The 1984 Charlevoix microgravity survey.

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INTRODUCTION

The 1984 microgravity survey contract at Charlevoix was awarded to SIAL Compagnie Internationale de Geophysique inc. of Montreal. In 1983, the network had been expanded on the South shore of the St Laurence river and for that reason, 3 new sets of air ties were added to link the two shores by helicopter. A total of 32 sets of ties were measured with a modified technique, notably with the use of three LaCoste & Romberg model D gravity meters. Three observers participated in the single June-July survey.

THE NETWORK

With the expanded network (five more gravity stations on the South shore of the St Lawrence river) and the inclusion of a third instrument, the total number of tie sets was reduced from 33 to 32 in order to accomodate the extra time needed to observe each station and the 3 new sets of air ties. The number of long distance ground ties was reduced to a minimum in order to speed up the survey.

The increased number of instruments was implemented so as to reduce any bias due to individual instrumental characteristics. Later analysis would employ all observations instead of concentrating on the results of any one particular instrument.

Tie lines were also reorganized and one station was dropped entirely from the 1983 network in order to maintain a homogeneous error distribution (Figure 1). The air ties were established between stations of station pairs 906176-905183, 906876-905283, and 907576-905583 and each set contained the same number of observations as the ground ties (6 gravity differences).

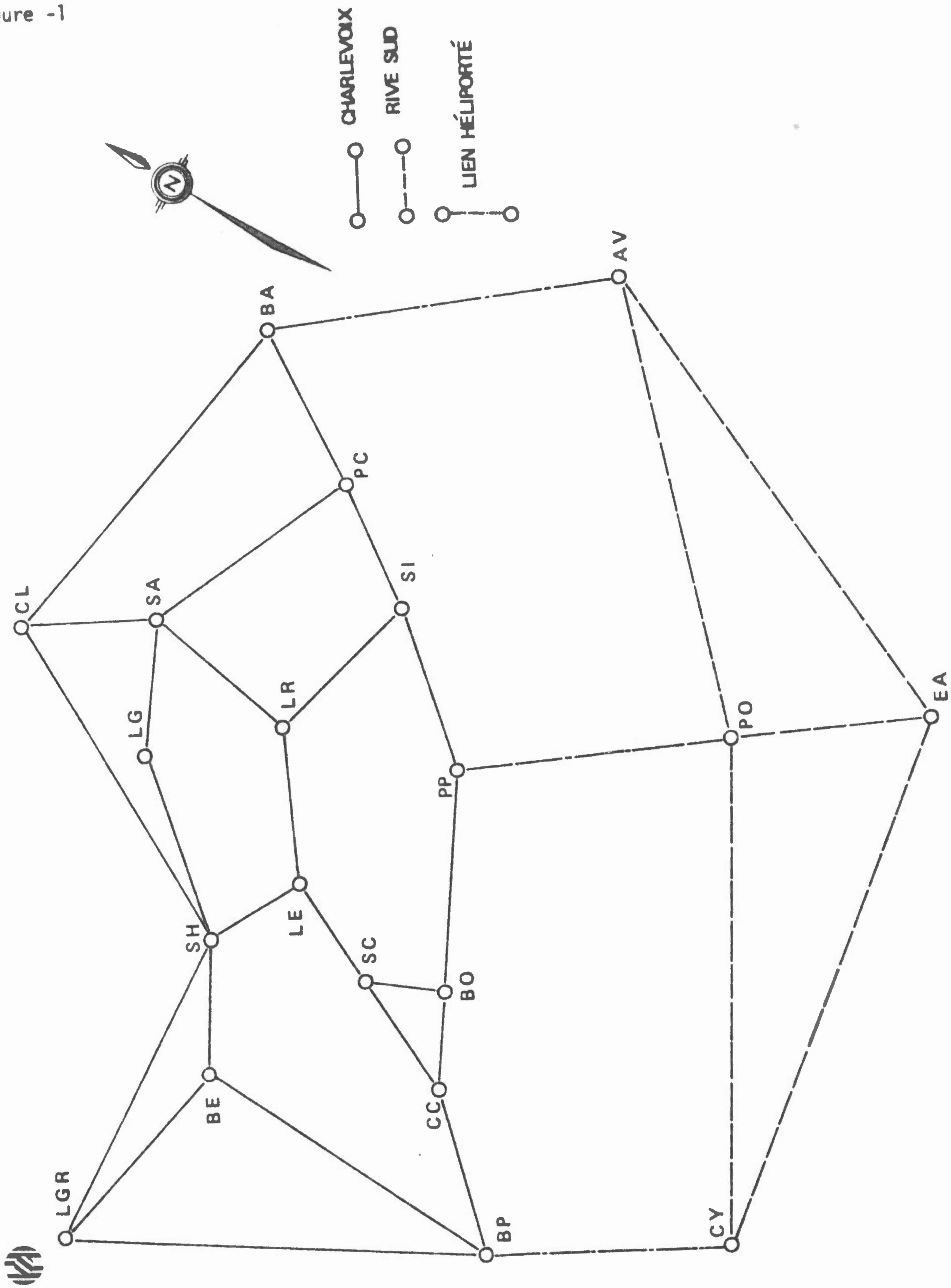
The network was structured so that each station would be linked on the average to three other stations. Only a few stations differed from this standard and indeed, these bases show different error levels. Those with fewer links have greater errors and the reverse is true for those with more links to the rest of the network (Table 3.).

