Current Status and Future Prospects for the Australian Antarctic Geodetic Network

Gary Johnston, Nicholas Brown and Michael Moore

Abstract The Australian Antarctic Geodetic Network consists of over 400 survey marks installed since the 1960's. This multipurpose network provides pivotal information for the International Terrestrial Reference Frame and allows us to monitor the movement of tectonic plates and the intraplate movement of the Antarctic continent. Furthermore, it supports many Australian science initiatives including post glacial rebound studies, rifting in the Amery Ice Shelf and geological mapping. Originally established using terrestrial surveying techniques, the accuracy of Network has improved over time with the help of space based techniques and in the future, as more continuous GPS sites become active, the potential science outcomes will increase significantly.

1 Background

The Australian Antarctic Geodetic Network (AAGN) (Geoscience Australia, 2001) is an essential component of the global reference frame which supports science programs such as plate tectonics, sea level rise, post-glacial rebound and geospatial activities such as mapping. Over the years, geodetic survey marks have been installed in rock outcrops and observed using both conventional surveying and space geodetic techniques (Fig. 1).

Major installation campaigns took place in the northern Prince Charles Mountains (PCM's) from 1965 to 1976, the southern PCM's in the 1970's which included Mt Komsomolskiy, the most southerly exposed rock site in the PCM's. Observations to these sites were performed using intersecting angles and loops of angle and distance observations, some of which were greater than 100 km long.

Gary Johnston
Geoscience Australia, GP0 Box 378, Canberra, ACT 2601

Nicholas Brown
Geoscience Australia, GP0 Box 378, Canberra, ACT 2601

Michael Moore
Geoscience Australia, GP0 Box 378, Canberra, ACT 2601

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Fig. 1 Classical terrestrial surveying techniques (*left*) and GPS space based technique (*right*)

In more recent years, space geodetic observations, firstly Doppler NAVSTAR techniques and then the Global Positioning System (GPS) have been used to strengthen the geodetic network. GPS negated the need for stations intervisibility and consequently baseline lengths could be increased until intercontinental baselines were achievable.

Since 1990, GPS has been the primary tool for geodetic surveying in the AAGN. Originally it was used in an exclusively baseline mode over relatively short distances to improve to the accuracy of the existing network, and more recently it has allowed the establishment of new stations in a short period of time.

2 Status of Australian Antarctic Geodetic Network

The AAGN (Fig. 2) is comprised of 403 survey marks which extend from Proclamation Island (65°50′S) to Mt. Komsomolskiy (75°16′S) and from Campbell Nunatak (110°45′E) to Widows (45°27′E). The horizontal positional uncertainty (Table 1) of these survey marks varies greatly across the area due to the manner in which they have been observed, that is, by conventional techniques or by GPS.

In late 1993 Continuous GPS (CGPS) sites were established at Casey, Davis and Mawson (Fig. 3) and in the June of 1995, Macquarie Island was introduced as the fourth CGPS site in the AAGN (Geoscience Australia, 2008). Data from these CGPS sites is transferred back to Australia for distribution to the international community, in particular the International GNSS Service (IGS) (IGS, 2008).

