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Micro-Gravity Measurements in Northern Victoria Land, Antarctica, as Contribution to Geodynamic Investigations – a Feasibility Study

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Abstract: This project comprises micro-gravity measurements in northern Victoria Land, Antarctica, using the existing Italian network with the basis Gondwana. The purpose was to add gravity data to the already collected deformation data. We used three gravimeters in parallel to increase the number of readings and – in parallel – to reduce the necessary flights to the points. With this project we could prove that such measurements are possible under the prevailing conditions (strong variations of temperature, air-pressure and elevation), and we could provide a first data set, which will serve as a reference for future work.

Zusammenfassung: Das hier vorgestellte Projekt umfasst Schweredifferenzmessungen im nördlichen Victoria Land an Punkten des italienischen Netzes für die Erfassung von Deformationen. Die Basisstation war Gondwana. Ziel war, die von den Italienern beobachteten Deformationen durch Schweredifferenzen zu ergänzen. Dabei setzten wir drei Gravimeter gleichzeitig ein, um einerseits die Anzahl der Beobachtungen zu vergrößern, um andererseits aber auch mit relativ wenigen Flügen auszukommen. Mit den Arbeiten konnten wir beweisen, dass derartige Messungen unter den vorherrschenden Bedingungen (Temperaturänderungen, Luftdruckvariationen, große Höhendifferenzen) möglich sind. Es ist ein erster Datensatz erstellt worden, der als Referenz für zukünftige Untersuchungen dienen kann.

INTRODUCTION

The idea of performing micro-gravity measurements in northern Victoria Land (NVL) arose when we realized that within the Italian Antarctic programme in NVL repeated GPS-measurements are being carried out at well installed points in that area (VLNDEF: Victoria Land Network for Deformation Control; MANCINI 2000, MANCINI et al. 2004). Although the deformations obtained over a period of four years are quite small (seasons 1999-2000, 2000-2001, and 2002-2003; CAPRA et al. 2007), we expect from gravity observations additional information about on-going tectonic processes and/or mass changes caused by possible changes in the ice cover. Of course, such information will be available only by repeated measurements not before some years; but with our measurements we have now prepared the basis for such investigations.

Micro-gravity monitoring has been applied successfully in areas of active volcanism (see e.g. RYMER 1991; the results obtained by the author at three volcanoes are summarized in JENTZSCH et al. 2004). The advantage is that these measurements do not require a topographic reduction because the measurements are always carried out at the same points. Thus, the instrumental resolution and the measurement conditions, respectively, are the only limits for the resolution and accuracy of the measurements. In order to receive a reliable database we used three well-calibrated gravimeters together and repeated the measurements several times. Problems may occur due to snowfall, and – in this case – snow heights would have to be measured. But generally, the points are so exposed that local effects of the changing snow cover are not to be expected.

Using several gravimeters in parallel goes back to the procedures the colleagues in Fennoscandia applied: They used even more than three gravimeters during measurements along the so-called land-uplift lines which connected points in Norway, Sweden and Finland, and were repeatedly observed (MÄKINEN et al. 1985, EKMAN & MÄKINEN 1996) to determine the uplift after the ice retreat (GIA, glacial isostatic adjustment).

Actually, it was intended to get started with a small project to gain experiences before planning more comprehensive measurements. Since this was not possible because there was no Italian expedition in 2008/09, we decided to restrict ourselves to the vicinity of Terra Nova Bay under the possibilities offered by the Expedition GANOVEX X (Fig 1).

DIETRICH et al. (2001, 2004) have already carried out repeated GPS- and gravity observations in Antarctica, amongst others within the Chile-German expedition PATRIOT during the season 2004/2005 and in Dronning Maud Land (2003/2005). The aims of these works were similar, namely the determination of velocities of surface deformations as well as the variations of the gravity field and the detection of ice-induced mass changes and deformations of the crust (visco-elastic response).

But using only one gravimeter reduces the reliability and resolution of the observations. Therefore, we used three gravimeters in parallel. Our measurements were intended to prove if such measurements were even possible under the conditions of points at different elevations, helicopter transport, and strong temperature variations.

