRS	←	■	←	←	←	■		
Uncorrected	ProXRS	←	■	←	←	←			
WAAS	ProXRS	■	↑	■	←				
WAAS	GPSMAP76	■	↑	↑					
WAAS	SX-Blue	■	↑						
CDGPS	GPSMAP76	←							

FULL CANOPY		CDGPS SX-Blue	CDGPS GPSMAP76	WAAS SX-Blue	WAAS GPSMAP76	WAAS ProXRS	Uncorrected ProXRS	Montreal ProXRS	Ottawa ProXRS
P. Smith College	ProXRS	←	←	←	←	←	■	■	■
Ottawa	ProXRS	←	←	←	←	←	■	■	
Montreal	ProXRS	■	■	■	←	←	■		
Uncorrected	ProXRS	■	■	■	←	←			
WAAS	ProXRS	■	■	■	■				
WAAS	GPSMAP76	■	■	■					
WAAS	SX-Blue	■	■						
CDGPS	GPSMAP76	■							

Lower cross-track error	
←	To left
↑	Above
■	No difference in cross-track error

Figure 3. Comparisons of relative performance.

By knowing precisely the start and end times of each circuit, a theoretical number of points to capture for each circuit can be calculated. Figure 4 shows the actual number of logged positions expressed as a percentage of the theoretical. There is not much difference overall among the units in the open canopy condition (>90%). Very little difference also exists in both the partial and full canopies (80-90%), except for unexplained low values for the ProXRS using WAAS.

It has long been known that the presence or absence of hardwood leaves, as well as other environmental factors such as wetness of foliage, can affect the quality of the GPS data. The relationship between these factors and data quality has not been well documented yet. Our study gathered foliage condition and weather information throughout the collection period. When data was separated by leaf-on and leaf-off season, average circuit cross-track errors for all equipment/correction combinations were smaller in the leaf-off season. Figure 5 shows the differences in cross-track errors for leaf-on versus leaf-off.

Many parameters relating to satellite constellation as well as weather data were recorded throughout the study. While initial analysis indicates that there may be some relationship between cross-track error, foliage wetness and wind strength, this data requires additional detailed analysis.

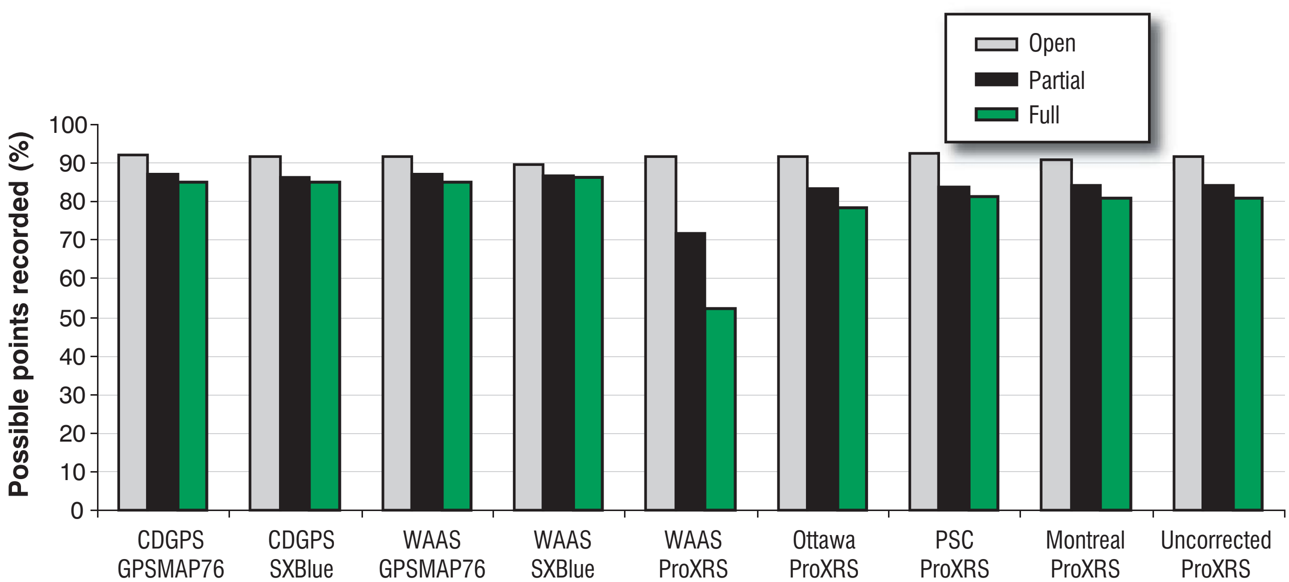

Figure 4: Percent of potential positions recorded.