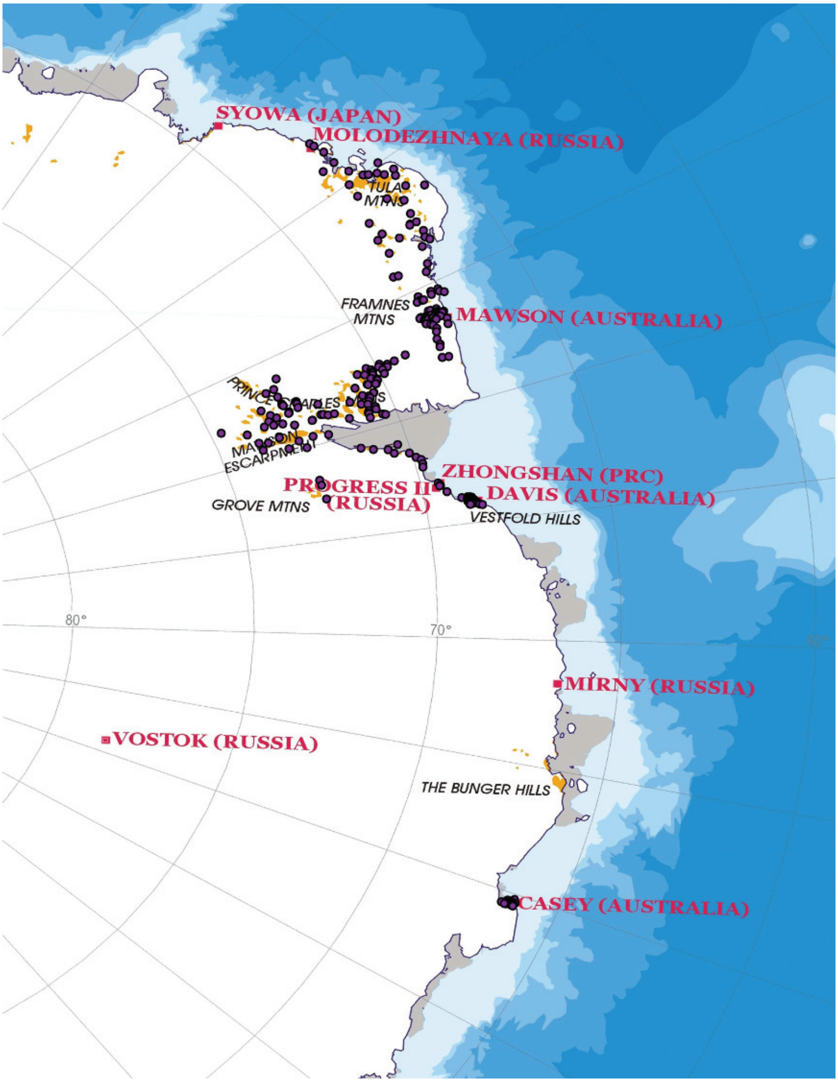

Fig. 2 The AAGN

Table 1 Summary of horizontal positional uncertainties of all AAGN sites

Horizontal Positional Uncertainty (m)	Number of Sites
< 0.01	51
0.02–0.05	29
0.06–0.10	51
0.11–0.50	86
0.51–2.00	85
> 2.00	101

