Reference Level Stability
of the
Canadian Superconducting Gravimeter Installation

J.B. Merriam\textsuperscript{1}, S. Pagiatakis\textsuperscript{2} and J. Liard\textsuperscript{2}

\textsuperscript{1}University of Saskatchewan
Department of Geological Sciences
114 Science Pl
Saskatoon, SK
S7N 5E2
jim.merriam@usask.ca

\textsuperscript{2}Geodetic Survey Division
Natural Resources Canada
615 Booth Street
Ottawa, Ont.
K1A 0E9

ABSTRACT

The Canadian Superconducting Gravimeter Installation (CSGI) operates a GWR TT70 superconducting gravimeter at a site near Cantley, Quebec. An adjacent pier is the reference point for the Canadian Absolute Gravity Station (CAGS) JILA-2 absolute gravimeter. The co-location of the two instruments provides an opportunity to examine the drift of the superconducting gravimeter and to search for spurious signals in either instrument. It is known that the superconducting gravimeter suffers from occasional tares, but the extent to which there are spurious signals on any time-scale is unknown. Nine separate experiments have been conducted since February 1998, in which the absolute gravimeter was dedicated to rapid sampling of gravity for about a week. From these we have calibrated the superconducting gravimeter, established the drift, and assessed the level of spurious gravity signals in both instruments. The calibration factor recovered from these experiments is $-78.3 \pm 0.1$ microgal/V. During the period from early 1998 to late 1999, the superconducting gravimeter maintained a constant reference level to better than three microgals. However, in
early 2000, the level of the absolute gravimeter rapidly diverged from that of the superconducting gravimeter achieving a maximum recorded difference of fourteen microgal during April 12-13 2000. As of June 2000 the absolute gravimeter had recovered and the offset between the two is again only two microgal. There is occasionally a rough correlation between the (tide and pressure corrected) residuals of the two gravimeters at the microgal or better level on time-scales down to about a day. However, in several experiments no correlation was apparent and excursions of the absolute gravimeter of several microgal persisting for several hours were noted. Most of the variance of the absolute gravimeter residuals seems to be at periods of hours to a day, and there are occasionally episodes of several hours duration when the instrument reads low by several microgal.

Introduction

The co-location of an absolute gravimeter (AG) and a superconducting gravimeter (SG) is advantageous to both, because the SG offers rapid, precise samples of relative gravity while the AG delivers absolute gravity measurements although of less precision. Indeed, absolute gravimeters are often used to calibrate superconducting gravimeters (Hinderer et al, 1991), and superconducting gravimeters have been used to assess the precision of absolute gravimeters (Okubo et al, 1997). SG’s are subject to tares, or sudden offsets in reference level. These are routinely detected and repaired, but the only way of assessing the reliability of this procedure is by reference to an absolute gravimeter. Accumulated tares of about 14 $\mu$gal have been removed from the SG data used here. The small residual offset between AG and SG of $\pm 3 \mu$gal suggests that the detection and correction procedure is working well. In this work, we examine the residuals of both AG and SG to try to establish the level of spurious, or instrumental, signals in both.

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The SG can be calibrated against the AG, because the earth tide provides a large signal which both instruments easily detect. The SG samples are at one second intervals and these are filtered and re-sampled to the times of the AG samples (nominally at one minute intervals). A least squares solution for a calibration
factor, an offset, and a drift is then performed. Since the Earth tide is about 300µgal, and the one minute samples of AG have a standard deviation of about 3µgal, this procedure provides a calibration factor good to about 0.1 percent, with a few days observations. The calibration experiments are usually scheduled when the Earth tide is near a maximum to take full advantage of the range. Figure 1 shows a typical calibration, performed in Dec 1999. The dots are the AG observations and the calibrated SG observations are shown as a solid line. After correcting for the earth tide and atmospheric pressure, the residuals (Figure 2) show that the noise in AG is considerably larger than in SG - \( \sigma_{AG} \approx 3\mu gal \) \( \sigma_{SG} \approx 0.2\mu gal \). The one minute AG samples are the average of ?? individual drops, so only the smoothing supplied by averaging has been applied. The SG data are one second samples filtered and decimated to one minute samples. Thus, the SG data has benefited from a more aggressive filtering than the AG data and these numbers somewhat overstate the case for lower noise levels in the SG.