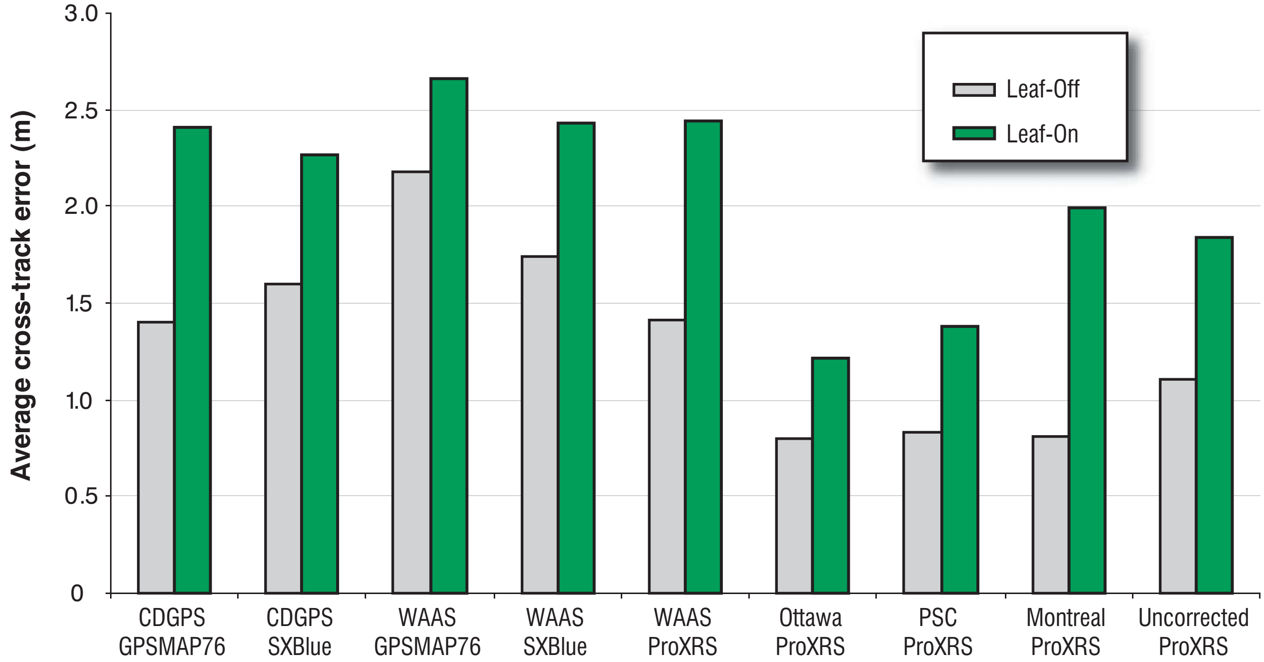

Figure 5: Average cross-track errors during leaf-on and leaf-off.

Discussion

Cross-track error

Cross-track error measurements in kinematic tests such as done in this study offer an interesting characteristic: they show better accuracy than stationary tests of the same receiver. This is illustrated in Figure 6 where an actual positional error of 2 m provides only a 0.5-m kinematic cross-track error. This phenomenon means that GPS receivers used in dynamic mode will typically get better cross-track error than the manufacturers' static specifications.

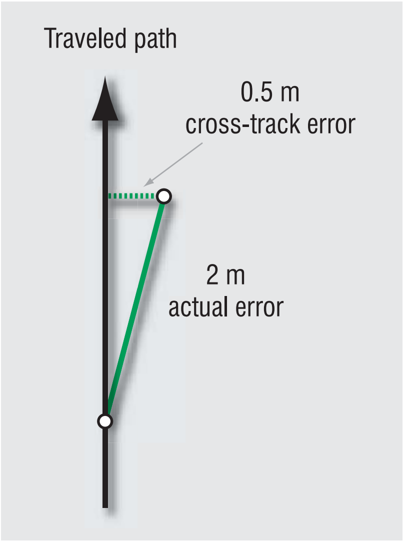

Figure 6: Example of actual and cross-track errors.

An actual 2-m error could provide a cross-track error ranging from 0 m to 2 m. The expected average cross-track error for any GPS receiver in dynamic mode can be calculated by multiplying the manufacturer's static accuracy specifications by 0.707. For example, a static specification of 1.2 m (RMS) will provide a cross-track error of 0.85 m (RMS).

