INTEGRATION OF ATLANTIC GEOSCIENCE CENTRE MARINE GRAVITY DATA INTO THE NATIONAL GRAVITY DATA BASE

Joint Publication of Earth Physics Branch

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ABBREVIATIONS AND ACRONYMS USED IN THIS REPORT

AGC	Atlantic Geoscience Centre (a division of The Geological Survey of Canada)
ASSOB	Adjustment of Sea Surface Observations (EPB software system)
BIO	Bedford Institute of Oceanography (east coast oceanographic institution comprising regional marine science arms of three federal departments: Fisheries and Oceans; Energy, Mines and Resources; and Environment)
BNULL	Base Null (gravity value which would be observed by Gss-2 meter if MSD value were zero and VCO count were 65000 - see section 4.4.1)
CGSN	Canadian Gravity Standardization Network
CHS	Canadian Hydrographic Service (a branch of Department of Fisheries and Oceans)
CSS	Canadian Scientific Ship
DEMR (or EMR)	Department of Energy, Mines and Resources
DFO	Department of Fisheries and Oceans
DHI	German Hydrographic Institute
EPB	Earth Physics Branch (formerly Dominion Observatory)(a branch of the Department of Energy, Mines and Resources)
GPS	Global Positioning System
GSC	Geological Survey of Canada (a branch of Department of Energy, Mines and Resources)
IGSN 71	International Gravity Standardization Network established in 1971
MSD	Main Spring Divisions (for Gss-2 sea gravity meters)

NGDB National Gravity Data Base

VCO Voltage Controlled Oscillator (used to convert the voltage output from AGC Gss-2 gravimeters to a frequency which can be counted to provide a digital output value)

1.0 PROJECT DEFINITION

The objective of this project was to edit all AGC marine gravity data acquired between 1964 and 1984, merge them with EPB marine gravity holdings, adjust all data to a common absolute datum, and incorporate the resulting data set into the National Gravity Data Base.

2.0 PARTICIPANTS

Atlantic Geoscience Centre

J.M. Woodside	-	Project coordination at AGC, data analysis and liaison with EPB
D.E. Beaver	-	Recomputation of AGC gravity data
P.R. Girouard	-	File handling and profile plot generation
D. Hoffer	-	Compilation of dock station ties to national networks and compilation of Gss-2 gravimeter calibration data
B.L. Johnston	-	Assignment of quality factors and data editing
B.D. Loncarevic	-	Historical background and notes on Kss-30 operation.
R.F. Macnab	-	Data quality control and report editing
W. Prime	-	Data handling software development and operation
K.G. Shih	-	AGC data management software

Earth Physics Branch

R.K. McConnell	-	Project management at EPB; analysis of adjustments
R.J. Buck	-	Design of modifications to NGDB; conversion of adjustment software from CYBER to VAX computers
R.V. Cooper	-	Profile plot analysis; interactive data editing; reduction and editing of EPB data
D.B. Hearty	-	Management of NGDB operations; liaison with AGC re data

transmittal and various plotting operations

J.F. Halpenny - Applicon colour maps

P.J. Kane - Software development related to NGDB modifications

J.F. Rupert - Development of interactive editing software and a variety of programs for manipulation, analysis and display of data; modifications to ASSOB system to accommodate AGC data; carried out all production computing related to data conversion, merging, adjustment and analysis.

3.0 INTRODUCTION

In the early 1950's the Dominion Observatory, now Earth Physics Branch (EPB), Department of Energy, Mines and Resources (DEMR), undertook a national gravity mapping program with the objective of providing reconnaissance scale gravity mapping (6 - 16 km spacing) over the sovereign territory of Canada. To date EPB has acquired the necessary coverage over 90% of land areas, 80% of ice covered channels of the Arctic archipelago, most of Hudson's Bay and all of the west coast offshore. Mapping of the east coast offshore area, which began in 1964 and is about 80% complete, has been carried out primarily by the Atlantic Geoscience Centre (AGC), a division of the Geological Survey of Canada (GSC), with the participation, in recent years, of EPB.

In the past AGC and EPB treated and stored their data independently, partly because of their physical separation and different mandates. The availability of high speed data communications and the need to consolidate gravity data holdings for the benefit of all data users combined to facilitate merging of AGC data with EPB data in Ottawa into a truly national data base for gravity measurements.

This report documents a major collaborative effort of AGC and EPB over the past two years to rigourously edit and adjust all existing EMR marine gravity data in the east coast offshore. The result has been the creation of a homogeneous data set for that region which has been made available to users through the National Gravity Data Base at EPB.

4.0 DATA ACQUISITION

4.1 HISTORICAL BACKGROUND

The first shipboard gravimeter measurements in Canada were performed by

D. Bower of the Dominion Observatory on board USS "ARCHERFISH" in 1960. The measurements were taken along the coast of Nova Scotia and Labrador and in Hudson Bay. The cruise did not produce any useful gravity data but valuable experience was gained concerning the navigational requirement for gravity measurements and the acceleration environment on board vessels.

The continuing programme of sea-surface gravity measurements in Canada started in 1963 with an evaluation of the comparative merits of LaCoste-Romberg and Askania sea gravity meters on board CSS BAFFIN in October 1963 (Bower and Loncarevic, 1966). As the result of this evaluation, BIO acquired one Askania gravimeter with Gss2-17 gravity sensor and Anschutz gyro table.

The first survey application of this equipment in 1964 led to the discovery and mapping of the "Orpheus" anomaly (Loncarevic and Ewing, 1966). In the same year a pilot multi-disciplinary survey in the Bay of Fundy was carried out, establishing the principles of cooperation between the hydrographic and geophysics groups at BIO (Blandford, 1964). A memorandum of understanding between DEMR and DFO formalized this collaboration through the establishment of the principle of multiparameter surveying.

In 1965, Gss2-17 was used on transect measurements across the Atlantic, around Labrador Sea, on surveys in the Western Approaches to the English Channel, on the Mid-Atlantic Ridge and in Hudson Bay. As part of these projects, a digital data and acquisition system based on the PDP-8 minicomputer was designed and evaluated.

Major equipment acquisitions followed in 1966: a second gravimeter, with the Gss2-26 sensor, an electrically erected gyro for the Anschutz platform, a LaCoste-Romberg Geodetic land meter for harbour ties and PDP-8 based data acquisition systems for both Askania gravimeters. It was thus possible to conduct concurrent gravity surveys on the Grand Banks and the Mid-Atlantic Ridge.

Multidisciplinary surveys on the Grand Banks continued in 1967 while the following two years saw a comprehensive survey of the Gulf of St. Lawrence and a major operation on the Mid-Atlantic Ridge. During this time navigation using the US Navy Transit satellite system was implemented.

A third Askania system was acquired in 1972 from United Geophysical Co. This system using sensor Gss2-27 served as a back-up either at sea or in the laboratory. Eventually, a fourth system was acquired from the German Hydrographic Office as a source of spare parts. Most of these systems were traded back to the manufacturers when it was decided in 1980 to purchase a new generation sea gravimeter system, Kss-30, from Bodenseewerke Geosystem GmbH.

In 1970, a Navigation Development group was formed within the Canadian Hydrographic Service to advance the practice of navigation on Canadian research ships. A major achievement of this group was the development in 1978 of BIONAV, one of the first integrated navigation systems. At the same time shipboard computers were upgraded by replacing the original PDP-8 with more powerful HP-2100 computers. The result of these two developments was a capability to adjust the navigation and to complete the preliminary data reduction before the ship returned to port.

The first LaCoste-Romberg sea gravimeter was acquired by EPB in 1972. After extensive use, primarily on the west coast, this system was supplemented by the acquisition, in 1979, of LaCoste-Romberg Straight Line sea gravimeter SL-1.

In addition to the 1963 evaluation, a second comparison of LaCoste-Romberg and Askania meters was carried out in 1972 (Valliant <u>et al</u>., 1976).

An attempt in 1974 to compare LaCoste Romberg, Askania Gss2 and Gss3 meters (the latter borrowed from the German Hydrographic Office) was terminated prematurely when the ship, M.V. MINNA, sank in the Labrador Sea, fortunately without the loss of life or equipment. Because the Gss3 data provided the best data, it was selected over the other two for use in the present analysis.

During a multidisciplinary survey of the Laurentian Channel in 1984 (BAFFIN 84-044) Kss30-12 and SL-1 operated side-by-side throughout the project, providing a valuable intercomparison. The cruise also marked the first use of the GPS navigation with the aim of using the east-west velocity directly for computation of Eotvos correction.

4.2 DESCRIPTION OF SURVEYS

4.2.1 Location of Surveys

In Table I, surveys are listed by year with type of survey, location, and number of adjusted data points. Figure 1 shows the data acquisition in line-kilometres of gravity data per year and Figure 2 shows the geographic distribution of the data. Early cruises tend to be concentrated in mid-latitudes, relatively close to home base in Dartmouth, Nova Scotia. Extension of systematic mapping into the Labrador Sea and reconnaissance surveys as far north as Kane Basin followed improvement to LORAN-C, widespread use of satellite navigation, and the integration of various navigation techniques. Upon completion of systematic mapping as far north as Davis Strait, this type of activity shifted south again because of the absence of sufficiently accurate navigation aids in Baffin Bay and the Arctic.

TABLE Ia

DATA IDENTIFICATION		NO. OF GRAVITY RECORDS	FINAL[15] PROJECT WEIGHT	BAY OF FUNDY, GULF OF MAINE	SCOTIAN SHELF	GRAND BANKS	N.E. NEWFOUNDLAND SHELF	GULF OF ST. LAWRENCE	LABRADOR SEA	DAVIS STRAIT	BAFFIN BAY	EAST ARCTIC SOUNDS	BEAUFORT SEA	WEST COAST	HUDSON BAY, FOXE BASIN	MID-ATLANTIC RIDGE	INTERNATIONAL	FOOTNOTE
EPB PROJECT	AGC CRUISE																	
64718	BAFFIN 64-018	9 191	0.6003		B													14,15
64719	BAFFIN 64-019	7 233	0.5292	A														
64727	HUDSON 64-027	5 862	0.0798		a	A												
65706	HUDSON 65-006	(25 184)	--		b	b										A	A	1,11
65724	HUDSON 65-024	11 362	0.2067					b	b						B			
65734	HUDSON 65-034	(2 281)	--		C													2,11
66708	BAFFIN 66-008	8 421	0.4655			A												
66710	HUDSON 66-010	2 923	0.0284		C													
66719	HUDSON 66-019	19 735	0.0338		b	b										A		
67714	BAFFIN 67-014	58 203	0.7552			A												
68721	BAFFIN 68-021	58 922	2.3319		b			A										
68722	HUDSON 68-022	51 102	0.1962		b	b										A		
69702	BAFFIN 69-002	(14 336)	--		c	c											c	3,11
69721	BAFFIN 69-021	46 321	1.2568					A										
69750	HUDSON 69-050	7 850+	0.3170		b	b	b			b	b	b	b	A			b	4
70702	BAFFIN 70-002	11 267	0.0343														c	
70721	BAFFIN 70-021	11 088	2.1768		b	b	b			b	b	b	A	b				
71714	HUDSON 71-014	(27 954)	--	A	a													5,11
71717	BAFFIN 71-017	62 331	0.7429		a	A												
71732	HUDSON 71-032	40 548	0.1230		b		b	b	b	b	B	B			b			
72709	DAWSON 72-009	24 304	0.0780		a	A												
72715	MINNA 72-015	54 559	1.2653		a	A	A											
72721	HUDSON 72-021	25 378	0.8272		B	b												
72725	HUDSON 72-025	31 657	1.2076		a	a	a		A									
72736	HUDSON 72-036	3 045	0.6358		c													
73706	HUDSON 73-006	20 392	0.3685		B	B		b										
73711	HUDSON 73-011	33 731	0.3788		B	b												
73714	BAFFIN 73-014	25 156	0.1139					A	a	a	a	A						
73719	MINNA 73-019	51 949	0.4840		a	a	A											
73727	DAWSON 73-027	31 428	0.1487		b			b	B									
73734	DAWSON 73-034	11 211	1.1139		b	B												
74702	BAFFIN 74-002	(23 206)	--		c												c	11,12
74715	BAFFIN 74-015	5 880	0.1749					A	a	a	a	A						13
74723	MINNA 74-023	(37 652)	--			a	a		A									6,11

TABLE Ia - CONTINUED

DATA IDENTIFICATION: EPB PROJECT	DATA IDENTIFICATION: AGC CRUISE	NO. OF GRAVITY RECORDS	FINAL[15] PROJECT WEIGHT	BAY OF FUNDY, GULF OF MAINE	SCOTIAN SHELF	GRAND BANKS	N.E. NEWFOUNDLAND SHELF	GULF OF ST. LAWRENCE	LABRADOR SEA	DAVIS STRAIT	BAFFIN BAY	EAST ARCTIC SOUNDS	BEAUFORT SEA	WEST COAST	HUDSON BAY, FOXE BASIN	MID-ATLANTIC RIDGE	INTERNATIONAL	FOOTNOTE
74726	HUDSON 74-026	31 448	0.1237					b	b	B	B	B						
74109	MINNA 74-023	(11 408)	--			a	a		A									6,11
74709	MINNA 74-023	11 436	0.5356			a	a		A									6
75779	HUDSON 75-009(1)				b	A												7
75779	HUDSON 75-009(2)	52 647	0.3706		b	A												7
75789	HUDSON 75-009(3)	25 102	1.2774				A											7
75709	HUDSON 75-009(4)						b		b									7
75709	HUDSON 75-009(5)	27 815	0.2711				b	b	A									7
75791	KARLSEN 75-018A	(103980)	--		a		A	a	A									8,11
75792	KARLSEN 75-018B	92 524	0.6527		a		A	a	A									8
76701	BAFFIN 76-001	56 433	0.1856		b	b											A	
76791	KARLSEN 76-019A	83 786	2.3144			b										A		
76792	KARLSEN 76-019B	(90 085)	--		a		A	a	A									8,11
76723	HUDSON 76-023	21 292	0.9624				b	b	b	b	B	b						
76725	HUDSON 76-025	(19 986)	--				c		c	c	c	C						9,11
76729	HUDSON 76-029	28 780	0.2405						b	b	B							
77714	HUDSON 77-014	13 913	0.8687		b	b	b											
77791	KARLSEN 77-016A	(38 181)	--				a		A									8,11
77792	KARLSEN 77-016B	32 560	0.4056				a		A									8
77721	HUDSON 77-021	(19 076)	--				c	c	c									9,11
77724	HUDSON 77-024	8 859	0.0839						c	c	c	c						
77727	HUDSON 77-027	14 317	0.2550						c	c	c	c						
78716	HUDSON 78-016	10 834	0.1211		c	c	c		c									
78791	KARLSEN 78-019A	23 323	1.6649				a		A									8
78792	KARLSEN 78-019B	(24 086)	--				a		A									8,11
78720	HUDSON 78-020	11 696	1.3300		b	b	b											
78723	HUDSON 78-023	(21 526)	--				c											10,11
78726	HUDSON 78-026	7 429	0.3063				c	c	c	c	c							
78729	HUDSON 78-029	23 657	0.1283						c	c	c							
79713	HUDSON 79-013	21 476	1.2155			b	b		b									
79719	HUDSON 79-019	12 540	1.5387						c									
79109	BAFFIN 79-015	8 562	2.4371		A	a												
80728	HUDSON 80-028	17 223	0.8514						c	b	c							
80731	BAFFIN 80-031	20 368	1.1302						A	A								

TABLE Ia - CONTINUED

DATA IDENTIFICATION		NO. OF GRAVITY RECORDS	FINAL[15] PROJECT WEIGHT	BAY OF FUNDY, GULF OF MAINE	SCOTIAN SHELF	GRAND BANKS	N.E. NEWFOUNDLAND SHELF	GULF OF ST. LAWRENCE	LABRADOR SEA	DAVIS STRAIT	BAFFIN BAY	EAST ARCTIC SOUNDS	BEAUFORT SEA	WEST COAST	HUDSON BAY, FOXE BASIN	MID-ATLANTIC RIDGE	INTERNATIONAL	FOOTNOTE
EPB PROJECT	AGC CRUISE																	
80735	HUDSON 80-035	13 727	0.4037						A	A								
80737	HUDSON 80-037	1 383	0.3633			c		c										
81738	DAWSON 81-038	43 676	0.8481						A	A								
81745	HUDSON 81-045	17 653	0.3734			c	c		C	C	c	c						
82909	BAFFIN 82-039	12 339	0.5218	A	A	a												
83735	BAFFIN 83-035	18 363	0.6852	A	A													
84909	BAFFIN 84-044	36 426	4.1355		A	A												
		1532636 (excluding numbers in parenthesis)																

1,081,810 data including any cruises with A in them (70.6% of all cruise data).

113,907 type C only = 7.4% of all data.

B cruises account for 22% of data.

943,452 type A only (excluding surveys outside of eastern Canada)
(138,358 data of type A elsewhere).

FOOTNOTES TO TABLE Ia

1. Cruise rejected because of bad crossovers (data quality poor).

2. Cruise rejected because of high standard deviation.

3. Cruise rejected because of mechanical failure in gravity meter mid-cruise (i.e. tensioning spindle broke).

4. This cruise, known as HUDSON '70, was a circumnavigation of North and South America. Only data from eastern Canada are present in the data base.

5. Cruise rejected because of poor cross-overs. A number of small tares during the cruise were corrected later (Watts, 1974) but the results are still suspect. This area was partly resurveyed later (see 82909 and 83735).

6. These three projects represent data from three gravity meters during the same cruise. Project 74109 was rejected because it had a larger standard deviation and more data rejections than 74709, and 74723 had less areal coverage because of problems with the gyrostabilized gravity meter platform. Data for 74709 were retained. These data were from DHI linear meter Gss-3.

7. Cruise 75-009 was broken into five phases and carried out in different geographical areas with different personnel and different goals. Data were grouped into three EPB projects for convenience.

8. These surveys employed two gravity meters operating together. Because of data redundancy, data were retained from only one meter. Choice of data set was based on the meter performance (e.g. lower standard deviation, fewer rejected values), on greater number of crossovers, or, when these two factors did not indicate a quality differential, by random choice.

9. Cruise rejected on basis of poor data and on the apparent absence of a geophysicist on the ship to supervise gravity meter operation and data collection and processing.

