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Journal of Geodynamics 38 (2004) 225–236
JOURNAL OF GEODYNAMICS
http://www.elsevier.com/locate/jog

Preface to the Global Geodynamics Project

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Received 29 June 2004; accepted 9 July 2004

Abstract

I review some features of the Global Geodynamics Project during its initial phase of operation 1997–2003. These fall into three categories: (1) instrumental—the development of the superconducting gravimeters during this time; (2) organizational—how the various SG groups have come together to improve their installations and provide their data; and (3) scientific—what have been some of the notable observational achievements of the project. This overview is then followed by a brief description of some of the new tasks for GGP Phase 2 (2003–2007).

1. Historical introduction

The Global Geodynamics Project (GGP) was conceived during the same time that Study of the Earth's Deep Interior (SEDI) was being planned at the ISECALM (initial acronym for SEDI) Workshop in Trieste, 1986. At that time a number of different areas of geophysics came together to initiate a cooperative and concerted effort to make progress on problems of the deep interior. Melchior1[1] spoke of the recent improvement between spring gravimeters and superconducting gravimeters (SGs) and Smylie discussed the possibility of detecting core dynamics using the SGs. Smylie and Crossley carried the enthusiasm of the workshop back to Canada where eventually the theoretical geodynamics group (Aldridge, Rochester, Mansinha, Merriam and others) decided to acquire one of the 'new' SGs. The instrument was funded in 1987 and installed in Cantley, Quebec, in 1989. Subsequently the Canadians put forth a proposal for the

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[1] Sadly, Paul Melchior passed away recently.

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doi:10.1016/j.jog.2004.07.002

existing worldwide SG stations to form an international project (GGP) to cooperate on data collection and exchange (Aldridge et al., 1991). At that time there were 11 instruments operating, all of them the original full-size TT models: one each in Strasbourg, Wettzell, Brussels, and Wuhan, four in Japan, two in Richmond, Florida (including one of John Goodkind's UCSD instruments) and the Cantley instrument. In 1990, at the Walferdange Workshop on non-tidal gravity changes—intercomparison between absolute and superconducting gravimeters, we noted ". . . despite all good intentions, data sets of substantial length and quality have rarely been obtained in the 9 years of recording" (Aldridge et al., 1991). The reasons for this were varied, but up to then gravimeter data had been collected almost entirely for local experiments and projects and record continuity was of secondary importance.

In our first GGP proposal, we used the term global geodynamics to signify that the signals we (the Canadians) were most interested in were global in nature, i.e. oscillations of the inner core and within the liquid core, polar motion and wobbles. The scope of the final proposal included many more projects than the deep Earth, spanning a whole range of deformations from seconds to decades. It was of course recognized that the measurement of gravity at a single location is dominated by the Earth tides and includes local (and regional) environmental effects such as the atmosphere and hydrology. Between 1991 and 1997 there were extensive discussions within the Earth tides community on how to fulfill the aims of the original proposal, and some of the original ideas (such as a network of SGs within Canada and a data center in Canada) did not survive. Nevertheless the international community was able to agree on the main points of the project and engage in a pilot project to test the data exchange formats. In 1987 GGP was endorsed by SEDI as one of its 'projects', and as such GGP came under the umbrella of the IUGG in a loose way. The official start of GGP was not to be until 1 July 1997, with about 17 instruments participating, and the subsequent history of the project is well documented in the series of 13 GGP Newsletters (http://www.eas.slu.edu/GGP/ggpnews.html).

Since 1997 the progress of GGP has been steady and productive, and in mid-2003 GGP began a second phase of continuing observations that will last up to the next IUGG in 2007. Notable among the recent developments was the incorporation of GGP into the structure of the International Association of Geodesy (IAG); GGP is officially as an inter-Commission project, responding to Commission 3 (Earth Rotation and Geodynamics) and Commission 2 (The Gravity Field). In the future GGP will become part of integrated global geodetic observing system (IGGOS). Another point of interest is that the Japanese component of GGP has developed into a strong sub-organization with a GGP Japan Center at the National Astronomical Observatory in Mizusawa, administered in cooperation with the Ocean Research Institute, Tokyo.

