GeoForschungsZentrum Potsdam

SEAL SEA LEVEL CHANGE

Geodetic and Paleo-Shoreline Evidence of Glacial-Isostatic Adjustment in the Churchill Region, Canada: Reanalysis and Inversion in Terms of Mantle Viscosity

Detlef Wolf, Volker Klemann, Johann Wünsch, Fei-Peng Zhang
Geodesy and Remote Sensing, GeoForschungsZentrum Potsdam, Germany

Summary

We reanalyse geodetic and geomorphologic evidence of glacial-isostatic adjustment (**GIA**) in the Churchill region, Hudson Bay, Manitoba. In particular, we compare our interpretations of the individual data sets with previous analyses.

1. For the relative sea-level (**RSL**)-height change estimated from the tide-gauge (**TG**) record, we demonstrate a pronounced sensitivity of the rate inferred to the observation interval considered.
2. The gravity change determined on the basis of several absolute-gravity (**AG**) campaigns shows some scatter in the rates obtained, with the most recent estimate suggesting a value of about −2 μGal/a. The topographic-height change monitored by the permanent Global Positioning System (**GPS**) station constitutes the shortest time series. Here, our analysis returns a rate of land uplift of about 11.4 mm/a, which is close to the rates obtained in previous studies.
3. Finally, we compile evidence of late- and post-glacial RSL based on a variety of sea-level indicators (**SLIs**) from the Churchill region.
4. Forward modelling is applied for the inference of mantle viscosity using standard earth and ice models. The results show the overall consistency of the individual data sets. The optimum values are about 3×10^{20} Pa s and 1.6×10^{22} Pa s for the upper- and lower-mantle viscosities, respectively.

REFERENCES
Barnett (1966) Can. J. Earth Sci., 3, 77--88.
Barnett (1970) Can. J. Earth Sci., 7, 626--627.
Dohler & Ku (1970) Can. J. Earth Sci., 7, 607--625.
Hagedoorn et al. (2004) Abstract EGU04-A-00377, Poster P0018.
Lambert et al. (1994) Geophys. Mon., 82, 1--7, AGU, Washington.
Lambert et al. (2001) Geophys. Res. Lett., 28, 2109--2112.
Lambert (2003) Pers. Comm.
Larson & van Dam (2000) Geophys. Res. Lett., 27, 3925--3928.
Martinec (2000) Geophys. J. Int., 142, 117--141.
Park et al. (2002) Geophys. Res. Lett., 29, doi:10.1029/2001GL013782.
Tushingham (1992) Can. J. Earth Sci., 29, 2418--2425.
Vanicek & Nagy (1979) Techn. Rep., 66, Dep. Surv. Eng., Univ. NB.

1. TG evidence for glacial-isostatic uplift

Figure 1

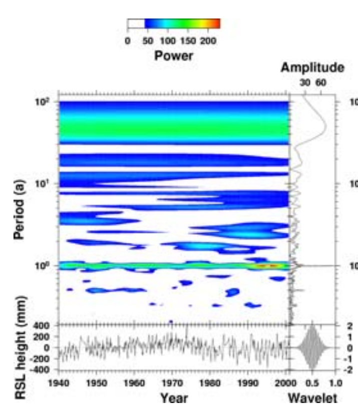
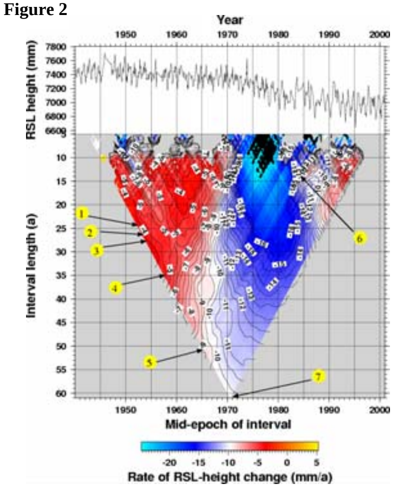


Figure 2



Using monthly means for the TG record of Churchill provided by the Permanent Service for Mean Sea Level (PSMSL), we analyse its quasi-periodic component using the continuous-wavelet analysis diagram (**CWAD**, **Fig. 1**). The panels show the wavelet scalogram (upper left), the Fourier amplitude spectrum (upper right), the detrended time series (lower left) and the analysing Morlet wavelet (lower right) for the RSL-height change, s'. The linear component of the TG record is analysed using the linear-trend analysis diagram (**LTAD**, **Fig. 2**). The original time series (top) displays as the most prominent feature a change in trend during the decade 1970—1980, supposedly related to the diversion of the Churchill River entering into Hudson Bay. The contour plot (bottom) of the estimated linear trend as a function of the mid-epoch of the observation interval considered shows that this decade of enhanced sea-level fall has also influenced the linear trends inferred since that time (numbered arrows indicate the trend values estimated in previous studies, **Table 1**). In the **CWAD** (**Fig. 1**), the impact of the diversion is reflected by a period of the order of 50 a.

