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Calibration values for gravity base stations, McMurdo Station and Scott Base, Ross Island, Antarctica

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Abstract: New reference gravity values are provided for gravity base stations at McMurdo Station and Scott Base. The new values are obtained by a relative survey including the Hut Point base station (an International Satellite Triangulation station; 77.8448°S, 166.6418°E; 982975.65 mGal) located 110 m north of Scott's 1901 Discovery Hut at McMurdo Station. This site is the only remaining station tied by previous surveys to the now defunct SATGRAV base Station located in the former Building 57, which was, in turn, measured by an absolute meter in 1995. New values are 982970.41 mGal for the THIEL-1 Station (77.8490°S, 166.6794°E) at McMurdo Station, 982973.40 mGal for the MMD-N Station (77.8491°S, 166.7567°E) at Scott Base, and 982977.83 mGal for the newly established SBG-1 Station (77.8499°S, 166.7667°E) under the flagpole at Scott Base. Our difference values are very consistent with previous surveys, including Nakagawa's value for MMD-N at Scott Base, which is within 0.2 mGal of our new value.

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Key words: gravity surveys, La Coste & Romberg gravity meter

Introduction

Gravity is an important tool for defining sub-surface, sub-ice and sub-sea geological structures on a range of scales (local to continental). Making absolute measurements of gravity is both time consuming and requires the deployment of expensive equipment that is sensitive to subtle changes in environmental conditions. Thus most measurements are made using relative meters that are less sensitive to environmental conditions but are reliant on well-calibrated base stations in order to tie field values to points of known gravity. This is especially critical as the interpretation of the gravity signature is dependent upon anomalies from calculated theoretical gravity (e.g. Lowrie 2008). Well calibrated gravity base stations are rare in Antarctica as the access points to the continent are limited in number and suitable locations are generally restricted to solid bedrock which is also limited in its extent in Antarctica.

Large programmes of geological and geophysical exploration have and continue to rely on base station ties at McMurdo Station and Scott Base for investigations of sub-ice structure and geology beneath the East Antarctic ice sheet (e.g. AGAP; http://www.ldeo.columbia.edu/~mstuding/%7emstuding/AGAP/; 16 January 2009) and beneath the West Antarctic Ice Sheet (e.g. WAIS; http://neptune.gsfc.nasa.gov/wais/; 16 January 2009) as well as beneath the Ross Sea (e.g. ANDRILL; http://www.ANDRILL.org; 16 January 2009) and in broader definition of the Transantarctic Mountain structure and history of the West Antarctic Rift (e.g. Siddoway 2008).

Recent construction of new buildings at McMurdo Station and Scott Base, however, has resulted in the loss of several of the gravity base stations established during and shortly after the IGY (Behrendt *et al*. 1962). The establishment of a new gravity base station at Scott Base (SBG-1) by Antarctica New Zealand has required a base station calibration survey of the remaining stations (Fig. 1) in order to provide a reference value for the new station at Scott Base.

Previous surveys

Gravity surveys in the Ross Sea region of Antarctica have generally relied on a relative, branched gravimetric connection between Antarctica and the IGSN-71 by Nakagawa (1983). Nakagawa (1983) provided values for four stations on Hut Point Peninsula; two at Scott Base (MMD-L and MMD-N; Fig. 1), and two at McMurdo Station (MMD-C and MMD-D; Fig. 1). Ceruti *et al*. (1992) established an absolute base station at Mario Zuchelli Station (Terra Nova Bay) and provided a relative tie to station MMD-L at Scott Base that was 0.25 mGal lower than that of Nakagawa (1983; Table I).

