Modelling recent airborne gravity data over the Antarctic Peninsula for regional geoid improvement

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Summary There is a strong link between SCAR and IAG bodies in promoting long-term efforts to close the continental-wide data gaps that still remain in terrestrial gravity coverage over Antarctica. Airborne gravimetry provides the only feasible technique to survey large areas. A variety of aerogravity surveys have been accomplished, and several new ones are planned within the framework of the International Polar Year 2007/2008. In the Antarctic Peninsula region, the British Antarctic Survey has carried out a number of airborne and terrestrial gravity surveys. We have chosen Palmer Land to determine the regional geoid, since a recent aerogeophysical survey provides high-quality and homogeneous gravity data. To improve the regional geoid the Remove-Compute-Restore technique is applied, where long-wavelength information from a global satellite-derived gravity field model and short-wavelength information from topography are utilized. Our regional geoid improvement adds a threshold of about 5m to the global model and shows several new details.

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Gravity field in Antarctica and the benefit of aerogeophysics

Huge gaps in terrestrial gravity data coverage remain in Antarctica. Due to its vast extent and hostile environment, detailed surveys are both difficult and restricted to relatively small areas.

The only technique capable of surveying larger areas is aerogravimetry, e.g. (Bell et al., 1999). An accelerometer measures the specific force in the vertical direction, which, subtracted from kinematic vertical acceleration yielded by GPS, gives the scalar gravity. GPS data (and Inertial Navigation System (INS) data when available) provide the necessary correction terms to account for the moving reference frame induced by the airplane. Standard airborne gravity surveys utilize modified LaCoste-Romberg or BGM-3 air-sea gravimeters. Additional geophysical equipment, like ground penetrating radar (to measure ice surface, internal ice layers and bedrock), magnetometers and laser altimeters or scanning lasers, may enhance the capabilities of aerogeophysical platforms.

When examining the global gravity field solutions, it becomes clear that a big step forward has been made with two dedicated satellite gravity missions already in orbit (CHAMP and GRACE). A third mission, GOCE, will be started by the end of the year. However, the satellite data feature two significant limitations when investigating the Antarctic continent. First, there is still a polar gap due to the orbit inclination of the satellites. For GRACE this gap is about 100km (diameter due to orbit inclination of 89.5°), for GOCE it will be larger with about 1300km (orbit inclination 95.5°). Second, in the standard gravity field solutions provided by the analyses centers, the resolution (full wavelength) is limited to about 300km for GRACE and 200km for GOCE. This is due to the characteristics of the observation techniques and to the global harmonic base functions used to determine the solutions. Hence, there is the need to close the polar data gap and to densify the information provided by the satellite missions in order to improve spatial resolution.

In order to pursue the goal to reach a complete terrestrial gravity data coverage in Antarctica the International Association of Geodesy (IAG) Commission Project 2.4 "Antarctic Geoid" was initiated, and is chaired by the lead author (Scheinert, 2005). Its geodetic background is to contribute to the determination of the outer gravity field of the earth, i.e. to determine a detailed geoid in Antarctica. This goal can be reached only in close cooperation with other Antarctic sciences, especially geophysics. Therefore, a close linkage is being maintained with the Scientific Committee on Antarctic Research (SCAR) Expert Group on Geodetic Infrastructure in Antarctica (GIANT) and its work program project 3 "Physical Geodesy" (chaired by M. Scheinert and A. Capra) (Scheinert et al., 2006).

The International Polar Year 2007/2008 offers a promising framework for new aerogeophysical surveys. Within several IPY projects it is planned to carry out such surveys, e.g. (Studinger et al., 2006). Together with further activities like ground based gravity surveys and static observations (absolute and tidal gravimetry) this will substantially improve the data foundation to determine the Antarctic geoid and gravity field.

Our presentation focuses on the Antarctic Peninsula. In this region, a variety of gravity surveys has been conducted by the British Antarctic Survey (BAS) over the last decades. Data coverage and the process of the regional geoid improvement will be discussed in the following sections.