2. Instrumentation

The initial development of the SG was a research project that was proven in concept by Prothero and Goodkind (1968). Much of the development then passed to Warburton (then a postdoctoral fellow) and Goodkind, and the development remained a research project for a number of years until impressive results started to appear (e.g. Warburton and Goodkind, 1977). The installation of the first commercial observational models (TT40) did not come until 1981 in Brussels after the formation of the Goodkind, Warburton, and Reinemann (GWR) company; the early history of the installations can be seen in Table 2. Between the conception of GGP in 1986 and its official launch in 1997 the number of instruments had risen to about 17, and a new compact design (instruments labeled CO) was running at Boulder, Membach,

Table 1
SG stations of the GGP Network, as of 10 June 2004

	Station	Location	Country	Responsibility	Institute	Latitude (+N, −S)	Longitude (+E, −W)
1	BA	Bandung	Indonesia	S. Takemoto	Kyoto U.	−6.8964	107.6317
2	BE	Brussels	Belgium	B. Ducarme	ROB Brussels	50.7986	4.3581
3	BH	Bad Homburg	Germany	B. Richter	IFAG/IERS Frankfurt	50.23[a]	8.61[a]
4	BO	Boulder	USA	D. Robertson	U. Colorado	40.1308	254.7672
5	BR	Brasimone	Italy	G. Casula	INGV Bologna	44.1235	11.1183
6	CA	Cantley	Canada	J. Merriam	U. Saskatchewan	45.5850	284.1929
7	CB	Canberra	Australia	T. Sato	NAO Mizusawa	−35.3206	149.0077
8	CO	Concepcion	Chile	B. Richter	IFAG/IERS Frankfurt	−36.82[a]	−73.05[a]
9	ES	Esashi	Japan	T. Sato	NAO Mizusawa	39.1511	141.3318
10	KY	Kyoto	Japan	S. Takemoto	Kyoto U.	35.0278	135.7858
11	MA	Matsuchiro	Japan	Y. Imanishi	U. Tokyo	36.5430	138.2070
12	MB	Membach	Belgium	M. van Camp	ROB Brussels	50.6093	6.0066
13	MC	Medicina	Italy	S. Zerbini	U. Bologna	44.5219	11.6450
14	ME	Metsahovi	Finland	H. Virtanen	FGI Masala	60.2172	24.3958
15	MO	Moxa	Germany	G. Jentzsch	FSU Jena	50.6447	11.6156
16	NY	Ny-Alesund	Norway	T. Sato	NAO Mizusawa	78.9306	11.8672
17	PO	Potsdam	Germany	J. Neumeyer	GFZ Potsdam	52.3806	13.0682
18	ST	Strasbourg	France	J. Hinderer	EOST Strasbourg	48.6217	7.6838
19	SU	Sutherland	S. Africa	J. Neumeyer	GFZ Potsdam	−32.3814	20.8109
20	SY	Syowa	Antarctica	K. Shibuya	NIPR Tokyo	−69.0067	39.5857
21	VI	Vienna	Austria	B. Meurers	U. Vienna	48.2493	16.3579
22	WA	Walferdange	Luxembourg	O. Francis	MNH Walferdange	49.6650	6.1530
23	WE	Wettzell	Germany	B. Richter	IFAG/IERS Frankfurt	49.1440	12.8780
24	WU	Wuhan	China	H.-P. Sun	IGG Wuhan	30.5159	114.4898

Most recent coordinates are given; in some cases minor differences exist between epochs.
[a] Approximate coordinates.

Strasbourg, Vienna, and Wettzell. Clearly the beginning of the GGP had a significant impact on increasing the number of new stations, and many groups recognized the benefits of a belonging to a coordinated global project. At present, the number of installations has risen to 24 (Table 1), but this includes the closing down of three stations (Table 2).