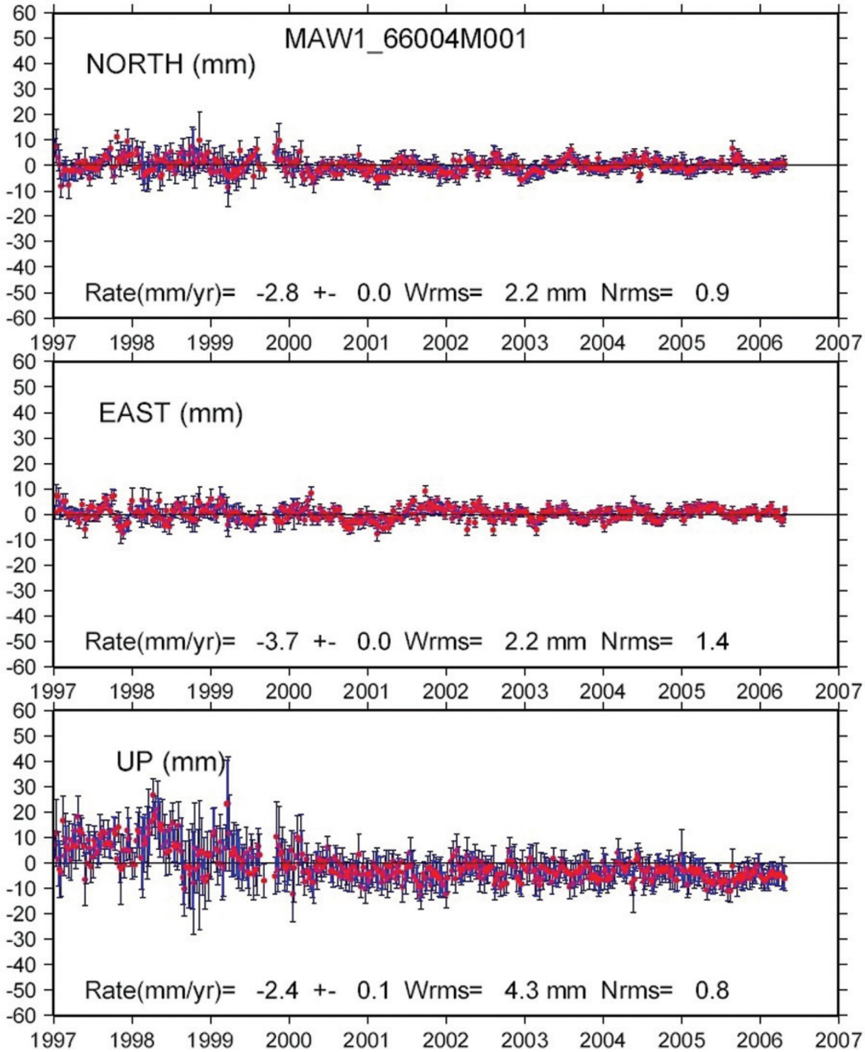

Fig. 3 GPS time series from Casey, Davis and Mawson CGPS stations from 1997 to 2007

Data from these sites is processed by the IGS analysis centres to determine coordinates for the stations in the latest International Terrestrial Reference Frame (ITRF, 2008) (currently ITRF2005). The remainder of the AAGN is constrained to the ITRF coordinates of these four stations and adjusted using Least Squares techniques, thus propagating ITRF2005 coordinates through the network.

In recent years, Geoscience Australia and The Australian National University has been attempting to augment the CGPS network with pseudo / part-time CGPS sites in the Grove Mountains (2000–2007), (Fig. 4) Wilson Bluff (2002–2007), Landing Bluff (2000–2004), Dalton Corner (2000), The Bunger Hills (2006–2007) and

