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Australian gravity base-station network: 1980 survey

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In 1980, a gravity base-station network of 67 airports throughout Australia was surveyed with seven LaCoste & Romberg gravity meters, and tied to sites of six 1979 absolute gravity measurements. Two computer adjustments of the gravity meter observations were made, firstly with two and secondly with six absolute measurements to control scale and datum. Comparison of the adjustments shows that the absolute measurements are consistent with one another to within experimental error. The gravity values calculated in the computer adjustment using the weighted results of the six absolute sites have been adopted as the best values for the Australian National Base-station Network (Isogal 84 values). The values have a precision of 0.1 $\mu m.s^{-2}$, and an accuracy of about 0.3 $\mu m.s^{-2}$. A polynomial is derived for revising earlier gravity values to be consistent with the new base-station values.

Introduction

The Australian gravity base-station network provides the reference stations defining scale and datum for reduction of gravity meter readings made during all gravity surveys on the Australian landmass and surrounding ocean. The scale defined by the network is used to change differences in gravity meter readings to differences in acceleration; the datum is used to convert differences in acceleration to actual acceleration at each observation point.

In any measurement system, it is desirable to have standards that are of higher accuracy than required for routine measurement. An increase in accuracy of gravity standards is required because of the following advances in gravity and geoidal measurements in the last 20 years:

1) routine use of LaCoste and Romberg gravity meters in government and private company field surveys, requiring a more accurate base-station network for adequate datum control for survey integration;

2) use of groups of gravity meters in crustal movement surveys for earthquake prediction, requiring accurate scale control;

3) control of datum and scale of land gravity so that small-amplitude long-wavelength errors do not affect geoids calculated from land gravity observations; and

4) in metrology the accuracy of gravity values is a limiting factor in the standards of some quantities, such as the volt.

The base-station network used until the present was based on gravity meter observations made in 1964–67. These observations and the derived gravity values had known errors of 2 $\mu m.s^{-2}$, which was too high for a national base-station network controlling measurements of precision 0.2 $\mu m.s^{-2}$. In 1979, Soviet apparatus was used to measure absolute gravity at six sites within or near Australia (Arnautov & others, 1979) to an accuracy of 0.15 $\mu m.s^{-2}$, and in 1980, precise observations were made at 67 airports throughout Australia using seven LaCoste & Romberg gravity meters.

This report gives an adjustment of the 1979 absolute values and the 1980 regional network to give improved values of gravity at the 67 airports. These are used to obtain better values for the previous, more dense, network of 200 stations. The base-station corrections can be generalised by a polynomial and applied as a small correction to all gravity values within Australia.

Absolute measurements 1979

Absolute measurements of gravitational acceleration were carried out during April and May 1979 at five sites in Australia and one site at Port Moresby, Papua New Guinea (Fig. 1)(Arnautov & others, 1979). The measurements have a reported precision of about 0.06 $\mu m.s^{-2}$, and an accuracy of about 0.15 $\mu m.s^{-2}$. The reported absolute values have to be corrected by removing the Honkasalo correction (Uotila, 1980).

Absolute measurement of acceleration due to gravity is determined by direct observation of a body during free rise and fall in a vacuum. In practice, the effective site of the measurement is about 1.2 m above the floor, and the vertical gravity gradient at the absolute site is measured so that gravity meter observations can be made on the floor beneath the measurement site.

Table 1. The vertical gradient at absolute gravity sites ($\mu m.s^{-2}m^{-1}$)

	1979		1980							Mean
	G252	G460	G20	G101	G132	G252	G460	G518	G525	
Sydney	3.23†	3.19	3.29	3.21	3.29	2.74*	3.25	3.15	2.98	3.20
Port Moresby		3.13								3.13
Hobart		2.74		2.76	2.75	2.74	2.75	2.73	2.42*	2.74
Alice Springs	2.98	3.06		3.79	2.83	2.98	2.92	2.79	2.73	2.90
Darwin	2.98	3.10		3.14	3.03	3.41*	2.96	3.09	3.17	3.07
Perth	3.45	3.41	3.41		3.80*		3.42	3.70		3.48

† meter G525 not G252
* values rejected in calculating mean

Table 1 gives the gradient measurements taken during the 1979 absolute survey (Arnautov & others, 1979) and those at the time of the 1980 gravity meter survey. The results are similar, so the 1979 results have been used in the calculations below. The measured gravity intervals at any site differ between meters by up to 0.3 $\mu m.s^{-2}$ (presumably because of the circular error in the reading screw), and hence the gradient measurement has the potential for introducing significant errors into the primary gravity network. The measured gradient values differ from the theoretical gradient of 3.086 $\mu m.s^{-2}$ by up to 0.4 $\mu m.s^{-2}$, and the theoretical values are clearly not accurate enough for this purpose.

1980 Australian gravity base-station survey

From 30 January to 1 April 1980, gravity meter ties were made between 67 airports and the five absolute gravity stations in Australia (Fig. 1). Flight lines were mainly north–south to try to control errors in the previous control survey of 1964–67, which had mainly east–west flights. Ties were also made to accurate geodetic position stations – the lunar laser ranging station at Orroral near Canberra, the satellite laser ranging stations at Yarragadee near Geraldton, and Orroral near Canberra, and radio telescopes used for VLBI near Alice Springs, Parkes, Narrabri, Sydney, Canberra, and Hobart.

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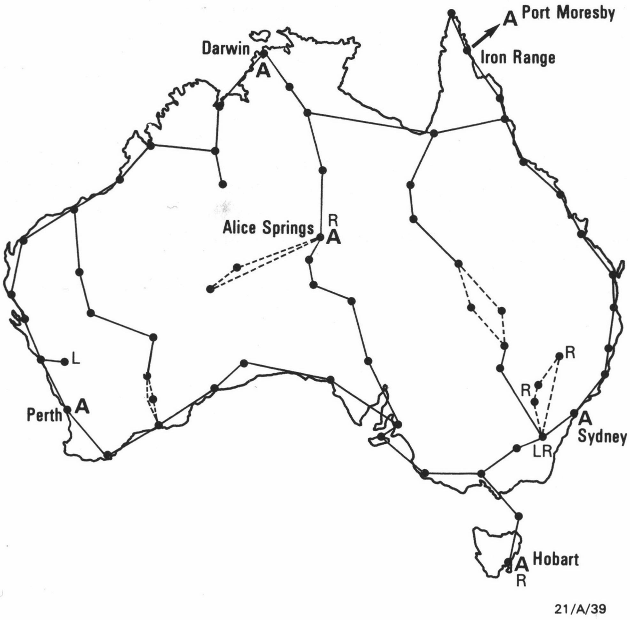

Figure 1. Traverses of the Australian gravity base-station survey of 1980.
A, absolute gravity sites; L, laser ranging sites to satellites or the Moon; R, sites of radio telescopes used for Very Long Baseline Interferometry.

