Absolute gravity and GPS measurements of uplift in Quebec and eastern Ontario, Canada

J.A. Henton, J.O. Liard, M.R. Craymer, C. Gagnon, and E. Lapelle

Natural Resources Canada, Geodetic Survey Division, Ottawa (Ontario) Canada

CANADA'S NATURAL RESOURCES NOW AND FOR THE FUTURE nrcan.gc.ca

INTRODUCTION: The Nouveau Quebec-Labrador region was the site of one of the major ice domes of the Laurentide Ice Sheet and is currently experiencing postglacial rebound. Geodetic data provide a useful and accurate method of measuring the pattern and rates of contemporary uplift in this region. In order to monitor the temporal variations in gravitational potential resulting from regional glacial isostatic adjustment, a number of absolute gravity sites have been established in northern Quebec. These absolute gravity field stations are co-located with the pillar monuments of the Canadian Base Network (CBN). Accurately positioned three-dimensionally with GPS, the CBN can serve as a monitoring network for deformation studies of the Canadian landmass. Issues such as mass redistribution or changes in density contrasts within the Earth may be better addressed by monitoring positional changes (primarily height changes) and integrating these observations with gravitational variations. The comparison of the temporal rate of change of gravity with the GPS height rate is thus highly desirable. Recent velocity estimates based on both the multiple-epoch GPS network surveys as well as the preliminary results from absolute-gravity trends indicate regional uplift. These preliminary results also exhibit general agreement among the uplift rates for GPS radial velocities, gravity trends, and predictions of vertical crustal motion from postglacial rebound models.

Regional GPS Uplift Rates

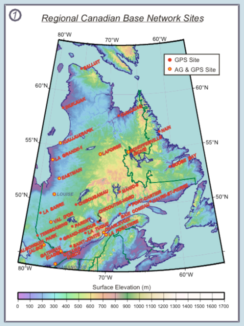
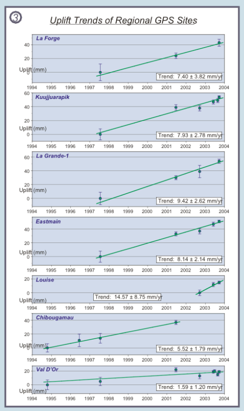


FIGURE 1. Location of select regional sites of the Canadian Base Network. Initiated in 1994, the CBN is a national network of pillar monuments with forced-centering plates for Global Positioning System (GPS) receiver antennae. The GPS sites with co-located absolute gravity (AG) observations are indicated.

FIGURE 2. Canadian Base Network (CBN) pillar at La Grande-1 (James Bay Region, Quebec).



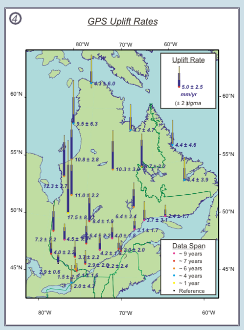
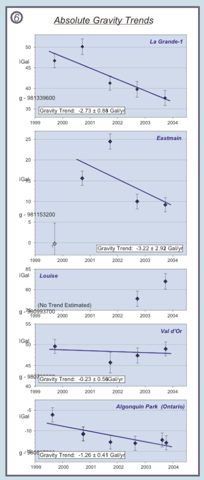


FIGURE 3. GPS-determined uplift trends for select regional CBN sites. The variation of GPS heights (with 1-sigma error bars) for each survey epoch are plotted with their respective trends. The trends (± 2-sigma) are determined from weighted linear regression. The positions and uplift trends are with respect to the reference site at ALGO (Algonquin Park) whose position remains fixed during the analyses.

FIGURE 4. Map of observed CBN vertical velocities. As ALGO (Algonquin Park) is held fixed during processing, the CBN radial rates are adjusted by the vertical velocity determined from the ALGO continuous-GPS record. [This USGS-published velocity is a North America fixed reference frame derived from ITRF97; refer to: http://quake.wr.usgs.gov/research/deformation/gps/] For this region the highest uplift rates are in the vicinity of James Bay through to southwestern Labrador; the rates decrease to the south and towards the coastal Atlantic margins.

Regional Gravity Trends

FIGURE 5. JILA-2 absolute gravimeter at La Grande-1 (James Bay Region, Quebec). Acquired in late 1985, the JILA-2 operates by using the free-fall method. This instrument has been upgraded three times since its acquisition with new computer control, new lasers, GPS clock and ancillary equipment. These upgrades were necessary in order to make it more efficient, field-worthy, lighter and easier to use. For the sites of the James Bay/Nouvelle Quebec Region, JILA-2 is generally operated within a tent in an often challenging environment.