In 1995, absolute gravity was measured in the SATGRAV station in Building 57 at McMurdo Station (Sasagawa *et al*. 2004; Fig. 1; Table I). The SATGRAV Station appears to be the same as Station MMD-D measured by Nakagawa (1983). However, there is some confusion over the respective measurement heights by the two surveys. Sasagawa *et al*. (2004) also performed a relative tie to Station MMD-L that gave a value that was 0.40 mGal lower than that of Nakagawa (1983; Table I) and only 0.15 mGal lower than the value of Ceruti *et al*. (1992), which Sasagawa *et al*. (2004) considered to be within error considering the

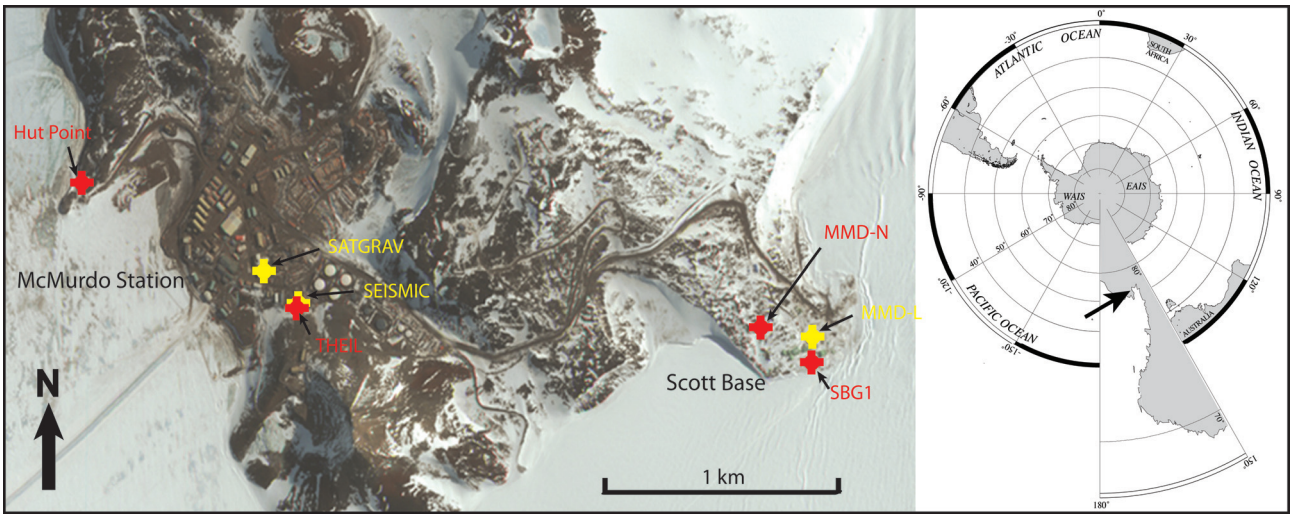

Fig. 1. Location of gravity base stations on Hut Point Peninsula. Hut Point, THIEL, MMD-N and SBG-1 were operative in 2008. SATGRAV, SEISMIC and MMD-L no longer existed in 2008.

limitations of relative measurements over long distances at the high end of the range of the relative meters.

More recently, following the construction of the Science Support Centre at McMurdo Station, and the loss of the SATGRAV Station, Diehl (2008) used the International Satellite Triangulation Station on Hut Point along with the new THIEL-1 Station (Fig. 1) and the remnants of the SEISMIC Station (MMD-C of Nakagawa 1983) beside the demolished FSTOP (formerly the Thiel Earth Science Laboratory) as base stations. Diehl (2008) adopted the value of Nakagawa (1983) for the SEISMIC Station as the tie for her survey (Table I), but also reported calibrations for the SATGRAV, SEISMIC, THIEL-1 and Hut Point stations made by Butcher in 1993 (Table I), which she did not finally adopt. In 2000, as part of the SOAR program (Holt 2001), Anandakrishnan was one of the last to occupy the SATGRAV Station and provide ties to the SEISMIC and Hut Point stations. He only reported meter readings (http://www.geosc.psu.edu/~sak/soar-grav.html; 16 January 2009) which we have been able to convert to milligals using the calibration table for their meter.

Base station descriptions (2008)

In 2008, only one of Nakagawa's (1983) original stations remains (MMD-N at Scott Base). At McMurdo Station, the Hut Point International Satellite Triangulation station marker remains, as does the Thiel-1 Station, although the nearby construction of an, as yet unfilled fuel tank, may compromise this site in the near future. The concrete pad for a new station was established beneath the Scott Base flag pole in the 2007/2008 summer season.

