Evaluating EGM2008 over East Antarctica

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Abstract

The release of EGM2008 and associated products such as grids of mean dynamic ocean topography offer the possibility of utilising the extensive historical record in Antarctica with today's modern satellite sensing techniques. In this study, we use data acquired at the Mawson, Davis, Casey and Scott and McMurdo stations in East Antarctica to investigate the performance of EGM2008 over this region. EGM2008 over Antarctica is entirely dependent on the EGM2008-adopted global GRACE satellite-derived gravity field. This is in contrast to most other regions of the Earth, where there are also contributions from terrestrial gravity and/or altimeter satellites. We determine, over East Antarctica, and at our four test sites that EGM2008 should be used with caution when precisions better than one metre are required. The precisions at the test sites are better than this, but the evidence is that the four test sites are probably not representative of the large area of East Antarctica they are being forced to represent. Notwithstanding any of the above, EGM2008 represents a significant step forward in East Antarctica and that the use of test stations and regions where there is little or no complementary data is a valid method of investigating the performance of the model.

1. Introduction

The needs and uses for heights relative to the geoid in Antarctica are as great as elsewhere over the Earth's surface; it is just that the applications are different. Of particular importance, at this moment, are studies aimed at re-evaluating and connecting historical surveys with modern surveys for the task of deducing ice mass change over decadal time periods.

In the Australian ANARE (Australian National Antarctic Research Expeditions) context, extensive optical levelling surveys were done on the Amery Ice Shelf and the Wilkes Local Ice Cap (cf. Figure 1).

- On the Amery Ice Shelf, Corry (1986, 1987 and 1996) observed a central flow line of some 400 km in 1968. In 1996, Phillips and Craven (Phillips 1999) recovered eight of the original poles placed by Corry in 1968. King et al. (2007) performed a complete re-adjustment of Corry's horizontal observations, and then made a comparison with GPS and INSAR data. The height data has now been reprocessed and comparative studies made with ICESat and GPS data (King et al. in press).
- On the Wilkes Local Ice Cap, optical levelling was undertaken by McLaren in 1965 (McLaren 1968) and Pfitzner the following year (Pfitzner 1980). A re-occupation program was trialled in the Austral Summer of 2004-2005 with GPS and ICESat observations. This data is not yet fully analysed due, in part, to the datum connection difficulties and, in part, due to difficulties associated with estimating ice flow velocities.

Figure 1 is an AVHRR (Advanced Very High Resolution Radiometer) image of Antarctica. It shows the Trans Antarctic Mountains, which divide the continent into East and West Antarctica. The two regimes are very different. East Antarctica is dominated by the high plateau, in-excess of 3000 m altitude, and steep slopes to the coast, which is generally in close proximity to the Antarctic Circle. West Antarctica is lower, generally about 2200 m in elevation. The West Antarctic coastline is far from uniform with two major seas, Ross and Weddell, extending to 78°S and a third smaller sea, Bellingshausen, extending to 72.5°S.

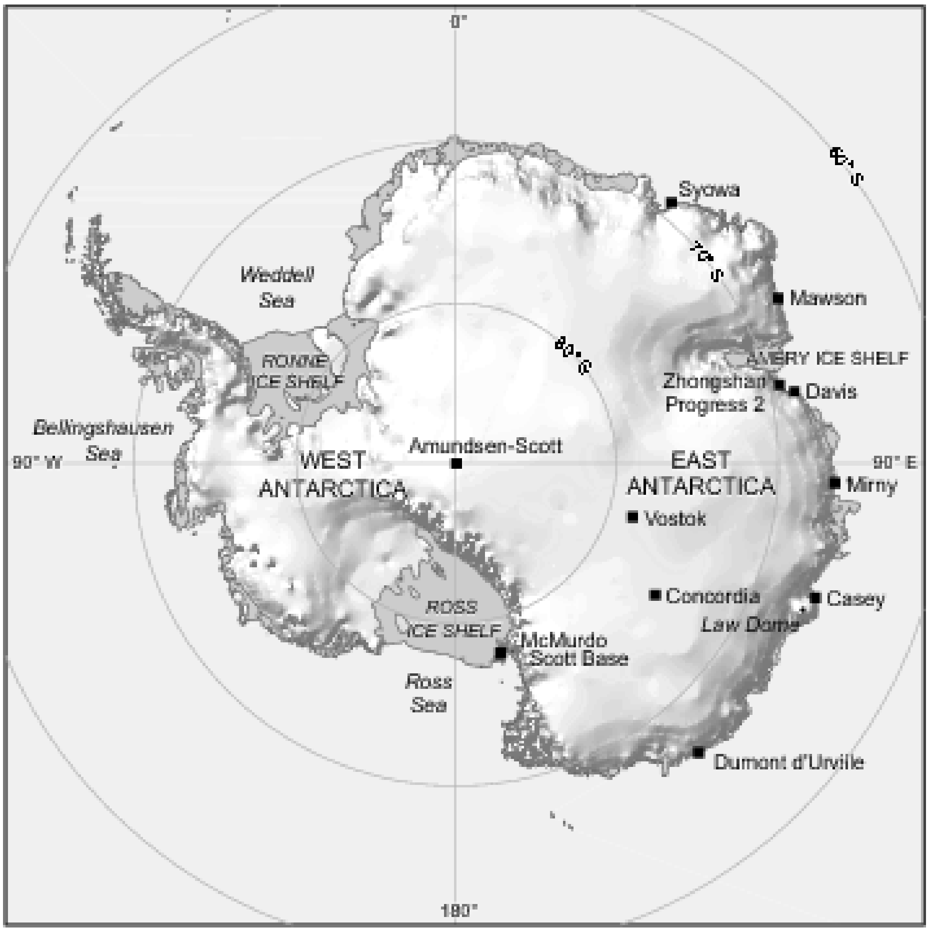

Figure 1: Map of Antarctica derived from AVHRR imagery. Polar stereographic projection with elevation shading and principal ice shelves and the three major regional seas.

