Regional geoid and gravity field from a combination of airborne and satellite data in Dronning Maud Land, East Antarctica

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Summary A variety of gravity observations in Antarctica has recently become available through extensive efforts of airborne surveys. Aircraft serving as multi-instrumentation platforms provide measurements on gravity, bedrock topography, ice surface topography and ice thickness. Collected datasets are valuable in terms of resolution and homogeneity, which make them suitable for studying regional geoid determination in selected Antarctic regions. Within this context the German joint project VISA provided an excellent database for improving the regional geoid by combining gravity and topographic data from aerogeophysical observations with long-wavelength information from global gravity field models. Using the remove-compute-restore technique in conjunction with least-squares collocation, a regional geoid for Dronning Maud Land, East Antarctica, has been derived. A signal threshold of up to 6 m added to the global model that was used as a basis can be expected. The accuracy of the regional geoid will be estimated to be at the level of 15 cm.

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Introduction

The new datasets provided by the satellite missions CHAMP, GRACE and GOCE (to be launched by the end of 2007) enable a homogeneous determination of the gravity field. Furthermore, in the polar regions ice surface heights will be determined in a similar quality by ICESat. These new satellite data will be validated and densified by the German joint project VISA (Validation, Densification and Interpretation of Satellite Data for the Determination of Magnetic Field, Gravity Field, Ice Mass Balance and Structure of the Earth Crust in Antarctica, uitilizing Airborne and Terrestrial Measurements) of TU Dresden and AWI Bremerhaven.

For this purpose western and central Dronning Maud Land (DML), East Antarctica, were chosen as area of investigation for the above mentioned Validation, Densification and Interpretation of Satellite Data. Airborne as well as terrestrial observation campaigns were carried out to provide appropriate datasets on height and gravity as well as on temporal height and gravity changes, on magnetics, glaciology and seismology. In combination with the satellite data these measurements will be applied to yield more detailed models of the gravity field and the regional geoid, of the crustal structure and litosphere dynamics and of the dynamics and mass balance of the Antarctic ice sheet in the area.

Observation campaigns

Between 2001 and 2005 four airborne observation campaigns and two terrestrial observation campaigns were carried out in western and central DML in order to conduct geodetic and geophysical measurements (Fig. 1, left). The scientific program of the aerogeophysical campaigns for the observation of the gravity field, magnetic field, ice surface height and ice thickness (Radio Echo Sounding (RES)) contains more than 80.000 profile kilometers with a line-spacing between 10 and 20 kilometers (Riedel and Jokat, 2007). The terrestrial field work took place at two different areas, during the season 2003/04 at Schirmacher Oasis - Potsdam Glacier - Wohlthat Mountains and one year later (season 2004/05) at Heimefrontfjella - Kirwanveggen. More than ten GPS and seismometer stations on bedrock were installed, kinematic GPS profiles, relative gravimetry on ice and ground penetrating radar (GPR) measurements were carried out as well as samplings of firn cores and snow pits (Anschütz et al., 2007; Anschütz et al., 2006; Scheinert et al., 2005; Nixdorf et al., 2004).

