Effect of Burgers rheology on Glacial Isostatic Adjustment models

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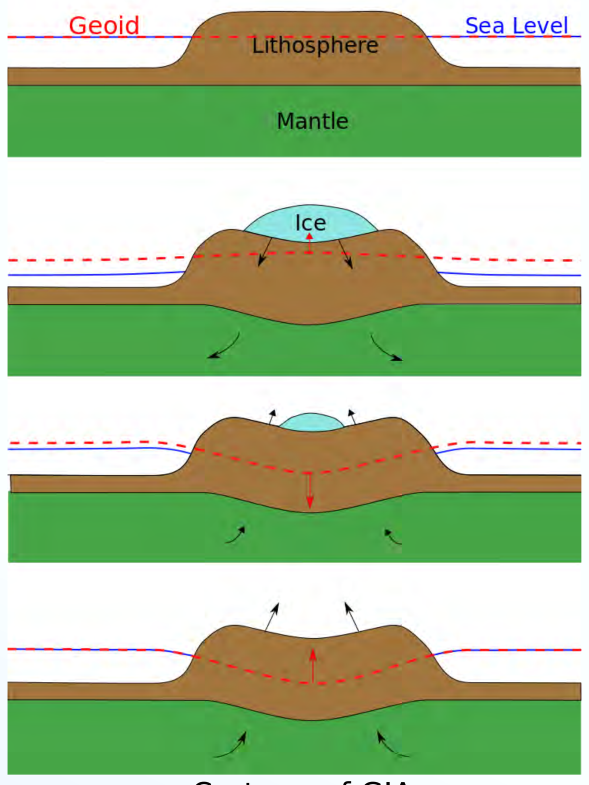
Introduction

The phenomenon by which **Earth deforms** after a change in **ice surface loading**, called **Glacial Isostatic Adjustment (GIA)**, depends on ice loading history, as well as **Earth rheology**. Considering that it occurs on time scales ranging from a hundred years to a thousand years, a **viscoelastic** behavior is usually assumed, generally based on the classic linear **Maxwell rheology**. However, the existence of different heterogeneities in the mantle and the observation of post-seismic rebound suggest another assumption : the **Burgers rheology**, which includes **transient viscosity**. In this work we **compare** the Earth's response to GIA for compressible models with Maxwell and Burgers rheologies.

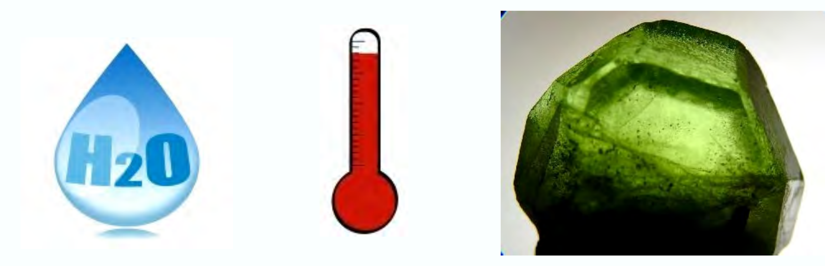


Cartoon of GIA

The mantle as a Burgers material

Expected by the existing heterogeneities

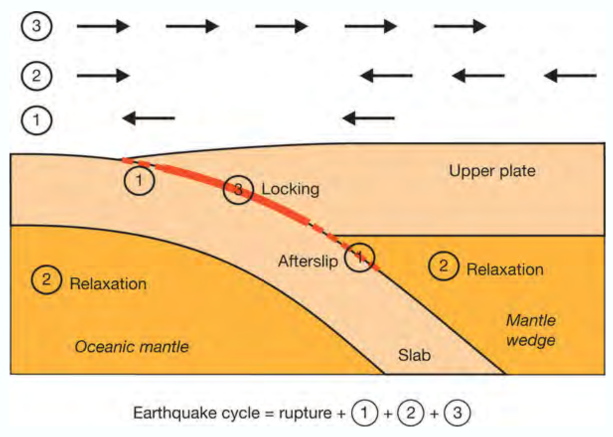
- A monocristal exhibits a Maxwell behavior
- Parameters governing the viscosity of a monocristal and that are found heterogeneous within the mantle :



