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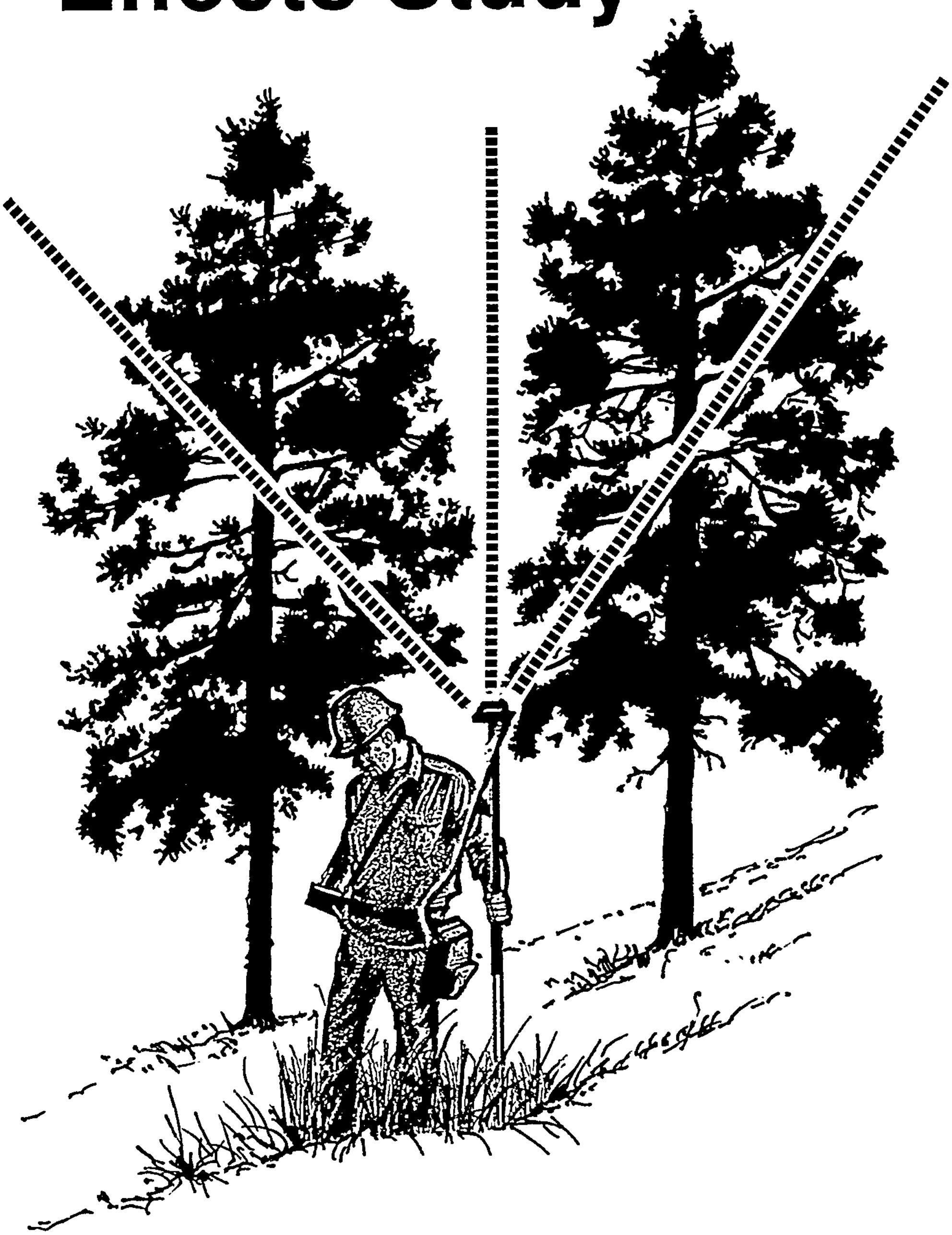
Global Positioning System Canopy Effects Study



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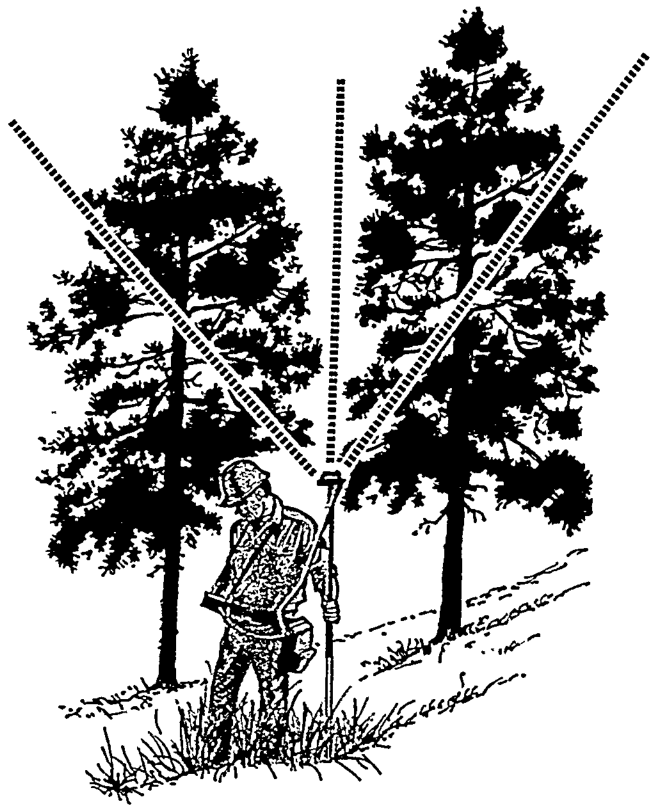

Frederick L. Gerlach
Professor, University of Montana, School of Forestry

Anthony E. Jasumback
Project Leader

Technology & Development Program
Missoula, Montana 59801

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Field Coordinate Locator

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INTRODUCTION

Background

Experiences with the Global Positioning System (GPS) navigation in forestry field conditions have been less than satisfactory. This study of canopy effects was initiated to explore reported problems.

