Absolute gravity measurements in Antarctica during the International Polar Year

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Summary Gravity measurements, combined with precise positioning measurements and satellite gravity measurements, are necessary to separate the effects of past and present deglaciations on the variation of the Earth's gravity field. During the International Polar Year, we will make absolute gravity measurements at 6 stations in Antarctica. This program is the follow-up of measurements made at the Dumont D'Urville station, in Terre Adélie, in 2000 and 2006. It will be followed by another measurement at Dumont D'Urville station in 2010.

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Introduction

The Earth's gravity field is a fundamental geodetic parameter. It is determined by ground (relative and absolute gravimetry), sea (relative sea-surface gravimetry), and aiborne measurements. Satellite measurements, for instance by CHAMP (Challenging Minisatellite Payload for Geophysical Research, launched in 2000) or GRACE (Gravity Recovery and Climate Experiment, launched in 2002), have provided a uniform and global coverage of the field, this coverage being, however, of limited spatial resolution and accuracy. The GOCE (Gravity Field and Steady-state Ocean Circulation Explorer) satellite will be launched in 2007 to improve the spatial resolution. Clearly, both satellite and surface measurements are necessary to determine accurately the Earth's gravity field.

Precise geodetic measurements in the polar regions, which are poorly known from that point of view, are also needed. In 1998, we initiated a 5 year-program funded by IPEV (Institut Polaire Français Paul-Emile Victor) that consisted in making absolute gravity measurements in Antarctica (Dumont d'Urville station in Terre Adélie) and on the French sub-Antarctic islands (Kerguelen, Crozet, Nouvelle-Amsterdam). It was extended until 2006 with a second measurement in Terre Adélie. The scientific goals were to provide data to the International Absolute Gravity Base Network IAGBN and link geodetic or geophysical sites (GPS, DORIS, VLBI stations etc.) to the absolute reference points by using a relative gravimeter. Moreover, we have been able to repeat absolute measurements in Kerguelen and Terre Adélie and show how the gravity field is varying with time. We used an FG5 absolute gravimeter designed by Micro-g Solutions. This instrument is presently the most precise in the world (Vitushkin et al. 2002), since its precision and accuracy are as low as 1 to 2 microgals (1 microgal $= 10^{-9}\,g$, where g is the surface gravity) (Van Camp et al. 2003; Van Camp et al. 2005).

In 2006, a new proposal has been funded by IPEV to continue absolute gravity measurements to study the time variation of gravity in both the Arctic and Antarctic regions. Gravity variations near the poles are mainly related to two geophysical phenomena. The first one is the post-glacial rebound (PGR) subsequent to the last deglaciation that occurred a few tens of thousands years ago. The second one is the present-day ice melting (PDIM), which is a consequence of the global warming. Absolute gravity measurements are now widely used to study deglaciation issues (Wahr et al. 2001a, b; Lambert et al. 2001; Mäkinen et al. 2004; Sato et al. 2006). The superposition of the effects of past and present deglaciations in precise positioning measurements (GPS, DORIS, VLBI), ground gravity (absolute gravimetry) and space gravimetry (GRACE) has been recently studied by Velicogna and Wahr (2006) and Chen et al. (2006). The scientific studies of global change and PDIM are, of course, of the uttermost importance for the prediction of the sea level rising (Alley et al. 2005; Douglas 1997; Milne et al. 1999; Mitrovica and Davis 1995; Mitrovica and Milne 2003; Miller and Douglas 2004; Peltier 1998; Tamisiea et al. 2001; Vaugham 2005; Zwally et al. 2005).

In particular, recent results about Greenland (Velicogna and Wahr 2005; Chen et al. 2006) and Antarctica (Velicogna and Wahr 2006), based on the analyis of GRACE data, suggest a loss of ice mass that will increase the mean ocean level. The global decrease of ice mass in Antarctica is, however, controversial. Other studies suggest that the melting of the ice is not homogeneous over the continent but, on the contrary, is more pronounced in Western Antarctica than in Eastern Antarctica (Ramillien et al. 2006). As in the Arctic region, the viscous deformation of the PGR (Ivins et al. 2003; Ivins and James 2005) is superposed on the elastic deformation due to the present deglaciation (Sasgen et al. 2005). By itself, none of the measurement methods (positioning, ground or space gravity) can separate the present and past deglaciations (Argus et al. 1999; Wu et al. 2002). Only the combination of gravity and vertical displacements data allows for a separation of those two effects (van Dam et al. 2000; Wahr et al. 2001a, b for Greenland). Indeed, for a viscous rheology, the variation of gravity and vertical displacement are related by a simple relationship that remains valid for a large number of models of the mantle viscosity and thickness of the elastic lithosphere (Han and Wahr, 1995; Wahr et al. 1995). Besides, the validity of this relationship was confirmed by joint campaigns of absolute gravity and GPS measurements of the PGR in North America (Larson and van Dam 2000; Lambert et al. 2001).