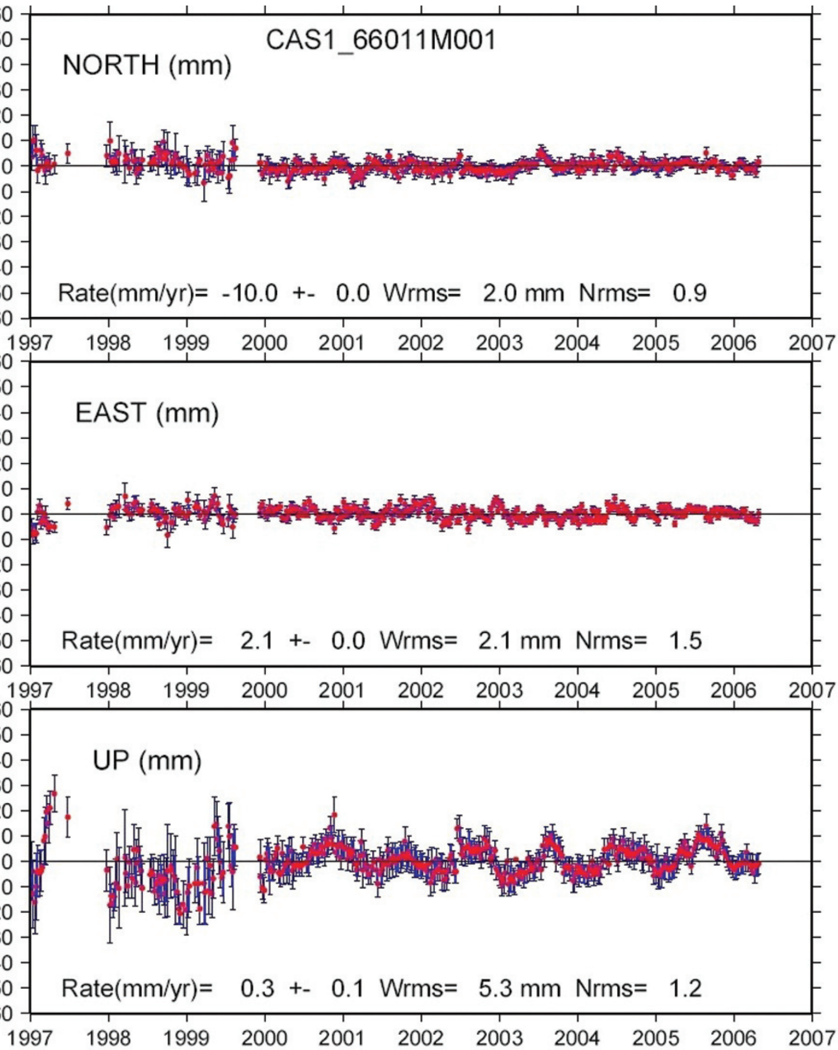

Fig. 3 (continued)

Richardson Lake (2006–2007). To date, the sites operate predominantly over the Austral summer period when solar power maintains battery voltage; however, sustaining power supply in the winter months continues to be difficult. Geoscience Australia has attempted to use wind turbines to charge the batteries with little success to date.

Since 1997, Geoscience Australia has also been undertaking GPS campaigns to upgrade the AAGN. These campaigns have concentrated on the southern PCM's

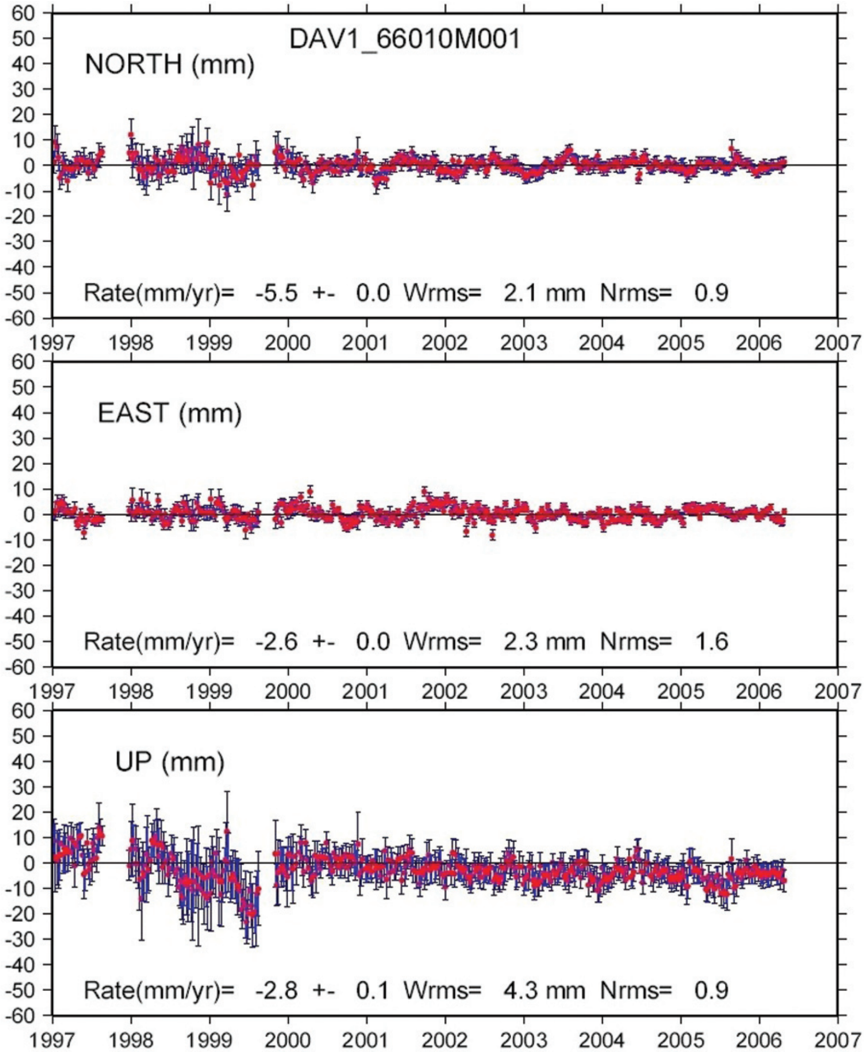

Fig. 3 (continued)

where large coordinate uncertainties exist due to cumulative propagation errors from the constrained sites at Davis and Mawson.