The USDA Forest Service Missoula Technology and Development Center (MTDC) has pioneered GPS forest applications. In 1986, MTDC established a Satellite Navigation Field Evaluation Facility (SNFEF) at Lubrecht Experimental Forest in cooperation with the Montana Forest and Conservation Experiment Station (School of Forestry, University of Montana, Missoula, MT, (Amundsen 1986)). The evaluation facility was designed to provide test and evaluation situations typical in operational forestry and to provide typical settings for training users of GPS navigation receivers. MTDC has evaluated GPS receivers at this facility since 1987 (Jasumback 1988). A series of field training seminars was presented through the UM Center for Continuing Education in 1988 (Gerlach and Jasumback 1988). Results of GPS evaluation and testing form the substance of this report.

The Problem

Experiences with GPS navigation receivers have shown that topography and vegetation (trees or a vegetation canopy over the receiver antenna) may block or attenuate the GPS satellite radio signals. Topography generally produces a complete blockage of the signal pathway. A vegetation canopy may produce complete attenuation to little or no apparent affect on the signal pathway. As a rule, a vegetation canopy causes some operational inefficiency in the operation of GPS receivers. Also, the accuracy of GPS positioning may be affected.

MTDC and the Montana Forest and Conservation Experiment Station attempted to learn more about the effects of canopy on the operational efficiency of the receivers, the elements of canopy structure that may be causing the effects, and the differences in operational efficiency that might be achieved by antenna height and antenna type.

Elements of the Global Positioning System

Implementation of GPS began in 1978, under the direction of the Department of Defense, to provide worldwide navigation and positioning service for military defense and general civil applications. GPS consists of three major components: (1) A Space Segment is composed of a system of orbiting satellite vehicles (SVs). Each SV or NAVSTAR (for Navigation Satellite Timing and Ranging) is capable of emitting coded and synchronized radio signals into surrounding space. A GPS receiving instrument locks on to the signals from multiple satellites, determines the distance to each satellite, and performs a solution for the position of the receiving antenna. The NAVSTAR launch schedule expects to have a full constellation of twenty-four SVs in orbit by 1992 providing worldwide twenty-four hour coverage for civil and military applications. For national security reasons, the civil applications may not be given the same precision (p-code) as for military applications. (2) A Control Segment consists of a major control center and several transceiving monitor stations around the earth. Its purpose is to control SV orbit, communications, and code, timing and ranging parameters. (3) The User Segment consists of thousands (potentially millions) of GPS receiving instrument operations (Wells 1987).

GPS receivers exist at two levels — one for geodetic or high precision surveying and one for navigation or low-precision surveying. Generally, high precision surveying is served by a GPS surveying instrument and low-precision surveying uses a GPS navigation receiver. The differences are related related to the number of receiving channels, code/phase receiving capabilities, data recording/processing capabilities, power requirements, weight, and cost. The weight of navigation receivers is down to three and one half pounds and the cost is down to less than $20K. Price reductions are expected to continue as the number of users increase. This study used the first navigation receivers weighing less than ten pounds with the control/display/recording unit and power supply (Trimble Navigation, Ltd. PATHFINDER) (Trimble Navigation 1988).

GPS Surveying

The precise survey level of GPS receiver operation requires lengthy (15 to 90 minutes) periods of observations with automatic data recording and post computer processing of the data. During these periods position data is collected simultaneously from four or more SVs and continuously through the period usually at one second intervals. The resulting relative precision of the positions is closely related to the integrity of the continuous and simultaneous data collection. The precision is also related to the number of receivers and receiver stations occupied simultaneously. If one position is occupied by one receiver, the mode of operation is autonomous. If more than one station is simultaneoulsy occupied by a receiver, the mode of operation is differential.

Precise GPS surveying (first order) requires that observation points be unobstructed by buildings, trees, poles, bushes, and topography for the entire sky from ten degrees above the horizon. This is required to minimize the loss of data due to signal interruption and is especially important in differential mode operations when corrections are obtained by using simultaneous signals from several of the same satellites at two or more stations. The relative position determination precision in differential mode operations may be as high as 2 to 4 ppm (1/250000).

GPS Navigation /Low Precision Surveying

In contrast, the navigation level of GPS operation has lower precision requirements and more relaxed guidelines for field operation. From experience, however, it is obvious that operating clear of obstructing objects is preferred. The practical characteristic of forestry work makes such operation hard to find. Therefore, the development of practical guidelines for operating GPS receivers under a forest canopy is essential for forestry work.

