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CANADIAN EVALUATION OF THE MACROMETER INTERFEROMETRIC SURVEYOR

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Woburn, Massachusetts, USA.

ABSTRACT

CANADIAN EVALUATION OF THE MACROMETER™ INTERFEROMETRIC SURVEYOR

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H. D. Valliant

A field trial with the MACROMETER™ INTERFEROMETRIC SURVEYOR was made in the vicinity of Ottawa, Canada during July and August 1983, using two V-1000 single frequency receivers. Despite persistent hardware problems 26 baseline determinations were made over a variety of distances, ranging from 30m to 65 km. Reduction of the data using Macrometrics, Inc. software showed an agreement with conventional values on the short baselines, 30 m and 2200 m, of 4 and 9 mm respectively. On longer baselines from 13 to 65 km. the standard deviation of a single observation ranged from 0.3 to 3.0 ppm of the baseline length in all three coordinates. Latitudes and longtitudes on the longer baselines also agree with currently available geodetic values to within a few ppm of the baseline length. Height differences appear to within 25 cm of the estimated geoid heights. Agreement is generally within the error limits of established data. An improved definition of the geodetic network is required before a more definitive comparison can be made.

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RESUME

UNE EVALUATION CANADIENNE DU MACROMETER INTERFEROMETRIC SURVEYOR

H. D. Valliant

Pendant les mois de juillet et août 1983, on a effectué un essai sur le champ du MACROMETER INTERFEROMETRIC SURVEYOR aux alentours d'Ottawa au Canada, utilisant deux récepteurs V-1000 à fréquence unique. Malgré les problèmes persistants d'équipement, on a recueilli 26 observations à partir d'une variété de lignes de référence, allant de 30 m jusqu'à 65 km. A l'aide du logiciel de Macrometrics Inc., on a réduit les données couvrant les lignes courtes, soit 30 m et 2200 m, et on a obtenu un accord avec les valeurs conventionnelles de 4 et 9 mm respectivement. Sur les lignes plus longues de 13 à 65 km, l'écart type d'une seule observation varie, dans les trois coordonnées, entre 0.3 et 3.0 ppm de la longueur de la ligne. Sur les lignes plus longues, il y a un accord de quelques ppm entre les latitudes et les longitudes obtenues et les valeurs géodétiques disponibles. Les différences de hauteur semblent être à moins de 25 cm des hauteurs établies du géoïde. En général, il y a conformité en dedans des limites d'erreurs des valeurs conventionnelles. On a besoin d'une meilleure définition du réseau géodétique avant qu'on puisse effectuer une comparaison plus définitive.

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INTRODUCTION

The Earth Physics and Surveys and Mapping Branches of the Department of Energy Mines and Resources and the Survey Engineering Department of the University of New Brunswick (UNB) jointly undertook to test and evaluate the MACROMETER™ INTERFEROMETRIC SURVEYOR for Canadian needs. The Macrometer model V-1000 is a single frequency geodetic positioning instrument using the 19-cm radio signals broadcast from Global Positioning System (GPS) satellites without requiring use of the broadcast codes. Detailed descriptions of the Macrometer equipment have been published by Counselman and Gourevitch (1981) and Counselman and Steinbrecher (1982). It is capable of generating relative positions (three coordinates) with high precision and point positions with less accuracy. In this test only its capability in the high precision relative positioning mode is investigated.

Objectives of the test were to obtain first hand information related to geodetic and crustal dynamic applications as well as providing hands-on experience in its operation under typical field conditions. A further objective was to obtain a data set for use by UNB in pursuing their program of fundamental research in GPS technology.

THE OPERATION

LOCATION:
The test was located in the vicinity of Ottawa, Canada in order to provide ready access to laboratory facilities and to minimize logistic problems. Although the selection of the test site is fully described elsewhere (Valliant, et al 1983), a map of the test area is reproduced in Figure 1. The site was chosen to provide a variety of baselines ranging from 30 m to 65 Km. Two short baselines, whose lengths, 30 and 2200 m, are known with millimeter accuracy were chosen from the National Geodetic Baseline (NGBL). The remaining stations were selected from the National Geodetic Framework to provide a braced quadrilateral with legs ranging from 13 to 65 Km in length.

OBSERVING SCHEDULE:
With the present GPS constellation, the satellites are visible for nearly 8 hours each day permitting thirty observing sessions from July 19, 1983 to August 19, 1983. The first two sessions comprised three one-hour observations on each of the short baselines. Sessions 3 to 26 were five hour observations on the longer baselines of the test quadrilateral and sessions 27 to 30 were three hour observations on baselines selected to fill in data voids created by equipment malfunctions. The schedule of observations is listed in Table 1. The maximum number of visible satellites increased from 5 to 6 after session 15 with the launching of NAVSTAR 8.

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As one objective was to investigate the limits of precision for crustal dynamic applications, five-hour observing sessions were chosen for the quadrilateral instead of the more usual three-hour period. This decision was made feasable by new software that became available from Macrometrics, Inc., around the same time as the test.

ANTENNA OFFSET:

The short baseline stations (Stations 6A, 7, and 51), located on the NGBL, consist of a concrete pier on bedrock with a stainless steel plate and attachment screw embedded in its top. A Tribrach mount was threaded directly on the screw and tightened against the stainless steel plate to receive the Macrometer antenna.

Weighted tripods (Fig 2) were cemented to bedrock at each of the field sites. A recepticle bracket was positioned directly over the control point with an optical plummet and clamped in place. The position of the bracket was checked before and after each occupation of the site. After checking the tripod alignment the optical plummet was replaced with the Macrometer antenna without unclamping the bracket or Tribrach mount. No evidence of any relative motion of the tripod was observed.

