AN IMPROVED GRAVITY BASE-STATION NETWORK OVER THE ANTARCTIC PENINSULA

By R. G. B. RENNER

ABSTRACT. A network of 25 new gravity base station was established in 1975–76 during a joint USARP–BAS doppler satellite programme. Station positions and gravity values are given.

SYSTEMATIC gravity surveys on the Antarctic Peninsula were started by the British Antarctic Survey in 1959 when measurements were taken along the coasts of Graham Land and the South Shetland Islands (Griffiths and others, 1964). Gravity base stations were established and linked to the international network via the Falkland Islands and South America. This link was subsequently strengthened using a LaCoste and Romberg geodetic gravimeter (Kennett, 1965). Several hundred gravity stations have since been measured by British Antarctic Survey geophysicists over the Antarctic Peninsula and Alexander Island. However, as the survey extended to more remote areas, errors of measurement accumulated, contributory factors including inadequate topographic control and logistic constraints which prevented frequent base-station re-occupations. A doppler satellite project over the Antarctic Peninsula in 1975–76 presented an opportunity to enlarge and strengthen the gravity base-station network.

Doppler satellite positioning uses known satellite orbits to determine the coordinates of ground stations relative to a geocentric framework. This framework can then be related to a more conventional geodetic reference datum. Although the doppler system is basically concerned with the determination of individual station coordinates, a systematic station distribution can provide the basis for regional mapping control. As a survey technique, its potential value to Antarctic geodesy is considerable and therefore a joint United States Antarctic Research Program–British Antarctic Survey (USARP–BAS) doppler satellite positioning programme was commenced during the austral summer of 1975–76. The aims of this project were two-fold:

i. To reduce to a common datum independent topographic traverses previously carried out over the Antarctic Peninsula–Ellsworth Mountains area by surveyors of both the United States Geological Survey (USGS) and the British Antarctic Survey.

ii. To provide adequate control points for existing and future topographic maps over areas of mutual interest, the maps incorporating data from both LANDSAT imagery and tricamera air photography.

The USGS provided two experienced field personnel, J. W. Schoonmaker, Jr. and K. W. Gatson, both of whom were familiar with doppler satellite techniques and conventional topographic surveys, a Geoceiver doppler survey system for the tracking, receiving and recording of satellite data and facilities in the USA for subsequent data processing and analysis. The British Antarctic Survey was responsible for ship and air transport to and within the operational area, for logistic support, base facilities and additional field assistants where required.

Because of the anticipated accuracy in coordinates, the frequency of return visits necessary to refuel the aircraft and the favourable distribution of proposed doppler localities, it was considered ideal to use the project simultaneously to improve the gravity base-station network. A geophysicist was therefore attached to the survey team.

FIELD OPERATIONS

In January 1976 the base station at Adelaide Island (lat. 67°46′S, long. 68°55′W) was the main field operations centre for the British Antarctic Survey. For the purpose of the

doppler survey, it was ideally situated, for it was from here that the Survey's two De Havilland Twin Otter aircraft operated, permitting areas as widely separated as northern Graham Land and the Ellsworth Mountains to be visited. Most of the stations were established using aircraft support but for those localities on the west coast of Graham Land ship-to-shore landing parties were necessary. RRS *Bransfield* and the United States National Science Foundation RV *Hero* participated in these landings while a helicopter from the Royal Navy ice-patrol vessel HMS *Endurance* was used to ferry the surveyors to Stonington Island.

Those sites dependent upon aircraft support required in addition to air crew a minimum three-man field party consisting of two USGS surveyors and a BAS geophysicist. Providing both equipment and weather were satisfactory, the time spent at each locality was proportional to the station's priority. For primary stations, i.e. those at established traverse points, a minimum of 14 satellite passes was required; these normally took about 24 h. At lower-order (LANDSAT image control) stations the necessary three passes took around 6 h. Ideally, the pre-selected points were on rock (Fig. 1) and photo-identifiable on US Navy tricamera

Fig. 1. Doppler satellite station 200860, Charcot Island. The antenna is on-centre with the receiving apparatus down-slope towards the aircraft.

air photographs. It was not always feasible to erect the receiving antenna on-centre and in such instances the antenna was offset (Fig. 2) and its position relative to the selected point resected using a Wild T-2 theodolite and a Hewlett-Packard HP 3805A infra-red distance measuring instrument. Whenever feasible, gravity measurements were taken at the pre-selected locality but on several occasions the terrain was considered too severe to risk the gravimeter being back-packed to the exact site. Secondary on-rock stations were therefore established, marked by a small cairn, and surveyed relative to the doppler satellite station.