Seven LaCoste & Romberg gravity meters were used: the Bureau of Mineral Resources (BMR) meters G20, G101, G132, G252, G460, G518, and a Geological Research and Development Centre (GRDC) of Indonesia meter, G525. Gravity meter readers were P. Wellman and J.W. Williams of BMR and M. Untung of GRDC. Transport between airports was by a chartered light aircraft (Piper Navajo), and took 165.2 flying hours. Transport within each town was by car.

Observations at airports A,B,C,D,.. can be made two ways: 'ladder sequence' A-B-C-D...D-C-B-A, and 'drift-control sequence' A-B-A-B-C-B-C-D-C-D... Ladder sequence was chosen for this survey for the following reasons: (a) air transport costs are lower, because each leg is flown twice, not three times; (b) observations are more symmetrical and independent, because a single set of observations is made in each direction, and, generally, observations are made during different days; and (c) a stronger network results, because a greater number of different airports is observed during one day.

At each airport, two stations were observed, if possible, outside separate buildings. The two stations were always observed in the same order. The use of two stations increases the probability that one will be recoverable in the future, and it is a check at each airport on gravity meter misreading or malfunction. After the second station at each airport was read, the gravity difference between stations was calculated for each meter. One or two readings were repeated if a discrepancy was found greater than 0.3 $\mu m.s^{-2}$ from the mean value of all meters. Flights between airports averaged 1.23 hours, and time at each airport averaged 0.8 hours.

The original survey plan was modified during the survey because of the following problems: runway too wet for use – Calvert Hills; difficulty in obtaining permision to land – Meningie, Wanaaring; runway abandoned – Old Balgo Hills Mission, Mundiwindi, Katherine; destruction or partial destruction of previous gravity stations at the airport – Wiluna, Norseman, Abminga, Thargominda; and difficulty in obtaining aviation fuel during an industrial strike – Dubbo.

After the survey, the gravity meters used were tested for their sensitivity to temperature, pressure, battery voltage, and magnetic field (Williams, 1983). The effects were small, so no corrections were made to the gravity meter readings.

Reduction of gravity meter observations

The gravity meter observations were reduced at Earth Physics Branch Ottawa, using existing computer programs for tie processing and adjustment. The tie processing program applies the manufacturer's dial-response correction tables and Earth-tide corrections to calculate raw gravity intervals.

The adjustment computer program uses the following observational equation to adjust the raw gravity intervals (McConnell & Ganter,1971):

$$\sqrt{p_n}\,(g_i - g_j - k_m \Delta G_{ij} - d_m \Delta T_{ij} = e_{ij}),$$

where p_n is the observation weight, g_i is the unknown gravity value of control station i, g_j is the unknown gravity value of control station j, k_m is the unknown calibration correction factor for instrument m, ΔG_{ij} is the observed gravity difference between gravity stations i and j (raw gravity intervals), d_m is the unknown drift rate, ΔT_{ij} is the time interval between the observations at control stations i and j, and e_{ij} is the unknown observation error.

The observed intervals for each gravity meter were weighted according to an overall factor for that meter, determined from residuals of a previous adjustment. Residuals with a magnitude above three standard deviations in the final adjustment were rejected (73 intervals, 3% of all intervals) together with all intervals of more than 7 hours duration, to eliminate overnight measurements; 2358 intervals were used to solve 152 unknowns.

Two computer adjustments were made with the final data set, differing only in the number of absolute gravity stations used to control datum and scale. Adjustment one used only Hobart and Darwin absolute stations, and adjustment two used all six absolute stations, Port Moresby being included by the use of a previous tie to Iron Range airport (Table 2). The adjusted values differ by 0.11–0.20 $\mu m.s^{-2}$. These differences are caused almost solely by both Hobart and Darwin being 0.11 $\mu m.s^{-2}$ higher than the datum defined by the average of the absolute stations. The calculations show that the use of all six absolute measurements, rather than just two, does not distort the gravity meter adjustment and, hence, the two sets of information are consistent within experimental error.

Table 2. Absolute sites: values from measurement and adjustments ($\mu m.s^{-2}$)

	Measured value	Measured minus Adj.2	Measured minus Adj.1	Adj.1 minus Adj.2
Darwin C	9 783 009.59 ± 0.14	+0.11	-	+0.11
Iron Range K*	9 783 317.62 ± 0.28	−0.35	-0.55	+0.20
Alice Springs B	9 786 308.00 ± 0.14	+0.07	-0.04	+0.11
Perth D	9 794 036.94 ± 0.14	−0.11	-0.31	+0.20
Sydney C	9 796 376.18 ± 0.15	−0.11	-0.28	+0.17
Hobart B	9 804 178.34 ± 0.14	+0.11	-	+0.11

*The Iron Range value was calculated as follows:

Port Moresby absolute value	9 782 022.08 ± 0.14
Honkasalo correction	+0.34
Tie to 7390.0176 Port Moresby airport	−36.09 ± 0.10
Tie to 7390.1073 Iron Range airport	+ 1 328.17 ± 0.24
Tie to 6600.0025 terminal Iron Range	+3.12 ± 0.04
Value at 6600.0025 Iron Range	9 783 317.62 ± 0.28

Some separate adjustments were carried out using (i) Earth tides calculated by Longman's formula, which uses a constant amplification and zero phase lag for the various waves, and (ii) Earth tides calculated using the constants and phase lags for the waves measured by Ducarme & others (1976) and Ducarme & Melchior (1978) for Australian sites. There was no significant difference in the gravity values calculated from Longman's formula or from measured Earth-tide corrections. This was not unexpected, as the program adjusts station-to-station interval rather than actual station values.