Dead reckoning and smoothing

Dead reckoning is the process of estimating a position by applying a course, speed and time to the last known position. Some GPS receivers do this for a period when signals are lost and a GPS position can not be calculated. Dynamic positional smoothing is a mathematical calculation performed on-the-fly that uses modified dead reckoning to predict where the next position will be (Figure 7). If the next calculated position is not exactly the same as the one predicted by dynamic smoothing, the position is pulled slightly toward the predicted position and then recorded.

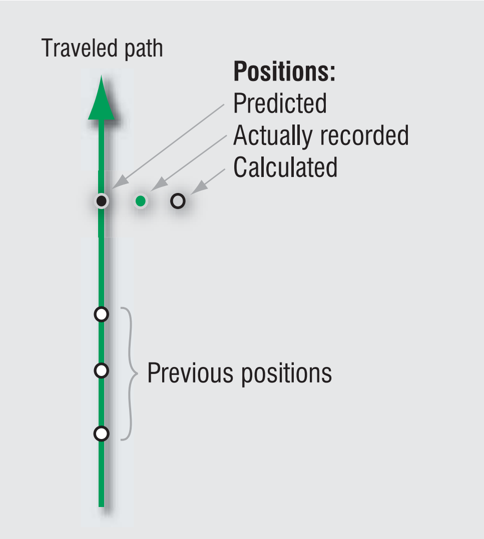

Figure 7: Dynamic smoothing.

This has the effect of smoothing out a traveled path and has led some people to believe that certain GPS receivers that strongly smooth the data are more accurate. Smoothing will provide smaller cross-track errors if the traveled path is straight or has only very gradual curves. However, it can produce significant misrepresentations when the traveled path has sharp turns (Figure 8). Of the receivers involved in this test, the GPSMAP 76 appears to have a smoothing function while the SXBlue and ProXRS perform no dead reckoning or dynamic smoothing. Given that the polygons surveyed had relatively few sharp turns, this is the most likely explanation for the good relative performance of the GPSMAP 76 in terms of both cross-track errors and percentage of points recorded.

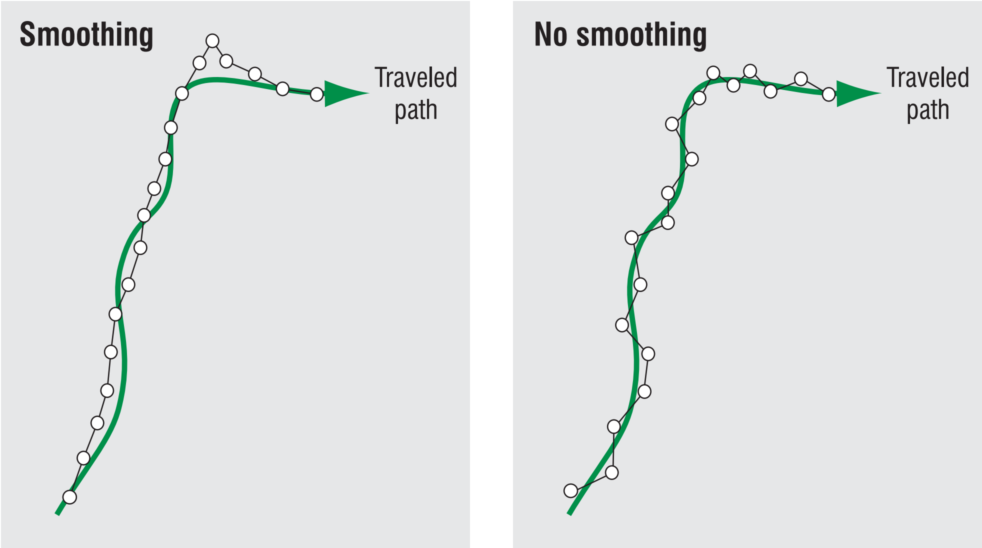

Figure 8: Smoothing vs. no smoothing.

Accuracy

The results of the analysis of variance (Figure 3) indicate that the equipment combinations show distinct differences in the open canopy conditions, with the ProXRS generally providing the best results. However, all equipment/correction combinations provided a mean circuit average cross-track error of less than 1.75 m, which is within the generally accepted levels of accuracy for forestry. Therefore, any of these equipment combinations are suitable in an open canopy. On the other hand, their performance variance under full canopy was so great that few significant differences were identified – although the ProXRS data post-processed with Ottawa and Paul Smith College corrections stood out. Even post-processing did not necessarily guarantee better results as demonstrated by the Montreal post-processed data. Therefore, even under full canopy, receiver choice or real-time correction choice made no real difference, but for the opposite reason: the circuit average cross-track errors are so variable.