Water content Temperature Mineral composition

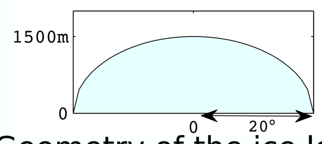
- Mix of 2 Maxwell materials ⇔ Burgers[1]

Observed with post-seismic rebound[2],[3],[4]

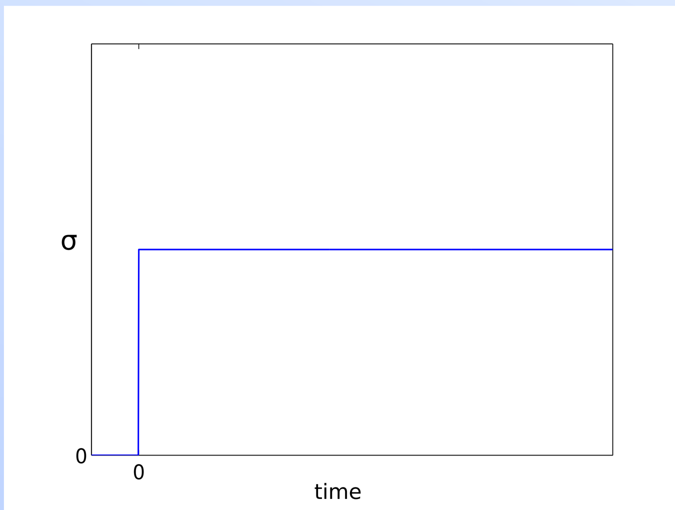


Cartoon of the different sources affecting ground response during the seismic cycle. Post-seismic rebound operates at No.2.

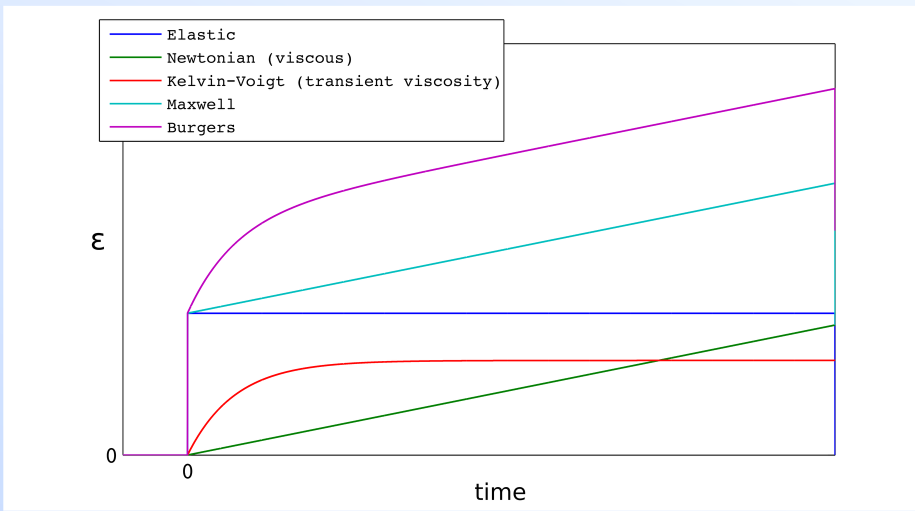
Differences between rheologies



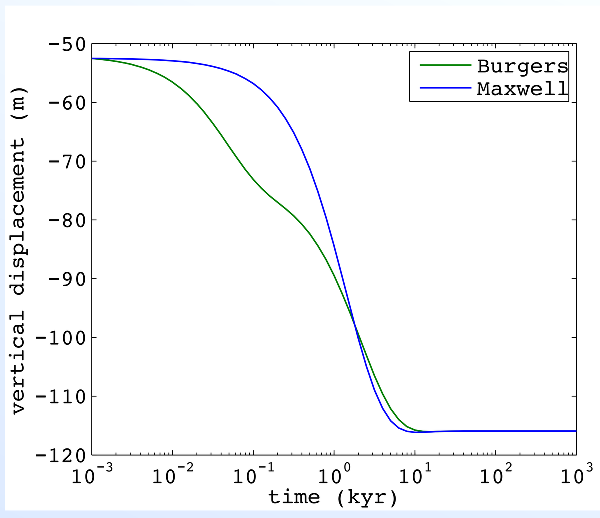
Geometry of the ice load.