The adjustment theory assumes that the observational errors are normally distributed and there are no other errors. The residuals of the final adjustment (adjustment 2) give a chi-square sum of 23.7 for 7 degrees of freedom, so the distribution is not normal. Relative to the normal curve, the number of residuals is higher for near-zero values and large magnitude values. The large magnitude residuals are thought to be due to misreadings, lag in instrumental recovery after flights, and errors induced by vibration during readings. It is believed that, as a result of the great redundancy of observations in this survey, these large residuals will have negligible effect on the calculated gravity values. The calculated standard error of the residuals is 0.25 $\mu m.s^{-2}$. Plotting of the errors on probability paper shows that the majority of them belong to a normal curve of standard deviation 0.22 $\mu m.s^{-2}$; this is larger than the error for short time-interval ground measurements of about 0.15 $\mu m.s^{-2}$. (Wellman & others, 1974).

The adopted values for the computer adjustment of the 1980 gravity meter survey, using the 1979 absolute gravity measurements for datum and scale, are listed in Appendix 1 (Isogal 84 values). The formal precision of the values calculated in the computer adjustment ranges from 0.091 to 0.155 $\mu m.s^{-2}$. At the 95 per cent confidence level, the accuracy of the values is thought to be better than 0.6 $\mu m.s^{-2}$. The Honkasalo correction has not been applied.

Comparison with recent international measurements

Table 3 shows that Isogal 84 values differ only slightly from IGSN 71 values (Morelli & others, 1971). Individual values differ by less than 0.9 $\mu m.s^{-2}$. The differences vary systematically with absolute gravity, so there is a slight local scale difference. A comparison with Japanese 1983 values (Nakagowa & others, 1983) shows small residuals, except -0.6 $\mu m.s^{-2}$ at Hobart. (Table 4).

Table 3. Comparison of IGSN 71 and Isogal 84 values ($\mu m.s^{-2}$)

	IGSN 71 value	Honkasalo correction	IGSN 71 + H.C. minus Isogal 84
Darwin L	9 783 006.1	+0.032	+0.18
Cairns A	9 784 862.4	+0.28	+0.42
Townsville A	9 786 097.4	+0.25	+0.82*
Mount Isa J	9 786 044.1	+0.23	−0.10*
Alice Springs J	9 786 393.9	+0.19	+0.04
Mackay J	9 787 198.8	+0.23	+0.41*
Rockhampton K	9 788 600.4	+0.19	+0.25
Maryborough A	9 790 073.2	+0.16	+0.57
Brisbane J	9 791 455.7	+0.13	+0.70*
Grafton K	9 793 153.7	+0.10	+0.00
Perth K	9 793 863.2	+0.06	-0.90
Kempsey J	9 794 123.8	+0.07	-0.23
Canberra J	9 796 063.9	+0.00	-0.25*
Sydney A	9 796 718.6	+0.02	-0.15*
Albury K	9 797 517.0	-0.02	-0.44*
Melbourne M	9 799 473.5	-0.05	-0.50

* value not based on direct reoccupation.

Table 4. Comparison of Japanese 1983 and Isogal 84 values ($\mu m.s^{-2}$)

	Japanese value	Japanese minus Isogal 84
Port Moresby D	9 782 022.74	-0.03*
Cairns A	9 784 862.13	-0.13
Townsville O	9 786 096.87	-0.17
Sydney T	9 796 856.54	-0.21
Melbourne V	9 799 317.24	-0.10
Hobart U	9 804 351.29	-0.61

* value not based on direct reoccupation.

Comparison with Isogal 65 values

The gravity values used in the present Australian national gravity data bank are based on 200 airport base stations. These base stations were established during 1964-67, and the values presently used are those calculated directly after this survey (Isogal 65 values). The main purpose of the 1980 survey was to calculate a transformation for these stations from Isogal 65 values to values correct in absolute scale and datum.

Figure 2. Australian gravity base-station network in 1980.
Thick lines and big dots are higher accuracy traverses of the 1980 survey; thin lines and small dots are the lower accuracy transverses of the 1964-67 survey. Calibration ranges are listed in Table 5.

The 1964-67 survey consisted of mainly east-west traverses between airports with similar gravity (Fig. 2), the measurements being made by three gravity meters of different type (Barlow, 1970; McCracken, 1978). A 'drift control sequence' of observations was used. The observed gravity intervals between adjacent airports were later recalculated to take into account Earth tides (Appendix 1 & 2 of McCracken, 1978). We have adjusted these intervals to the preferred gravity meter scale factors of McCracken, and, by averaging the results of the three meters, have obtained a mean observed interval.

Gravity values have been calculated as follows. Isogal 84 values (Appendix 1) have been adopted for the airports occupied in 1980. For airports not occupied in 1980 (Fig. 2) the mean observed intervals of the 1964-67 traverses have been adjusted to the Isogal 84 values by distributing errors equally between them. The magnitude of the adjustments is shown in Figure 3.

Table 5. Gravity intervals for Australian calibration ranges ($\mu m.s^{-2}$).