Mask parameters vs. accuracy

Our analysis used ProXRS data collected with very loose mask parameters. A small sample of the WAAS-corrected ProXRS data, filtered to remove points with a PDOP greater than 6, indicated that in difficult canopy conditions, circuit average cross-track error can be improved by about 1 m and standard deviation reduced by about 1 m as well. However, the filtering also resulted in a 35% reduction in points. Combined with the already low percentage of possible points recorded (Figure 4), this reduction may result in too few points to adequately define a feature's shape.

Applications

In forestry, GPS is used for two primary applications: area determination and accurate placement of a line. The first does not require high accuracy of each point, because in kinematic mode, it has a 50% chance of falling on one side or the other of the travel path, resulting in the cross-track error of half the points being off-set by that of the other half. This results in a fairly good area calculation regardless of the magnitude of the average cross-track error. The more important consideration in this task is to ensure that positions are recorded regularly and especially at strategic points so as to ensure that no large areas are omitted by a period of lost positions. For example, in a worst case scenario, if a GPS receiver recorded points consistently 4 m outside the travel path for a complete circuit of an 80-ha polygon, this would result in an area over-calculation of 1.4 ha (1.8%). An error of this same scale could occur from simply failing to record positions for about 5 min while walking a polygon. Figure 4 suggests that this sort of lost recording time is more likely to be a consequence of poor data collection practices than equipment choice.

Systematic cross-track errors or lost positions have a greater relative impact as the block size gets smaller.

The second primary use of GPS – placement of a line such as a riparian zone boundary – requires higher accuracy but is done in real time and usually under full canopy where higher cross-track errors are experienced. Our study shows that upgrading receivers or changing type of differential correction does not necessarily improve kinematic accuracy under canopy. In this situation, it is even more critical that field workers use best practices when gathering GPS data.

Best practices and this study

In several ways, this study did not represent best practices of GPS data collection.

Firstly, once the GPS receivers began logging, they were not checked to ensure continued good operation until after the circuit was completed. Best practices require that the user continuously monitors receiver performance. Secondly, although care was taken to ensure that the antennae were mounted on the transport pack with a good attitude, they may have moved during data collection, resulting in poorer reception. Thirdly, in order to gather a full range of data for analysis, some of the receiver settings may not have been optimal for the conditions, in particular, the masks on the ProXRS. As such, the data that was used for analysis represents what might be obtained by a field worker who took little care in how a survey was conducted. However, data was collected in a similar manner for all receiver/correction combinations.

WAAS and CDGPS

Although CDGPS produced lower mean circuit cross-track errors and smaller standard deviations than WAAS, an analysis of variance showed that there was no significant difference between them. This result may not hold true throughout Canada, particularly at more northern latitudes further from the WAAS reference station network.

Between February and April 2006, the WAAS satellite that provided the correction message for this study was moved from its location at the time of the study to a position far to the west. This resulted in a change in the ability of GPS receivers to acquire the WAAS signal. It became easier in western Canada, but more difficult in eastern Canada. During the study, these satellite signals came in from the south-east at about 34° above the horizon, but are now coming in from the south-west at about 7° above the horizon. Since this move, two new WAAS satellites have begun broadcasting test messages and are expected to become fully operational in the autumn of 2006. The new satellites will provide better WAAS service to most areas of Canada, especially in the west. Until these become operational, some manufacturers have provided firmware updates to allow their receivers to utilize the test messages. Users should investigate the implications of these changes for operations in their region.

Implementation

Whether for area determination or boundary placement, either in open, partial or full canopy, the choice of receiver or type of differential correction probably has less effect than the methodology and techniques used to collect GPS data. If used with best practices, less expensive receivers can provide the accuracy generally required for most forestry applications.

Where critical boundary location under full or partial canopy requires less than 2 or 3-m accuracy, good GPS gathering practices with a more expensive receiver are recommended. For documentation of the location in a GIS database, post-processing of the data is preferable. For navigation of such boundaries within 5-m accuracy, WAAS or CDGPS combined with even a low-cost receiver and best practices will provide suitable results.

If accurate GPS work is required under hardwood cover, a 0.5 to 1-m advantage may be gained if the task can be scheduled for the leaf-off season.

Although less expensive GPS receivers may provide suitable accuracy when used with best practices, it should be borne in mind that these units often lack the ability to record additional feature data.

Acknowledgements

The author thanks Jean-Yves Lauture, from Geneq Inc, Montreal, Quebec, for assistance and loan of the Panasonic Toughbook data loggers and the SXBlue GPS receivers.

The author also thanks Vern Vogt, from Base Mapping and Geodetic Services Branch, Ministry of Agriculture and Lands, British Columbia, for loan of the CDGPS receiver.