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ACCURACY AND PRECISION TESTS USING DIFFERENTIAL GPS FOR NATURAL RESOURCE APPLICATIONS

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INTRODUCTION

The use of global positioning system (GPS) receivers is gaining widespread use, both for forestry and many other natural resource applications. A number of studies have recently been carried out to determine the effectiveness of GPS in such applications. Few of them, however, have identified the actual accuracy level of code-correlating GPS receivers as compared to accurately surveyed control points.

Code-correlating receivers are typically used in forestry applications. These receivers have manufacturer-specified accuracies ranging from 15–25 m (standard GPS positioning); in differential mode (differential GPS positioning or DGPS), manufacturer-specified accuracies range from 1–5 m.

For this project, baseline studies were conducted to determine the accuracy level of Garmin SRVY II code-correlating receivers. This technical report provides a summary of the accuracy tests undertaken, and presents some preliminary results from typical field applications.

METHODS AND MATERIALS

Digital Base Maps and Desktop Mapping Software

One of the principal reasons for using GPS in natural resource applications is to gather position information on geographic features that are represented on maps by points, lines, and polygons. To this end, GPS positional data was stored in digital format and later represented on appropriate digital maps at various field locations. National Topographic Series (NTS) digital base maps at a scale of 1:250 000 were used to represent areas of regional extent, and 1:20 000 digital Ontario Base Maps (OBMs) were used at a local level. Desktop mapping software (QuikMAP, DOS/Windows) and GPS linkage software (QuikELINX, DOS/Windows) were used to automatically convert and plot the GPS point, line, and polygon information on the appropriate base maps.

Nondifferential GPS (Standard GPS)

Standard GPS positions were collected for comparison with real-time DGPS (RT-DGPS) and postprocessed DGPS (PP-DGPS). For this test, a Garmin SRVY II GPS receiver was set up on a surveyed position (control point), and both averaged and dynamic position data were collected.

Postprocessed Differential GPS

Postprocessed DGPS accuracy tests were conducted for comparison with results derived from RT-DGPS. Two Garmin SRVY II GPS receivers were used; one for the base station (Control Point 1) and one at the remote location (Control Point 2)(Fig. 1).

Real-time Differential GPS

Real-time DGPS is the method by which differential GPS accuracies are obtained on a real-time basis. Two methods were employed to test the real-time differential accuracy of the GPS receivers; one using a United States Coast Guard radio beacon transmitter, and a second using ultra-high frequency (UHF) radio modems.

United States Coast Guard Real-time DGPS

The United States and Canadian coast guards are developing a RT-DGPS service throughout the Great Lakes, the eastern and western coasts of North America, and the Gulf of Mexico to provide the required differential correction to DGPS-capable receivers that are within range of transmitting radio beacons. The service will be used primarily

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for navigation, but may also be applied on land when within range of radio beacon transmitters.

To use this service, the GPS receivers must be designed to accept the appropriate digital format of the data. This format is referred to as the RTCM-104 format (Radio Technical Commission for Maritime Services Special Committee 104). In addition, a GPS receiver must be connected to a radio beacon receiver (or radio modem) that has been tuned to the appropriate United States Coast Guard frequency.

To carry out accuracy tests for this project, the GPS antenna was positioned on a surveyed control point (Fig. 1), and a radio beacon antenna was placed on the roof of a nearby building. The radio beacon receiver was then tuned to the Whitefish Point, Michigan, transmitter frequency (318 KHz).

Real-time DGPS Using UHF Radio Modems

For locations that are out of range of United States Coast Guard radio beacon transmitters, it is possible to duplicate the above process using a base station GPS receiver and a radio modem. The modem transmits the required DGPS correction at a predetermined frequency to a remote GPS receiver that is connected to a radio modem. However, the GPS receiver at the base station must have the capability to produce the DGPS corrections in the RTCM-104 digital format. To provide full satellite coverage, the base station GPS receiver should be capable of tracking up to eight GPS satellites. Once again, the base station and remote GPS antennae were located at the surveyed positions described earlier (Fig. 1).

GPS Data Gathering

For each of the DGPS and GPS methods previously described, two types of data were gathered; averaged positions and dynamic positions.

Averaged positions represent a series of averages calculated over 15-, 30-, and 60-minute intervals (Table 1, Fig. 2) at various times of the day over a period of 2 months. This sampling approach, designed to introduce randomness to the geometry of the GPS constellation, ensured that results would have a general application. For all methods, deviation of the average (in meters) from a known control point was noted for the northing, easting, and elevation values.

For the RT-DGPS, using radio modems and the postprocessed DGPS, 30- and 60-minute averages did not improve the results of 15-minute averages. Therefore, no detailed sampling was undertaken for 30- and 60-minute durations.