10. Cruise rejected because of poor determination of Eotvos corrections and data redundancy - other cruises surveyed the area better (e.g. 75789, 73719, 75792).

11. Values for number of gravity records within parentheses are the original number of data prior to deletion. Although here rejected, the data are available in unadjusted form on archived tapes.

12. Cruise rejected because of large tare between days 035 and 069 and low importance placed on data (two isolated tracks between Nova Scotia and Guyana).

13. Survey in Lancaster Sound did not collect gravity data i.e. magnetics and bathymetry only.

FOOTNOTES TO TABLE Ia - CONTINUED

14. Classes of data:

    A Top priority, important or major surveys, generally multiparameter cruises jointly run by Canadian Hydrographic Service with Atlantic Geoscience Centre and Earth Physics Branch of EMR.

    B Geophysical cruises, often including seismics; interlining of type 'A' cruises and tie lines or cross-lines.

    C Lowest priority; cruises for geological or oceanographic sampling, cruises for testing instruments or training personnel, potential field data from ships of opportunity including foreign vessels, lines laid out without proper grid or navigational control.

    a,b,c - As for A, B and C respectively, but of lesser quantity, coverage, and quality.

15. Final project weight is assigned by the least squares adjustment program to optimize the adjustment results. It is thus a measure of data quality and consistency for a given data subset (project) within the full data set. Higher weight is placed on cruises that best strengthen the final solution. Low weight cruises may be internally consistent but fit less well within the full data set.

TABLE Ib

CORE CRUISES FORMING BASIS OF DATA BASE IN EASTERN CANADA'S OFFSHORE

DATA IDENTIFICATION		NO. OF GRAVITY RECORDS	FINAL PROJECT WEIGHT	BAY OF FUNDY, GULF OF MAINE	SCOTIAN SHELF	GRAND BANKS	N.E. NEWFOUNDLAND SHELF	GULF OF ST. LAWRENCE	LABRADOR SEA	DAVIS STRAIT	BAFFIN BAY	EAST ARCTIC SOUNDS	BEAUFORT SEA	WEST COAST	HUDSON BAY, FOXE BASIN	MID-ATLANTIC RIDGE	INTERNATIONAL	FOOTNOTE
EPB PROJECT	AGC CRUISE																	
64719	BAFFIN 64-019	7 233	0.5292	A														
64727	HUDSON 64-027	5 862	0.0784		a	A												
66708	BAFFIN 66-008	8 421	0.4655			A												
67714	BAFFIN 67-014	58 203	0.7552			A												
68721	BAFFIN 68-021	58 922	2.3319					A										
69721	BAFFIN 69-021	46 321	1.2568					A										
71714	HUDSON 71-014	(27 954)	--	A	a													
71717	BAFFIN 71-017	62 331	0.7429		a	A												
72709	DAWSON 72-009	24 304	0.0780		a	A												
72715	MINNA 72-015	54 559	1.2653		a	A	A											
72725	HUDSON 72-025	31 657	1.2076		a	a	a		A									
73714	BAFFIN 73-014	25 156	0.6134					A	a	a	a	A						
73719	MINNA 73-019	51 949	0.4840		a	a	A											
74715	BAFFIN 74-015	5 880	0.1749					A	a	a	a	A						
74709	MINNA 74-023	11 436	0.5356			a	a		A									
75779	HUDSON 75-009	52 647	0.3706			A												
75789	HUDSON 75-009	25 102	1.2774				A											
75709	HUDSON 75-009	27 815	0.2711						A									
75792	KARLSEN 75-018B	92 524	0.6527		a		A	a	A									
76791	KARLSEN 76-019A	83 786	2.3144		a		A	a	A									
77792	KARLSEN 77-016B	32 560	0.4056				a		A									
78791	KARLSEN 78-019A	23 323	1.6649				a		A									
79109	BAFFIN 79-015	8 562	2.4371		A	a												
80731	BAFFIN 80-031	20 368	1.1302						A	A								
80735	HUDSON 80-035	13 727	0.4037						A	A								
81738	DAWSON 81-038	43 676	0.8481						A	A								
82909	BAFFIN 82-039	12 339	0.5218	A	A	a												
83735	BAFFIN 83-035	18 363	0.6852	A	A													
84909	BAFFIN 84-044	36 426	4.1355		A	A												
		943 452 (excluding 71714)																

YEAR	LINE KM	EACH * EQUALS 1000 KM
64	7285	*******
65	3611	****
66	9895	**********
67	18385	******************
68	34896	***********************************
69	17171	*****************
70	7067	*******
71	32773	*********************************
72	43812	**
73	54846	***
74	29442	*****************************
75	62504	***
76	59643	**
77	21966	**********************
78	24202	************************
79	23933	************************
80	16512	*****************
81	19113	*******************
82	19039	*******************
83	5723	******
84	11383	***********

Figure 1. GRAVITY DATA ACQUISITION BY YEAR

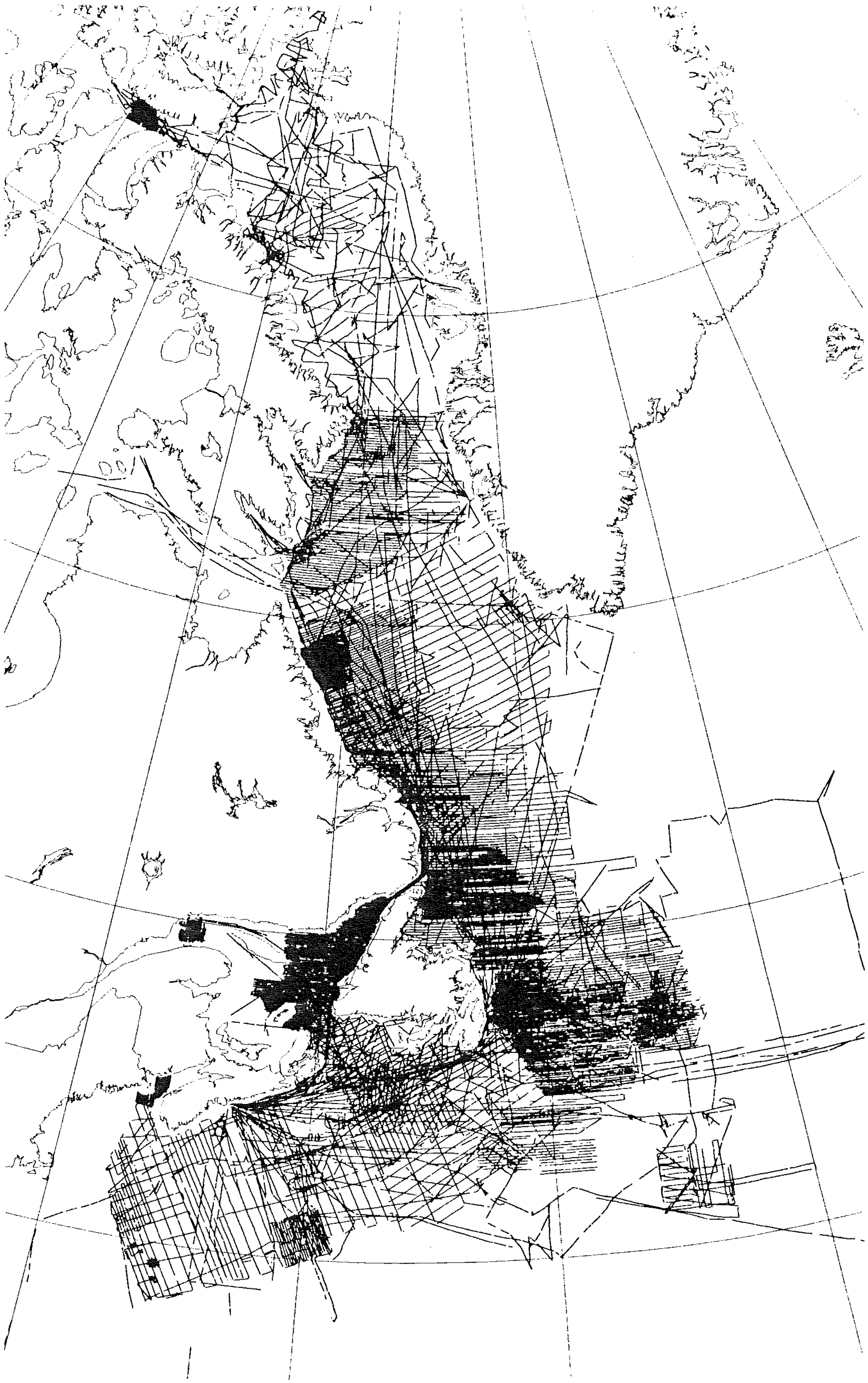

Fig. 2 Data Distribution after Editing

4.2.2 Classification of Surveys

Data fall into three general classifications. Type A cruises are joint CHS-AGC multiparameter mapping cruises or major AGC surveys carried out using similar survey design criteria. Type B cruises often included other goals (e.g. seismic refraction experiments) and were not usually carried out in a regular grid pattern. Type B cruises, however, do provide some important cross lines or tie lines as well as interlining through Type A surveys.

All gravity, magnetic, and bathymetry data not meeting the criteria of Type A or B are relegated to Type C. Type C cruises include instrument evaluation cruises, geological or oceanographic sampling cruises, cruises for which navigation was poor or instrumentation poorly monitored, and other such cruises for which the quality of data is unassessable. This type makes up about 7% of the data compared to about 23% for Type B and 70% for Type A.

4.2.2.1 Survey Specifications

The bulk of the east coast data was obtained over grids of closely spaced lines on Type A cruises. Line spacing for these cruises is determined by the needs of CHS whose minimum line spacing is more than adequate to meet the needs of regional gravity and magnetic mapping offshore. Guide lines for multiparameter cruises require line spacing to increase with increasing depth of water as follows:

- 1 nm. (1.9 km) line spacing to 200 m depths
- 2.5 nm. (4.6 km) line spacing to 1000 m depths
- 5 nm. (9.3 km) line spacing to 3000 m depths
- 10 nm. (18.5 km) line spacing everywhere
- 20 nm. (37 km) line spacing for lines on which reconnaissance seismic reflection measurements are made .

This pattern of coverage is reflected in Fig. 2 where dense coverage follows the shallow areas such as Saglek Bank, Grand Banks, and Gulf of St. Lawrence.

In early years, before advanced navigational techniques became available, great care was taken to obtain good positioning for Type A cruises. For example, in the eastern Gulf of St. Lawrence on surveys 68721 and 69721, a Decca Lambda system was installed and maintained by CHS to ensure ship's position to ± 100 m in the active ranging mode. This compares favourably with the ± 150 m accuracies estimated for LORAN-C positions in Labrador Sea in the mid to late 1970's. For other types of cruises, the quality of the navigation improved with time as new navigation systems became available. The use of satellite navigation beginning in 1968 produced a significant improvement in positioning for Type B and C surveys. Consistency of quality improved after 1979 when the BIO integrated navigation system, BIONAV, became operational and widely used on cruises of all types.

4.2.3 Survey Procedures

Survey procedures evolved over the years as new data acquisition and processing systems were developed and as navigation systems changed.

Base ties were made at least every 2-3 weeks with contemporaneous calibrations of the gravity meters (see Section 4.4). Long straight lines with minimal course and speed changes or corrections were especially important for early cruises when ship's position was not determined as often or as accurately as in later years. It was considered better to diverge from a planned line than to maintain the line by constantly adjusting ship's heading. East-west lines were preferred because ship's speed is generally less variable than ship's heading and the Eotvos effect is less dependent on heading variations along an east-west line than along a north-south line.

On some of the better Type A surveys, one cross line might be run for every five survey lines; however, for the majority of cruises, a cross-line for every 20 or more survey lines was more common. Furthermore, cross lines were usually run near the ends of survey periods on an opportunity basis rather than being incorporated in the survey plan. Procedures improved in latter years of the programme as increased frequency of crosslines became an integral part of the survey design.

Watchkeeping procedures at sea were carefully monitored except for some Type C surveys. A variety of log books were maintained, and analogue chart records were annotated frequently with time and instrument settings. This system ensured that events important to a later understanding of the data signal and noise would be available. All log entries and data acquisition were intercorrelated by reference to a common time base controlled by a single accurate master clock. All systems were checked at least half-hourly including gravity meter operation, temperature, platform level.

Data reduction and editing aboard ship within one day of acquisition was usually realized. This permitted a check on data and watchkeeping quality and the identification of interesting geophysical anomalies. It also ensured that instrumental problems were noticed and resolved early.

4.2.4 Sources of Error

Gravity measurements made at sea are all subject to errors resulting from navigational inaccuracy, offlevelling of the gyro-stabilized platform, scale factor inaccuracy, poor calibrations, poor base ties, tares, environmental noise from vibration and thermal stress, and so on. Beam-type meters are subject also to cross-coupling effects; Askania beam-type meters which accounted for the bulk of the marine gravity measurements on the east coast are sensitive to fluctuations in the lamp current for illumination of the photo-cell. Linear meters such as the EPB LaCoste-Romberg SL-1, DHI Askania Gss-3, and the AGC Bodenseewerk Kss-30 used in recent years, are much less subject to tares and are free of cross-coupling errors. Good reviews of these sources of error in gravity measurements are available (e.g. Dehlinger, 1978; Talwani, 1970).

a) Eotvos related errors

Modern gravity meters are still restricted in the accuracy of gravity measurements they can make at sea by the accuracy of the Eotvos correction. Eotvos corrections must be computed with sufficient frequency and accuracy to define the vertical accelerations sensed by the gravity meter as a result of variations in the ship's course and velocity (in an absolute, 'over-the-- ground', sense). To correct for Eotvos variations to 1 milligal at mid-- latitudes, velocity and course must be measured to better than 0.2 knots (370m/hr.) and 1° respectively, which, for a sampling rate of 2 minutes between fixes implies a relative fix accuracy of 5m. Filtering of the computed Eotvos correction must be matched to the intrinsic filtering of the gravity signal by the gravity meter to preserve phase and amplitude of the Eotvos effect. If the Eotvos correction is computed from smoothed and infrequently sampled navigation, errors of several mGals may be left in the gravity signal. On the other hand, Eotvos corrections computed from frequently sampled but noisy navigation can introduce equally large errors.

For most Type A surveys, ship's position was determined every ten minutes. For early surveys of this type, however, a subset (say 1/2 hour samples) was used for gravity processing. In this case, heading and speed vari ations with periods less than thirty minutes from such causes as current and wind variations and fishtailing of the ship could have produced errors of the order of one or two mGals in gravity. These errors might be as large as 5 mGals, for Types B and C surveys for which ship's positions might have been recorded less frequently.

With the introduction of BIONAV in 1979, dead reckoning between fixes improved through the capability to optimize several sources of navigational information with complementary characteristics.

b) Cross-coupling errors

The cross-coupling effect in beam-type sea gravimeters results from the introduction of a spurious vertical acceleration of the beam when horizontal accelerations of the ship are large and in phase with the ship's vertical motion. Cross-coupling errors tend to be larger than errors due to navigation but are more accurately measurable and much less frequent in occurrence. In rough weather, cross-coupling effects of the order of 35 mGal may be observed. For most operations, however, the cross-coupling effect was less than one mGal. Operational difficulties with the Gss2 cross-coupling computer led to the decision not to apply cross-coupling corrections to the Askania data but rather to simply edit out data obtained during periods of high cross-coupling identified by the rough character of the analogue records. Cross-coupling corrections to the LaCoste-Romberg data are applied internally during data acquisition. The newer linear meters (Kss-30-12 and SL-1) are not subject to cross-coupling effects.

c) Off-levelling errors

Off-levelling of the gravity meter is not considered to be a serious source of error in this data set. Small errors may have been introduced in early surveys due to use of the long period bubbles on the Anschutz platform which were systematically in error when subjected to asymmetric horizontal accelerations. In some cruises there were short periods of off-levelling attributable to gyro-platform malfunction. Where identified (as in project 73719), the data during those periods was deleted or flagged as lower quality. This source of error is considered to be negligible within the current data set mainly because data obtained during major ship manoeuvers (e.g. turns) have been excised, and minor manoeuvering does not result in significant off-levelling (see for example, Talwani, 1970).

d) Measuring spring calibration errors

Measuring spring scale factors are good to 0.1% for all the gravimeters used. Thus, over the 2500 mGal maximum range of the surveys a maximum datum error of 2.5 mGals could be expected. Calibration procedures are discused in section 4.4.

Small residual scale errors may remain in some of the older data because the meters had been opened and worked on prior to a spring calibration over the European range in 1976 (e.g. the overhaul of meter Gss2-17 by the manufacturer in the winter of 1971-72), but it is believed from the current results and analysis of old data sets that such residual errors are negligible.

e) Datum errors and system calibration errors

Datum errors introduced from uncertainties in the port base gravity values, gravimeter readings in port and system calibration errors are estimated to be less than 0.2 mGals. All Gss2 systems calibrations were reviewed and the results recompiled in those cases where there were redundant data and the original selection of calibration data could be improved. Analysis of the residuals on port ties in the cross-over adjustment show no evidence of scale errors stemming from system calibration.

f) <u>Errors induced by lamp brightness variations (for Gss-2 meters)</u>

The Gss2 beam position is determined by differential voltage from a split photocell illuminated by a bulb mounted on the frame through a slit in a plate attached to the beam. Often when the lamp was 'burning in' or in the process of 'burning out', sputtering of metal from the filament, at the molecular level, would cause variations in lamp brightness. Current variations caused similar fluctuations which were always accompanied by small variations in the observed gravity of up to 5 or 10 mGal. Such behaviour occurred on projects 68722 and 80728. In all cases where the lamp current in the Askania meters was observed to fluctuate, data were deleted from the data set.

g) <u>Tares</u>

Tares, or sudden shifts in the level of observed gravity, occur occasionally in response to shocks to the gravity meter or mechanical aging processes in the meter. Those larger than the rejection limit (Sec. 5.6.3) are detected and removed during the process of least squares adjustment of the data set. For example, on project 78720 a tare of about 85 mGal occurred at 2020 G.M.T. on day 183 when a large explosion was detonated during a seismic refraction experiment. This tare is probably responsible for the peak of about 80 mGal in the histogram of adjusted minus observed gravity values (Figure 9).

h) <u>Miscellaneous Errors</u>

Editing did not remove all easily correctable errors and a small number of erroneous MSD values (see Section 4.4.1) caused a section of observed values on project 67714 to be about 100 mGal too high. These were shifted in the adjustment but show up in the histogram of adjusted minus observed gravity values in Figure 9.

