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Application of Real-Time DGPS and Real-Time Tracking for Fire and Resource Managers

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This file report is an unedited, unpublished report submitted as partial fulfilment of NODA/NFP Project #4226, "Application of real-time differential GPS and real-time tracking for fire and resource management".

The views, conclusions, and recommendations contained herein are those of the authors and should be construed neither as policy nor endorsement by Natural Resources Canada or the Ontario Ministry of Natural Resources.

APPLICATION OF REAL-TIME DGPS AND REAL-TIME TRACKING FOR FIRE AND RESOURCE MANAGEMENT

NODA Project #4226

FINAL REPORT

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SUMMARY

NODA/NFP Project No. 4201, "Application of Portable GPS/Desktop Mapping for Fire Management Support", assessed the capability of a GPS/desktop-GIS to meet the operational requirements of fire management. The current project was designed to assess the capabilities and limitations of a GPS/desktop-GIS for advanced applications that require greater accuracy and a 'real-time' response capability, and to illustrate its applicability and utility for aerial spraying.

Several methods of GPS positioning using code-correlating receivers were tested against second order control points to determine accuracy and precision limits. These methods included: standard GPS positioning, real-time DGPS using the USA Coast Guard radio beacon at Whitefish Point, Michigan, real-time DGPS using UHF radio modems, and postprocessed DGPS for comparison.

The results of accuracy tests for real-time DGPS indicated that it is possible to establish survey control and carry out kinematic real-time DGPS surveys that meet the standard 1:20 000 OBM horizontal position accuracy requirements using standard code-correlating GPS receivers and UHF radio modems. Results can be quickly incorporated and overlayed on a digital OBM using desktop GIS.

Tests indicated that the U.S. and Canadian coast guard radio beacon signals can be received inland in areas of low relief, but they do not penetrate Canadian Shield terrain north of Lake Superior. The range of operation for real-time DGPS using UHF radio modems is dependent on the surrounding topography and the antenna height. The range of operation for real-time tracking using UHF radio modems for aircraft or vehicles is similar to or less than the range of operation for real-time DGPS.

The necessity of using real-time DGPS is dependent on several factors, such as: the availability and accessibility of U.S.A./Canadian coast guard differential corrections; the extent to which navigation is a critical component to the application; the number of applications that require Differential GPS; the topographic relief and nature of the terrain; and the accuracy requirements of a particular application.

The project demonstrates the potential for GPS/desktop-GIS with real-time capability to meet many resource management requirements resulting from environmental concerns and new timber management practices. Potential natural resource applications are described. Together, both projects demonstrate the economic benefits of this technology.

INTRODUCTION

The use of global positioning system (GPS) receivers is gaining widespread use in forestry and many other natural resource applications. Together with desktop mapping and geographic information systems (desktop-GIS), these two technologies are providing support for the development of comprehensive integrated resource management systems for planning and decision making (i.e., Ontario Ministry of Natural Resources, Fire Management Information System (FMIS)).

NODA/NFP Project No. 4201, "Application of Portable GPS/Desktop Mapping for Fire Management Support", assessed the capability of a GPS/desktop-GIS to meet the operational requirements of fire management (Tortosa 1995). The current project was designed to follow up on the earlier one. The aim was to assess the capabilities and limitations of a GPS/desktop-GIS for advanced applications that require more accuracy and a 'real-time' response capability.

Greater accuracies can be achieved through the use of differential GPS (DGPS). A real-time data gathering capability can be achieved through the use of radio telecommunications and data telemetry. When this project was designed, a detailed analysis of the real-time capability that related to natural resource applications had not previously been done. Natural resource personnel had expressed a need for higher accuracies than are now available from standard GPS positioning, and a similar accuracy for navigation and tracking capability.

The GPS/desktop-GIS portable system was also tested against the Novatel GPS guidance system (AgNav) used for aerial spraying by the Canadian Forest Service's Forest Pest Management Institute (FPMI) to determine how well it could perform similar accuracy and navigation tasks. The intent was to see if the GPS/desktop-GIS technology could be transferred to small private-sector firms and provide them with some of the capabilities of the AgNav system. The GPS/desktop mapping system tranforms the GPS data into point, line, or polygon database files that can be immediately overlaid directly on any digital base map for the area at any scale and for a variety of map projections.

The project also examined how this new technology could be applied in future, when new timber management practices and environmental controls are implemented by forest products companies.

METHODOLOGY AND MATERIALS

Background

The project was subdivided into two main phases that ran concurrently to make use of common resources. A third phase was devoted to data analysis and an assessment of the results. Both real-time differential GPS (RT-DGPS) and real-time tracking/mapping (RT-tracking) utilize similar telecommunications technology, so these aspects of the project were completed in parallel.

Because RT-DGPS and postprocessed DGPS (PP-DGPS) are used for better accuracy, detailed tests were completed against surveyed control points to assess the accuracy and precision limits that could be expected during the field applications. Discussions were held with Ministry of Natural Resources (OMNR) personnel to determine the general level of accuracy that is currently required and that may be required in future (Table 1).

The results of field trials that were undertaken are summarized in Table 2 and the field trial locations are shown in Figure 1. Real-time DGPS and RT-tracking trials were completed in the Sault Ste. Marie and Ranger Lake areas for both airborne and ground applications. Real-time DGPS ground applications were completed at Abitibi-Price's Camp 34 near Iroquois Falls. Airborne trials were completed at the Sault Ste. Marie airport, and were followed by both ground and airborne trials near Thessalon, over a portion of the Kirkwood Forest (75 km east of Sault Ste. Marie).

Digital Data Preparation

One of the principal reasons to use GPS for natural resource applications is to gather position information in digital format for geographic features, represented by points, lines, and polygons. To this end, GPS positional data was stored as standard ASCII and DBF digital file formats, and represented on appropriate digital maps for each of the field locations.

Energy, Mines and Resources (E.M.R) 1:250 000 digital base maps were used to represent areas of regional extent; for the Sault Ste. Marie, Ranger Lake, and Iroquois Falls field sites, digital

Table 1. Strategic response questionaire, MNR provincial GPS workshop, Frost Centre, December 7, 1994.

GPS application	Current positioning accuracy needs (m)	Future positioning accuracy needs (m)
Growth and yield plot location	<10	No change
Wetland boundaries	<10	No change
Area of national scientific interest	<10	<10
Aquatic macrphyte perimeter mapping	<10	<10
Assessment plots (visual marker)	<10	10-15
Horizontal/Vertical ground control	0.001	No change
Photo plots	2-5	?
Compliance reporting	10-50	?
Radio position tracking		
Airborne:	50-100	No change
Ground:	<10	No change
OBM map revision		
1:20 000 scale	<10 (x,y)	?
1:10 000 scale	<5 (x,y)	?
Boundary and reserve locations/areas	10-15	No change
Hazards (e.g., abandoned mines)	10-15	No change
Oil well locations	10	No change
Values (e.g., endangered species)	10	No change
FRI updates (e.g., cutovers, plantations, wood lots)	10	No change
Roads (OBM)		
1:20 000	10	?
1:10 000	5	?
Ownership and land tenure	?	?
Vehicle tracking	100	No change
Forest ecosystem classification	10	No change
Trails	10	No change
Aggregates	10	No change
Aerial spraying	10	No change
Defoliation mapping	10	No change

Table 2a. Completed DGPS applications.

RT-DGPS (USCG)

Terrain type	Sites	GPS system	Description
Shield	Ranger Lake area	ELIRIS	Air and ground
Urban/wildlife	Sault Ste. Marie area	ELIRIS	Ground

RT-DGPS (UHF telemetry)

Terrain type	Sites	GPS system	Description
Shield	Ranger Lake area	ELIRIS	Air and ground
Urban/wildlife	Sault Ste. Marie	ELIRIS	Ground
Lowlands (James Bay)	Iroquois Falls area	ELIRIS	Ground
Low relief	SSM airport	ELIRIS/FPMI	Air and ground
Shield	Thessalon area	ELIRIS/FPMI	Air

RT-Tracking (UHF telemetry)

Terrain type	Sites	GPS system	Description
Shield	Ranger Lake area	ELIRIS	Air and ground
Urban/wildlife	Sault Ste. Marie area	ELIRIS	Ground
Lowlands (James Bay)	Iroquois Falls area	ELIRIS	Ground

Table 2b. GPS accuracy and precision tests.

	Location	Averaging time (min.)/No. of samples			System
Std-DGPS	SSM-office	15/20	30/20	60/20	ELIRIS
	SSM-airport		60/10		ELIRIS
	SSM-airport	500 points/20 samples			FPMI
DGPS	SSM-office	(ELIRIS internal files)			ELIRIS
RT-DGPS	SSM-office	15/10	30/10	60/10	ELIRIS
(USCG)	SSM-airport		60/10		ELIRIS
RT-DGPS	SSM-office	15/10	30/10	60/10	ELIRIS
(UHF)	SSM-airport		30/1		ELIRIS
	SSM-airport	30/1			FPMI

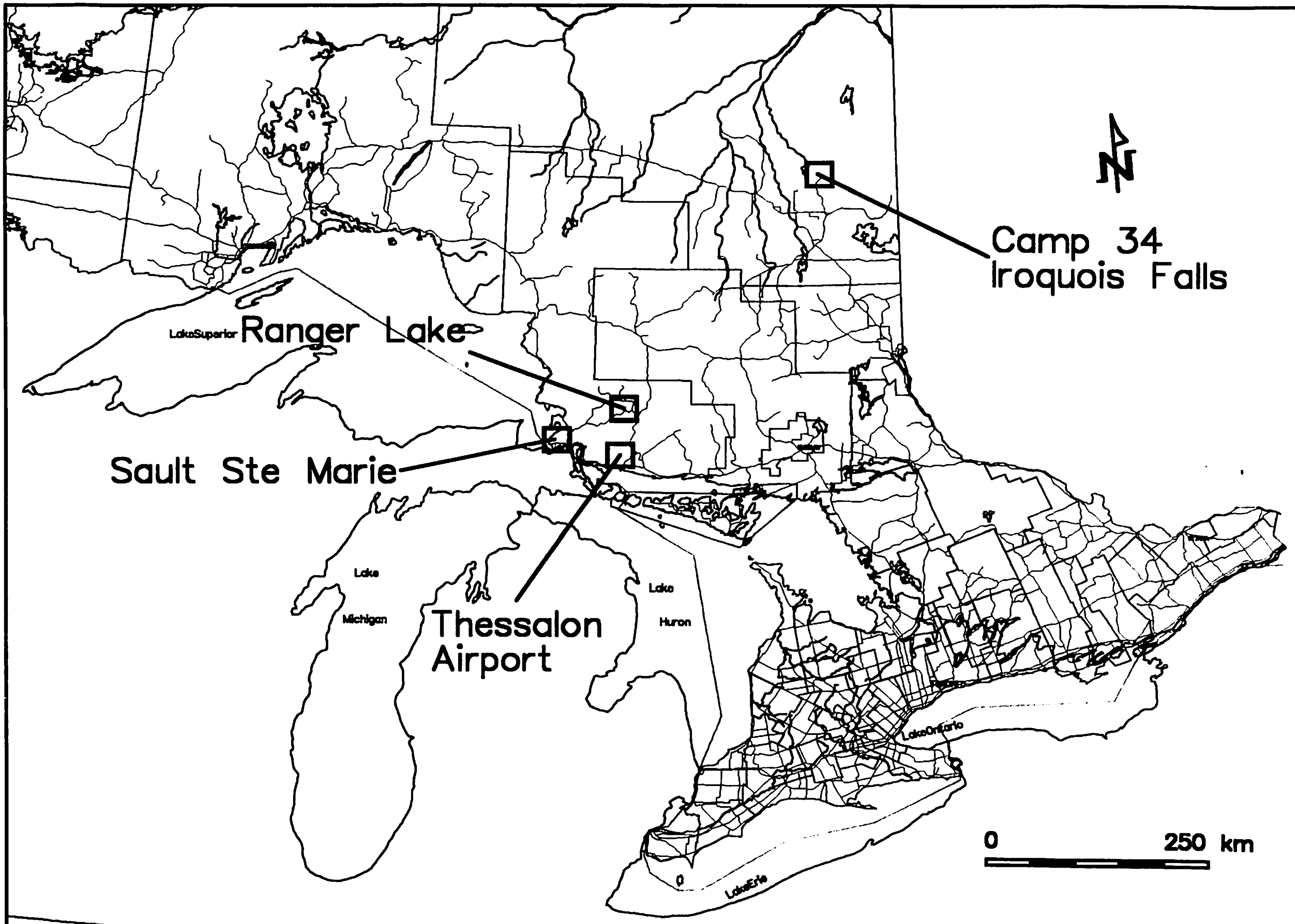


Figure 1: Location of trial test areas.

map sheets 41K, 41J, 41N, 41O, 42A, and 42H were subdivided into four major themes: drainage, topographic contours, transportation, and miscellaneous.

Digital Ontario Base Maps (OBMs) at a scale of 1:20 000 were used where available. For the Thessalon field site, the available digital OBMs were subdivided into the same major themes as the 1:250 000 scale EMR maps. For the Camp 34 site near Iroquois Falls, Abitibi-Price provided digital OBMs and digital forest stand maps in Arc/Info format. These were converted into QuikMAP format and subdivided into drainage, road, and forest stand themes.

For the area around Sault Ste. Marie, a 1:2000 simplified digital city map was used. The airstrip at the Sault Ste. Marie airport was surveyed using differential GPS. The GPS positions were then transferred to the desktop mapping software and overlaid on the digital city map as three lines representing the runway median and runway boundaries. This resulted in a more accurate representation of the runway than was available from the 1:2000 map.

GPS data were transferred as point database information and converted into polyline and polygon database files where appropriate. GPS data gathered from the FPMI GPS system datafiles were postprocessed into standard ASCII files (Dr. Robert Mickle, Atmospheric and Environmental Services, Ministry of the Environment), which were then converted into QuikMAP point and polyline database files. 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 onto the appropriate basemap. Real-time tracking positions were automatically saved into QuikMAP database point files and later converted into polyline files.

Real-time DGPS and Real-time Tracking Technology and Methods

American and Canadian coast guard radio beacons

The United States Coast Guard (USCG) and Canadian coast guard are developing a RT-DGPS service throughout the Great Lakes, eastern and western coasts of North America, and the Gulf of Mexico. The DGPS services provide the required differential correction to DGPS-capable receivers that are within range of the transmitting radio beacons. The system's primary use is for water navigation, but it can also be used on land within range of a radio beacon transmitter (Fig. 2).

To use the 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 No. 104). In addition, a GPS receiver must be connected to a radio beacon receiver (i.e., a radio modem) that has been tuned to the appropriate radio beacon frequency.