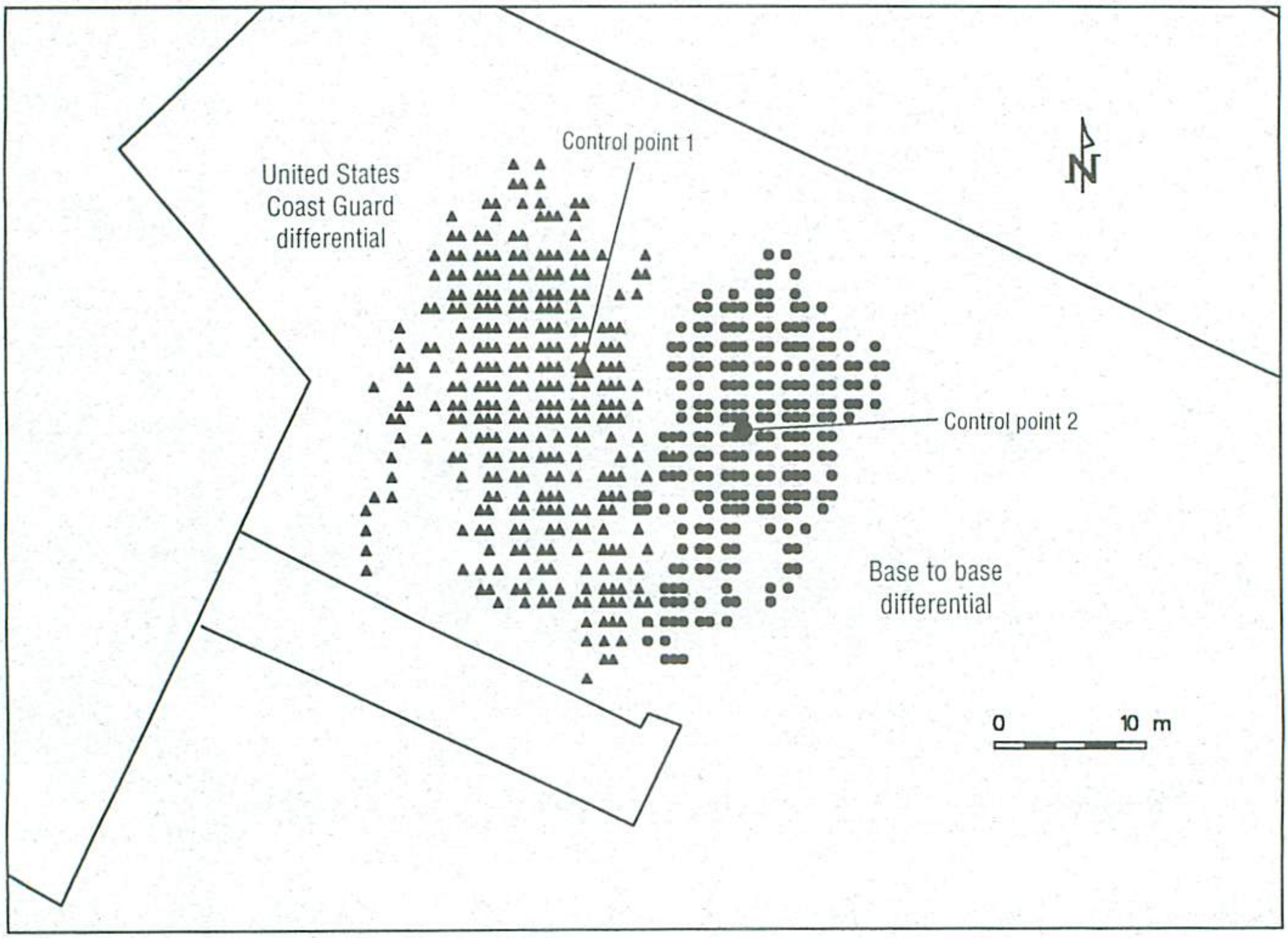

Figure 1. Dynamic, real-time differential GPS positions using the United States Coast Guard and UHF radio modems relative to second order control points. Garmin SRVY II GPS receivers were used.

Table 1. Accuracy and precision test summary for a Garmin SRVY II GPS receiver.

	15-minute Sampling Interval Accuracy: Average, Range				30-minute Sampling Interval Accuracy: Average, Range			60-minute Sampling Interval Accuracy: Average, Range		
Departure from control point	Easting (m)	Northing (m)	Change in elevation	Number of averages	Easting (m)	Northing (m)	Number of averages	Easting (m)	Northing (m)	Number of averages
Standard GPS	-3,+30 to -30	+6,+25 to -25	+3,+60 to -40	20	-4,+10 to -15	-1,+10 to -15	20	-2,+5 to -10	0,+10 to -10	20
Postprocessed differential GPS	0,+1 to -1	0,+2 to -1	0,+2 to -2	10			Not determined			
U.S. Coast Guard RT-DGPS	-4, 0 to -6	-2, 0 to -6	+6,+10 to 0	10	-4,-2 to -6	-3,0 to -6	10	-4,-2 to -6	-2,0 to -4	10
UHF radio modem RT-DGPS	0,+2 to -1	0,+2 to -1	-6,0 to -10	10			Not determined			