THE SURVEY

As in the previous years, the survey included two instrument calibrations, one before and one after the main campaign in Charlevoix. An added series of tests was also done by helicopter in order to determine if the noise level on the meters was increased in the helicopter when compared to ground transportation.

The calibration located between Ottawa and Gananoque was done by the crew of SIAL on the 11th and 12th of June, 1984.

Figure -1


CHARLEVOIX
RIVE SUD
LIEN HÉLIPORTÉ
N
BA
AV
PC
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BP
CY

Instruments D6 and D27 achieved the stipulated calibration quality (see Appendix A) but the third meter, D28, had to return for an extra set of measurements with little improvement unfortunately (see Table 4 in Appendix A).

From the 13th to the 16th of June, the crew started the survey under supervision at Charlevoix, with a reconnaissance tour of the South shore stations on the 16th.

On the 28th and 29th of June, the instruments were tested in the helicopter and subsequently were used in the three sets of air ties across the Saint Lawrence River. No extra measurements were necessary for these ties.

The Charlevoix survey ended on the 30th of June and the calibration network was reoccupied on the 1st and 2nd of July. However, an observer had to come back on the 4th to recalibrate D27 which had not achieved the desired quality level.

The survey lasted one day less than predicted by SIAL and the helicopter flights did not require extra tie time so that for once a company made a profit and did not just break even.

The company delivered their report by mid-July shortly after the end of the survey.

DIFFICULTIES

Apart from small delays and one flat tire, the main causes of aggravation were instrumental. The response of the meter D27 seemed to have been very unstable. Instrument D28 did not behave normally at the begining of the survey but after some adjustments, it performed very well.

Instrument D27 had unpredictable drift that degraded survey quality in both the calibration and the Charlevoix networks. Rapid drifting occured on occasion after unclamping the instrument. It became more difficult to null this meter within the normal four minute waiting period after unclamping. If the reading was overestimated by 2 to 5 microgals near the end of the 4 minutes, the dial would be wound backward and rewound forward to eliminate backlash effects. The new null might occasionally be off by about 20 microgals!

Thus, the results of D27 were slightly worse than the other two in the analysis and this forced the program to reject more D27 values.

Instrument D28 started the Charlevoix survey with a few bad sets of ties that had large standard deviations. In fact, all the repeated or restarted ties in the network were due to this meter. The instrument showed large fluctuations in its readings (up to 200 microgals) and no external cause was found for these bad results such as a poor battery cable. The problem disappeared when the crew decided for some obscure reason to reset the meter (RESET screw) all the way to its limit and back to its normal setting. Standard deviations were quite acceptable after that episode.

Instrument D6 remained the work-horse of our D-meter stable.

Finally, a minor accident occured near the end of the survey at Charlevoix. One of the observers hurt himself on broken glass near one of our road-side stations, during the last few observations of the air-ties. I took him to the Baie St Paul hospital and later helped the rest of the crew finish the day's work. The following day, the injured observer was able to finish the survey with some difficulty.

The accident was due to inattention on the part of the crew who was by the end of the survey under a lot of stress. Long hours and limited resources were partly to blame.

SURVEY RESULTS AND EVALUATION

Table 1 compares the 1983 survey with the 1984 survey. As a whole, the gravity values have not changed by more than the noise level in the data. However, four (4) stations have changed by more than 10 microgals between the two years (marked by '*'); two of these stations (906476 & 906676) are located on loose soil and not on bedrock like the rest of the network. Station 907376 had occasionally changed by that much in the past but the other station (907076) had consistently remained stable before 1984.

The statistics of the 1984 survey (Table 2) are similar to the 1983 surveys even with 3 instruments instead of two. The survey technique was modified in order to accomodate the extra meter.

First modification: the number of gravity differences for each set of ties was reduced from 8 to 6 for each instrument. This provided a total of 24 individual differences instead of the nominal 16 because of the added instrument. The reduced number of differences per instrument brought also to the survey an unexpected bonus, namely each set of ties was actually executed faster than the older technique even though three instruments were read on each station instead of two. Transit time taken to go between stations is thus shown to have been a major part of the total survey time.

Second modification: the criterion for quality control was reworded so that a set of ties became acceptable only when the total variance of all three individual gravity differences was less than 300 microgal-squared. This gave some leeway to the survey crew if one instrument had poor results while the other two behaved very well. In fact, fewer extra observations were taken for each set of ties as compared to previous surveys.