Electronic interference, stray voltages in signal cable, and vibration are examples of other sources of error. Electrical noise is usually obvious and correctable by deletion of sections of data. Vibration-induced errors may be the cause of the offsets noted in projects 71732, 73719, and 68722 which produced the small peak at -30 mGals in the histogram of differences between observed and adjusted gravity values (Figure 9). Subtle vibration effects may be more difficult to identify. In surveys where ship- board conditions do not change for long periods of time, this type of error is more likely to show up as a DC shift and would then be correctable during the adjustment process. Vibration-induced effects from the intermittent operation of motors on the ship would be detectable (and therefore removable) as short uncharacteristic excursions of gravity values from the norm. The editing process (see Section 5.2 and 5.5.2) would remove any significant errors of this type.

Occasionally, as on project 73719, large unexplained linear drifts have occurred. These have been corrected through the inclusion of a drift term in the crossover adjustment (see Section 5.6.4.2).

4.3 PORT BASES

4.3.1 Procedure for establishing new port bases

LaCoste and Romberg land gravimeter G-112 was acquired by AGC in 1966 for use in creating harbour base stations for marine surveys. This generally involved establishing a dock station as close as possible to the marine gravimeter by making one or more ties to the nearest CGSN station. Prior to 1966 dock stations established by EPB had been used. Table II lists harbour, base stations used for all projects along with their control.

The general procedure used to set up harbour bases follows the established practice for gravity control surveys on land. A number of ties was made from a CGSN station or other AGC harbour station to the new station. In the case of stations established outside Canada ties were made to IGSN 71 stations (Morelli et al., 1974).

Harbour base stations were set up to ensure that marine surveys were consistent in datum with the CGSN and IGSN 71. Many of these stations were established to provide datum control for only one survey and were therefore not well marked or documented. An unusual example of this is station 9398-76 in St. John's Harbour, which was established in the gravity lab of CSS Hudson while the ship was in dry-dock. Station 9398-76 could never be re- occupied but served the purpose of tying the marine measurements to known control stations in St. John's. A comprehensive review of AGC base station information (Hoffer, 1982) has allowed us to isolate poorly documented or poorly controlled base stations and compile a set of harbour bases which are reusable. Reoccupation of many of these harbour bases has improved the accuracy of their g values.

4.4 GRAVIMETER CALIBRATION

Calibrations of marine gravimeters are carried out to establish an accurate spring scale factor for each gravimeter, its mechanical and electronic drift during a survey, and a calibration of its analogue chart recorders.

Gravimeter manufacturers issue a scale factor for each gravimeter.

Table II
Port Stations Used On Each Project
In Sequence Of Observation

Project Number	Port Station (EPB Number)		Port Name	
64-718	9601-71	, 9601-71	Halifax	- Halifax
64-719	9601-71	, 9601-71	Halifax	- Halifax
64-727	9601-71	, 9601-71	Halifax	- Halifax
65-724	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9823-64	Halifax	- Churchill
	9823-64	, 9823-64	Churchill	- Churchill
	9823-64	, 9601-71	Churchill	- Halifax
66-708	9601-71	, 9601-71	Halifax	- Halifax
66-710	9601-71	, 9601-71	Halifax	- Halifax
66-719	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9501-66	Halifax	- Ponta Delgada
	9501-66	, 9601-71	Ponta Delgada	- Halifax
67-714	9352-81	, 9851-67	Nanisivak	- St.John's
	9851-67	, 9853-67	St.John's	- St.John's
	9853-67	, 9854-67	St.John's	- St.John's
	9854-67	, 9854-67	St.John's	- St.John's
	9854-67	, 9856-67	St.John's	- St.John's
	9856-67	, 9856-67	St.John's	- St.John's
	9856-67	, 9601-71	St.John's	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9858-67	Halifax	- St.John's
	9858-67	, 9859-67	St.John's	- St.John's
	9858-67	, 9601-71	St.John's	- St.John's
	9601-71	, 9601-71	Halifax	- Halifax
68-721	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9183-68	Halifax	- Cornerbrook
	9183-68	, 9601-71	Cornerbrook	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9186-68	Halifax	- Sydney
	9186-68	, 9183-68	Sydney	- Cornerbrook
	9183-68	, 9601-71	Cornerbrook	- Halifax
	9601-71	, 9186-68	Halifax	- Sydney
	9186-68	, 9183-68	Sydney	- Cornerbrook
	9183-68	, 9190-68	Cornerbrook	- Cornerbrook
	9190-68	, 9601-71	Cornerbrook	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax

Table II
Port Stations Used On Each Project
In Sequence Of Observation

Project Number	Port Station (EPB Number)		Port Name	
68-722	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9181-68	Halifax	- Ponta Delgada
	9181-68	, 9189-68	Ponta Delgada	- Ponta Delgada
	9189-68	, 9189-68	Ponta Delgada	- Ponta Delgada
	9189-68	, 9601-71	Ponta Delgada	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
69-721	9355-66	, 9185-68	Halifax	- Sydney
	9185-68	, 9183-68	Sydney	- Cornerbrook
	9183-68	, 9183-68	Cornerbrook	- Cornerbrook
	9183-68	, 9185-68	Cornerbrook	- Sydney
	9355-68	, 9183-68	Sydney	- Cornerbrook
	9183-68	, 9185-68	Cornerbrook	- Sydney
69-750	9510-70	, 9512-70	Vancouver	- Victoria
	9512-70	, 9512-70	Victoria	- Victoria
	9512-70	, 9512-70	Victoria	- Victoria
	9512-70	, 9512-70	Victoria	- Victoria
	9512-70	, 9512-70	Victoria	- Victoria
	9512-70	, 9511-70	Victoria	- Victoria
	9511-70	, 9601-71	Victoria	- Halifax
70-702	9601-71	, 9501-70	Halifax	- Bridgetown
	9501-70	, 9503-70	Bridgetown	- Nassau
	9503-70	, 9601-71	Nassau	- Halifax
70-721	9513-70	, 9514-70	Victoria	- Thule
	9514-70	, 9601-71	Thule	- Halifax
71-717	9601-71	, 9602-71	Halifax	- St.John's
	9602-71	, 9601-71	St.John's	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9402-72	Halifax	- St.John's
	9401-72	, 9601-71	St.John's	- Halifax
	9601-71	, 9601-71	Halifax	- Halifax
	9601-71	, 9401-72	Halifax	- St.John's
	9401-72	, 9363-74	St.John's	- St.John's
	9363-74	, 9601-71	St.John's	- Halifax
71-732	9601-71	, 9514-70	Halifax	- Thule
	9514-70	, 9604-71	Thule	- Godthaab
	9604-71	, 9601-71	Godthaab	- Halifax
72-709	9352-81	, 9352-81	Nanisivak	- Nanisivak
	9352-81	, 9352-81	Nanisivak	- Nanisivak
	9352-81	, 9352-81	Nanisivak	- Nanisivak
72-715	9601-71	, 9475-77	Halifax	- St.John's
	9475-77	, 9363-74	St.John's	- St.John's
	9363-74	, 9475-77	St.John's	- St.John's
	9475-77	, 9475-77	St.John's	- St.John's

Table II
Port Stations Used On Each Project
In Sequence Of Observation

Project Number	Port Station (EPB Number)	Port Name
72-721	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9601-71	Halifax - Halifax
72-725	9601-71 , 9601-71	Halifax - Halifax
72-736	9601-71 , 9601-71	Halifax - Halifax
73-706	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9187-68	Halifax - Sydney
	9187-68 , 9601-71	Sydney - Halifax
73-711	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9601-71	Halifax - Halifax
73-714	9601-71 , 9403-73	Halifax - Father Point
	9403-73 , 9601-71	Father Point - Halifax
	9601-71 , 9601-71	Halifax - Halifax
73-719	9601-71 , 9857-67	Halifax - St.John's
	9857-67 , 9857-67	St.John's - St.John's
	9857-67 , 9474-77	St.John's - St.John's
	9474-77 , 9474-77	St.John's - St.John's
	9474-77 , 9474-77	St.John's - St.John's
	9475-77 , 9601-71	St.John's - Halifax
73-727	9351-81 , 9404-73	Halifax - Goose Bay
	9404-73 , 9351-81	Goose Bay - Halifax
73-734	9601-71 , 9601-71	Halifax - Halifax
74-709	9861-62 , 9363-74	Halifax - St.John's
	9363-74 , 9361-74	St.John's - Halifax
	9361-74 , 9331-74	Halifax - Godthaab
	9331-74 , 9861-62	Godthaab - Halifax
74-715	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9403-73	Halifax - Father Point
	9403-73 , 9601-71	Father Point - Halifax
74-726	9601-71 , 9506-74	Halifax - Thule
	9506-74 , 9604-71	Thule - Godthaab
	9604-71 , 9601-71	Godthaab - Halifax
75-709	9851-67 , 9851-67	St.John's - St.John's
	9851-67 , 9604-71	St.John's - Godthaab
	9604-71 , 9601-71	Godthaab - Halifax
75-779	9601-71 , 9851-67	Halifax - St.John's
	9851-67 , 9402-72	St.John's - St.John's
	9402-72 , 9601-71	St.John's - Halifax
75-789	9601-71 , 9601-71	Halifax - Halifax
	9601-71 , 9851-67	Halifax - St.John's
75-792	9601-71 , 9553-75	Halifax - St.John's
	9551-75 , 9553-75	St.John's - St.John's
	9353-75 , 9553-75	St.John's - St.John's
	9553-75 , 9601-71	St.John's - Halifax
76-701	9601-71 , 9391-76	Halifax - Dakar
	9391-76 , 9391-76	Dakar - Dakar
	9391-76 , 9391-76	Dakar - Dakar
	9391-76 , 9601-71	Dakar - Halifax

Table II
Port Stations Used On Each Project
In Sequence Of Observation

Project Number	Port Station (EPB Number)		Port Name	
76-723	9351-81	, 9397-76	Halifax	- Thule
	9397-76	, 9402-72	Thule	- St.John's
76-729	9402-72	, 9398-76	St.John's	- St.John's
	9398-76	, 9402-72	St.John's	- St.John's
76-791	9601-71	, 9404-73	Halifax	- Goose Bay
	9404-73	, 9404-73	Goose Bay	- Goose Bay
	9404-73	, 9396-76	Goose Bay	- Goose Bay
	9396-76	, 9856-67	Goose Bay	- St.John's
	9856-67	, 9856-67	St.John's	- St.John's
	9856-67	, 9601-71	St.John's	- Halifax
77-714	9471-77	, 9355-66	Argentia	- Halifax
77-724	9604-71	, 9397-76	Godthaab	- Thule
	9397-76	, 9397-76	Thule	- Thule
	9397-76	, 9137-82	Thule	- Holsteinsborg
77-727	9397-76	, 9137-82	Thule	- Holsteinsborg
77-792	9396-76	, 9475-77	Godthaab	- St.John's
	9474-77	, 9476-77	St.John's	- Postville
	9476-77	, 9601-71	Postville	- Halifax
78-716	9363-74	, 9601-71	St.John's	- Halifax
78-720	9251-78	, 9251-78	Halifax	- Halifax
78-726	9601-71	, 9397-76	Halifax	- Thule
78-729	9397-76	, 9137-82	Thule	- Holsteinsborg
	9137-82	, 9601-71	Holsteinsborg	- Halifax
78-791	9601-71	, 9476-77	Halifax	- Postville
79-109	9861-62	, 9861-62	Halifax	- Halifax
	9861-62	, 9861-62	Halifax	- Halifax
79-713	9601-71	, 9272-79	Halifax	- St.John's
79-719	9272-79	, 9601-71	St.John's	- Halifax
80-728	9397-76	, 9137-82	Thule	- Holsteinsborg
	9137-82	, 9137-82	Holsteinsborg	- Holsteinsborg
	9137-82	, 9604-71	Holsteinsborg	- Godthaab
80-731	9851-67	, 9604-71	St.John's	- Godthaab
	9604-71	, 9601-71	Godthaab	- Halifax
80-735	9137-82	, 9601-71	Holsteinsborg	- Godthaab
	9604-71	, 9861-62	Godthaab	- Halifax
80-737	9604-71	, 9861-62	Godthaab	- Halifax
81-738	9351-81	, 9137-82	Halifax	- Holsteinsborg
	9137-82	, 9801-72	Holsteinsborg	- Godthaab
	9801-72	, 9801-72	Godthaab	- Godthaab
	9801-72	, 9351-81	Godthaab	- Holsteinsborg
81-745	9352-81	, 9604-71	Nanisivak	- Godthaab
	9604-71	, 9851-67	Godthaab	- St.John's
82-909	9861-62	, 9861-62	Halifax	- Halifax
	9861-62	, 9861-62	Halifax	- Halifax
83-735	9391-83	, 9391-83	Halifax	- Halifax
84-909	9214-73	, 9895-62	Halifax	- Sydney

Gss-2 scale factors provided by Askania were good to 5%. The scale factor is obtained over a small gravity range (10-200 mGals) which is insufficient for Canadian operation due to the large gravity range (2500 mGals) over which our gravimeters must operate. To overcome this problem, the gravimeters are taken over established land based calibration lines.

4.4.1 Calibration of Askania Gravimeters

a) Spring Calibration

The Gss-2 gravimeters were calibrated in April 1976 over a range of some 2000 mGals between Eibsee in southern Germany and Hammerfest in northern Norway as part of a joint calibration experiment with the German Hydrographic Institute in Hamburg.

Revised scale factors for the three AGC meters are shown in Table III. The largest change in scale factor was about 2.5% for Gss2-17 which had not been taken over the European calibration range. Its recalculated scale factor is based upon repeated ties between bases at Thule in Greenland and Halifax, N.S., and upon comparison with Gss2-26 on the ship during the surveys 76791 and 76792. A scale factor for the German Hydrographic Institute meter used on project 74709 was obtained from a comparison with LaCoste-Romberg S-56 as part of the least squares adjustment of that survey. All gravity data obtained using these four meters were recomputed using the revised calibration constants.

b) Measuring System Calibration

Port calibrations are used to establish the drift of the gravimeter and its electronics, and the calibration of the analogue chart recorders used during a survey. These calibrations are performed while the vessel is

TABLE III

GRAVITY METER CONSTANTS

GSS-2 GRAVITY METER	TIME CONSTANTS[1] (in minutes) MECHANICAL	ELECTRICAL	UPPER SPRING SCALE FACTORS (mGal/spring division) NEW	OLD[2]	LOWER SPRING SCALE FACTORS (mGal/spring div.)
17	4.00	0.95	0.5043	0.5168	1[3]
26	4.15	1.07	0.4986	0.4985	0.997
27	5.10	1.10	0.4742	0.4722	0.9922

Footnotes:

1 Two types of damping filter out high frequency noise in the gravity meter: 1) a large permanent magnet surrounding the beam creates eddy currents in the beam which damp its motion in the magnetic field; 2) electronic RC-filtering of the voltage signal from the meter. These are the times required for a gravity fluctuation to attain $(1-{}^{1}/e)$ or 63.2% of its value.

2 Old values of the scale factors were those used prior to the European calibration experiment in 1976. All pre-1976 data were re-computed with the new values.

3 Lower spring factors are from the manufacturer's Test Certificates for each meter. No value was given on the Test Certificate for Meter 17.

securely berthed at a wharf which has an established gravity value.

The procedures followed during port calibrations were standardized and rigidly followed. A special form was used to record all the data required. When the meter had stabilized after several hours, the beam was swung up and down by adjusting the MSD[1] settings by 300 divisions (about 150 mGal). The VCO counts were recorded for each MSD value after waiting for 30 minutes. In 1975, a shorter method of determining the VCO count for each MSD setting was developed. In this method, three consecutive one minute VCO counts were recorded after a 13 minute wait, and the final VCO count was computed from the exponential delay curve defined by these one minute values. At least six sets of high and low MSD settings were obtained. The new procedure shortened the calibration time from 6 hours to 3 hours with no loss in accuracy. VCO counts obtained using this method were rejected if they deviated by more than

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[1]To understand the rationale behind the measuring system calibration it is necessary to understand the procedure of Gss-2 data reduction at AGC. AGC's computation of gravity requires VCO counts (a digital value representing the beam position), MSD counts (Main Spring Divisions for the upper spring setting values) and the two calibration constants which convert both to mGals. A gravity meter zero reading (called BNULL) is the basis on which the gravity value is calculated. BNULL is defined as the gravity value which would be observed if the MSD value were zero and the VCO count were a value of 65,000 (i.e. mid-scale, as values vary from 60,00 to 69,000). It should always be the same in the absence of drift. The observed gravity can be defined as

$$Gobs = BNULL + (MSD\ value)*K1 + (VCO-65000)*K2$$

where K1 and K2 are the calibration constants for the MSD and VCO respectively. The calibration constants and base gravity value (corrected for elevation difference between harbour base and sea gravimeter) can be used to compute BNULL from

$$BNULL = Gbase - MSDbase*K1 - (VCObase-65000)*K2$$

Because BNULL is identified with the harbour reference value of gravity, the Gss-2 meters are essentially reset to measure the correct gravity value at the start of each survey period.

30 counts (0.03%) from each other. For a good calibration, the errors should be less than 0.000050 mGal/VCO count and less than 0.4 mGal for BNULL. If the errors were too great, the calibration was extended, or repeated when conditions were more stable. This method also provided a calibration of the analogue chart recorders, so that data could be recovered from them if the digital system failed.

The average error for 300 BNULL calibrations made over a period of 20 years for all three GSS-2 meters is 0.130 mGal with only 6 individual values exceeding 0.4 mGal. The average error for the VCO counter calibration is 0.000010 mGals/VCO count for these 300 calibrations. The importance of calibrating the VCO counter is shown by the fact that its scale factor in mGal/VCO count varied by a factor of up to 3 over three years.

4.4.2 Calibration of LaCoste-Romberg Gravimeters

a) Port Calibration

When the ship is tied up to a wharf and the gravimeter reading is stabilized, the readout values in dial divisions and the height in feet from the dockside control station to water level are recorded in the survey log book. A similar base reading is taken each time the ship returns to port.