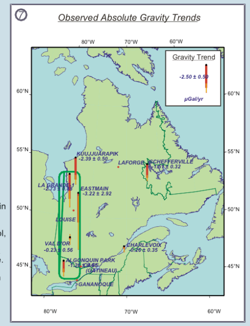
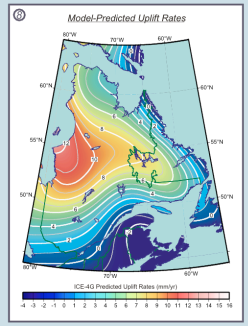


FIGURE 6. Absolute gravity regression plots. The gravity values determined for each site occupation are plotted with their respective (~95%) confidence limits (determined from the cumulative error budget for each measurement). The gravity trends are determined from weighted linear regression. The ~2-sigma confidence limit given for each regression trend is scaled by an estimated variance factor.

FIGURE 7. Map of observed absolute gravity trends. The trend for each of the sites is determined from a weighted linear regression of the observed gravity values. (The dashed-green line encircles those sites whose data is shown in Figure 6.) The absolute-gravity trends for this region show decreasing gravity with time, due to the observed pattern of regional uplift.

Comparison of Uplift Rates



Uplift Rate Comparison

Station Name/ Location	GPS Uplift Rate (mm/yr)	Abs-Gravity Rate (mm/yr)	PGR Model (mm/yr)
Schefferville	9.7 ± 2.2	10.1 ± 2.1	8.2
La Forge	10.3 ± 3.9	(1 Obs.)	9.4
Kuujjuarapik	10.8 ± 2.8	15.9 ± 3.3	12.1
La Grande-1	12.3 ± 2.7	18.2 ± 5.9	11.5
Eastmain	11.0 ± 2.2	21.5 ± 19.5	10.6
Louise	17.5 ± 8.8	(2 Obs.)	8.8
Val D'Or	4.5 ± 1.3	1.5 ± 3.7	4.6
Algonquin Park	2.9 ± 0.6	8.4 ± 2.7	1.8
Gananoque	2.0 ± 4.3	(1 Obs.)	0.0
Charlevoix	4.2 ± 1.9	1.7 ± 2.3	-0.2

FIGURE 8. Regional map of model-predicted uplift rates. The present-day predicted uplift rates shown are from the glacial isostatic adjustment model ICE-4G (Peltier, 1994).

FIGURE 9. Comparison of uplift rates for GPS observations, gravity trends, and model predictions. The gravity trends are converted to vertical velocities using a theoretical relationship of -0.15 mGal/mm for the Laurentide uplift (Lambert et al, 2001). The post-glacial rebound predictions for the sites are interpolated from the ICE-4G model. Although many of the results are preliminary, there is good general agreement between the observed (GPS & AG) trends both with each other and with the model-predictions. (The GPS-determined uplift rate (~1 year data span) for Louise is extremely preliminary. The cause of the observed variability in the Eastmain AG record is, at present, not fully understood.)

Acknowledgements

The authors wish to gratefully acknowledge the dedicated individuals who provided the vital technical field assistance during these surveys.

References

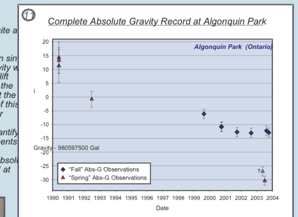
Lambert, A., N. Courtier, G.S. Sasagawa, F. Klopping, D. Winester, T.S. James, J.O. Liard, New constraints on Laurentide postglacial rebound, Geophys. Res. Lett., 28, 2109-2112, 2001.
Peltier, W.R., Ice-age paleotopography, Science, 265, 195-201, 1994.
Wessel, P. and W.H.F. Smith, New version of the Generic Mapping Tools released, EOS Trans. Amer. Geophys. U. 76

Natural Resources Canada
Geodetic Survey Division
Canada Centre for Remote Sensing
Geomatics Canada
615 Booth Street
Ottawa, Ontario, Canada

Natural Resources Canada · Ressources naturelles Canada · Canada

Gravity Monitoring at Algonquin Park

SUMMARY: Co-located with the Canadian Geodetic Long Baseline Interferometry site at the Algonquin Radio Observatory (A.R.O.), the Canadian Active Control System's continuous GPS station at Algonquin Park, Ontario (ALGO) serves as an important reference site for many regional surveys, including this study. A.R.O. has thus been singled out as a key field station where a comparison of the temporal rate of change of gravity with the GPS radial position rate of change is highly desirable. Unfortunately, to date, the uplift rate determined from the gravity trend at Algonquin Park appears much larger than the GPS-observed and model-predicted rates. With the gravity measurements taken at the stable base of the Algonquin Radio Observatory's 46m VLBI telescope, the cause of this apparently high uplift rate is unknown. Although the data will be further analyzed for possible instrumental offsets or biases, it is likely that the gravity trend is biased by variations in the local mass budget due to environmental or hydrological effects. To quantify these effects, we have begun more frequent (~monthly) absolute gravity measurements. Additionally, pending further testing and evaluation, data from an autonomous, continuously-recording (but yet to be installed) gravimeter will be coupled with the absolute measurements to develop and test models of seasonal variations in the gravity field at A.R.O. due to groundwater effects.