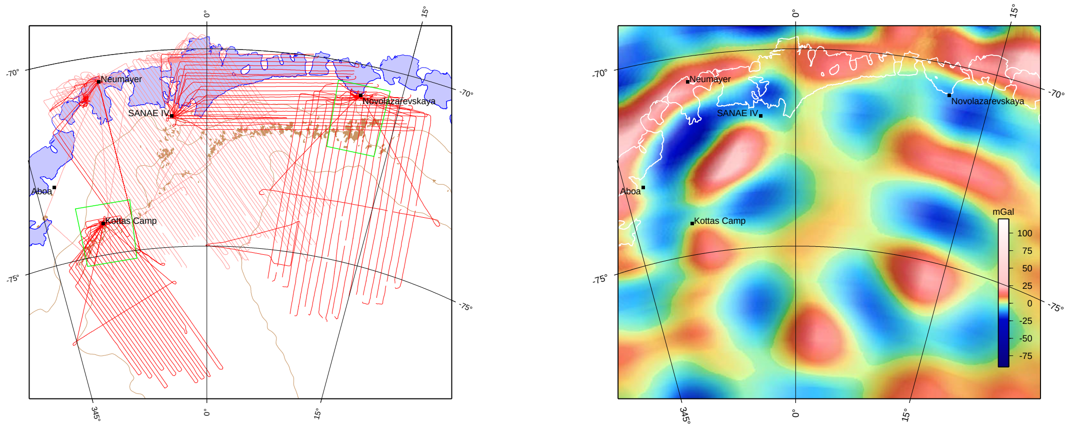

Figure 1: Left - Overview of the area of investigation. Flight-lines of the aerogeophysical campaigns are plotted as red lines. The two green boxes denote the areas of the terrestrial field work. Right - Gravity anomalies from global model EIGEN-GL04C (Förste et al., 2006), harmonic window for spherical harmonic degrees 121 to 360. This wavelength part is uncertain due to the lack of terrestrial data in the area of investigation.

Regional Geoid Improvement

High-resolution models of the Earth gravity field have been obtained by combining satellite observations from CHAMP and GRACE with terrestrial data. Latest examples of these combination models are EIGEN-CG03C, EIGEN-GL04C (Förste et al., 2005; Förste et al., 2006) and GGM02C (Tapley et al., 2005). In Antarctica, the determination of the global gravity field is problematic due to the remoteness (often inaccessibility) and harsh conditions the terrestrial gravity data coverage features very large gaps. Only for a few smaller regions ground-based or airborne measured gravity was included into the combined gravity model.

In order to improve the terrestrial gravity coverage and to determine the Antarctic geoid, the IAG Commission Project 2.4 "Antarctic Geoid" (chaired by M. Scheinert) was set up, and is closely linked to SCAR Expert Group on Geodetic Infrastructure in Antarctica (GIANT) project 3 "Physical Geodesy". An overview on the situation is given in Scheinert (2005) and the strategy of regional geoid improvement is discussed in Scheinert et al., (2007b) for the Prince Charles Mountains region, East Antarctica (PCMEGA) and Scheinert et al. (2007a) for Palmer Land, Antarctic Peninsula.

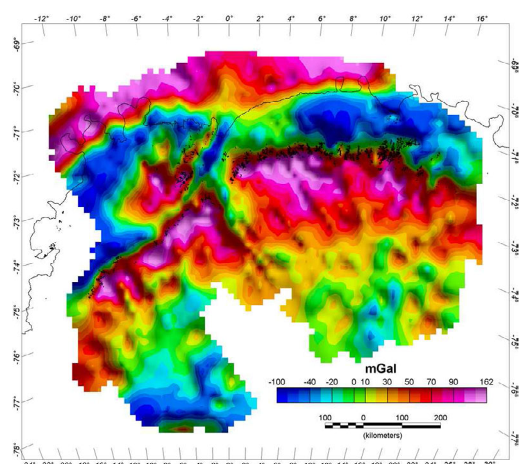

Figure 2: Free-air Anomalies (preliminary results with a spatial resolution of 15 kilometers)

Within this context, the VISA observation campaigns described above provide an excellent database for the validation of the gravity field and, more importantly, for the determination and improvement of the regional geoid. Fig. 2 shows preliminary results for the free-air anomalies derived from airborne measurements over the western and central Dronning Maud Land (DML) with a spatial resolution of 15 kilometer (Riedel and Jokat, 2007). Compared with the subglacial topography (Fig. 3, left panel) the strong correlation between these two datasets is clearly visible. The right panel of Fig. 3 shows the ice surface height in the area of investigation. The datasets of Fig. 3 allow the derivation of the ice thickness, which is needed in addition to the subglacial topography for the computation of an improved geoid. The high resolution of these datasets make them much more suitable than BEDMAP data (Lythe et al., 2000), which were a valuable source of information prior to the VISA radar observations in DML.