The control station gravity value extrapolated to water level is obtained by multiplying the height of the dockside control station above water level by the free air correction factor and adding this value to the dockside control station value, i.e.

$$GR = (H * 0.3086) + GC$$

where GR is the control station value in mGals at water level,

H is the station height in metres above water level, and

GC is the dockside control station value in mGals computed from ties to other bases in the vicinity.

The gravimeter reading is converted from dial divisions to milligals by multiplying it by the manufacturer-supplied Interval Factor and adding it to the value for the control station at water level. If this is the first reading of the survey, it will be equivalent to the milligal value of the first control station at water level from which the survey originates. Subsequent auto-reader calibration values at the same dockside control station are calculated as follows:

$$GO(N) = (A(N) - A(1)) * IF + GR(1)$$

where N is 1, 2, 3 .....

GO (N) is the gravimeter milligal value at water level,

A(1) is the initial gravimeter reading in dial divisions during the first calibration,

A(N) is any subsequent reading in dial divisions,

IF is the manufacturer-supplied factor (Interval Factor) for converting the gravimeter reading in dial divisions to milligals, and

GR(1) is the value of gravity at the control station extrapolated to water level when the first port reading was taken.

5.0 DATA PROCESSING

5.1 SHIPBOARD DATA REDUCTION

Data reduction procedures for the Askania meters as developed by AGC are described by Shih (1973) and Haworth and Loncarevic (1974). The general approach was to operate on the data with an inverse filter to restore the signal attenuation and phase lag introduced by the internal damping of the

Gss-2 gravity meters. Corrections for cross-coupling errors were not applied but the data were rejected when these errors become excessive.

In the period previous to BIONAV the computing of the Eotvos correction was based on velocities derived from course and speed assumed as constants along straight-line track segments. With BIONAV came velocities for Eotvos correction automatically calculated from integrated navigation systems at one minute intervals. AGC gravity observations are also made at one minute intervals.

Free air anomalies were computed on an off-line minicomputer and plotted along with bathymetry and magnetic anomalies as profiles for editing before storage on magnetic tape for office use. In the eighties because of improved computer technology AGC's geophysical data were reduced mainly by SHIPAC, a disc-based data processing system (Macnab, 1983).

Data from the Lacoste and Romberg gravity meters are recorded on magnetic tape at 10 second intervals after prefiltering with 3 cascaded 20 second RC filters. An off-line minicomputer further filters the data digi- tally using a 60 point convolution filter supplied by the manufacturer. Additional filtering is unnecessary (Valliant et al., 1974), so no other processing is applied at this time to the data. As part of the on-line system the computer calculated a correction for cross-coupling effects from the three components of acceleration as measured by accelerometers located on the stable platform. Corrected and filtered data were subsampled at five minute intervals and stored on magnetic tape or floppy disks.

Velocities used to compute Eotvos were obtained on an off-line computer by differentiating the five minute position samples with a five point convolution filter (Lanczos, 1964). All data were subsequently combined on a magnetic tape at five minute intervals. Each five minute record contained Julian day, time in hours and minutes, latitude and longitude in decimal degrees, observed gravity value uncorrected for Eotvos, Eotvos correction, free air gravity value, depth. All further data processing was performed in Ottawa using these data.

The Bodenseewerk Kss-30 gravimeter has a built-in pre-processor which does filtering, Eotvos correction and Free Air anomaly calculations (from external navigational information) and Bouguer anomaly calculation (if digital depths are available). Provided the external inputs are sufficiently accurate, the only postprocessing needed is to remove the drift and to apply a harbour base offset.

5.2 EDITING OF DATA AT AGC

A major part of the data editing takes place before the data are brought ashore, thus shore-based editing is more of a final check of the data than a major procedure. It is during this stage of data analysis that drift information is studied, quality factors assigned, and any residual problems from a cruise resolved.

Most of the data in this data set were reprocessed ashore using ancillary information obtained during the survey (such as knowledge of periods of poor navigation, offleveling, tares, etc.). Automatic checks for unusual gradients or amplitudes in the time-series data from each survey are made in the processing software. Profiles of all the data were automatically produced for final checking prior to data storage.

In preparing and compiling the complete data set for storage in the National Gravity Data Base in Ottawa, all the data were again reprocessed, this time utilizing improved base station and calibration information (Hoffer, 1982). The same process of editing was repeated, and the data were rescanned for errors or problems. Types of problems which were encountered and solved included erroneous MSD (spring) settings (resulting in temporary datum shifts in multiples of approximately 50 mGal), spikes or parts thereof (often a single bad value could be missed in the examination of a profile plot), and sections of poor data (which were intentionally left in the original data set but which could be removed because they have been replaced by data in recent surveys).

5.2.1 Assignment of Quality Factors

The quality of data varies within a survey as a function of weather, navigational, and a variety of additional factors. Quality factors are assigned to reflect as objectively as possible the variations in quality of data within individual surveys, and from survey to survey.

The principal criterion for the assignment of quality factors is the level of high frequency (non-geologic) variability in the gravity trace. This variability will be due mainly to Eotvos variations which are not defined by the available navigation data, and occur most often when rough seas cause yawing of the ship. The rougher the seas, the higher the errors from off-levelling and cross-coupling. Thus quality factors reflect the precision of the data over a period of hours. They do not reflect the presence of systematic errors which will be detected later in the network adjustment.

The method used for assigning quality factors is simply to scan all the profile plots with a clear plastic template which is calibrated with error bars. The quality factor reflecting the worst variability within a section of data (Figure 3) is assigned according to the following codes:

QUALITY FACTOR (Q)	GRAVITY VARIABILITY
5	± 1 mGal
6	± 3 mGal
7	± 5 mGal
8	± 10 mGal or more
9	Excessive (deleted data)

5.3 PREPARATION OF DATA TAPES FOR TRANSMISSION TO EPB

Assigned quality factors were digitized and merged with the gravity values to which they applied. As the data were merged and reformatted they were also checked for time errors, for missing quality factors, and for missing deletions (data identified as bad but which somehow missed being deleted). The data files so created contained one cruise or survey per file and were blocked as 40 records, or stations, per block and 100 characters per record.

Two auxiliary files containing project and control data were created to accompany the main data set for later merging in the data base. The project file included the names of chief scientists or project officers (as well as those individuals specifically responsible for the geophysical data on cruises where the chief scientist was not a geophysicist), verbal description and geographical limits of the survey area, instrumentation used, type of survey, navigation type, and so on.

The control data set contains the harbour base identification and location, time of tie, instrument used, observed gravity and elevation. Normally, a reading is taken at the beginning of a period of surveying and then

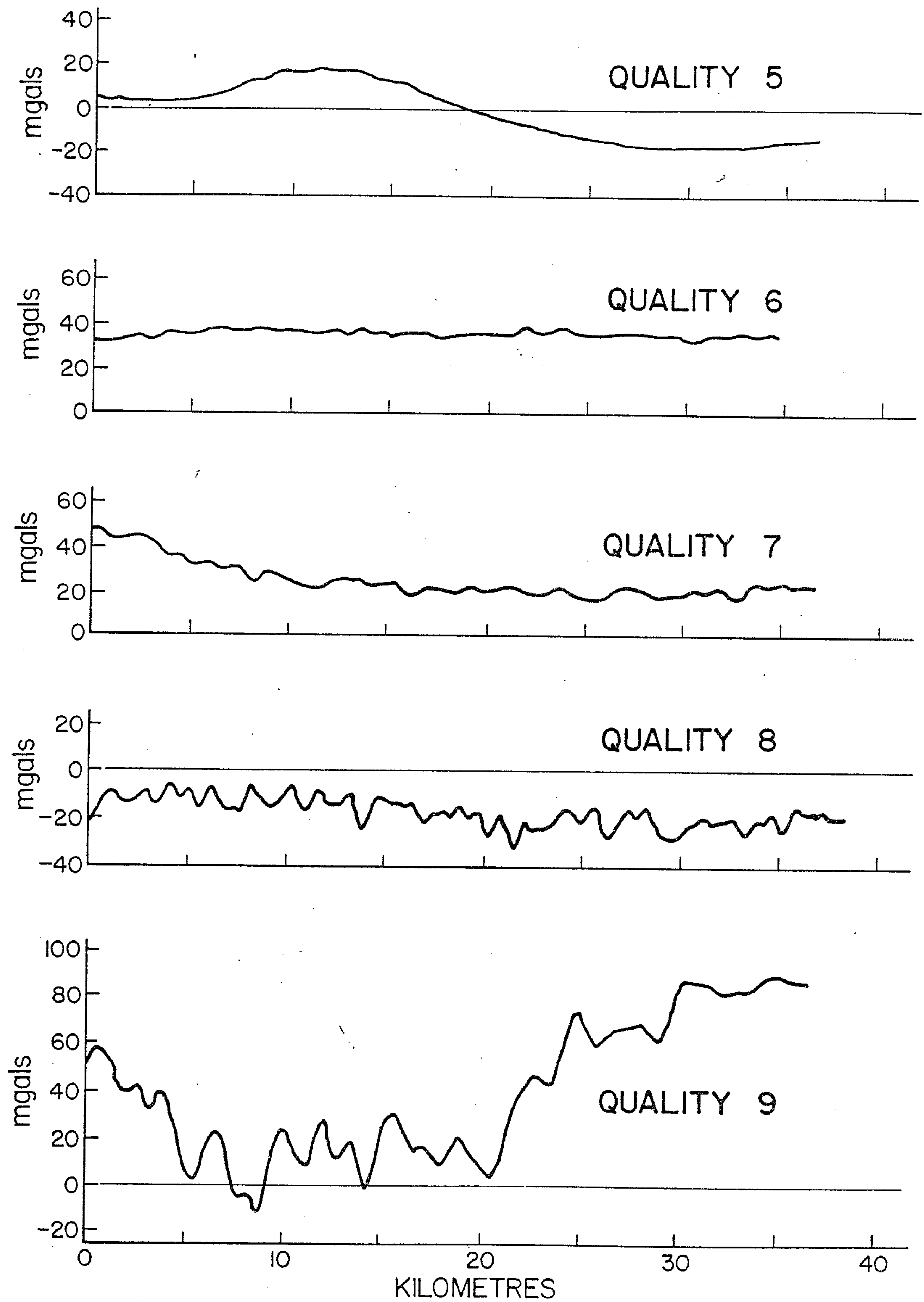

Figure 3. Typical gravity profiles of each quality level.

at the end; so there are two control records for each leg of a survey. Comparison of observed gravity with the harbour base before and after each leg of a cruise provides drift data for the gravity meter and provides an absolute datum for the survey. As noted in section 4.4.1, however, the Gss-2 gravity meters used at AGC were tied to the reference frame via an arbitrary base gravity reading, BNULL, which is reset at each harbour base. It is necessary therefore to calculate from BNULL the raw gravity reading which appears in the control data.

5.4 CONVERSION OF AGC DATA TO EPB FORMAT

AGC data were compiled in two parts. The first part, herein called the Northern data set, consisted of surveys north of latitude 52°N. The second part, principally from south of 52°N, is referred to as the Southern data.

The Northern data were converted from the AGC 4-word binary format to EPB 22-word binary format on the CDC CYBER computer. The data were made into indexed sequential files, indexed by time (19th word) of each record. When the processing software was moved to the VAX 11/780 computer, these data were converted to a coded format.

The Southern data were converted from the AGC 4-word binary format to a coded format on the CYBER for subsequent transfer to the VAX 11/780 computer.

Once the two data sets were on the VAX disk they were converted to an indexed sequential file with a 54-byte binary record in preparation for editing and ASSOB processing.

5.4.1 Merging of AGC and EPB data

EPB data were retrieved from archive tapes in 22-word binary format.

Since the EPB files already contained some AGC data, the AGC data sets were deleted. In the case of multiple gravity meters on one cruise, preliminary crossover adjustments of the multiple meter surveys were done to determine the best meter; the others were then deleted. The EPB and AGC data sets were then merged. It should be noted that EPB data is sampled at 5-minute intervals along track except for project 84909 which has 1-minute samples. AGC data is sampled at 1-minute intervals.

5.5 DATA EDITING AT EPB

Preliminary crossover adjustments indicated that the AGC data still contained a significant number of spurious values, i.e. data points at or near turns or isolated gross navigation errors. To ensure uniformity, the complete data set was examined and edited using an interactive graphics program developed specifically for that purpose.

5.5.1 Track and Profile Plotting

Track plotting software was developed as a modification of GENPLOT to display the spatial distribution of the data. This program plotted the position and time of the data by project at a scale of 1:500000 with a latitude span of 3 degrees and a longitude span of 5 degrees. The profile plot software was developed to plot the data versus time. The fields plotted against time were free air, Eotvos, depth and observed gravity. These were plotted in 14 day strips, with 3 strips per plot sheet.

In the fall of 1983 track and profile plots were created for each project in the Northern data set. The track plots were used to identify ship turns which needed to be deleted from the data set. The profile plots were used to identify areas where the data quality was poor or areas where the data values were in error.

These plots were not created for the Southern data set because it was found that the interactive editing program was a better tool to identify and delete data.

5.5.2 Interactive Data Editing Criteria

At this stage in the editing, 'deletion' is the only task performed because it is assumed that all necessary correction of the data has been completed. Remaining bad data are usually single-value spikes (which are difficult to catch on profile plots) and Eotvos-related problems.

Special attention is required for positively correlated shifts of the observed gravity and Eotvos effect. The Eotvos effect is expected to vary smoothly and slowly to match the normal motion of the ship. If navigation is insufficient to define the Eotvos effect, the result is discrete steps in what should be a continuous variation of the Eotvos (Figure 4a). The gravity will be similarly uncertain, with the magnitude of the uncertainty of the same order as the Eotvos steps, on both sides of each step. Excision of several minutes of gravity data at each jump should result in a trace which would show a smooth gravity profile if the ends of each gap were to be joined by a continuous line. This is only done when the steps in the gravity (i.e. the uncertainty) are unacceptable in the data set. If the effect of a step in the Eotvos is buried in noise on the gravity trace (Figure 4b), the quality factor assigned will reflect this and it is not necessary to delete data (i.e. the gravity noise is as great or greater than navigational noise in the Eotvos effect). Likewise, if both gravity and Eotvos profiles exhibit continuous and frequent steps back and forth, it will not be clear what is correct and what is not; and the quality factor assigned will reflect the uncertainty in the gravity data caused by the navigational uncertainty (Figure 4c). Such navigational uncertainty may result, for example, from frequent cycle jumps in a noisy Loran-C signal. If such variations are greater than 10 mGal, the pertinent section of line is deleted.

Just as frequent oscillatory steps in the Eotvos result in ambiguity in the gravity field, a single step in the middle of a short isolated section of line causes the same uncertainty: Which level is correct? The quality factor assigned to that section of line will reflect the uncertainty as to whether the first or second part of the line is correct (Figure 4d). If the step in the data is greater than 10 mGal, then the section of data in question is deleted.

Where there has been a sudden course or speed change, with a concomitant shift in Eotvos, and the gravity trace exhibits the resulting Eotvos variation, that part of the trace is deleted. There is usually a gap in the data during the course or speed change. The gravity profile usually shows an up-turn or a down-turn which is out of character with the rest of the profile and correlates in time with the ship's manoeuver (Figure 4e).

Most periods of sudden Eotvos change are removed prior to this stage of editing and there will be a gap in the gravity data. The Eotvos effect on the gravity may not have been completely removed sometimes (because the navigation does not define it) thus leaving residual error. In a case like this, if the period of gravity deleted was not long enough, there will still be a turn-up or a turn-down in the gravity trace, as noted above. These tail ends can be removed. There are, however, occasions when such up-turns or down-turns are real and should be left in (Figure 4f). If the bathymetry also turns up or down at the edge of a data gap, the correlated gravity variation is probably real and is left in. Likewise, if the trace looks as if it would be continuous through the data gap, as in the case of a turn down followed by a turn-up below it, or vice versa, then the data gap is probably in the middle of a real gravity gradient and the 'tails' are retained (Figure 4g).

In accepting that gravity variations which correlate with bathymetric variations are usually legitimate, it is often true, especially where water is shallow, that there will be gravity variations for which there is no accompanying bathymetric variation. These are caused by geologic variations below the sea floor and are obviously important to retain. It is therefore a matter of developing a 'feel' for, or understanding of, how the gravity field is likely to vary in a given area and deciding accordingly whether gravity variations are probably real or not. In simplest terms, this means understanding how the magnitude and wavelength of gravity anomalies vary as a function of depth to source and density contrast, and relating this to the geology of the area. Thus in shallow continental shelf regions where juxtaposition of rocks of variable density contrast occur, perhaps as the seaward extension of known continental rocks and structures, gravity anomalies may be of short wavelength and medium amplitude whereas over deep water the variations will be broader and less pronounced. Conversely, short sharp gravity variations observed over deep water are unlikely and are deleted when encountered.