As is to be expected with sophisticated instrumentation, manufacturing research and production experience developed rapidly, especially with today's technology. Of the 17 instruments recording at the start of GGP, few of them prior to the CO model design were duplicates of each other. Most of the TT models had design differences between them that arose from developments aimed at solving the problems of drift, offsets, and tilts and as well as rapid improvements in other design features. Despite this heterogeneity and the subsequent improvements, the best of the early TT instruments are still running today, with some excellent long-term recordings (at Cantley, Metsahovi, Esashi, and Wuhan). The overall accuracy of the SGs has remained at about the 0.1 microgal level first discussed by Goodkind (1991) and more recently confirmed in the Moxa dual sphere sensor (Kroner et al., 2001). The experience at Strasbourg, however, clearly showed improvements from the T005 full-size instrument to the CO26 model in noise (Rosat et al., 2002, Fig. 12), and lower drift rates (Amalvict et al., 2001).

Table 2
Number of months of 1-min data at ICET, as of 18 June 2004

Station	Pre-GGP															GGP Phase 1							GGP Phase 2			Total
	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2003	2004	2005	
BA																1	12	12	12	12	7					56
BE	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	6	12	12	9							39
BO														9	12	12	12	12	12	12	12	6	4	x		103
BR									r	r	r	r	r	1	12	12	12	12	1							50
CA								2	12	12	12	10	x	7	12	6	12	12	12	12	6					127
CB																6	12	12	12	12	12	x				66
ES							r	r	r	r	r	r	r	r	r	6	12	12	12	12	12					66
KY							r	r	r	r	r	r	r	r	r	6	12	12	12	12	7					61
MA														r	r	6	12	12	12	12	6					60
MB														9	12	12	12	12	12	12	12	6				99
MC															r	r	12	12	12	12	12	6	6			72
ME													4	12	12	12	12	12	12	12	12	5				105
MO																		r	12	12	12	6	6	4		52
NY																		4	12	12	7					35
PO											5	12	12	12	12	12	7									72
ST						r	r	r	r	r	r	r	r	r	r	10	12	12	12	12	12	6	6			82
SU																			10	12	12	6	6			46
SY												D	D	D	D	6	12	12	12	D	D	D				42
VI														r	r	6	12	12	12	12	12	x				66
WE*						r	r	r	r	r	r	r	r	r	6	12	12	6	12	12	12	6	5			83
WU					r	r	r	r	r	r	r	r	r	r	r	1x	12	12	12	12	10					58
Total																										1440

Data is being added continuously, so this is only a snapshot representation. *Notes*: (r) recorded data not in database; (x) recording interrupted (e.g. computer problem, instrument change or upgrade) recording stopped, instrument decommissioned; (D) Syowa raw data 1 August 1993 to 31 January 2003 available on DVD; (*) data for WE after April 2001 is available only in post-processed format.

It should be noted that the 0.1 microgal accuracy refers (perhaps surprisingly) both to the difference signal between either two sensors in the same cryogenic dewar, and to two independent instruments. Goodkind (1991) remarks that a dual sphere model should in principle perform better than a single instrument, but design difficulties unfortunately have not been able to fully capitalize on this expectation. One physical limitation may be the instability of the magnetic flux on the surface of the niobium sphere, despite precise temperature and electronic control. Improvements have been realized in two other areas, however, one being the reduction in instrument offsets (unexplained jumps between sequential values) and the second is in the drift of the sensor with time.

The better instruments nowadays are able to perform with only a few offsets per year (aside from obvious external causes such as He refilling), and with drift rates of a 1–3 microgal/year as measured by close comparisons with well-maintained absolute gravimeters. It is still true, however, that predicting the drift performance of a particular SG is both an art as well as a reproducible science, despite 30 years of development. From a manufacturing point of view the compact SG appears now to have reached a design plateau (Richter and Warburton, 1997) and a new field-transportable instrument has been developed and installed in Concepcion, Chile. This SG requires no helium refills and can be operated, or at least monitored, remotely by Internet (Warburton et al., 2000; see also Ritschel and Neumeyer, 1995). The time history of the SG data is shown in Table 2.