The height of the antenna above the control point was measured by lowering a graduated rod through its sighthole as reenacted in Fig. 2. Variations in antenna height of a few millimeters from set-up to set-up were recorded due to the adjustment of the tribrach leveling screws.

It is therefore assured that the horizontal position of the antenna was maintained with a zero offset ±0.5 mm throughout the test and that the elevation offset was also determined to ±0.5 mm.

OPERATIONAL DIFFICULTIES:

Operational problems arose from three areas: 1) V-1000 receiver malfunctions, 2) power supply malfunctions and 3) operator errors. Occurrences of these difficulties are summarized in Table 1. Approximately 27% of the baseline observations had insufficient data for data reduction or were rejected for other reasons as summarized in Table 2. Variable amounts of data, up to approximately 50%, were also lost from many of the remaining observations when the equipment was inoperative for short time intervals during an observing session. The number of observations obtained for each baseline observation is included in the tables with the results.

V-1000 RECEIVER MALFUNCTIONS: Both receivers evidenced an intermittent problem which caused them to lose the satellite signals part-way through an observing session. Normal operation could be restored by "booting" the system, but a variable amount of data was lost depending on how swiftly the operator recognized the condition and took remedial action. Receiver No. 903 was particularly troublesome displaying this fault with increasing severity from session 4 to the end. Initially there was only one interruption per session due to this cause but 903 deteriorated over the course of the month until in the end it caused several interruptions during any one session.

POWER SUPPLY MALFUNCTIONS: The field power supply provided with the equipment offered two alternative power sources. One, an inverter, requiring 30 amps, was connected to the vehicle's alternator. To use this system the automobile engine had to be operated throughout the 5 hr observing session. Two, an ac motor-generator with a 3 1/2 hour fuel capacity was also provided. There was however no provision to switch from one power source to the other without interruption.

Neither system proved ideal for the five hour observations that were being tried for the first time. An initial attempt to refuel the generators while they were running proved both dangerous and unreliable as even slight fuel sloppage would stop the generator. An attempt to rig auxiliary fuel tanks was only slightly better as air locks in the supply tube sometimes interrupted fuel flow and stopped the generator. A final attempt to resolve this problem for one of the units was to connect two additional marine batteries in parallel with the existing battery and operate from the inverter, requiring the vehicle engine to be started intermittently to maintain battery charge. The other unit was deployed as often as possible at the one site where ac line power is available.

An uninterruptable power source with about a 15 minute capacity should be considered a prerequisite for reliable field operations. Fifteen minutes would be more than adequate to switch generators, do minor repairs on a generator, or switch to inverter power. This could be easily achieved by using a dc generator to keep the battery charged while the system obtains ac power from the inverter.

OPERATOR ERRORS: In order to give as many personnel as possible the opportunity for hands-on training, observing duties were rotated amongst 10 operators, only one of whom had prior experience with the equipment. This parade of novice operators did little to mitigate the hardware problems and was the direct cause of a few data loses as noted in Tables 1 and 2. The combination of malfunctioning hardware and novice operators is always potentially difficult; unexpected hardware responses cause nervous fingers. The chief drawback was that remedial action was not as fast as it might have been when instrument failures did occur. On the other hand the speed with which the observers were able to acquire sufficient knowledge to operate the system (normally about three observing sessions) even under unusual circumstances, attests to its ease of operation.

DATA REDUCTION

For the purpose of this report only results from data as processed with software provided by Macrometrics with the system is considered. Data from sessions 1 and 2 were processed with the older software packages INTERF and LSQ. The rest of the data were processed with the new INTRFT and LSQT programs. The newer programs offer improved orbit modelling allowing increased accuracy from longer observation sessions to be realized.

Once a few "bugs" in the new software were corrected by Macrometrics no particular difficulty was encountered in processing the data. The location and correction of "slipped" cycles is a somewhat subjective process that is not particularly difficult but which was made abnormally tedious by the many data drop-outs due to the hardware malfunctions noted above. The quality of the interactive software, its ease of use, and its error recovery procedures are truly impressive.

The data reduction process is basically an iterative procedure performed on an off-line processor. Raw data collected by the V-1000 receivers in bubble memory and transferred to cassette are first processed by the interferometry program INTRFT producing a file of phase differences. This program permits locally observed meteorological data (temperature, pressure, and humidity) to be input instead of standard default values for atmospheric corrections. A least squares adjustment of this data is next performed by program LSQT. At this stage, the data may be edited with the aid of CRT plots of single or double difference residuals and other built-in diagnostics. In particular, it is necessary to find and correct for lost cycles which appear as a discontinuity in the residual plots of an integral number of cycles. Judgement is required in deciding which satellite signal to correct, especially on long baselines where the noise-level may approach a cycle or more. Cycle slips from such causes as occlusion by tree branches are not difficult to deal with. The case where there is a complete break in the data as would result for example from a power outage is more tedious.

In addition to processing the data with default meteorological values they were processed twice more using locally observed meteorological data. It was suggested (Dr. C. Counselman, private communication) that local meteorological data observed at ground level might not be particularly representative of the portion of the atmosphere through which the signals are transmitted. Better results might therefore be expected by using some value representative of general conditions for both sites rather than the observed values at each site. For comparison the data were reduced using the average of the observed data at both sites, as well as the individually observed data from each site as tabulated in Table 3.