Where a short section of gravity data does not fit in with the rest of the data before and after it, either because it is more than 10 mGal higher or lower than its surroundings or because the noise or variability charac-

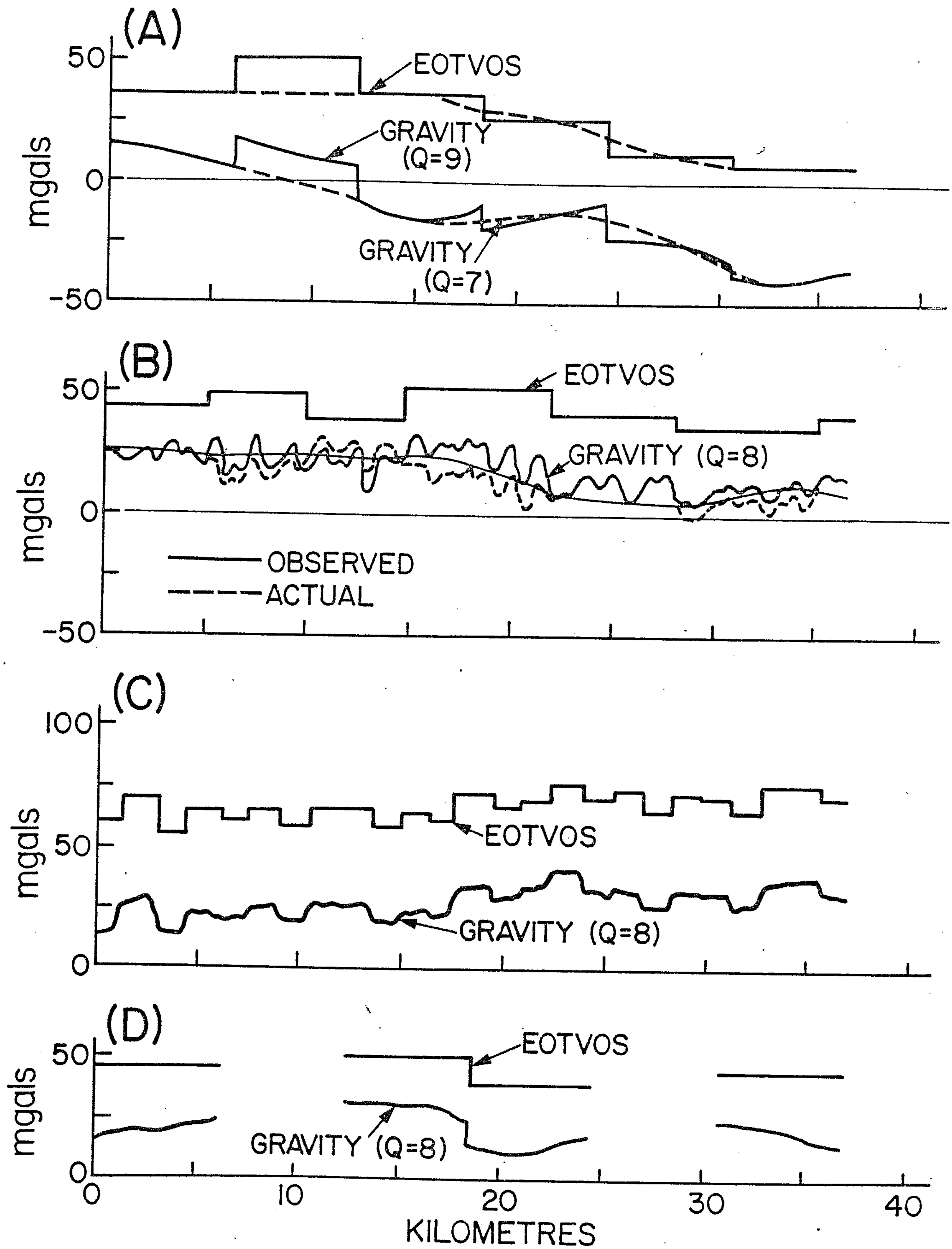

Figure 4. Typical profiles encountered in editing.

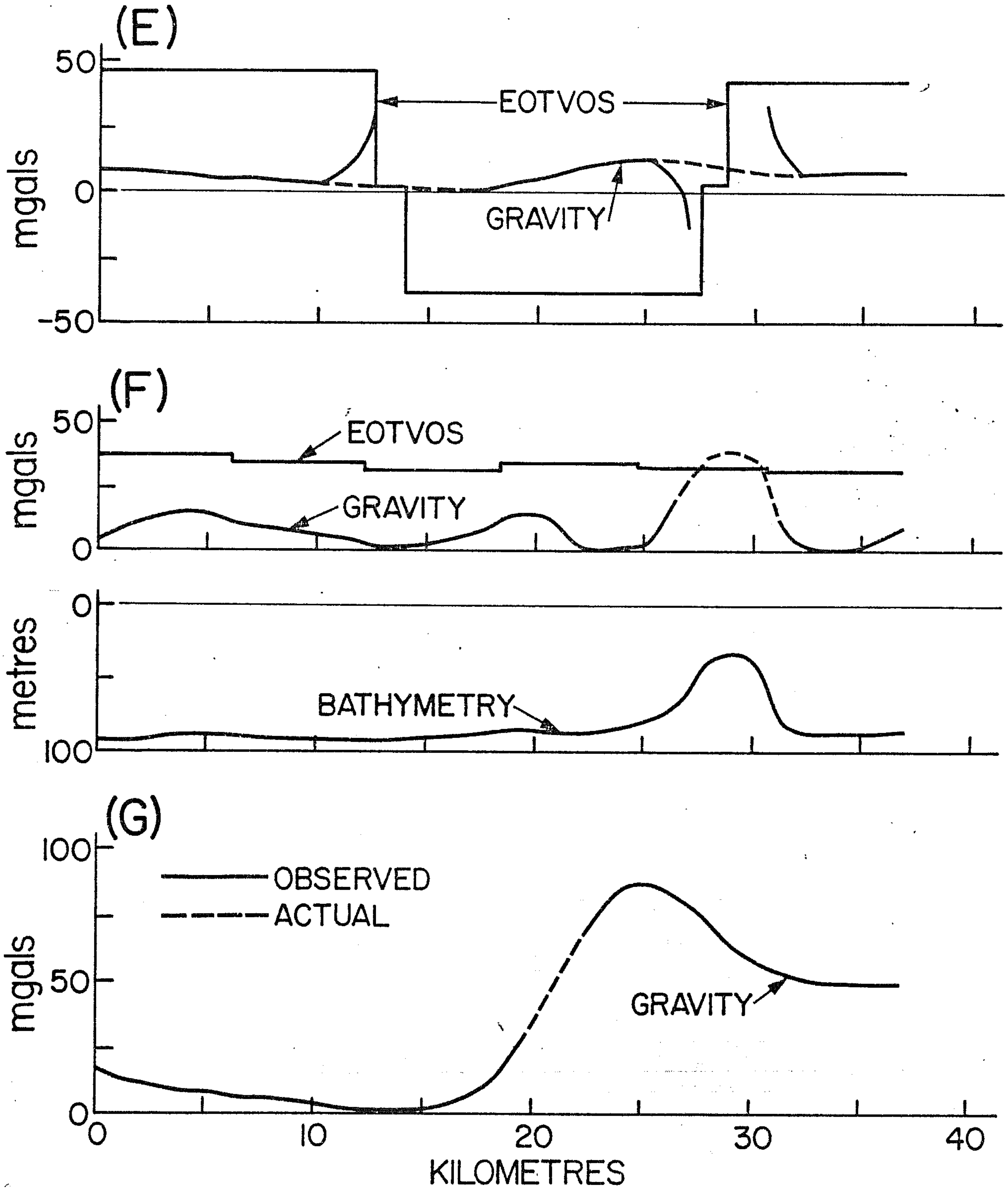

Figure 4. (continued)

teristics are grossly different, that section is deleted (Q=9 section in Figure 4a).

The criterion of ruthlessness is always tempered by an appreciation of the desirability of protecting even the most subtle gravity anomaly resulting from real geologic variation. We delete where data are of doubtful validity and where the quality factor does not reflect the level of variability, but we do not delete if there is no evidence that the gravity anomaly is improbable. This is the philosophy which was followed in editing all data for the data base.

5.5.2.1 Software Development

An interactive graphics program was developed at EPB to permit on-line examination and deletion of data. The data files were converted into indexed sequential files by project so the user could view and edit the sections of data in any order. The program displays observed gravity, free air anomaly, Eotvos, depth and the AGC gravity quality factor versus time (Figure 5).

The original version of the program was written in Fortran for CDC CYBER and used the Tektronics Plot 10 Advanced Graphics Routines for use on a Tektronics 4010 Interactive Graphics Terminal. When the ASSOB system migrated to the VAX 11/780 computer, the editing program was modified to use the Data Plotting DPICT/VGL Interactive Graphics Software. Since the VAX is a virtual memory computer, this allowed additional improvements to the program.

5.5.2.2. Procedures

Each project was passed through the editing program. The operator would

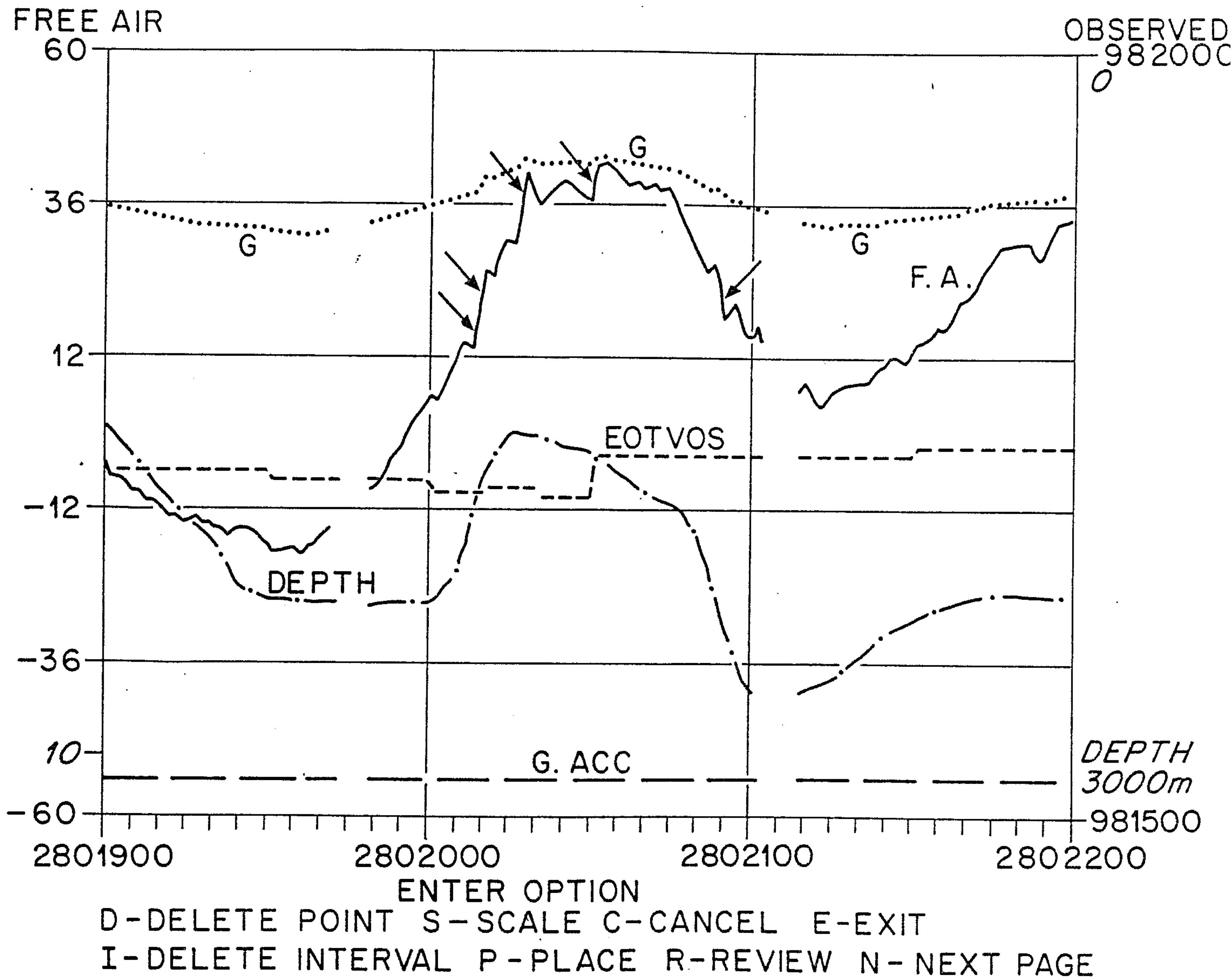

Figure 5. Typical screen display from the interactive editor EDPLOT. Shown on the screen are observed gravity (small dots labelled G, scale on right axis), free-air anomaly (solid line F.A., scale on left axis), Eotvos effect (short dashes labelled EOTVOS, same scale as free-air anomaly), depth (dot-dash, scale on right), AGC quality factors (long dashes G.ACC, scale at lower left), and Julian day and time along x-axis.

view the data in one to twenty-four hour segments on the graphics screen where he would look at the data and determine which segments should be deleted on the basis of the criteria outlined above. Appendix A describes usage of program EDPLOT.

5.5.3 Effect of Data Deletion on Coverage

Tables IV and V show the deletion of data at various stages of processing. While the total loss of data appears large, the loss of information in the sense of regional gravity coverage is very small indeed. This is evident from a visual inspection of Figs. 6 and 7 which show data coverage before editing and after adjustment respectively.

5.6 CROSSOVER ADJUSTMENTS

The dynamic gravimeter adjustment system, called ASSOB, consists of a suite of computer programs which find crossovers in the data set, create a set of observation equations from the crossover data, solve these equations by least squares and compute various statistics.

5.6.1 Definition of a Crossover

A crossover is the point at which two sea gravity track segments intersect. A track segment is an imaginary line joining two sequential gravity observations which are five minutes or less apart in time and less than three kilometres apart in distance. At each crossover two observed gravity values are interpolated from the values at either end of the respective line segments.

Table IV
SUMMARY OF DATA DELETIONS

	AGC DATA 1 min samples	EPB DATA 5 min and 1 min samples	Total
Original data set*	2,166,603	83,672	2,250,275
Low quality cruises deleted	153,549	0	153,549
Redundant data (multiple meters)	293,984	11,408	305,392
Edited out at EPB, pre-adjustment	229,471	3,452	232,923
Edited out at EPB during adjustment	25,726	49	25,775
Reduction due to data compression	1,164,502	29,054	1,193,556
Total records remaining	299,371	39,709	339,080

*after the editing process described in Section 5.2

TABLE Va

GRAVITY DATA VOLUME AND DISPOSITION BY PROJECTS

EPB PROJECT NUMBER	INST	AGC CRUISE NUMBER	RECORDS SUPPLIED	RECORDS[1] DELETED PRE-ADJ	QUALITY 8 REMOVED	QUALITY 9 REMOVED	RECORDS DELETED EDITOR	RECORDS DELETED POST-ADJ	ADJUSTED RECORDS	COMPRESSED RECORDS
64718	A017	64-018	9765	471	266	40	165	103	9191	1892
64719	A017	64-019	8627	1394	122	83	1189	0	7233	1633
64727	A017	64-027	6952	1061	866	5	190	29	5862	1196
65706	A017	65-006	25184	25184	2741	180	BAD CROSSOVERS			
65724	A017	65-024	12245	539	0	529	10	344	11362	2340
65734	A017	65-034	2281	2281	83	16	LARGE S.D.			
66708	A017	66-008	8534	113	36	59	18	0	8421	1723
66710	A017	66-010	3298	375	243	33	99	0	2923	607
66719	A017	66-019	20915	1180	156	184	840	0	19735	4083
67714	A017	67-014	60631	1259	325	370	564	1169	58203	11915
68721	A017	68-021	61345	2356	780	277	1299	67	58922	12136
68722	A026	68-022	56839	5346	1131	171	4044	391	51102	10480
69702	A017	68-002	14336	14336	13389	90	BAD CRUISE			
69721	A026	68-021	47705	1353	264	157	932	31	46321	9520
69750	A017	68-050	10412	2562	1267	482	813	0	7850	1608
70702	A026	70-002	14574	3307	2771	38	498	0	11267	2307
70721	A026	70-021	42102	10855	185	429	10241	20159	11088	2273
71714	A017	71-014	27954	27954	8553	426	BAD CRUISE			
71717	A026	71-017	63470	1037	429	174	434	102	62331	12925
71732	A006	71-032	47763	7000	1034	4506	1460	215	40548	8315
72709	A026	72-009	26468	2134	1580	60	494	30	24304	4932
72715	A026	72-015	55720	1161	0	121	1040	0	54559	11168
72721	A027	72-021	27382	2004	0	85	1919	0	25378	5222
72725	A026	72-025	32529	872	0	185	687	0	31657	6448
72736	A026	72-036	4088	1036	891	16	129	7	3045	624
73706	A027	73-006	20872	480	0	16	464	0	20392	4161
73711	A027	73-011	38059	4249	680	59	3510	79	33731	6973
73714	A017	73-014	28984	3437	1017	762	1658	391	25156	5172
73719	A026	73-019	52667	693	0	68	625	25	51949	10573
73727	A027	73-027	36431	4959	972	1211	2776	44	31428	6407
73734	A026	73-034	18207	6973	6892	21	60	23	11211	2259
74109	S056	74-023	11408	11408	0	0	LARGER S.D. AND MORE REJECTIONS THAN 74709			
74702	A026	74-002	23206	23206	2125	55	LARGE S.D.			
74709	A003	74-023	11472	21	0	0	21	15	11436	11432
74715	A026	74-015	6308	428	0	39	389	0	5880	1221
74723	A017	74-023	37652	37652	4974	343	LESS COVERAGE THAN 74709			
74726	A027	74-026	98530	66893	37564	10756	18572	189	31148	6428
75709	A027	75-009	32033	4218	3699	164	355	0	27815	5759
75779	A027	75-009	57193	4507	3160	167	1180	39	52647	10843
75789	A027	75-009	28293	3089	826	172	2901	102	25102	5234
75791	A026	75-018	103980	103980	11417	692	TOSS UP, PICKED 75792			
75792	A017	75-018	103724	11070	10135	540	395	130	92524	18672
76701	A017	76-001	71957	15524	13608	236	1680	0	56433	11457
76723	A027	76-023	22158	857	0	401	456	9	21292	4344
76725	A027	76-025	19986	19986	0	290	BAD CRUISE , NO GEOPHYSICIST			

TABLE Va (continued)

GRAVITY DATA VOLUME AND DISPOSITION BY PROJECTS

EPB PROJECT NUMBER	INST	AGC CRUISE NUMBER	RECORDS SUPPLIED	RECORDS[1] DELETED PRE-ADJ	QUALITY 8 REMOVED	QUALITY 9 REMOVED	RECORDS DELETED EDITOR	RECORDS DELETED POST-ADJ	ADJUSTED RECORDS	COMPRESSED RECORDS
76729	A027	76-029	29765	742	0	592	150	243	28780	5911
76791	A026	76-019	92461	8534	7855	594	85	141	83786	16942
76792	A017	76-019	90085	90085	5871	5929	LARGER S.D. THAN 76791			
77714	A027	77-014	14225	282	60	37	185	30	13913	2843
77721	A027	77-021	19076	19076	1238	739	BAD CRUISE NO GEOPHYSICIST			
77724	A027	77-024	9874	1015	443	3	569	0	8859	1828
77727	A027	77-027	15229	912	267	18	627	0	14317	2988
77791	A027	77-016	38181	38181	5683	261	77792 HAS MORE CROSSOVERS			
77792	A017	77-016	36111	3218	2634	485	99	333	32560	6577
78716	A027	78-016	11864	905	120	49	736	125	10834	2203
78720	A027	78-020	12378	477	211	26	240	205	11696	2405
78723		78-023	21526	21526	3883	1089	BAD EOTVOS			
78726	A027	78-026	7473	31	0	16	15	13	7429	1516
78729	A027	78-029	34787	10991	6417	2962	1612	139	23647	4868
78791	A026	78-019	24115	792	761	0	31	0	23323	4693
78792	A017	78-019	24086	24086	540	0	MORE REJECTIONS THAN 78791			
79109	S056		8562	0	0	0	0	0	8562	8561
79713	A027	79-013	21965	481	0	163	318	8	21476	4372
79719	A027	79-019	13519	979	502	189	288	0	12540	2578
80728	A027	80-028	27726	9807	77	106	9624	696	17223	3525
80731	A026	80-031	20564	196	0	32	164	0	20368	4115
80735	A027	80-035	16323	2596	2195	128	273	0	13727	2780
80737	A027	80-037	1416	33	0	6	27	0	1383	281
81738	A026	82-038	48237	4551	2384	1122	1045	10	43676	8806
81745	A027	81-045	19831	2073	1269	333	471	105	17653	3581
82909	I001		12371	32	0	0	32	0	12339	12339
83735	K012	83-035	24427	6064	5449	538	77	0	18363	3709
84909	I001		39859	3399	0	0	3399	34	36426	7377
TOTALS # OF PROJECTS 73			2250275	691864[2]	182041[3]	40125[4]	81364	25775	1532636	339080

1. Records deleted pre-adjustment are total of records deleted by editor, and records eliminated because they were quality 8 or 9.