In the Sault Ste. Marie area the USCG radio beacon at Whitefish Point, MI, was used for both ground and airborne trials. The radio beacon operates at a frequency of 318 KHz (kilohertz), with a DGPS positioning accuracy of ± 5 m within a range of 100 km. This beacon provided an optimal source to test the inland range of RT-DGPS (Fig. 2).

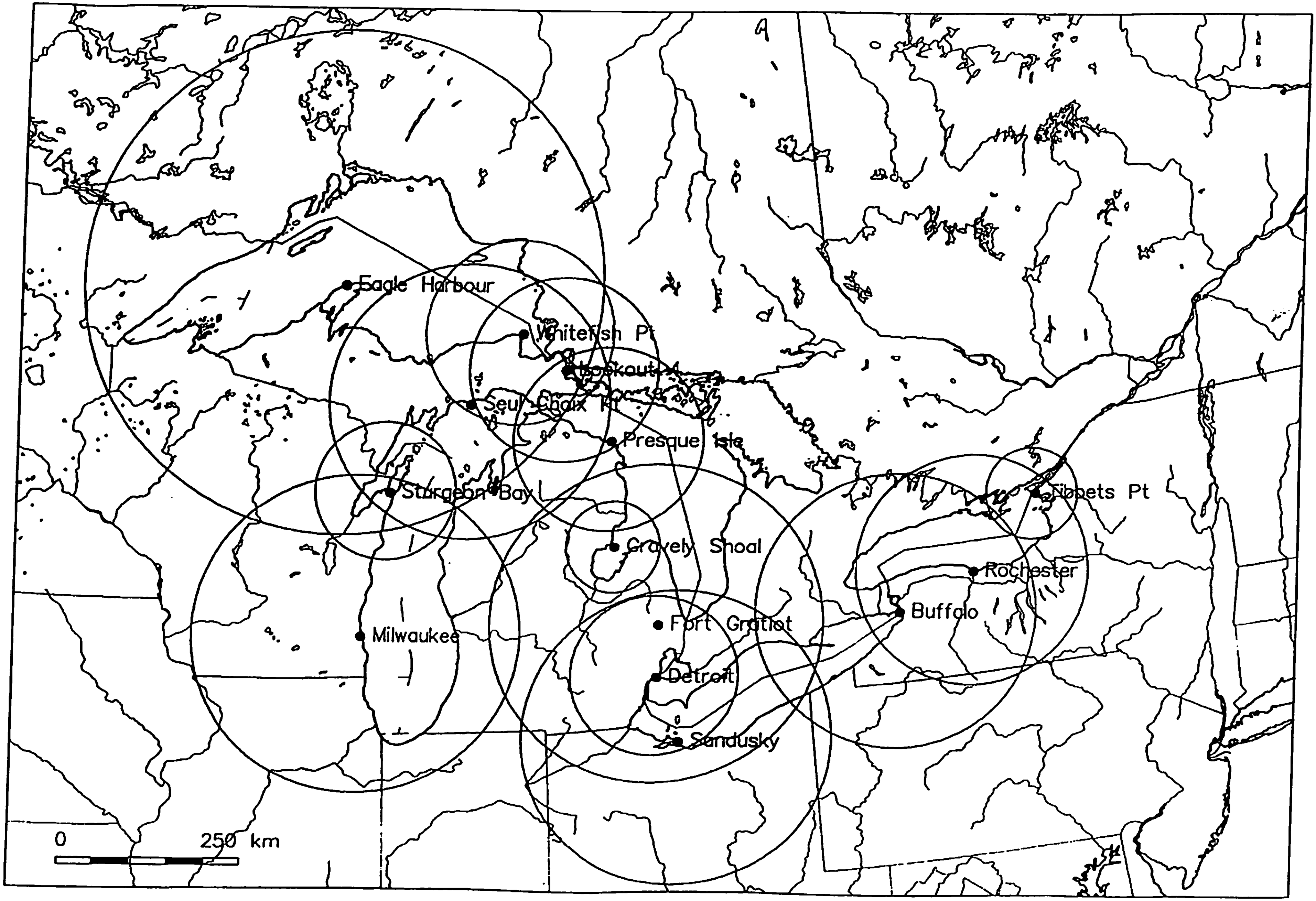


Figure 2: United States Coast Guard Radio Beacon Locations and Range.

Hardware and software requirements

To have RT-DGPS capability, the GPS receiver must be capable of importing the RTCM-104 format that contains the differential corrections. As a position is calculated by the GPS receiver, the correction is automatically applied and displayed on the screen and saved to memory.

The Garmin SRVY II GPS receiver was selected for this project because of the good results obtained when it was used for NODA project 4201 (Tortosa 1995) and because it has RT-DGPS capabilities. In addition, a radio beacon receiver is required to convert the radio message into the standard RTCM-104 digital format. For this project, the MBX1 radio beacon receiver was used because of its portability and availability (Appendix 1).

System setup

For ground operations the GPS receiver was mounted on the vehicle dashboard and connected to the radio beacon receiver via an RS-232 cable. External magnetic mount antennas for the GPS and radio beacon were placed on the vehicle roof and connected to the instruments using coaxial cable. A 12 volt D.C. power source was provided by a vehicle cigarette lighter adapter.

For airborne operations the system was set up in an A-Star helicopter. The helicopter carried a Garmin GPS navigation receiver, so the external GPS antenna on the aircraft was used. The radio beacon antenna was tested in two positions: 1) attached in a horizontal position to a non-active HF antenna that protruded 1 m in front of the helicopter, and 2) attached in a vertical position to one of the landing struts.

UHF Telemetry

For locations that are out of range of the USCG radio beacon transmitters, it is possible to duplicate the same 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. This method was tested to determine the range of operation under several different terrain conditions. A similar method is used by the FPMI AgNav Guidance System and is described in Appendix 1.

Hardware and software requirements

The GPS receiver at the base station must be able to produce the DGPS corrections in the RTCM-104 digital format (or in the manufacturer's proprietary format) and should be capable of tracking up to eight GPS satellites. Garmin SRVY II GPS receivers were used for both base and remote functions.

For radio telemetry, Pacific Crest Corporation radio modems were used with both the base and remote GPS receivers. The radio modem used with the base GPS receiver converts the RTCM-104 digital data into a radio frequency signal, which is received at the remote location and converted back into digital data. The radio modems operate in the ultra-high frequency (UHF) range of 458.8125 megahertz (MHz), and use a standard wide-spectrum UHF antenna. A 35-watt radio frequency amplifier was used to boost the transmitted signal.

The radio modems are configured to operate with a transmission rate of up to 9600 bits per second (BPS) and a baud rate of 4800. These and other variables (e.g., frequency) can be altered using configuration software and saved to the radio modem's firmware. Once the initial radio modem configuration is complete no further changes are required.

UHF Telemetry System Setup

Ground vehicle

The setup for RT-DGPS with UHF telemetry is similar to the setup used for the USCG radio beacon.

Helicopter

For airborne operations the system was set up in an A-Star helicopter. The Garmin SRVY II GPS receiver was connected to a Garmin external GPS antenna on board the aircraft. The radio modem was connected to the Garmin via an RS-232 cable, and the UHF coaxial cable was connected to an antenna taped to the plexiglass inside the cockpit. An independent 12 volt D.C. battery was used as the power source.

For RT-tracking a radio modem was used to transmit the GPS position from the remote location (the aircraft). At the base station a radio modem was connected directly to a desktop or notebook computer. The GPS-calculated positions at the remote location were transmitted by the radio modem to the base, where they were plotted directly by the desktop mapping software (QuikMAP).

Fixed wing aircraft (FPMI)

For the RT-DGPS comparison tests between the FPMI Novatel GPS and the SRVY II GPS receivers, the SRVY II GPS antenna was initially mounted to a strut in the rear window of the aircraft cockpit. The radio modem UHF antenna was similarly mounted. During the initial flight tests it was found that there was a significant loss of DGPS positioning when the aircraft changed orientation; the loss was attributed to the masking effect of the metal strut adjacent to the GPS antenna, which blocked the GPS satellite signal. The UHF antenna had no apparent difficulty with signal reception. For subsequent trials in the Thessalon area, the GPS antenna was positioned such that no immediately adjacent metal obstacles were present; the result was continuous RT-DGPS coverage.

Due to the limited space on the aircraft's instrument panel, the Garmin GPS receiver could not be mounted in a position where it was easily visible or accessible to the pilot. Consequently, no attempt was made to use the instrument for RT-DGPS navigation.

Base station antenna placement

Base station GPS antenna

At each field site the base station GPS antenna was placed at a known geographic position or surveyed control point in an unobstructed location (Table 3). At locations where surveyed control points were unavailable, two 1-hour standard GPS averages were taken over a period of 2 hours. If the readings were within several metres of each other, they were averaged. The averaged position was then used as the known geographic position. The base station GPS was

Table 3. RT-DGPS base station locations and description.

Site	Antenna type	Height above ground	Description
Sault Ste. Marie	Garmin SRVY II base	10 m	ELIRIS office 2nd order survey control
Sault Ste. Marie	UHF base antenna	15 m	ELIRIS office roof
SSM Airport	Garmin SRVY II base	5 m	Steel pole, GPS-derived control point
SSM Airport	UHF base antenna	5 m	Steel pole
SSM Airport	FPMI Novatel GPS base	5 m	Steel pole, GPS-derived control point
SSM Airport	FPMI UHF base antenna	5 m	Steel pole
SSM Airport	Garmin SRVY II base	1 m	Ministry of Transport, 2nd order survey control
SSM Airport	UHF base antenna	2 m	Steel pole
SSM Airport	FPMI Novatel GPS base	1 m	Ministry of Transport, 2nd order survey control
SSM Airport	FPMI UHF base antenna	2 m	Steel pole
Ranger Lake	Garmin SRVY II base	15 m	Building roof, GPS-derived control point
Ranger Lake	UHF base antenna	15 m	Aluminum pole, office building roof
Iroquois Falls	Garmin SRVY II base	5 m	Office roof, GPS-derived control point
Iroquois Falls	UHF base antenna	10 m	Steel pole
Thessalon	Garmin SRVY II base	5 m	Trailer roof, GPS-derived control point
Thessalon	UHF base antenna	5 m	Trailer roof
Thessalon	FPMI Novatel GPS base	5 m	Trailer roof, GPS-derived control point
Thessalon	FPMI UHF base antenna	5 m	Trailer roof

not required for RT-tracking.

Base station UHF antenna

At each field site, the radio modem base station antenna was positioned at a temporary location, such as the roof of a building (Table 3). The antenna was placed to reflect similar temporary conditions that might be expected during field operations. The height of the transmission antenna was therefore restricted to easily accessible locations. The UHF antenna served for both the RT-DGPS transmission and RT-tracking.

Accuracy and Precision Tests

Many forestry applications typically use code-correlating GPS receivers. They have manufacturer-specified accuracies that often range between 15 and 25 m (kinematic, non-DGPS, with selective availability off), and in differential mode, manufacture-specified accuracies in the range of 1-5 (kinematic, with selective availability (S/A) off) (GPS World, January 1994).

Baseline studies were conducted to determine the level of accuracy of the code-correlating receivers (Garmin SRVY II) measured against surveyed control points. The details of the accuracy and precision test are described in Tortosa and Beach (1995). This report briefly describes and elaborates on the results of that study.

Four GPS methods were evaluated for their accuracy and precision: standard GPS, postprocessed differential GPS, real-time differential GPS, and USA/Canada coast guard differential GPS. For each of the methods, two types of data were gathered: averaged positions and dynamic positions. Comparative tests were also completed using the FPMI Novatel GPS and the Garmin SRVY II receiver used for the project.

Averaged positions represent a series of averages calculated at 15-, 30-, and 60-minute intervals (Table 4) at various times of the day, over a period of 2 months. This sampling approach was designed to introduce randomness to the geometry of the GPS constellation so that the results would have general application. For all methods the deviation of the average (in metres) from a known control point was noted for the northing, easting, and elevation.

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

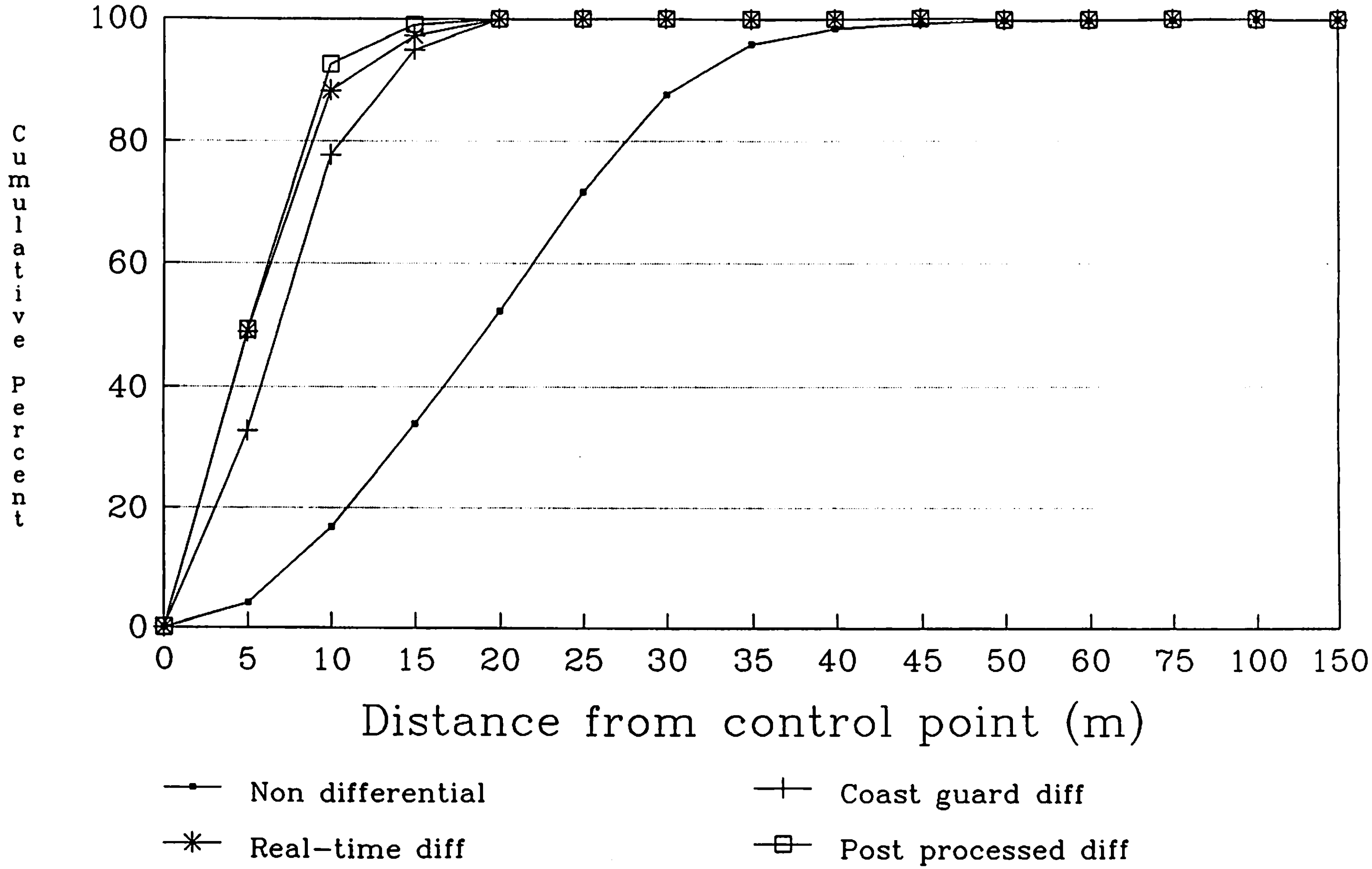
2.5 FPMI (AgNav) Novatel GPS/Garmin SRVY II Comparison Test

In addition to the baseline testing against surveyed control points, the Garmin SRVY II was tested in parallel with the FPMI Novatel GPS receiver. It is known to have a manufacturer-specified differential accuracy down to 1 m.