On completion of the required number of satellite passes, the party was transferred to the next locality, often via Adelaide Island or Fossil Bluff, thus permitting frequent re-occupation of these previously established base stations. All of the doppler satellite stations were left monumented, usually by a 6.5 cm circular USGS brass tablet (Fig. 3) surmounted by a rock cairn.

TABLE I. GRAVITY BASE STATIONS OCCUPIED DURING THE 1975–76 USGS–BAS DOPPLER SATELLITE PROGRAMME

Locality	*USGS station reference*	*Gravity station description*	*Air-photograph identification number*	*International spheroid*			*WGS 72 spheroid*			*Surveyed height above sea-level* (m)	*Absolute value of gravity* (m s^{-2})
				Lat. °*S*	*Long.* °*W*	*Height relative to spheroid* (m)	*Lat.* °*S*	*Long.* °*W*	*Height relative to spheroid* (m)		
Cobalescou Island	201040*	Summit of central and highest of three rises forming the island. Marked by cairn over metal pin in rock signifying site of original trigonometrical station	26FID19 103	64°10′46.42″	61°39′01.96″	—103	64°10′44.10″	61°39′01.96″	76	24.3 (BAS)	9.822887
Seymour Island	200972	Argentine Marambio station. At VOR building 200 m north-east of main base complex. Station occupied at plaque set in porch entrance. Plaque reads "Servicio de Hidrografia Naval Universidade Buenos Aires No. 92"	TMA 1352 F31 216	64°14′08.21″	56°37′12.77″	54	64°14′05.89″	56°37′12.77″	233	196 (Instituto Antártico Argentino)	9.822334
Anvers Island	201255	United States Palmer station. At bronze disc stamped "International Triangulation Station 050 1969" surrounded by steel ring set in concrete pier standing about 10 cm above surrounding rock mass	TMA 2357 F32 005	64°46′29.05″	64°03′07.23″	—144	64°46′26.77″	64°03′07.23″	34	14.9 (USGS)	9.823031
Wiencke Island	201030*	BAS refuge hut at Damoy Point. Station on rock 13 m south of centre of north side of hut, 2.4 m west of and approximately 0.5 m lower than highest point of outcrop. Marked by USGS tablet stamped "Alex B 1975–76" cemented in rock	26FID15 064	64°49′06.42″	63°30′16.38″	—153	64°49′04.14″	63°30′16.38″	25	10 (BAS—aneroid barometer traverse to sea-level)	9.823005
Larsen Nunatak	200890	Argentine Matienzo station. On flat 3 m square cement flagpole foundation approximately 9 m from and midway between living quarters and generator garage	TMA 2143 F31 323	64°58′35.50″	60°04′15.94″	—130	64°58′33.23″	60°04′15.94″	48	25 (Instituto Antártico Argentino)	9.823290
Galindez Island	201020	BAS Faraday station. At astrofix FF(204) 2 m from south-east corner of main base complex. Marked by bronze disc cemented in bedrock and stamped "FIDS Hydro Survey 1958"	26FID31 080	65°14′46.96″	64°15′23.69″	—150	65°14′44.71″	64°15′23.69″	28	7.3 (BAS)	9.823396
Jason Peninsula	200981	On small nunatak identifiable on FID 1 : 200 000 sheet 66 60. Marked by USGS tablet stamped "Bran 1975–76" loosely placed under 1.5 m rock cairn. Beneath cairn chip out of rock signifying exact locality	TMA 2152 F31 316	66°14′06.31″	61°32′26.25″	—8	66°14′04.13″	61°32′26.25″	185	Not known	9.823901
Rothera Point	200960	On small rock outcrop approximately 90 m north-west of BAS Rothera station. Marked by USGS tablet "Rothera Grav. 1975–76" set in 0.4 m concrete square	26FID66 159	67°34′09.92″	68°07′30.94″	—151	67°34′07.83″	68°07′30.94″	23	12.1 (BAS)	9.824817