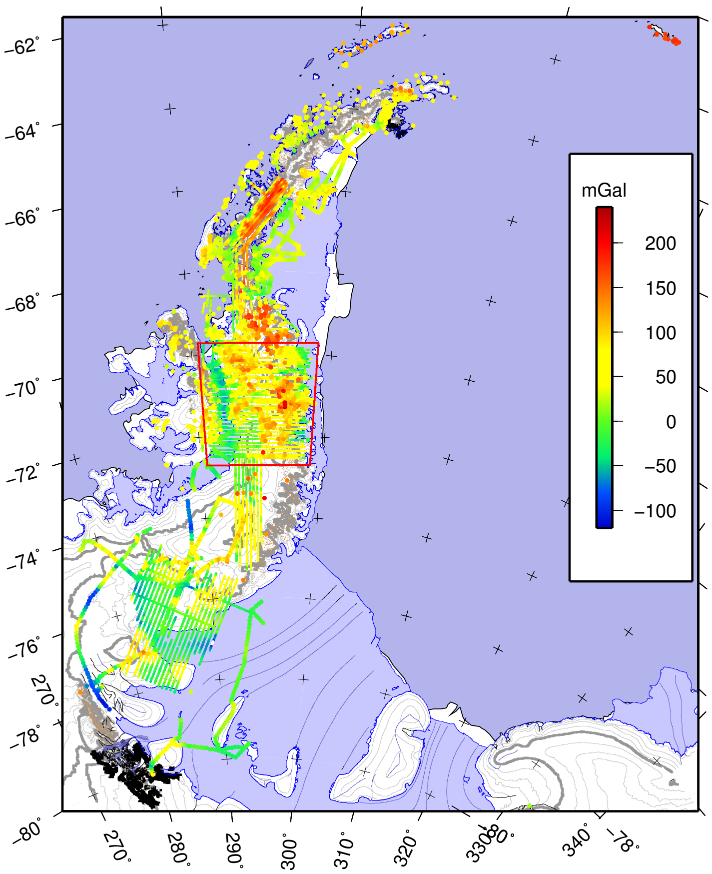

Figure 1: Overview on the BAS gravity data holdings for the Antarctic Peninsula region. Free-air gravity values are plotted as color-coded points, thus revealing the airborne flight grids and ground-based gravity lines, respectively. The red box denotes the area of our new regional geoid. (Map source: SCAR Antarctic Digital Database v4.0)

Aerogravity and land-gravity surveys

Approximately 20,000 line km of new aerogravity data were acquired over Palmer Land during the 2002/2003 field season (Ferraccioli et al., 2006). A previous survey was flown over the Evans Ice Stream region and collected approximately 11,500 km of airborne gravity data (Jones et al., 2002). Together with gravity data obtained during earlier land-based surveys (Renner et al., 1985; Maslanyj, 1991; McGibbon and Smith, 1991; Herrod and Garrett, 1986) these form the source for BAS gravity data holdings over the Antarctic Peninsula region. Free-air gravity anomalies derived from airborne gravity have mean accuracies of 5 mGal or less for wavelengths greater than 9 km. Complete Bouguer and isostatic anomalies have been computed from aerogravity and utilized to discuss compositional and tectonic segmentation of the Antarctic Peninsula magmatic arc (Ferraccioli et al., 2006) and to delineate subglacial rifts under the Evans Ice Stream (Jones et al., 2002). More recently airborne gravity data have provided a geophysical tool to study the setting and interior of James Ross Island, a prominent Antarctic volcano (Jordan et al., 2007). Land-gravity observations have also been used in combination with regional aeromagnetic data to study the Antarctic Peninsula magmatic arc, but the sparseness of the data hindered detailed geological interpretations (Garrett, 1990). The data coverage is shown in Fig.1, where gravity data points from all surveys (airborne and terrestrial) are combined. The red box shows the Palmer Land region, where a regional geoid improvement was carried out.

Regional geoid determination over Palmer Land

To determine a new regional geoid over the Palmer Land region, the so-called “Remove-Compute-Restore Technique” (RCRT) is utilized (Forsberg and Tscherning, 1997). This technique has previously been successfully applied for regional geoid improvements over East Antarctica in the Prince Charles Mountains region (Scheinert et al., 2007) and in Dronning Maud Land (Müller et al., 2007).

The different steps of this technique are illustrated in Fig.2. The upper left panel (Fig.2a) shows the original gravity data at the nominal flight level (2,800m). Since the normal gravity values (system GRS80) used for reduction of the airborne gravity data were computed at the same (nominal) flight level, the resulting values are gravity disturbances according to the geodetic definition (Hackney and Featherstone, 2003). Furthermore, the physical earth surface has been chosen as boundary surface. Practically, this is accomplished in such a way that the bedrock topography (Fig.2b) and the (mean) ocean surface are used, respectively. The effect of the ice cover is reduced in the gravity disturbances by the application of a modified Bouguer reduction taking the ice thickness heights into account. Considering the choice of the boundary surface, where the gravity disturbances are referred to, the surface that will be computed by the RCRT is the quasigeoid instead of the geoid. The quasigeoid is a surface that runs close to the geoid and coincides with the geoid at the oceans.

Both surfaces can be easily transformed into each other.

In the remove step, a long-wavelength gravity signal is substracted from the gravity disturbances using the global model EIGEN-CG03C (Förste et al., 2005) up to degree and order 120, i.e. equivalent to a spatial resolution of approx. 300km. This information comes from the satellites CHAMP and GRACE only and can therefore be regarded as consistent and homogeneous. The quasigeoid effect of this band-limited global model is shown in Fig.2c. A short-wavelength signal is then subtracted from the data using the bedrock topography (Fig.2b) that was taken from the BEDMAP project (Lythe et al., 2000). Since the gravity disturbances are highly correlated with bedrock topography, this remove step resembles the computation of Bouguer anomalies and reduces the high-frequency content in the data. In the compute step, the resulting bandpass-filtered gravity disturbances are transformed into a band-pass filtered quasigeoid using a least-squares collocation method (Tscherning and Rapp, 1974). Finally, the quasigeoid effects of the global model and of the topography are added back yielding the improved regional quasigeoid. The preliminary result is shown in Fig.2d. All computations were carried out using the GRAVSOFT package (Forsberg et al., 2003). By comparing the quasigeoid from the global gravity model (Fig.2c) with our new (preliminary) regional quasigeoid (Fig.2d) it can be seen that the latter adds a further signal threshold of about 5 m and many more details due to the higher resolution of the airborne gravity and topography data.