GPS antennae for both systems were located at a surveyed control point. To establish the standard GPS accuracy for the Novatel GPS receiver, 20 averaged positions, each consisting of

Table 4. Accuracy and precision test summary for 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			



PDOP range 1.2–3

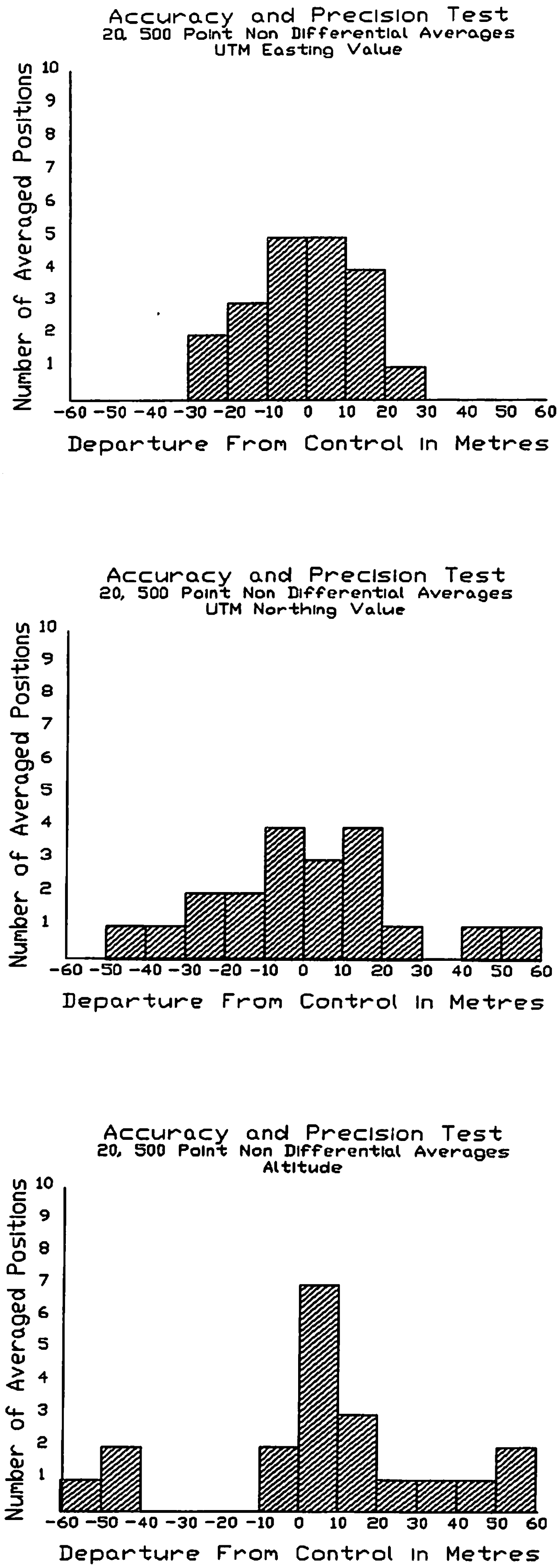


Figure 4: Histograms of the averaged departure for the easting, northing, and elevation from a control point using the FPMI Novatel GPS receiver.

500 readings, were taken at the control point (Fig. 4). Each averaged position represents a total of 100 seconds of data collection (at 5 positions per second); the FPMI/Novatel base station software did not have the capability of adjusting the 500 position default.

For the RT-DGPS test, GPS antennae for both systems were located at the control point, and the differential corrections were transmitted to the respective systems on board the FPMI aircraft at a fixed location on the ground. Dynamic DGPS positions were collected for both systems over a period of 30 minutes. The GPS data was later transferred to the mapping software and the number of positions falling within a specified radius of the average were tabulated and plotted as cummulative frequency distributions and as histograms (Figs. 4 and 5).

RESULTS

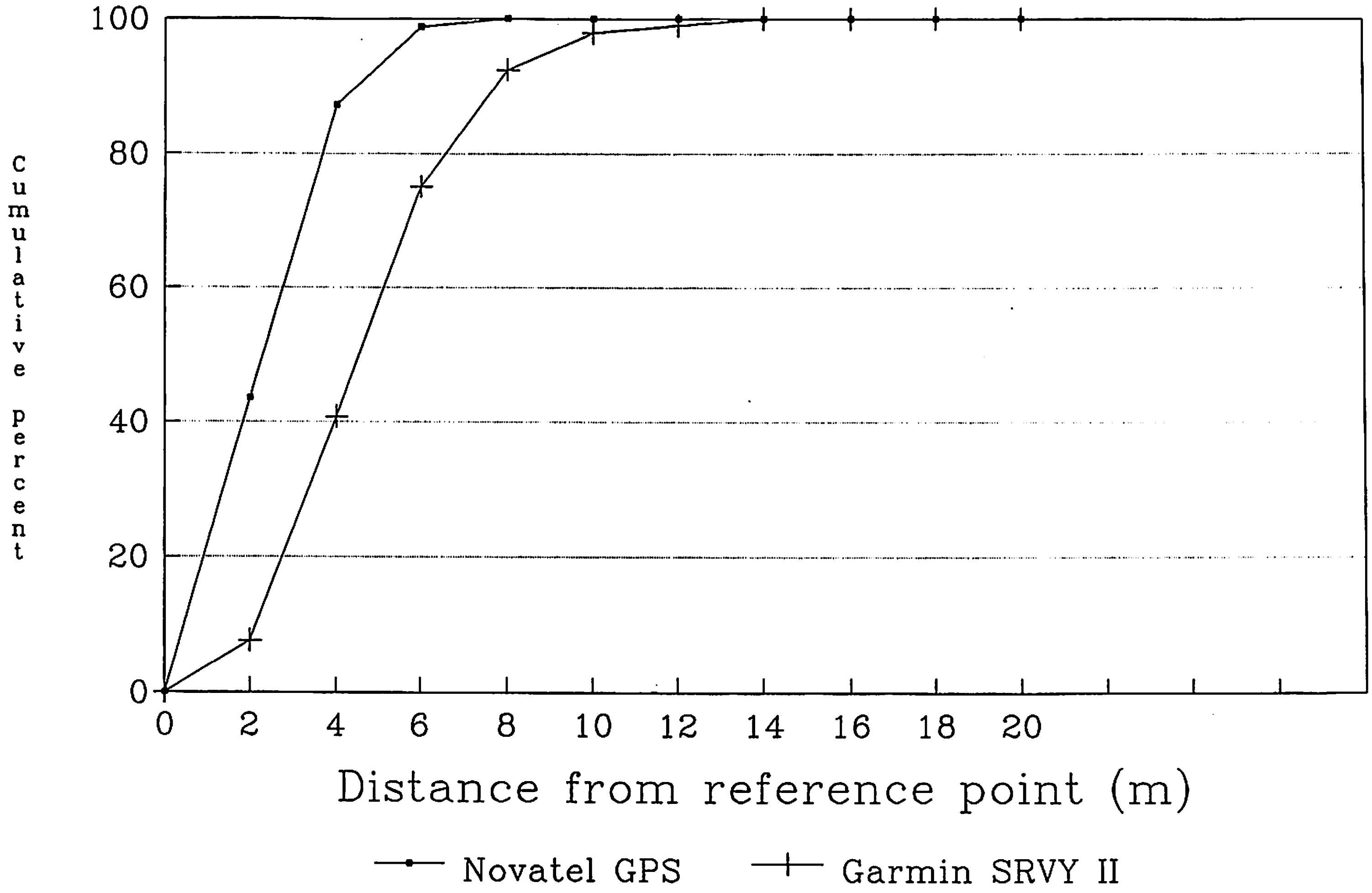
Accuracy and Precision Tests

Standard GPS accuracy (Garmin SRVY II)

The results of the field testing indicate that 90% of the uncorrected GPS positions fall within 30 m of the control point (Fig. 3). Selective availability, although generally quoted as ranging between ±50 m, is cyclical over time, so there are periods of short duration when S/A may approach zero. With sampling intervals of 30- and 60-minutes, the GPS positions approach a normal distribution with an average close to 0 (Table 4).

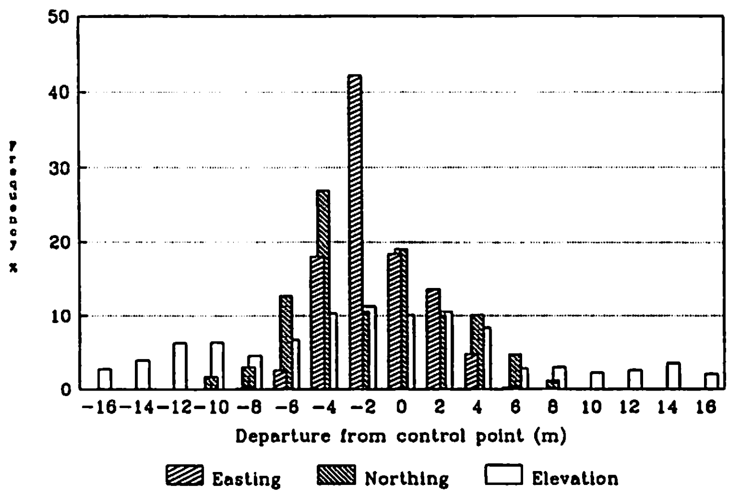
USCG real-time DGPS

A cummulative frequency distribution of dynamic RT-DGPS positions shows that 80% of the

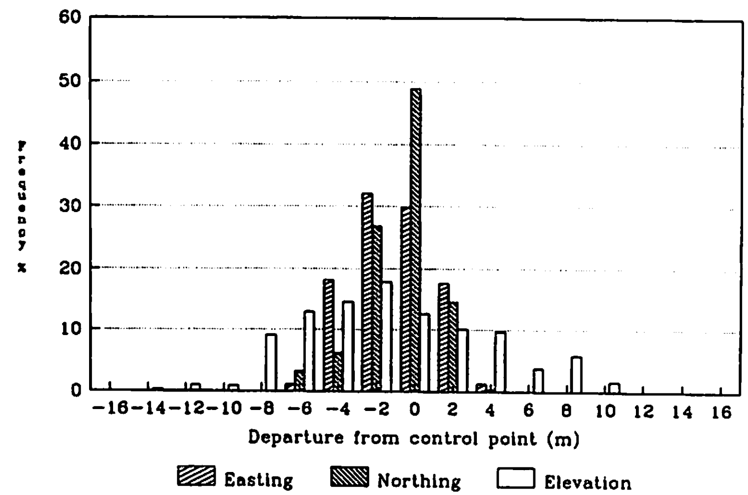


100
80
60
40
20
0
Cumulative percent
0
2
4
6
8
10
12
14
16
18
20
Distance from reference point (m)
Novatel GPS
Garmin SRVY II

Fig. 6



Garmin SRVY II



Novatel GPS

GPS positions fall within a 10-m radius of the control point (Fig. 3). Averaging can achieve accuracies in the order of ±5 m with a 15-minute sampling interval (Table 4). There is no clear improvement in the level of accuracy with 30- and 60-minute sampling intervals. Notably, the averaged RT-DGPS positions will be skewed up to several metres due to a NAD83 (USCG radio beacon control point) to NAD27 (Sault Ste. Marie control point) datum conversion error (Tortosa and Beach 1995).

Postprocessed and Real-time DGPS

The accuracy of both these methods is similar. Both techniques are alike in that the differential correction is done by the postprocessing software (PP-DGPS), whereas for RT-DGPS the correction is done by the firmware in the GPS receiver. The results indicated that when both methods use a 15-minute sampling interval, a 0 ±1 m level of accuracy can be achieved (Table 4). Also, there is no improvement with a 30- and 60-minute sampling interval due to the accuracy limits imposed by the GPS receiver hardware (i.e., it is not capable of submetre accuracy).

FPMI (AgNav) Novatel GPS/Garmin SRVY II Accuracy

The results of the test against a second order control point indicated that static, 500-point (100 second) averages have departures from the survey control that are ±30 m (easting), ±60 m (northing), and ±60 m (elevation) (Fig. 4). The wide dispersion is primarily due to the short data collection period, because the GPS S/A imposes a ±50 m inaccuracy on the position. It varies from 0–50 m when measured over a longer time interval than 100 seconds.

A comparison of the cumulative frequency distribution of positions between the Novatel GPS and the Garmin GPS demonstrates that 80% of the DGPS positions for the FPMI Novatel GPS fall within 4 m of the average, compared with 7 m for the SURVY II GPS (Fig. 5). The RT-DGPS positions determined by both instruments display a normal distribution about the mean (Fig. 6). These data, along with the scatter diagram (Fig. 7), confirm the higher precision and accuracy of the Novatel GPS in real-time differential mode.

Flight line comparisons between the Novatel GPS and the Garmin SRVY II using RT-DGPS over the Sault Ste. Marie airport runway (Fig. 8), show slight differences (approximately 2–4 m) between each other and the runway centre line. The differences in the flight line tracks are due to variations in the accuracy of the GPS receivers, the original DGPS static survey of the runway, and aircraft flight variations.

Comparisons of map outputs from both systems demonstrate the usefulness of incorporating desktop mapping software to represent GPS data (Fig. 9). The FPMI GPS system represents the GPS positions on a cartesian cordinate grid (UTM coordinates) with no background map information.