RESULTS

SHORT BASELINES:

The results from observations on the short baselines are summarized in Table 4. As the relative positions of stations on the NGBL have been determined to a millimeter or better, horizontal distances may serve as ground-truth for comparison with the GPS observations. Agreement to 3.3 and 9.3 mm respectively, was observed for the 30 m and 2200 m baselines respectively. Although the absolute positions for the NGBL stations are not well established, a comparison between coordinate values agrees to better than 3 cm. in the worst case.

LONG BASELINES:

Results for the long baselines are given in Table 5. The precision ranges from .27 to 3.3 ppm of the baselength and the mean standard deviation is 1.1 ppm. Mean positions derived from GPS observations compare with coordinates obtained from the Geodetic Survey May 1976 adjustment (Table 6) to within 3.7 ppm of the baselength (Table 7). As GPS heights are measured with respect to the reference ellipsoid, an accurate comparison between known (Table 6) and observed (Table 5) heights is impossible since sufficiently accurate estimates of geoid heights are not available. The differences between GPS and published heights agree to within 25 cm of the geoid heights (Table 7) estimated using Rapp's (1981) geopotential coefficients.

Precision of the geodetic values for the length of the baselines is estimated at 18 to 32 mm (one sigma) depending on the distance. Only the METCALFE-PANMURE baselength differs significantly from published values with an observed difference in baselength of -169 mm.

METEOROLOGICAL DATA:

The results from including average and site specific meteorological data is summarized in Tables 5A and 5B. The effect of including these data was insignificant in latitude and longtitude for both cases. Also mean latitudes and longtitudes are virtually unchanged by these corrections (Table 7). Including meteorological corrections seems to produce a systematic perturbation in the observed heights however. Unfortunately without a more accurate knowledge of the geoid it is impossible to ascertain if the correction is beneficial or not. However, the precision is decreased in three out of 6 cases for site specific corrections and in one case for average corrections. There is therefore no evidence to indicate that using locally observed meteorological data, instead of the default values in the Macrometrics software, has any significant effect. This result is possibly due to the shortness of the baselines which assures that the ray paths are nearly coincident and therefore inconsistent with models for atmospheric corrections.

CONCLUSIONS

With one exception baselengths measured with the Macrometer system compare with conventional positions within the error limits of the conventional data. A more rigorous adjustment of the Geodetic network, possibly including additional conventional measurements is needed before a more definitive comparison can be obtained. This work is currently in progress and will be the subject of a further report when completed.

Precision is more important than absolute accuracy for crustal dynamic applications because changes in position are being sought. The doubt generated by the hardware problem is most unfortunate. Nearly all baseline determinations suffered some data loss, some as much as 50%, and the results are no doubt degraded by this lost data. The magnitude of the effect is determined not only by the quantity of data lost but also by the time of its occurrence as the geometry of the observed constellation also affects the accuracy. Consequently no quantitive conclusion regarding the upper limit of precision for crustal dynamic applications can be drawn except to say that it is probably better than 1.5 ppm (standard deviation of a single normalized baselength observation) for baselines up to 65 km. This may be compared with the precision of the best obtainable horizontal control of about 0.5 ppm. In the latter case distances are measured optically with continuous meteorological data being observed along the ray path by aircraft. Assuming that data observed on different days are independent and the errors random the precision of the mean of four Macrometer observations could be expected to be better than 0.7 ppm. Preliminary results from UNB (Private communication, R. Langley) suggests that combining data from several observing sessions yields better precision than treating the data as several independent observations. Even with quadruple redundancy the cost of obtaining data with the single frequency Macrometer appears to be equivalent to that of optical methods with aerial meteorological observations, but GPS measurements have the advantage of not being constrained by the need for sites to be intervisible. A dual-frequency model, currently under design, might prove to be much more cost effective for baselines longer than those used for this test.

ACKNOWLEDGEMENTS:
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S. Bell also served as one of the observers willingly transferring his knowledge to the Canadian observers. B. Brookes, D. McArthur, K. Lockhead, R. Morris, C. Penton, and P Taylor of the Geodetic Survey of Canada, D. Wells and R. Santerre of the University of New Brunswick also served on the observing team. G. Fraser of the Geodetic Survey coordinated logistics.

D. Gilbert of Macrometrics and J. Kouba of EPB kindly reviewed this manuscript and J. Liard translated the Abstract to French.

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FIGURES:

Fig 1: Location of the test site in the Ottawa, Ont. region.

Fig 2: The METCALFE site showing tripod installation detail and the height measuring rod being lowered through the antenna sighthole.

TABLE 1

OBSERVATION SUMMARY

SESSION	DAY	BASELINE	S/N 903 FAILURE	S/N 903 POWER FAILURE	S/N 906 FAILURE	S/N 906 POWER FAILURE	OPERATOR ERROR	REMARKS
1	200	6A - 7						
2	201	6A - 51					X	NO REBOOT BETWEEN OBSERVATIONS
3	202	METC - PANM			X			BAD ANTENNA CABLE
4	203	MORR - METC	X					
5	204	METC - 6A						AURORA OBSERVED
6	205	MORR - 6A	X					
7	206	PANM - 6A	X					
8	207	PANM - MORR	X					
9	208	METC - PANM	X					CLOCK LOST SYNCH AFTER REBOOT
10	209	METC - MORR			X			CLOCK LOST SYNCH AFTER REBOOT
11	210	METC - 6A			X	X		LIGHTNING INDUCED FAILURE
12	211	MORR - 6A	X					
13	212	PANM - 6A						
14	213	PANM - MORR				X		
15	214	METC - PANM				X		
16	215	METC - MORR	X					
17	216	METC - 6A	X					
18	217	MORR - 6A	X	X				
19	218	PANM - 6A	X					
20	219	PANM - MORR		X			X	SPLIT FILES
21	220	PANM - METC	X					
22	221	METC - MORR				X		
23	222	METC - 6A			X			
24	223	MORR - 6A						
25	224	PANM - 6A	X					
26	225	PANM - MORR	X					
27	226	PANM - METC					X	STOPPED CLOCK
28	227	PANM - METC	X					
29	228	PANM - METC	X					
30	229	MORR - 6A	X					