Conclusion

Airborne gravity data have been used to derive an improved regional (quasi-) geoid for Palmer Land, Antarctic Peninsula. The great value of aerogeophysical observations has also been discussed. We anticipate to extend the regional geoid

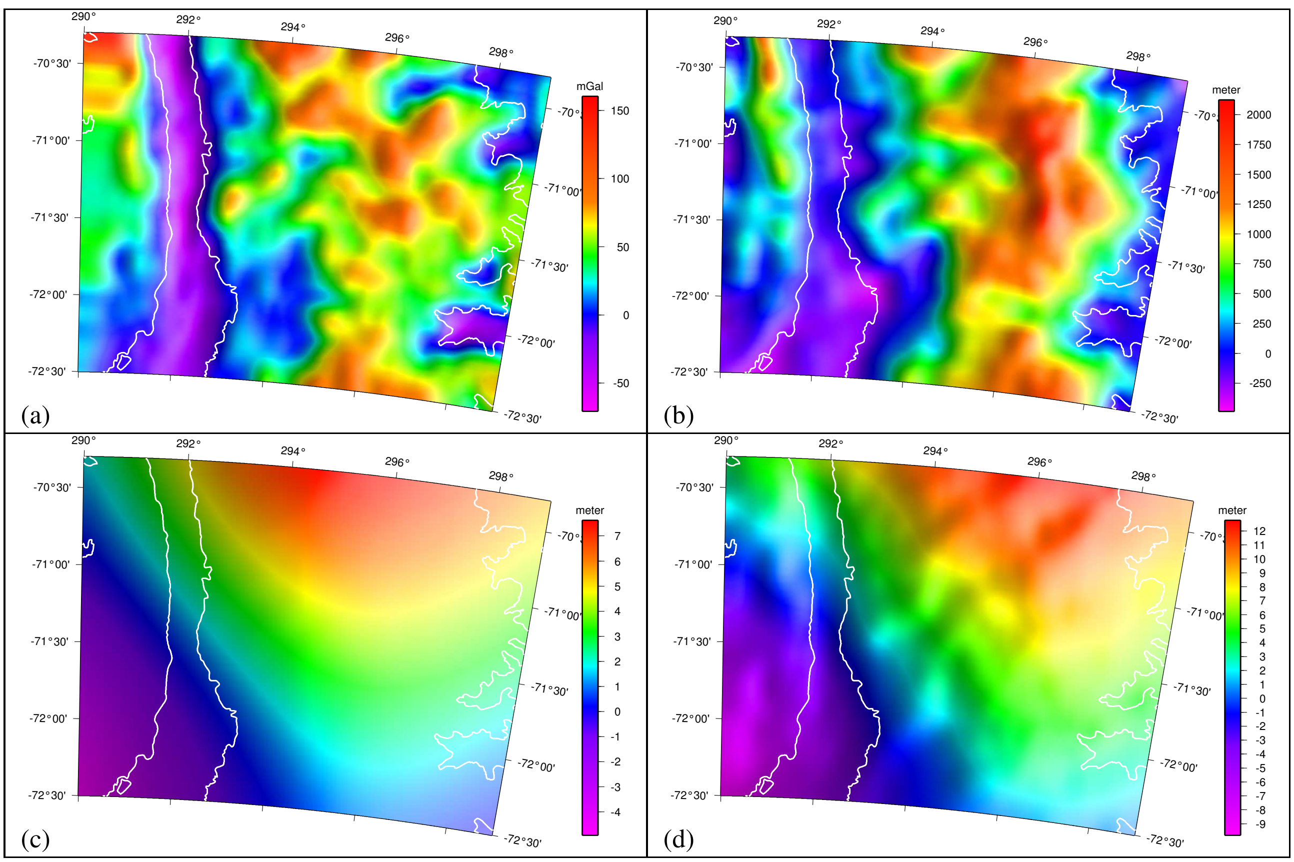

Figure 2: Data sets and regional geoid improvement over Palmer Land. (a) Gravity disturbances at nominal flight height (2,800m)(Ferraccioli et al., 2006); (b) Bedrock topography (Lythe et al., 2000); (c) Quasigeoid from the global gravity model EIGEN-CG03C up to degree and order 120 (Förste et al., 2005); (d) Improved quasigeoid. Coastlines are plotted as white lines (comp. Fig.1; source: SCAR Antarctic Digital Database v4.0).

improvement strategy to the entire Antarctic Peninsula region. For this goal, we plan to combine additional near-surface (terrestrial, airborne and shipborne) gravity data with satellite data (especially altimetry over the Antarctic oceans). An improved regional geoid will support a lot of different applications, not only in geodesy but also in neighbouring disciplines. For example, a detailed geoid information is essential to study the balance and dynamics of ice shelves (Horwath et al., 2006).

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