2. Neglecting rejected or redundant cruises 232923 records were deleted pre-adjustment.

3. Neglecting rejected or redundant cruises, 121544 quality 8 records were removed

4. Neglecting rejected or redundant crusies, 10110 quality 9 records were removed

5. A project represents a gravity meter survey, which may be part of a cruise. For cruises with more than one gravity meter, a project identification is assigned each gravity meter.

TABLE Vb

GRAVITY DATA VOLUME AND DISPOSITION BY YEAR

YEAR	NUMBER OF PROJECTS	RECORDS SUPPLIED	RECORDS DELETED PRE-ADJ	QUALITY 8 REMOVED	QUALITY 9 REMOVED	RECORDS DELETED EDITOR	RECORDS DELETED POST-ADJ	ADJUSTED RECORDS	COMPRESSED RECORDS
64	3	25344	2926	1254	128	1544	132	22286	4721
65	3	39710	28004	2824	725	10	344	11362	2340
66	3	32747	1668	435	276	957	0	31079	6413
67	1	60631	1259	325	370	564	1169	58203	11915
68	2	118184	7702	1911	448	5343	458	110024	22616
69	3	72453	18251	14920	729	1745	31	54171	11128
70	2	56676	14162	2956	467	10739	20159	22355	4580
71	3	139187	35991	10016	5106	1894	317	102879	21240
72	5	146187	7207	2471	467	4269	37	138943	28394
73	6	195220	20791	9651	2137	9093	562	173867	35545
74	6	188576	139608	44664	11193	18982	204	48764	19081
75	5	325223	126864	29237	1735	4021	271	198088	40508
76	6	326412	135728	27334	8042	2371	393	190291	38654
77	6	132696	62684	10325	1543	1480	363	69649	14236
78	7	136229	58808	11932	4142	2634	482	76939	15685
79	3	44046	1460	502	352	606	8	42578	15511
80	4	66029	12632	2272	272	10088	696	52701	10701
81	2	68068	6624	3653	1455	1515	115	61329	12387
82	1	12371	32	0	0	32	0	12339	12339
83	1	24427	6064	5449	538	77	0	18363	3709
84	1	39859	3399	0	0	3399	34	36426	7377
TOTALS	73	2250275	691864	182041	40125	81364	25775	1532636	339080

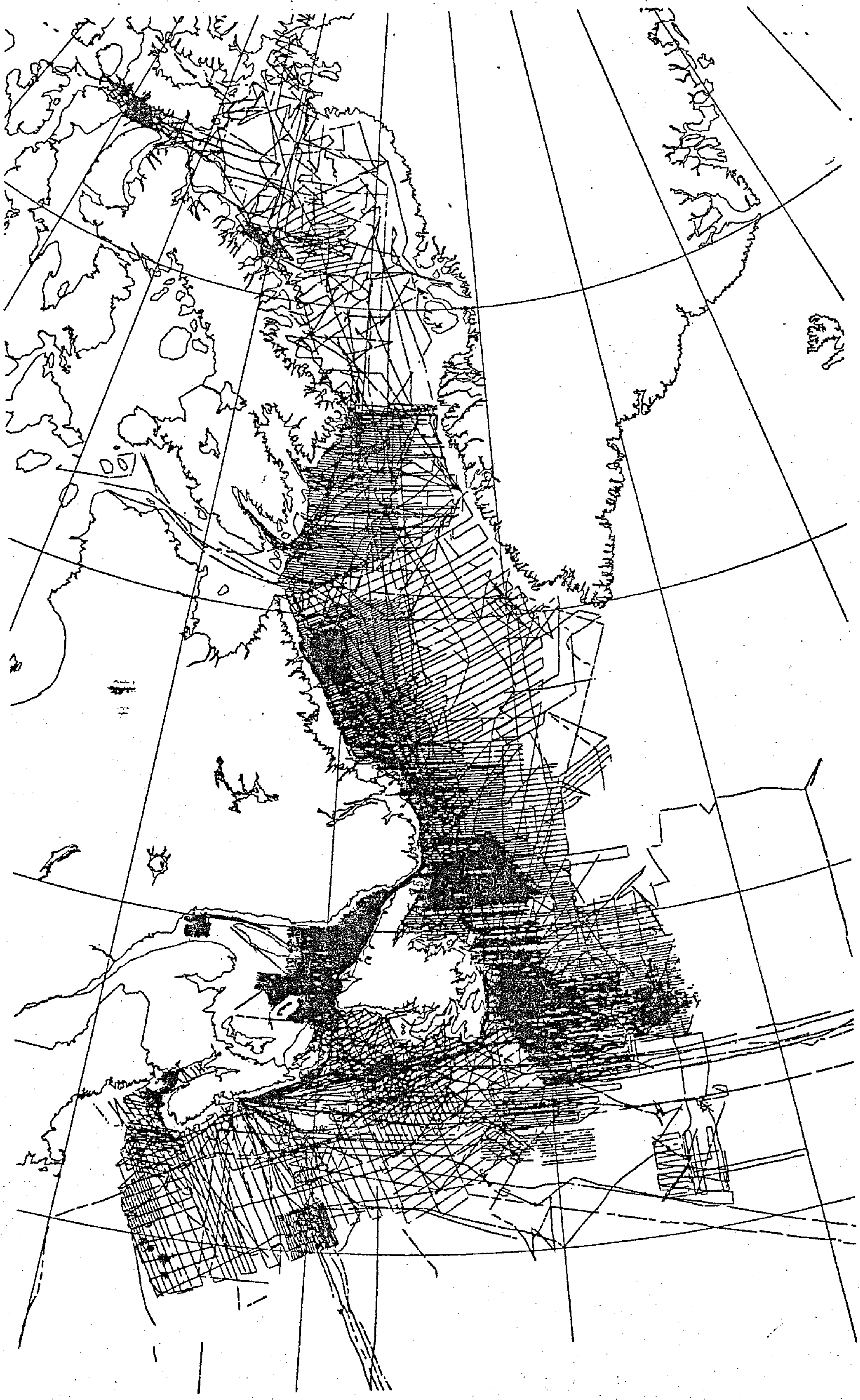

Figure 6. Data distribution before editing.

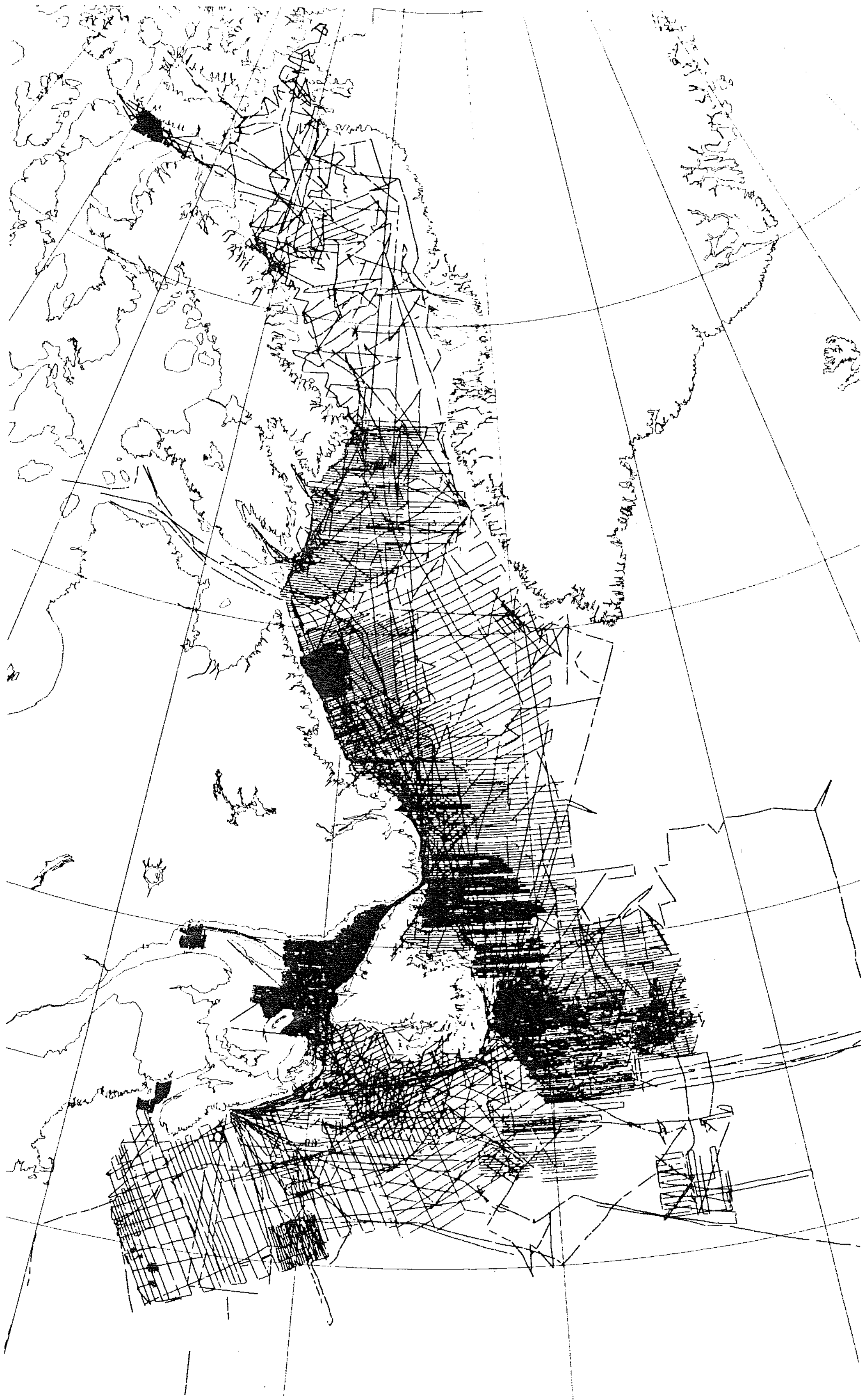

Fig. 7 Data Distribution after Editing

5.6.2 Locating a Crossover

The edited data file, a time sequential binary file containing the position of each observation in geographical coordinates, is converted into track segments and then sorted by ascending longitude. These line segments are then compared against each other to see if they intersect; if they do, the location, the interpolated time, and the interpolated observed g-value for each track segment are recorded and the crossover is assigned a unique number. The crossovers are then passed through another program which pools the crossovers within seventy-five metres of each other, i.e. they are assigned the same crossover number. The assumption here is that the gravity field is constant over horizontal distances of 75 m.

5.6.3 Adjustment Methodology

The information that is required by the adjustment system is supplied in two files: the observation equation file and the specification file.

a) Observation Equations

The observation equation file contains records which describe the network formed by the intersecting ship tracks. Each record describes one gravity interval along a track between two adjacent crossovers and is of the form given by the mathematical model (Section 5.6.3.1)

b) Specification File

The specification file (INSPEC) contains a list of trial gravity values for each port base and crossover. Trial gravity values for the port bases are the known gravity values at that base; these values are fixed in the adjustment. For the first adjustment the crossover trial gravity values were the mean of the interpolated observed gravity values at the cross-over. Since the raw data had many tares of 50 to 100 mGals, a tare table was incorporated so that the known value of tares could be taken into account before the averaging of the trial gravity values at the cross-overs. The tare table was used for the first adjustment only. For subsequent adjustments the trial crossovers' g-values were the adjusted values from the previous adjustment. The INSPEC file also contains a list of parameters for the adjustment which include a list of g-values to be held fixed (port bases), instrument scales, weights to be used for data from each instrument, rejection limits, drift intervals and program output parameters.

5.6.3.1 Mathematical Model

The observed gravity difference between successive crossovers along the ship's track is represented by a simple equation which includes unknowns for the gravity values at the two crossovers and a linear drift rate for a specified time interval during the course of a survey. In previous marine gravity processing projects at EPB more complex models, e.g. including high order drift terms, scale factor and cross coupling terms, have generally been unsuccessful due to the fact that these effects are masked by navigation errors (difficult to model) or the noise level of the gravity observation itself.

The assumption of linear independence of the observation equations, which is implicit in the weighting system used, is not theoretically correct since there is only one gravity reading at a given crossover along a given track. As a matter of expediency, however, this simplified weighting system has proved to be effective provided that its limitations are recognized.

The gravimeter observations are represented by a system of n equations in four unknowns:

$$g_i - g_j - K_l \Delta R_{ij} - d_p \Delta T_{ij} = 0 \qquad (1)$$

where g_i and g_j are the unknown gravity values at two successive crossovers i and j along the ship's track. Some of the g_i's or g_j's may be port stations,

K_l is the unknown scale correction factor for the l^{th} gravimeter,

ΔR_{ij} is the measured gravity difference between crossover i and j corrected for all known instrumental (except spring calibration) and environmental effects,

d_p is the unknown drift rate for the p^{th} drift interval. Drift intervals are defined by the user and may span any interval of time during the course of a survey,

ΔT_{ij} is the time difference between crossover i and j,

Substituting trial values g_i°, g_j°, K_l°, d_p° for g_i, g_j, K_l, d_p respectively, equation (1) becomes:

$$(g_i^\circ + \delta g_i) - (g_j^\circ + \delta g_j) - (K_l^\circ + \delta K_l)\,\Delta R_{ij} - (d_p^\circ + \delta d_p)\Delta T_{ij} = 0 \qquad (2)$$

We may define a quantity V° such that

$$V^\circ = -(g_i^\circ - g_j^\circ - K_l^\circ \Delta R_{ij} - d_p^\circ \Delta T_{ij})$$

Equation (2) then becomes

$$\delta g_i - \delta g_j - \delta K_l \Delta R_{ij} - \delta d_p \Delta T_{ij} = V^\circ$$

or, in matrix notation

$$A\,\delta X = V^\circ$$

Introducing a weight matrix P:

$$P = \begin{vmatrix} \frac{1}{\sigma_1{}^2} & & & & 0 \\ & \frac{1}{\sigma_2{}^2} & & & \\ & & \frac{1}{\sigma_3{}^2} & & \\ & & & \cdot & \\ 0 & & & & \frac{1}{\sigma_n{}^2} \end{vmatrix}$$

where σ_1^2, σ_2^2, ...σ_n^2, are the a priori or a posteriori estimated variances of the observations.

The least squares solution of equation (4) is:

$$\delta X = (A^T P A)^{-1} A^T P V^\circ$$

The least squares estimates for the unknown are then obtained from

$$X = X_o + \delta X$$

where X_o is the vector of trial values for the unknowns.

The weighted residuals for the observation equations are then given by:

$$PV = PV^\circ - PA\delta X$$

The variance of unit weight is given by
$S_o^2 = \frac{V^T P V}{n-r}$ and the expected value of $S_o{}^2$ is 1

The a posteriori estimate of variance for any gravimeter is:
$S_l^2 = \frac{\Sigma V_l{}^2}{n_l - 1}$ where the summation is carried out over the residuals on the observations with the l^{th} gravimeter.

For the first adjustment all weights are set to 1.0 and the rejection limit, v√p, set to a large value, typically 30 or more for the adjustments described here. In this case, all equations with residuals (V° values) greater than 30 will be rejected. On subsequent cycles of the adjustment the adjusted crossover gravity values from the previous run will be used as trial values for the current run. The rejection limit will be lowered progressively to a value of 5 on the final run. Observations rejected on early runs may, of course, re-enter the adjustment as the adjusted crossover values stabilize.

5.6.3.2 Software Description

The crossover adjustment is a series of five computer programs written in the FORTRAN 77 language which are run in sequence and which share data and parameter files. These programs and files are described below.

Program FORMAT reads a file which contains trial gravity values for the crossovers, trial scale constants for the instruments, trial rates of instrumental drift, and other specifications for the adjustment. It checks the format of and the values in each record of this file, and counts the numbers of unknowns.

Program EDITOR reads in these same values and stores them in a table in memory. It reads in a file of observations, looks up each crossover, instrument and drift term in the table, and assigns the appropriate pointer to each. It also computes a trial residual for each observation. The output of this program is a file of indexed observations with their trial residuals, and a file containing the table; both these files are used by the subsequent programs.

The system of observations can be solved in two ways - by matrix inversion using program MATRIX or by the Gauss-Seidel iterative method using program SEIDEL. Both programs read in the file of indexed observations and perform the computations required to obtain the solution vector. Both programs write out a file containing this solution vector; program MATRIX also writes out a vector of error estimates.

Program STATS reads in the indexed observations, the solution vector and the error estimates, and computes a new residual for each observation. It lists the unknowns and the observations, performs a number of statistical computations which are helpful in analysing the adjustment, and writes out a file of trial values and specifications which can be read in by program FORMAT to perform another cycle of adjustment.

5.6.4 Adjustment Results

5.6.4.1 Preliminary Adjustments

Preliminary adjustments using subsets of the data were carried out for the following purposes:

(a) to develop a general impression of the precision and accuracy of the data

(b) to determine what modifications, if any, were required to the crossover adjustment software to accommodate AGC data

(c) to determine how the AGC quality factors, which estimated the precision of the data, were related to its accuracy as estimated from the combined adjustment of a number of interlaced surveys

(d) to examine the consistency of the gravimeter scale correction factors assigned by AGC

(e) to identify cruises or cruise segments which should be deleted before the final adjustment.