Instrument performance is only partially measured in the time domain. For many purposes, the SG performance in the frequency domain, looking for time harmonic signals, is of more interest. In this respect the performance of SGs has remained more or less unchanged, with the best instruments being able to resolve signals such as seismic normal modes and small tides at the 1 nanogal (10^{-12} g) level or less. This performance rivals that of the best seismometers in the long period seismic band (periods >500 s, e.g. Rosat et al., 2002), as has no equal at longer periods. Note that the quantization level of a single SG observation is about 0.1 nanogal with a 7.5 digit voltmeter, assuming it measures the full unfiltered gravity signal, so we are getting close to this limit for the weakest signals observed to date.

Because of these factors, the ability to stack signals from many SGs is now a technique that must be used wherever possible. Unfortunately for local or regional monitoring, the resource demands of the dewar and the logistics of running multiple SGs at nearby sites has been a major factor against using the instruments in arrays. With the size reduction to the compact (and field) models, the problem has come down to one of cost and the choice of suitable test projects to request funding. This is, however, one of the goals of the current phase of GGP.

3. Organization

As indicated above, prior to GGP the various SG scientists and groups more or less treated the SG as a research instrument, to be used for recording tides, performing calibrations and generally experimentation. Although several instruments were engaged in almost continuous tidal recording, the available of data was by request only, and the format and treatment of the data varied from one station to the next.

The main goal of GGP was to provide challenges to the community: (a) to insist on a quality site and data acquisition system that did justice to the sophistication and potential of the instrument; (b) to urge the stations to adopt a common format for the data; and (c) to send the data on a regular basis to a central database where it could be archived and made available to the general scientific community. The first issue, that of a suitable site, turned out to be a deciding factor for moving some stations, generally from urban to country areas. Examples are Wuhan and Brussels, the former moving to a quieter space geodesy site in 1997 and the latter, although it was never moved (the original un-cooled T002 instrument continued uninterrupted until 2000), a replacement site was found in 1996 at Membach (a seismometer station) for the new CO21 model (Francis, 1997). Generally, new sites have been selected with GWR recommendations in mind, while taking advantage of stations where existing scientific infrastructure is able to support the SGs. One requirement that has been difficult to satisfy is to find bedrock sites, and those SGs that are on sediments can be noticeably affected by an excessive response to seasonal effects, e.g. Medicina (Zerbini et al., 2002).

As far as data acquisition systems were concerned, it became apparent during the early 1990s that the various SG groups were not going to be able to agree on a single design for the data acquisition (i.e. the sampling and recording aspects at the output of the GWR-provided filter boards). Part of this reluctance was the commitment of most established groups to their own local instrument culture and expertise, and partly the lack of a turnkey system from the manufacturer. Consequently, GGP agreed to provide the general specifications of the system and let the various groups work out the details. Some tough choices at this early stage have paid off as time progressed, for example, the specification of high rate sampling (preferably 1 s for gravity and pressure), and the use of a high quality voltmeter with 7.5 digit accuracy sampling the whole signal allows the data to be useful to the seismologists. A significant step was the provision of the standardized GGP1 and GGP2 filter board by GWR; this enabled every group to install more or less the same anti-aliasing filter, or a similar copy.

By far the largest change in the tidal community however, was the decision to adopt a common format for data exchange. The choice was fairly clear, because of the development of the ETERNA programs for tidal processing that many groups had started to use (Wenzel, 1997). Technically called the Preterna format, this became know as the GGP format that is universally used by all SG groups (to my knowledge). Another feature of the data format is that groups would send uncorrected data (i.e. raw data decimated without any treatment) in 1 min files, a month at a time. This data was originally protected for a year within the original station, and a further year within the GGP community before it became available to groups outside (through the database). Such a restriction of the data was initially sufficient to encourage all SG groups to participate in GGP, giving them a lead time to look at their own data first, while still moving data towards general circulation.

The final major hurdle for SG groups was to agree to keep their instruments sited and maintained for the 6 years of the original GGP observation period. This placed unnatural restrictions on some groups who wanted to move the SGs around for shorter length experiments or those who wanted to do experiments with the instrument. Yet, to everyone's credit, almost all groups were able to keep recording for the 6 years at their original site, which has allowed an impressive amount of useful data to be accumulated. This continuity has had many good side effects, one of which has been the realization of experiments unforeseen within the original GGP.