Real-time DGPS and Real-time Tracking Field Trials

United States Coast Guard radio beacon field trial

For those areas that are within range of a USCG/Canada coast guard radio beacon, this is a useful method of acquiring RT-DGPS capability. To determine the system's usefulness, the

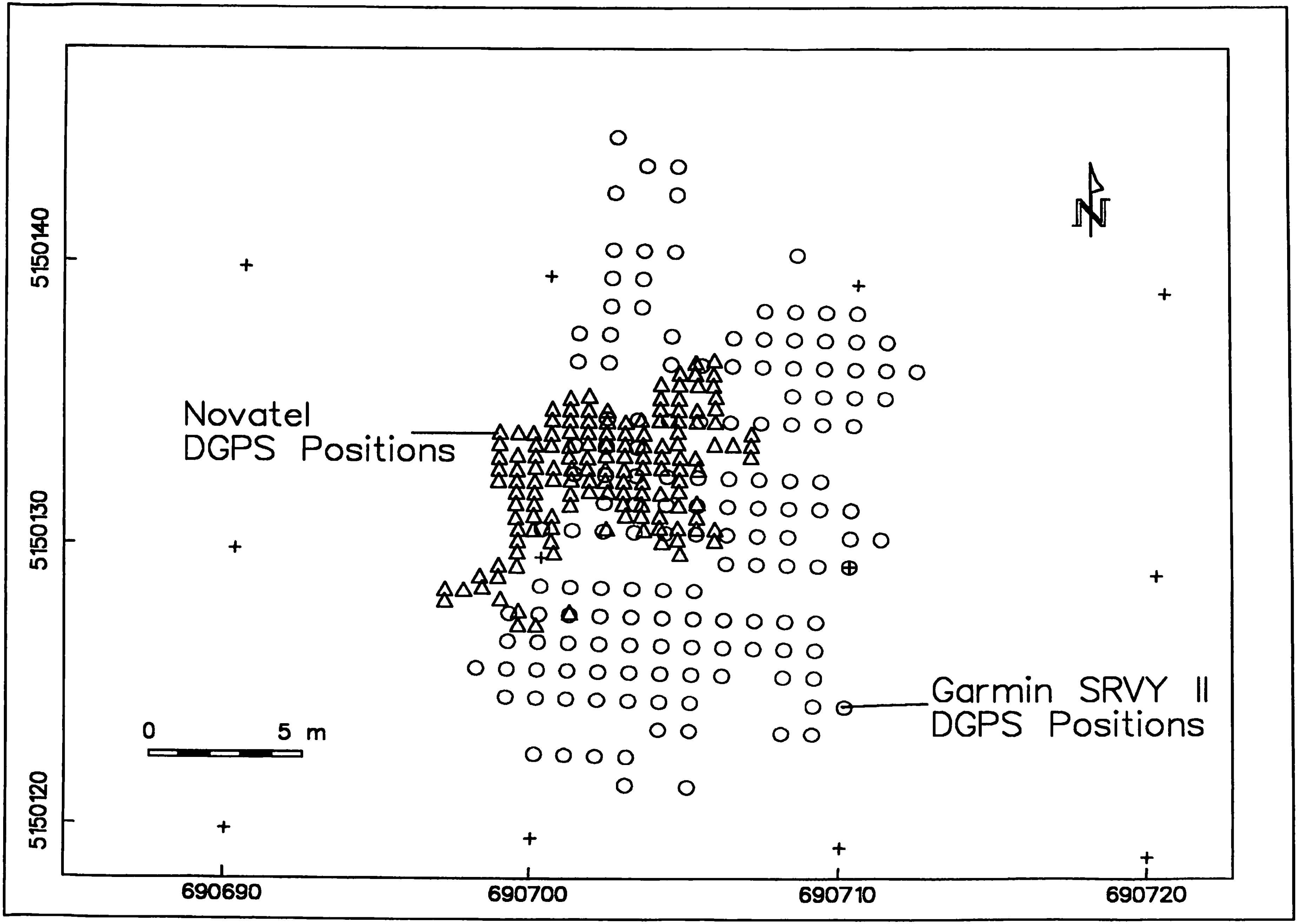


Figure 7: Dynamic, real-time DGPS positions collected at the FPMI aircraft at a fixed position using the Garmin SRVY II and Novatel GPS receivers.

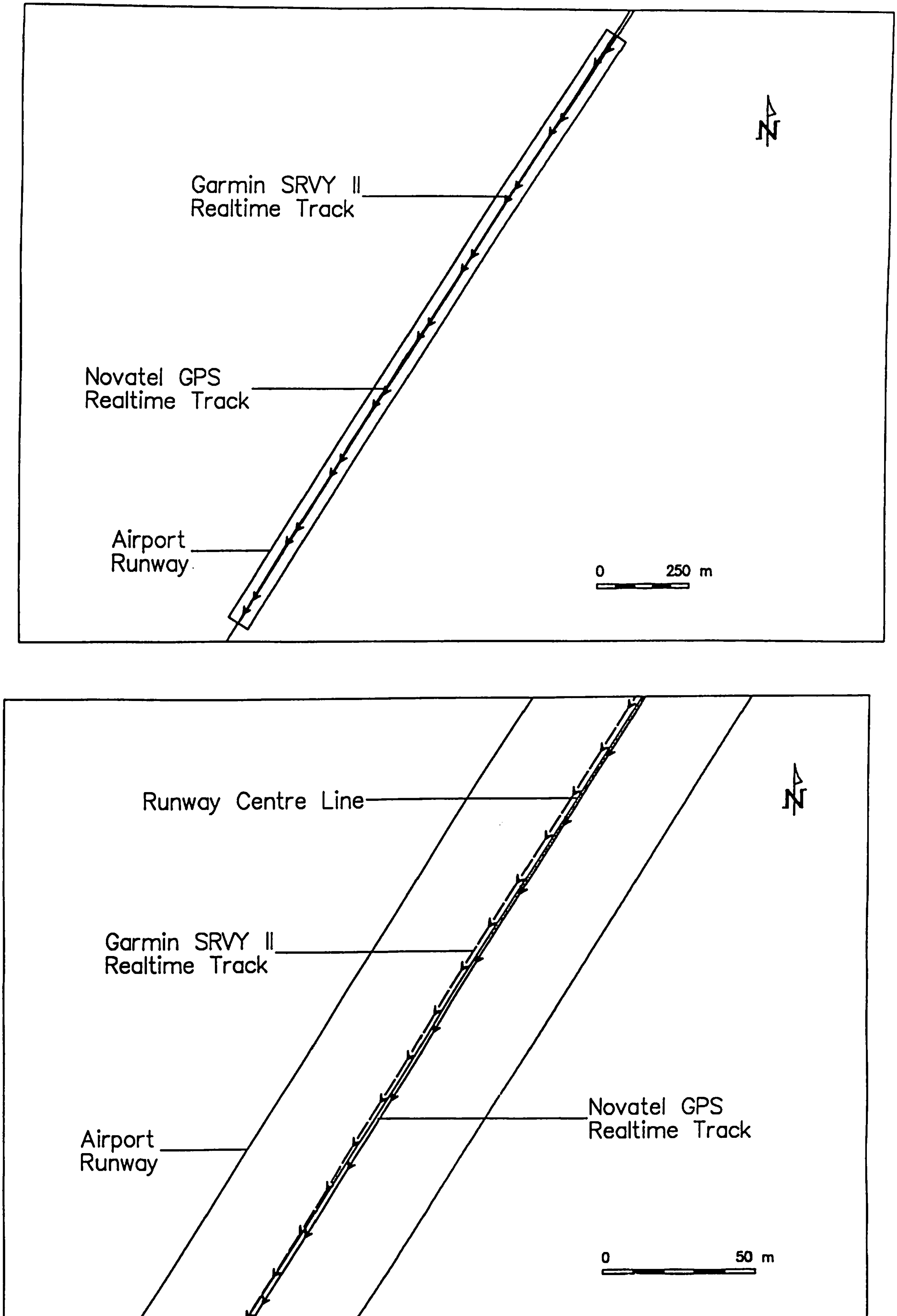
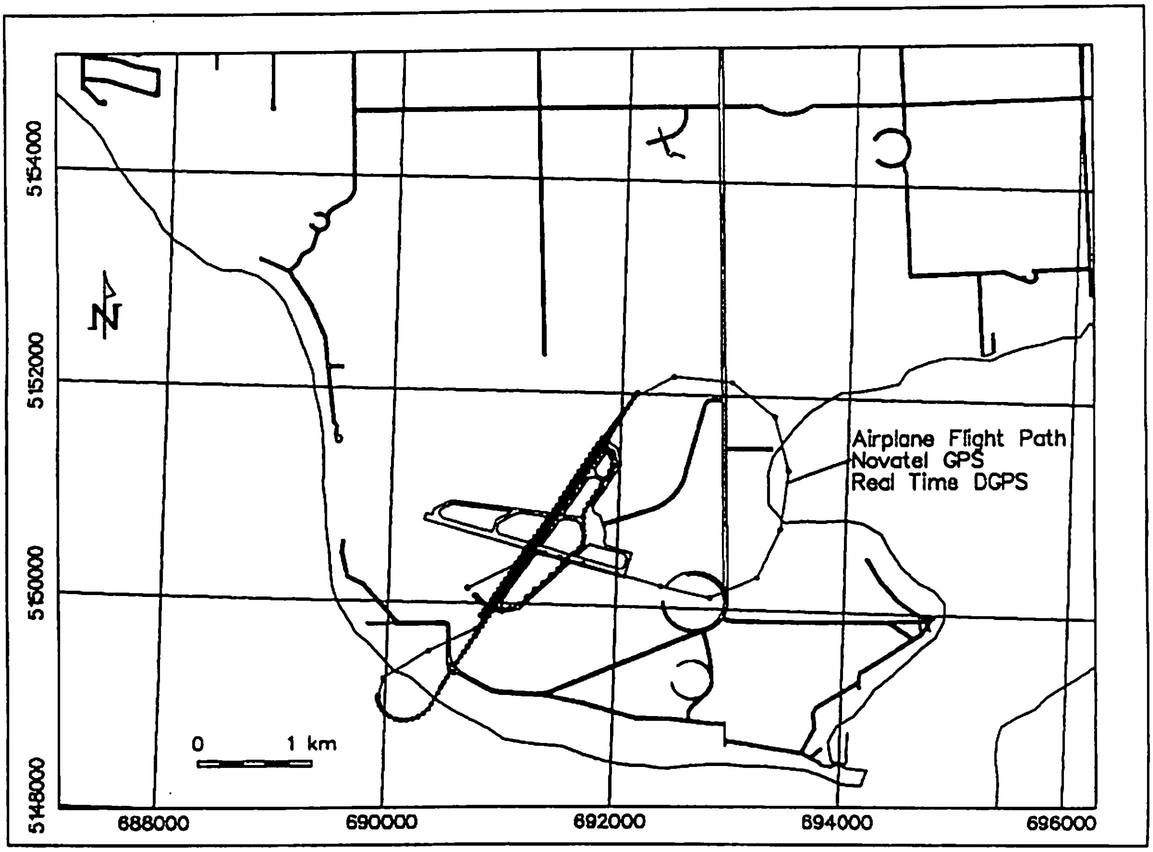


Figure 8: Flightlines for the FPMI aircraft at the Sault Ste. Marie airport runway using real-time DGPS for the Garmin SRVY II and the FPMI Novatel GPS receivers.



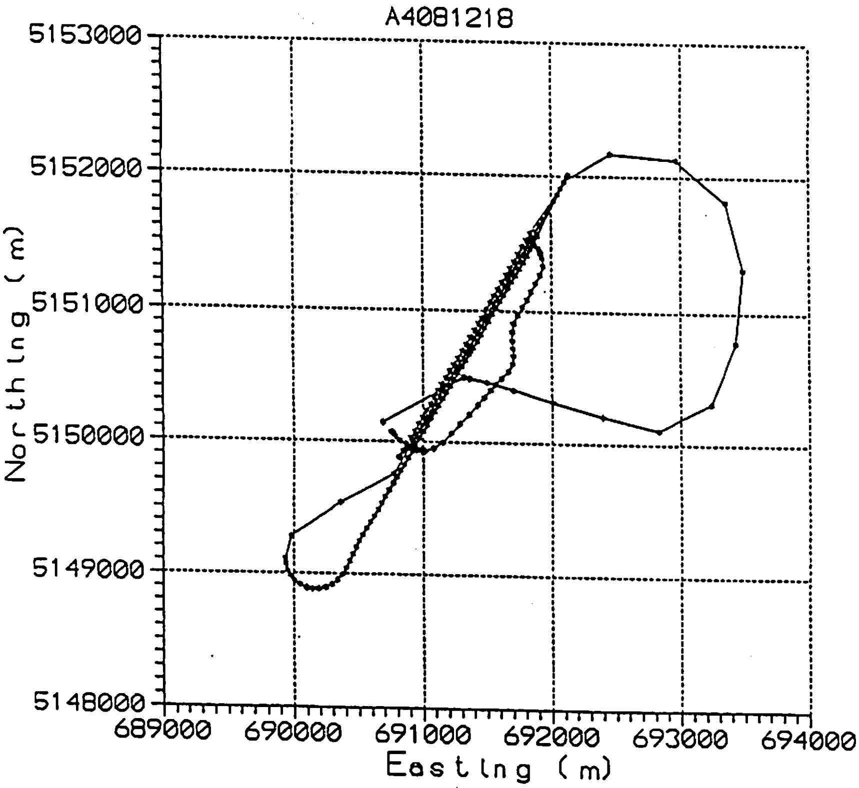


Figure 9: Comparison of printed/plotted output from the GPS/desktop mapping system (top) versus the FPMI Novatel GPS system (bottom).

range limits of the USCG radio beacon located at Whitefish Point, Michigan, were tested.

The USCG RT-DGPS was tested for ground operations by travelling north and east from Sault Ste. Marie to Heyden, Goulais River, Searchmont, and Ranger Lake; and also east and north from Sault Ste. Marie to Bruce Mines, Thessalon, and Ranger Lake (Fig. 10). The USCG signal was received in areas with low relief and below 1200 feet elevation above sea level (asl). Entering the Canadian Shield, a transition zone of about 5–10 km exists where the signal is intermittent, after which reception fades.

Two airborne trials were completed from the MNR Ranger Lake fire attack base using the USCG radio beacon. In the first trial, with the high frequency (HF) antenna mounted in a horizontal position, the USCG signal was not received from an elevation of up to 3000 feet for a distance of 30 km west of Ranger Lake. In the second trial, with the HF antenna in a vertical position, USCG signal reception and differential positioning was obtained 30 km south of Ranger Lake. This position approximately coincides with the start of the 1200 foot topographic contours (Fig. 10).