TABLE 2

LIST OF DELETIONS

DAY	OBS	CHI2	CLOCK BIAS	PHYSICAL REASON
202	63	49	672	BAD ANTENNA CABLE; EXCESSIVE CLOCK BIAS
203	-	-	-	LARGE SYSTEMATIC RESIDUALS; UNABLE TO REDUCE DATA
208	-	-	-	LARGE SYSTEMATIC RESIDUALS; UNABLE TO REDUCE DATA
219	137	688	216	CHI2 > 2*OBS; EXECESSIVE CLOCK BIAS
224	-	-	-	INSUFFICIENT DATA
225	90	294	43	CHI2 > 2*OBS; LARGE UNCERTAINTIES.
226	135	33	1.5E06	OPERATOR ERROR: CLOCKED STOPPED PRIOR TO OBSERVATION.
229	-	-	-	INSUFFICIENT DATA

LINES DELETED 27%

TABLE 3
SITE DATA

CENTRAL EPOCH	SER # 903	PRESS	RH	TEMP	ANT HEIGHT	SER # 906	PRESS	RH	TEMP	ANT HEIGHT
		MBAR	%	C	METRES		MBAR	%	C	METRES
200 23 59	6A013.200	1003.50	60	26.0	0.128	70013.200	1003.41	51	26.0	0.126
201 01 45	6A023.201	1003.59	69	23.2	0.128	70023.201	1003.59	69	23.2	0.126
201 02 30	6A033.201	1002.97	82	20.0	0.128	70033.201	1002.97	82	20.0	0.126
201 23 56	51A13.201	1003.89	66	24.5	0.128	6A013.201	1003.19	50	27.0	0.127
202 01 41	51A23.202	1003.26	83	20.3	0.128	6A023.202	1002.45	71	21.2	0.127
202 02 26	51A33.202	1002.97	82	19.0	0.128	6A023.202	1002.27	64	21.5	0.127
203 00 25	METC3.202	995.65	81	16.4	1.336	PANM3.202	990.75	93	15.9	1.665
204 00 21	METC3.203	997.83	56	20.8	1.336	MORR3.203	999.93	62	19.6	1.534
205 00 17	6A6A3.204	994.85	46	23.1	0.127	METC3.204	992.34	48	21.4	1.336
206 00 13	MORR3.205	998.44	67	20.9	1.535	6A6A3.205	999.61	63	22.2	0.124
207 00 09	6A6A3.206	1004.16	55	21.5	0.127	PANM3.206	994.67	44	22.4	1.662
208 00 05	PANM3.207	997.70	42	22.8	1.665	MORR3.207	1004.38	56	21.4	1.535
209 00 01	METC3.208	1002.52	41	27.0	1.337	PANM.208	995.77	36	27.5	1.662
209 23 57	METC3.209	1005.36	69	24.0	1.338	MORR3.209	1005.74	63	24.6	1.533
210 23 50	METC3.210	1003.11	82	25.3	1.338	6A6A.210	1005.72	84	25.7	0.124
211 23 46	MORR3.211	1008.41	69	22.9	1.535	6A6A.211	1010.14	55	24.9	??
212 23 38	PANM3.212	995.15	96	19.9	1.662	6A6A.212	1004.55	91	20.5	0.125
213 23 38	PANM3.213	991.95	76	23.4	1.662	MORR3.213	999.17	76	23.4	1.533
214 23 34	METC3.214	1006.40	60	22.9	1.338	PANM3.214	1000.69	56	24.0	1.662
215 23 30	METC3.215	1004.53	54	25.9	1.333	MORR3.215	1005.41	61	25.7	1.531
216 23 26	METC3.216	1006.20	76	23.3	1.333	6A6A3.216	1009.34	69	24.1	0.120
217 23 22	6A6A3.217	1006.93	71	26.1	0.122	MORR3.217	1005.41	64	26.5	1.529
218 23 18	PANM3.218	993.12	74	25.3	1.662	6A6A3.218	1001.75	64	26.5	0.122
219 21 14	PANM3.219	991.91	48	26.6	1.662	MORR3.219	999.21	50	26.9	1.533
220 21 10	METC3.220	991.91	83	22.4	1.334	PANM3.220	986.33	91	20.6	1.661
221 21 06	METC3.221	1004.81	55	16.8	1.332	MORR3.221	1006.40	55	17.3	1.531
222 21 02	METC3.222	1005.59	54	17.9	1.334	6A6A3.222	1008.52	61	18.2	0.121
223 20 58	MORR3.223	1002.68	65	19.9	1.532	6A6A3.223	1004.17	55	19.9	0.121
224 20 54	PANM3.224	997.34	59	19.8	1.663	6A6A3.224	1006.37	55	20.6	0.121
225 20 50	PANM3.225	1002.68	65	19.9	1.662	MORR3.225	1009.60	51	20.2	1.532
226 23 36	METC3.226	1008.23	51	22.5	1.337	PANM3.226	1001.64	54	22.5	1.661
227 23 32	METC3.227	1006.47	45	24.0	1.336	PANM3.227	1000.65	52	23.4	1.661
228 23 28	METC3.228	1004.30	57	24.9	1.335	PANM3.228	998.36	56	25.4	1.661