Table 1

No	Author(s)	Obs. interval	s' (mm/a)	ε (mm/a)
1	Barnett (1966)	1940—1964	-4.1	-
2	Dohler & Ku (1970)	1940—1967	-3.9	0.7
3	Barnett (1970)	1940—1968	-3.9	-
4	Vanicek & Nagy (1979)	1940—1975	-4.5	0.3
5	Tushingham (1992)	1940—1991	-8.8	0.3
6	Tushingham (1992)	1977—1991	-4.4	2.4
7	This study	1940—2001	-9.7	1.0

2. AG and GPS evidence for glacial-isostatic uplift

Since 1987, AG campaigns have been regularly carried out at Churchill. The linear trends determined on the basis of this evidence correspond to rates of gravity change, *g'*, between −1.60 and −2.13 μGal/a (**Table 2**). The rates of topographic-height change, *h'*, estimated for Churchill are inferred from the height time series provided by the local GPS station since 1995 and range between 10.7 and 13.0 mm/a (**Table 3**). The new rate obtained in the present study is based on a global network of 273 GPS stations and loosely constrained global-network solutions determined by the GeoForschungsZentrum (GFZ) Potsdam. A characteristic feature of the GFZ algorithm is that position time series are constructed for each site separately using weekly or daily solutions. For Churchill, a step is assumed at MJD 51902 (**Fig. 3**), where a change from weekly to daily means was implemented.

Figure 3

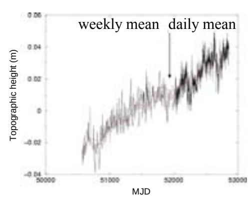


Table 2

Author(s)	Obs. interval	g' (mm/a)	ε (mm/a)
Lambert et al. (1994)	1987—1991	−1.60	-
Lambert et al. (1998)	1987—1995	−1.64	0.17
Larson & van Dam (2000)	1993—1999	−1.54	0.48
Lambert et al. (2001)	1987—1999	−2.13	0.23
Lambert (2003)	1987—2003	−2.0	0.11

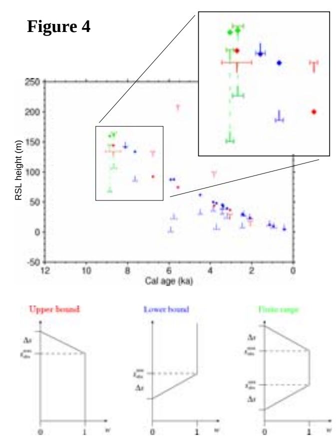
Table 3

Author(s)	Obs. interval	h' (mm/a)	ε (mm/a)
Larson & van Dam (2000)	1996—2000	10.7	0.23
Park et al. (2002)	1995—1999	13.0	0.33
This study	1996—2003	11.35	0.7

3. SLI for evidence of post-glacial RSL

The SLIs from the Churchill region consist of several types of fossil sample and have been mainly compiled by Art Dyke (Geological Survey of Canada). The RSL diagram (**Fig. 4**, top) shows the RSL height, *s*, and calibrated age of all SLIs and also indicates whether a particular SLI provides an upper bound, a lower bound or a finite range for the past RSL. To quantify the fit in the forward modelling procedure, a simple Fuzzy-set analysis is adopted, where the three types of SLI are taken into account by three types of membership function, *w* (**Fig. 4**, bottom), where Δ*s* the RSL-height error, determined by conversion of the dating error.

Figure 4



4. Forward modelling

To invert the GIA evidence in terms of mantle viscosity, we use the Pleistocene ice model ICE-3G and perform a series of forward computations for a radially symmetric, self-gravitating and viscoelastic earth model. The computational algorithm is based on the spectral finite-element method for determining the earth's response to the last deglaciation (Martinec, 2000) and the time-domain method for solving the sea-level equation (Hagedoorn et al., 2004). The elastic stratification of the earth model agrees with PREM, the lithosphere thickness is fixed to 100 km and the upper- and lower-mantle viscosities are free parameters. **Figure 5** shows the misfit between the observational and computational rates of RSL-height change (top left), gravity change (top right), topographic-height change (bottom left) and the misfit between the observational and computational RSL height (bottom right). The optimum values are about 3×10^{20} Pa s and 1.6×10^{22} Pa s for the upper- and lower-mantle viscosities, respectively.

Fig. 5