Table 1.
Gravity values from network adjustments (milliGals)

Station		June-July 1983	S.E.	Octo-Novem 1983	S.E.	June-July 1984	S.E.	
905183	CY	980701.383	2.5	980701.389	2.8	980701.391	2.6	
905283	PO	---789.139	2.0	---789.137	2.3	---789.141	2.5	
905383	EA	---707.693	2.0	---707.694	2.3	---707.696	2.7	
905483	MC	---731.318	2.4	---731.315	2.7	not surveyed ...		
905583	AV	---804.893	fix	---804.895	fix	---804.902	2.5	
906176	BP	---752.559	2.6	---752.566	2.9	---752.570	2.4	
906276	CC	---741.716	2.7	---741.728	2.9	---741.725	2.5	
906376	BE	---753.070	2.6	---753.067	2.8	---753.070	2.4	
906476	BO	---733.858	2.5	---733.857	2.9	---733.871	2.4	* 13
906576	SH	---748.030	2.6	---748.034	2.6	---748.034	1.9	
906676	SC	---756.741	2.4	---756.738	2.8	---756.752	2.4	* 11
906776	LE	---733.994	2.3	---733.992	2.7	---733.992	2.2	
906876	PP	---776.488	2.2	---776.489	2.5	---776.495	2.2	
906976	LG	---748.581	2.2	---748.573	2.3	---748.583	2.0	
907076	LR	---776.204	2.0	---776.202	2.2	---776.214	1.9	* 10
907176	SI	---801.589	2.0	---801.585	2.3	---801.594	2.1	
907276	SA	---755.400	fix	---755.400	fix	---755.400	fix	
907376	CL	---802.843	1.7	---802.845	1.6	---802.855	1.8	* 10
907476	PC	---814.378	1.7	---814.370	1.9	---814.376	1.9	
907576	BA	---783.506	1.9	---783.503	2.1	---783.511	2.1	
937180	LGR	--703.437	2.6	---703.441	2.8	---703.436	2.5	

Table 2.
Adjustments statistics
(milliGals)

	June-July 1983	Octo-Novem 1983	June-July 1984
STD	0.0100	0.0114	0.0104
CHI sqr	8.73	13.68	15.02 (13 deg. of fr.)
SD D06	0.0092	0.0085	0.0094
SD D27	0.0095	0.0105	0.0105
SD D28	---	---	0.0100
READINGS	632	634	639
REJECTED	16	6	18

Table 3

Network structure 1984

Station	Error (microgals)	Number of ties to station
905183	1.8	3
905283	1.6	4
905383	1.9	3
905583	1.8	3
906176	1.5	4
906276	1.6	3
906376	1.7	3
906476	1.6	3
906576	1.3	5
906676	1.6	3
906776	1.6	3
906876	1.4	3
906976	2.0	2
907076	1.6	3
907176	1.5	3
907276	1.5	4
907376	1.6	3
907476	1.6	3
907576	1.6	3
937180	1.7	3

Third modification: air ties combined with ground ties. Although the network is designed to have a homogeneous error distribution, the combination of two different methods of meter transportation could have introduced an imbalance in the error budget. For this reason, we had the survey crew build a "transit" case for the three meters that would fit in the helicopter, none having been designed or built prior to the survey by EPB.

On the 28 of June, 1984, a wooden enclosure suspended by rubber springs to a simple frame was tested in the helicopter with the three instruments aboard. Only D28 was read at the St Irenee airport where the test was performed. It consisted of six flights up and down with readings at each landing.

The difference between consecutive readings should have been theoretically zero since we read on the same spot. We measured a mean difference of -2.17 with a standard deviation of 5.42 microgals. This error level corresponds very well with the type of level observed during ground transport in Charlevoix and thus showed that the structure of the network could remain stable with the combination of two different types of meter transports.

The final modification: the survey technique did not use as in the previous years, the "loop closure" quality control. However, the crew being used to the old method, monitored all loops as a kind of performance test of their own survey. They found that with three instruments involved only one loop seemed to have not closed properly.

SUMMARY

Helicopter ties and the addition of a third instrument were successfully integrated into the regular Charlevoix network surveys. Previous surveys using only two meters took longer than this survey simply because of the extra time involved in travelling between stations. Furthermore, poor repeatability on helicopter surveys (eg. Manic 3, 1976) has been overcome by the use of a vibration insulating transport case for the meters.

The successful use of a helicopter has allowed us to expand our survey area at Charlevoix to nearly twice the previous extent. This expanded network will help us test new geophysical models concerning the Charlevoix seismic zone.

Our survey technique has matured enough to enable us to design new networks for diverse terrain conditions and to perform gravity measurements with systematically high accuracy.

Appendix A

The following pages are excerpts from the Charlevoix contract OSQ84-00056 dealing with the quality control of the calibration and survey results. Table 4 is from the final report of the company which details the calibration results of all three instruments.