	Gravity stations		Gravity interval	Standard error of mean	Ref.
	IGC	BMR numbers			
Townsville	L-M	6091.0151-6091.0251	605.54	0.12	1
Brisbane	D-N	6091.0147-6091.0247	582.51	0.03	1
Sydney	N-O	6091.0105-6091.0205	590.03	0.08	1
Sydney		8291.0105-6091.0205	583.37	0.04	2
Canberra	L-K	6491.0304-6491.0204	547.72	0.02	1
Canberra	S-T	7691.0104-7691.0204	560.02	0.02	
Canberra	Q-R	7490.0001-7490.0020	2295.73	0.13	1
Melbourne	P-Q	6091.0101-6091.0201	530.26	0.10	1
Melbourne		8090.0301-8090.0401	1707.15	0.08	
Hobart	L-M	6091.0160-6091.0260	546.48	0.06	1
Adelaide	J-K	6091.0108-6091.0208	626.60	0.05	
Adelaide	J-T	6091.0108-6793.0208	1158.71	0.04	
Alice Springs	M-L	6091.0235-6091.0135	521.68	0.05	
Darwin	P-Q	8090.0332-8090.0432	314.16	0.04	
Perth	M-L	6091.0217-6091.0117	540.18	0.20	1
Perth	V-Y	7391.0117-7391.0217	542.42	0.30	1
Perth		8090.0317-7391.0217	541.82	0.05	

1. Wellman & McCracken, 1975
2. Williams & Murray, in prep.

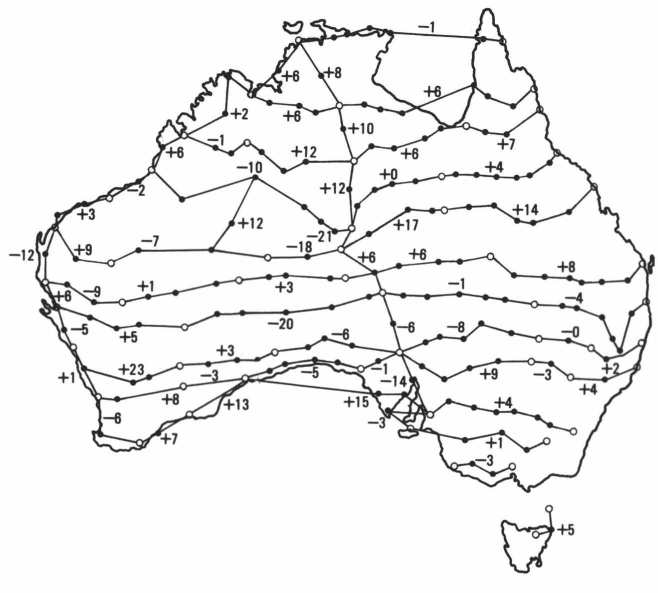

Figure 3. Differences between intervals calculated for Isogal 84 values (at airports with large dots) and intervals between these towns from 1964-67 measurements.
(Unit 0.1 $\mu m.s^{-2}$).

The differences between Isogal 65 (BMR unpublished) and Isogal 84 values have been calculated for each airport, and this difference is contoured in Figure 4. The differences are due to three factors. The main change of approximately 140 $\mu m.s^{-2}$ is due to the change in the world gravity datum from Potsdam datum to IGSN 71 datum (Morelli & others, 1971). The strong north-south gradient is due to a scale change from 'the mean Australian milligal' (Dooley, 1965) to the scale defined by the weighted results of the Soviet absolute measurements (Arnautov & others, 1979). The irregularity in this gradient is due to errors in the observation and reduction of the 1964-67 survey.

Future high-accuracy field surveys should use the Isogal 84 values directly to control datum and scale. Although the gravity meter readings of old surveys could in theory be recalculated to correct scale and datum by using individual Isogal 84 values directly, this is unlikely to be done, because of the large amount of work it requires. Rather, old surveys can be corrected by a polynomial expression of the gravity change of Figure 4.

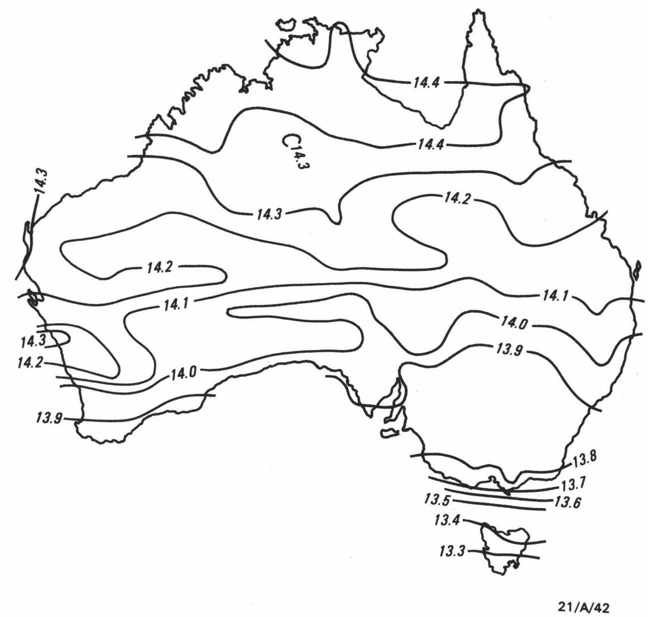

Figure 4. Differences between Isogal 65 and Isogal 84 gravity values.
(Unit 10 $\mu m.s^{-2}$).

The polynomial was derived by least-squares fitting a fifth order polynomial to the differences between the Isogal 65 and Isogal 84 values within Australia. If the difference has a value of V at latitude D°S, longitude F°E, then

$$Y = (D - 25.0°S,\ X = (F - 135°E), \text{ and}$$
$$V = 14.1660 - 0.183800 \times 10^{-2}X + 0.0405366 \times Y - 0.220256 \times 10^{-3}X^2 + 0.476101 \times 10^{-3}XY + 0.709150 \times 10^{-3}Y^2 + 0.166350 \times 10^{-5}X^3 + 0.166350 \times 10^{-5}X^3 - 0.964709 \times 10^{-4}X^2Y - 0.373075 \times 10^{-4}XY^2 - 0.147880 \times 10^{-3}Y^3 + 0.915962 \times 10^{-6}X^4 + 0.764998 \times 10^{-6}X^3Y - 0.772339 \times 10^{-7}X^2Y^2 - 0.673367 \times 10^{-5}XY^3 - 0.982392 \times 10^{-5}Y^4 + 0.910128 \times 10^{-8}X^5 + 0.147126 \times 10^{-6}X^4Y + 0.666914 \times 10^{-7}X^3Y^2 + 0.568814 \times 10^{-6}X^2Y^3 + 0.456620 \times 10^{-6}XY^4 + 0.438121 \times 10^{-6}Y^5$$

The standard deviation of the differences from the computed values is 0.52 $\mu m.s^{-2}$.

