Absolute Gravity and Global Positioning System Measurements of Glacial Isostatic Adjustment in Eastern Canada

J.A. Henton,[1] J.O. Liard,[1] M.R. Craymer,[1] T. James,[2] C. Gagnon,[1] and E. Lapelle[1]

[1] Natural Resources Canada
Canada Centre for Remote Sensing
Geodetic Survey Division
Ottawa, Ontario, Canada

[2] Natural Resources Canada
Geological Survey of Canada
Pacific Geoscience Centre
Sidney, B.C., Canada

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

Regional GPS Uplift Rates

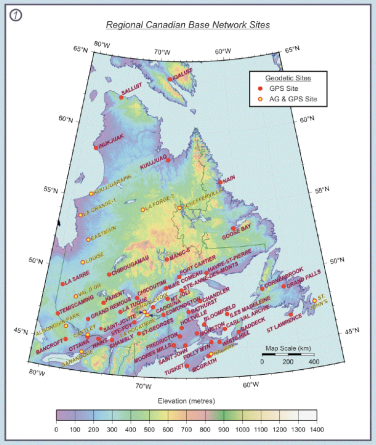
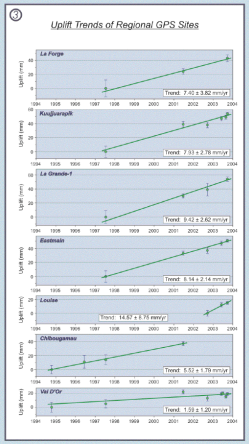


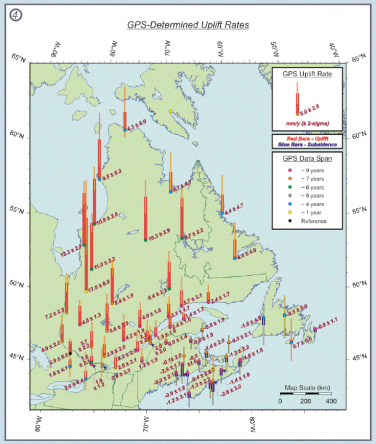
FIGURE 1. Location of select regional sites of the Canadian Base Network. Initiated in 1994, the CBN is a national network of pillar monuments with forced-centering plates for Global Positioning System (GPS) receiver antennae. The GPS sites with co-located absolute gravity (AG) observations are indicated.

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

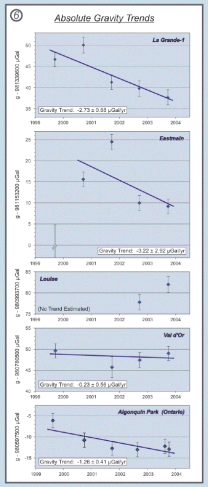
FIGURE 3. GPS-determined uplift trends for select regional CBN sites. The variation of GPS heights (with 1-*sigma* error bars) for each survey epoch are plotted with their respective trends. The trends (± 2-*sigma*) are determined from weighted linear regression. The positions and uplift trends are with 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 [USGS-published velocity; *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



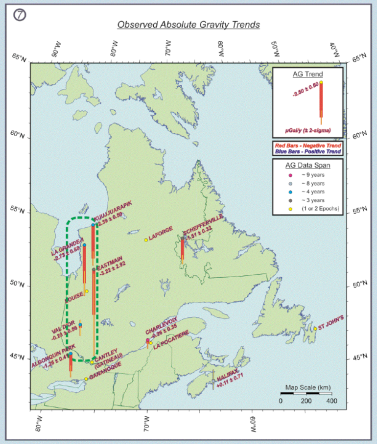
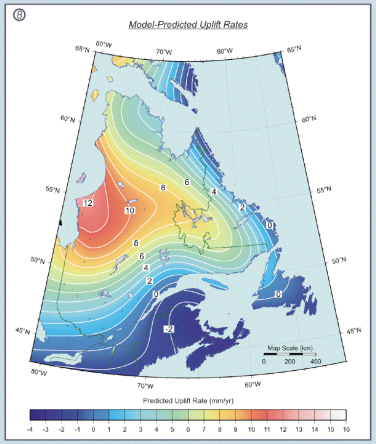


FIGURE 5. JILA-2 absolute gravimeter at La Grande-1 (James Bay Region, Quebec). Acquired in late 1985, the JILA-2 operates by using the free-fall method. This instrument has been upgraded multiple times since its acquisition with new computer control, new lasers, GPS clock and ancillary equipment. These 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. In order to monitor the temporal variations in gravitational potential resulting from regional glacial isostatic adjustment, an array of absolute gravity (AG) sites has been established in northern Quebec. The gravity values determined for each site occupation are plotted with their respective (~95%) confidence limits. 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 typically 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	8.3
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.)	8.6
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 ± 4.4	(1 Obs.)	0.0
Charlevoix	2.2 ± 2.4	1.7 ± 2.3	-0.2
La Pocatiere	2.0 ± 2.0	(2 Obs.)	-0.5
St. John's	-0.9 ± 1.1	(1 Obs.)	-1.3
Halifax	-2.6 ± 3.0	-0.7 ± 4.7	-2.8

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 (VM1) [*Peltier*, 1994].

FIGURE 9. Comparison of uplift rates for GPS observations, gravity trends, and model predictions. Issues such as mass redistribution or changes in density contrasts within the Earth may be better addressed by monitoring positional changes (i.e., primarily height changes) and integrating these observations with gravitational variations. 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.)

Discussion of Preliminary Results & Future Work

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. High-precision geodetic observations are providing a useful and accurate method of measuring the pattern and rates of contemporary uplift in this area. For this region the highest observed uplift rates are in the vicinity of James Bay through to southwestern Labrador; the rates then decrease to the south and towards the coastal Atlantic margins.

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. However, there are a few exceptions.

- Most notably, 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.

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.
- New (repeated) absolute gravity & GPS measurements are planned for Gananoque, Ontario in 2004.
- In order to densify the array of AG stations and to facilitate comparisons with GPS-determined rates, planning is now underway for the occupation of suitable CBN sites with an A-10 (*Micro-g Solutions*) absolute gravimeter. It is hoped that the AG 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 should facilitate this work.

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*, 329, 1995.

Contacts & Correspondence

Natural Resources Canada
Geodetic Survey Division
Canada Centre for Remote Sensing
Earth Sciences Sector
615 Booth Street
Ottawa, Ontario, Canada
K1A 0E9

Natural Resources Canada | Ressources naturelles Canada

Canada

Poster Contribution G41B-02 - 2004 CGU/AGU Joint Assembly - Montreal