Adelaide Island	200950	At site of original astrofix at the BAS Adelaide station (vacated in 1976–77). Locality on summit of small rock outcrop approximately 60 m north-west of main station complex. As original site marker damaged, new one installed labelled "Adelaide Astrofix" and cemented into top of 0.19 m by 0.39 m concrete post	TMA 2163 F33 149	67°45′39.54″	68°45′57.29″	—136	67°45′37.46″	68°54′57.29″	38	25.4 (BAS)	9.825136
Adelaide Island	200951	At bench mark on south side of southernmost hut. It is marked by a brass plate	TMA 2163 F33 149	67°45′43.99″	68°45′56.30″	—157	67°45′41.91″	68°54′56.30″	17	4.3 (BAS)	9.825190 (previously established by Griffiths and others, 1964; Kennett, 1965)
Three Slice Nunatak	200991*	By survey cairn on rock ridge at south-west end of nunatak. Marked by brass cartridge case cemented in bedrock 1 m below ridge crest	TMA 1818 F33 014	68°02′12.10″	64°59′13.57″	312	68°02′10.04″	64°59′13.57″	486	254.6 (BAS)	9.824540
Stonington Island	201000	On concrete survey pillar 40 m north-west of BAS station complex (vacated in 1974–75)	HMS *Endurance* RN/4/73 Jan. 1973 No. 039	68°11′09.61″	66°59′45.66″	—145	68°11′07.57″	66°59′45.66″	29	15.7 (BAS)	9.825094 (previously established by Griffiths and others, 1964; Kennett, 1965)
Alexander Island	200871*	On prominent rock shoulder on the north ridge of the most southerly of three small rock peaks, approximately 2 km north of a north-west ridge of Havre Mountains. Station marked by a cairn over a cartridge case. Access from west via windscoop and snow ridge	TMA 2135 F31 303	69°07′36.41″	71°36′39.55″	640	69°07′34.43″	71°36′39.55″	833	813.6 (BAS)	9.823888
Charcot Island	200860	Highest point of small nunatak on north coast of island. Marked by USGS tablet stamped "Jon 1975–76" set loosely in rock. Cairn 0.6 m high built over tablet and 2.4 m tent pole extends from cairn	TMA 2136 F32 340	69°45′00.59″	75°15′10.92″	—49	69°44′58.66″	75°15′10.92″	125	Not known	9.826031
Alexander Island	200830*	On small moraine 230 m bearing 099° true from BAS Fossil Bluff station. Marked by cartridge case set in 5 gallon cemented drum level with ground surface	TMA 1845 F31 202	71°19′26.99″	68°16′48.92″	—101	71°19′25.19″	68°16′48.92″	70	62.8 (BAS)	9.826624
Alexander Island	200930	On concrete guy block on south-east side of BAS Fossil Bluff station. Marked by brass plate	TMA 1845 F31 202	71°19′25.57″	68°17′11.24″	—96	71°19′23.78″	68°17′11.24″	75	67.0 (BAS)	9.826641 (previously established by Griffiths and others, 1964; Kennett, 1965)
Gluck Peak	200850	At highest point of nunatak marked by USGS tablet stamped "Curleen 1975-76" cemented into very friable volcanic rock	TMA 2133 F33 206	71°42′34.36″	72°41′24.87″	188	71°42′32.60″	72°41′24.87″	358	356.8 (BAS)	9.826354
Lassiter Coast	201052	Summit of minor nunatak approximately 500 m west of USGS survey station No. 201051. Cairn 0.8 m high. No other marker	TMA 1745 F31 022	73°06′42.62″	62°49′52.18″	1 339	73°06′40.97″	62°49′52.18″	1 508	1 591.0 (USGS)	9.824298
Eklund Islands	200842	At foot of north-west rock ridge, of largest island. Ridge forms obvious route to summit. Marked by 1 m high cairn. No other marker	TMA 2075 F32 268	73°13′51.51″	71°57′27.14″	87	73°13′49.88″	71°57′27.14″	256	Not known	9.827640