Later testing in Sault Ste. Marie determined that signal reception from the USCG radio beacon does not change, whether the antenna is horizontal or vertical. The lack of signal reception at high elevations may be due to several factors, such as ground propagation of the HF signal (i.e., it is designed to be used in marine/ground applications), interference from radio equipment on board the aircraft, and a low signal-to-noise ratio.

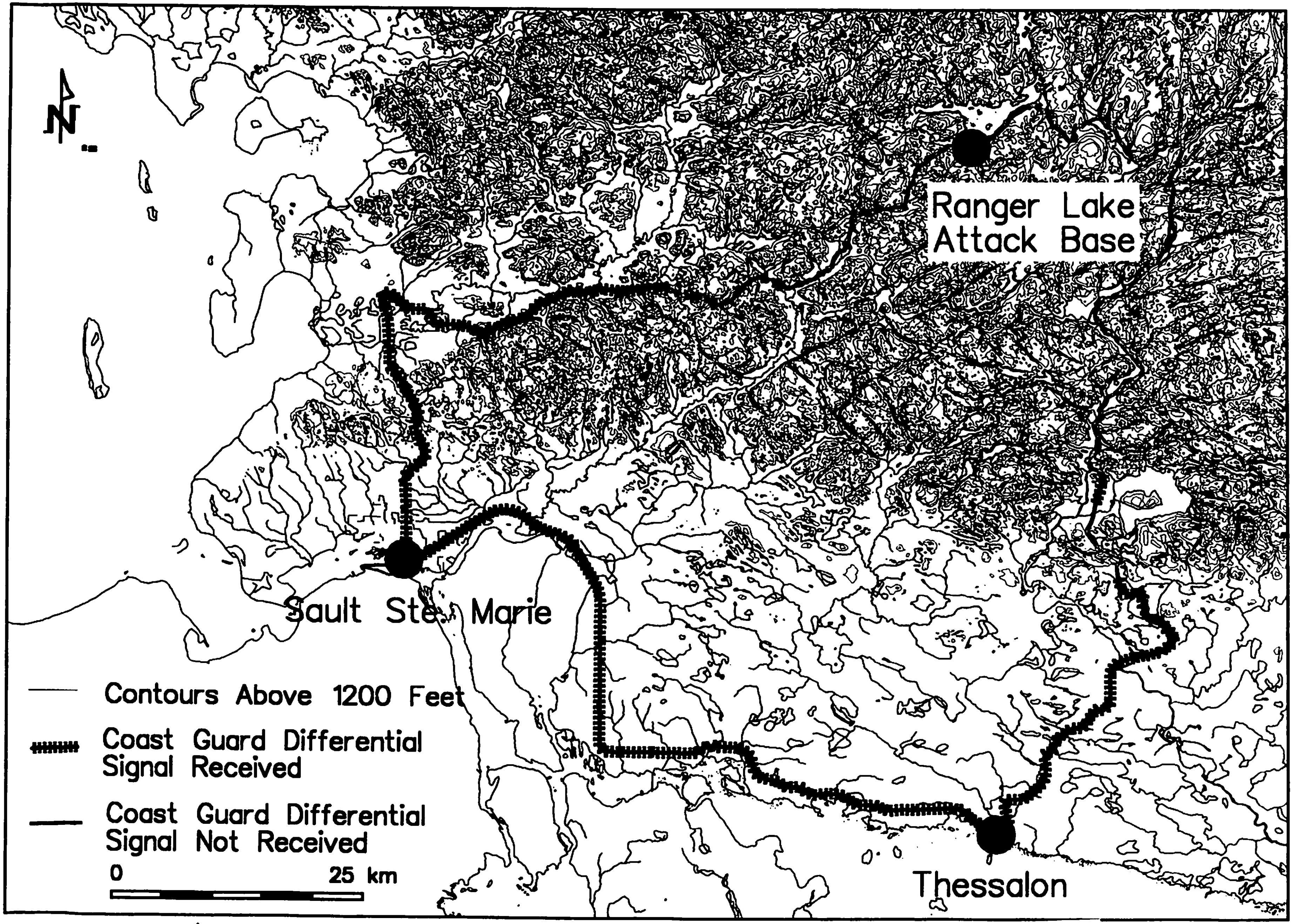


Figure 10: Range of the United States Coast Guard signal from Whitefish Point, Michigan using ground-based real-time DGPS. Note loss of signal past the 1200 foot contour within Canadian Shield terrain.

UHF Telemetry Field Trials

Sault Ste. Marie area

Preliminary testing of the system was carried out in an urban setting to determine the expected range of operation. Sault Ste. Marie is located in a basin formed by the St. Mary's River and to the north it is bounded by the Canadian Shield. Within the St. Mary's River basin there are rolling hills. From the base station RT-DGPS was possible throughout the Sault Ste. Marie area, except for some locations that were in the shadow of the transmitter (Fig. 11). The accuracy of the RT-DGPS positions is revealed when the DGPS data file is transferred to a 1:2000 scale map of the city. The positions are generally within the road boundaries defined on the digital map (Fig. 12). The accuracy of the 1:2000 digital basemap is ±10 m.

A test to determine the distance that a vehicle could be tracked resulted in a smaller range of operation, compared with the RT-DGPS signal reception. A transition zone, similar to the one for RT-DGPS signal reception, occurs where a vehicle is discontinuously tracked (Fig. 13). The smaller range of operation for tracking may in part be due to the signal attenuation caused by buildings, hills, and obstacles between the UHF vehicle transmitter/antenna and the base station.

Ranger Lake area

The Ranger Lake area consists of uneven, broken topography, typical of Canadian Shield terrain. With the DGPS base station set up at the Ranger Lake fire attack base, the helicopter was flown at 3000 feet asl along radial flight lines. The differential GPS signal was received up to 50 km north and south, and 10-20 km east and west of the base station. The difference in range was

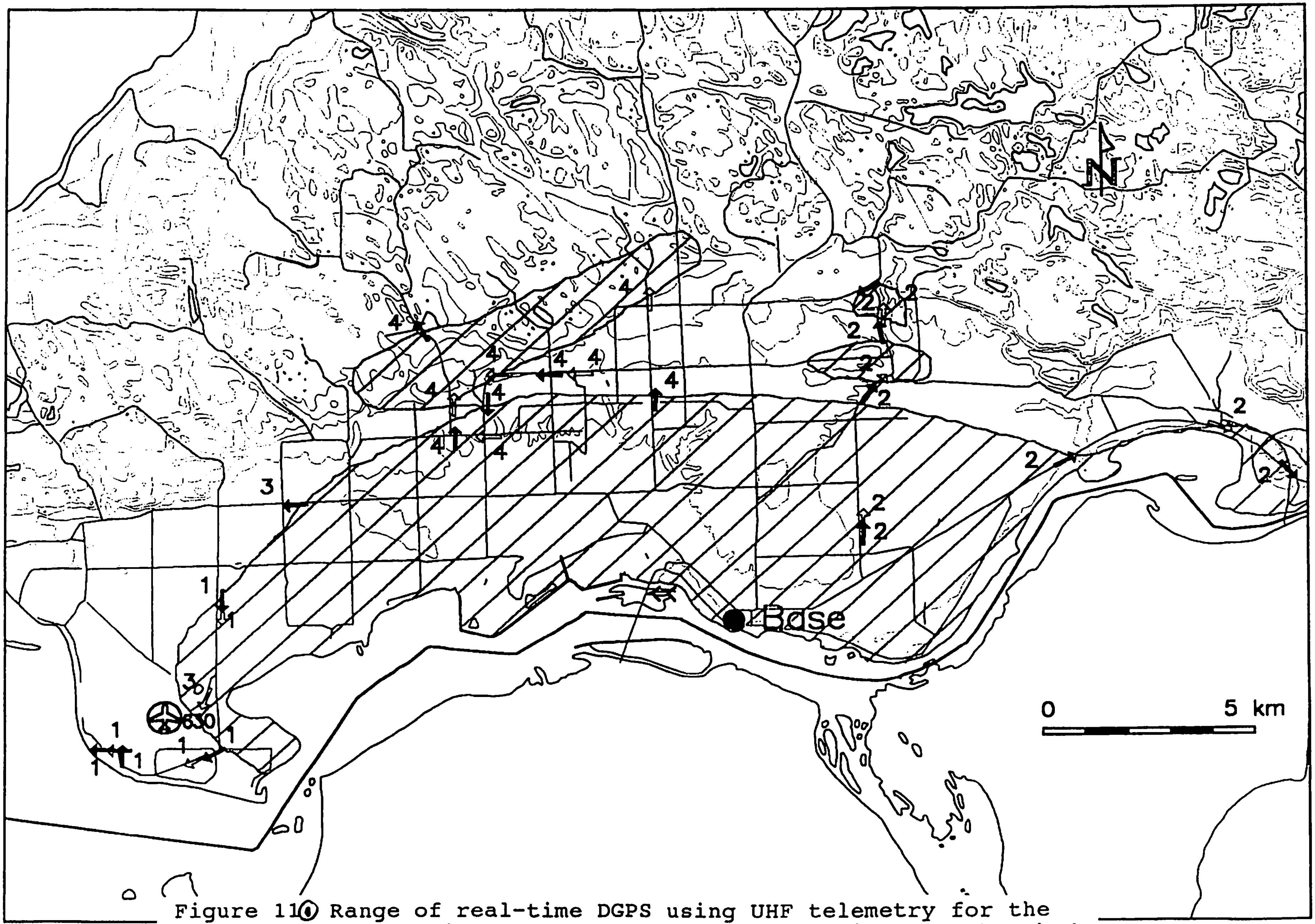


Figure 11(Range of real-time DGPS using UHF telemetry for the Garmin SRVY II GPS in the greater Sault Ste. Marie area (hatched area). Filled arrows represent loss of signal, open arrows represent regained signal, numbers represent different traverses.

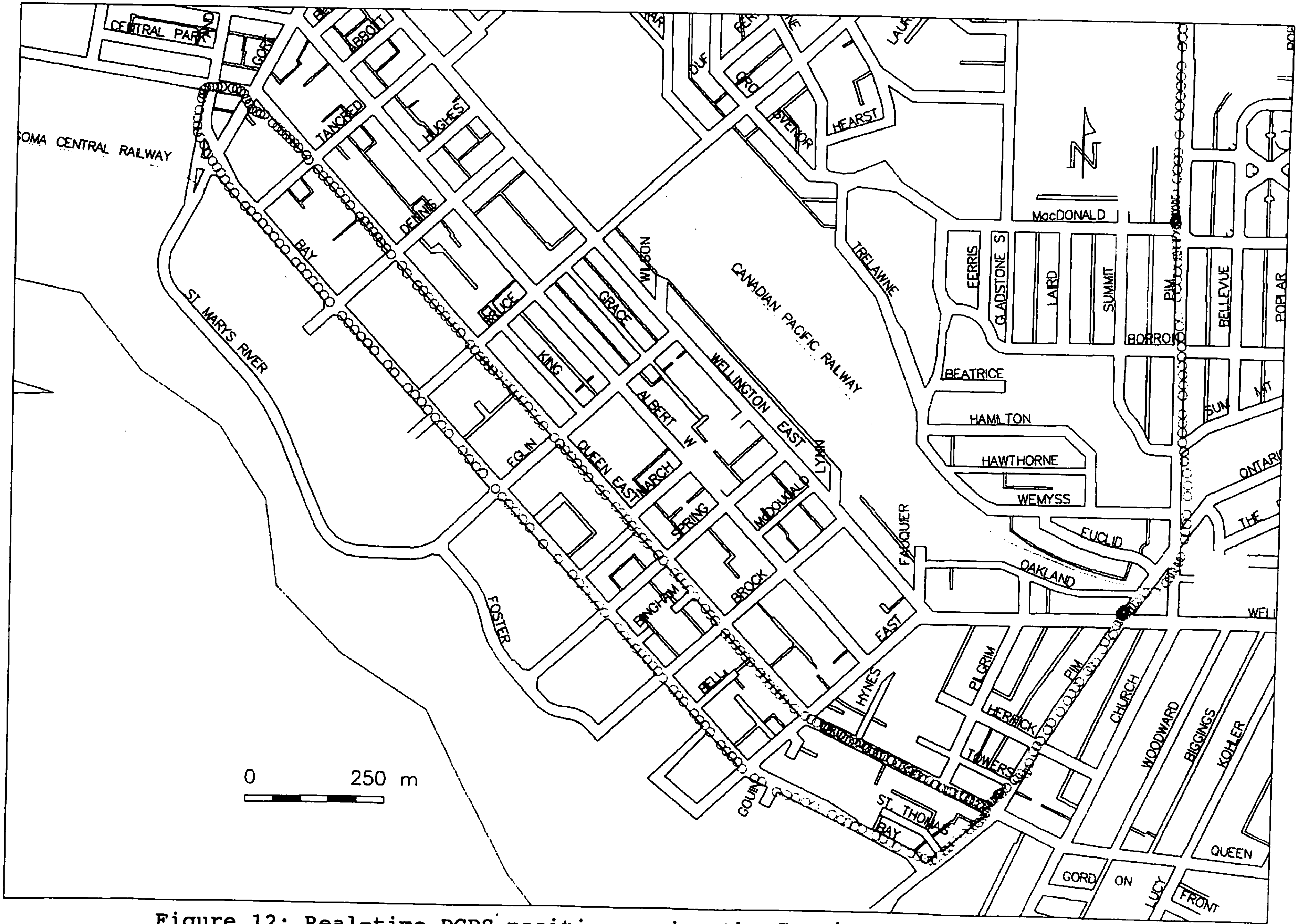


Figure 12: Real-time DGPS positions using the Garmin SRVY II and plotted on 1:3,000 scale city map