TECTONIC SETTING OF THE AREA OF NORTHERN VICTORIA LAND

The West Antarctic Rift System is the result of late Mesozoic and Cenozoic extension between East and West Antarctica, and represents one of the largest active continental rift systems

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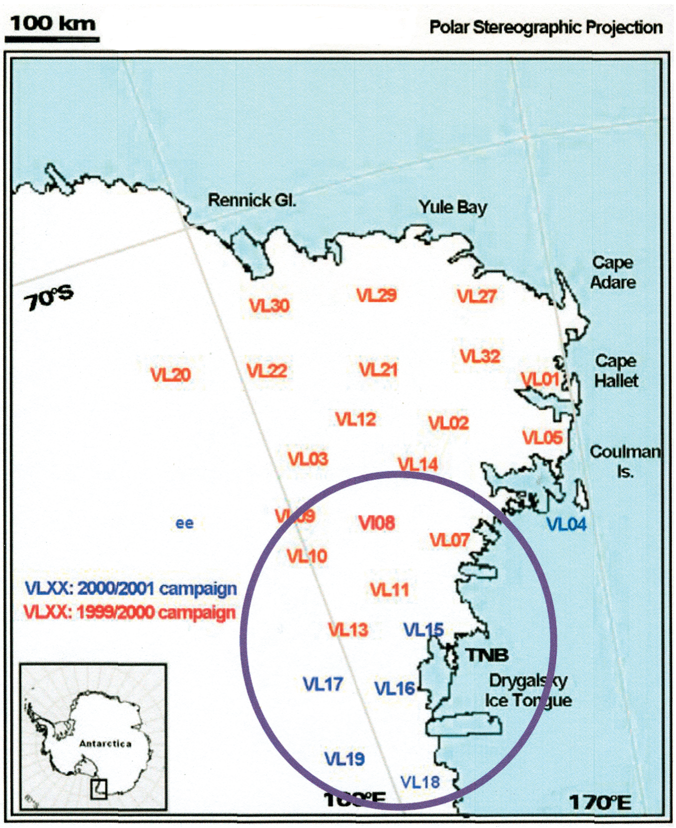

Fig. 1: Northern Victoria Land with the GPS-points of the Italian VLNDEF project (from Capra pers. comm.). The circle encompasses the points used for the gravity measurements. In this area we visited 13 points with three gravity meters, most of them more than twice, using the Gondwana Station as the reference. The North-South extension is about 250 km, West-East is about 100 km. TNB marks the Terra Nova Bight with station Gondwana (GOND).

Abb. 1: Nördliches Victoria Land mit den GPS-Punkten des italienischen VLNDEF-Projektes. Der Kreis umfasst die hier vermessenen Punkte. Es wurden insgesamt 13 Stationen aufgesucht mit drei Gravimetern, die meisten davon mehr als zweimal, mit Gondwana als Referenz. Die Nord-Süd-Ausdehnung liegt bei 250 km, in Ost-West-Ausdehnung ist es etwa 100 km. TNB markiert die Terra Nova Bucht mit unserer Referenzstation Gondwana (GOND).

on Earth. But the timing and magnitude of the plate motions leading to the development of this rift system remain poorly known, because of a lack of magnetic anomaly and fracture zone constraints on seafloor spreading. Magnetic data, gravity data and swath bathymetry were collected in several areas of the south Tasman Sea and northern Ross Sea. These results made it possible to calculate mid-Cenozoic rotation parameters for East and West Antarctica. These rotations show that there was roughly 180 km of separation in the western Ross Sea embayment in Eocene and Oligocene time. This episode of extension provides a tectonic setting for several significant Cenozoic tectonic events in the Ross Sea embayment including the uplift of the Transantarctic Mountains and the deposition of large thicknesses of Oligocene sediments. Inclusion of this East-West Antarctic motion in the plate circuit linking the Australian, Antarctic and Pacific plates removes a puzzling gap between the Lord Howe Rise and Campbell Plateau found in previous early Tertiary reconstructions of the New Zealand region. Determination of it also resolves a long-standing controversy regarding the contribution of deformation in this region to the global plate circuit linking the Pacific to the rest of the world (e.g. Behrendt et al. 1991, 1993, Cande et al. 2000, Decesari et al. 2007). The results obtained up to now indicate that considerable crustal deformation has taken place and is still ongoing.

