THE ABSOLUTE GRAVITY STATION AND THE MT. MELBOURNE GRAVITY NETWORK IN TERRA NOVA BAY, NORTH VICTORIA LAND, EAST ANTARCTICA

G. CERUTTI\textsuperscript{1}, F. ALASIA\textsuperscript{1}, A. GERMAK\textsuperscript{1}, E. BOZZO\textsuperscript{2}, G. CANEVA\textsuperscript{2}, R. LANZA\textsuperscript{3} and I. MARSON\textsuperscript{4}

\textsuperscript{1}Istituto di Metrologia G. Colonnetti, CNR, Strada delle Cacce, 73, 10135 Torino, Italy
\textsuperscript{2}Dipartimento Scienze della Terra, Università di Genova, Viale Benedetto XV, 5, 16132 Genova, Italy
\textsuperscript{3}Dipartimento Scienze della Terra, Università di Torino, Via Valperga Caluso, 37, 10125 Torino, Italy
\textsuperscript{4}Istituto di Miniere e Geofisica Applicata, Università di Trieste, Via Valerio 10, 34127 Trieste, Italy

Abstract: The program initiated during 1989/90 summer expedition, as part of the Earth Science Project in Antarctica sponsored by the Italian government (CNR and ENEA), was primarily designed to determine the gravity datum through absolute measurement of the gravity acceleration and settle a gravity network to monitor the volcanic activity around Mt. Melbourne. Fourteen gravity station points were installed. In the 1990/91 expedition, the team of the Istituto di Metrologia “G. Colonnetti” CNR established the Antarctica’s first absolute gravity site. A total of 166 symmetrical rise and fall g measurements were taken at the Italian Terra Nova Bay Station from 20 to 27 December. Assumption of an error budget of 3--4 $\mu$gal due to systematic sources gave a final g value at 0.91 m above the floor level of 982 854 919 $\mu$gal (standard error $= 0.9 \mu$gal). Establishment of the gravity datum in Antarctica, with the highest accuracy currently obtainable will help in definition of the geodetic reference level and may serve as reference for further detailed surveys and detection of long term, time-dependent gravity variations associated, for instance, to volcanic activity. Bouger anomaly data from the Mt. Melbourne gravity network showing that the main feature of the regional field is a strong gradient decreasing westwards are in good agreement with previous findings.

Key words: absolute gravity, Terra Nova Bay Station, gravity network, Bouger anomaly, Mt. Melbourne, North Victoria Land

Introduction

The establishment of the gravity datum is of fundamental importance in exploration of an unsurveyed area. Either a combination of relative and absolute gravimetry or absolute gravimetry alone can be used. In the first case, an absolute site is connected with the site where the datum has to be established, using one or more relative gravimeters. One advantage of this method is that relative gravimeters are easily transported. Several ties are required in order to ensure satisfactory accuracy. Absolute gravimetry, on the other hand, gives the highest accuracy currently achievable, since the measuring techniques are based on atomic properties.

The establishment of the gravity datum in Antarctica is very important. Besides its use as a reference site for terrestrial metrology, an absolute site serves as reference for studies of long-term gravity variations, as well as in integrated geodesy for the four-dimensional definition of the position of a given site and its variations. These two topics are nowadays considered of high importance, and a worldwide project, called the International Absolute Gravity Basestations Network (IAGBN) has been sponsored by the International Gravity Commission. The absolute site at Terra Nova Bay is not one of the primary IAGBN sites; however its establishment helps the aims of the global network.

The absolute measurements have been performed with Istituto di Metrologia G. Colonnetti (IMGC) transportable gravity meter from 20 to 27 December 1990. The absolute station was used as the reference for monitoring, by means of a relative network, long-term, time-dependent gravity variations associated with the volcanic activity of Mt. Melbourne, and as a datum for gravity surveys in North Victoria Land.

The IMGC Absolute Instrument and Method

The transportable absolute gravimeter (Figs. 1 and 2) developed by IMGC in cooperation with Bureau International des Poids et Mesures, Sevres, France (Cannizzo et al., 1978; Bray and Marson, 1981) has been used since 1975 to settle absolute sites in Italy, Austria, Switzerland, France, Belgium, Germany, England, Denmark, Sweden, Norway, Finland, USA and People’s Republic of China in projects mainly devoted to establishment of gravity datums and scales, and the long-term monitoring of time-dependent gravity variations.