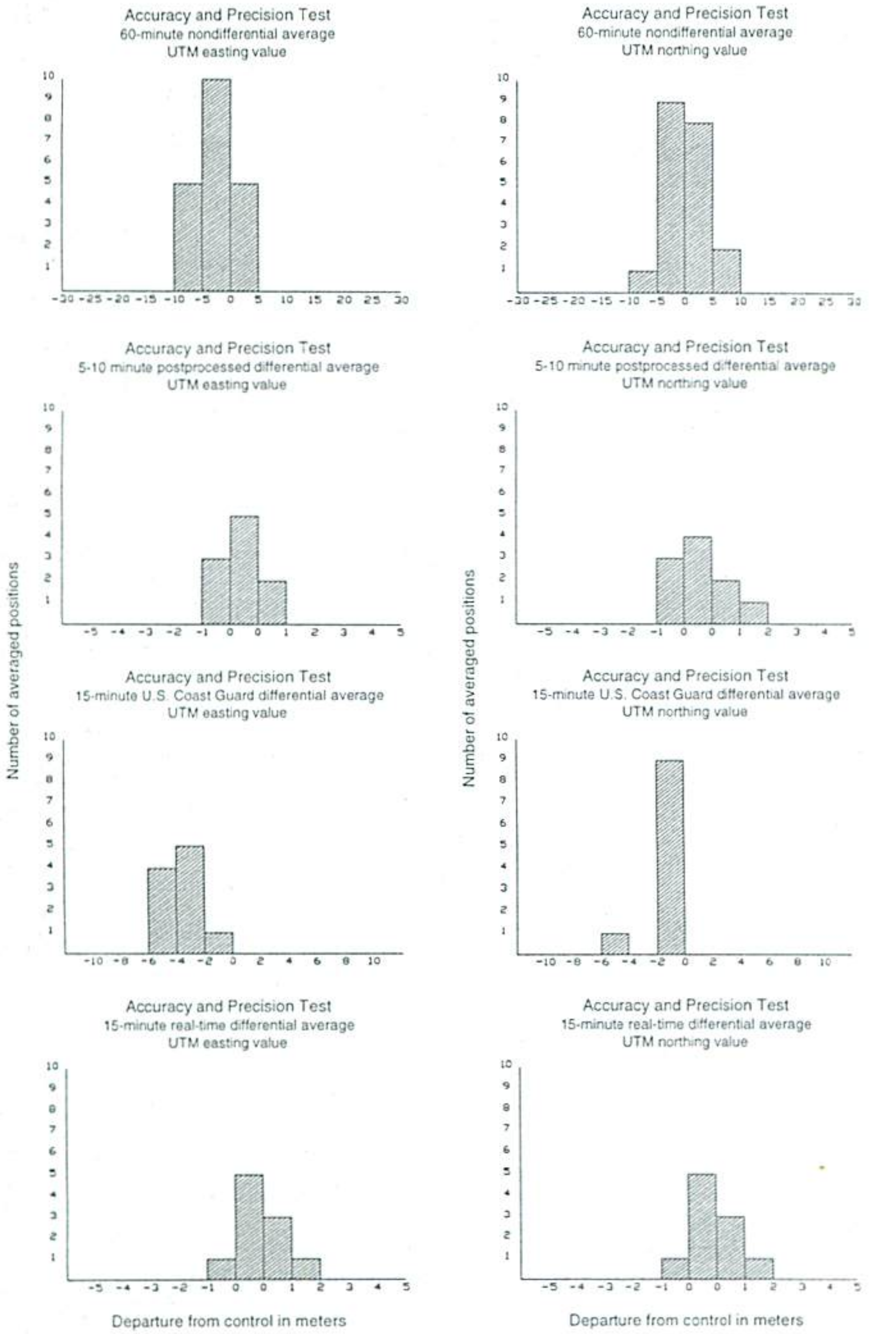

Figure 2. Histograms of the averaged DGPS and GPS positions (easting and northing) for 15- and 60-minute sampling intervals, respectively.

Dynamic positions represent single DGPS and GPS positions plotted relative to a control point. The GPS data were transferred to the mapping software using the GPS linkage. The number of positions falling within a specified radius of the control point was tabulated and plotted as a cumulative frequency distribution (Fig. 3).

RESULTS

Accuracy and Precision

Non-DGPS (standard GPS)

A cumulative frequency distribution indicates that 90 percent of the dynamic GPS positions fall within 30 m of the control point (Fig. 3).

Averaged positions show improvement in precision and accuracy from 15- to 30- and 60-minute sampling intervals (Table 1). The data progressively approaches a normal distribution for the 30- and 60-minute sampling intervals (Fig. 2).

Postprocessed DGPS

The cumulative frequency distribution of the dynamic DGPS positions indicates that 90 percent of these fall within 10 m of the control point (Fig. 3). A frequency distribution of the departure from the control point for the northing, easting, and elevation values (Fig. 4) indicates a normal distribution for a 15-minute sample (780 positions).

The averaged positions display a symmetrical distribution, with an accuracy of 0 (±1 to 2 m) for the 10-minute sampling interval. This

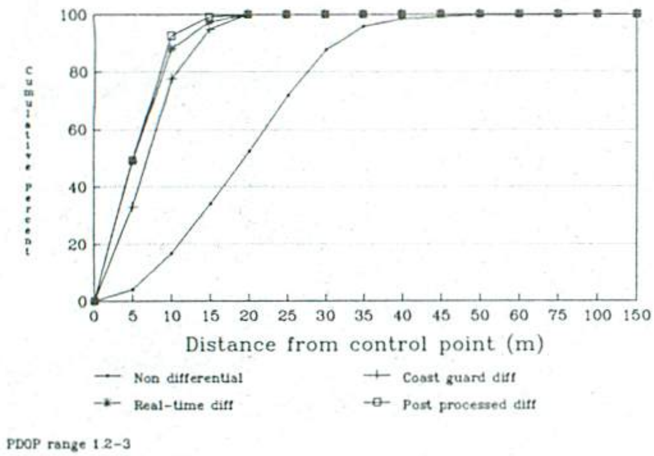

Figure 3. Cumulative frequency distributions of DGPS and GPS dynamic positions with distance from a control point, using the Garmin SRVY II.