The first set of preliminary adjustments began early in 1984 using a subset referred to as the Northern data and consisting of 32 surveys located primarily in an area north of 52°N. The first problem encountered was the generation of several thousand false crossovers due to the interaction of five minute LaCoste-Romberg data with one minute Askania data acquired simultaneously on the largest survey in the area (Labrador Sea Cruise 74-002). The phenomenon occurs because the geographical positions of the one minute samples do not lie exactly on a straight line between the five minute samples. Thus the Askania one minute track segments frequently crossed at a very small angle with the corresponding five minute LaCoste-Romberg segment generating up to four false crossovers for each five minutes of ship track. The problem was circumvented by using only five minute samples for all meters in subsequent preliminary adjustments.

On the first adjustment of the Northern data (25,353 equations, 10,206 unknowns) with rejection limit set at 50 mGal and all surveys weighted 1.0 no measurements were rejected and only four residuals were in excess of 10 mGals. Standard deviations of the observations i.e. the variability of the observed values with respect to the adjusted values at the crossovers varied from 1.25 mGals for the best survey to 3.7 mGals for the worst. Nine more adjustments were run on this data set, gradually reducing the rejection limit to three and removing the data from the gravimeter with the highest standard deviation from each of the multiple meter cruises.

Assuming that the Southern data would be of similar quality to the Northern data, the initial adjustment (17,168 observations, 9,503 crossovers) was run with a rejection limit of 20 and weights of 1.0. Expecting less than 10 rejections we were astonished to obtain 754. Detailed examination of the rejections revealed that a large proportion were due to offsets in the data, some as large as 100 mGals. These introduced large biases into the trial gravity values and consequently resulted in the rejection of a significant amount of good data along with the bad. One solution to this problem would have been simply to increase the rejection limit to about 110 mGals and recycle the solution many times, lowering the rejection limit on each cycle. Since each solution requires several hours of computer time, however, we considered it more effective to modify the software to obtain more accurate trial gravity values for the first cycle of any new adjustment. This was done in two ways: first, by compiling a 'tare table' containing the gravimeter identifier, time span, approximate size of known large tares and, secondly, after using this table to correct the preliminary g values, to further refine them by averaging the two preliminary values at a crossover.

With the above modifications an acceptable solution was obtained after three cycles of the adjustment, updating the trial gravity values with the results of the previous adjustment, and using rejection limits of 30, 8 and 5 respectively. On the final cycle 337 observations were rejected.

An experimental adjustment of subsets of the data, classified according to quality factor, indicated a rough correspondence between data accuracy and assigned quality. Only the Northern data were so analysed. Adjustment weights and standard deviations were compiled by project for a) all data (quality 5, 6, 7 and 8), b) data of quality 7 or better (91% of the data), and c) data of quality 6 or better (73% of the data). After two adjustment iterations higher weights had been assigned to the higher quality data and weight-adjusted standard deviations were lower for the better quality data.

Although there is a general correspondence between quality factors and accuracy, there were cases of specific projects showing low weights and high standard deviations when only the better quality data were analysed. This behaviour is attributed to deterioration in the structure of the network of crossovers. Thus the adjustment statistics must be taken to indicate the quality of data sub sets within the larger database. The quality factors are more general indicators of quality for data values and serve a useful screening function. These conclusions and the trade-off between the advantage of ignoring poorer data (to maintain quality of data) and the need to include as many data as possible (to maintain structural quality of network) were kept in mind when it was decided to restrict the data base to data of quality 7 or better.

Our experience in marine gravity adjustments has shown that it is rarely worthwhile to attempt to solve for drift in crossover adjustments. Generally, errors due to drift are rather small in modern, properly maintained and operated gravimeters. Drift of a few mGals or more during a leg of a cruise are usually due to instrument malfunction or, more commonly, to vibration or mechanical shock. In such cases the drift is difficult to model. Tares of magnitude greater than the rejection limit will, of course, be removed in the crossover adjustment. Smaller ones will go undetected and their effect will simply propagate into the surrounding crossovers. In the case of the Northern data the use of linear drift terms for each port to port leg of each cruise produced no significant improvement in the solution. To prove that there are exceptions to all rules, however, the Southern data set yielded seven significant linear drift terms, six of which applied to project 73719. A second order drift model tried in an attempt to effect some further improvement in project 73719 was unsuccessful.

Solving for scale unknowns is generally impractical in marine gravity adjustments since the network consists of a large number of small gravity intervals each with a relatively large error estimate (1 to 2 mGals). The body of the net is, as well, tied rather weakly to the port (fixed) gravity values. Error estimates on the determination of scale are therefore very large indeed. The mean residual for each gravimeter on each cruise was examined for large values (significantly different from zero) which could indicate scale factor inconsistencies. In spite of the fact that the GSS-2 meters have not had spring calibrations since 1976 no anomalous values were noted. The LaCoste-Romberg meters have been calibrated regularly since their acquisition and no anomalies were expected.

Conclusions drawn from this preliminary analysis of the Northern and Southern data sets were:

(a) with relatively minor modifications the existing crossover adjustment programs in ASSOB would handle AGC data,

(b) once the redundant data had been removed from multiple meter cruises we could expect to obtain standard deviations of the order of 1.5 mGals with 3% data rejection,

(c) although quality factors are a rough indication of data accuracy, care must be taken in screening out poorer data because the resulting loss in connectedness of the network can cause a decrease in accuracy of adjusted data,

(d) with the exception of two cruises, significant drift as manifested in the port-to-port closures appeared to be discontinuous, i.e. mostly tares,

(e) there was no evidence of systematic error due to inconsistencies in gravimeter calibration,

(f) several cruises have redundant data (multiple meters) and others are of such low quality that deletion is warranted.

5.6.4.2 Final Adjustment

For the final crossover adjustment, the Northern and Southern data sets were combined. Since there was a certain degree of interlacing between the two data sets it was necessary to recompute crossover positions and interpolated gravity values. This resulted in generation of 44,014 observations between 21,813 crossovers. Trial gravity values were computed as in the partial adjustments (Sec. 5.6.4.1) and the system of observation equations solved several times by Gauss-Seidel iteration, lowering the rejection limit, $v\sqrt{p}$, on each solution and updating the trial values with the adjusted crossover gravity values from previous solution. All observation weights were held at the same value until the last solution where the weights computed from the next to last solution were used. As in the partial adjustments, rejected measurements from the previous solution were reconsidered on each subsequent run. The rejection limit on the final run was 5. Gravity values at the 53 port stations were held fixed as were the gravimeter scale factors. The six significant drift segments identified in the partial adjustments (all for cruise 73719) were included as unknowns. Their solution values ranged from 0.029 to 0.104 mGals/hr. Eighty-five observations were rejected. Each rejection was inspected visually by plotting the residuals at the affected, and nearby, crossovers to ensure that the adjustment algorithm had made a reasonable decision. The standard deviation of the unweighted residuals on the final solution was 1.60 mGals. A histogram of weighted residuals is shown in Figure 8.

Figure 9 is a histogram showing the difference between the raw and adjusted gravity values. The outliers at about -100 and +80 mGal were attributed in section 4.2.4 to an MSD error and a tare respectively. As also

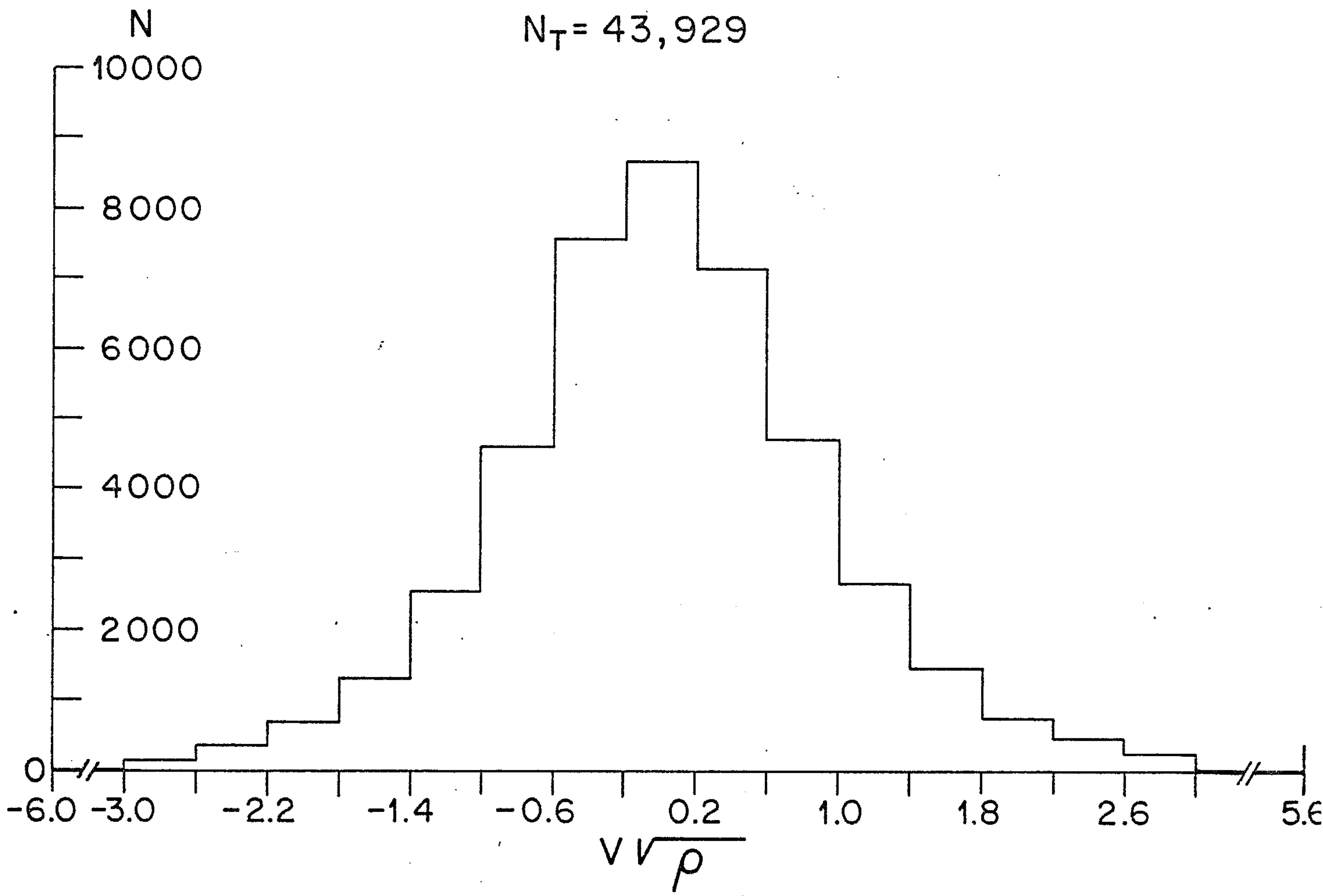

Figure 8. Histogram of weighted residuals from the final adjustment.

RANGE IN MGals

lower	upper	number	
-107.5	-102.5	10	:
-102.5	-97.5	0	:
-97.5	-92.5	0	:
-92.5	-87.5	0	:
-87.5	-82.5	0	:
-82.5	-77.5	0	:
-77.5	-72.5	0	:
-72.5	-67.5	0	:
-67.5	-62.5	0	:
-62.5	-57.5	0	:
-57.5	-52.5	0	:
-52.5	-47.5	68	:
-47.5	-42.5	1158	:
-42.5	-37.5	1578	:
-37.5	-32.5	1476	:
-32.5	-27.5	2567	:
-27.5	-22.5	993	:
-22.5	-17.5	1867	:
-17.5	-12.5	4527	: *
-12.5	-7.5	13952	: ****
-7.5	-2.5	75529	: **********************
-2.5	2.5	174072	: **
2.5	7.5	46888	: *************
7.5	12.5	8638	: **
12.5	17.5	3019	: *
17.5	22.5	816	:
22.5	27.5	81	:
27.5	32.5	10	:
32.5	37.5	6	:
37.5	42.5	7	:
42.5	47.5	0	:
47.5	52.5	0	:
52.5	57.5	0	:
57.5	62.5	0	:
62.5	67.5	0	:
67.5	72.5	0	:
72.5	77.5	216	:
77.5	82.5	1403	:
82.5	87.5	180	:
87.5	92.5	19	:
92.5	97.5	0	:
97.5	102.5	0	:
102.5	107.5	0	:

Figure 9. HISTOGRAM OF DIFFERENCES BETWEEN ADJUSTED AND OBSERVED GRAVITY VALUES (compressed data)

suggested in section 4.2.4, the small peak at about -30 mGal might be the result of vibration induced errors; however, alternate or additional sources of these discrepancies may be small tares or lamp current fluctuations.

A summary of the final adjustment statistics is given in Table VI.

The Gauss-Seidel method does not yield an inverse matrix and consequently error estimates for the solution values (crossover gravity values and drift) are not available. The normal matrix of dimension 21,766 x 21,766 was too large to invert with existing computer facilities in EMR and therefore an alternative method of estimating the accuracy of the adjusted crossover gravity values was required. This is discussed in Sec. 5.6.4.3.

5.6.4.3 Crossover Error Estimates

In order to obtain error estimates for adjusted crossover gravity values, two test areas were chosen, each somewhat different in crossover structure (Figure 10 and Figure 11), and of such a size that the normal matrix could be easily inverted. In effect, each of the two areas chosen was used to simulate the range of behaviour of error estimates one might obtain from an inversion of the complete crossover network.

The ratio of port ties to crossovers in the complete network is about 1 in 40. Therefore each of the test areas, containing 505 and 530 crossovers respectively, was assigned five simulated port ties. Since the standard deviation of the unweighted residuals on the port ties from the complete network was 1.6 mGals and the port end of each of these ties has zero error, i.e. is held fixed, port ties for the test areas were simulated by weighting five crossovers, chosen at random at the extremity of each area, at a value of $1/(1.6)^2 = 0.4$.

TABLE VI

FINAL ADJUSTMENT STATISTICS

Project	Gravimeter	Accepted Measurements	Rejected Measurements	Residuals Mean	Residuals RMS
74709	A-03	1087	2	-0.105	1.359
71732	A-06	754	2	0.045	2.849
64718	A-17	444	2	0.386	1.290
64719	A-17	66	0	-0.074	1.371
64727	A-17	312	1	0.038	3.537
65724	A-17	417	4	-0.028	2.199
66708	A-17	96	0	-0.105	1.458
66710	A-17	29	0	0.191	5.828
66719	A-17	390	0	-0.022	5.442
67714	A-17	1693	12	-0.019	1.151
68721	A-17	3566	2	0.037	0.654
69750	A-17	192	0	0.107	1.766
73714	A-17	992	4	0.046	1.276
75792	A-17	2206	2	0.029	1.237
76701	A-17	152	0	0.101	2.310
77792	A-17	909	2	0.053	1.568
68722	A-26	1229	3	0.039	2.256
69721	A-26	1529	3	0.049	0.891
70702	A-26	37	0	0.116	5.371
70721	A-26	1024	0	0.025	0.667
71717	A-26	1840	4	0.028	1.160
72709	A-26	555	1	-0.014	3.581
72715	A-26	1510	0	0.076	0.886
72725	A-26	825	0	0.009	0.910
72736	A-26	637	1	0.124	1.245
73719	A-26	944	1	-0.033	1.437
73734	A-26	146	1	-0.008	2.963
74715	A-26	165	0	0.050	2.389
76791	A-26	2600	3	0.037	0.657
78791	A-26	575	0	-0.003	0.775
80731	A-26	502	0	-0.005	0.941
81738	A-26	763	1	0.066	1.083
72721	A-27	462	0	0.029	1.099
73706	A-27	595	0	0.052	1.645
73711	A-27	590	1	0.064	1.622
73727	A-27	1314	3	0.049	2.590
74726	A-27	702	1	0.073	2.835
75709	A-27	557	0	-0.016	1.920
75779	A-27	1039	2	0.087	1.637
75789	A-27	1156	4	0.067	0.883
76723	A-27	635	1	0.003	1.019
76729	A-27	811	3	0.007	2.039
77714	A-27	522	1	0.047	1.072
77724	A-27	198	0	-0.215	3.374
77727	A-27	320	0	0.152	1.959
78716	A-27	117	2	-0.038	2.871
78720	A-27	417	1	0.040	0.886
78726	A-27	346	1	-0.030	1.806
78729	A-27	509	2	0.028	2.791
79713	A-27	600	2	-0.013	0.907
79719	A-27	648	0	0.009	0.806
80728	A-27	441	4	0.033	1.083
80735	A-27	308	0	0.069	1.570
80737	A-27	72	0	0.064	1.657
81745	A-27	433	2	-0.082	1.630
83735	K-12	388	0	-0.008	1.208
82909	L-01	715	0	-0.029	1.384
84909	L-01	1169	1	0.005	0.492
79109	S-56	689	0	0.004	0.641
	Totals	43929	85		

After computing crossovers and recycling the solution as in previous adjustments, but using a matrix inversion solution, it was found that error estimates on crossover gravity values ranged from 1.3 to 2.2 mGals in the northern (Labrador Sea) area and from 1.5 to 2.9 mGals in the southern (Grand Banks) area. The larger error estimates in the southern test area reflect its poorer crossover structure. A visual inspection of the overall network (Figure 2) shows that the southern test area represents a near "worst case" situation in that it has a very low density of crossovers. It is therefore reasonable to conclude that for the overall network an accuracy (1σ) of the adjusted crossovers allowing for unmodelled sources of systematic error is about 2.5 mGals.

5.6.4.4 Evaluation of Depths at Crossovers

In order to assess the quality of AGC bathymetric data introduced to the data base with the gravity, depth crossovers and pseudocrossovers (i.e. geographically, but not temporally, close values) were examined. Several distribution patterns emerged for crossover discrepancies greater than 20 m. Rows of bad crossovers traced to bad lines running through the data were responsible for a large number of fairly easily-removed bad data. A large number of bad crossovers occurring at places where large gradients in depth were known (such as the continental shelf break and the edges of banks or channels) were attributed to possible navigational errors, loss of bottom by echo-sounder or depth-digitizer, or watchkeeper error. There were also a relatively small number of randomly- distributed bad crossovers.