GPS navigation receivers are usually single or dual channel with sequential satellite signal reception of the SVs C/A code (coarse/acquisition code). The C/A code is available for civil use and the p-code (precise) is reserved for military operations. Most recently, multiple channel navigation receivers have been developed. These receivers monitor SV signals continuously using multiple continuous channels.

Survey grade receivers may be independent of the P-code and relying instead on the measurement of wave phase for precise range determination. Navigation level instruments are used much of the time in a real time and autonomous mode of operation using the C/A code for ranging. Real time differential operations are possible when adequate data links exist between remote and reference station receivers, but differential mode and post data processing are more common for low pricision survey applications.

PROCEDURES

The Canopy Study

Two Trimble Navigation PATHFINDER receivers (Figure 1) were used to produce position determination in both the autonomous and differential modes. This was done on several dates using test courses A & B and the Lubrecht Base Station (Figure 2). The facility has been described in previous reports (Sears et al. 1987; Jasumback 1988). The Lubrecht Base Station position (latitude, longitude, and height above ellipsoid) has been determined by a precise GPS survey. Its relative position accuracy in latitude and longitude is in the realm of 1:250,000. The positions of the A & B course stations have been determined by conventional EDM traverse methods deriving coordinates from the Lubrecht Base Station. Course A is located in a clearcut area. All of the A1 stations are in the center of the clearcut and each has completely open sky (10 degrees above horizon). The A2 stations are located on the border of the clearcut and some sky visibility is obstructed by the adjacent forest canopy. Stations A31 and A41 are located in the adjacent forest canopy. Course B is located in a forest canopy that has been altered by thinning treatments. The B1 stations are all located within the thinning treatment area; B2 stations are located in the original canopy and the treatment area. These locations create canopy changes in a relatively small area, minimizing travel time between

Figure 1.—Trimble Navigation, Ltd. PATHFINDER GPS receiver at Lubrecht base station.

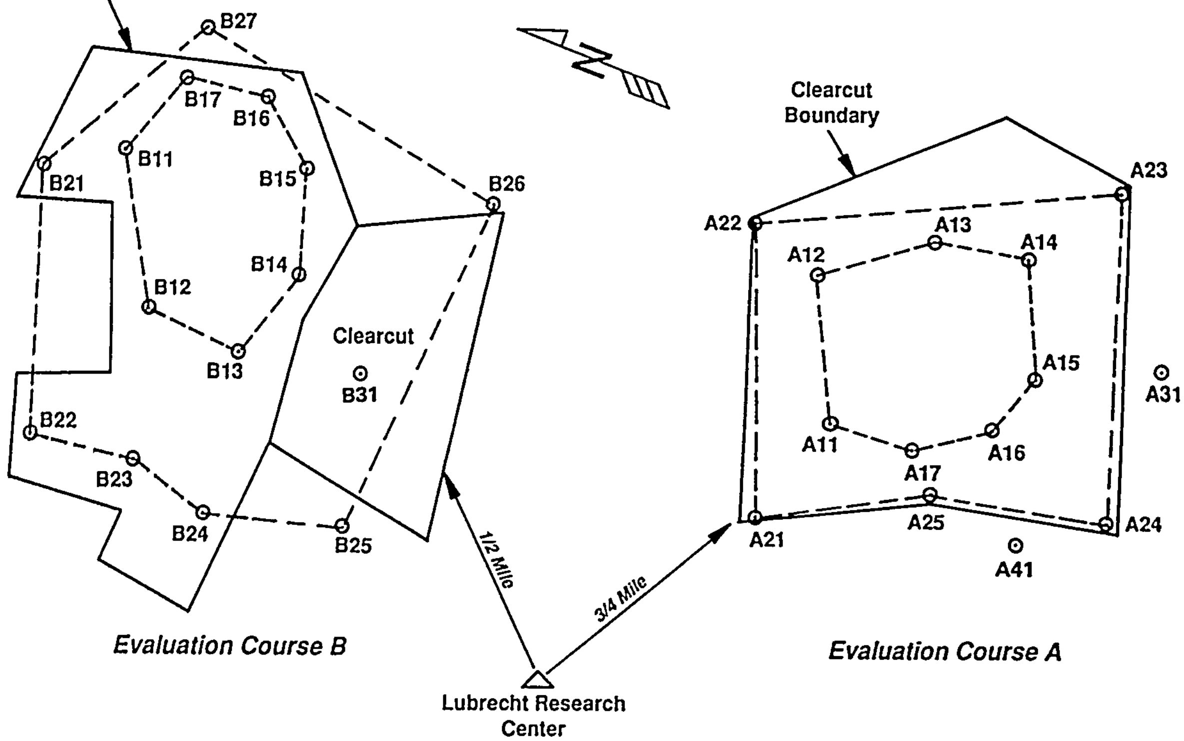

Figure 2.—Schematic diagram of course A and B.

stations. These canopy differences may be best described by the hemispheric photographs taken with the camera pointed vertically at the station (Figures 3 to 5). The B course stand is mostly lodgepole pine growing in a previously burned area. Tree heights vary from about 30 to 60 feet and tree diameters from about 3 to 8 inches. Occasional smaller and larger trees occur on the area. The topography is nearly flat on the A course and slightly rolling on the B course. Both areas slope gently to the northwest. The Lubrecht Base Station is in an open meadow near the Castles Forestry Center at the Lubrecht Forest Headquarters. It is also essentially unobstructed by tree canopy or topography.