GEODETICAL RESULTS

The Italian programme of repeated GPS-measurements carried out at well installed points in that area (Fig. 1; Mancini 2000, Mancini et al. 2004) revealed quite small, but significant deformations over a period of four years (seasons 1999-2000, 2000-2001, and 2002-2003, Capra et al. 2007). The analyses of the data obtained up to now provide absolute horizontal velocities ranging between 17 mm per year and 8 mm per year, with greater motions in the north. The relative motions obtained by subtraction of a rigid plate motion (using the results from the permanent GPS-station TNB1 installed at the Italian Mario Zucchelli Station) reveal neo-tectonics and may help to improve the understanding of the geologic development.

For the vertical, motions were detected with an average of +1.3 mm per year. Subtracting the velocities observed at the continuous station TNB1 the relative horizontal velocities are per year for the east direction, whereas for the vertical +0.4 mm per year were obtained (errors are in the order of ±0.1 mm). These are essential boundary conditions for the detection of the glacial isostatic adjustment (GIA) and other geophysical signals, and to redefine theory and other numerical models used without any direct measurement (Capra et al. 2007).

GRAVITY FIELD, ICE COVER AND ISOSTASY

Gravity research in the area has two different aims: First, of course, to derive the Bouguer anomaly for the investigation of the crustal structure. The second aim concerns the gravity changes induced by changes of the ice cover and/or tectonic deformation. In connection with air-borne measurements the Bouguer anomaly was already derived for the area of NVL (Reitmayr 2003). We hope to shed some more light on the gravity field and crustal dynamics in future by joint interpretation of the gravity and magnetic fields available in that area, also off-shore. This topic is under consideration in the frame of a research proposal by Jentzsch, Damaske and Läufer funded by DFG (doctoral thesis under preparation).

An explanation with a changing crustal thickness by isostatic models as well as models for glacial isostatic adjustment (GIA) is still lacking. The new measurements add new data, and they also add a dynamic component with increasing importance with time: Gravity variations measured on the surface to complement gravity variations derived from satellites.

With respect to the already observed vertical movements of about +0.4 mm per year and taking into account the available accuracy and resolution of repeated gravity measurements of about 10 μGal gravity variations should rise above the signal-to-noise ratio after some 20 years – additional signals, e.g. from mass-loss due to ice retreat could alter this estimation.

Ivins et al. (2003) derive vertical movements in the order of 1.5 mm per year in North Victoria Land with a gradient of about 1 mm per year over our area. Further, SHEPHARD et al. (2012) report about new findings concerning ice retreat in West Antarctica and models of surface mass balance and glacial isostatic adjustment to estimate the mass balance. For the West Antarctic ice shield a dramatic mass-loss is documented for the past decade, which should be seen in gravity signal as well.

We used gravimeters in the same way the Nordic colleagues did concerning their work along the so-called Land-Uplift-Lines in Fennoscandia (MÄKINEN et al. 1985, EKMAN & MÄKINEN 1996): After several decades and many campaigns (repeated about every five years) they could distinguish between the free air effect and the Bouguer effect on gravity (visco-elastic response), and, thus, find a model for postglacial rebound for Fennoscandia.

Therefore, it is advisable to repeat the measurements every three to five years to create a reliable database, and to increase the points by the other available points of the Italian network.

MICRO-GRAVITY MEASUREMENTS AND PRELIMINARY RESULTS

The gravity measurements were carried out with the relative gravimeters G-085 and G-858 provided by the Technical University of Berlin (Geodesy and Geoinformatics), and the gravimeter G-662, owned by the Leibniz-Institute for Applied Geophysics, Hannover. All gravimeters are equipped with electrostatic feedback systems, which were carefully calibrated before the expedition. These three gravimeters were already in use by us and, thus, well known as some of the best gravimeters available in Germany (KRONER et al. 2006).

Every measurement consisted of at least three single readings, noted after at least two minutes after adjustment, repeated twice. We noted the value of the dial as well as the feedback voltage. In this way obvious miss-adjustments were revealed. Later, the mean of the remaining readings is used for the final adjustment of the network. It was intended to measure at all points at least three times to obtain nearly ten measurements each (with three gravimeters). The order of the measurements was always G-085 first, then G-858 and G-662. But due to the weather conditions it was not always possible to complete the tour as intended. Therefore, the distribution of the data is somewhat inhomogeneous. The order of the measurements as well as the connections realized are given in Table 1.