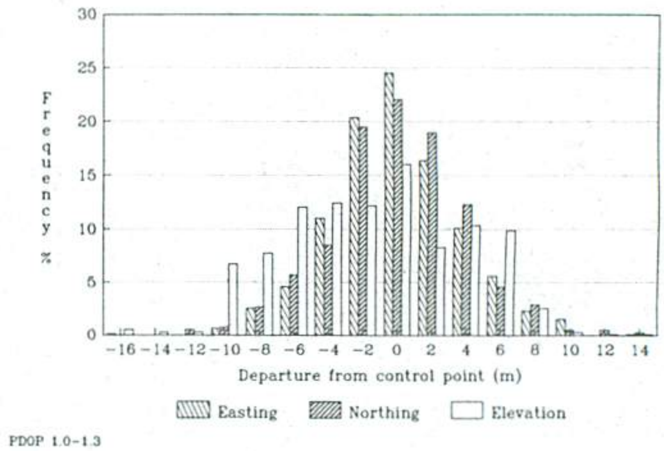

Figure 4. Frequency distribution of the departure from the control point for the easting, northing, and elevation for a 15-minute sampling interval of DGPS dynamic positions.

level of accuracy does not improve with 30- or 60-minute sampling intervals, because the accuracy represents the hardware limitations of the GPS receiver (not a submeter instrument).

Real-time DGPS using UHF radio modems

The cumulative frequency distribution of the dynamic RT-DGPS positions, comparable to that obtained from postprocessed DGPS, indicates that 90 percent of the positions fall within a 10-m radius of the control point (Fig. 3).

The distribution of RT-DGPS positions about the control point approximates the shape of an ellipse, with the long axis oriented in a north–south direction (Fig. 1). It is assumed that this shape is caused by the geometry of the GPS constellation at this location in the northern hemisphere.

Averaged positions display a symmetrical distribution for the 15-minute sampling interval, with an accuracy of 0 (±1–2 m). This accuracy does not improve with 30- or 60-minute sampling intervals for the reasons previously mentioned.

Real-time DGPS using United States Coast Guard signals

A cumulative frequency distribution of dynamic RT-DGPS positions indicates that 80 percent fall within a 10-m radius of the control point (Fig. 3).

The distribution of United States Coast Guard RT-DGPS positions about the control point approximates the shape of an ellipse, with the long axis oriented in a north–south direction (Fig. 1). As for the previous example, the ellipsoidal distribution is assumed to be caused by the geometry of the GPS constellation at this location in the northern hemisphere.

The averaged positions for the 15-minute sampling interval have an accuracy of -4 (easting) and -2 (northing), with a range of 0 to -6 m (Table 1, Fig. 2). This accuracy does not improve with 30- or 60-minute sampling intervals for the reasons previously mentioned.

There is an apparent shift in the position of the data cluster and the position averages relative to the control point (Fig. 1). This negative shift is not present in the data when other DGPS methods are used. The shift to negative values is attributed to errors introduced by the North American Datum NAD83 (U.S. Coast Guard control point) to NAD27 conversion used by the GPS receiver. The NAD27 1976 adjustment used for the surveyed control points is not included in the NAD27 Canada conversion used by the Garmin SRVY II (or other similar GPS receivers). For the real-time DGPS test using radio modems, both control points are based on the NAD27 1976 adjusted datum; therefore, no apparent shift is observed.

Elevation

Although a determination of elevation was not required for the field applications, a number of tests were made to establish the accuracy of the code-correlating receiver.

Averaged elevations for non-DGPS over 15-minute sampling intervals display a crude normal distribution, with a mean of +3 and a range between -40 and +60 m (Table 1). For the 30- and 60-minute sampling intervals (i.e., 30 minutes: +5, ±25 m; 60 minutes: +8.5, ±25 m) the precision improves, but a longer sampling interval is required to attain greater confidence (120-minute sampling interval). The determination of elevation using standard GPS is subject to higher variability than is the case for horizontal positions.

Averaged elevations for postprocessed DGPS, using 5–10 minute sampling intervals display an accuracy of 0 ±2 m (Table 1). These results reflect accuracies similar to those acquired for averaged horizontal positions.

Average elevations of the RT-DGPS, using UHF radio modems and a sampling interval of 15 minutes, range from 0 to -10 m below the control point. The negative skew cannot be explained.

Averaged elevations for the USCG RT-DGPS, using 15-minute sampling intervals, range from 0–10 m above the control point. This may be due to the NAD83 to NAD27 conversion error, using the GPS receiver NAD27 Canada datum previously described.

Field Trials

Ground application

A RT-DGPS test using UHF radio modems was undertaken in August 1994 at Abitibi-Price's Camp 34 site north of Iroquois Falls, Ontario (Fig. 5). The objective of the trial was to determine the accuracy and range of operation of the RT-DGPS method, using a temporary GPS base station and a vehicle-mounted remote GPS receiver.

The temporary base station was set up in one of the Abitibi-Price field offices. The GPS antenna was placed in an unobstructed location on the roof of the office building, and a radio modem base station UHF antenna was placed at a height of 10 m above the ground. A temporary control point was established by taking two 1-hour averages, and then averaging them to arrive at a final position.

Several of the accessible logging roads that traverse the property were driven during a 1-day period. The RT-DGPS data was transferred to the mapping system as polylines, and overlaid on the OBM digital base maps provided by Abitibi-Price.

The results indicate that in areas of low relief, such as those at Camp 34, it is possible to transmit RT-DGPS corrections over a distance of up to 50 km at an antenna height of 10 m, using a 35-watt radio frequency amplifier. A greater operating range would be expected if a higher antenna was used.

The resulting RT-DGPS positions and polyline fall within and parallel to the boundaries of the roads on the digital OBM (Fig. 5). This reflects a level of accuracy for RT-DGPS that falls within the specifications of the digital OBMs (±10 m), and is consistent with the results of the accuracy tests.

Airborne application

The Kirkwood Forest, situated 10 km north of Thessalon, Ontario, was selected as the site to complete aerial trials using Canadian Forest Service (CFS)–Sault Ste. Marie aircraft. Digital OBMs were available for the area, and a grid of forest access roads served as a guide for the aircraft. The intent of the field trial was to test the accuracy of the Garmin SRVY II GPS system and to compare the results to the standard accuracy of an OBM.