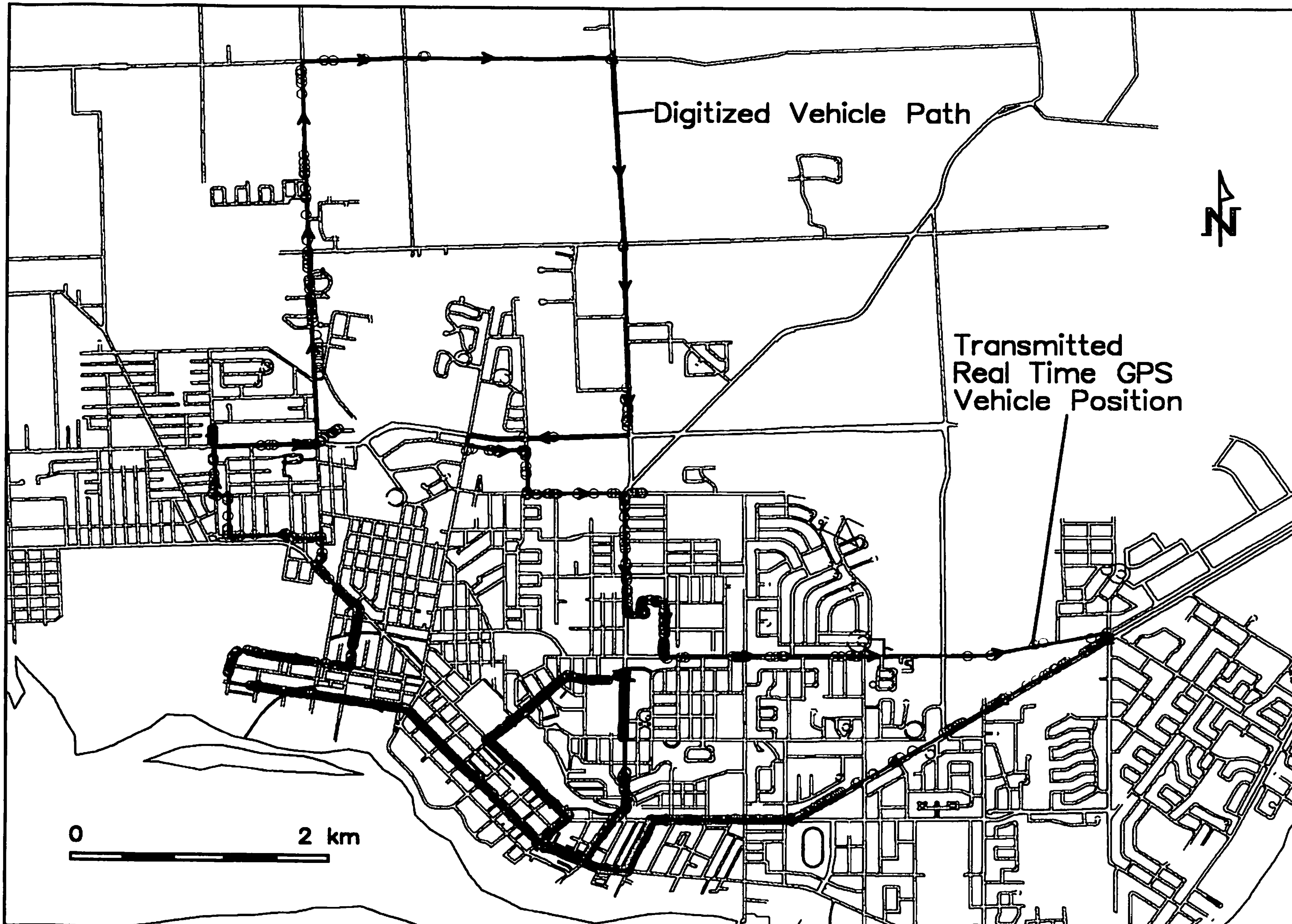


Figure 13: Range of real-time GPS tracking using UHF telemetry in the greater Sault Ste. Marie area.

likely due to hills immediately east and west of Ranger Lake that caused blockage of the UHF signal; to the north and south the area is more open (Fig. 14).

An attempt to use RT-DGPS to remap Fire 28, located southwest of Ranger Lake, proved to be difficult because of the loss of the UHF signal as the helicopter flew the fire boundary. To map the boundary the helicopter must attain a high enough elevation to receive the UHF signal. Flying at high elevation results in a less accurate tracing of the fire boundary by the pilot. Unless the UHF transmitter can be located closer to the area of the fire, or unless the UHF antenna can be located at a higher elevation, there appears to be limited benefit in using RT-DGPS to map fire boundaries.

On the ground the RT-DGPS range was determined by driving the Ranger Lake road to the east and west. UHF signal reception is restricted to within 5 km of the Ranger Lake Base Station, and the topographic relief produces shadow zones (Fig. 14).

For RT-tracking, several flight lines were flown radially outward from the Ranger Lake fire attack base (Fig. 15). GPS positions were logged on the GPS receiver and also transmitted to the control centre at Ranger Lake. A comparison of the logged flight path with the tracked flight path indicates that a significant loss of signal occurred when the helicopter was moving away from Ranger Lake. As the helicopter turned to return to base, the signal reception improved dramatically. This can be attributed to the placement of the UHF antenna in the helicopter cockpit; as the aircraft moved away from the control centre, the helicopter fuselage caused a

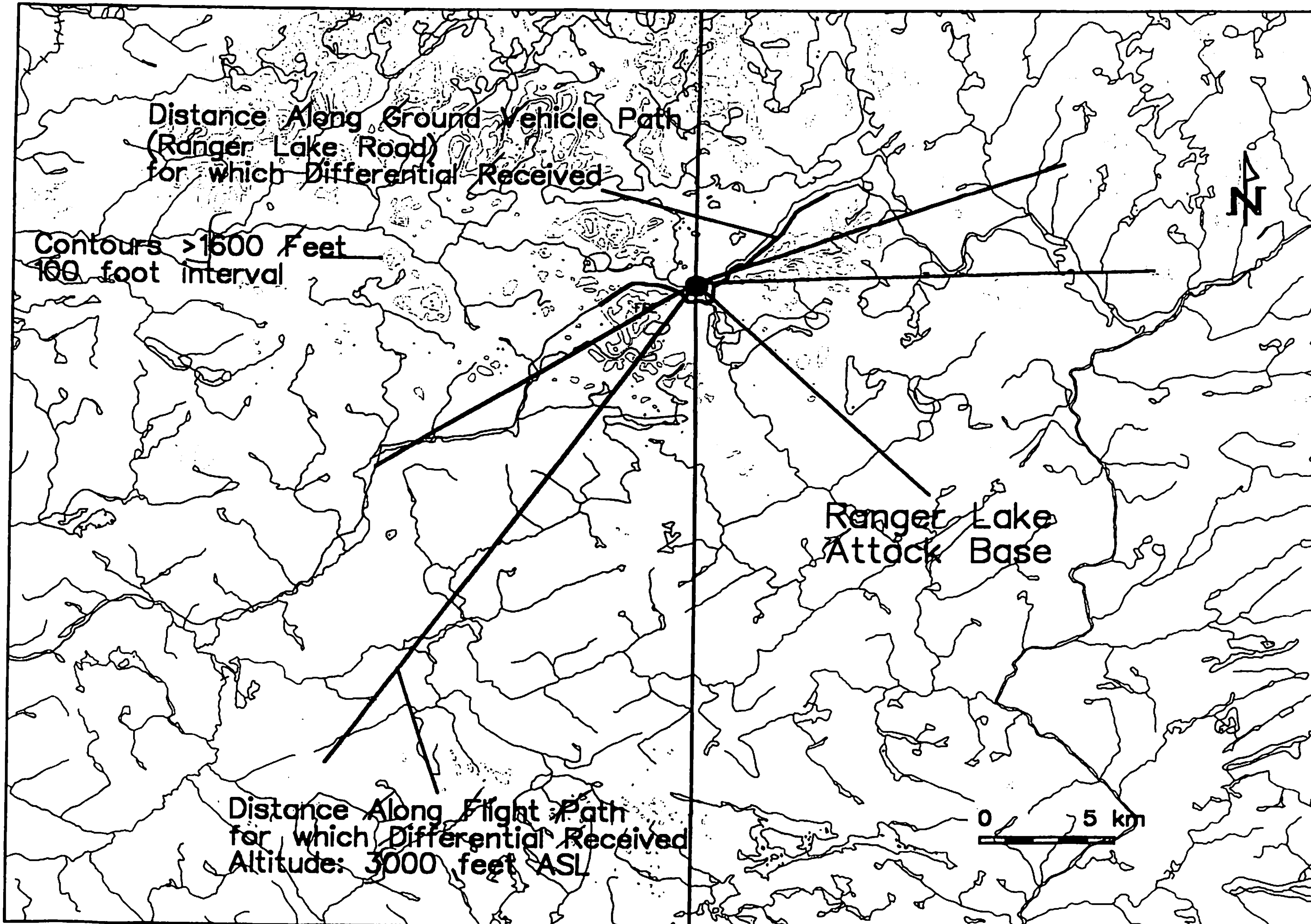


Figure 14. Range of real-time DGPS using UHF telemetry and Garmin SRVY II GPS receivers in the Ranger Lake area.

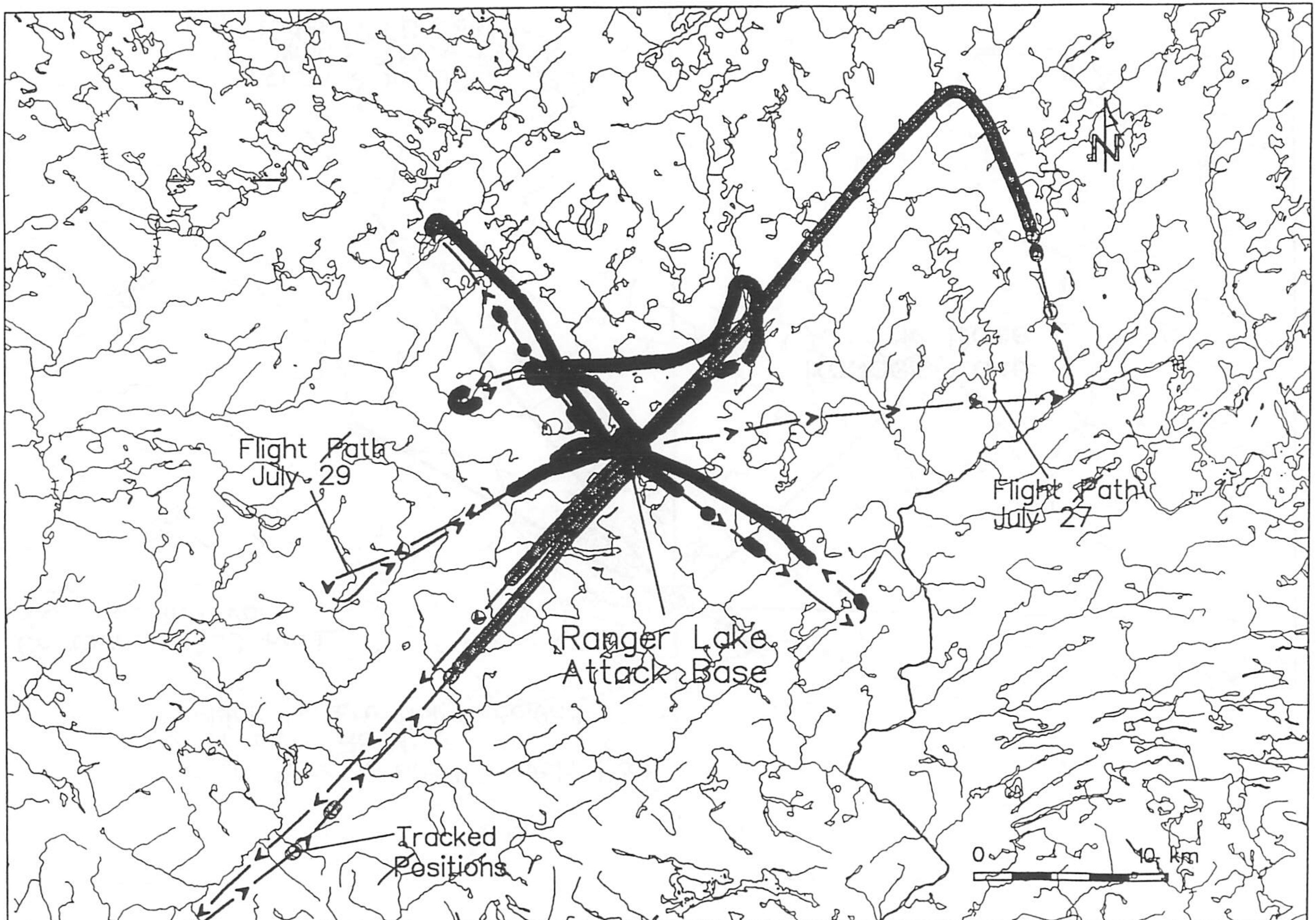


Figure 15. Range of real-time GPS tracking (aircraft) using UHF telemetry and Garmin SRVY II GPS receivers.

dampening of the signal that resulted in poor reception; there was no signal impediment after the aircraft turned toward Ranger Lake. Given these limitations, an aircraft can be confidently tracked for 10–20 km from the control centre. Although no attempt was made to track a vehicle during the Ranger Lake field trials, the RT-DGPS ground limits provided a reasonable model for the expected range of operation using RT-GPS tracking.

Iroquois Falls area

Field trials of the GPS/desktop mapping system were completed at Abitibi-Price's Camp 34, 80 km north of Iroquois Falls. The Camp 34 area is characterized by low relief. It forms part of the margin of the Hudson Bay Lowlands (Fig. 16). Camp 34 and the DGPS base station are situated on a knoll that rises slightly above the surrounding land. The GPS antenna was placed on the roof of the office, which provided a location with no signal obstacles. The radio modem base station UHF antenna was placed at a height of 10 m above ground. A temporary control point was established by taking two 1-hour measurements and 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 collected RT-DGPS data was then transferred to the mapping system as points and polylines, and overlaid on the OBM digital basemaps provided by Abitibi-Price. The operating range was determined to be 15–30 km from the base station. Minor UHF signal loss occurred for short distances along the route due to signal blockage caused by the topography.