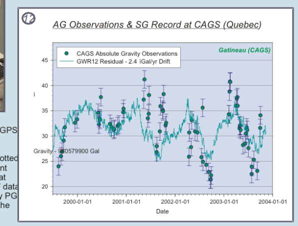


FIGURE 10. Algonquin Radio Observatory. The pillar and antenna of the continuous GPS tracking site ALGO is shown in the foreground of the 46m VLBI telescope.

FIGURE 11. All absolute gravity measurements at A.R.O. The AG observations are plotted with their respective (~95%) confidence limits. Note the apparent offset between recent "spring" (i.e. spring & early summer) and "fall" (late summer & fall) observations. Note that the Algonquin Park gravity trend illustrated in the previous sections used only the "fall" data. Although this "fall-only" uplift rate is greater than that observed by GPS or predicted by PGR models, it is apparent that it is less than the trend that would be determined from either the "spring-only" data or from all absolute gravity data at A.R.O.

FIGURE 12. Comparison of GWR12 and JILA-2 absolute gravity observations at the CAGS. The Canadian Absolute Gravity Site (CAGS) is located in Cantley, Quebec (near Ottawa, Ontario) and houses the superconducting gravimeter (SG) GWR12. Predicted tidal, pressure, and polar motion effects are removed from the SG record and daily averages of the residual signal are plotted (corrected for a -2.4 Gal/yr drift rate). Frequent absolute gravity measurements with the JILA-2 are made adjacent to the GWR12 installation. These AG observations are generally consistent with the residual SG record. The seasonal variation visible in this record correlates to water-level records from wells adjacent to the CAGS.

FIGURE 13. D-28 relative gravimeter. Following testing and evaluation at the CAGS, this autonomous, continuously-recording spring-gravimeter will be installed at A.R.O. Coupled with AG measurements, the data obtained from D-28 will be used to further develop and test models of seasonal variations in the gravity field at Algonquin. These models will be used to then refine the uplift trend determined from the absolute gravity record at A.R.O.

Discussion of Preliminary Results & Future Work

There is good general agreement among the uplift rates for GPS velocities, gravity trends, and model predictions. However, there are a few exceptions.

- The cause of the apparently large variability of the gravity values at Eastmain is, at present, unknown. The suitability of the site as an absolute gravity station will be re-evaluated.
- The observed uplift determined from the gravity trend at Algonquin Park is much larger than the GPS-observed and model predicted rates. With the gravity measurements taken at the stable base of the Algonquin Radio Observatory's 46m VLBI telescope, the cause of this apparently high uplift rate is unknown. The data will be further analyzed for possible instrumental offsets or biases. Changes in the local mass budget due to environmental or hydrological effects will be investigated through the on-site installation of a continuously recording gravimeter (see below).

Continuing work and measurements are planned for this region including the following.

- The establishment and occupation of a new absolute gravity site near the Laforge CBN site (located approximately half-way between La Grande-1 and Schefferville) occurred in the Fall of 2003.
- GPS observations at co-located CBN sites were collected during the 2002 and 2003 gravity surveys and GPS measurements will be included in future absolute gravity surveys.
- New (repeated) absolute gravity & GPS measurements are planned for Gananoque, Ontario in 2004.
- A GPS campaign for the reoccupation of the CBN stations in eastern Canada is planned for 2005.
- Planning is underway for the occupation of all suitable (out of a total of ~170) CBN sites with an A-10 (Micro-g Solutions) absolute gravimeter. It is hoped that these gravity measurements at CBN sites will be repeated at least every five years.
- To quantify variations in the local mass budget due to environmental or hydrological effects at Algonquin Park, we have begun more frequent absolute gravity measurements at A.R.O. The A-10 gravimeter will facilitate this work.
- Additionally, pending further testing and evaluation, data from an autonomous, continuously-recording (but yet to be installed) relative gravimeter will be coupled with the absolute measurements to develop and test models of seasonal variations in the gravity field at A.R.O. due to groundwater effects.

American Geophysical Union - 2003 Fall Meeting - Contribution G21C-028