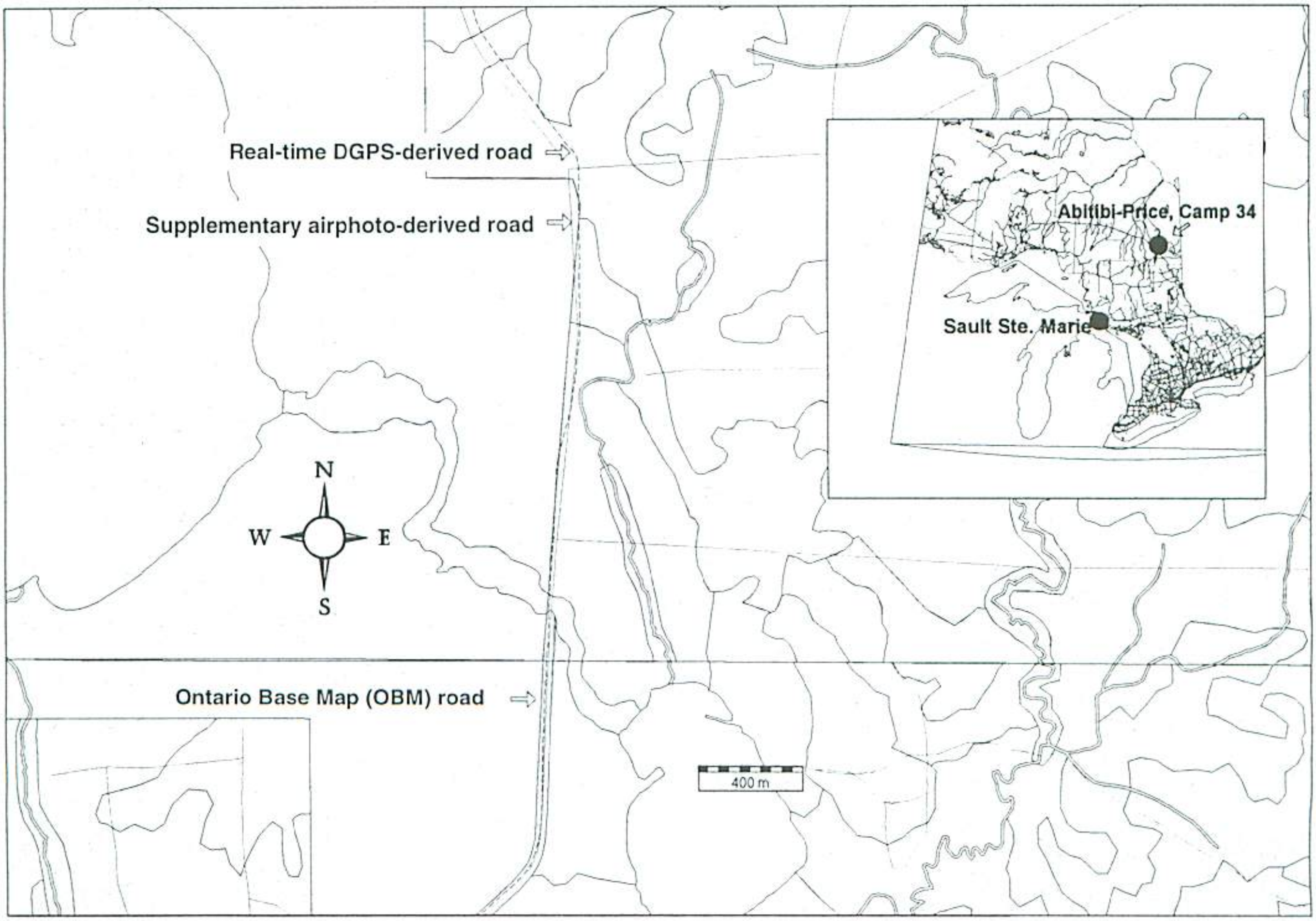

Figure 5. Digital OBM showing both OBM- and supplementary airphoto-derived roads. The real-time differential GPS track has been overlaid.

A differential base station for the Garmin SRVY II GPS receiver was located near a landing strip, and the GPS and UHF antennae were located on the roof of a trailer. A reference control point was established using the method described previously.

Throughout the survey the aircraft flew within a radius of 10 km of the base stations and without any loss of the UHF signals or differential GPS corrections. Four forest access roads, oriented in a north–south direction, were flown twice from north to south.

Using the GPS/desktop mapping system, the RT-DGPS data was transferred to the desktop mapping software, converted into points and polylines, and overlaid on the OBM road network. The results indicate that the nearly coincident flight lines display minor differences with the position of the OBM secondary roads (Fig. 6).

SUMMARY AND DISCUSSION

Nondifferential GPS

The results of the field tests indicate that 90 percent of the uncorrected GPS positions fall within 30 m of the surveyed control point. Selective availability is generally quoted as ranging between ±50 m. However, because selective availability is cyclical over time, it may approach zero during periods of short duration.

When sampling intervals are 30 or 60 minutes, the GPS positions approach a normal distribution, with an average close to zero (Fig. 2). This is useful for remote forestry operations where no survey control is available. Using this method, survey control can be established that meets the 1:20 000 OBM horizontal position accuracy requirements for the representation of geographic information, such as roads. A minimum 60-minute sampling interval, with a Position Dilution of Precision (PDOP) range of 1.0–1.5 and capable of tracking six to eight satellites, is recommended to achieve this accuracy. To establish elevation, a minimum 2-hour sampling time, with similar PDOP and satellites, is recommended to meet the 1:20 000 OBM vertical position accuracy requirements.