The biggest of these campaigns was the Prince Charles Mountains Expedition of Germany and Australia (PCMEGA). A network of twenty-one accurate geodetic/geodynamic control points was established over the southern PCM's, a number of which were placed adjacent to existing AAGN stations and connected using terrestrial observations (Fig. 5). Geodetic GPS observations from these stations have significantly improved the accuracy of the AAGN and it will allow neotectonic

Fig. 4 Pseudo/Part time continuous GPS sites at Grove Mountains and Bunger Hills

research to be undertaken once a second epoch is observed. A summary of CGPS and campaign GPS data observed in the AAGN to date is shown in Table 2.

Gravity observations were also taken at twenty-four stations during PCMEGA and connected back to the Mawson and Davis gravity network marks (Geoscience Australia, 2004). These results permit ground calibration for the airborne gravity

Table 2 Geoscience Australia's GPS data catalogue

Region	1995	1998	2000	2001	2002	2003	2004	2005	2006	2007
Amery Ice Shelf				■						
Bunger Hills									■	
Casey	■	■	■	■	■	■	■	■	■	■
Davis	■	■	■	■	■	■	■	■	■	■
Richardson Lake										■
Grove Mountains			■	■	■	■	■	■	■	■
Heard Island	■		■	■		■	■			
Landing Bluff			■				■			
Larsemann Hills		■	■	■			■	■		■
Macquarie Island	■	■	■	■	■	■	■	■	■	■
Mawson	■	■	■	■	■	■	■	■	■	■
PCM's		■	■		■	■	■			■
Rauer Islands							■			

Fig. 5 PCMEGA GPS observations have strengthened the geodetic network

surveys as well as a densification of the gravity network which is very sparse over this part of Antarctica.

3 Vestfold Hills Geometric Geoid Determination

The Vestfold Hills is a worksite and playground for all expeditioners at Davis station. Those venturing into the Vestfold Hills from Davis station are commonly using GPS as a tool for science and navigation. Given that GPS receivers only capture the height above the ellipsoid, Fig. 6 displays the need to convert this value to the orthometric height, that is, a more practical height which approximates the height above means sea level (MSL).

The height above MSL (H) is closely approximated by the ellipsoidal height (h) (acquired by GPS) minus the geoid to ellipsoid separation (N).

Due to the sparseness of ground gravity data and geometric control over Antarctica, a local gravimetric geoid model is not readily available. Currently, the best geoid model available is the Earth Geopotential Model 1996 (EGM96) (NASA, 2004), however, it has inaccuracies due to the fact that most of the satellites utilised for data capture were not polar orbiting and geometric control of the satellite orbits is weakest in the southern latitudes. The consequence is an inaccurate gravimetric geoid model over Antarctica.

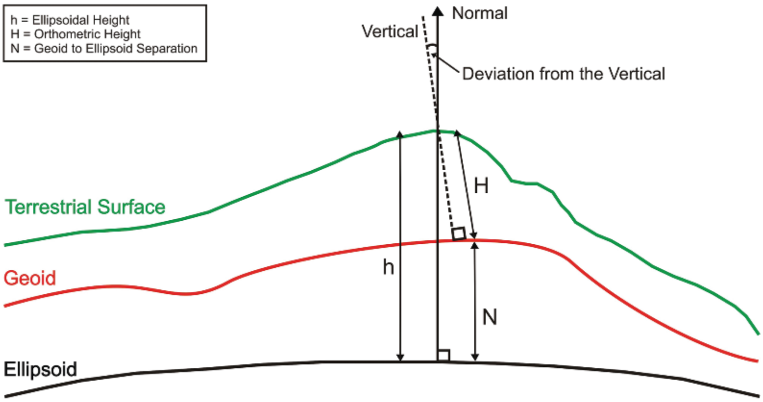

Fig. 6 Offsets between the ellipsoid, geoid and terrestrial surface

The Vestfold Hills contain many saline and freshwater lakes. To facilitate the accurate measurement of their heights 90 benchmarks were placed in the vicinity of each of these lakes through the 1980s and the majority of them have been connected to the Davis height datum using third or fourth order-levelling techniques.