This instrument uses a symmetric rise-and-fall method. A retroreflecting mirror (corner cube) is launched vertically in a vacuum chamber for each measurement, using complete trajectory (about 20 cm) to derive the gravity acceleration value. The advantages of this method are that it cancels out sources of errors generated by the frequency of the interference signals, the resistance of the residual air in the vacuum chamber, and the finiteness of the speed of light.

A Michelson interferometer is used (Fig. 1) to measure time and distances. The moving mirror is, of course, the corner cube itself, while the fixed mirror is formed by placing another corner cube on the inertial mass of a long-period vertical seismometer.

Accuracy is dependent on that of the time and length.

Fig. 1. Schematic diagram of measurement method of the absolute gravity meter. The physical principle is the symmetrical free rise and fall of a body in the gravitational field, observed in its upwards and downwards motion in vacuum by means of interferential techniques. A laser interferometer observes the position of a moving mirror projected vertically by a catapult, while the times corresponding to successive positions of the body in its trajectory are measured and stored by a time digitizer. The data obtained for each flight (about 700 relative positions and times) are used in the least squares adjustment of the best trajectory to obtain a value of $g$ at height $H$.

Fig. 2. The IMGC apparatus for absolute gravity measurement in laboratory operating conditions.

standards employed. These are set by an atomic (rubidium) frequency clock and a He-Ne laser stabilized on an iodine cell ($10^{10}$ stability) or a Lamb-dip ($10^9$ stability) can be used. Departures from the theoretical conditions, of course, are the main source of errors, especially: deviations from verticality, rotation of the moving corner cube, and motion of the reference mirror.

The total error budget under good experimental and environmental conditions can be computed as follows:

- differential pressure and outgassing: $2.0 \mu$gal
- differential temperature: $1.0 \mu$gal
- magnetic field gradient: $0.5$
- electrostatics: $0.5$
- attraction of apparatus: $0.5$
- verticality: $1.0$
- laser wavelength: $1.0$
- rotation: $2.0$
- floor recoil and tilt: $1.0$
- electronic phase shift: $<0.1$
- rms total: $3.6$

Under anomalous conditions, errors of some tens of $\mu$gal are possible.

Results

The instrument has been operated at the Italian Absolute Gravity Station (IAGS) in Terra Nova Bay Station, coordinates: Lat (S) 74°41'36.13", Long (E) 164°05'59.26", Height 54.3 m calculated in WGS84 system (Fig. 3).

The site was prepared during the 1989/1990 expedition. Two pillars were erected directly on the bedrock. A platform was built to hold a mobile laboratory (Fig. 4).

The environmental conditions inside the laboratory were of good quality and no peculiar events were observed.

A total of 166 independent measurements were performed. Their standard error (63% confidence) of 0.9 $\mu$gal confirms the good conditions of the experiment. It is worth noting that the IMGC instrument enables this high precision to be reached with relatively few observations, due partially to the symmetry of the flight, and the stability and
Fig. 3. Sketch map with the locations of the absolute (IAGS) and the relative (IRGS) gravimetric stations in the area of the Terra Nova Bay Italian Station (c) in North Victoria Land (b) East Antarctica (a). The Magnetic Station Point A (MSPA) is also shown.

Fig. 4. The absolute gravimetric station (IAGS) in Terra Nova Bay Station.

g \quad \begin{array}{cccc}
    \text{height} & \text{standard} & \text{total} \\
    \text{above floor} & \text{error} & \text{error} \\
    \text{(μgal)} & \text{(μgal)} & \text{(μgal)} \\
    982 & 854 & 919 & 0.911 & 0.9 & 4
\end{array}

This value of $g$ was reduced to the ground level (982 855 244 ± 7 μgal) by means of a relative gravimeter. However measurements made directly at the absolute point are preferable.

