Post-glacial rebound in North America: ice load parameters from an NA inversion of Holocene sealevel observations.

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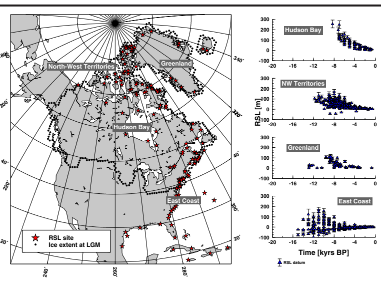
Abstract

The influence of ice load evolution on glacial isostatic adjustment (GIA) has been widely recognized. In the past decades, inference of ice load parameters has often been derived from a suite of surface geophysical observables (e. g. relative sea-level, RSL, curves) associated with the post-glacial deformation of the Earth. Geophysical inversion techniques have been used to constrain ice time-history and to examine the link between data-sets and geophysical models. These models include an ice-load component, mostly based on geological and glaciological evidence, and a rheological component, specified by a viscosity profile for the Earth's mantle. Usually the ice thickness is partly undetermined and a great deal of uncertainty can also be found in the lateral extent of the large ice sheets. As a consequence, very different ice models can be generated from the same glaciological data. Here, we solve the problem of the determination of the ice sheets parameters from relative sealevel (RSL) observations by a non-linear, global directed, inversion technique based on the Neighbourhood Algorithm (NA) method (Sambridge, 1998) . At this purpose, we introduce a new ice load model for the Laurentide ice sheet, based on principles from the ice flow dynamics. Our ice model consists of seven different parabolic ice domes covering the area of the North America, Innuitian and Greenland regions. Isochrons for ice retreat as well as the ice thickness at the center of each dome are assumed *a priori* as in the ICE3G model by Tushingham and Peltier (1991). An ice-sheet scaling parameter is introduced for each element of the ice aggregate and the NA inversion technique is applied to constrain these scaling factors using 131 RSL time-series as observed data–set. RSL synthetic predictions are computed solving the sea-level equation for a viscoelastic spherically symmetric incompressible Earth according to the formulation presented by Farrel and Clark (1976) in which the eustatic, the glacio-isostatic and the hydro-isostatic terms are taken into account and the fixed-shorelines approximation is adopted. The viscosity profile is the same as Tushingham and Peltier (1991), with the lower mantle, transition zone and shallow upper mantle with viscosity of 1, 1 ans 2 in Haskell units. Compared with the ICE3G model, our preferred North America ice sheet shows (1) a significant and sizable reduction of the ice thickness over most of the ice-covered region and (2) a relatively slow increase of the ice thickness with distance from the ice margin in the Hudson Bay region.

Relative Sea Level data-set and computation

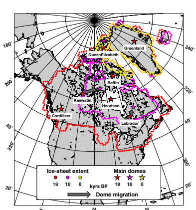


Our data-set is composed of 131 relative sea-level (RSL) curves. All RSL sites are located in the near-field of the North America ice-sheet. RSL predictions are computed using a semi–spectral code, developed by *Spada & Stocchi* (2004).

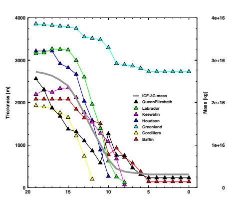
Ice-sheet model

The ice–sheet model is based on three "a priori" conditions: (1) the isochrones of the ice–sheet retreat, taken from ICE-3G model; (2) the ice–load chronologies for the main domes that compose the ice–sheet; and (3) a quasi–parabolic profile.

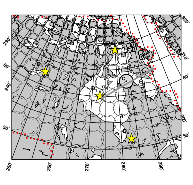
(1) Ice–sheet during time



(2) Ice thickness vs. time for main domes



(3) Quasi–parabolic profile



➠ Ice thickness $h_P(t)$ at each point P:

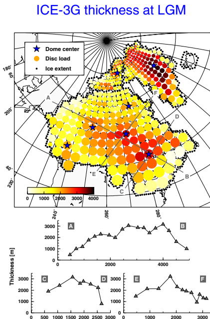
$h_P(t) = \max_i \; h_i(t)$ for $i = 1, ..., N_d$ where

$$h_i(t) = H_i(t)\sqrt{\frac{\cos\theta_i - \cos\alpha_i}{1-\cos\alpha_i}},$$

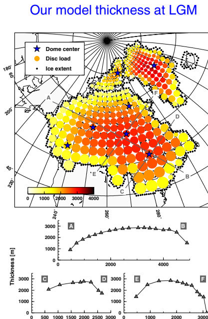
$H_i(t)$ is the thickness in the center of the i-th dome and N_d is the number of main domes.