MMD-N (77.8491°S; 166.7567°E) at Scott Base is the only remaining station measured by Nakagawa (1983). It is marked by a brass USAP disc inscribed with "USAP Gravity Station" (Fig. 2a) set in a concrete pad behind the Seismic Hut on the Hill 160 m north of the Hatherton Laboratory (Fig. 2A).

SBG-1 (77.8499°S; 166.7667°E) at Scott Base is first reported here. It is marked by a Brass Land Information NZ Survey Mark inscribed with "SBG-1" (Fig. 2b) set in a concrete pad beneath the Scott Base flagpole (Fig. 2B).

THIEL-1 (77.8490°S; 166.6794°E) at McMurdo Station is a brass disk inscribed with "Thiel 2000–2001" (Fig. 2c) mounted in a concrete pier (Fig. $2C_2$) inside Building 146 (Fig. $2C_1$). A secondary base station (THIEL-2) is set in a concrete pad outside Building 146.

Hut Point (77.8448°S; 166.6418°S) at McMurdo Station is a brass disk inscribed with "International Satellite Triangulation Station No. 53, BC-4, 1969" (Fig. 2d) set in a concrete marker, which lies 110 m north of Scott's Discovery Hut. It lies a few metres north of the 1 m tall concrete "Astro Pier" which is also part of the International Satellite Triangulation Network (Fig. 2D).

Measurements

On 3 November 2008, the four remaining gravity base stations at McMurdo Station and Scott Base were occupied with a LaCoste & Romberg G-meter three times in succession. Additional measurements were made on 2, 5 & 6 November for comparison. Three separate readings were averaged for each occupation at each station to give a reading range. No drift was observed over the four days of measurement. The results are shown in Table II.

Discussion

The only Hut Point gravity station with an absolute measurement is the now defunct SATGRAV Station. A direct

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Table I. McMurdo Station and Scott Base Gravity Base Station data.

Station ID	Datum information	Site description	Published values (mGals)	Calibrated values (mGals)	Error (mGals)	Notes
Hut Point	77.8448°S 166.6418°E 17.6 m	International Satellite Triangulation Station behind Scott's Discovery Hut from McMurdo Station	982976.62[b]	982975.65[w]	±0.03[β]	Still operational.
MMD-L	77.8250°S 166.8033°E 20.0 m	Cast in 44 gallon drum near the Scott Base bus stop	982976.614[n] 982977.007[s] 982976.860[c]		±0.005[s]	Also referred to as Gravity Station Scott Base (GSSB) by Sasagawa *et al.* (2004). Destroyed in construction of the Hillary Field Centre.
MMD-N	77.8491°S 166.7567°E 33.2 m	Concrete Slab behind Seismic Hut from Scott Base	982973.204[n]	982973.40[w]	±0.06[γ]	Still operational.
SATGRAV	77.8487°S 166.6744°E 35.1 m	Marker in Gravity Hut (Building 57) at McMurdo Station	982973.458[n,#] 982972.95[b] 982973.087[s]		±0.002[s, δ]	Vertical gradient of 3.28 mgal.cm^{-1} determined by Sasagawa *et al.* (2004). Also referred to as MMD-D by Nakagawa (1983) when the marker was within the garage (Building J-58). Relative height of measurements between Building 57 and 58 is unknown. Marker in Building 57 destroyed in the construction of the Science Support Center.
SEISMIC	77.8487°S 166.6800°E 49.3 m	Marker in concrete pad behind FSTOP (originally Thiel Earth Science) building at McMurdo Station	982969.852[n] 982970.18[b]			Also referred to as MMD-C by Nakagawa (1983). Destroyed in construction of new fuel storage tank.
THIEL-1	77.8490°S 166.6794°E 46.2 m	On concrete pier inside Building 146 at McMurdo Station	982969.7277[d] 982970.52[b]	982970.41[w]	±0.06[γ]	Still operational.
SBG-1	77.8499°S 166.7667°E 9.2 m	Concrete slab beneath Scott Base flagpole		982977.83[w]	±0.06[γ]	Newly established in 2008.