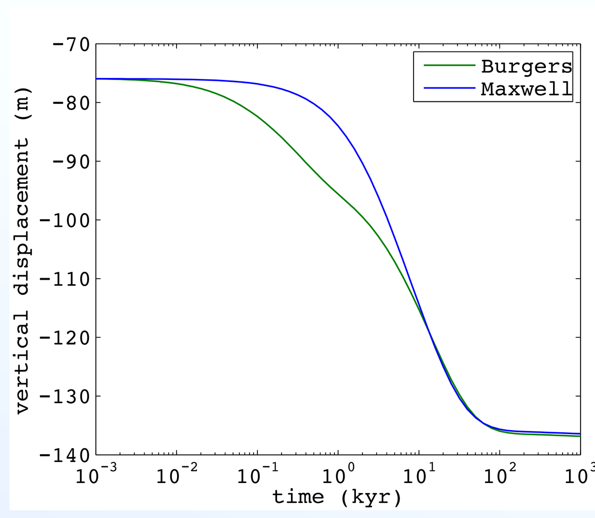
Heaviside time loading.



Deformation response for a 1D non-self-gravitating homogeneous material with different rheologies.



Deformation response at the loading center for a self-gravitating homogeneous Earth.

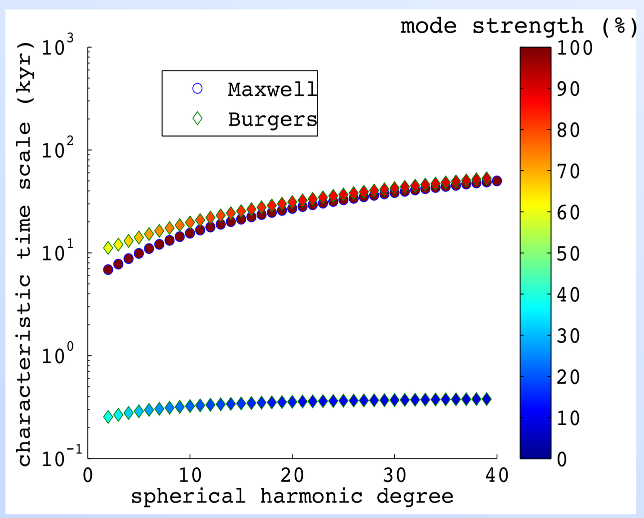


Deformation response at the loading center for a self-gravitating Earth with 5 layers (lithosphere, upper and lower mantle, outer and inner core).

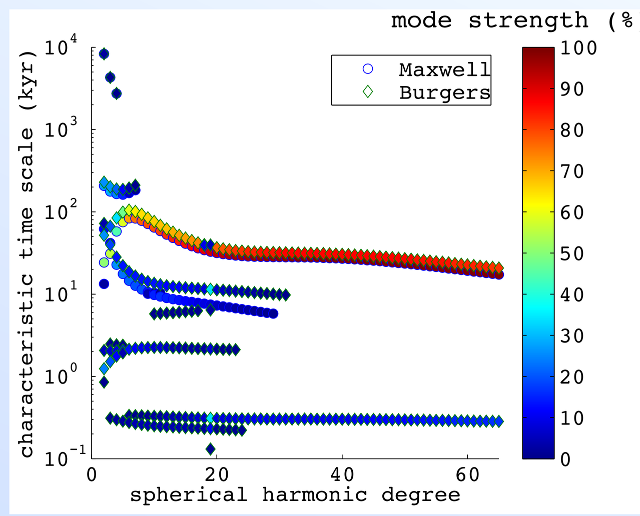
Burgers rheology includes an **additionnal transient relaxation** mode compared to Maxwell rheology.

Since only the viscous behaviour is modified, the very short time scales (**elastic**) response remains the **same as for Maxwell**.
Since the self-gravity imposes the isostasy in the final state, the very long time scales (**fluid**) response remains the **same as for Maxwell**.

For a realistic Earth, **several more characteristic time scales** appear, due to interaction between the layers.
These are mostly strong at low spherical harmonic degree and especially **important to assess the rotational response** of the planet.