ICE-3G vs. our ice–sheet model

ICE-3G thickness at LGM



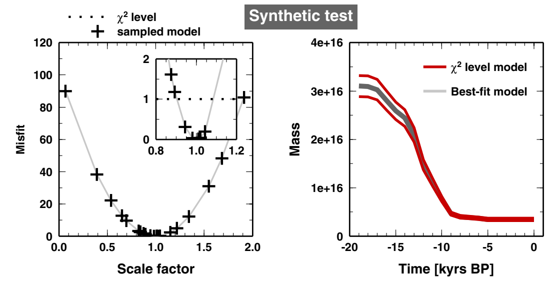
Our model thickness at LGM

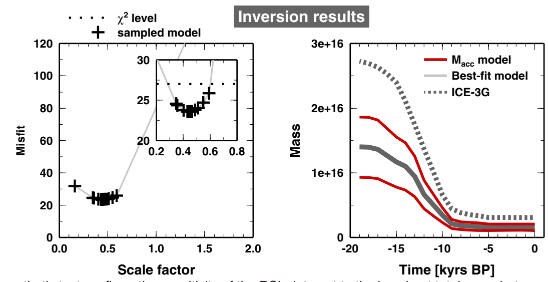


In our model:
➠ ice-sheet profiles are smoother than ICE-3G profiles;
➠ ice–sheet mass is larger than ICE-3G profiles.

Total ice-sheet mass inversion

As a first step, we constraint the total ice–sheet mass using a Neighbourhood Algorithm search (*Sambridge*, 1999). We measure the fit to the RSL data-set as a function of a single scale factor for the ice thickness of all the main domes. In the synthetic test, the χ^2 expectation value (i.e. misfit equals to one) is shown. In the inversion, M_{acc} misfit value is computed using a Fisher test at 95% confidence level.

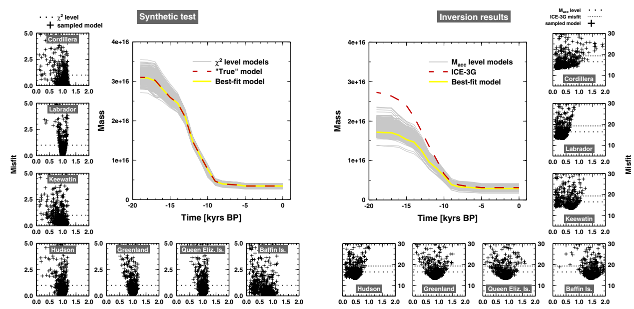




➠ The synthetic test confirms the sensitivity of the RSL data-set to the ice-sheet total mass between 0 and 10 kyrs BP.
➠ A substantial mass–reduction is needed to optimize the fit to the RSL data–set.

Dome thickness inversion

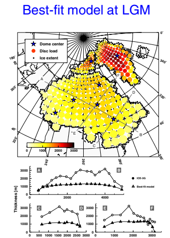
We perform an inversion of the RSL data–set to constrain the ice–thickness of each single dome. We adopt the same search scheme as in the previous inversion. A scale factor for each dome is employed to modify the ice–thickness through time.



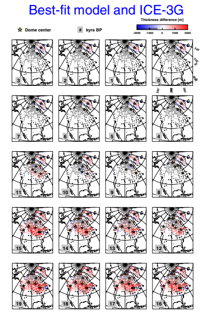
➠ The synthetic test enlightens that coastal domes (i.e. Labrador, Hudson Queen Elizabeth and Greenland) are well resolved from the RSL data–set.
➠ Total mass of the ice-sheet is almost the same as in ICE-3G model in the $0-11$ kyrs BP time–window.

Discussion

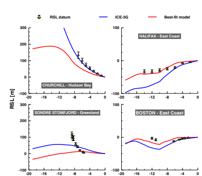
Best-fit model at LGM



Ice-thickness difference between Best-fit model and ICE-3G



RSL data-set fit



♡ **Roughness in the ice-sheet profiles model are not–necessary to improve fit to the data.**
♣ **Time dependent scale factor for each dome could be used in future inversions.**
♢ **Ice–sheet total mass is controversial, but not constrained before 11 kyrs BP**
♠ **Other data-set will be added (i.e. VLBI and GPS) to constraint the present-day crustal deformation.**

REFERENCES
Sambridge , M., Geophysical inversion with a neighbourhood algorithm – I. Searching a parameter space, *Geophys.J.Int.*, **138**, 479–494, 1999; Spada, G. & Stocchi, P., Solving the sea–level equation, Samizdat Press, 2004; Tushingham, A. M. & Peltier, W. R., Ice-3g: a new global model of late pleistocene deglaciation based upon geophysical predictions of post-glacial relative sea level change. *J. Geophys. Res.*, 96, B3, 4497–4523, 1991.