Depending on the local conditions like the horizontal and/or vertical distances between the helicopter landing spot and the point itself the time for completing the work at one point was about 40 minutes for the measurements (adjustment of the gravimeters and taking readings as described above) and up to 20 minutes for the transportation. Thus, it was possible to build up a routine to measure with several gravimeters one after another. The GPS-equipment was installed by the Italian colleagues at the beginning and removed just before the end of the season. Thus, we received averaged GPS-observations.

Table 2 contains all the points visited, their coordinates as well as the preliminary gravity differences obtained. We used Gondwana Station as reference station, and every day was started with taking measurements there; upon return, again a measurement was taken.

Difference measurements taken

GOND	-	TNB (B)	xxx xxx xxx
GOND	-	VL15	xxx xx xxx
GOND	-	VL07	xxx xxx xxx xxx
GOND	-	VL08	xxx
GOND	-	VL10	xxx xxx
GOND	-	VL11	xxx xxx
GOND	-	VL13	xx xxx
GOND	-	VL06	xxx xxx
GOND	-	VL18	xxx xxx
GOND	-	VL19	xxx
TNB (B)	-	TNB1 (ref)	xxx xxx
VL07	-	VL08	xxx xxx xxx
VL08	-	VL10	xxx xxx
VL11	-	VL13	xxx
VL13	-	VL17	xxx xx
VL15	-	TNB (B)	xxx
VL15	-	VL16	xx xxx
VL16	-	VL17	xx
VL16	-	VL18	xxx
VL17	-	VL19	xxx
VL18	-	VL19	xxx

Measurements at the individual points

GDW	xxx xxx xxx xxx xxx xxx xxx xxx xx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx
TNB (B)	xxx xxx xxx xxx
TNB1 (ref)	xxx
VL06	xxx
VL07	xxx xxx xxx
VL08	xxx xxx xxx
VL10	xxx xxx
VL11	xxx xxx
VL13	xx xxx xxx
VL15	xxx xx xxx
VL16	xx xxx xxx
VL17	xx xxx xxx
VL18	xxx xxx xxx
VL19	xxx xxx xxx

Tab. 1: GANOVEX X 2009–2010 measurement statistics; due to a breakdown of the battery of G-662 one loop could not be completed with this gravimeter. Therefore, in some cases only two crosses are given. Each x denotes one gravimeter.

Tab. 1: GANOVEX X 2009–2010: Zusammenstellung der Messungen. Jedes x steht für ein Gravimeter. Wegen Batterieausfalles am Gravimeter G-662 sind bei einigen Stationen nur zwei Geräte aufgeführt.

This led to the question concerning the number of stations possible during one flight. The best result was obtained when measuring six points plus the two reference measurements at Gondwana Station. This meant about eight hours measuring time plus more than two hours flight time. But we also had to experience the negative extreme. Only one station possible due to strong winds at the other places – and five hours work. To avoid breakdowns, it is recommended to use new batteries. We only suffered one battery breakdown from an old battery, which had to be replaced by a spare-one.

Name	GPS-No	North longitude	East longitude	Elevation above sea level [m]	Gravity differences to GOND [μm s^{-2}]
Gondwana	GOND	-74.633560	164.220855	10	0
Terra Nova building	TNB (B)	-74.698806	164.102943	15	61
Terra Nova Ref.	TNB1-GPS	-74.698806	164.102943	72	-172
Mt. Melbourne	VL06-GPS	-74.350001	164.690649	2732	-6,884
Mt. Monteagle	VL07-GPS	-73.759900	165.379302	2100	-6,147
Mt. Jiracek	VL08-GPS	-73.764285	163.739536	2655	-7,568
Archambault Ridge	VL10-GPS	-73.688456	162.768594	2619	-7,896
Mt. Baxter	VL11-GPS	-74.371428	162.541668	2362	-6,708
Mt. Larsen	VL13-GPS	-74.847797	162.204969	1510	-4,626
Inexpressible Island	VL15-GPS	-74.934264	163.715667	29	131
Cape Philippi	VL16-GPS	-75.232561	162.545487	311	-1,370
Evans Height	VL17-GPS	-75.095135	161.538744	683	-2,779
Starr Nunatak	VL18-GPS	-75.898533	162.593712	58	-571
Mc Daniel Nunatak	VL19-GPS	-75.804974	161.781615	809	-2,427