TABLE 4

SHORT BASELINE RESULTS

BASELINE	DAY	CHI2	NUMBER OF OBSERVATIONS	LATITUDE (deg)	LONGTITUDE (deg)	ELEVATION (m)	HORIZ DIST (m)
6A - 7	200	51	133	45 23 55.13149 (.002)	75 55 22.48169 (.002)	76.631 (.004)	30.481
	200	112	211	55.13140 (.001)	22.48159 (.001)	76.633 (.003)	30.481
	200	22	110	55.13153 (.003)	22.48154 (.002)	76.618 (.010)	30.477
MEAN				55.13147	22.48161	76.627	30.4796
GROUND TRUTH *				55.13131	22.48157	76.629	30.4829
DIFFERENCE (METRES)				0.005	0.001	-0.002	-0.0033
6A - 51	201	140	149	45 23 07.16341 (.004)	75 56 37.25070 (.005)	70.172 (.008)	2230.077
	201	242	168	07.16353 (.004)	37.25066 (.003)	70.179 (.009)	2230.074
	201	80	104	07.16349 (.010)	37.25078 (.008)	70.193 (.035)	2230.076
MEAN				07.16348	37.25071	70.181	2230.0757
GROUND TRUTH *				07.16263	37.25020	70.190	2230.0850
DIFFERENCE (METRES)				0.026	0.011	-0.009	-0.0093

* Latitudes, longtitudes and elevations are provisional values; only mean sea level distances are well established.

Formal computed uncertainty is quoted in brackets in metres.

TABLE 5

LONG BASELINE RESULTS: EDITED FOR FAULTY DATA

BASELINE	DAY	CHI2	NUMBER OF OBS	LATITUDE (deg)	LONGTITUDE (deg)	ELEVATION (m)	HORIZ DIST (m)
METC - PANM	214	135	141	45 20 18.81541 (.070)	76 11 04.59667 (.137)	152.950 (.089)	57929.872
[57 Km]	220	65	128	18.81648 (.052)	04.59658 (.088)	152.921 (.062)	.876
	227	86	165	18.81746 (.087)	04.59711 (.101)	153.172 (.092)	.893
	228	119	198	18.81546 (.097)	04.59208 (.107)	152.995 (.098)	.774
MEAN				18.81630	04.59561	153.0095	57929.854
STANDARD DEV		SECONDS		.00097	.00236		
		METRES		.030	.052	.113	.054
		PPM BASELINE		0.53	0.91	1.98	0.95
METC - 6A	204	111	131	45 23 55.79029 (.039)	75 55 21.44774 (.077)	76.238 (.045)	40294.902
[40 Km]	210	36	96	55.79173 (.033)	21.44977 (.067)	76.340 (.043)	.961
	216	81	173	55.79205 (.030)	21.44831 (.052)	76.290 (.037)	.936
	222	12	90	55.79088 (.090)	21.44558 (.062)	76.317 (.100)	.867
MEAN				55.79123	55.44785	76.296	40294.917
STANDARD DEV		SECONDS		.00080	.00174		
		METRES		.025	.038	.044	.041
		PPM BASELINE		0.62	0.95	1.10	1.03
MORR - 6A	205	106	119	45 23 55.79328 (.042)	75 55 21.44212 (.071)	77.624 (.041)	26488.732
[27 Km]	211	149	111	55.79226 (.053)	21.44024 (.091)	77.630 (.050)	.778
	217	53	149	55.79572 (.019)	21.44951 (.034)	77.575 (.023)	.560
	223	49	180	55.79415 (.014)	21.44653 (.026)	77.646 (.018)	.633
MEAN				45 23 55.79385	75 55 21.44460	77.619	26488.676
STANDARD DEV		SECONDS		.00146	.00420		
		METRES		.048	.092	.031	.090
		PPM BASELINE		1.78	3.41	1.15	3.33
PANM - 6A	206	72	116	45 23 55.79429 (.028)	75 55 21.44547 (.049)	77.320 (.029)	21589.740
[22 Km]	212	140	120	55.79446 (.014)	21.44621 (.014)	77.336 (.033)	.727
	218	125	155	55.79467 (.030)	21.44636 (.048)	77.312 (.037)	.726
MEAN				45 23 55.79447	75 55 21.44601	77.323	21589.731
STANDARD DEV		SECONDS		.00019	.00048		
		METRES		.006	.011	.012	.008
		PPM BASELINE		.27	.50	.55	.36
PANM - MORR	207	95	112	45 26 34.29252 (.008)	76 15 18.81644 (.007)	89.509 (.020)	12843.312
[13 Km]	213	155	119	34.29307 (.023)	18.81416 (.044)	89.512 (.024)	.325
MEAN				45 26 34.29280	76 15 18.81630	89.511	12843.319
STANDARD DEV		SECONDS		.00039	.00032		
		METRES		.013	.007	.002	.009
		PPM BASELINE		1.00	0.54	0.15	0.69
METC - MORR	209	33	124	45 26 34.28993 (.031)	76 15 18.81960 (.063)	88.578 (.035)	66268.001
[65 Km]	215	141	166	34.29284 (.060)	18.82729 (.096)	88.641 (.073)	.189
	221	82	145	34.28929 (.085)	18.81736 (.121)	88.542 (.091)	7.949
MEAN				45 26 34.29069	76 15 18.82142	88.587	66268.046
STANDARD DEV		SECONDS		.00189	.00521		
		METRES		.059	.114	.054	.126
		PPM BASELINE		0.91	1.75	0.83	1.94

Formal computed uncertainty is quoted in round brackets in metres.
Approximate baseline lengths are quoted in square brackets.