As is clear from the papers in this volume, as well as the many other publications arising from GGP, the sheer number and breadth of projects is testament to the goodwill of the community to make this cooperation work. One significant benefit has been the number of graduate students trained in the developing world of high precision gravimetry. I have not been able to count the number of theses published arising from the data, but it could number up to 20. Many of these students have now grown up in the world of GGP and with the general availability of more and more GGP data, the project looks like it will be self-sustaining for a good time to come.

A final comment about organization refers to the recent inclusion of GGP within the re-invigorated IAG structure as an inter-commission project, with primary reporting duties to Commission 3 (Earth Rotation and Geodynamics) and affiliation also with Commission 2 (The Gravity Field). As such, GGP still runs itself as before, but we have the benefit of an official place in the scientific world that gives us a role within IAG. The former loose association with SEDI is thereby superceded, but from a research point of view, this changes nothing about what we do and how we do it. We are particularly indebted to Veronique Dehant, President of Commission 3, for her timely encouragement and lobbying for the inclusion of GGP in IAG.

4. Achievements and issues

Instead of the traditional viewpoint that goes from one end of the spectral scale to the other, let us review some GGP highlights from the largest signals we can see to the smallest (and beyond). At the same time, we point out remaining issues that need further work.

4.1. Tides

The solid Earth tides are by far the largest, omnipresent, gravity variations, and clearly GGP, or more correctly the SG, has allowed significant advances in tidal modeling. This is particularly true in the signal to noise ratio with which small tides can be extracted from a record. This is clear both for linear tides (e.g. Florsch et al., 1995; Ducarme et al., 2002) and non-linear tides in the open ocean (e.g.. Merriam, 1995; Boy et al., 2004). Obviously with long records, diurnal and semi-diurnal tides can now be resolved at the nanogal level. This has had two significant consequences: first, the requirement for developing a very precise tidal theory for the solid earth tidal series that has now produced two 'benchmark' developments: Roosbeek (1995) and Hartmann and Wenzel (1995), the latter including up to 12,935 waves in its most precise form. Second, it is now within the ability of SG tidal gravimetric factors to distinguish between different ocean tidal models that were developed from satellite data sets, e.g. Baker and Bos (2003), Boy et al. (2003). An elegant use of SG data by Sato et al. (2001) was to measure the non-tidal stearic effect—the effect of thermal expansion of ocean water, with no mass change, on sea surface heights—that is an observation unique to SGs.

The contribution of SGs has also strengthened the agreement between space geodetic techniques (e.g. VLBI) and gravimetry for the determination of the parameters of the free core nutation (FCN). In particular, the gravimetrically determined Q factor is now an order of magnitude higher than previously estimated, thanks to the use of a more sophisticated non-Gaussian statistical model of the resonance (Florsch and Hinderer, 1998), and in agreement with VLBI estimates. There still remains, nonetheless, some tidal issues, one of which is the lack of precise ocean loading for the small waves, and another is the possibility of the lateral variation of the solid Earth tidal factors with tectonic provenances, first raised by Melchior (1995).

4.2. Earthquakes and normal modes

SGs, in common with all other gravimeters, naturally record earthquakes on top of the tidal signals, and occasionally the surface waves from large events can reach appreciable fractions of the tidal amplitudes.

The sampling time for most SGs, in the range 1–5 s, is however too coarse for event arrival detection or true waveform inversion, but the data is suitable for normal mode analysis (Zürn et al., 1995). Indeed for many years, SGs have recorded earthquakes that are generally regarded as noise from the tidal gravity point of view, and only relatively recently have SGs been taken seriously as long period seismometers, e.g. Kamal and Mansinha (1992), Banka and Crossley (1999), and van Camp (1999). Notable work by Rosat et al. (2004) and Roult et al. (2004), coinciding with the analyses of Widmer-Schnidrig (2003), have now established the legitimacy of the SG as a serious seismic instrument, and one that should play a useful role in the future. The current limited geographic coverage of SGs compared to seismic networks will restrict the improvement that can be expected, but the excellent quality of most SGs can be used to good effect.