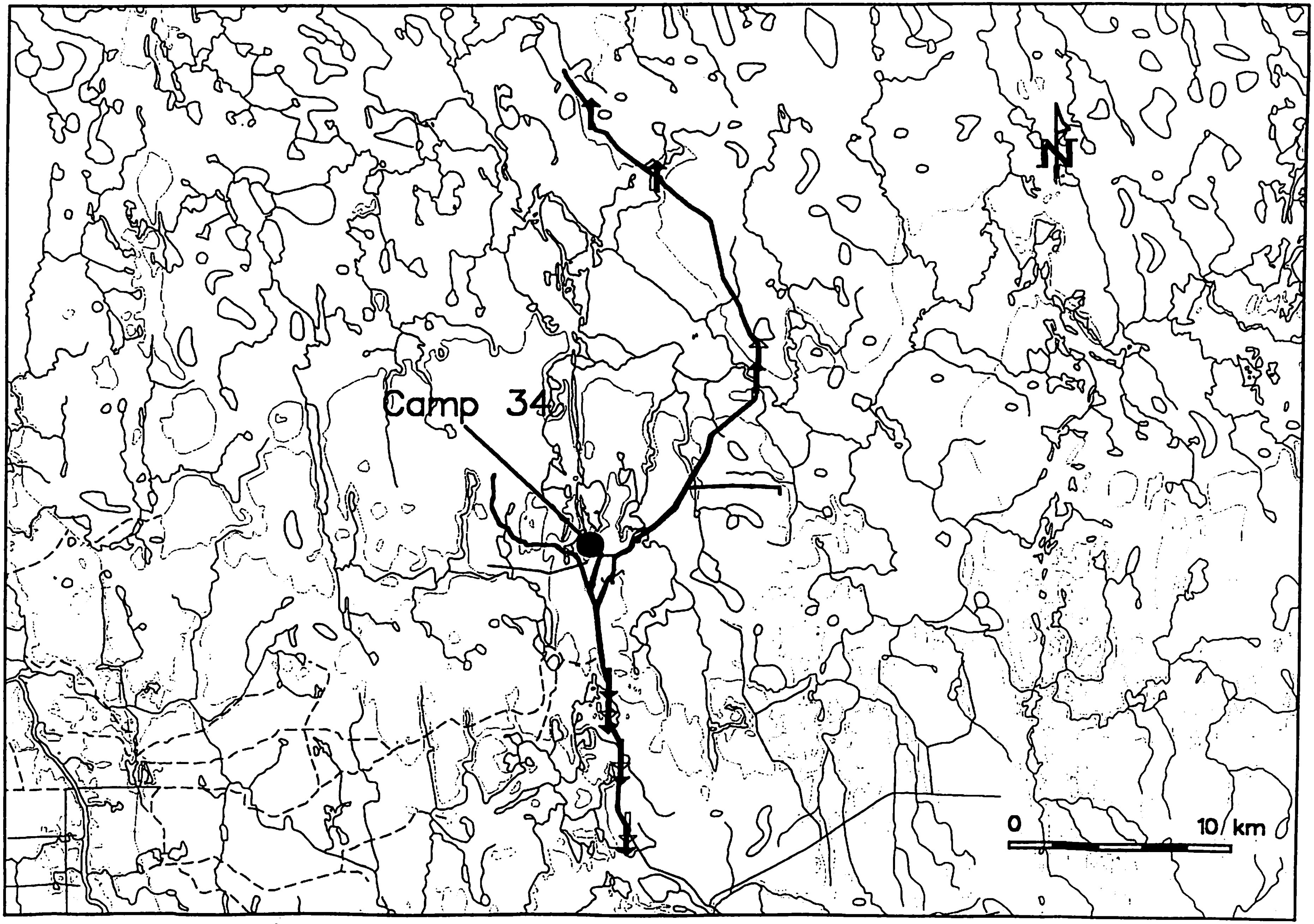


Figure 16. Range of real-time DGPS using UHF telemetry and Garmin SRVY II GPS receivers. Filled arrows represent loss of signal open arrows represent signal regained.

The resulting RT-DGPS corrected positions and polylines fall within and parallel to the boundaries of the roads on the digital OBM (Figs. 17a and b). Figure 17a shows a portion of two OBM map sheets, with the OBM road on the southern sheet continuing on the northern sheet as a road that was derived from information provided by supplementary aerial photos (SAP). The DGPS-derived road, represented as a line with arrows that indicate the direction of travel, coincides with the centre of the OBM road. The SAP-derived road approximately coincides with the DGPS-derived road.

Forest access road mapping at Abitibi-Price's Camp 34 demonstrates the accuracy of the RT-DGPS method, and by analogy, the postprocessed DGPS method, when applied to a 1:20 000 OBM with both the original and SAP-derived road locations. Only a limited amount of RT-tracking was attempted in the Camp 34 area because it was found that the range for RT-tracking was similar to RT-DGPS using the same UHF telecommunications setup.

Thessalon area

The Kirkwood Forest, located 10 km north of Thessalon, was selected as an appropriate site to complete the aerial trial using the FPMI 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 both the FPMI Novatel GPS and the Garmin SRVY GPS systems, and compare the results to the standard accuracy of an OBM.

The Kirkwood Forest is located in a valley that is bounded on the north and south by hilly

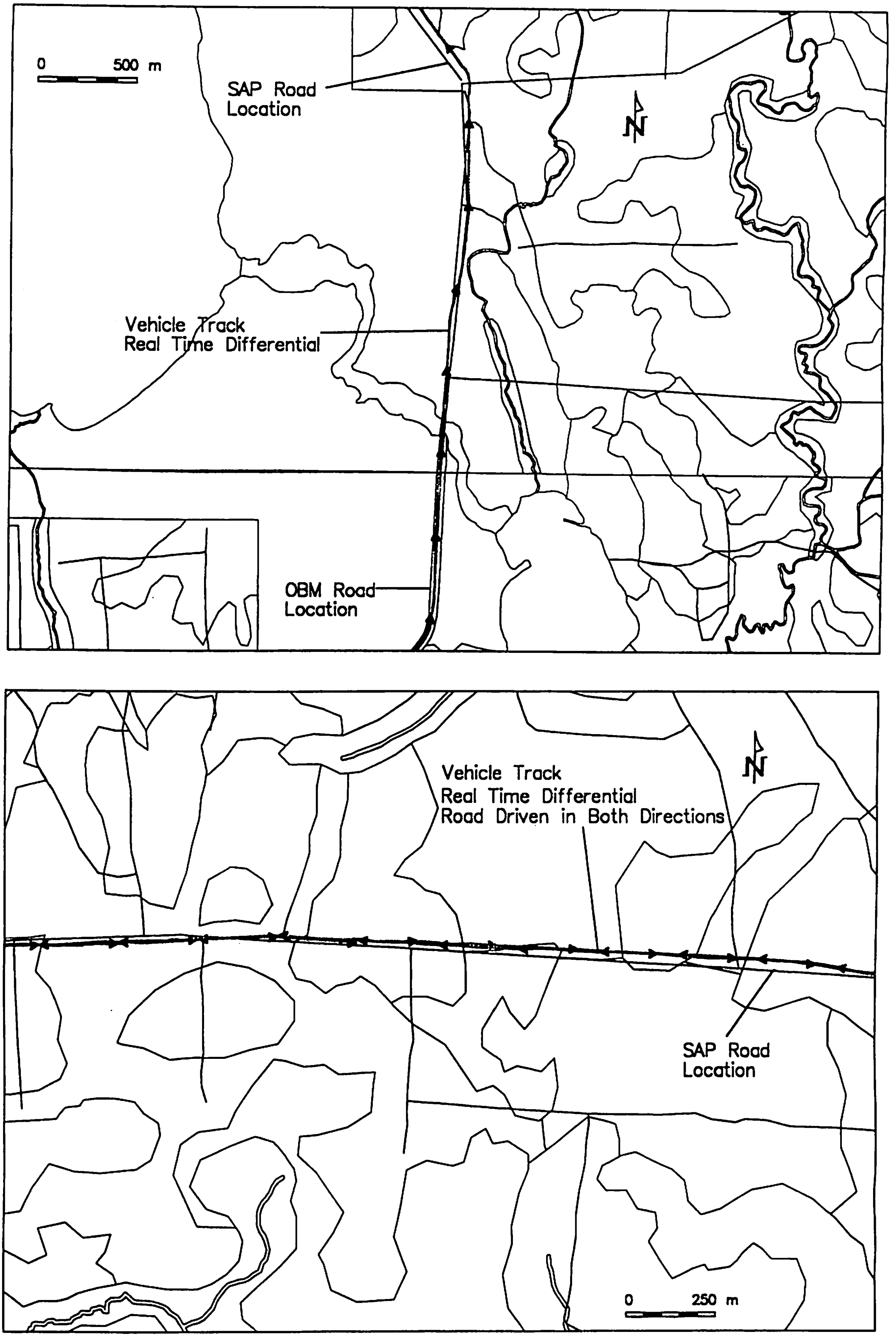


Figure 17a (top) & 17b (bottom): Digital OBM showing both OBM and SAP-derived roads with real-time DGPS tracks overlayed. Arrows indicate direction of travel.

Canadian Shield topography. Differential base stations for the Novatel GPS and Garmin SRVY II GPS receivers were located near a landing strip, and the respective GPS and UHF antennae were located on the roof of a trailer.

Throughout the survey the aircraft flew within a radius of 10 km of the base stations without any loss of the UHF signals or differential GPS corrections. Four north-south oriented forest access roads were flown twice, and mapped once by a ground vehicle.

Using the GPS/desktop mapping system, the RT-DGPS data were transferred to the desktop mapping software, converted into points and polylines, and overlaid on the OBM road network. The results indicated nearly coincident flight lines for both the north and south tracks (Fig. 18). There is a small displacement between the OBM secondary roads and the flight lines, which is also reflected in the ground-based road mapping.

The road mapping was less accurate due to the irregularity of the roads, the slower speed of the vehicle, and the accuracy of the survey. Higher than expected precision dilution of position (PDOP—a measure of GPS accuracy) was encountered through the Kirkwood Forest because of the regular pattern of the pine plantations. Stand regularity and low satellite elevation combined to produce difficult conditions for the GPS signal to penetrate. This caused the GPS receiver to select less appropriate satellites, and resulted in poorer satellite geometry.

SUMMARY AND DISCUSSION

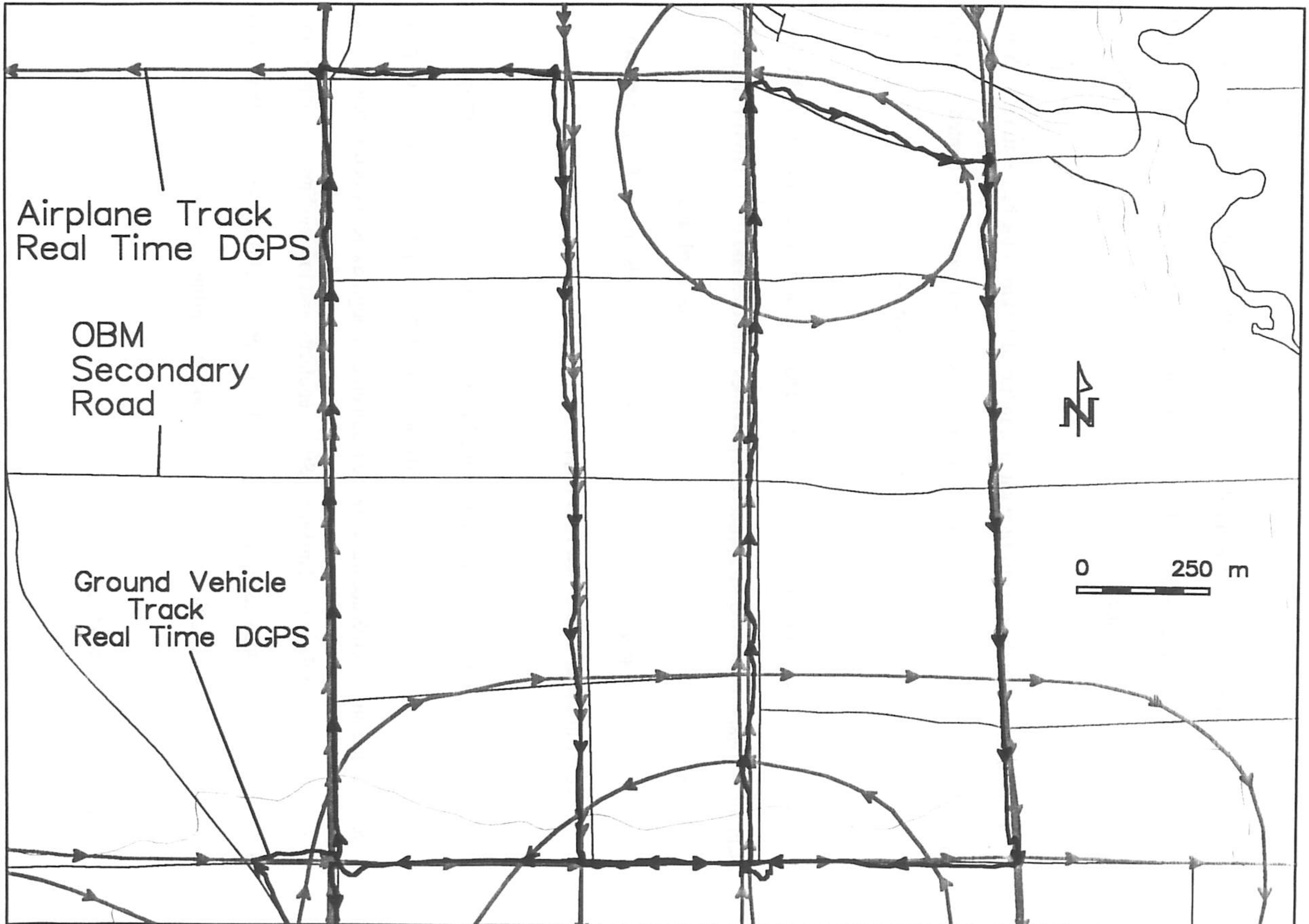


Figure 18: Airborne and ground real-time DGPS positions using UHF telemetry and the Garmin SRVY II GPS receiver for a portion of the Kirkwood Forest north of Thessalon.

Standard GPS Positioning

The results of the field tests of the Garmin SRVY II GPS receiver indicate that 90% of the uncorrected GPS positions fall within 30 m of the control point. Selective availability, though generally quoted as being ±50 m, is cyclical over time, so that there are periods of short duration when S/A may approach zero.

With sampling intervals of 30- and 60-minutes, the GPS positions approach a normal distribution, with an average departure from the control close to 0 ± 1 m. This is useful for remote forestry operations where no survey control is available, and can be used to establish a survey control that meets the 1:20 000 OBM horizontal position accuracy requirements for the representation of geographic information (Ont. Min. Nat. Resour. 1994). To achieve this accuracy, a minimum 60-minute sampling interval with a PDOP ranging from 1.0–1.5 units is recommended. For elevation, a minimum 2-hour sampling time, with similar PDOP values, is recommended to meet the 1:20 000 OBM vertical position accuracy requirement.

For the FPMI Novatel GPS, the wide variation in the averaged GPS positions is primarily due to the short data collection period. There is insufficient time in a 100-second averaging period to average the effects of S/A. This imposes a ±50 m inaccuracy on the GPS position calculated, which varies from 0–50 m over time. This has significant implications for aerial navigation and mapping applications at locations where a known control point or surveyed location is not present. The relative accuracy of the survey may have differential accuracy, but the 'absolute' position will not be correct. Furthermore, this also has implications if the GPS data is to be transferred to a GIS or desktop mapping system and represented on accurate digital OBMs.