Observed gravity values based on Potsdam datum (Isogal 65 base-station values) should be reduced, using the 1930 International Gravity Formula for normal gravity : g_N = 9 780 490. (1 + 0.005 288 4 $\sin^2$ D − 0.000 0005 9 $\sin^2$ 2D) $\mu m.s^{-2}$, where D is latitude. Gravity values consistent with the IGSN 71 system (Isogal 73, Isogal 74, Isogal 84 base-station values) should be reduced, using the 1967 International Gravity Formula of g_N = 9 780 318 (1 + 0.005 302 4 $\sin^2$ D − 0.000 0005 9 $\sin^2$ 2D) $\mu m.s^{-2}$.

Provided the formula for normal gravity that is appropriate to the datum used for observed gravity is employed, the computed anomalies will be similar irrespective of that datum; the difference between anomalies calculated by the two systems varies gradually from 28 $\mu m.s^{-2}$ at 10°S to -32 $\mu m.s^{-2}$ at 44°S. If the matching datum and formula are not used, then the calculated anomaly values will be in error by about 140 $\mu m.s^{-2}$.

Discussion

This work is a step in the continuing process of defining the gravity field more accurately. The history of Australian gravity measurements including gravity control networks has been given by Day (1966) and Dooley & Barlow (1976).

The gravity datum for Australia has been defined as 9 799 790 μm.s^{-2} at Melbourne A in 1950 (Dooley & others, 1960), as 9 796 718.6 μm.s^{-2} at Sydney A in 1973 (Boulanger & others, 1973), and as the weighted mean of six absolute measurements in this paper.

The gravity scale was defined by relative pendulum measurements as the 'mean Australian milligal' in 1965 (Dooley, 1965), was redefined from the results of GAG-2 gravity meter measurements in 1973 (Boulanger & others, 1973), was measured by OVM pendulums in 1975 (Gusev, 1975), and in this paper is redefined using the weighted results of six absolute gravity measurements.

The gravity base-station network was measured as a set of 59 relative pendulum measurements in 1950 (Dooley & others, 1960), was recalculated as a network of gravity meter readings in 1962 (Dooley, 1965), was measured as a network of sites at 200 airports in 1964–67 (Barlow, 1970), and was recalculated in 1975 (McCracken, 1978). The 1980 remeasurement at 67 of the airports is reported in this paper. The increase in accuracy and precision of the base-station values with time is shown in Table 6.

Table 6. Australian gravity base stations: approximate precision and accuracy (μm.s^{-2}).

		Precision	Accuracy
1950–51	pendulum observations	4.3	140
1962	network adjustment	1.6	140
1965–67	Isogal survey	1	140
1975	network adjustment	1	2
1984	survey and adjustment		
	stations not occupied	1	1
	stations occupied	0.1	0.2

In this paper there are several changes in the method of calculation and application of the gravity control network. Previously, datum was transferred from Potsdam in Europe or overseas using relative pendulums or gravity meters, and the 'best' value at a 'National Gravity Base Station' was adopted. Scale was defined by adopting measurements of gravity difference. In this paper, no actual measured values are adopted, because both datum and scale are defined by the weighted results of six, scattered, absolute gravity measurements.

Previously, the gravity stations with the most accurately known values were within buildings where pendulum or absolute gravity measurements had been made. In this paper, the airport stations used for comparison of the absolute stations have the most accurately known values.

Before 1973, field surveys were completely recalculated when new values of the gravity network became available. The change of datum and scale of 1973 was applied as a linear correction, g(Isogal 73) = 9 796 718.6 + 1.000 511 8 [g(Isogal 65) − 9 796 857.4] μm.s^{-2}. The new values (Isogal 84 values) are taken to be temporary, and vary gradually with position. It is recommended, therefore, that adjustments to Isogal 84 be by polynomial or approximate methods, as it is likely that further small adjustments to base-station values will be required in the future.

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References

Arnautov, G.P., Boulanger, Yu.D., Karner, G.D. & Shcheglov, S.N., 1979 – Absolute determination of gravity in Australia and Papua New Guinea during 1979. *BMR Journal of Australian Geology & Geophysics*, 4, 383–393.

Barlow, B.C., 1970 – National report on gravity in Australia, July 1965 to June 1970. *Bureau of Mineral Resources, Australia, Record*, 1970/62.

Boulanger, Yu.D., Shcheglov, S.N., Wellman, P., Coutts, D.A., & Barlow, B.C., 1973 – Soviet-Australian gravity survey along the Australian Calibration Line. *Bulletin Geodesique*, 110, 355–366.

Day, A.A., 1966 – The development of geophysics in Australia. *Journal and Proceedings, Royal Society of New South Wales*, 100, 33–60.

Dooley, J.C., 1965 – Australian gravity network adjustment, 1962. *Bureau of Mineral Resources, Australia, Report*, 72.

Dooley, J.C., & Barlow, B.C., 1976 – Gravimetry in Australia, 1819–1976. *BMR Journal of Australian Geology & Geophysics*, 1, 261–271.

Dooley, J.C., McCarthy, E., Keating, W.D., Williams, L.W., & Maddern, C.A., 1960 – Pendulum measurements of gravity in Australia. *Bureau of Mineral Resources, Australia, Bulletin* 46.

Ducarme, B. & Melchior, P., 1978 – A trans-world gravity profile. *Physics of the Earth and Planetary Interiors*, 16, 257–276.

Ducarme, B., Melchior, P., Mather, R.S., & Barlow, B.C., 1976 – Tidal gravity profiles in Australia and Papua New Guinea (1974–1976). *Unisurv* G, 25, 17–53.

Gusev, N.A., 1975 – Determination of gravity acceleration at Port Moresby (Papua New Guinea) and Hobart (Australia) with OVM pendulum apparatus. *Bureau of Mineral Resources, Australia, Record* 1975/106.

McConnell, R.K, & Ganter, C, 1971 – Adjustments and analyses of data for IGSN 71. *In* Morelli, C., & others. The international gravity standardization net 1971. *International Association of Geodesy, Paris, Special Publication* 4.

McCracken, H.M., 1978 – Australian gravity network adjustment, 1975. *Bureau of Mineral Resources, Australia, Report* 207; *BMR Microform* MF68.