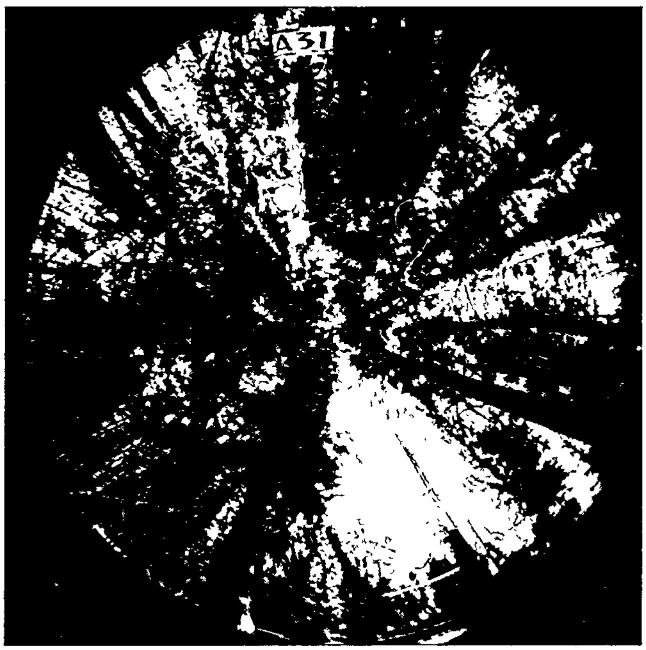

Figure 3.—Hemispheric photograph at A31.

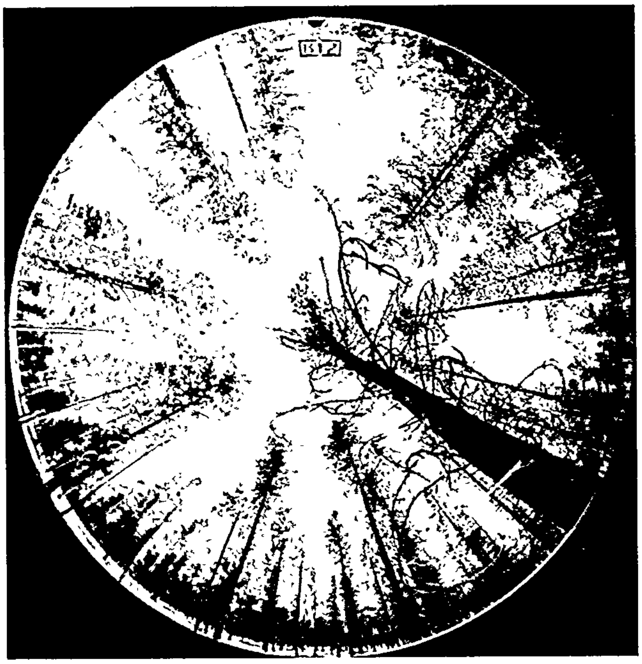

Figure 4.—Hemispheric photograph at B12.

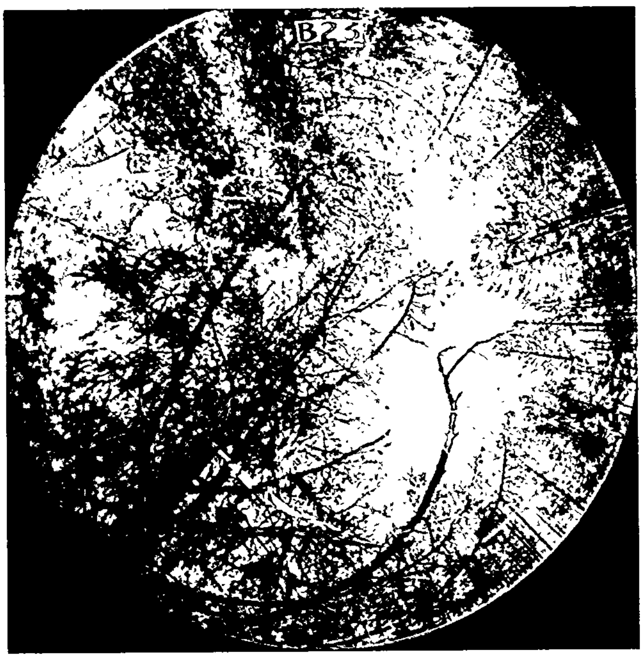

Figure 5.—Hemispheric photograph at B23.

Operating Situation Comparisons

The data collected by the PATHFINDER receivers compares several operating situations. These situations are described as follows:

1) Comparison of the Helix and Microstrip antennas in the open.
This comparison was conducted on the A course using stations A11 and A31. The two receivers were operated simultaneously at each of the stations recording a short time-period of position data. Each antenna was 5.5 feet high. They were operated side by side approximately two feet apart. There was no apparent effect from the closeness of the two antennas. The receivers were set to identical position and recording parameters. Station A11 is in the open and the canopy condition at A31 is shown in Figure 3. The antennas were switched on the receivers at each station to isolate any receiver bias or proximity effect. The data collection period for each receiver was nearly identical at each station and each antenna switch. A summary of the data produced in this comparison is shown in Table 1. All of the position data in this comparison and others were post-processed using the Trimble Navigation PFINDER software on microcomputers. PFINDER accompanies the PATHFINDER receiver. The control/display/recording unit on the receiver is a POLYCORDER with a PATHFINDER operating system installed. The operating system facilitates all of the required field operations, including data recording and downloading of data to a microcomputer.)