Absolute gravity measurements during the IPY

From 2007 to 2010, we will investigate the gravity variation and vertical displacement in Spitzberg and East Antarctica, where absolute gravity measurements have already been made. We will repeat the gravity measurements and combine them with precise positioning measurements using GPS, VLBI, or DORIS methods. Furthermore, we will compare both types of ground measurements with space measurements of gravity (GRACE) or altitude (ERS 1-2, RADARSAT, ENVISAT, ICESAT).

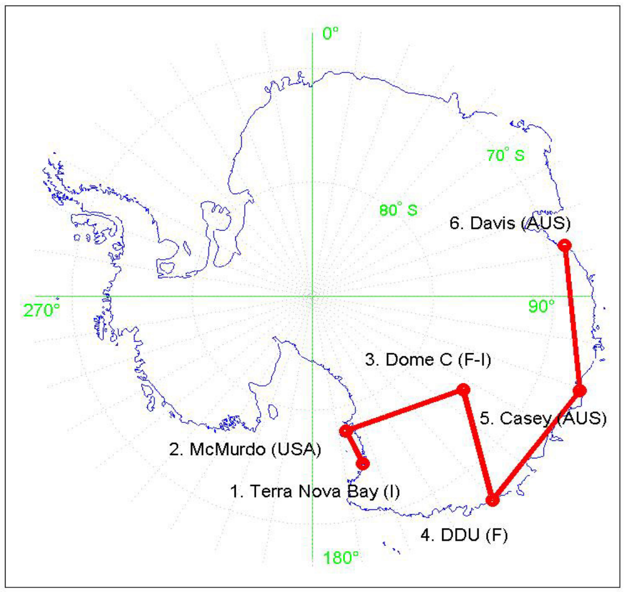

Figure 1. Location of the stations selected for absolute gravity measurements in Antarctica during the IPY.

In Antarctica, during the International Polar Year, we will make absolute gravity measurements at 5 stations on the East coast and 1 station, Concordia, located approximately 1000 km from the coast (Fig. 1). GPS and DORIS receivers are already operated at the stations. This program is a straightforward continuation of our former program that included gravity measurements in 2000 and 2006 at Dumont d'Urville (DDU). It results from this study that both the gravity variation and vertical displacement are very small, in agreement with the models of deglaciation. In order to confirm this result, we will make two extra measurements at the DDU station. Actually, we will make two campaigns of measurements. The first one will include measurements at 6 bases during the IPY: Terra Nova Bay (TNB, Italy), Mc Murdo (USA), Dôme C-Concordia (France and Italy), Dumont d'Urville (France), Casey (Australia), and Davis (Australia). These stations are equipped with permanent GPS receivers meant for geodetic applications (Negusini et al. 2005 for TNB, Tregoning et al. 1999, 2000 for Davis, Bouin and Vigny 2000 for DDU and Casey). Gravity measurements at TNB, McMurdo, and DDU will be repeated for the third time, whereas we will make the first measurements at the other 3 stations. The second campaign in 2010 will only involve a gravity measurement at DDU.

The first measurement on ice, at Concordia, is significant. Although it raises technical difficulties that have been given much thoughts and should be overcome, it will provide a reference value for the A10 portable absolute gravimeter that, in the IPEV program entitled 'TASTE-IDEA' (Trans-Antarctic Scientific Traverses Expeditions-Ice Divide of East Antarctica), will be transported by plane from Concordia. Indeed, each time that the convoy will stop during those traverses, the A10 gravimeter will leave Concordia by plane and join the convoy to make a 24 hours measurement before going back to Concordia. Consequently, a reference value for *g* is needed at Concordia to make sure that the A10 gravimeter is working properly. Although we have chosen the Concordia station because the ice creep is very low, this is not zero. Therefore, it must be taken into account if the gravity measurement is to be repeated in the future. To monitor the deformation of the ice, we will add to the gravity measurement (i) a precise positioning measurement by using a differential GPS at the Italian permanent station (TNB) and (ii) a link to the GPS station by using precise leveling techniques.

Finally, we note that the Davis station is equipped with a permanent GPS receiver and belongs to a network of stations dedicated to the monitoring of the PGR near the Lambert glacier (Zwartz et al. 1999; Tregoning et al. 2000).

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