A compilation of new airborne magnetic and gravity data across Dronning Maud Land, Antarctica

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Summary The evolution of the South Atlantic region including the Weddell Sea and its adjacent areas is of crucial importance for understanding the processes of the structure and tectonics of the Antarctic lithosphere, its relation to geodynamic processes, especially to the timing and geometry of the initial stages of the Mesozoic break-up between Africa, Antarctica and South America. For unravelling the geological evolution of Antarctica prior to the break-up of Gondwana, the sub-glacial geology is of utmost importance. Understanding the sub-ice geology allows reconstruction of ancient mountain chains (collision zones) across continents, which are separated by large ocean basins in the present world. Since only the peaks of the Dronning Maud Land (DML) mountains can be geologically sampled, geophysical methods are required to uncover the geological structure beneath the ice. Therefore, extensive airborne surveys were conducted across DML between 2001 to 2005 to close data gaps and to improve existing data sets.

Citation: Riedel, S., Jokat, W. (2007) A compilation of new airborne magnetic and gravity data across Dronning Maud Land, Antarctica: *in* Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 149, 4 p.

Introduction

As part of the VISA project (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) the survey area extended almost 1,000,000 km^2. These surveys address the major structures of the East Antarctic Craton and the continental margin. The compilation of previous regional Russian investigations (magnetic, gravity) gave a first impression on the sub-glacial geology (Aleshkova et al., 2001; Golinsky et al., 2001). The new results provide a new and more detailed insight and significantly extend existing data sets.

The extent of the survey areas from 14°W to 20°E and from 70°S to 78.5°S is large enough to fully recognize long-wavelength regional anomalies. However, even smaller features could be mapped, owing to an average line spacing of about 10 km. The VISA project was subdivided into 4 austral-summer campaigns:

VISA I, lasted from 12/2001 to 02/2002 and contained 100 flight-hours with 27,700 profile km. The survey area was located from 4°W to 10°E and from 70°S to 75°S with Neumayer Station (Germany) and E-Base (South Africa) as base stations. Three GPS reference stations were established at various locations in DML: Kohnen Station, Bleskamin Ice Rice and Sörasen. Additionally, magnetic base stations were established at E-Base, Kohnen and Neumayer Station.

The VISA II campaign (12/2002 to 01/2003) amounted to 54.5 hours flying time, with 13,300 profile km. As gravity measurements do not allow frequent flight level changes, a level of 3960 m was adopted for most flights due to surface topography and cloud level. The spacing of the parallel profiles is 10 km. For post-processing two GPS reference stations were established: at Kohnen, at Weigel Nunatak near Kottas Camp, and close by the seismic array Watzmann at Halvfarryggen. Additionally, magnetic base stations were established at Kohnen and Kottas Camp. Furthermore, GPS data and magnetic data were collected at the geophysical observatory of Neumayer.

All flights for VISA III (12/2003 to 02/2004) amounted to 133 hours of flying time (31,150 profile km). The survey flights were carried out from Novolazarevskaya (Novo) runway and SANAE IV. While the profiles flown from Novo runway had a spacing of 20 km, a constant flight level of 4000 m, and a north-south orientation (6°W to 20°W and 71.5°S to 76.5°S), the flights from SANAE IV had a spacing of 10 km and the flight levels decrease to 1500 m towards the north (1°W to 16°E and 70°S to 71.5°S). Four GPS reference stations were established at DML25 next to Kohnen, at Weigel Nunatak near Kottas Camp, FOR1 at Schirmacher Oasis and Novo Runway. A magnetic base station was set up at Novo Runway. Furthermore, GPS data and magnetic data were obtained at the geophysical observatory at Neumayer and SANAE IV.