2) Comparison of Helix and Microstrip antennas under the canopy.
This comparison was conducted on the B course at stations B15 and B16. The two receivers were operated simultaneously at each station over two observation days. The position and recording parameters were identical for each and the antenna height was 5.5 feet. The recording time-period was long, approximating the daily time-period for the present GPS positioning opportunity. The antennas were switched between stations (at B15 the first day and B16 on the next day). Table 2 is a summary of the data produced in this comparison. The data recording in this comparison was supplemented with a TV camera of voice and optical coverage of the POLYCORDER display. This TV record was used to provide current satellite almanac data in all subsequent comparisons.

3) Comparison of antenna heights under canopy.
In this and subsequent comparisons, one receiver was on the Lubrecht Station operating as a reference or base receiver for the differential mode. The antenna height comparisons were made over a period of three days. The heights compared were at 5.5, 15 and 25 feet. Results are discussed in the analysis section.

4) Comparison of short time-periods in open and under canopy.
This comparison results from data collected at A and B

Table 1. — Helix and Microstrip Antenna Comparison at A11 and A31.

Station	Position NAD83 (1)				Antenna Position (2)		Difference Position-Antenna (3)		RMS		Position Records	
		°	′	″	Helix ″	Micro ″	Helix ″	Micro ″	Helix	Micro	Helix	Micro
A11	φ	46	53	08.74	8.60	8.60	0.14/4.2	0.14/4.2	4.34	3.70	RCVR	RCVR
	λ	113	26	25.85	26.21	26.15	-0.36/8.3	-0.30/6.9	5.94	4.39	#1	#2
	Z			1273m	1277m	1278m	-4m	-5m	11.34	8.59	183	183
	φ				8.61	8.61	0.13/3.9	0.13/3.9	2.59	2.01	RCVR	RCVR
	λ				25.86	25.84	-0.01/0.2	0.01/0.2	6.55	4.57	#2	#1
	Z				1280m	1278m	-7m	-5m	6.24	5.16	177	181
A31	φ	46	52	59.77	59.51	59.80	0.26/7.8	-0.03/0.9	8.84	9.68	RCVR	RCVR
	λ	113	26	28.16	27.93	28.04	0.23/5.3	0.12/2.8	21.78	17.48	#1	#2
	Z			1283m	1287m	1283m	-4m	-0m	17.00	8.95	258	134*
	φ				59.69	59.67	0.08/2.4	0.10/3.0	10.38	8.06	RCVR	RCVR
	λ				27.97	27.88	0.19/4.4	0.28/6.5	15.11	13.23	#2	#1
	Z				1284m	1283m	-1m	-0m	15.69	10.00	459	449

* *Number of records were the same for equal observation time.*

1 *Station position latitude and longitude in degrees, minutes and seconds. Height above ellipsoid in meters.*

2 *Receiver determined position for each antenna type.*

3 *Difference between station position and antenna position in seconds/meters.*

Table 2.—Helix and Microstrip Antenna Comparison at B15 and B16.

	Position Record Efficiency					Position Accuracy			
						Antenna—Station			
Station	Record Length (seconds)	Percent 3D	Seconds* Total Records	Seconds** 3D Records	Date/ Remarks	dlat ″	dlon ″	dhae m	Antenna Type
B15	9000	42	3.35	7.91	111088	+0.066	-0.079	3	Micro
B16	8460	51	2.68	5.22		-0.030	-0.157	10	Helix
B15	7920	45	3.03	6.76	111188	-0.060	-0.259	21	Helix
B16	5580	30	3.48	11.70		+0.318	-0.073	9	Micro

* *Seconds required to produce a position record (2D or 3D).*

** *Seconds required to produce a 3D position record.*

course stations (A11 to A21 and B11 to B31). A summary of the position and record results is given in Table 3. A11 to A17 and B31 are clear to the sky at 10 degrees above the horizon. B11 to B17 and A21 are obstructed by a tree canopy. A21 is on the edge of the clearcut at course A. B31 is in a small clearcut near the B course where all other stations are in a forest canopy situation. All of these stations were occupied for very short periods (approximately two minutes or until approximately one hundred twenty 3D records were obtained) while a second receiver was operating as a reference receiver at the Lubrecht Base Station. A comparison of record acquisition efficiency and position accuracy between the open and the canopy is found in Table 4. Additional short time-period observations are summarized in Table 5.

Table 3. — In the Open and Under the Canopy Comparison Summary of Position Records and Mean Position Results.