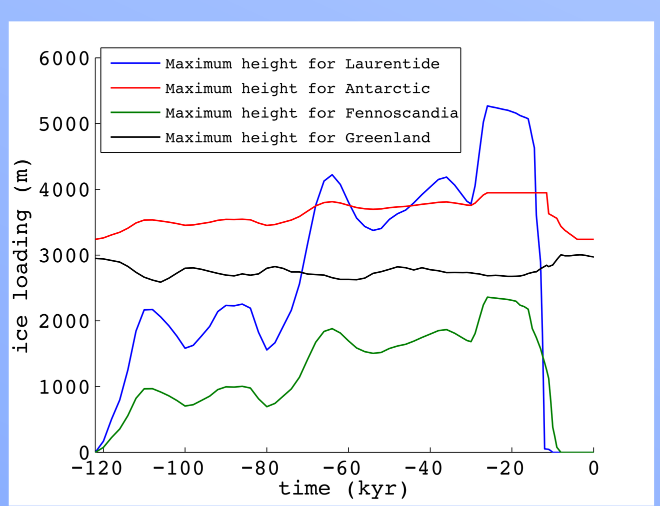


Power spectrum for the response of a homogeneous Earth. Mode strength is defined as $\frac{h_j^l}{\sum_j h_j^l}$ with h_j^l the amplitude of mode j at degree l. Only modes with strength greater than 1% are represented.



Power spectrum for the response of a 5-layers Earth. Mode strength is defined as $\frac{h_j^l}{\sum_j h_j^l}$ with h_j^l the amplitude of mode j at degree l. Only modes with strength greater than 1% are represented.

Application to Ice-5G[5] loading model

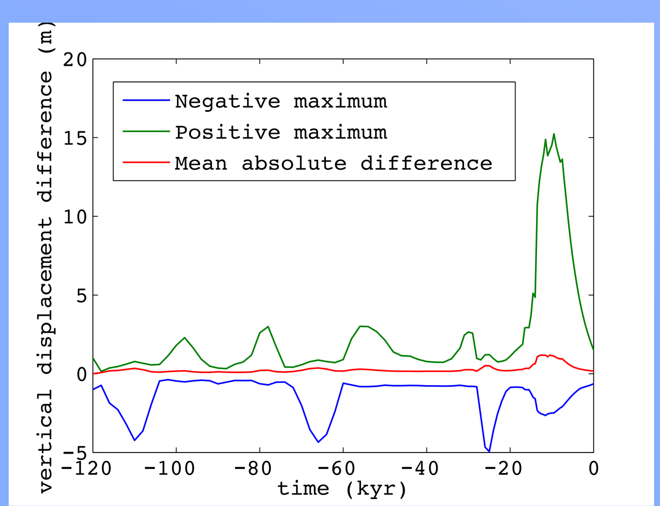


Ice loading during the last glacial cycle according to Ice5G model.

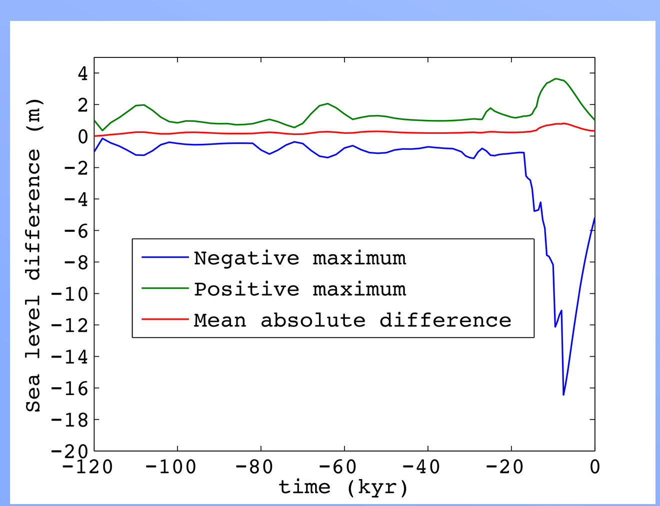
Differences in both vertical displacement and sea level reach a maximum of **15 % of the total signal** at -7.5 kyr.