VISA IV flights conducted in Western Dronning Maud Land with Neumayer and Kottas Camp as main bases for the aero-geophysical programme from 12/2004 to 01/2005. The survey area was located from 14°W to 0° and from 74°S to 78.5°S. The spacing of the parallel profiles was 10 km, with flight altitudes of 3200 m. GPS reference stations and magnetic base stations were established at Amundsenisen and Kottas Camp. Additional GPS and magnetic data were obtained from Neumayer Station and SANAE IV.

Instrumentation and processing

The AWI owned Polar2 aircraft, a Dornier 228-101, was used for the surveys. The platform was equipped with ice penetrating radar, gravity meter, magnetometers, laser altimeter, combined with auxiliary basis meteorological and navigation systems. All aero-geophysical data (magnetic, gravity, radio echo sounding) were acquired simultaneously at a constant barometric altitude yielding a surface clearance of up to 400m over the mountainous terrain. Typical ground speeds for the surveys were about 70m/s.

Magnetic system

Two Scintrex (Cs2) Cesium magnetometers were placed in the wing-tips, sampling the total intensity of the magnetic field at a rate of 10 Hz. Additionally, a triaxial fluxgate system was used for compensation of the aircraft in the inducing magnetic field. Owing to the inducing effect of the Radio Echo Sounding system (RES), only the right wing sensor can be used for further interpretation.

To monitor the geomagnetic activity, several base stations were set up in combination with the magnetic observatories at Neumayer Station, SANAE and Novolazarevskaya to acquire diurnal variations with up to 10 seconds sampling interval. Owing to the size of the survey areas the use of several base stations is important which show differences in phase and amplitude. Unfortunately, nearly 10% of the flights took place on days with strong magnetic gradients and amplitudes of up to 100 nT. In general, diurnal variations were typically <30 nT. These variations were corrected using low-pass-filtered magnetic base station data.

Minimizing the differences at the intersection points was achieved with a statistical leveling method using always a zero-order trend (blockshift) due to the limited number of tie-lines. The overall error at line-intersections was very variable, with a mean value of 5 nT and standard deviation of 15 nT (preliminary results). The resulting magnetic anomaly data were gridded using a Minimum Curvature routine to produce a magnetic anomaly map (Fig.1).