Sta/ File/ Interval	Time/ Records/ 3-D Recs	%-Recs 3-D	Diff.[1] Corr. Recs.	Station Position NAD83 (HAE)	Auto-[2] Position SSF $\bar{x}$	Diff-[3] Position COR $\bar{x}$	Auto Minus Sta	Diff- Minus Sta	Auto RMS m	Diff- RMS m
				° ' "	"	"	"	"		
Lubrecht	5640s			ϕ 46 53 36.063	35.958		-0.105		5.38	
B082488A	989		Base	λ 113 27 02.256	02.280		+0.024		9.95	
5s	784	79	Sta	Z 1250m	1250.97m		-1m		10.48	
A11	150s			ϕ 53 8.741	8.676	8.718	-0.065	-0.023	1.63	2.76
R0824A11	119			λ 26 25.852	26.118	25.83	+0.266	-0.022	3.84	7.06
1s	119	100	119	Z 1273m	1269.70m	1241.13m	+3m	+32m	3.18	8.24
A12	160s			ϕ 9.601	9.528	9.558	-0.073	-0.043	2.40	2.71
R0824A12	128			λ 24.062	24.270	24.054	+0.208	-0.008	6.10	7.38
1s	128	100	101	Z 1273m	1271.73m	1242.18m	+1m	+31m	4.82	6.03
A13	129s			ϕ 7.971	7.860	7.944	-0.111	-0.028	2.53	3.56
R0824A13	101			λ 20.181	20.412	20.196	+0.231	+0.016	4.77	6.56
1s	101	100	101	Z 1279m	1282.11m	1248.69m	-3m	+31m	4.71	7.12
A14	167s			ϕ 5.711	5.618	5.688	-0.083	-0.023	2.56	3.85
R0824A14	106			λ 20.591	20.772	20.640	+0.181	+0.049	4.63	7.41
1s	106	100	106	Z 1284m	1286.67m	1253.79m	-3m	+31m	5.92	9.42
A15	169s			ϕ 3.501	3.372	3.498	-0.164	-0.003	2.68	3.73
R0824A15	122			λ 22.751	22.956	22.782	+0.205	+0.031	4.26	6.07
1s	122	100	122	Z 1283m	1203.23m	1253.54m	-10m	+31m	7.70	8.13
A16	172s			ϕ 3.681	3.588	3.690	-0.093	+0.009	2.79	5.02
R0824A16	135			λ 26.072	26.196	26.124	+0.124	+0.052	3.97	5.21
1s	135	100	135	Z 1279m	1291.44m	1251.34m	-10m	+30m	7.70	8.13
A17	239s			ϕ 5.971	5.814	5.892	-0.157	-0.079	2.77	3.18
R0824A17	152			λ 26.832	26.778	26.814	-0.065	-0.018	3.20	5.37
1s	148	97	90	Z 1279m	1290.42m	1255.51m	-15m	+19m	7.37	9.08
A21	413s			ϕ 10.671	10.212		-0.459		10.62	
R0824A21	152			λ 28.382	27.906		-0.476		8.20	
1s	148	31	0	Z 1266m	1307.46m		-41m		14.09	
Lubrecht	3870s			ϕ 46 53 36.063	35.958		-0.099		4.20	
B082488B	770		Base	λ 113 27 02.256	01.896		-0.360		4.60	
5s	770	100	Sta	Z 1250m	1251.80m		-2m		14.07	
B13	364s			ϕ 53'40.302	40.254	40.388	-0.048	+0.036	8.13	10.25
R0824B13	240			λ 26'38.153	37.764	38.106	-0.389	-0.047	11.04	12.60
1s	154	64	154	Z 1244m	1245.76m	1228.70m	-1m	+16m	14.98	17.79
B14	252s			ϕ 39.102	29.240	39.264	+0.138	+0.162	7.06	6.80
R0824B13	133			λ 34.933	34.668	35.034	-0.265	+0.101	9.63	8.79
1s	98	74	98	Z 1271m	1245.16m	1211.79m	+26m	+60m	14.28	12.20

Table 3 (continued)