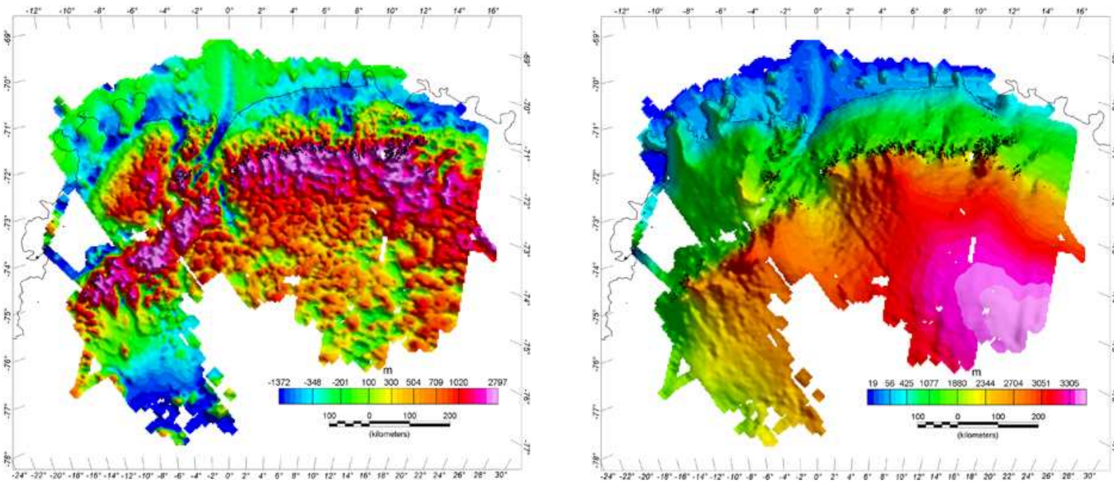

Figure 3: Left - Subglacial Topography, Right - Ice surface height (preliminary results)

Problems occur especially in Antarctica when satellite observations from CHAMP and GRACE up to a certain spherical harmonic degree (typically 120) are combined with terrestrial data. Geophysically extrapolated gravity anomalies do not necessaily reflect the actual gravity field in Antarctica, though they are essential to derive a globally complete data coverage needed for the solution of the closed surface integrals. For this reason, shorter wavelength information (higher than spherical harmonic degree 120) is unreliable for most Antarctic areas (Fig. 1, right). This is demonstrated by comparing the gravity anomalies from EIGEN-GL04C for a harmonic window (degrees 121 to 360) (Fig. 1, right) with the free-air anomalies derived from VISA airborne measurements (Fig. 2). While a high correlation can be seen near the coastline, it diminishes in the southern part of DML.

For the calculation of the regional geoid the remove-compute-restore technique (RCRT) was applied. This technique is discussed in detail e.g. in (Forsberg and Tscherning, 1997) and (Sjöberg, 2005) and was also used in the PCMEGA case (Scheinert et al., 2007b). In the remove step, a long-wavelength part (predicted by a global gravity field model) and a short-wavelength part (predicted by topography) are removed from the original gravity data. In the compute step, the obtained band-pass filtered gravity anomalies are transformed into geoid heights, using least-squares collocation in this study. Least-squares collocation offers the advantage of providing error estimates for the resulting geoid. After having carried out the compute step, the long-wavelength part and the short-wavelength part are restored in the geoid. For the computations, we make use of the program package GRAVSOFT (Forsberg et al., 2003; Tscherning, 1974), which offers a variety of tools for the geodetic gravity field modelling.

Conclusion

Combining gravity and topographic data from VISA aerogeophysical campaigns with a global gravity field model a regional geoid for Dronning Maud Land, East Antarctica, will be presented. Studies in other regions of Antarctica (Scheinert et al., 2007a; Scheinert et al., 2007b) have shown that a signal threshold of up to 6 m to the global gravity field model that was used as a basis can be expected when comparing the improved geoid with the global model up to spherical harmonic degree 120. The accuracy of the regional geoid is estimated to be at the level of 15 cm. Considering the current data situation in Antarctica, the accuracy level of 0.1 m is a realistic and appropriate goal for this area of the world. The data coverage in Antarctica will most likely be subject to major improvements when further airborne surveys are carried out. The International Polar Year 2007/ 2008 provides a reasonable framework for international and interdisciplinary cooperation in that field. SCAR-GIANT project 3 "Physical Geodesy" and IAG Commission Project 2.4 "Antarctic Geoid" work towards the goal of closing the gaps in the gravity data coverage and at improving the geoid in Antarctica.

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