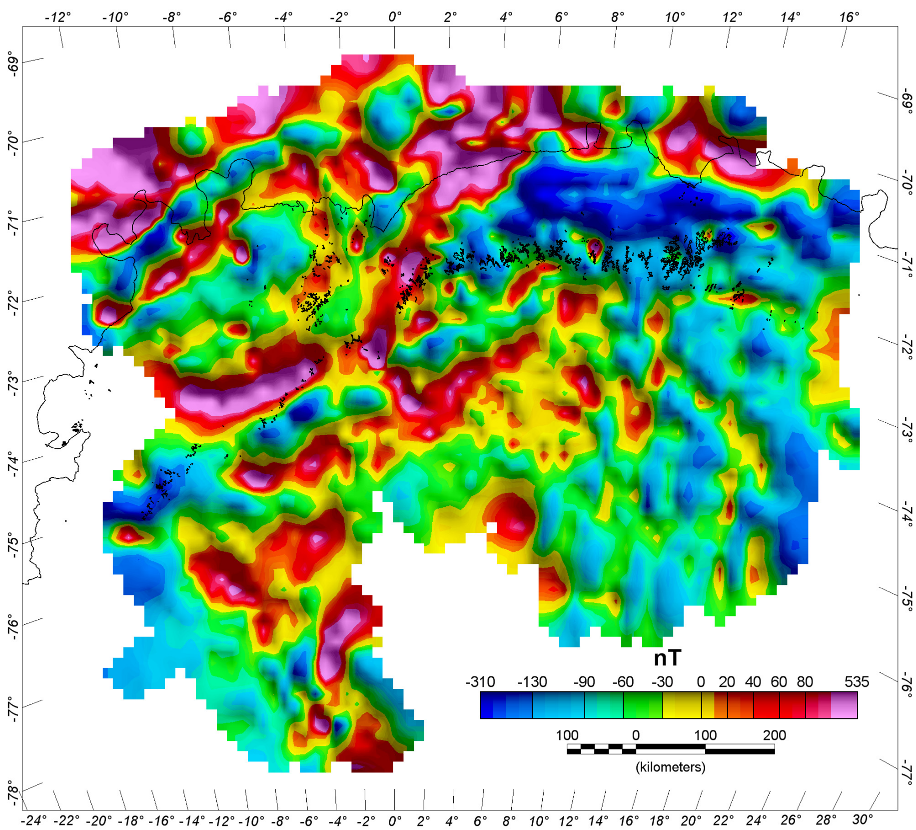

Figure 1. Compilation of preliminary results of the Magnetic Anomaly Map, gridding cell size is 15km.

Gravity system

The airborne gravity system was a LaCoste Air-Sea system (S56), modified by ZLS. The gravimeter consists of a highly damped, zero-length spring type sensor and uses spring tension and beam velocity to obtain relative gravity variations. The acceleration sensor is kept vertical by a 2-axis stabilised platform, with periods of 2 and 4 minutes. Gravity readings were taken at a frequency of 1 Hz. The resolvable wavelength of the filtered gravity signal is about 90 seconds. With respect to flight velocity this corresponds to 6-7 km spacing resolution.

Inflight navigation was realised by the aircraft systems: GNS-X (Global Wulfsberg), INS (Honeywell, Lasernav II) system and barometric altitude sensor. The position of the aircraft was recorded by two GPS receivers (Trimble SSI 4000) for scientific purpose and differential post-processing. The GPS phase was recorded at a sample rate of 1 Hz. Several GPS base stations on solid ground were deployed to archive the short and moderate GPS baseline. Differential GPS positions were calculated for each flight using the Trimble Geomatic Office software, with nearby stations, precise ephemeredes, ionosphere-free solution and the Niell tropospheric model.

The surveys were tied to a local gravity base (i.e. base camp), which again was tied to the International Gravity Standard Network (IGSN-71) station, at the University of Cape Town, (South Africa) using a portable gravimeter. To correct for instrumental drift and calibration procedures normal ground measurements were made before and after each survey flight. The S56 shows a 4 mGal drift per survey with respect to the land gravity meter.

To calculate the free-air anomaly, several corrections and reductions were applied, namely for drift, for normal gravity, for Eötvös effect, for tilt effect of the platform, and the free-air reduction.

Aircraft accelerations caused by turbulences and altitude changes required editing of few lines. Statistical leveling, using a zero-order-trend, was performed, resulting in the RMS of the differences at the crossover points of 4 mGal, with a standard deviation of 5 mGal after leveling (Fig.2. preliminary results).