These benchmarks have been used to create a geometric geoid. GPS observations were recorded on 23 of these benchmarks by Geoscience Australia and students from the University of Tasmania to compute the ellipsoidal heights. The geoid to ellipsoid separation value is derived by subtracting the orthometric height (observed by levelling) from the ellipsoidal height.

The derived geoid to ellipsoid separation values were used to develop a geometric geoid over the Vestfold Hills (Fig. 7). The benchmarks closer to the plateau (eastern side of Fig. 7) have not been connected to the Davis height datum and as a result the grid is weaker in that part of the Vestfold Hills, however, it is a more accurate representation of the geoid to ellipsoid separation values than the EGM96 (Fig. 8) which differs from the geometric model by approximately two meters near the plateau. This shift is possibly due to a lack of data in the EGM96 model.

This is only the first attempt at creating a geometric geoid for the Vestfold Hills and will undoubtedly be strengthened in future seasons as more of these lake benchmarks are coordinated using accurate GPS techniques.

4 Future Prospects

Increasingly, users of the AAGN are expecting it to be an active network rather then a passive network consisting of unoccupied survey marks. Already researchers are using GPS equipment of their own to position themselves within the framework of the ITRF as realised through the CGPS sites at Casey, Davis and Mawson. Therefore, the need to enhance the accuracy of the existing marks based control

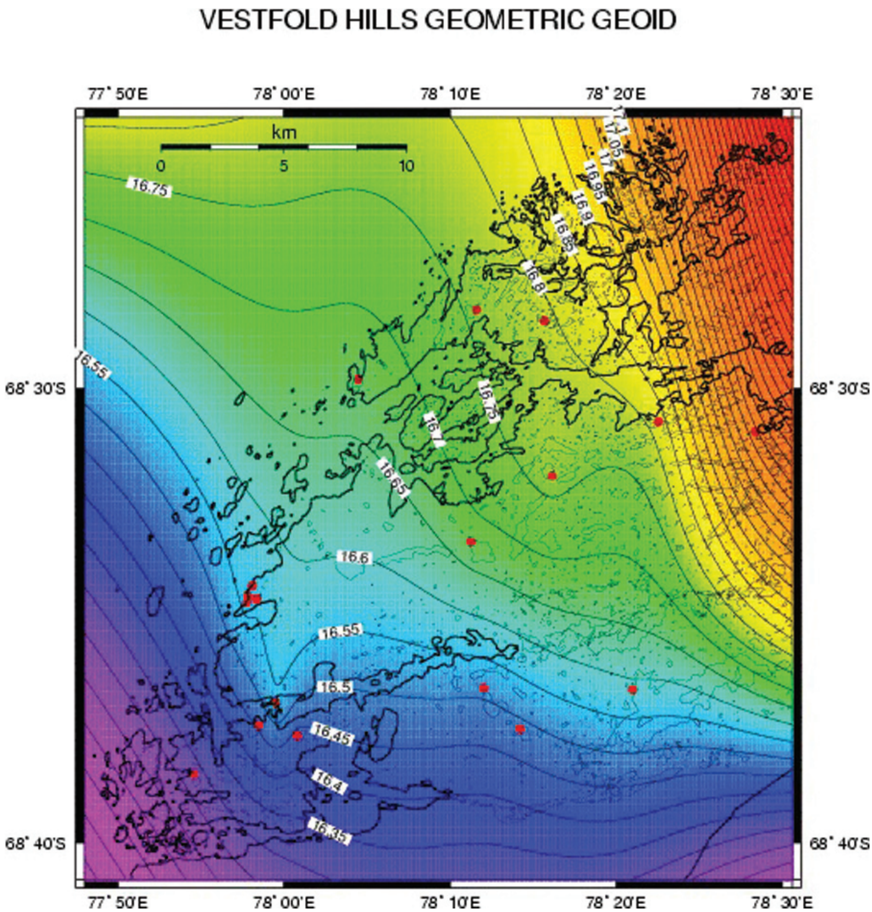

Fig. 7 Vestfold Hills Geometric Geoid

network is diminishing and the need for active Global Navigational Satellite System (GNSS) stations whose data is available to the broader research community is increasing.