Morelli, C., Ganter, C., Honkasalo, T., McConnell, R.K., Tanner, J.B., Szabo, B., Uotila, U., & Whalen, C.T., 1971 – The international gravity standardization net 1971. *International Association of Geodesy, Paris, Special Publication* 4.

Nakagawa, I., Nakai, S., Shichi, R., Tajima, H., Izutuya, S., Kono, Y., Higashi, T., Fujimoto, H., Murakami, M., Tajima, K., & Funaki, M., 1983 – Precise calibration of scale values of LaCoste & Romberg gravimeters and international gravimetric connections along the circum-Pacific zone. Final report on 'Precise calibration of scale values of LaCoste & Romberg gravimeters and contribution to the reform of the International Gravity Standardization Net 1971', 117 pp.

Wellman, P., Boulanger, Yu.D., Barlow, B.C., Shcheglov, S.N., & Coutts, D.A., 1974 – Australian and Soviet gravity surveys along the Australian Calibration Line. *Bureau of Mineral Resources, Australia, Bulletin* 161.

Wellman, P. & McCracken, H.M., 1975 – Gravity measurements on Papua New Guinea crustal movement survey markers, and along the Australian Calibration Line, 1975. *Bureau of Mineral Resources, Australia, Record* 1975/126.

Williams, J.W., 1983 – LaCoste & Romberg gravity meters; laboratory investigations into the effects of changes in air pressure, temperature, and meter supply voltage. *Bureau of Mineral Resources, Australia, Record* 1983/3.

Uotila, U.A., 1980 – Note to the users of International Gravity Standardization Net 1971. *Bureau Gravimetrique International, Bulletin d'Information*, 47, 15–16.