Sta/ File/ Interval	Time/ Records/ 3-D Recs	%. Recs 3-D	Diff.[1] Corr. Recs.	Station Position NAD83 (HAE)	Auto-[2] Position SSF x̄	Diff-[3] Position COR x̄	Auto Minus Sta	Diff- Minus Sta	Auto RMS m	Diff- RMS m
				° ′ ″	″	″	″	″		
B15	312s			φ 38.112	38.382		+0.150		4.55	
R0824B15	159			λ 33.013	37.796		-0.216		5.07	
1s	0	0	0	Z 1245m	1256.68m		-2m		0.01	
B31	165s			φ 38.272	33.382	38.526	+0.110	+0.254	3.53	8.39
R0824B31	119			λ 37.643	37.440	27.842	+0.203	+0.199	3.34	7.05
1s	118	100	118	Z 1250m	1249.29m	1211.28m	+1m	+39m	6.67	14.53
Lubrecht	9240s			φ 46 53 36.063	36.186		+0.123		7.19	
B0826888	1632		Base	λ 113 27′02.256	2.238		-0.018		7.34	
5s	1466	90	Sta	Z 1250m	1240.35m		+10m		9.24	
B31	188s			φ 38.272	38.400	38.310	+0.128	+0.038	3.36	3.96
R0826B31	121			λ 37.643	37.548	37.686	-0.059	+0.043	9.92	9.54
1s	121	100	121	Z 1250m	1238.39m	1218.50m	+12m	+32m	6.87	8.67
B14	723s			φ 39.102	39.294	39.132	+0.192	+0.030	7.11	2.46
R0826B14	131			λ 34.933	35.046	35.424	+0.113	+0.491	15.96	7.55
1s	17	13	17	Z 1271m	1245.44m	1227.84m	+16m	+41m	5.32	4.58
B15	357s			φ 38.112	38.250	37.998	+0.138	-0.114	4.82	2.81
R0826B15	179			λ 33.013	33.102	33.168	+0.089	+0.155	5.76	6.15
1s	54	30	54	Z 1254m	1246.40m	1227.94m	+8m	+26m	4.48	7.72
B16	604s			φ 39.012	38.754	39.162	-0.258	+0.150	18.42	8.12
R0826B16	201			λ 30.493	30.456	30.140	-0.037	-0.253	30.78	11.60
1s	61	30	61	Z 1250m	1266.65m	1223.19m	-17m	+26m	26.20	18.41
B17	416s			φ 41.092	41.196	41.178	+0.104	+0.086	4.59	5.12
R0826B17	254			λ 30.133	30.288	30.126	+0.155	-0.007	5.62	9.14
1s	81	32	81	Z 1248m	1245.52m	1223.21m	+3m	+37m	9.34	12.24
B11	393s			φ 43.162	43.128	43.284	+0.056	+0.122	7.71	8.04
R0826B11	209			λ 32.453	32.610	32.622	+0.157	+0.169	8.60	6.84
1s	54	26	54	Z 1244m	1207.97m	1207.97m	+0m	+36m	12.58	15.64
THI	382s			φ 43.572	43.698		+0.126		6.24	
R0826THI	237			λ 33.643	33.852		+0.209		5.93	
1s	0	0	0	Z 1243m	1240.66m		+2m		0.00	
B12	264s			φ 43.282	53.998		+0.716		14.35	
R0826B12	108			λ 35.733	36.084		+0.351		12.12	
1s	0	0	0	Z 1241m	1240.66m		+0m		0.00	

[1] *Number of 3D position records used for differential corrections.*

[2] *Mean position determined from all records in PATHFINDER SSF file.*

[3] *Mean position determined from all differentially corrected records in COR file.*

Table 4. — A Comparison of Record Acquisition Efficiency and Position Accuracy Between the Open and the Canopy.

Station	Record Length	Position Record Efficiency in Open: Percent 3D	Percent Differential	Seconds/ Total Rec.	Seconds/ 3D Rec.	Date/ Remarks	Position Accuracy in Open: Autonomous (−station) dlat ″	dlon ″	dhae m	Differential (−station) dlat ″	dlon ″	dhae m
A11	150s	100	100	1.26s	1.26s	082488	-0.065	+0.266	−3	-0.023	-0.022	−32
A12	160	100	100	1.25	1.25	A-Course	-0.073	+0.208	−1	-0.043	-0.008	−31
A13	129	100	100	1.28	1.28		-0.111	+0.231	+3	-0.027	+0.016	−31
A14	167	100	100	1.58	1.58		-0.083	+0.181	+3	-0.023	+0.049	−31
A15	169	100	100	1.39	1.39		-0.164	+0.205	+10	-0.003	+0.031	−30
A16	172	100	100	1.27	1.27		-0.093	+0.124	+12	+0.009	+0.052	−28
A17	239	97	59	1.57	1.61	PDOP	-0.157	-0.054	+15	-0.079	-0.018	−19
B31	165	100	100	1.39	1.39	B-course	+0.110	-0.203	+12	+0.254	+0.199	−32
B31	188	100	100	1.55	1.55	082688	+0.128	-0.059	+1	+0.038	+0.043	−39
x̄	171s	99.7	95.4	1.39s	1.40s		0.109	0.170	7	0.055	0.049	30
						w/o B31	0.106	0.181		0.030	0.028	
		Position Record Efficiency in Canopy					**Position Accuracy in Canopy**					
A21	413s	31	0	1.55s	5.04s	082488	-0.459	-0.476	+41			
B13	364	64	64	1.52	2.36	PDOP	-0.048	-0.389	+ 2	+0.036	-0.047	−16
B14	252	74	74	1.89	2.57		+0.138	-0.265	−26	+0.162	+0.101	−60
B15	312	0	0	1.96	∞		+0.150	-0.217				
B14	723	13	13	5.52	42,53	082688	+0.192	+0.113	−26	+0.030	+0.491	−41
B15	357	30	30	1.99	6.61		+0.138	+0.089	+8	-0.114	+0.155	−26
B16	604	30	30	3.00	9.90		-0.258	-0.037	+17	+0.150	-0.253	−26
B17	416	32	32	1.64	5.14		+0.104	+0.155	−3	+0.086	-0.007	−37
B11	393	26	26	1.88	7.28		+0.056	+0.157	−0	+0.122	+0.169	−36
THI	382	0	0	1.61	∞		+0.126	+0.209				
B12	264	0	0	2.44	∞		+0.716	+0.351				
x̄	407s	27	24	2.27s	10.18s	∞	0.217	0.223	15	0.100	0.175	35
						w/o A21& B12	0.134	0.181	12	0.100	0.175	35

Table 5.—Short Time-Period Observations Under the Canopy.