4.3. Earth wobbles and rotation

To date the FCN is one of only two wobble modes of the Earth that have been detected in gravity records, the other is the Chandler wobble (CW). The former is observed because of the tidal forcing very close to the resonance, and the latter is determined from the change in latitude of a station. The separation of the annual and Chandler components of wobble is now possible due to the long recordings from GGP, but many other annual signals appear in gravity due to seasonal environmental effects, so the annual effect of any one component is uncertain. By removing an annual term first, the Chandler gravimetric factor can be recovered consistently with a value of 1.18 (e.g. Loyer et al., 1999), slightly higher than the nominal value of 1.16. The phase is significantly different from the purely elastic value of 0°, but this does not immediately translate into mantle anelasticity due to the variable excitation.

Of the other two possible wobble candidates, i.e. free inner core nutation (FICN) and the inner core wobble (ICW), neither appear very promising for GGP due to the small amplitude of the former (far from a tidal resonance), or the requirement of a long observing time for the latter, perhaps about 10 years (Crossley, 2004).

4.4. The atmosphere

Despite the large number of papers appearing in the last 10 years on the effect of the atmosphere on gravity, many experts continue to use the simplest of all corrections, the nominal scalar admittance of -0.3 microgal/hPa for many studies. It has been shown repeatedly that with careful computations a global atmospheric correction can do a better job (e.g. Boy et al., 2002), especially using the non-inverted barometer effect over the oceans. The issue is, however, that is still a large calculation for routine work, and not always justified.

Of recent interest is the extension of the atmospheric correction to a layered atmosphere using high resolution ECMWF data (temperature, humidity with altitude) that is important in the reduction of long-term seasonal effects in gravity, particularly in connection with the new satellite missions (e.g. Wahr et al., 1998). The computations are extensive, but the real problem is the inaccessibility of the data for the epoch required, as the high resolution ECMWF data is not available cost-free, except to limited scientific groups.

4.5. Hydrology

If the past decade in gravity recording has taught us anything, it is that environmental factors related to hydrology (including groundwater levels, humidity, soil moisture, soil compaction, porosity, permeability and rainfall) are of utmost importance in understanding the seasonal changes in gravity. Such signals not only provide direct attraction effects but also load the crust in the near and far field regions, so contributing to a complex variation in the gravity field that can range up to several microgal over the course of a year. This effect can therefore rival the polar motion (at certain epochs), and oceanic and atmospheric effects.

Unfortunately, SG stations have not routinely collected all this kind of data, and only a few groups have attempted to provide a complete picture of the gravity variations at a single site. A notable exception is the station MC where most of the signal can be explained (i.e. modeled) by a combination of seasonal hydrology and atmospheric effects and vertical GPS-measured motion, as described in Zerbini et al. (2002). Inevitably the modeling of the gravity becomes much easier if one invokes empirical admittances between different parameters and gravity, but this approach cannot provide a physical model of the complexity at a single site. Much like the problems with measuring Earth strains, the observations need to be correlated at many distance scales (m to km) and this quickly becomes expensive in resources, even if the instrumentation was readily available.

4.6. Statistics of residual gravity data

It has been realized for a long time (e.g. Warburton and Goodkind, 1977; Jensen et al., 1995) that the residual spectrum of gravity data is red, rather than white, meaning that the power spectral density rises at low frequencies. Tests show that a $1/f^2$ distribution (f, frequency) is a good approximation, signifying a Brown noise (random walk) model for the residuals that reflects a similar spectrum in the atmosphere. The typical gravity series is also time dependent in amplitude and phase and is best characterized as quasi-stationary. The time variation arises from wind-driven wave motion in the oceans at short periods (5–10 s) and hydrological and atmospheric effects at longer periods.

The non-stationarity of the gravity residuals means that Fourier-based spectra approximate at best (Pagiatakis, 2000), and that processing using non-least squares methods is more appropriate for certain purposes. This has been recognized by Imanishi et al. (2002) in connection with calibration, and is an essential factor in dealing with the log normal distribution of the Q factor in retrieving the FCN parameters (Florsch and Hinderer, 1998).