[b] Butcher (2003; in Diehl 2008)
[c] Ceruti *et al.* (1992)
[d] Diehl (2008)
[n] Nakagawa (1983)
[s] Sasagawa *et al.* (2004)
[w] This paper
[β] direct tie to absolute measurement
[γ] indirect tie to absolute measurement
[δ] absolute measurement
[#] It is unclear whether SATGRAV is at the same height as MMD-D of Nakagawa (1983)

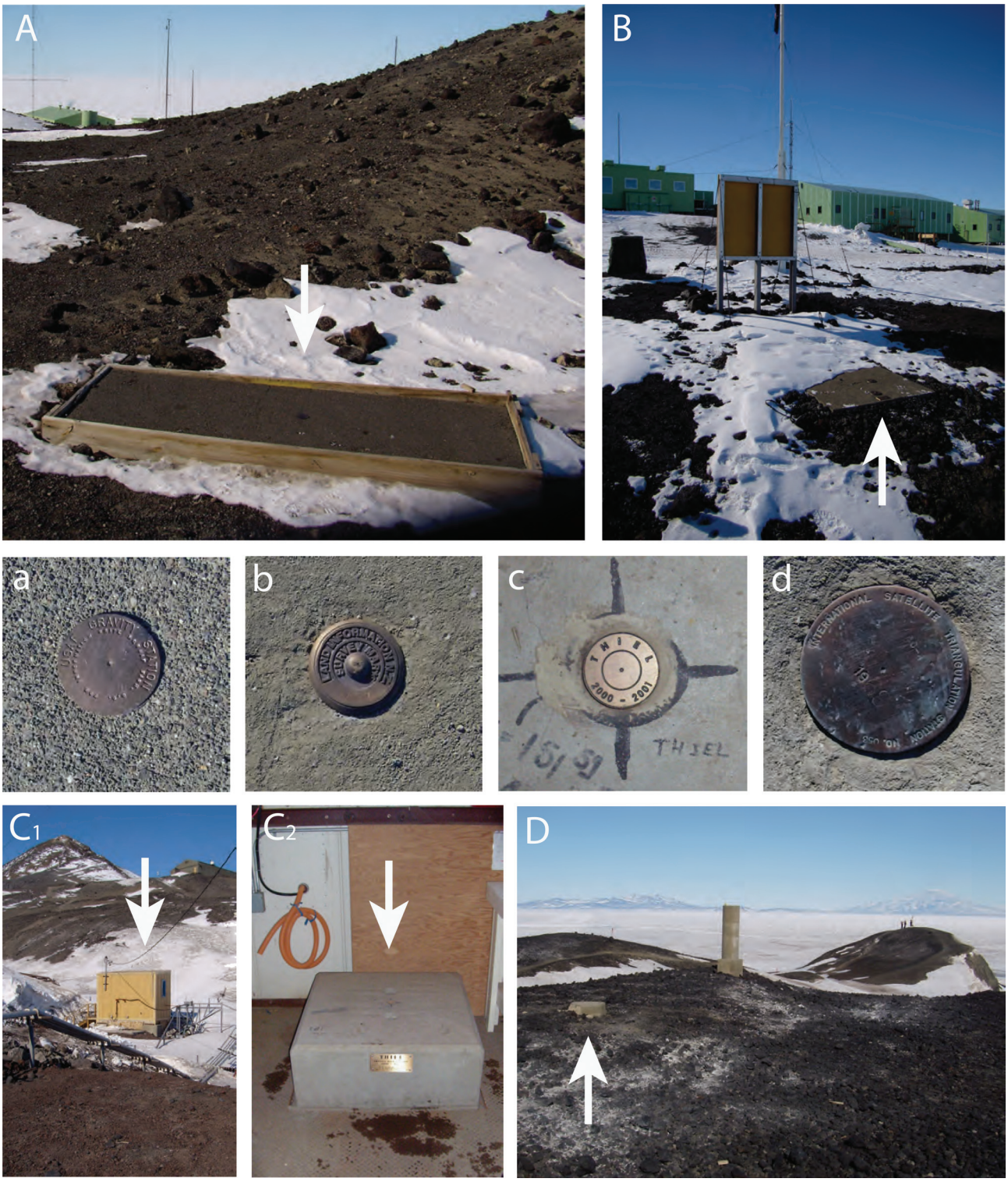

Fig. 2. Photographs of gravity base stations on Hut Point Peninsula. A. MMD-N at Scott Base, B. SBG-1 at Scott Base, C. THIEL-1 at McMurdo Station, D. Hut Point at McMurdo Station. Lower case letters illustrate the marker pins at each location, respectively.