Figure 1. Absolute gravity (dots) from a calibration run in December 1999 and superconducting gravimeter data (solid line) interpolated to the sample times of the absolute gravity data. The SG data have been calibrated by least squares fitting a calibration factor and offset between AG and SG.

An offset between AG and SG can result from tares, drift, or other spurious changes in gravity. The SG data are routinely examined for tares and those greater than about 0.2µgal, that complete within a minute, are easily detected and corrected. Smaller tares, or larger but slower changes in level, cannot be reliably determined to be instrumental in origin and are left in the record. The ability to reliably detect tares is thus crucial to the maintenance of a reference level by the SG and to the use of the SG in long period gravity.
The measured offsets are shown in Figure 3, together with the mean of all offsets. There is no apparent trend over the two year span, however, if the experiments in which either of the instruments was known to be operating poorly are excluded (March and April of 2000, for the AG and June 1999 for the SG) there does appear to be some evidence for a secular decrease in offset. The fitted levels (excluding the above) stay within ±3µgal of the mean. The individual errorbars on measured offsets are considerably smaller than the variance of offsets measured in the nine experiments. Clearly systematic changes in level are occurring in one or both instruments. During April 12-13 2000 the offset between AG and SG reached more 14 microgal (Figure 4). It is certain that the AG was in error during this period as it was well outside the historical range for this time of year, whereas the SG was close to the expected level. Furthermore, the AG exhibited an anomalous pressure gravity admittance during this period. There is also an episode when SG was not operating well, June 15-23, 1999. During this period the SG exhibited several large negative excursions from a base level lasting for nearly a day. The cause is unknown. Discounting the three experiments during which one of the gravimeters was not operating well, and the coincidence of level, ±3µgal is even more remarkable.

A statistical analysis of all known tares suggests that uncorrected tares - those smaller than about 0.2µgal - would amount to an accumulated offset of less than a microgal in two years. Gaps in the record greatly increase the odds of a tare being undetected, but the only large gaps are in February 1998, and even in this instance the largest undetected tare is probably no greater than a microgal. Thus, it is unlikely that the offset history can be explained by un-corrected tares. It is also extremely unlikely that undetected and uncorrected tares could account for the changes in offsets that occur between experiments. For example, between September 9, and September 23, 1999, the offset changed by about 4 microgal. Discounting the possibility of uncorrected tares, this suggests that one, or both, of the instruments exhibited a spurious change in gravity during this period.
Figure 3. The offset between AG and SG data determined by the nine calibration experiments. The offset is AG-SG(calibrated)-985779939. Discounting the two anomalous experiments when the AG was clearly not performing properly (March and April 2000), the offsets are within ±3µgal of the mean.

To test the hypothesis that there are irregular, short term, spurious changes in gravity in the either gravimeter, the residuals from each calibration experiment were compared. Both AG and SG data were smoothed with a thirty point Gaussian filter. The smoothed residuals are shown in the series of graphs in Figure 4. There is some degree of correlation between the smoothed AG and SG, for example, September 2-9 1999 and June 1-4 2000, suggesting that these are real changes in gravity and that the AG is responding at the microgal level. However, most graphs generally show little or no correlation between SG and AG even when one or both are recording large apparent changes in gravity. For example, in September 23-30 1999, AG often differs by 5 microgal or more from SG for periods of up to a day.

Summary

The calibration experiments reported here have established a calibration constant for CSGI of \(-78.3 ± 0.1µgal/V\). Furthermore, observations of the tide suggest that this factor is stable to within one part in 10^4 over a three year period. The offset between SG and AG has been found to be stable to within ±3µgal over a two year period. This suggests that tares, which amount to about 14µgal net in three years can be very reliably determined, and that the SG can reliably maintain an absolute reference level for periods of at least two years.
Figure 4. The residuals of figure 2 smoothed with a thirty point Gaussian smoothing filter. There is some rough correlation between the AG and SG data on time-scales of a day or more, but very little correlation on time-scales shorter than a day. Occasionally the AG may have excursions relative to the SG of about 2 microgal persisting for several hours.

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REFERENCES