Rydberg Peninsula	200920*	At summit of small rock outcrop on north coast lying 20 km north-east of Mount Combs and 10 km south-west of Sims Island. Marked by USGS tablet stamped "Boshier 1975–76" secured in granite erratic	TMA 1937 F33 105	73°19′21.03″	78°53′03.96″	236	73°19′19.40″	78°53′03.96″	405	Not known	9.827713
Gomez Nunatak	200820	Marked by USGS tablet stamped "Nancy S 1975–76" at summit of nunatak. Cairn erected over tablet. Gomez Nunatak has a spectacular windscoop associated with its eastern side	TMA 1743 F32 190	73°56′08.13″	68°37′43.32″	1 374	73°56′06.55″	68°37′43.32″	1 543	1 548.0 (USGS)	9.824530
Smith Peninsula	200020*	Towards east end of Hutton Mountains, approximately 12 km north of Mount Light and 30 km east of Mount McElroy. Marked by USGS tablet loosely placed in cleaved sediments and capped by a 1 m cairn	TMA 1875 F31 102	74°10′01.85″	61°54′59.87″	—114	74°10′00.30″	61°54′59.87″	55	Not known	9.826324
Lassiter Coast	201060	Located beneath 0.6 m cairn towards east end of obvious spur trending west from USGS survey station No. 201061. Latter marked by USGS tablet stamped "Adriana 1969–70"	TMA 1737 F33 130	74°27′15.32″	64°33′48.15″	1 218	74°27′13.79″	64°33′48.15″	1 386	1 468.0 (USGS)	9.825218
Dodson Peninsula	200811*	On prominent isolated north-east–south-west-trending nunatak with large exposed scree slope to north. Station located at highest point identified by a 1 m rock cairn and a 2.5 m tent pole. Beneath cairn a USGS tablet stamped "Gray 1975–76"	—	75°27′54.11″	64°58′40.93″	902	75°27′52.67″	64°58′40.93″	1 069	Not known	9.826919
Orville Coast	201071	On small exposure of cleaved rocks at summit of rounded predominantly snow-covered nunatak. Marked by USGS tablet stamped "Ingeburg 1969–70". Cairn with survey signal erected	TMA 1736 F33 075	75°34′11.64″	66°49′56.44″	1 161	75°34′10.21″	66°49′56.44″	1 328	1 405.6 (USGS)	9.825991
Quilty Nunataks	200802	On unnamed nunatak by Mount Horne. Gravity station established at foot of ridge leading to summit and marked by a small rock cairn. (Doppler site at summit marked by standard USGS tablet.)	TMA 1857 F31 178	75°43′48.91″	71°43′00.85″	663	75°43′47.49″	71°43′00.85″	830	Not known	9.827312
USGS Siple Station	200790	Adjacent to 10 cm square wooden post located approximately 6 m north of north-east corner of main (1970–77) Siple Station complex. Driven into top of post, then 1.3 m (February 1976) above snow surface is USGS tablet stamped "Janie 1974–75"	—	75°56′25.06″	84°14′55.44″	891	75°56′23.67″	84°14′55.44″	1 058	1 280† (USGS)	9.826271
Sentinel Range, Ellsworth Mountains	200910	On bedrock at northern end of small nunatak at south side of snow-covered valley. Lies 1.5 m north of highest point and marked by USGS tablet stamped "A2E 1963–64"	TMA 566 F33 223	77°31′04.76″	86°21′37.01″	1 372	77°31′03.51″	86°21′37.01″	1 538	1 587.0 (USGS)	9.826195
Heritage Range, Ellsworth Mountains	200901	Highest point of top of westernmost of Wilson Nunataks. Monumented and surmounted by a cairn and signal marker	TMA 1034 F33 168	80°02′01.27″	80°53′47.47″	625	80°02′00.26″	80°53′47.47″	789	837.20 (USGS)	9.828800