tie between this and the also now defunct MMD-L Station at Scott Base was performed by Sasagawa *et al*. (2004). This confirmed the value obtained from a tie to the Base Station at Mario Zuchelli Station (Terra Nova Bay) by Ceruti *et al*. (1992), which also has an absolute measurement. Both values were slightly higher than the value assigned by Nakagawa (1983; Table I). The only other ties from the SATGRAV Station were made by Anandakrishnan

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Table II. Relative measurments of gravity base stations existing in 2008.

Location	Date	Time*	Average reading	Reading range	Gravity (mGal)[#]
SBG1	02-Nov-08	11:12 am	6336.33	0.02	6629.30
MMD-N	02-Nov-08	11:39 am	6332.06	0.10	6624.83
THIEL-1	02-Nov-08	1:42 pm	6329.14	0.01	6621.78
Hut Point	03-Nov-08	3:02 pm	6334.18	0.02	6627.05
THIEL-1	03-Nov-08	3:22 pm	6329.18	0.08	6621.82
MMD-N	03-Nov-08	3:46 pm	6331.98	0.03	6624.75
SBG1	03-Nov-08	4:05 pm	6336.21	0.00	6629.17
Hut Point	03-Nov-08	4:28 pm	6334.20	0.01	6627.07
THIEL-1	03-Nov-08	5:12 pm	6329.14	0.00	6621.78
MMD-N	03-Nov-08	5:45 pm	6331.99	0.02	6624.76
SBG1	03-Nov-08	6:03 pm	6336.22	0.04	6629.18
Hut Point	03-Nov-08	6:24 pm	6334.19	0.05	6627.06
THIEL-1	03-Nov-08	6:46 pm	6329.20	0.08	6621.84
SBG1	03-Nov-08	7:10 pm	6336.30	0.04	6629.27
MMD-N	03-Nov-08	7:25 pm	6332.07	0.04	6624.84
Hut Point	05-Nov-08	2:17 pm	6334.20	0.03	6627.07
THIEL-1	05-Nov-08	2:38 pm	6329.18	0.02	6621.82
SBG1	05-Nov-08	3:17 pm	6336.31	0.04	6629.28
MMD-N	05-Nov-08	3:30 pm	6332.10	0.10	6624.87
THIEL-1	06-Nov-08	3:10 pm	6329.24	0.00	6621.88

*New Zealand Summer Time
[#] No drift correction

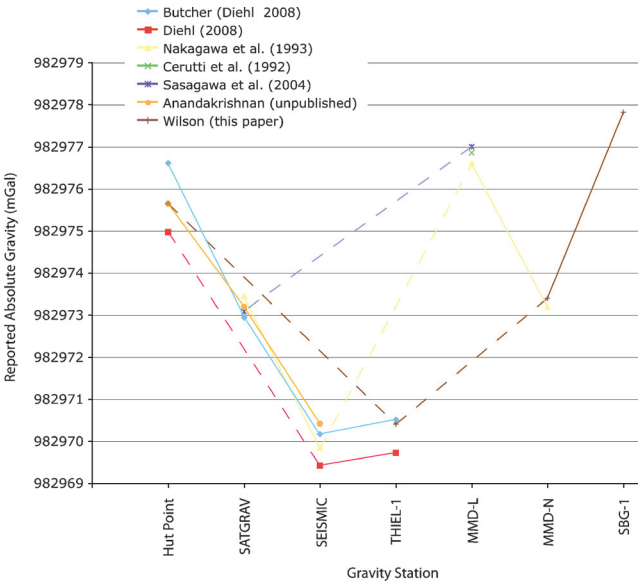

Fig. 3. Gravity survey ties for previous, current and new gravity base stations on Hut Point Peninsula. Solid lines indicate station-to-station ties. Dashed lines indicate ties without intermediate stations included.