TABLE 5A

LONG BASELINE RESULTS
AVERAGE METEOROLOGICAL CORRECTION INCLUDED

BASELINE	DAY	CHI2	NUMBER OF OBSERVATIONS	LATITUDE (deg)	LONGTITUDE (deg)	ELEVATION (m)
METC -PANM	214	135	141	45 20 18.81541 (.070)	76 11 04.59665 (.137)	152.950 (.089)
[57 KM]	220	65	128	18.81647 (.052)	04.59650 (.089)	152.921 (.062)
	227	86	165	18.81746 (.087)	04.59711 (.101)	153.172 (.092)
	228	119	198	18.81547 (.097)	04.59206 (.107)	152.994 (.098)
MEAN				45 20 18.81620	76 11 04.59558	153.009
STANDARD DEV		SECONDS		0.00098	0.00236	
		METRES		0.030	0.052	0.113
		PPM BASELINE		0.53	0.91	1.98
METC - 6A	204	111	131	45 23 55.79031 (.039)	75 55 21.44778 (.077)	76.237 (.045)
[40 Km]	210	37	96	55.79170 (.034)	21.44969 (.068)	76.343 (.044)
	216	81	173	55.79204 (.030)	21.44826 (.052)	76.291 (.037)
	222	12	90	55.79088 (.090)	21.44558 (.062)	76.317 (.100)
MEAN				45 23 55.79123	75 55 21.44783	76.297
STANDARD DEV		SECONDS		0.00080	0.00171	
		METRES		0.025	0.038	0.045
		PPM BASELINE		0.62	0.95	1.10
MORR - 6A	205	106	119	45 23 55.79327 (.042)	75 55 21.44212 (.071)	77.620 (.041)
[27 Km]	211	149	111	55.79227 (.053)	21.44029 (.091)	77.630 (.050)
	217	54	149	55.79573 (.019)	21.44957 (.035)	77.574 (.023)
	223	49	180	55.79415 (.014)	21.44653 (.026)	77.646 (.018)
MEAN				45 23 55.79386	75 55 21.44783	77.618
STANDARD DEV		SECONDS		0.00148	0.00421	
		METRES		0.048	0.092	0.031
		PPM BASELINE		1.78	3.41	1.15
PANM - 6A	206	74	116	45 23 55.79423 (.029)	75 55 21.44537 (.050)	77.284 (.029)
[22 Km]	212	85	120	55.79446 (.014)	21.44626 (.014)	77.336 (.033)
	218	125	155	55.79466 (.031)	21.44639 (.048)	77.313 (.037)
MEAN				45 23 55.79445	75 55 21.44601	77.311
STANDARD DEV		SECONDS		0.010	0.012	0.026
		METRES		0.45	0.55	1.18
		PPM BASELINE				
PANM - MORR	207	66	112	45 26 34.29293 (.008)	76 15 18.81645 (.007)	89.516 (.020)
[13 Km]	213	155	119	34.29306 (.023)	18.81616 (.044)	89.514 (.024)
MEAN				45 26 34.29300	76 15 18.81630	89.511
STANDARD DEV		SECONDS		0.00016	0.00032	
		METRES		0.005	0.007	0.002
		PPM BASELINE		0.38	0.54	0.15
METC - MORR	209	32	124	45 26 34.28990 (.031)	76 15 18.81947 (.063)	88.581 (.035)
[65 Km]	215	166	141	34.29286 (.060)	18.82733 (.095)	88.642 (.073)
	221	82	145	34.28930 (.85)	18.81738 (.121)	88.542 (.091)
MEAN				45 26 34.29070	76 15 18.82139	88.588
STANDARD DEV		SECONDS		0.00191	0.00524	
		METRES		0.059	0.115	0.050
		PPM BASELINE		0.91	1.77	0.77

Formal computed uncertainty is quoted in round brackets in metres.
Approximate baseline lengths are quoted in square brackets.