Tab. 2: Names and coordinates of GPS points and preliminary (rounded) gravity differences regarding GOND in μm s^{-2}; Terra Nova Ref. is the geodetic reference point on top of the hill above Mario Zucchelli Station; TNB (B) is the reference point inside a hangar where absolute gravity was measured. The higher resolution (nm s^{-2}) was provided by the precise data analyses (see Tab. 3). Our measurements at Mt. Melbourne were carried out by invitation of the Italian partner.

Tab. 2: Bezeichnungen und Koordinaten der GPS-Punkte und vorläufige Schweredifferenzen zu GOND in μm s^{-2}. Terra Nova Ref. Ist der geodätische Referenzpunkt auf der Spitze des Hügels direkt hinter der Mario Zucchelli Station. TNB (B) ist der Referenzpunkt innerhalb des Hangars, auf dem die Absolutschwere bestimmt worden ist. Die höhere Auflösung (nm s^{-2} wurde durch die Analysen möglich (Tab. 3). Unsere Messungen auf dem Mt. Melbourne fanden auf Einladung der italienischen Partner statt.

Name	GPS-No	Readings	Δg [nm s^{-2}]	rms [nm s^{-2}]
Gondwana	GOND	80	0	49
Terra Nova building	TNB	24	60 675	98
Terra Nova Ref.	TNB1-GPS	6	-174 128	191
Mt. Melbourne	VL06-GPS	6	-6 898 447	171
Mt. Monteagle	VL07-GPS	17	-5 700 586	110
Mt. Jiracek	VL08-GPS	16	-7 561 680	117
Archambault Ridge	VL10-GPS	12	-7 889 645	136
Mt. Baxter	VL11-GPS	12	-6 702 274	132
Mt. Larsen	VL13-GPS	14	-4 619 520	122
Inexpressible Island	VL15-GPS	16	132 199	109
Cape Philippi	VL16-GPS	16	-1 367 577	112
Evans Height	VL17-GPS	15	-2 771 065	115
Starr Nunatak	VL18-GPS	18	-570 838	107
Mc Daniel Nunatak	VL19-GPS	11	-2 426 388	135

Tab. 3. Names and GPS-nos. of the observed points, number of connections, derived gravity differences regarding GOND and errors in nm s^{-2}; TNB is the reference point inside a hangar where absolute gravity was measured.

Tab. 3: Namen und GPS-Nummern der Messpunkte, Anzahl der Verbindungen, abgeleitete Schweredifferenz zu GOND sowie Fehler in nm s^{-2}; TNB ist der Referenzpunkt innerhalb des Hangars an dem die Absolutschwere gemessen worden war.

In all, Gondwana Station was connected with ten stations out of the network of 13, and eleven stations were connected to each other at least three times. 30 measurements were carried out at the reference station Gondwana (GOND) alone, and 34 measurements were done at the other points of the network (always with all three gravimeters).

The data were evaluated using the software GRAV (Wenzel 1993 unpubl.), which was completed by us, especially concerning the introduction of the feedback values. The final adjustment of all data was already completed (Jentzsch et al. 2014). This required a careful screening of the data of the individual gravimeters in order to sort out bad data. The results are given in Table 3 (from Jentzsch et al. 2014).

As it looks like, local ice thicknesses are not disturbing the data at the points, because there, we could always measure on the rock. But the general ice and snow cover may become a problem. Here we would need spatial data of the whole area. Model computations will be used to check this effect. On the other hand, we have improved the tidal model used up to now by taking into account the ocean tides as well. There existed a tide gauge record over more than one year at Mario Zucchelli Station just 7 km opposite to Gondwana Station, which was made available by the Italian colleagues. The ocean tidal corrections improved the data considerably due to the small distances to the ocean.