USA/Canada Coast Guard Differential GPS

Using the USCG radio beacon DGPS corrections from Whitefish Point, Michigan, it was possible to achieve accuracies in the order of ± 5 m with a 15-minute average over an 80 km baseline. However, the averaged DGPS positions will be skewed up to several metres from the control point due to a NAD83 to NAD27 datum conversion error (Tortosa and Beach 1995).

The results of the trials using the USCG/Canada coast guard RT-DGPS indicate that the radio beacon HF signal can be received inland in areas of low relief to the established range of operation for the radio beacon (100 km radius from Whitefish Point, MI). Only localized signal loss occurs due to obstruction or dampening of the signal. Significant signal loss occurred beyond 1200 feet elevation when over the Canadian Shield. In some areas characterized by wide valleys, the radio beacon signal can be received inland up to 25 km.

The radio beacon network is still incomplete and can only be used inland for about 25 km in Canadian Shield terrain near the Great Lakes. Only a few radio beacons in the United States and Canada are transmitting the DGPS corrections, so this method is currently not widely available to other users. However, the USCG/Canada coast guard differential GPS service is available for use by the general public, making it the most cost-effective solution for applications close to the Great Lakes, and in areas of low relief.

Real-time and Postprocessed DGPS

The accuracy of both postprocessed and RT-DGPS methods is similar, because both techniques use the same mathematical calculation. A 15-minute sampling interval is suitable to achieve a 0 ± 1 m level of accuracy. No improvement results from using a 30- and 60-minute sampling interval because this is the accuracy limit imposed by the GPS receiver hardware (i.e., it is not capable of submetre accuracy).

A comparison of the FPMI Novatel GPS and the Garmin SRVY II demonstrated the higher accuracy and precision of the Novatel GPS, with 80% of the DGPS positions falling within 4 m of the average, compared to 7 m for the SRVY II. Flight line comparisons also indicate a slightly higher accuracy for the Novatel GPS. The significance of these differences must be weighed against the aerial survey accuracy requirements and the map form in which the data is to be represented.

For areas that are not accessible to the coast guard radio beacons, UHF and VHF radio modems may be used to transmit the differential corrections. Results from the trials indicated that topography and antenna height were the most significant variables required to determine the range of operation for both RT-DGPS and RT-tracking. Lower frequencies, such as in the HF spectrum (i.e., USCG/Canadian coast guard), will provide a longer range, but these signals are affected by weather conditions, and the designation of a frequency is more difficult to obtain from the U.S. Department of Communications.

In the typically uneven Canadian Shield terrain north of Lake Superior, the RT-DGPS capability is limited to ground applications within 5 km of the transmitter at an antenna height of 15 m. A higher antenna height would increase the range, but the local relief would produce signal blockage and result in a patchwork of RT-DGPS capability, particularly in valleys and behind hills. Airborne applications are limited to a range of 20–50 km from the transmitter, and signal loss occurs if the aircraft flies at elevations at or below the surrounding topography. Similar signal reception problems occur with RT-tracking. In addition, the UHF transmitting antenna must be located in a position in or on an aircraft where the fuselage will not pose a barrier.

At Abitibi-Price's Camp 34, the low relief in the area allowed for a significant improvement in the range of ground operations to 15–30 km, with few areas of signal loss. The results of RT-DGPS road mapping demonstrate that the system's accuracy meets the requirements of the 1:20 000 OBMs. In addition, RT-DGPS methods are as accurate as SAP-derived forest road mapping. DGPS road updates can be completed very quickly and accurately, providing forest products companies with an alternative to the use of supplementary aerial photos or other mapping techniques.

Aerial and ground trials in the Kirkwood Forest resulted in continuous access to RT-DGPS corrections throughout the survey. An overlay of the flight lines and the GPS road mapping on the 1:20 000 OBM for the area indicates a small displacement between the GPS track and the OBM secondary roads. No comparison was available for the FPMI Novatel GPS flight lines due to technical problems encountered during postprocessing.

A comparison of RT-DGPS navigation using the FPMI Novatel GPS and the Garmin SRVY II was not possible, because the SRVY II GPS receiver was not accessible to the pilot. Based on the Garmin SRVY II specifications, the main limitation for accurate RT-DGPS navigation is the limited resolution of the course deviation index (CDI) scale bar on the instrument ($\pm$50 m). To be fully effective for RT-DGPS navigation a course deviation index lightbar is required with a resolution of $\pm$1 m.

Real-time Tracking

A shorter range of operation was encountered for RT-tracking than for RT-DGPS using UHF radio modems. The trials indicated that topography and antenna height were the two variables that most affected the operating range (similar to RT-DGPS). In addition, the position of the antenna in the vehicle or aircraft proved to be significant in determining the range of operation, due to blockage of the UHF signal by the aircraft fuselage. Surrounding topography, buildings, and structures can block the transmitted signal.

RECOMMENDATIONS AND CONCLUSIONS

The trials demonstrated the real-time DGPS and real-time tracking capabilities of the GPS/desktop mapping system in situations that required rapid deployment (e.g., a project fire attack base), and the ability of the system to adapt to a changing environment.

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

- The availability and accessibility of USCG/Canada coast guard differential corrections. As mentioned previously, the Coast Guard DGPS program is still under development and the range is restricted to the Great Lakes and near shore coastal areas.
- The extent to which navigation is a critical component of the application. As noted in Table 1, natural resource professionals must make use of DGPS accuracy to access and locate forest values that require RT-DGPS navigation.
- The number of applications that require DGPS. If a large number of resource professionals require differential GPS accuracy, then it may be more efficient to use real-time DGPS for all applications. This would eliminate the need to continuously collect pseudorange data, and the technical problems of making this data available for postprocessing.
- The topographic relief and nature of the terrain. As noted in this study, the use of RT-DGPS will have a restricted range in certain areas of the Canadian Shield.
- The accuracy requirements of a particular application. Many natural resource applications can achieve the required level of accuracy by using standard GPS positioning (e.g., mapping fire perimeters), without the need for DGPS.

It is believed that the most prudent way to incorporate RT-DGPS technology into an organization is by using a flexible approach. An easily transported RT-DGPS system can meet specific application requirements under many terrain conditions. These may be either permanent or temporary operations. A GPS/desktop mapping system is a useful technology that can be relocated quickly and easily, can be used to establish survey control at a remote location, and can meet the accuracy requirements of Ontario Base Mapping. The following sections provide examples of potential applications for forestry and natural resources.

Potential Forestry and Natural Resource Applications

Timber management and environmental sensitivity

New legislation and regulations in Ontario will result in stricter guidelines for timber harvesting operations. Currently, the layout of timber harvesting blocks is done by pace and compass, used to demarcate the cut boundaries. These tend to be straight-line, simple polygons that are relatively easy to establish in areas of low topography. In addition, the layout of these blocks does not require any detailed knowledge of stand type.

New requirements for selective logging practices, and the designation of areas for biodiversity, will result in complex polygons that contain multiple stand types. Accurately surveying the boundaries of these polygons is more complex, and involves many changes in direction and accurate positioning. The use of RT-DGPS will provide a technological tool to map out the required boundaries, and transfer the GPS locations to an OBM. At the completion of the harvest, the same area can be resurveyed on the ground or from an aircraft using DGPS to determine compliance with the previously established boundary.

Multiple land-use conflicts

In areas where there are competing uses for the land because of conflicting interests, GIS is being used to provide alternative solutions to meet the requirements of various stakeholders (e.g., Megasin Lake Environmental Assessment). The use of GIS creates options characterized by multiple and complex buffer zones. The implementation of the selected method to resolve a land-use conflict may, in turn, determine its feasibility. For example, the complex buffer zones determined using digital elevation modelling 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 combine the GPS real-time tracking capability with real-time DGPS to produce an automated tracking system. This can provide positioning information to a harvester operator or to a control centre. 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 to avoid a buffer edge. The buffer zone can be as complex as required, no detailed ground-based surveys need be completed, and harvest block compliance is met when the harvester reaches a buffer boundary.

Aerial spray and aerial mapping applications

The aerial trials completed during the project, and the comparative GPS tests carried out with the FPMI aircraft, showed that the RT-DGPS accuracies obtained using the Garmin SRVY II (GPS/desktop mapping system) compare favourably with those of the FPMI Novatel GPS system. The Garmin SRVY II is not designed for real-time differential navigation, and at a minimum requires a lightbar to aid the pilot.

The significance of this trial was to demonstrate that the level of accuracy required for many aerial spraying applications in the boreal forest can be achieved with the much less expensive

GPS equipment than is currently used (Novatel). In addition, the GPS/desktop mapping system demonstrated a superior capability in representing GPS information relative to standard maps.

For companies and governments involved in aerial spraying and other natural resource applications, both the accuracy achieved with postprocessing and RT-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. The ability to provide accurate maps of the surveys 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 benefit to government agencies because the audit aircraft for aerial spraying can be eliminated.

ACKNOWLEDGEMENTS

The author thanks Mr. Paul McBay and staff of the Ontario Ministry of Natural Resources' Regional Fire Centre and the Ranger Lake Attack Base for their support and assistance throughout the duration of the project. Mr. Art Robinson provided assistance during the aerial trials and information during the analysis and reporting stages of the project. Mr. George Stanclik and Mr. Erik Turk of Abitibi-Price provided digital base maps and logistical support during the field trials at Iroquois Falls, Camp 34. Paul Beach, ELIRIS Inc., provided field support, data processing and map production, and completed detailed accuracy and precision testing throughout the duration of the project.

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APPENDIX 1: System specifications

DATA LOGGING AND DGPS ON BOARD THE FPMI AIRCRAFT[1]

DGPS PARTS AND COMPONENTS

1. Agnav guidance system

   Tasks:

   (a) compute position 5x/sec by monitoring up to 8 satellites.
   (b) store area parameters and block locations.
   (c) display position in relation to block on moving map.
   (d) provide guidance (i.e., moving map or CDI bar).
   (e) record spray parameters.
   (f) provide position update for video stamping.
   (g) copy data to disk in a user-friendly format for downloading into GIS, ASM, or other files.

2. Light bar

   Tasks:

   (a) provide guidance on spray block or grid line.
   (b) provide warning on entering or leaving spray block.

3. Portable differential base station

   Tasks:

   (a) provides differential correction to mobile Agnav system in remote locations.
   (b) provides portable computer for postprocessing data.

4. ASM monitor:

   Tasks:

   (a) collects data from a number of sensors; averages and records data at 1-second intervals.

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[1] Provided by Mr. A. Robinson, Forest Pest Management Institute.

Listed below are the associated sensors and their use:

1. Temperature probe:
   Use:
   - (a) recording outside air temperature during flight.
   - (b) determine the inversion layer or height in conjunction with the radar altimeter.

2. Relative humidity sensor
   Use:
   - (a) recording relative humidity at spray height.

3. Radar altimeter
   Use:
   - (a) record spray height.
   - (b) measure canopy height and density.

4. Flow
   Use:
   - (a) record total emission.
   - (b) compute emission rate.
   - (c) compute application rate with position information.

5. Boom pressure
   Use:
   - (a) record pressure in spray booms.
   - (b) evaluate spray system and nozzle operation.

6. Atomizer RPM
   Use:
   - (a) aid to evaluate spray cloud at time of formation.

SUMMARY

From the above data, any given flight can now be evaluated, e.g., where and when it took place, the altitude, the conditions, and how different systems worked.

The system has four excitation channels that can be used for any number of functions, e.g., camera operation.

GPS/DESKTOP MAPPING SYSTEM (ELIRIS INC.)

HARDWARE

DGPS Base Station:

Garmin SRVY II GPS receiver

External magnetic mount antenna

Pacific Crest Corporation UHF radio modem DDR-96

Omni-directional UHF antenna

35-watt RF amplifier

Cables and connectors

DGPS REMOTE:

Garmin SRVY II GPS receiver

Detachable GPS antenna

Pacific Crest Corporation UHF radio odem DDR-96

Detachable UHF antenna

Radio beacon receiver MBX1 (Communications Systems International)

SOFTWARE

Garmin PC100S2 postprocessing software

QuikMAP desktop mapping software (Windows/DOS)

QuikELINX GPS linkage software

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Figure 1. Location of trial areas.

Figure 2. United States Coast Guard radio beacon locations and ranges.

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

Figure 4. Histograms of the averaged departure for the easting, northing, and elevation from a control point using the FPMI Novatel GPS receiver during accuracy and precision tests using 20, 500-point, non-differential averages.

Figure 5. Cumulative frequency distributions of real-time DGPS positions, with distance from a reference point, using the Garmin SRVY II GPS receiver and the FPMI Novatel receiver.

Figure 6. Frequency distribution of the departure from the control point for the easting, northing, and elevation using Garmin SRVY II and FPMI Novatel GPS receivers, using real-time GPS with a 15-minute scatter.

Figure 7. Dynamic, real-time DGPS postions collected by the FPMI aircraft at a fixed position using the Garmin SRVY II and Novatel GPS receivers.

Figure 8. Flight lines for the FPMI aircraft at the Sault Ste. Marie airport runway using real-time DGPS for the Garmin SRVY II and the FPMI Novatel GPS receivers.

Figure 9. Comparison of printed and plotted output from the GPS/desktop mapping system (top) versus the FPMI Novatel system (bottom).

Figure 10. Range of the United States Coast Guard signal from Whitefish Point, Michigan using ground-based real-time DGPS. Note loss of signal past the 1 200 foot contour within the Canadian Shield.

Figure 11. Range of real-time DGPS using UHF telemetry for the Garmin SRVY II GPS in the greater Sault Ste. Marie area (hatched area). Filled arrows represent loss of signal, open arrows represent regained signal, numbers represent different traverses.

Figure 12. Real-time DGPS positions using the Garmin SRVY II and plotted on 1:2 000 scale city map.

Figure 13. Range of real-time GPS tracking using UHF telemetry in the greater Sault Ste. Marie area.

Figure 14. Range of real-time DGPS using UHF telemetry and Garmin SRVY II GPS receivers in the Ranger Lake area.

Figure 15. Range of real-time GPS tracking (aircraft) using UHF telemetry and Garmin SRVY II GPS receivers.

Figure 16. Range of real-time DGPS using UHF telemetry and Garmin SRVY II GPS receivers. Filled arrows represent loss of signal, open arrows represent signal regained.

Figure 17a (top) and 17b (bottom). Digital OBM showing both OBM- and SAP-derived roads with real-time DGPS tracks overlayed. Arrows indicate direction of travel.

Figure 18. Airborne and ground real-time DGPS positions using UHF telemetry and the Garmin SRVY II GPS receiver over a portion of the Kirkwood Forest north of Thessalon.