The IAGS is located in an undisturbed area, almost 350 m apart from the helipad. It was thus logistically convenient to have another gravimetric station linked to the absolute one. Known as IRGS (Italian Relative Gravity Station) (see Fig. 3 and Table 1), it was located in the proximity to the helipad and was repeatedly connected to the IAGS by a sequence of 16 gravimetric ties from 5 January to 3 February 1991. The result, given as mean value and error of the mean, is:

$$g_{\text{IRGS}} = 982 863.89 \pm 0.033 \text{ mgal}$$

Gravity links were also performed between the IRGS and the Gravity Station Scott Base I-1957 (GSSB, not coinciding with an IGSN71 site) in both the 1989/90 and 1990/91
expeditions, and produced the following average value:

\[ g_{\text{GEOH}} - g_{\text{IRGS}} = 112.97 \pm 0.04 \text{ mgal} \]

Further ties to base stations will hopefully provide the absolute gravity datum for all surveys in North Victoria Land.

**The Mt. Melbourne Gravity Network**

Monitoring of the volcanic activity of Mt. Melbourne began in 1988. Five shallow bore-hole tilt stations and four seismic stations have been installed (Bonaccorso *et al.*, 1991a, 1991b), supplemented by a network of fourteen gravity and GPS sites (Fig. 5). During the 1989/90 expedition, gravity measurements were made at the network sites and the IRGS station. A LaCoste and Romberg gravimeter, model G number 927 was transported by a helicopter. Measurement at the IRGS was repeated at least every three hours, to compute and remove the instrumental drift. The coordinates and the adjusted gravity values plus standard deviation are reported in Table 1.

Despite the appreciable height differences of some sites and use of the helicopter, the results are reasonably good. The errors of the \( g \) values, of course, place a significance limit to the gravity variations detectable by the Mt. Melbourne network.

A preliminary Bouguer gravity map was computed, based on the 1967 formula for normal gravity and the density of 2.67 g/cm\(^3\) for the Bouguer correction. Initial digitalization of the topography was also undertaken to compute terrain corrections. The map of the complete Bouguer anomaly and the location of the sites are shown in Fig. 5. Its predominant feature is a pronounced SE-NW anomaly gradient, with the regional contours oriented roughly parallel to the coastline.

A high gradient from large negative Bouguer anomaly values over the Transantarctic Mountains to a generally positive ones over McMurdo Sound has been modelled as a thinning of the crust (from 40 to 27 km) from the mountains to the sound, combined with the effect of a high density zone at mid-upper crustal depths beneath it (Bennet and Sissons, 1984).

As part of the GANOVEX IV geophysical program in North Victoria Land, Durbaum *et al.* (1989) performed a gravity traverse across the Transantarctic Mountains from Mt. Melbourne to the Polar Plateau. Their results mainly show an anomaly decrease of more than 300 mgal northwards from the Ross Sea coast at Gerlache Inlet to the Polar Plateau near the origin of the Priestley Glacier, and

![Fig. 5. The Mt. Melbourne gravity network with schematic Bouguer anomaly contour lines (with terrain correction).](image-url)
are in agreement with the Antarctic crust models of Bentley (1983) and Kadina et al. (1983), showing: (i) strongly negative gravity anomalies in Victoria Land, where the mean crustal thickness is 40 km and (ii) high positive anomaly gradients between the Transantarctic Mountains and the Ross Sea, with a crustal thinning of about 15–20 km (Bozzo and Meloni, 1992). Additional data have been collected by Redfield et al. (1991) along the coast, linking the South of the Drygalski ice tongue to existing measurements within the Mt. Melbourne quadrangle (Redfield et al., 1992). These workers suggest that a substantial mass difference exists between the coastal areas of Mt. Melbourne quadrangle and those south of the Drygalski ice tongue.

Conclusions

Our absolute gravity measurements constitute the first high-accuracy determination of the gravity datum in Antarctica. They have demonstrated the feasibility of using transportable absolute gravity meters for geodetic and geophysical purposes, even in difficult and unusual environmental conditions.

The GPS and gravity network was established to study time-dependent gravity variations related to ground deformation and mass movements associated with the volcanic activity of Mt. Melbourne (see Kuroishi et al., 1991). It complements the ground tilt and seismic network operating at Terra Nova Bay Station, and is an initial step towards the carrying out detailed gravity surveys to provide additional constraints for investigations of the features of the Antarctic lithosphere in North Victoria Land and the Ross Sea region.

Acknowledgements

The Authors thank Antonio Marchetta and Renzo Maseroli of Istituto Geografico Militare and Daniele Postpischl and Alberto Gabellini of the Geodetic Team (PNRA) for their GPS measurements.

REFERENCES


