Effect of transient deformation in southeast Greenland

EGU Vienna 23-28 April 2023

EGU23-14958

Valentina R. Barletta[(1)], Andrea Bordoni[(2)] and Shfaqat A. Khan[(1)]

(1) DTU Space, Lyngby , Denmark, (2) DTU Compute, Lyngby, Denmark contact: vr.barletta@gmail.com / vrba@space.dtu.dk

Abstract

In the area of the Kangerlussuaq glacier, a large GPS velocities residual after removing predicted purely elastic deformations caused by present-day ice loss suggests the possibility of a fast rebound to little ice age (LIA) deglaciation. With Maxwell viscoelastic rheology Earth model we found a match for a rather thick lithosphere and a rather low mantle viscosity structure beneath SE-Greenland. Here we implement a Burgers rheology for a portion of the parameter space (viscosity of shallow and deeper upper mantle) using a ratio of 10 for the rigidity (mu) and a ratio of 100 for the viscosity (nu) applied to the whole upper mantle.

Maxwell models describe a steady state mantle deformation. Burgers models, instead, describe a time-varying mantle deformation, which include an initial fast transient components followed by a steady-state phase of mantle deformation (similar to Maxwell steady state).

1. Anomaly in GPS uplift residual in SE-Greenland

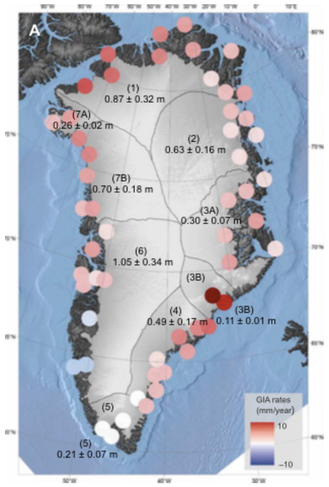

Figure1: GPS residual after removing the elastic contribution from the present day mass changes (picture from Khan et al. 2016)

Khan, S. A., Sasgen, I., Bevis, M., Dam, T. V., Bamber, J. L., Wahr, J., Willis, M., Kjær, K. H., Wouters, B., Helm, V., Csatho, B. M., Fleming, K., Bjørk, A. A., Aschwanden, A., Knudsen, P., & Munneke, P. K. (2016). Geodetic measurements reveal similarities between post–Last Glacial Maximum and present-day mass loss from the Greenland ice sheet. Science Advances, DOI: 10.1126/sciadv.1600931

2.Ice history in Kangerlugssuaq since Little Ice Age

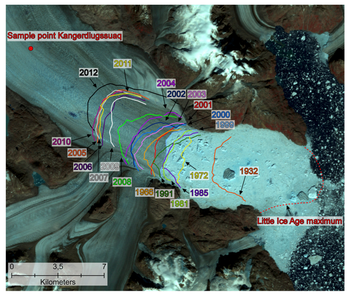

Figure2: from Khan et al 2014

Frontal position of Kangerlugssuaq Glacier from:

Oblique aerial image (1932)

Corona satellite (1966)

Vertical aerial image (1972, 1981)

Landsat 5 TM (1985, 1991)

Landsat 7 ETM+ (1999-2012)

S. A. Khan, K. K. Kjeldsen, K. H. Kjær, S. Bevan, A. Luckman, A. Aschwanden, A. A. Bjørk, N. J. Korsgaard, J. E. Box, M. van den Broeke, T. M. van Dam, A. Fitzner, Glacier dynamics at Helheim and Kangerdlugssuaq glaciers, southeast Greenland, since the Little Ice Age. Cryosphere 8, 1497–1507 (2014).