* Solution based on less than three passes.

† The author suggests that from an extrapolation of known ellipsoid-geoid separations over the Antarctic Peninsula an elevation approaching 1 100 m would be a more realistic estimate.

face page 146

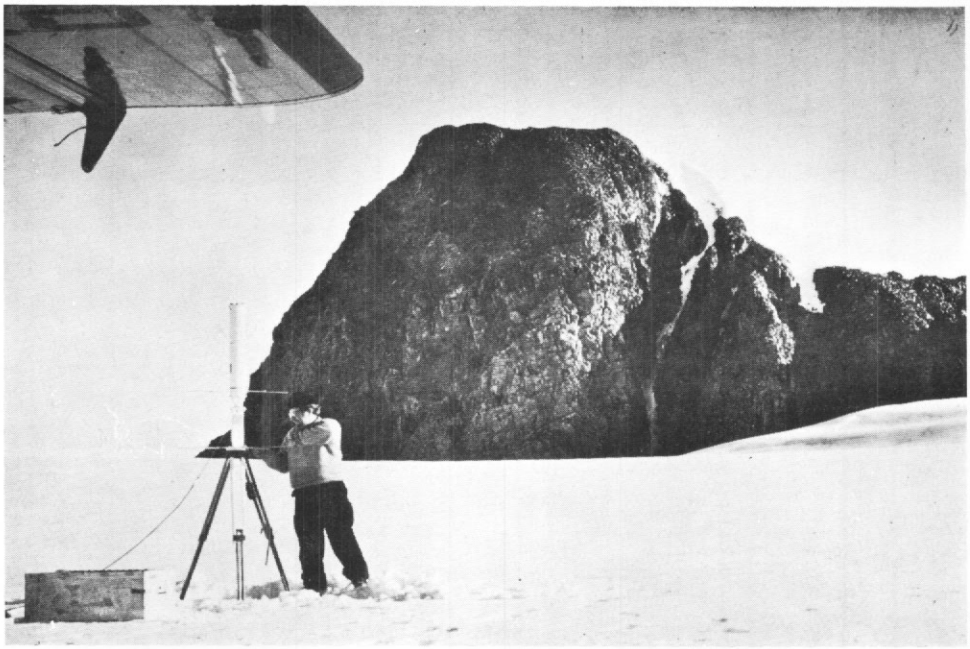

Fig. 2. Doppler satellite station 200842, Eklund Islands, with the antenna and recording apparatus offset. The gravity station is situated on the continuation of the rock ridge, off the picture to the right.

Fig. 3. Standard USGS Antarctic tablet (diameter 6.5 cm) secured in bedrock at an occupied doppler survey station.

TABLE II. GRAVITY VALUES AT 1975–76 USGS–BAS DOPPLER SATELLITE STATIONS

Locality	*Absolute value of gravity* ($m\ s^{-2}$)	*Theoretical value of gravity* ($m\ s^{-2}$) (*International Gravity Formula 1930*)	*Absolute gravity anomaly* (1 mgal = 10 g u)	*Elevation correction* (mgal)	*Bouguer anomaly* (mgal)
Cobalescou Island	9.822887	9.822365	+52.2	4.8	+57.0
Seymour Island	9.822334	9.822405	−7.1	38.5	+31.4
Anvers Island	9.823031	9.822784	+24.7	2.9	+27.6
Wiencke Island	9.823005	9.822815	+19.0	2.0	+21.0
Larsen Nunatak	9.823290	9.822925	+36.5	4.9	+41.4
Galindez Island	9.823396	9.823112	+28.4	1.4	+29.8
Jason Peninsula	9.823901	9.823782	+11.9	–	–
Rothera Point	9.824817	9.824654	+16.3	2.4	+18.7
Adelaide Island	9.825136	9.824776	+36.0	5.0	+41.0
Adelaide Island	9.825190	9.824777	+41.3	0.8	+42.1
Three Slice Nunatak	9.824540	9.824950	−41.0	50.1	+9.1
Stonington Island	9.825094	9.825044	+5.0	3.1	+8.1
Alexander Island	9.823888	9.825621	−173.3	160.1	−13.2
Charcot Island	9.836031	9.825993	+3.8	–	–
Alexander Island	9.826624	9.826888	−26.4	12.4	−14.0
Alexander Island	9.826641	9.826888	−24.7	13.2	−11.5
Gluck Peak	9.826354	9.827098	−74.4	70.2	−4.2
Lassiter Coast	9.824298	9.827831	−353.3	313.1	−40.2
Eklund Islands	9.827640	9.827890	−25.0	–	–
Rydberg Peninsula	9.827713	9.827935	−22.2	–	–
Gomez Nunatak	9.824530	9.828236	−370.6	304.6	−66.0
Smith Peninsula	9.826324	9.828347	−202.3	–	–
Lassiter Coast	9.825218	9.828483	−326.5	288.9	−37.6
Dodson Peninsula	9.826919	9.828942	−202.3	–	–
Orville Coast	9.825991	9.828988	−299.7	276.6	−23.1
Quilty Nunataks	9.827312	9.829058	−174.6	– (1 280 m a.s.l.) 377.1*	– +89.4
USGS Siple Station	9.826271	9.829148	−287.7	(1 100 m a.s.l.) 341.0*	+53.3
Sentinel Range, Ellsworth Mountains	9.826195	9.829786	−359.1	312.3	−46.8
Heritage Range, Ellsworth Mountains	9.828800	9.830657	−185.7	164.8	−20.9