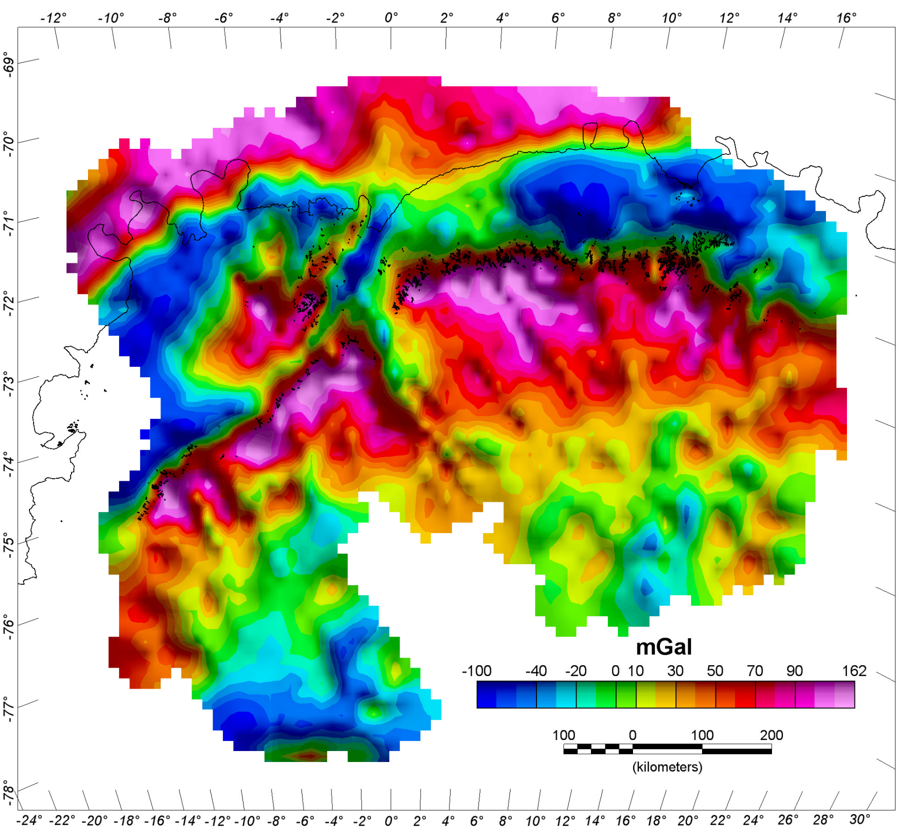

Figure 2. Compilation of preliminary results of the Free-Air Anomaly Map, gridded cell size is 15km.

Discussion

The geologic structure of DML is rather complex and reflects several tectonic events resulting in different crustal terranes. In the magnetic pattern, the western, central and eastern part show similarities as well as individual anomalies. Additionally, the map shows always an overprinting character of the magnetic anomalies that are associated with fragments of the Gondwana break-up.

As already known from other parts of world oceans, volcanic seaward dipping reflectors sequences do exist along the coast of western DML. They are located within the continent-ocean transition zone and are marked by high amplitude magnetic anomalies with strong gradients. The western part of DML is dominated by the Grunehogna unit, a cratonic fragment, with discrete intrusions and linear short wavelength anomalies. In the central part prominent NE-SW striking anomalies in the H.U. Sverdrupfjella and E-W trending anomalies in the Penksökket can be seen. The prominent Jutulstraumen-Penksökket anomaly marks significant changes in magnetic strike direction (Aleshkova et al., 2001; Golinsky et al., 2001). While the most eastern part of DML shows low amplitude, short wavelength anomalies with no or little continuity.

The free-air gravity correlates to the rugged relief and the morphology. The East Atlantic Craton Margin Anomalie (coast-parallel) which covers the continent-ocean transition shows strong gradients. Between ice shelf and the southern mountain range, we recorded negative gravity values of approximately 25 mGal, separated by trough-like minima with negative values of 50 to 75 mGal and less. These minima correspond well with the relief, calculated from RES and may be interpreted as sediment basins. Reitmayr (2005) gives another explanation: a zone in which the isostatic equilibrium has not been established. This still has to be proven. Another prominent gravity low shows the branch of the Jutulstraumen ice stream, a sub-ice continental rift structure in Western Dronning Maud Land (Ferraccioli et al., 2005). The area further to the south can be divided into two different regions. The mountaineous area of DML is associated with high amplitude gravity anomalies and can be distinguished from basin structures further to the south.

In this contribution we will present the latest compilation of the data shown above, including the Bouguer anomaly map.

Acknowledgments. I wish to thank the colleagues of TU Dresden, namely M. Scheinert and S. Roewer for their introduction to GPS-processing. U. Meyer, D. Damaske and F. Goldmann (BGR Hannover) are thanked for their technical support and M. Koenig (AWI) for many suggestions. Many thanks go to the members of the air-crew and the scientific leader. Preparation of this work was supported by the Deutsche Forschungsgemeinschaft (DFG) through the VISA Project, funded under grants Di 473/17-1 and Jo 191/8-1.

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