(http://www.geosc.psu.edu/~sak/soar-grav.html; 16 January 2009) to the Hut Point and defunct SEISMIC stations, respectively. Therefore, the only remaining station with a direct tie to an absolute gravity measurement is the Hut Point Station. Of the base stations remaining in 2008, THIEL-1 was assigned a value by Diehl (2008) who tied her measurements to those of Nakagawa (1983), and MMD-N has only been assigned a value by Nakagawa (1983). Table III lists all the

Table III. Relative differences measured between gravity base stations (mGals); + = row > column, - = row < column.

	Hut Point	MMD-L	MMD-N	SATGRAV	SEISMIC	THIEL-1	SBG-1
Hut Point				+2.565[a]	+5.375[a]		
				+3.67[b]	+6.44[b]	+6.10[b]	
					+5.534[d]	+5.229[d]	
			+2.25[w]			+5.24[w]	-2.18[w]
MMD-L			+3.410[n]	+3.156[n,#]	+6.762[n]		
				+3.920[s]			
MMD-N		-3.410[n]		-0.254[n,#]	+3.352[n]		
	-2.25[w]					+2.99[w]	-4.43[w]
SATGRAV	-2.565[a]				+2.810[a]		
	-3.67[b]				+2.77[b]	+2.43[b]	
		-3.156[n,#]	+0.254[n,#]		+3.606[n,#]		
		-3.920[s]					
SEISMIC	-5.375[a]			-2.810[a]			
	-6.44[b]			-2.77[b]		-0.34[b]	
	-5.534[d]					-0.305[d]	
		-6.762[n]	-3.352[n]	-3.606[n,#]			
THIEL-1	-6.10[b]			-2.43[b]	+0.34[b]		
	-5.229[d]				+0.305[d]		
	-5.24[w]		-2.99[w]				-7.42[w]
SBG-1	+2.18[w]		+4.43[w]			+7.42[w]	

[a] Anandakrishnan (http://www.geosc.psu.edu/~sak/soar-grav.html; 16 January 2009)
[b] Butcher (2003; in Diehl 2008)
[d] Diehl (2008)
[n] Nakagawa (1983)
[s] Sasagawa *et al.* (2004)
[w] This paper
[#] It is unclear whether SATGRAV is at the same height as MMD-D of Nakagawa (1983)

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available gravity difference data from various surveys including our new survey. Figure 3 illustrates the ties between the Hut Point gravity base stations for this survey and previously reported surveys and demonstrates strong agreement between the various ties. The exceptions are the ties of Diehl (2008) who, while measuring similar differences between stations, appears to be offset from other measurements by a fairly consistent 0.5 mGal and Butcher (in Diehl 2008) whose measurement for Hut Point seems to be out by more than one mGal (Tables I & III). Our survey confirmed the results of Anandakrishnan (http://www.geosc.psu.edu/~sak/soar-grav.html; 16 January 2009) for the Hut Point Station rather than those of Butcher (in Diehl 2008).

Given the good level of agreement between our ties and those of previous surveys, we have assigned new reference values to the three remaining stations (Hut Point, Thiel-1, and MMD-N) as well as the newly installed Scott Base Station (SBG-1). We have used our survey data tied to Hut Point, which is in turn tied to the absolute gravity value at SATGRAV by Anandakrishnan's survey (http://www.geosc.psu.edu/~sak/soar-grav.html; 16 January 2009). These new values along with calculated errors from the survey variability are given in Table I.

Conclusions

We have assigned updated absolute gravity values to the gravity base stations at McMurdo Station (THIEL-1 and Hut Point) and Scott Base (MMD-N), and provide a calibration for the new Scott Base gravity base station (SBG-1). The values are calculated from a new relative gravity tie using a LaCoste & Romberg G-meter. The calibration comes from a tie between the Hut Point Station and the SATGRAV Station, which was, in turn, measured using an FG5/102 absolute gravimeter by Sasagawa *et al*. (2004) in 1995 before it was destroyed in the construction of the Science Support Center at McMurdo Station.

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