Appendix 1. Gravity values at stations of the 1980 survey

Airport	Station location	Station number IGC	Station number BMR	Altitude (m)	Latitude (°)(′)	Longitude (°)(′)	Gravity values Isogal 65 ($\mu m.s^{-2}$)	Gravity values Isogal 84 ($\mu m.s^{-2}$)
Adelaide	terminal	45548N	6491.0308	.457	34 56.5	138 32.1	9 797 190.5	9 797 051.49
Adelaide	memorial	45548U	8090.0108	5	34 56.5	138 32.1		9 797 054.32
Albany	terminal	45747J	6491.0118	69.01	34 56.6	117 47.9	9 797 066.0	9 796 927.57
Albany	hangar	45747K	8090.0118	69	34 56.6	117 47.9		9 796 927.27
Albury	terminal	45466M	7591.1136	162.09	36 04.3	146 57.5	9 797 656.2*	9 797 517.42
Albury	hire car	45466N	8090.1136	162	36 04.3	146 57.5		9 797 518.47
Alice Springs	terminal	41933J	6491.0335	542.57	23 48.4	133 53.9	9 786 537.0	9 786 394.05
Alice Springs	D.O.T.	41933N	8090.0135	542	23 48.4	133 53.9		9 786 394.02
Alice Springs	absolute	41933B	7999.0135	580	23 43	133 50		9 786 307.93
Anna Plains	apron	38491K	6792.0227	17.35	19 15.3	121 30.6	9 786 244.7	9 786 102.32
Anna Plains	windsock	38491J	6792.0127	16.65	19 15.3	121 30.6	9 786 249.9	9 786 107.44
Balgo Hills	terminal	42007M	8090.1217		20 09.0	127 58.0		9 785 215.23
Bourke	hangar	45405J	6491.9107	106.43	30 02.6	145 57.1	9 793 200.8	9 793 061.22
Bourke	terminal	45405L	8090.1107	106	30 02.6	145 57.1		9 793 060.90
Brisbane	Ansett	41773R	7213.0147	7	27 25.8	153 04.9		9 791 458.09
Brisbane	TAA	41773T	7390.0247	7	27 25.8	153 05.0	9 791 595.7*	9 791 454.93
Caiguna	motel 5/6	45626K	6491.1122		32 16.3	125 29.0	9 794 957.6	9 794 817.68
Caiguna	toilets	45626M	8090.1122		32 16.3	125 29.0		9 794 816.91
Cairns	hangar	38265A	5099.9952	2.41	16 53.4	145 45.0	9 785 006.0	9 784 862.26
Cairns	terminal	38265N	8090.0152	2	16 53.4	145 45.1		9 784 862.86
Canberra	terminal	45459U	7791.0104	566.8	35 18.5	149 11.3		9 796 066.18
Canberra	aero club	45459N	6893.0204	565.89	35 18.4	149 11.2	9 796 205.2	9 796 066.45
Canberra	laser site	45459V	8090.0104		35 38.1	148 55.7		9 794 580.64
Carnarvon	terminal	42143J	6500.0124	2.62	24 53.0	113 39.7	9 789 439.3	9 789 296.55
Carnarvon	workshop	42143K	8090.0124	2	24 53.0	113 39.7		9 789 296.06
Ceduna	DOT shed	45523L	8090.0110	16	32 07.5	133 41.9		9 794 385.94
Ceduna	tarmac	45523J	6491.0110	16.42	32 07.5	133 41.9	9 794 524.2	9 794 385.09
Cobar	B of sign	45415J	6491.0143	217.98	31 32.5	145 47.8	9 794 031.5	9 793 893.43
Cobar	terminal	45415L	8090.0143	218	31 32.5	145 47.8		9 793 892.62
Cooktown	terminal	38255L	7090.1072	5.37	15 26.8	145 11.2	9 784 422.4*	9 784 278.40
Cooktown	house	38255N	8090.1072	5	15 26.8	145 11.2		9 784 278.27
Cunnamulla	tarmac	41885J	6491.9012	188.64	28 01.9	145 37.2	9 791 316.9	9 791 176.54
Cunnamulla	terminal	41885L	8090.1012	189	28 01.9	145 37.2		9 791 176.99
Daly Waters	mast	38363J	6491.0133	210.06	16 16.0	133 22.5	9 783 891.8	9 783 747.24
Daly Waters	terminal	38363K	6793.0133	210	16 16.0	133 22.5	9 783 891.3	9 783 746.73
Darwin	hangar	38320L	6491.0132	29.78	12 25.3	130 51.8	9 783 150.0	9 783 006.24
Darwin	DCA office	38320	8090.0132	29	12 25.3	130 51.8		9 783 007.00
Darwin	terminal	38320	8090.0232	27	12 25.3	130 51.8		9 783 009.16
Darwin	cali. 1	38320	8090.0332	50	13 13.9	131 06.8		9 783 145.42
Darwin	cali. 2	38320	8090.0432	185	13 20.9	131 07.9		9 782 831.26
Darwin	absolute	38320C	7999.0132	20	12 51.	131 08.		9 783 009.48
Derby	hangar	38473J	6491.0128	6.03	17 22.3	123 39.7	9 785 207.2	9 785 063.09
Derby	terminal	38473M	6500.0128	6.88	17 22.3	123 39.7	9 785 204.2	9 785 059.76
De Rose Hill	windsock	41963J	6491.9081	410.05	26 25.6	133 15.8	9 789 754.5	9 789 612.87
De Rose Hill	strip	41963L	8090.1081	410	26 25.6	133 15.8		9 789 610.95
Dubbo	tarmac	45428J	6491.9113	280.33	32 13.0	148 34.2	9 794 318.8	9 794 179.96
Dubbo	terminal	45428M	8090.1113	280	32 13.0	148 34.2		9 794 179.48
Esperance	terminal	45631J	6491.0113	142.84	33 41.0	121 50.1	9 795 803.8	9 795 664.98
Esperance	light base	45631L	8090.0113	143	33 41.0	121 50.1		9 795 664.85
Flinders Is.	terminal	49007L	6491.9140	30.92	40 05.7	148 00.3	9 802 044.9	9 801 910.32
Flinders Is.	garage	49007J	6491.1140	30.16	40 05.7	148 00.1	9 802 046.1	9 801 911.29
Forest	hangar	45608A	5099.9912	156	30 50.8	128 06.8	9 793 062.5	9 792 922.18
Forest	hangar	45608J	6491.0112	156	30 50.8	128 06.8	9 793 062.8	9 792 922.56
Geraldton	terminal	42184L	8090.0120	33	28 47.7	114 41.9		9 792 563.91
Geraldton	hangar	42184A	5099.9920	33.95	28 47.5	114 41.8	9 792 700.5	9 792 557.19
Geraldton	D.O.T.	42184M	8090.0220	32	28 47.7	114 41.9		9 792 562.16
Geraldton	sat. laser	42184	8090.0320	268.04	29 02.9	115 20.6		9 791 449.85
Geraldton	sat. laser	42184	8090.0420	268	29 02.9	115 20.6		9 791 445.70
Giles	met. area	42058K	6792.0173	596.08	25 02.0	128 18.0	9 787 693.0	9 787 551.51
Giles	windsock	42058L	6792.0273	578.66	25 02.6	128 17.7	9 787 725.6	9 787 584.36
Grafton	terminal	41792K	6491.9110	28.91	29 45.6	153 01.8	9 793 293.3	9 793 153.80
Grafton	terminal	41792M	8090.1110	29	29 45.6	153 01.8		9 793 153.61
Halls Creek	terminal	38487J	6491.0129	409.61	18 14.2	127 40.1	9 784 616.3	9 784 473.02
Halls Creek	workshop	38487K	8090.0129	410	18 14.2	127 40.1		9 784 471.67
Hamelin Pool	windsock	42164J	6792.9207	26.60	26 25.5	114 12.4	9 790 486.3	9 790 344.39
Hamelin Pool	pump hut	42164M	8090.1207	26	26 25.5	144 12.4		9 790 346.67
Henbury	windsock	41943K	6792.1037	425.50	24 35.0	133 13.9	9 787 841.2	9 787 698.45
Henbury	road gate	41843	8090.1037	425	24 35.0	133 13.9		9 787 693.32
Hobart	hangar	49027Q	7390.0260	3	42 50.4	147 30.4	9 804 476.5*	9 804 343.87
Hobart	terminal	49027U	8090.0160	3	42 50.3	147 30.3		9 804 351.90
Hobart	absolute	49027B	7499.0160	132	42 54.5	147 19.2		9 804 178.23
Iron Range	terminal	38223K	6600.0025	18.78	12 47.2	143 18.3	9 783 461.7	9 783 317.97
Iron Range	shed	38223J	6491.9073	17.6	12 47.3	143 18.3	9 783 449.1	9 783 305.48
Kalgoorlie	concrete	45601K	6491.0214	355.46	30 46.9	121 27.7	9 792 905.0	9 792 764.30
Kalgoorlie	hangar	45601A	5099.9914	355.75	30 46.9	121 27.7	9 792 907.3	9 792 766.49
Katherine	terminal	38342M	8090.1318	129.6	14 31.	132 22.		9 783 248.59
Katherine	D.O.T.	38342N	8090.2318	129	14 31.	132 22.		9 783 247.58
Kempsey	terminal	45312J	6491.9111	14.72	31 04.2	152 46.0	9 794 361.0	9 794 124.10
Kempsey	hangar	45312O	8090.1111	14	31 04.2	152 46.0		9 794 124.66
Kingscote	terminal	45557J	6793.9306	6.1	35 42.6	137 31.5	9 798 287.1	9 798 148.34
Kingscote	light-tower	45557L	8090.1306	6.1	35 42.6	137 31.5		9 798 148.38