Postprocessed and Real-time DGPS

The accuracy of both of these methods is similar because the techniques are alike: for postprocessed, differential GPS, data correction is completed by the postprocessing software in the computer; for real-time DGPS, GPS data correction is done immediately in the firmware of the GPS receiver. A 15-minute sampling interval is suitable to achieve a 0 (±1 m) level of accuracy. There is no improvement with

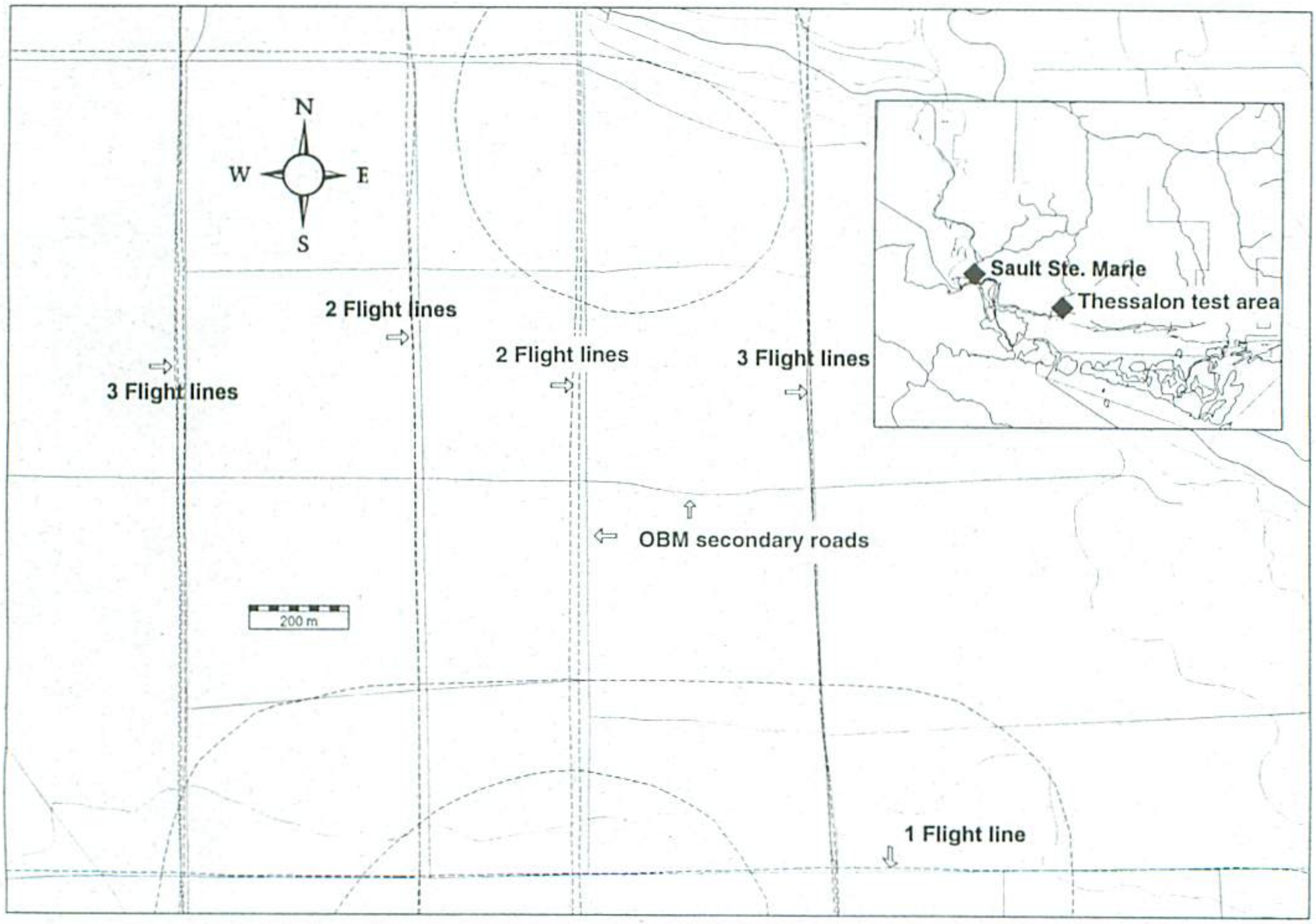

Figure 6. Airborne real-time differential GPS positions using ultra-high frequency (UHF) radio telemetry and the Garmin SRVY II GPS receiver for a portion of the Kirkwood Forest.

a 30- or 60-minute sampling interval because ±1 m is the accuracy limit imposed by the GPS receiver hardware (i.e., it is not capable of submeter accuracy).

United States Coast Guard Real-time DGPS

Tests demonstrate that accuracies in the order of ±5 m can be achieved over 80-km baselines. However, averaged RT-DGPS positions will be skewed up to several meters due to the NAD83 to NAD27 datum conversion error previously discussed. A 15-minute sampling interval is suitable to achieve this level of accuracy, and there is no clear improvement using 30- or 60-minute sampling intervals. The radio beacon system can only be used inland for about 50 km, and is dependent on local topography. Only a few radio beacons in the United States and Canada are transmitting the DGPS corrections, so currently this method is not widely available to public users.