Position Record Efficiency on B-Course							Position Accuracy on B-Course			
							Autonomous		Differential	
Station	Record Length	Percent 3D	Percent Differential	Seconds/ Total Rec.	Seconds/ 3D Rec.	Date/ Remarks	Minus dlat "	Station dlon "	Minus dlat "	Station dlon "
B25	179s	80	80	1.61	2.01	082988	+0.075	+0.061	+0.063	-0.053
B26	229	45	45	1.88	4.16		+0.062	+0.253	+0.080	+0.001
B27	252	61	17	2.19	3.60		+0.058	+0.167	-0.020	+0.005
B21	281	31	15	216	7.02		+0.098	+0.299	-0.100	+0.005
THI	721	0	0	1.63	∞		+0.102	+0.197		
B22	650	0	0	3.80	∞		-0.142	+0.086		
B23	271	0	0	1.60	∞	PDOP	+0.466	+0.654		
B24	130	0	0	1.17	∞	PDOP	+0.304	+0.526		
B14	288	36	24	1.81	5.05		-0.048	-0.193	-0.072	-0.073
B15	431	43	28	1.96	4.58		-0.264	-0.241	-0.024	+0.071
$\bar{x}$	343	30	21	1.98	>4.40		0.162	0.268	0.060	0.035
B25	201	93	29	1.48	1.59	091388	+0.165	-0.053	+0.273	-0.035
B24	298	56	0	1.52	2.73		-0.020	-0.194		
B23	406	58	0	1.43	2.48		-0.014	-0.090		
B22	279	56	56	1.82	3.24		+0.092	-0.022	+0.146	+0.212
B12	434	13	13	1.39	10.85		-0.076	-0.201	-0.070	+0.045
$\bar{x}$	324	55	19	1.53	4.18		0.073	0.112	0.163	0.097
B13	401	75	74	1.79	2.37	091488	+0.144	+0.157	+0.030	+0.085
B12	327	71	45	2.08	2.95		+0.140	+0.039	+0.014	-0.087
B11	677	7	6	2.03	30.77		+0.110	+0.049	-0.076	+0.487
$\bar{x}$	468	51	42	1.97	12.03		0.131	0.082	0.040	0.220
T$\bar{x}$	359	40	24	1.85	>5.61		0.132	0.194	0.081	0.097

5) Comparison of long time-periods in open and under canopy.
Table 6 illustrates the results of the data collected in these situations. All of the remote receiver data were collected at the B course stations under varying canopy conditions. In this case the stations were occupied for relatively long periods (thirty minutes or more) observing the satellites through a significant portion of their visibility. At the same time the Lubrecht Base Station was occupied by a reference receiver for differential mode operations and comparison to open sky data collection conditions during the same periods.

6) A comparison of SV skytracks, canopy structure and signal losses.
The results shown in Table 7 were derived from data produced through an interpretation of SV tracks across the visibility hemisphere at the B course stations. A circular graticule (Figure 6) was produced as an overlay to the hemispheric photographs at each station (Figures 3, 4 & 5). Current ephemeral data were collected through a voice/video recording of the PATHFINDER display at selected times (approximately five-minute intervals) during a recording session at the occupied stations. The ephemeral data were plotted on the graticule from which the tract for each SV was developed for that session. The other data collected at the same time included the position, SVs observed, SVs used, PDOPs, SNRs, time, and date. The GPS receiver was operating as a remote receiver at the same time a reference receiver was on the base station. The SV tracks were examined according to the type of material apparently obstructing the signal pathway. An interpretation was made of the obstructing material and the apparent cause (trunk, branch, foliage, or unknown) was determined as a percentage of the track sample. A "no apparent signal loss" condition was also examined and classed according to an apparent clear or obstructed pathway. The number of sample points along the track showing SNRs equal to or less than five were counted and determined as percentages of the total sample. All of these data are summarized in Table 7.

Table 6.-Long Time-Period Observations Under the Canopy.

Position Record Efficiency on B-course							Position Accuracy on B-course			
							Autonomous Minus Station		Differential Minus Station	
Station	Record Length	Percent 3D	Percent Differential	Seconds/ Tot. Rec.	Seconds/ 3D Rec.	Date/ Remarks	dlat "	dlon "	dlat "	dlon "
B16	7115s	13	?	4.25	31.62	102188	+0.051	+0.084	No Base Station	
B17	4760s	21	15	1.95	9.10	102288	+0.062	-0.397	-0.034	+0.095
B11	4020s	17	3	2.36	13.72		+0.056	-0.029	+0.320	+0.263
B12	5040s	44	29	1.98	4.52	102388	+0.308	-0.021	+0.062	-0.093
B23	4080s	28	4	2.14	7.67		-0.022	+0.120	+0.094	+0.066
A31	2760s	2	2	10.62	460.00	110288	-0.029	+0.182	-0.557	-0.214
B26	1580s	67	7	3.08	3.10	110588	+0.170	+0.127	-0.160	-0.131
B16	6060s	30	4	2.84	65.16	110888	+0.000	-0.307	-0.018	+0.101
B16	5100s	18	4	2.41	60.71	110988	+0.204	+0.017	-0.066	+0.029
$\overline{x}$		27	8	3.40	72.84		0.100	0.143	0.164	0.123