* Assuming an ice thickness of 1 690 m as measured at Siple Station (personal communication from R. H. N. Steed).

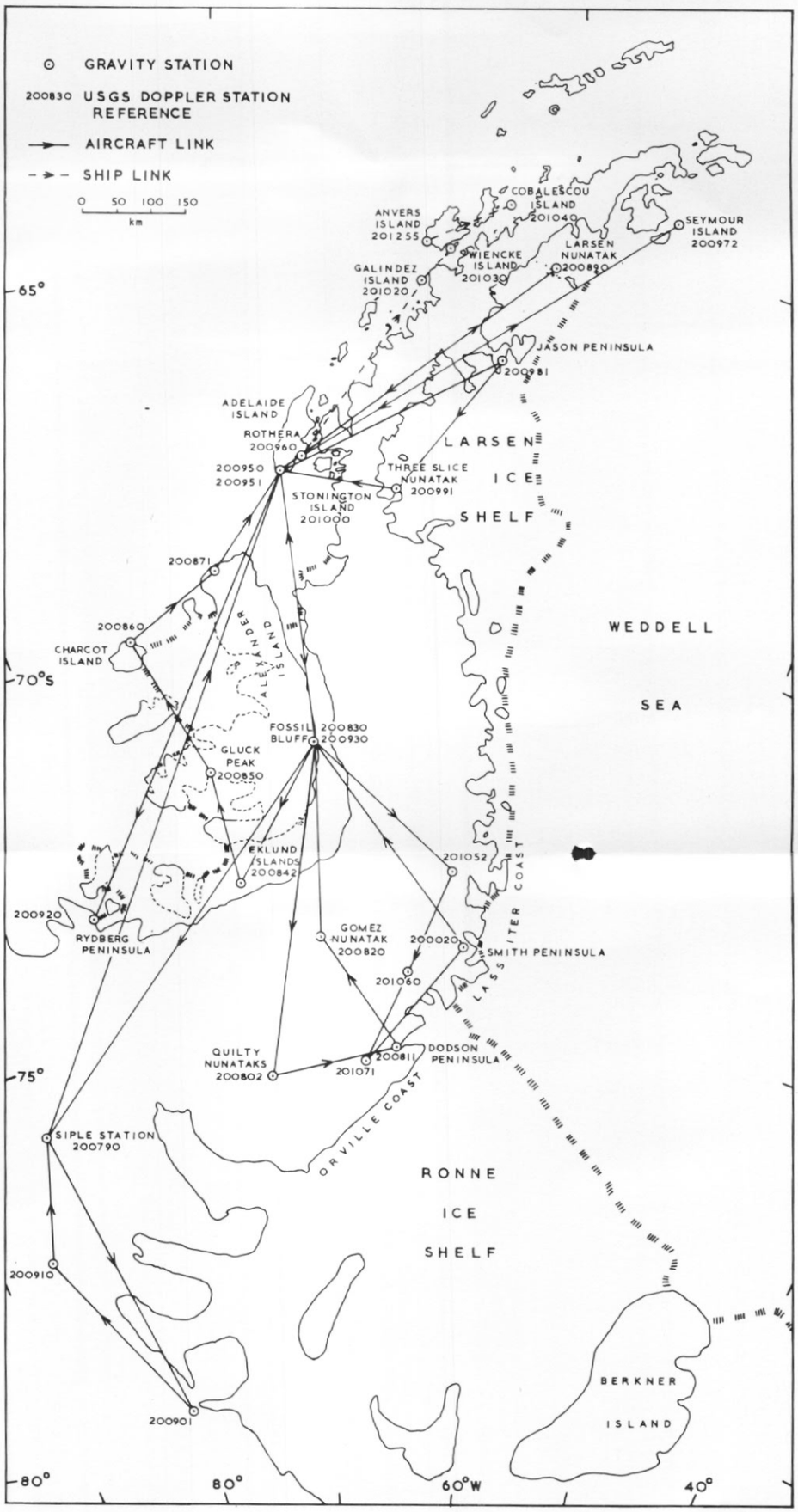

Fig. 4. Gravity station network established during the 1975–76 doppler satellite programme.

face page 148

A Worden Master gravity meter (No. 556) with geodetic dial was used throughout, with its thermostat adjusted to 47° F (8.3° C), meter temperature being maintained by an external 6 V power supply. Maker's calibration constants, determined in August 1973, were used in the data reduction.

The survey ran from 13 January to 26 March 1976, during which time 31 doppler stations were occupied at 28 widely distributed localities (Fig. 4).

Results

Doppler satellite coordinates for those localities where gravity observations were made are given in Table I relative to both the International spheroid (1924) and the World Geodetic System 72 (WGS 72) spheroid. Position certainty is largely a function of the number of acceptable satellite passes used in the solution of station coordinates and this number was dependent on the time spent tracking at each locality. At Adelaide Island and Stonington Island, a maximum of 32 acceptable passes was achieved, resulting in a position certainty (in three dimensions) of 10 m. The majority of stations are calculated to have an accuracy of 10–20 m. For those stations (Table I) marked with an asterisk, less than three passes were considered, resulting in latitude and longitude coordinates with a solution certainty of 50 m, although larger errors can be expected in their elevations relative to spheroid datum.

Absolute values of gravity were calculated relative to the base stations on Adelaide Island and Fossil Bluff. Gravimeter drift was recorded wherever possible and corrections applied accordingly. Overall drift for the period of the survey averaged 0.09 mgal h^{-1}, this including both static drift and that resulting from transport by aircraft, ship, skidoo and back-packing. Over