Forest Access Road Mapping

The forest access road mapping exercise at Abitibi-Price's Camp 34 demonstrates the accuracy of the RT-DGPS method. By analogy, the PP-DGPS method is confirmed when applied to a 1:20 000 OBM with both the original and supplementary airphoto-derived road locations (Fig. 5). Figure 5 shows a portion of two OBM map sheets, where the OBM road on the southern sheet continues on the northern sheet as a road derived from information provided by supplementary aerial photos. The DGPS-derived road, represented as a dashed line, coincides with the center of the OBM road. The supplementary airphoto-derived road coincides approximately with the DGPS-derived road. In other parts of the area, where the DGPS-derived road was mapped in both directions, the supplementary airphoto-derived road is displaced from the DGPS-mapped road by up to 50 m in some places.

These results demonstrate that for forest road mapping, DGPS methods are just as accurate as are supplementary air-photos. DGPS road updates can also be completed quickly and accurately, thereby providing forest products companies with a rapid, low-cost alternative to the use of supplementary aerial photos or other mapping techniques.

Airborne Tracking and Mapping

Aerial trials in the Kirkwood Forest resulted in continuous reception of the RT-DGPS corrections throughout the survey. An overlay of the DGPS-derived flight lines on the 1:20 000 OBM for the area indicated a small displacement between the GPS track and the OBM secondary roads (Fig. 6).

Although navigation was not possible due to the location and setup of the GPS receiver (inaccessible to the pilot), the main limitation for accurate RT-DGPS navigation is the low resolution (±50 m) of the course deviation index (CDI) scale bar on the instrument. To be fully effective for RT-DGPS navigation, a course deviation index light bar with a resolution of ±1 m is required.

For aerial spraying applications in the boreal forest, a DGPS system with an accuracy of ±10 m is sufficient. It improves current navigation methods (i.e., use of a navigator aircraft); provides a map that shows the spray block, flight lines, and spray swath; and provides an audit check that conforms to the accuracy of a 1:20 000 OMB.

CONCLUSIONS AND RECOMMENDATIONS

GPS and DGPS Accuracy

Both GPS and DGPS static position data approach a normal distribution about a control point. By using averaged positions it is possible to achieve increased accuracies. Averaged GPS positions fall within ±5 m of a control point; single position DGPS accuracies fall within ±10 m. This provides a benchmark test for GPS receivers that complies with the specified horizontal accuracies required for 1:10 000 and 1:20 000 OBMs.

Because of the limited variation in the manufacturers' specified accuracies, it would be expected that code-correlating GPS receivers similar to the Garmin SRVY II unit should exhibit comparable GPS and DGPS accuracies; each GPS receiver uses essentially the same mathematical functions to calculate a position. However, prior to undertaking any field work with a GPS receiver, where the data is to be used on OBMs, it is recommended that benchmark tests similar to those done for this project be completed to assess the accuracy of the instrument.

Ground and Airborne Mapping and Tracking Applications

From the airborne and ground trials completed during the project, the RT-DGPS accuracies obtained using the GPS/desktop mapping system compare favorably with the accuracy of the OBMs at a 1:20 000 scale.

Tests also demonstrated that the accuracy level of the GPS/desktop mapping system compares favorably with higher accuracy GPS receivers used for aerial spray applications at map scales of 1:20 000 and 1:10 000.[1]

For companies and government agencies involved in aerial spraying and other natural resource applications, both the accuracy achieved with postprocessing and real-time DGPS methods and the map output would serve to easily depict the location of the roads, flight lines, spray blocks, and spray swaths on a map base appropriate for the survey (Fig. 7). The ability to provide accurate survey maps while in the field would allow resource professionals to achieve a high level of confidence in the survey, and offer the opportunity to correct any errors or omissions. Finally, there is a cost saving to government agencies because the audit aircraft for aerial spraying can be eliminated.

[1] Tortosa, D. Application of real-time DGPS and real-time tracking for fire and resource management. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. Final Report, NODA Project 4226. (In prep.)

Application of Real-time DGPS for Natural Resource Management

Although technically feasible, the necessity of using RT-DGPS is based on a number of factors. These include:

a) The availability of, and access to, USA/Canada coast guard differential corrections. This coast guard DGPS program is still under development and the range is restricted to the Great Lakes and near-shore areas.

b) The extent to which navigation is a critical component of the application. Many natural resource managers require DGPS accuracy to access and locate forest values that require RT-DGPS navigation.

c) The number of applications that require differential GPS. If a large number of resource managers require differential GPS accuracy, then it may be more efficient to use RT-DGPS for all applications, thereby eliminating the need for continuous collection of GPS data for postprocessing.

d) The topographic relief and nature of the terrain. The use of an ultra-high frequency radio spectrum for RT-DGPS results in a short range in many areas of the Canadian Shield.

e) The accuracy requirements of a particular application. Many natural resource applications (e.g., mapping fire perimeters) can achieve the required accuracy using standard GPS positioning and without the need for DGPS.

A flexible approach is the most prudent method for incorporating new DGPS technology into an organization. An easily transported real-time (and postprocessing) DGPS system can meet specific application requirements under many terrain conditions. These may be either permanent or temporary operations. The GPS/desktop mapping system can be relocated quickly and easily into remote field operations, and is capable of establishing a reference position (control point) at the remote location that meets the accuracy requirements for OBMs.

Potential Forestry and Natural Resource Applications

Timber management and environmental sensitivity

Recent legislation and regulations in Ontario will result in stricter requirements for timber harvesting operations. In areas such as Abitibi-Price's Camp 34, the layout for timber harvesting is currently determined by the pace and compass method, which is used to identify the boundaries of selected areas. These tend to be straight-line, simple polygons, which are relatively easy to lay out in areas of low topography. In addition, the layout of these blocks does not require a detailed knowledge of stand types.