Laverton	windsock	42082K	6792.0215		28 37.0	122 25.0	9 790 966.4	9 790 826.31
Laverton	terminal	42082L	8090.0115		28 37.0	122 25.0		9 790 833.13
Mackay	tarmac	41819M	7390.0161	4	21 10.3	149 11.0	9 787 339.7*	9 787 197.56
Mackay	terminal	41819P	8090.0161	4	21 10.3	149 11.0		9 787 197.44
Maryborough	hangar	41752A	5099.9948	10.77	25 31.1	152 42.7	9 790 214.2	9 790 072.79
Maryborough	terminal	41752K	8090.0148	11	25 31.	152 43.		9 790 071.19
Meekatharra	terminal	42168J	6491.9090	517.07	26 36.6	118 32.7	9 789 183.0	9 789 040.60
Meekatharra	aeradio	42168K	6491.1090	517.55	26 36.7	118 32.9	9 789 194.6	9 789 051.75
Melbourne	Essendon	45474M	6491.0101	76.65	37 43.7	144 53.9	9 799 611.8	9 799 473.95
Melbourne	Essendon	45474	8090.0101	76	37 43.7	144 53.9		9 799 474.02
Melbourne	Tulla.	45474V	7213.0101		37 41.	144 51.		9 799 317.34
Melbourne	Customs	45474Z	8090.0201		37 41.	144 51.		9 799 343.80
Melbourne	Macedon	45474	8090.0301		37 30.	144 45.		9 798 834.98
Melbourne	Macedon	45474	8090.0401		37 23.	144 35.		9 797 127.83
Mount Gambier	terminal	45470J	6491.0107	63.29	37 44.7	140 47.1	9 799 772.2	9 799 634.71
Mount Gambier	hangar	45470K	8090.0107	63	37 44.7	140 47.1		9 799 628.96
Mount Isa	terminal	41909N	8090.0162	336	20 40.1	139 29.3		9 786 043.65
Mount Isa	fire stn	41909K	6491.9962	336.60	20 40.1	139 29.3	9 786 190.1	9 786 047.33
Mount Vernon	strip	42148K	6792.1210	399.53	24 13.5	118 15.0	9 787 908.1	9 787 766.99
Mount Vernon	windsock	42148J	6792.9210	398.83	24 13.4	118 15.1	9 787 911.2	9 787 769.91
Narrabri	terminal	45409J	6491.9108	222.99	30 19.1	149 49.5	9 793 113.9	9 792 974.39
Narrabri	windsock	45409M	8090.1108	223	30 19.1	149 49.5		9 792 978.43
Normanton	terminal	38271K	6491.0163	17	17 41.2	141 04.3	9 785 177.5	9 785 033.24
Normanton	DCA shed	38271M	8090.0163	17	17 41.2	141 04.3		9 785 032.02
Norseman	concrete	45621J	6491.9123	263.34	32 12.4	121 45.4	9 794 167.3	9 794 027.93
Norseman	toilet	45621K	8090.1123	263	32 12.4	121 45.4		9 794 027.68
Onslow	terminal	42115K	6792.0225	3.24	21 39.9	115 06.6	9 787 738.3	9 787 596.02
Onslow	windsock	42115L	8090.0125	3	21 39.9	115 06.6		9 787 594.91
Oodnadatta	terminal	41975J	6491.0136	112	27 33.4	135 26.1	9 790 999.4	9 790 859.16
Oodnadatta	shed	41975K	8090.0136	112	27 33.4	135 26.1		9 790 859.90
Parkes	radio tele	J	8090.0144	371	33 00.0	148 15.7		9 794 773.95
Parkes	radio tele	K	8090.0244	371.40	33 00.0	148 15.7		9 794 774.08
Perth	hangar	45715Y	8090.0117	14	31 56.0	115 57.4		9 793 861.19
Perth	catering	45715Z	8090.0217	14	31 56.0	115 57.4		9 793 862.13
Perth	absolute	45715D	7999.0117	300	31 43.	116 12.		9 794 037.05
Perth	hangar	45715K	6491.0317	15.08	31 56.2	115 57.3	9 794 004.1	9 793 864.16
Perth	terminal	45715U	6500.0117	14.44	31 56.0	115 57.4	9 794 006.9	9 793 866.83
Port Hedland	terminal	42108N	8090.0126	8	20 22.6	118 37.7		9 786 312.04
Port Hedland	D.O.T.	42108L	6792.0326	8.02	20 22.6	118 37.7	9 786 457.7	9 786 314.99
Rockhampton	fire stat.	41730K	6499.0149	9.82	23 22.7	150 28.5	9 788 742.0	9 788 600.34
Rockhampton	terminal	41730L	7090.0149	9	23 22.7	150 28.5		9 788 602.28
Sydney	Flight Fa.	45332T	6891.0305	6.37	33 56.1	151 11.2	9 796 995.5	9 796 856.75
Sydney	Air Amb.	45332Z	8090.0105	5	33 56.1	151 11.2		9 796 858.76
Sydney	absolute	45331C	7999.0105	62.7	33 52.	151 12.		9 796 376.29
Tennant Creek	terminal	38394K	6793.0134	375	19 38.5	134 10.9	9 785 289.4	9 785 145.83
Tennant Creek	power	38394A	5099.9934	375.02	19 38.5	134 10.9	9 785 289.2	9 785 145.45
Thargomindah	terminal	41873L	8090.1013	130	27 59.3	143 48.7		9 791 283.68
Thargomindah	cover	41873M	8090.2013	130	27 59.3	143 48.7		9 791 283.09
Thursday Is.	terminal	38202J	6691.9001	15.1	10 35.5	142 17.8	9 782 441.4	9 782 298.34
Thursday Is.	hangar	38202N	8090.1001	12.32	10 35.5	142 17.8		9 782 303.53
Townsville	terminal	38296O	7090.0151	4.43	19 15.4	146 46.2	9 786 240.2*	9 786 097.04
Townsville	hangar	38296S	8090.0151	4	19 15.4	146 46.2		9 786 098.68
Warburton	store	42066K	6491.9969		26 08.0	126 34.7	9 789 257.6	9 789 115.59
Windorah	terminal	41852J	6491.9023	131.71	25 24.8	142 39.8	9 789 428.3	9 789 286.59
Windorah	windsock	41852M	8090.1023	132	25 24.8	142 39.8		9 789 287.83
Woomera	terminal	45516J	6491.0138	166.78	31 09.5	136 48.3	9 793 727.5	9 793 587.81
Woomera	concrete	45516K	8090.0138	167	31 09.5	136 48.3		9 793 587.39
Wyndham	workshop	38458A	5099.9930	5.38	15 30.3	128 09.0	9 784 146.3	9 784 002.16
Wyndham	terminal	38458J	6491.0130	5.06	15 30.3	128 09.0	9 784 146.9	9 784 002.63