the longest loop of 86 h from Fossil Bluff to 201052 to 201060 to 201071 to 200020 and back to Fossil Bluff, the drift averaged 0.07 mgal h^{-1}. The average duration of the remaining loops was approximately 20 h. Insufficient control of known geoid to spheroid separations over the Antarctic Peninsula prevented the determination of heights above sea-level from doppler satellite observations. Bouguer anomalies (Table II) have therefore been calculated using known surface elevations, although the heighting accuracy of some of the more remote inland stations is questionable. A density value of 2.67 Mg m^{-3} was used in the reduction and theoretical values of gravity were obtained from the 1930 International Gravity Formula.

Acknowledgements

The author expresses his gratitude to the USGS, and in particular to the late W. R. MacDonald for the motivation and co-operation shown throughout this joint project. Thanks are also given to J. W. Schoonmaker and K. W. Gatson for their companionship during the field survey, to J. G. Kershaw for so expertly and tirelessly piloting the aircraft to and away from many demanding localities, and to S. Wormald and personnel at Adelaide Island and Fossil Bluff for keeping the full schedule operational. The assistance provided to the gravity programme by L. J. S. Sturgeon is gratefully acknowledged as also is the unselfish help so patiently given by Miss E. A. Fleming during the data collation. The author is indebted to Miss L. M. Windsor, Directorate of Overseas Surveys, for providing computed positions and clarifying some of the technicalities of doppler satellite survey.

MS received 17 February 1978

REFERENCES

GRIFFITHS, D. H., RIDDIHOUGH, R. P., CAMERON, H. A. D. *and* P. KENNETT. 1964. Geophysical investigation of the Scotia arc. *British Antarctic Survey Scientific Reports*, No. 46, 43 pp.

KENNETT, P. 1965. Revision of gravity links between South America and the Antarctic. *British Antarctic Survey Bulletin*, No. 7, 25–28.