These differences have to be mitigated by **changing the loading model** so that the sea level data would fit again.

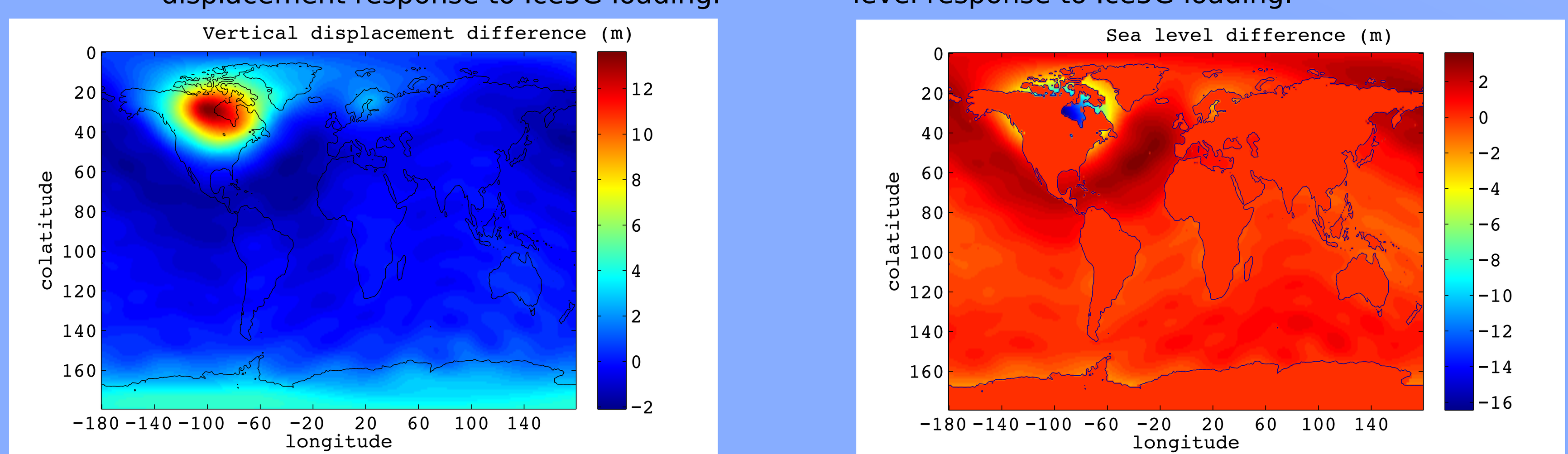
It could fix the **issue about** overestimating the **Antarctic icemelting**.



Difference between Burgers and Maxwell vertical displacement response to Ice5G loading.



Difference between Burgers and Maxwell sea level response to Ice5G loading.



Maps of the response difference at -7.5 kyr.

Perspectives of this work

Reconcile short and long term estimations for the mantle **viscosity.**

Perform an **inversion** of both the long-term **viscosity profile** and **ice distribution** during the last deglaciation that may lead to new estimations of :
- Long term viscosity profile
- Burgers parameters ratio
- Deglaciation timing
- Total ice mass at Last Glacial Maximum
- Relative amount of ice between the main ice caps

References

(1) E.R. Ivins and C.G. Sammis, Transient Creep of a composite lower crust, 1. Constitutive theory, Journal of Geophysical Research, Vol. 101, No. B12, 27981-28004
(2) F.F. Pollitz et al., 2006, Post-seismic relaxation following the great 2004 Sumatra-Andaman earthquake on a compressible self-gravitating Earth, Geophysical Journal International, Vol. 167, Issue 1, 397-420.
(3) F.F. Pollitz, 2005, Transient rheology of the upper mantle beneath central Alaska inferred from the crustal velocity field following the 2002 Denali earthquake, Journal of Geophysical Research, 110, B08407.
(4) O. Trubienko et al., 2013, Interpretation of interseismic deformations and the seismic cycle associated with large subduction earthquakes, Tectonophysics, Volume 589, Pages 126-141
(5) W.R. Peltier, 2004, Global glacial isostasy and the surface of the ice-age earth: The ICE-5G (VM2) Model and GRACE, Annual Review of Earth and Planetary Sciences, Vol. 32, 111-149