5. New goals for GGP Phase 2

At the last GGP meeting in Sapporo (IUGG, 2003) the GGP members made a commitment to continue the global recording and reporting of SG data for a further 4 years (2003–2007), in a similar format to the first stage. Officially called GGP Phase 2, there are some differences between this new phase and the initial phase for both the SG operators and the general scientific population. One widely voiced concern from both within and outside the GGP community was for SG data to be sent more rapidly to ICET after recording and released more quickly as open file data. The agreed time limits (cf. Section 3) are now 6 months for data to reach other SG groups, and 1 month for the data to be freely available to all scientists (these periods are doubled for Syowa station due to its remoteness). In addition, more sites are now making the data available in the raw format. The Japanese GGP sub-group, called the Ocean Hemisphere Project, publishes the data for six stations that can be found at the website (http://ohpdmc.eri.u-tokyo.ac.jp/). In addition, the Syowa station data for years 1993–2003 will shortly be available in its entirety on DVD (Shibuya, personal communication, 2004).

These are welcome developments that will enhance the usefulness of the GGP data outside the gravity community. In the same direction, the GGP community is discussing the probability of sending raw data to Incorporated Research Institutions for Seismology (IRIS) for use by the seismologists to add to the data set for determining Earth structure through the periods and Q's of the long period seismic normal modes. It is expected that an agreement will be reached at the Earth Tides Symposium in Ottawa (August 2004) to provide this high-rate data.

In addition, with the slow progress in getting absolute gravity data into an accessible database, it was decided that GGP should make available the AG data collected from permanent SG stations of GGP, in a suitable format. This proposal hopefully will mature in 2004.

A beautiful example of the unexpected benefit of high quality data is the recent work done on the European gravity field, using the existing SG stations. In 1997, we did not think of the potential to use this data in connection with the upcoming gravity satellite missions such as CHAMP and GRACE. In the last few years, however, it has become clear that the ground data are well correlated with expected continental hydrology-induced gravity changes (Crossley et al., 2003) and with the preliminary GRACE fields (Hinderer et al., 2004). Though there are questions as to the interpretation of what the SG is measuring, this promising research direction has benefited greatly from the presence of GGP. A fuller review of highlights of GGP can be found in Hinderer and Crossley (2004).

Concluding on a lighter topic, let me remind the GGP community of what I recall as probably the most memorable moment of the first campaign. It occurred at the GGP Workshop in Munsbach Castle, 1999, when Virtanen was describing the effect of snow cover on the residual gravity at Metsahovi. He showed a figure of gravity increasing by about 2 microgal over a 4-h period as men shoveled snow from the roof of the SG station. When a member of the audience asked why there was an interruption in the rise of gravity, Heikki said this was a 'tea break' (Virtanen, 2000, Fig. 3).

Acknowledgements

Many people have put their effort into assuring the success of GGP, most notably the scientists and staff who run the instruments on a day-by-day basis, and those who supervise students, write the papers and attend the conferences. There are some who deserve special mention and without whose efforts GGP might never have gone ahead. First is Bernard Ducarme (ROB), whose task is to coordinate the database and check the data; together with Leslie Vandercoilden and Marc Hendricx from ICET, they have worked tirelessly to improve ICET and respond to the demands of storing, organizing and correcting the GGP data and performing the tidal analyses. We acknowledge the enthusiastic expertise of Bernd Ritschel and J. Neumeyer at GFZ, who patiently waited until GGP decided that a joint cooperation between ICET and GFZ would enable the ICET database to function efficiently. We also recognize valuable support from scientists who, although they mostly did not have instruments of their own, they constantly encouraged us to improve our scientific efforts. Among these are Trevor Baker (UK), Walter Zurn (BFO), Rudi Widmer-Schnidrig (Stuttgart), Paul Melchior (ROB), Manfred Bonatz (Bonn) and the late Hans-Georg Wenzel (Karlsruhe), with apologies to others not mentioned. Someone who is at the heart of GGP success is Richard Warburton of GWR instruments in San Diego. Through his vision, GWR's commitment to continued production and support of their instruments has been an indispensable and outstanding contribution to the science we have been able to do.

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