Figure 2 shows an arrangement at point VL15 (Inexpressible Island). The reference point is on the upper end of the steel post just below the table screwed on it. This table proved to be unusable because of vibrations due to wind. Figures 3 & 4 give more details about the experiments, especially the steel post and the shielding against wind if necessary.

Depending on the weather the flights had to be planned and the schedules had to be adopted. In particular the strong catabatic winds proved to be very disturbing, measurements were simply impossible. On the other hand, we also experienced best conditions at critical points, unexpectedly. Thus, it was not possible to follow the previously worked out flight plan, and instead of 12 intended flights we had to use the helicopter 15 times (one flight invited by the Italian colleagues), and still we could not measure as much as we had planned. The flight distances are in the order of over 3,000 km.

FINAL RESULTS

Data analyses are already completed and Table 3 contains the results (from Jentzsch et al. 2014). Some figures can be stressed. The gravimeters are calibrated to 10^{-4}; although this

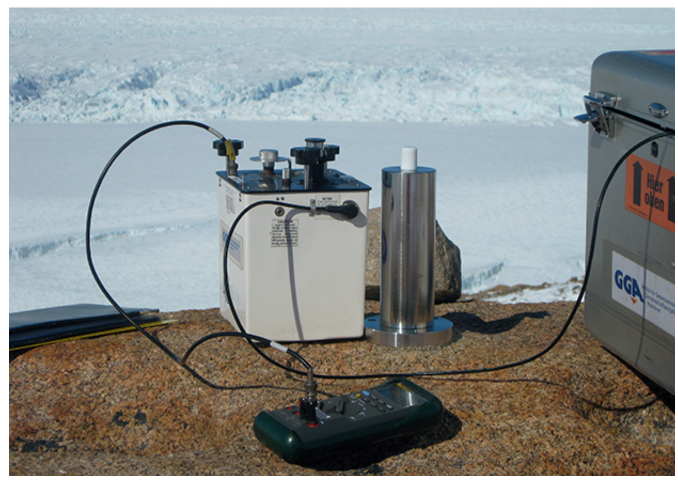

Fig. 3: Gravimeter G-662 at point Cape Philippi (VL16) beside the benchmark. In the background is the David Glacier continued by the Drygalski Ice Tongue to the left, (Photo: author).

Abb. 3: Messpunkt Cape Philippi (VL16) mit Gravimeter G-662 neben dem Edelstahl-Pfosten. Im Hintergrund ist der David Glacier mit der Drygalski Ice Tongue zur Linken, (Foto: Autor).

Fig. 2: Measurements at point VL15, Inexpressible Island. The table proved to be not usable due to unexpected vibrations. Here, G-662 is seen, the other two gravity meters are in the boxes behind. The arrow points to the top of the benchmark as the reference, (Photo: author).

Abb. 2: Messung an Punkt VL15, Inexpressible Island. Der aufgesetzte Tisch erwies sich als unbrauchbar wegen unerwarteter Vibrationen. Man sieht G-662, die anderen beiden Gravimeter im Hintergrund. Der Pfeil deutet auf den Bezugspunkt am Pfosten, (Foto: Autor).

Fig. 4: Measurements with G-858 at Mt. Jiracek (VL08). The boxes of the other gravimeters are used as windshields, the arrow points to the top of the benchmark. Circled below left is the helicopter pilot worrying for a developing whiteout, which appeared only some minutes later and forced us to abandon the measurement. The position of the pilot reveals that the climb up-hill was not that easy, (Photo: private).

Abb. 4: Messungen mit G-858 am Mt. Jiracek (VL08). Die beiden anderen Gravimeter dienen als Windschutz, der Pfeil deutet auf den Pfosten. Im Kreis sieht man den Piloten der zur Eile drängt, da sich ein „whiteout“ entwickelt; die Position des Pikoten zeigt, dass der Aufstieg zum Messpunkt nicht einfach war, (Foto: privat).

value was determined for the feedback only, we consider that the calibration of the dial is not better but similar. This means, that gravity differences between Gondwana and the high points like Mt. Jiracek or Archambault Ridge in the order of more than 6,500 μm s^{-2} (corresponding to 650 mGal, since 10 μm s^{-2} correspond to 1 mGal.) cannot be determined to better than 650 nm s^{-2} (or 65 μGal). This is not too bad, but by far not enough to separate the anticipated very small differences to be resolved later. But, the gravity differences between the points at about the same elevations seem reasonable for interpretations, because they are much smaller and, accordingly, the errors as well; and this is exactly what we need. Therefore, we tried to combine the points themselves rather than to link all the points to the reference GOND.