EGM2008 (Pavlis et al. 2008) uses three principal data types to derive a new Earth Gravity Model, which seeks to overcome many of the limitations of the earlier EGM96 model (Lemoine et al. 1998).

1. Terrestrial gravity anomalies. In Antarctica, terrestrial gravity observations were an integral part of the major over-snow traverses programmes conducted during the IGY(International Geophysical Year) 1957-1958 and the decade there after (see, e.g., Thiel et al. 1959, Hollin 1961 and Walker 1966). Unfortunately, these positions were poorly constrained until satellite Doppler positioning was introduced in the late 1970s, at which time the height system was changed to the geometric ellipsoidal system. Thus, it is not too surprising that EGM2008 contains no terrestrial gravity data over Antarctica.
2. Altimeter satellite-derived anomalies. There are two sources of gravity anomalies derived from altimeter satellites.

The first is the Sandwell data (cf. Sandwell and Smith 1997; http://topex.ucsd.edu/marine_grav/). Sandwell uses data from GEOSAT and ERS1, which imposes two limitations on the data set. The first is that the inclination of GEOSAT, 108 degrees, limits GEOSAT data to the band 72°S to 72°N. ERS1 has an inclination of 92 degrees and therefore significantly extends coverage in the Polar Regions. The second limitation is the footprint of the imaging system. In radar satellites such as GEOSAT, the effective size of this footprint varies from 2 km to 10 km depending antenna characteristics, the width of the transmitted pulse and surface roughness (e.g., Rees 2001). The impact is that as the footprint size increases, the reliability of heights decrease, especially when there is significant surface roughness or surface slope.

The second data set is that from the Danish National Space Center, DNSC, (http://www.space.dtu.dk/english.aspx). DNSC use data from many more satellites including ICESat, which has a 70 m footprint and a 94 degree inclination. The use of ICESat data for the recovery of gravity anomalies was pioneered by DNSC staff (Forsberg and Skourup 2005). Zwally et al. (2008) have also shown that gravity anomalies and sea-ice fee board data can be recovered from ICESat data using data over the Weddell Sea offshore West Antarctica (cf. Figure 1). The caveats for such processing include the level of bias in the "lowest-level" filtering scheme and the level of *a priori* knowledge assumed.

EGM2008 seeks to use the strengths of both the Sandwell and DNSC data sets. Thus, EGM2008 uses Sandwell data over the open oceans, while the DNSC data is used for the 195-km-wide coastal zone. There is also a transition zone over which this change occurs (Pavlis 2008, pers. comm.).

3. Global satellite gravity fields are regularly determined from the GRACE satellites in several modes (http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html). GRACE-only solutions have been published by: The Center for Space Research at the University of Texas (//http://www.csr.utexas.edu/grace/), GeoForschungsZentrum Potsdam (http://op.gfz-potsdam.de/grace/index_GRACE.html) and Institut für Geodäsie und Geoinformation, University of Bonn (http://www.geod.uni-bonn.de/), among others. EGM2008 uses the ITG-GRACE03s model, extending to degree and order 180 (http://www.geod.uni-bonn.de/itg-grace03.html). The limiting degree of the model is controlled by the crossover between signal recovery and calibrated, formal, errors. The initial presentation of this model at the Joint

International GSTM and DFG SPP Symposium in Potsdam on 15 October 2007 discussed model striations, particularly their likely causes. An alternative static model by Tapley et al. (2005) only extends to degree 120.

The problem faced in East Antarctica is that only data type 3 contributes to EGM2008, whereas most other regions, including the Arctic, have at least one additional data type.

2. The Functional Model

This study uses the well-known relationship between ellipsoidal height, h; orthometric height, H; mean dynamic topography of the ocean, MDT, and the geoid-ellipsoid separation, N:

$$h = (H\_msl + MDT) + N \quad (1)$$

where H_msl is the mean sea level (MSL) height of the tide gauge bench mark (TGBM), which needs to be 'corrected' to the geoid with the prevailing MDT.

3. Description of the Data

Some 30 nations operate Antarctic stations or bases (http://en.wikipedia.org/wiki/List_of_research_stations_in_Antarctica). Many of these nations contribute GPS data to the IGS (International GNSS Service) network, (http://igscb.jpl.nasa.gov/network/netindex.html). Seven stations in East Antarctica also contribute tide gauge data to the GLOSS network (http://www.gloss-sealevel.org/). The Antarctic programmes undertaken by most nations, especially in this instance by Australia and New Zealand, include precision levelling between the TGBM and the IGS GPS antenna, and precision GPS observations at the TGBM (http://www.antarcticanz.govt.nz and http://www.ga.gov.au/geodesy/antarc/antgauge.jsp).

This data provides the classical estimates of both the levelled height with respect to MSL, H_msl, and the ellipsoidal height, h, at the station IGS GPS receivers, the local TGBM and associated reference and intermediate marks of interest, e.g., marks used in previous geodetic missions such as PAGEOS (http://en.wikipedia.org/wiki/PAGEOS) or old IGS sites. In addition to this need, there have been special needs for levelled heights to determine the elevations of raised beaches, and aircraft runways. A notable example is the Vestfold Hills Survey, in the vicinity of the Davis Station (Johnston and Digney 2001).