New requirements for selection harvesting and the designation of areas for biodiversity will result in complex polygons with multiple stand types. Accurately surveying the boundaries of these polygons becomes a more complex problem that involves multiple changes in direction and

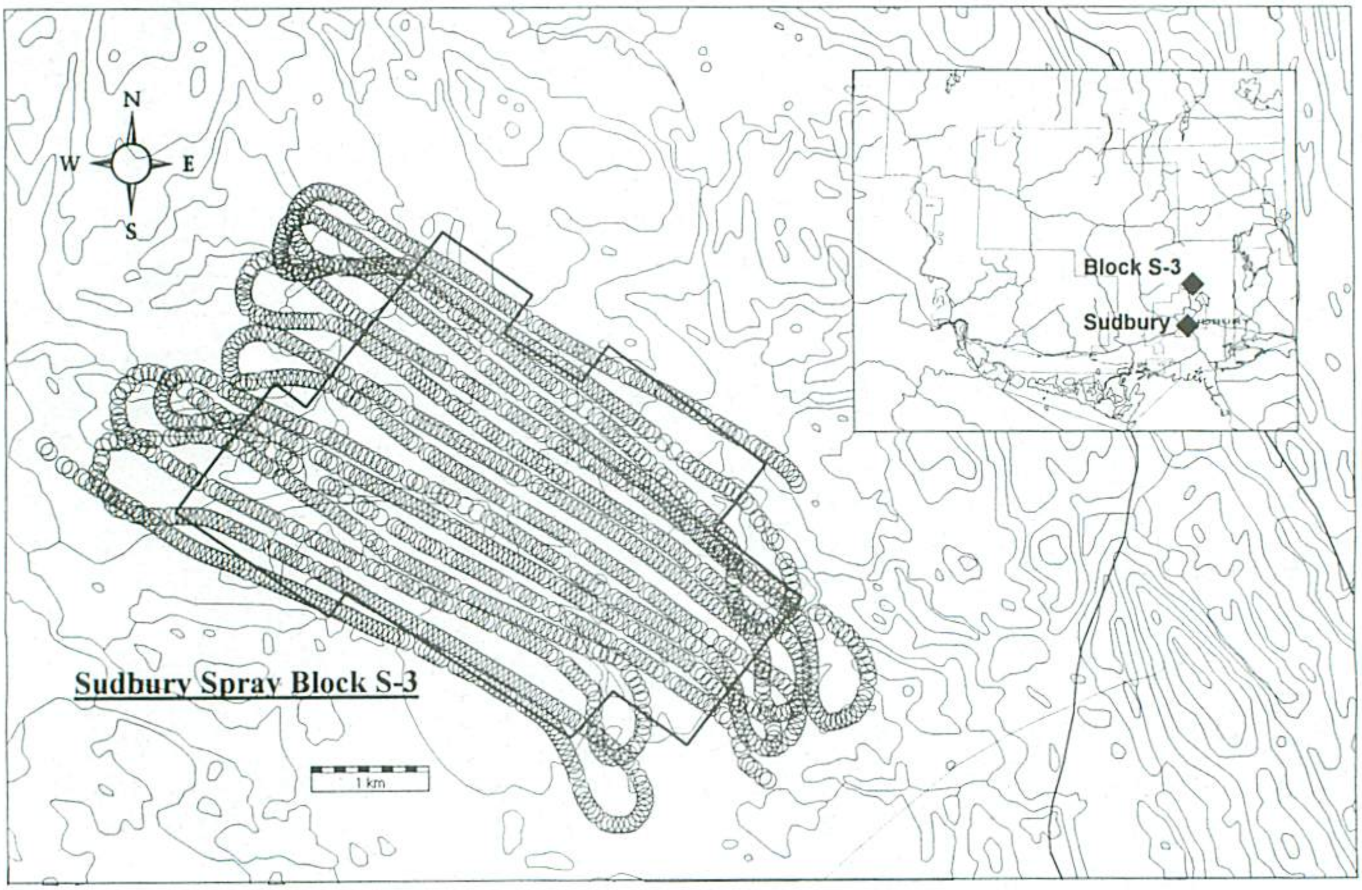

Figure 7. Track of aircraft over a spray block determined using postprocessed differential GPS. Booms on/off are not shown. The diameter of each circle represents a 200-m spray swath (two planes). (Illustration courtesy of Taylor Scarr, Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario.)

accurate positioning. The use of RT-DGPS provides a technological tool to map the required boundaries and transfer the GPS locations to an OBM/Forest Resource Inventory (FRI) map. At the completion of the harvest, the same area can be resurveyed using DGPS on the ground or from an aircraft to determine compliance with the previously established boundary.

Multiple land-use conflicts

In areas where competing uses for land result in conflicting interests, geographic information systems are being used to provide alternative solutions to meet the requirements of various stakeholders (Ontario Ministry of Natural Resources 1993). The use of GIS results in options characterized by multiple and complex buffer zones. The practical implementation of a method to resolve a land-use conflict will, in turn, determine its feasibility. For example, complex buffer zones determined using digital elevation modeling and visibility analysis techniques pose a significant challenge for harvest block layout, even when using ground-based RT-DGPS surveys.

An alternative solution is to blend a GPS real-time tracking capability with RT-DGPS to produce an automated tracking system. This can provide positioning information to a harvester operator or to a control center. By defining the harvest block polygon on the desktop mapping/GIS software, the DGPS position of the harvester can be compared with the polygon boundaries. Thus, the buffer edge can be avoided. The buffer zone can be as complex as required, no detailed ground-based surveys are needed, and compliance with the planned harvest block is easily reached.

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