Research fields such as neotectonics and post glacial isostatic rebound require accuracies only achievable using CGPS. Effort needs to be placed in developing autonomous remotely operating systems that operate reliably over both summer and winter periods. This will also allow the study of the seasonal effects on tectonic motion not to mention a large variety of glaciological topics. In addition to CGPS, site targeted campaigns of the type undertaken during PCMEGA will continue with the aim of direct geophysical interpretation rather the network enhancement.

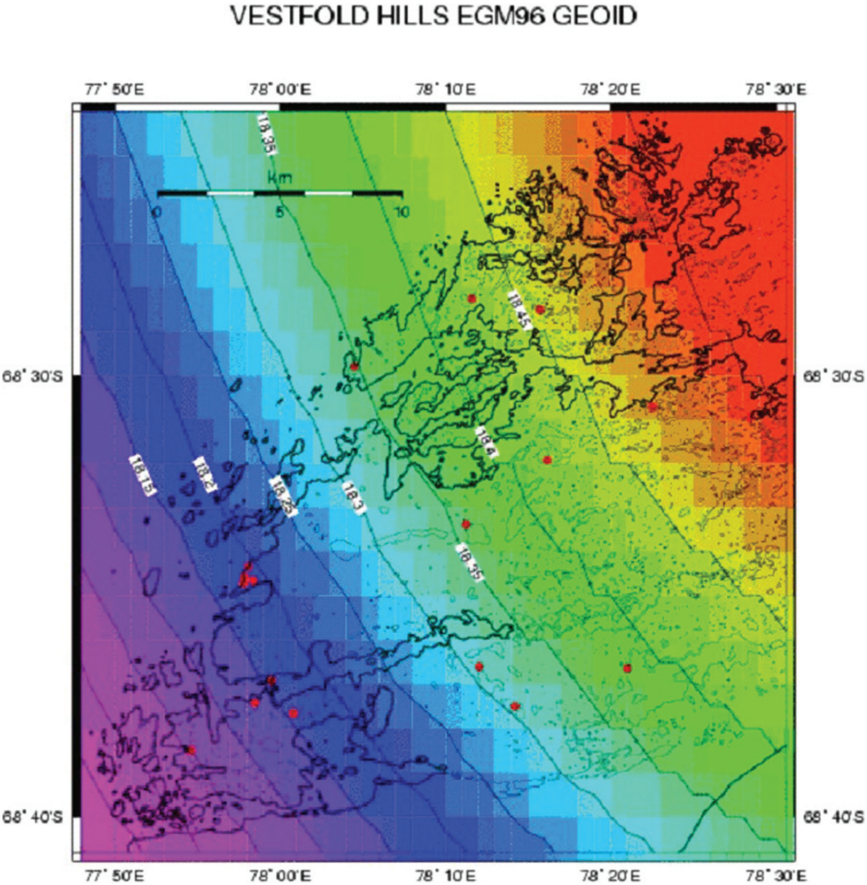

Fig. 8 Vestfold Hills EGM96 Geoid

The integration of GNSS with gravimetry and satellite based observations like GRACE (NASA, 2008) and InSAR will reveal geodetic accuracies not previously imagined.

5 Conclusion

Geodetic networks are a continually evolving infrastructure. As user requirements change and new techniques become available the design and functionality of the network needs to change as well. In the near future, there will be an increasing demand for a more active GNSS network and there is an emerging interest in the use of gravimetry as an independent constraint on height variation. Finally, the integration of all ground based techniques with the satellite techniques will result in a better understanding of the dynamics of Antarctica at local, regional and continental scales.

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