Although the set-ups of the gravimeters were more or less repeatable, there were some considerable differences due to wind and temperature conditions, which surely have consequences for the accuracy of the results. Thus, due to the environmental conditions we may not be able to achieve similar results concerning the errors as in our measurements at volcanoes of about ±100 nm s^{-2} to ±150 nm s^{-2} (±10 to ±15 μGal; Jentzsch et al. 2004). But, as a positive result we can mention that under favourable conditions we received for a single loop between Gondwana Station and Mario Zucchelli Station an error of ±4 μGal (±40 nm s^{-2}), which can serve as a lower bound for the errors. Thus, we expect that the data will be useful for the purposes mentioned above.

DISCUSSION AND CONCLUSIONS

The work started with this project marks the starting point concerning the investigation of the relation of deformation and gravity field variations in the area of northern Victoria Land. The central question is if deformation is accompanied by gravity field variations or if there are additional effects causing changes in gravity, e.g. like changes in the ice cover. This can only be answered after about 20 years and several campaigns. The results could contribute as another boundary condition to the numerical modelling of other geophysical and geodetical data, as mentioned above. It is certainly not to be expected to find strong changes due to fast elevation changes, but such measurements should be started now to create data for later comparison. Because of climate changes a retreat of the glaciers will be a signal to be observed, and, thus, a contribution to glacial isostatic adjustment (GIA) can be expected, although no modeling was done yet. Thus, as the colleagues in Fennoscandia we expect to distinguish between the free air effect and the Bouguer effect on gravity to find a model for postglacial rebound.

The first experience worth mentioning concerns the transport of the gravimeters with the airplane as cabin luggage. Because of new flight restrictions they had to be transported without the batteries, and this transport had to be negotiated with the airline prior to purchasing the tickets. The connectors being prepared beforehand, the batteries were purchased in New Zealand during the two days between arrival of the plane and departure of the Italian research vessel to Terra Nova Bay. On the way back the batteries were put into the personal luggage and returned with the ship.

In the helicopters, the gravimeters were transported on the rear seats, on the seat cushions, to minimise vibrations. Since the elevation differences were up to 2,600 m, the dial was turned using a small electric motor.

Although we had quite fortunate conditions concerning the temperature and the wind it is recommended for further measurements to insulate the gravimeters, e.g. by a material wrapped around to protect the casing from cooling too fast. Since the gravimeters have to be used close to the benchmarks and due to the limited area of rock available for the installation it is not possible to use them inside a bigger case with bottom holes for the foot screws. Further, the gravimeter campaign had to fit into the overall schedule of the expedition leading to the effect that not all favourable times could be used for gravimetry.

Finally, one person operating three gravimeters meant quite a big job. But the capacity of the helicopter is limited, and the flights often had to be shared with other projects. Therefore, it was necessary to rely on the accompanying colleagues as well as the pilots to help carrying the gravimeters to the points. For the future the recommendation is to use four gravimeters and two observers, which would increase the number of observations in a shorter time.

From the technical point of view, the question if micro-gravity measurements are feasible at the GPS-points in NVL following the usual practice (several gravimeters together; precise repetition of set-ups) can be answered with YES (!). Thus, we want to recommend to continue these measurements including more points already available from the Italian partners in NVL.

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The transport of the gravimeters in the plane as cabin luggage required two extra persons; Nadine John and Robert Schöner of our institute, also participating the expedition, thankfully volunteered to carry two gravimeters through check-in and customs.

The author needed help to carry the gravimeters to the measuring points; this help was provided by the colleagues who shared the flights, as well as by the pilots – many thanks! Thanks also to my co-workers Stephanie Zeumann and Marco Naujoks as well as the students Franziska Bock and Tobias Nickschick for their contribution to carefully calibrate the gravimeters at the vertical base line in Hannover.

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