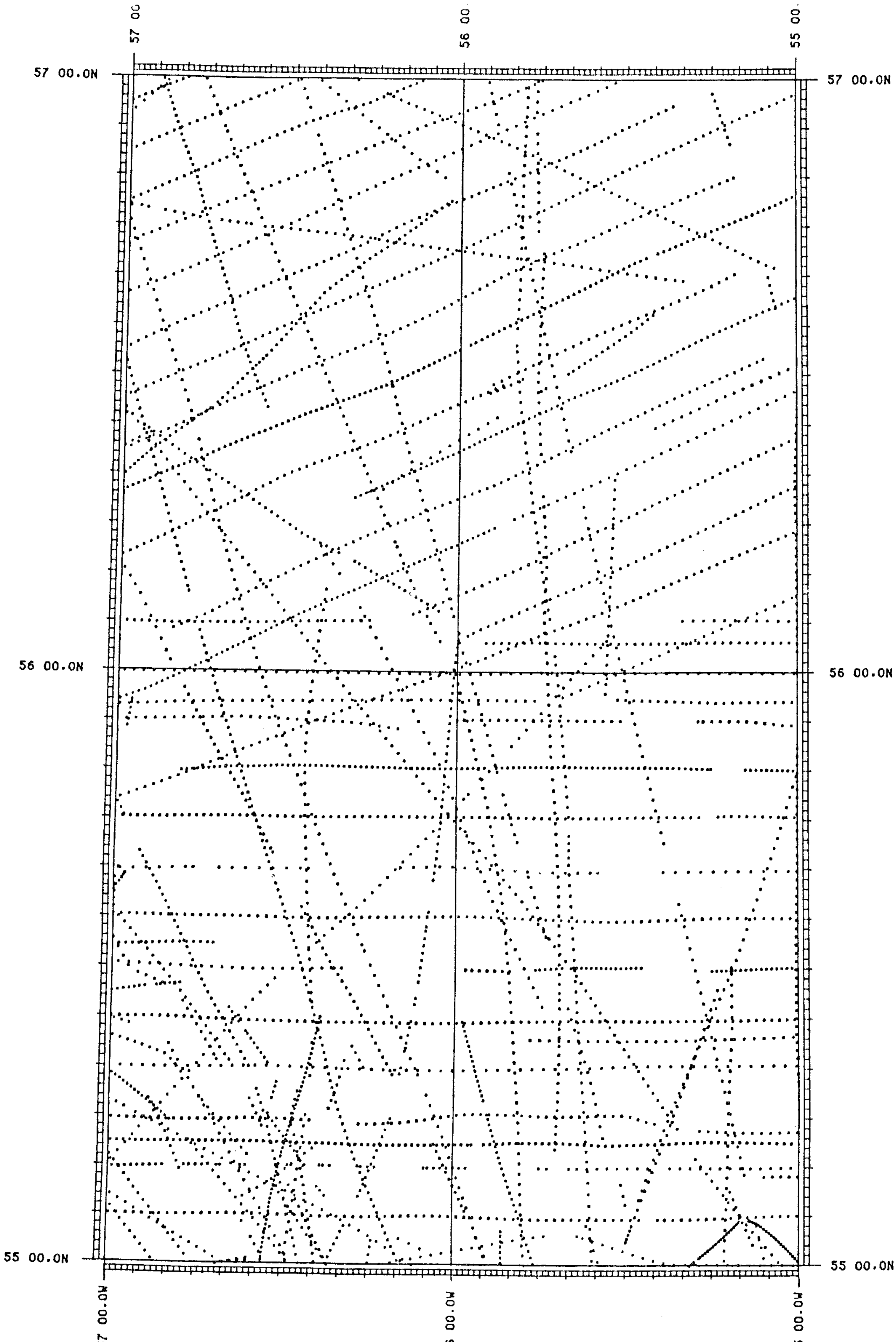

Fig. 10 Northern Test Area to Obtain Error Estimates

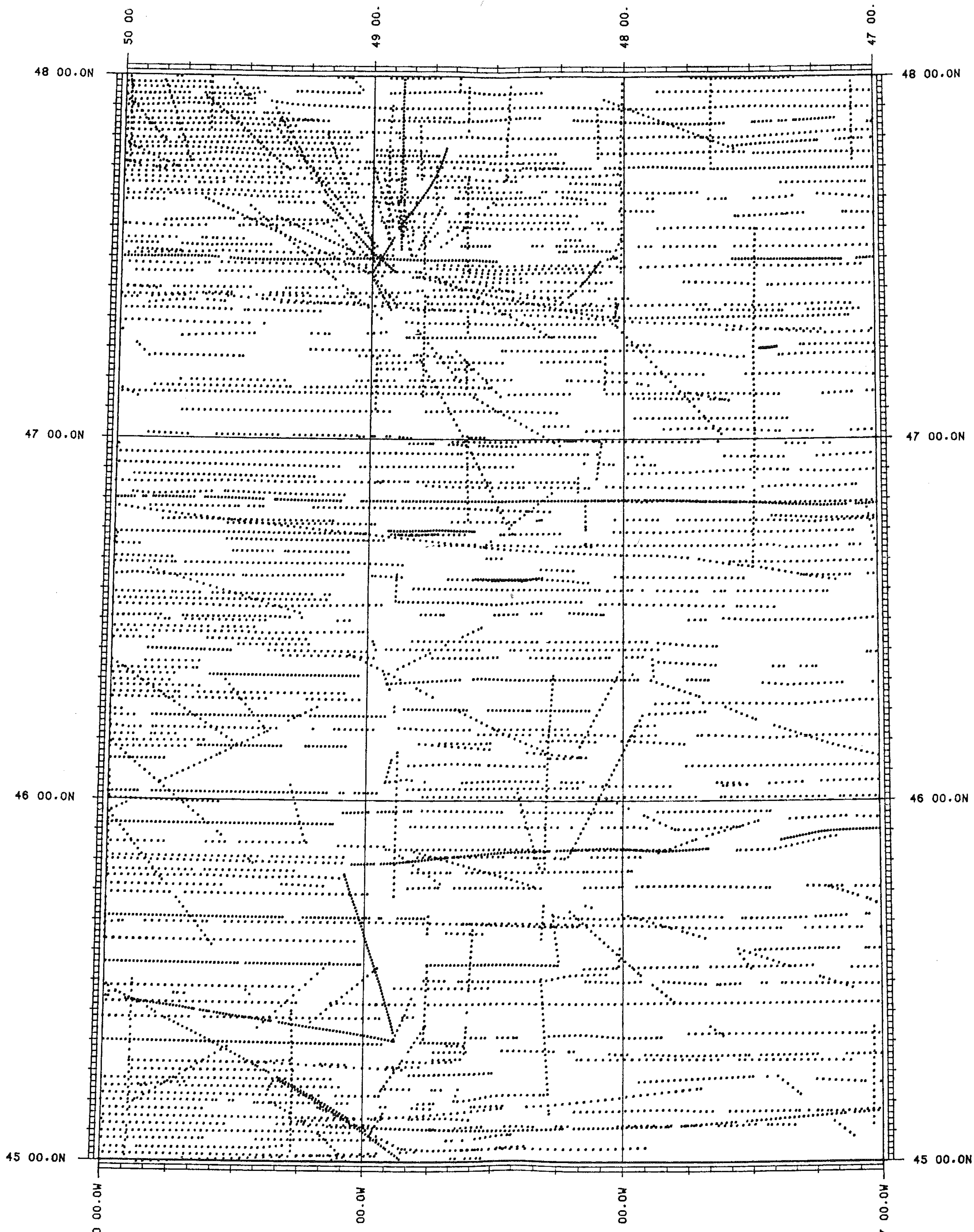

Fig. 11 Southern Test Area to Obtain Error Estimates

Two hundred and eighty-five internal crossovers greater than 20 m were identified out of a total of about 8550; and 1716 pseudocrossovers with discrepancies greater than 20 m were located for all cruises together. The majority of the bad pseudocrossovers could be attributed clearly to real bathymetric gradients between values. Removal of suspicious data was carried out ruthlessly to ensure that data surviving the purge were good.

Bad depth data originated in general on type B and C cruises. For this reason, deletion of large sections of suspect depth data has not caused serious deterioration in data coverage. A second period of evaluation of depth data by computer comparison of AGC bathymetry and currently available digital data files from CHS for some cruises (generally multiparameter cruises since 1976) indicates that most data purged from Type A cruises was in fact correct but had appeared erroneous because of large bathymetric gradients.

5.6.4.5 Data Reduction Between Crossovers

Once the adjustment of the crossover gravity values is completed, the gravity values between crossover points must be linearly adjusted to the crossover values. For any observation r along track between crossovers i and j, the adjusted value at r is given by

$$g_r^a = \left[\frac{(g_i^a - g_i^o) - (g_j^a - g_j^o)}{\Delta T_{ij}} \cdot \Delta T_{ir} \right] + g_r^o$$

where the other symbols are as defined in 5.6.3 and the superscripts a and o denote adjusted and observed values respectively. It should be noted that all data between successive crossovers is lost if the observation equation representing the measured difference between these two crossovers is rejected in the least squares adjustment.

5.7 DATA COMPRESSION

The 1-minute data were compressed into 5-minute values by averaging five 1-minute observed and adjusted gravity values, Eotvos correction and depths respectively. These averaged values were assigned the time and position of the third data point in each set of five. In the case where there were less than five data points spaced at 1-minute intervals, these points were averaged and assigned to the time and position of the data point closest to the centre of the interval. The 5-minute data was not affected by this data compression.

It should be noted that 5-minute samples have a geographic spacing of about 1.5 km given nominal ship speed of 10 knots. This spacing is well within the specification for the national gravity mapping program. In addition, except for very recent surveys using linear meters or areas of very steep gravity gradients, it can be shown that there is no additional information in the 1-minute data samples.

The effect of data compression on the volume of data is shown in Table V (Section 5.5.3).

6.0 SUMMARY

1. The result of this project is a homogeneous gravity data base for the east coast of Canada which has an overall accuracy of 2.5 mGals. The internal consistency varies from ± 1 to ± 5 mGals. A colour plot of the resulting free-air anomalies is shown in Figure 12.

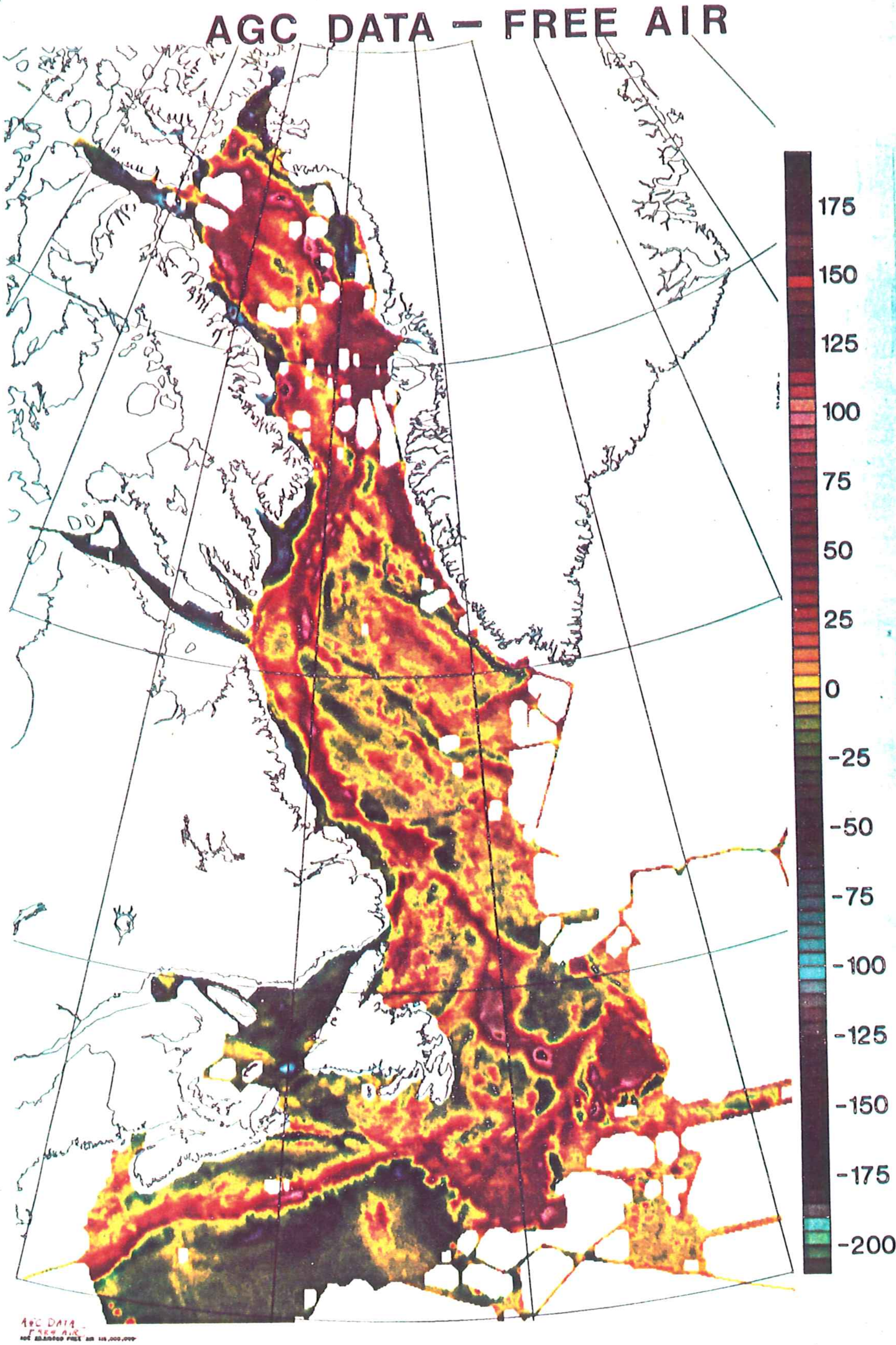

Fig. 12 Free Air Anomalies

2. Data from this project are now available to users through the National Gravity Data Base at EPB. Users at EPB, AGC and the Geodetic Survey of Canada have on-line access.

3. East coast gravity data can now be assessed in terms of coverage and accuracy with a view to developing a program for the acquisition of data to extend coverage or replace lower quality data.

4. The development of accurate (±5 m) digital bathymetric data bases is desirable to improve the accuracy of Bouguer anomalies computed from the present data base and essential to support future acquisition of airborne gravity data over oceanic areas.

5. This project has established effective working relationships between AGC and EPB which will be beneficial to future activities related to the acquisition, processing, interpretation, and dissemination of potential field data.

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APPENDIX A

PROGRAM EDPLOT

INTRODUCTION

The program EDPLOT is an interactive program for editing marine gravity data using the Tektronics graphics terminal and the Data Plotting DPICT/VGL software package. This program was developed for editing the AGC data and requires an indexed sequential file keyed by integer days, hours, minutes and seconds in one four byte integer.

I/O DESCRIPTION

Input File

user-specified - contains the indexed sequential file which is a binary file with the indexed keyword in the sixth to ninth bytes of each record. The keyword contains the time in julian days, hours, minutes and seconds from the beginning of the year in which the project was done.

Output File

output - contains a record of the editing session. It contains the date and time of the session as well as the project number and a list of deleted records.

INTERACTIVE PLOT

The plot fields are observed Gravity, Free Air, Eotvos, Depth and the

A.G.C. observed gravity quality factor against time in days. These fields are plotted on the Tektronics terminal in one hour to twenty-four hour sections (Figure 5, Section 5.5.2.2).

USER INPUT

The program will first request the name of the indexed sequential file to be used, and then display the project number of the field being edited and the first date and time of the data. The default values for the six scale limits for the plot area will then be displayed. These are free air minimum and maximum, observed gravity minimum and maximum and the time interval. To change these enter the number preceding the value you wish to change, the program will then prompt you to enter the new value, or type in an 8 and you can reset all the values. By entering a 9 the program will then plot the first section of data and ask you to choose one of the following options:

D - delete a point

I - delete an interval

S - rescale the plot area

P - place the plot at a nonsequential position

C - cancellation of editing of plot page presently in view (once the plot page has been changed no cancellations can occur)

R - review present page (redraw the present page)

N - next page (reposition of plot sequentially)

E - exit (stop program and close files)

To choose an option, enter the one character code and a carriage return.

DETAILED OPTION DESCRIPTIONS

D -- For option D (deletion of data point) the user moves the cross hairs using the joy stick, the two control knobs to the right of the key-board, or the cursor keys. The user places the cross hairs over the point to be deleted and types D. The program will stay in delete point mode until any other character other than D is entered.

I -- For option I (deletion of data interval) the user first places the vertical cross hair to the left of the interval to be deleted and types D, then places the vertical cross hair to the right side of the interval to be deleted and enters another D. The user may delete as many intervals as desired before returning to the option menu. To exit from this mode enter any character other than a D.

NOTES: (1) The position of the horizontal cross hair is irrelevant.

(2) For options D and I the points that are to be deleted will remain on the plot until the plot page has been redrawn. The plot page is redrawn when you exit the delete modes.

S -- For option S the present scale minima and maxima will be printed on the screen. The user will be asked to enter the new scale minima and maxima.

P -- For option P the present position of the plot file will be printed on the screen and the user asked to enter the new starting position for the plot page desired. This position is represented by the time of the readings and is given as day, hour and minute. e.g. 3021842 is day 302 at 18:42.

C -- Option C cancels all edits made on the presently displayed screen. To restore data deleted earlier in the session, the session must be restarted.

R -- Option R causes the screen (edited data) to be replotted.

N -- Option N is used to request the next plot page. The first portion of the new plot area will be the last portion of the previous plot area.

E -- Option E causes the program to terminate. The edited data file will be saved and a time-stamped listing of deleted points generated.

PROCEDURE FOR USE OF EDPLOT

1) Create an indexed sequential file using the program INDXSEQ. This program is located in the directory EPBVOL:[ADJUST.SUB.PROGS], access to this directory can be accomplished by entering @PROGS.

2) Run the program EDPLOT by entering RUN EDPLOT while in either of the directories EPBVOL:[ADJUST.SUB], or EPBVOL:[ADJUST.SUBPROGS], access to these directories can be accomplished by entering @ASSOB or @PROGS respectively.