TABLE 5B

LONG BASELINE RESULTS
SITE METEOROLOGICAL CORRECTION INCLUDED

BASELINE	DAY	CHI2	NUMBER OF OBSERVATIONS	LATITUDE (deg)	LONGTITUDE (deg)	ELEVATION (m)
METC - PANM	214	135	141	45 20 18.81547 (.070)	76 11 04.59679 (.137)	152.979 (.089)
[57 Km]	220	66	128	18.81648 (.052)	04.59652 (.089)	152.931 (.062)
	227	86	165	18.81745 (.087)	04.59709 (.101)	153.175 (.092)
	228	120	198	18.81539 (.097)	04.59193 (.108)	153.036 (.098)
MEAN				54 20 18.81620	76 11 04.59558	153.030
STANDARD DEV		SECONDS		0.00101	0.00245	
		METRES		0.031	0.054	0.106
		PPM BASELINE		0.54	0.95	1.85
METC - 6A	204	108	131	45 23 55.79030 (.039)	75 55 21.44777 (.076)	76.202 (.044)
[40 Km]	210	35	96	55.79171 (.033)	21.44976 (.066)	76.284 (.043)
	216	81	173	55.79204 (.030)	21.44826 (.052)	76.293 (.037)
	222	12	90	55.79127 (.088)	21.44600 (.061)	76.251 (.099)
MEAN				45 23 55.79133	75 55 21.44795	76.258
STANDARD DEV		SECONDS		0.00078	0.00155	
		METRES		0.024	0.034	0.041
		PPM BASELINE		0.60	0.85	1.02
MORR - 6A	205	106	119	45 23 55.79325 (.042)	75 55 21.44209 (.071)	77.615 (.042)
[27 Km]	211	148	11	55.79233 (.052)	21.44039 (.090)	77.666 (.050)
	217	53	149	55.79575 (.019)	21.44964 (.034)	77.542 (.023)
	223	49	180	55.79415 (.014)	21.44652 (.026)	77.691 (.018)
MEAN				45 23 55.79387	75 55 21.44466	77.628
STANDARD DEV		SECONDS		0.00148	0.00421	
		METRES		0.046	0.092	0.066
		PPM BASELINE		1.70	3.41	2.44
PANM - 6A	206	71	116	45 23 55.79448 (.028)	75 55 21.44573 (.049)	77.427 (.028)
[22 Km]	212	83	120	55.79444 (.014)	21.44625 (.013)	77.315 (.033)
	218	130	155	55.79464 (.031)	21.44639 (.049)	77.288 (.038)
MEAN				45 23 55.79452	75 55 21.44612	77.343
STANDARD DEV		SECONDS		0.00011	0.00035	0.074
		METRES		0.003	0.008	0.074
		PPM BASELINE		0.14	0.36	3.36
PANM - MORR	207	65	112	45 26 34.29240 (.008)	76 15 18.81625 (.007)	89.429 (.020)
[13 Km]	213	152	119	34.29303 (.022)	18.81608 (.043)	89.477 (.024)
MEAN				45 26 34.29272	76 15 18.81616	89.453
STANDARD DEV		SECONDS		0.00044	0.00012	
		METRES		0.014	0.003	0.034
		PPM BASELINE		1.08	0.23	2.62
METC - MORR	209	33	124	45 26 34.28990 (.031)	76 15 18.81945 (.063)	88.594 (.035)
[65 Km]	215	141	166	34.29288 (.060)	18.82744 (.096)	88.587 (.073)
	221	82	145	34.28931 (.085)	18.81739 (.121)	88.533 (.091)
MEAN				45 26 34.29070	76 15 18.82143	88.571
STANDARD DEV		SECONDS		0.00192	0.00530	
		METRES		0.060	0.117	0.033
		PPM BASELINE		0.92	1.80	0.51

Formal computed uncertainty is quoted in round brackets in metres.
Approximate baseline lengths are quoted in square brackets.

TABLE 6
PROVISIONAL VALUES FOR FIXED END OF BASELINES

STATION	LATITUDE (deg)	LONGTITUDE (deg)	ELEVATION (metres)
6A	45 23 55.79598	75 55 21.44516	77.085
7	45 23 55.13131	75 55 22.48157	76.629
51	45 23 07.16263	75 56 37.25020	70.190
MORRis	45 26 34.29253	76 15 18.81735	89.806
PANMure	45 20 18.81549	76 11 04.58789	153.956
METCalfe	45 14 34.01037	75 27 31.48309	102.590

PROVISIONAL VALUES FOR BASELINE LENGTHS
(metres)

METCalfe-PANMure	57929.685
METCalfe-6A	40294.926
MORRis-6A	26488.652
PANMure-MORRis	12843.321
METCalfe-MORRis	66267.982

Extracted from the Geodetic Survey of Canada May 1976 adjustment based on the Clark 1866 ellipsoid.

TABLE 7

COMPARISON WITH GEODETIC POSITIONS

(TABLE 6 minus TABLE 5)
(Standard Atmosphere)

BASELINE	LATITUDE DIFFERENCE			LONGTITUDE DIFFERENCE			BASELINE		HEIGHT DIFF.	GEOID DIFF.
	SECONDS	METRES	PPM	SECONDS	METRES	PPM	METRES	PPM	METRES	METRES
METC-PANM	-.00071	-0.022	-0.4	-0.00772	-0.170	-3.0	-0.169	-3.0	0.946	1.00
METC-6A	.00475	0.147	3.7	-0.00269	-0.059	-1.5	0.010	0.2	0.789	0.67
MORR-6A	.00213	0.066	2.4	0.00056	0.012	0.4	-0.024	-0.9	-0.534	-0.38
PANM-6A	.00151	0.047	2.1	-0.00085	-0.019	-0.9	0.032	1.5	-0.238	-0.33
PANM-MORR	-.00027	-0.008	-0.6	0.00105	0.023	1.8	0.003	0.2	0.295	0.05
METC-MORR	.00184	0.057	0.9	-0.00407	-0.089	-1.4	-0.065	-1.0	1.219	1.05
MEAN		0.048			-0.050					
STANDARD DEV.		0.060			0.072					

(TABLE 6 minus TABLE 5A)
(Average Meteorological Corrections)

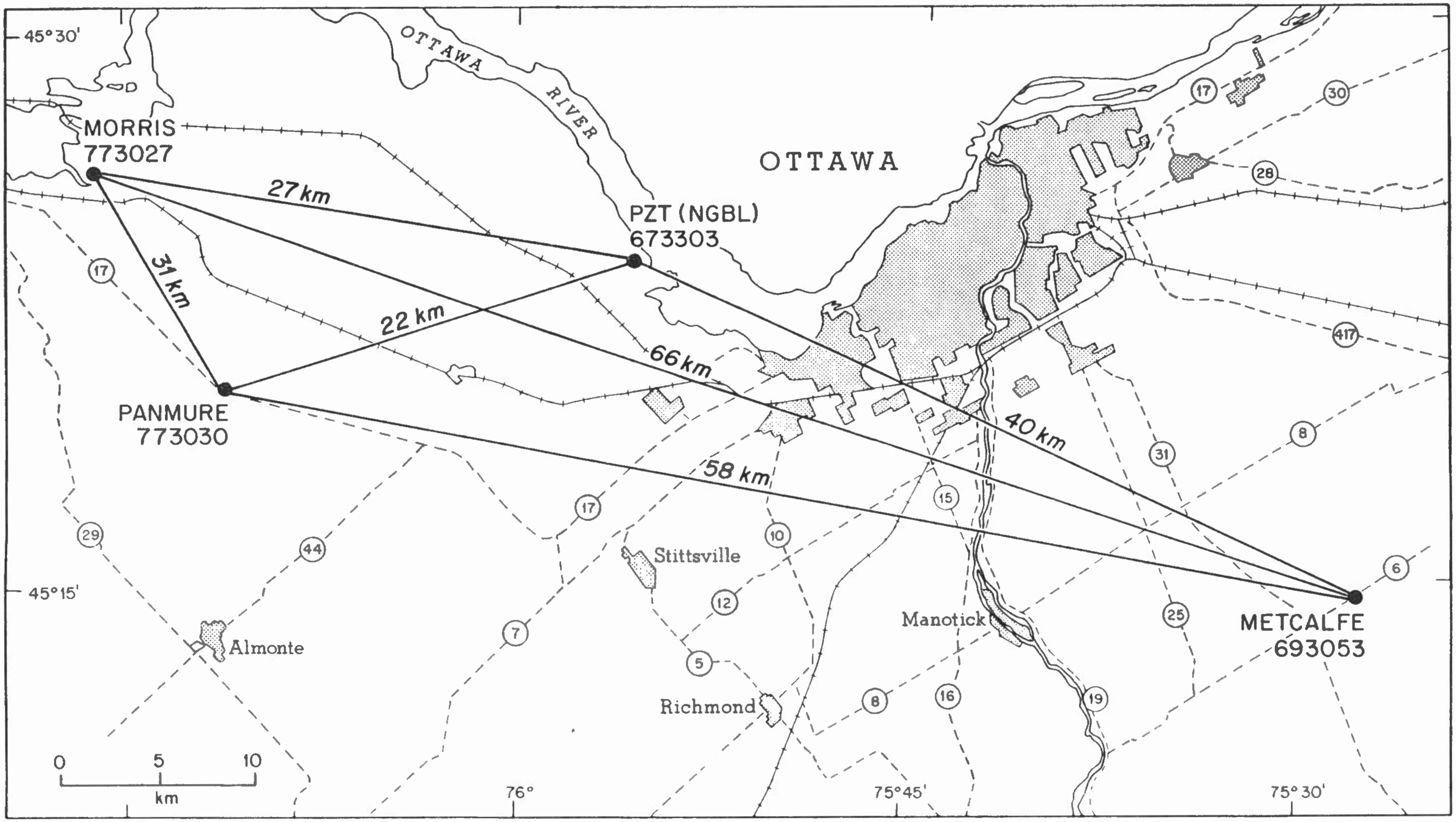
BASELINE	LATITUDE SECONDS	LATITUDE METRES	LATITUDE PPM	LONGTITUDE SECONDS	LONGTITUDE METRES	LONGTITUDE PPM	HEIGHT DIFF. METRES	GEOID DIFF. METRES
METC-PANM	-.00071	-0.022	-0.4	-0.00769	-0.169	-3.0	0.947	1.00
METC-6A	.00475	0.147	3.7	-0.00267	-0.059	-1.5	0.788	0.67
MORR-6A	.00212	0.066	2.4	0.00053	0.012	0.4	-0.533	-0.38
PANM-6A	.00153	0.047	2.1	-0.00085	-0.019	-0.9	-0.226	-0.33
PANM-MORR	-.00047	-0.015	-1.2	0.00105	0.023	1.8	0.295	0.05
METC-MORR	.00183	0.057	0.9	-0.00404	-0.089	-1.4	1.219	1.05
MEAN		0.047			-0.050			
STANDARD DEV.		0.061			0.072			

(TABLE 6 minus TABLE 5B)
(Site Specific Meteorological Corrections)

BASELINE	LATITUDE SECONDS	LATITUDE METRES	LATITUDE PPM	LONGTITUDE SECONDS	LONGTITUDE METRES	LONGTITUDE PPM	HEIGHT DIFF. METRES	GEOID DIFF. METRES
METC-PANM	-.00071	-0.022	-0.4	-0.00769	-0.169	-3.0	0.926	1.00
METC-6A	.00465	0.144	3.6	-0.00279	-0.061	-1.5	0.827	0.67
MORR-6A	.00211	0.065	2.4	0.00061	0.013	0.5	-0.543	-0.38
PANM-6A	.00146	0.045	2.0	-0.00096	-0.021	-1.0	-0.258	-0.33
PANM-MORR	-.00019	-0.006	-0.3	0.00119	0.025	1.9	0.353	0.05
METC-MORR	.00183	0.057	0.9	-0.00408	-0.089	-1.4	1.235	1.05
MEAN		0.047			-0.050			
STANDARD DEV		0.059			0.072			

ESTIMATED GEOID HEIGHTS BASED ON RAPP 1981 GEOPOTENTIAL COEFFICIENTS:

6A	-32.82
MORR	-33.20
PANM	-33.15
METC	-32.15


45°30'
OTTAWA RIVER
OTTAWA
MORRIS
773027
27 km
PZT (NGBL)
673303
31 km
22 km
66 km
40 km
58 km
PANMURE
773030
METCALFE
693053
17
30
28
417
17
8
31
15
10
17
44
29
Stittsville
12
6
25
45°15'
Almonte
7
5
Manotick
Richmond
8
16
19
0
5
10
km
76°
75°45'
75°30'