3. Estimate of ICE change since LIA

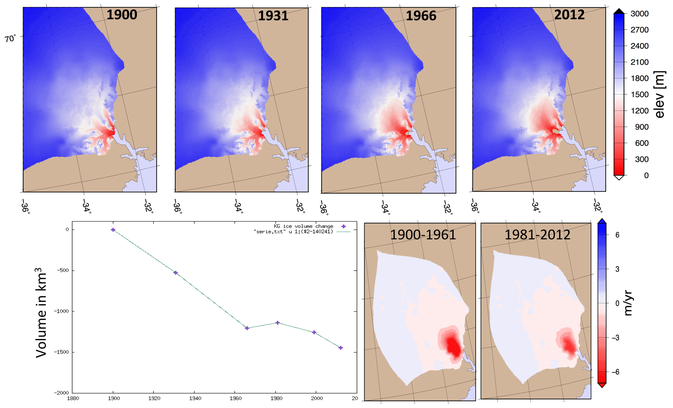

Figure 3: Reconstruction of the ice history since end of LIA (1900) based on data from Khan et al 2014

4. The (low-viscosity) mantle structure

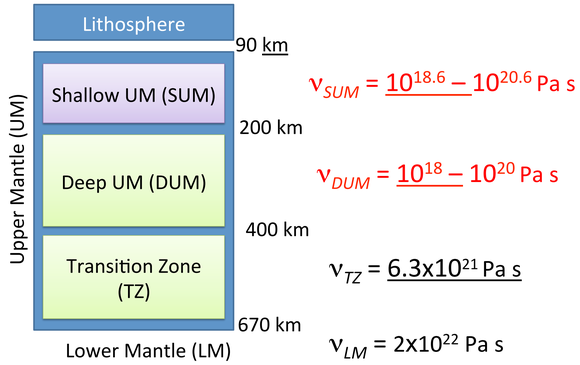

Figure 4: Scheme of the mantle structure. The viscosity range that we used is in red. The other parameters are fixed.

5. GNSS uplift rates

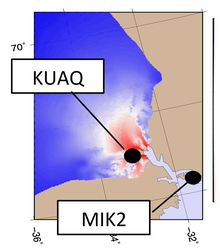

Figure 5: Position of the two GNSS stations that we used for comparison.

Updated GNSS uplift rates residual (Observed – Elastic). We updated the GPS time series up to 2020. The elastic correction include the mass changes from the ice sheet and peripheral glaciers too.

KUAQ 8.076 +/- 0.9 mm/yr

MIK2 7.713 +/- 0.5 mm/yr

6. Misfit with Maxwell rheology

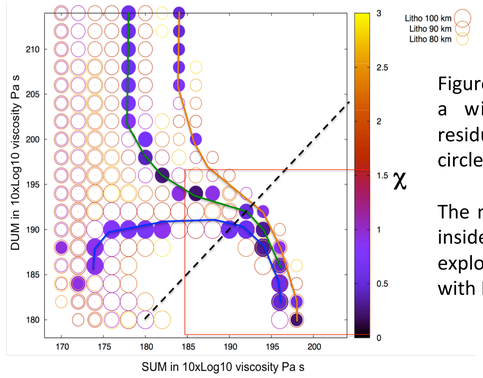

Figure 6: Misfit grid obtained previously with a wider parameter ranges and GNSS residuals from Khan et al 2016. The solid circles are those with Chi <= 1.

The most interesting results lies in the area inside the red square. So we chose to explore this portion of the parameter space with Burgers rheology.

7. Misfit with Burgers rheology

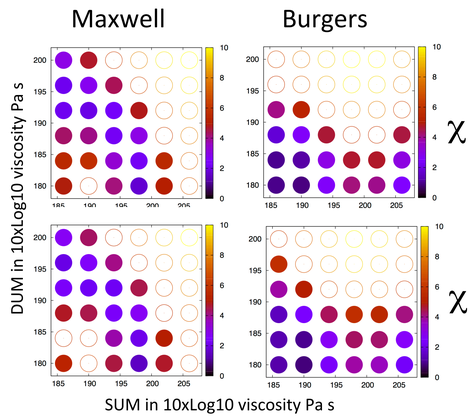

Figure 7: Misfit χ with respect to the updated residuals in KUAQ and MIK2.

The solid circles are those with Chi<= 5.8

The Maxwell and Burgers models are on the left and right column respectively. The bottom row represents the misfit for the same models of the top row after we added a contribution from a ice disk losing mass at a rate of 0.4 m/yr from 5000 to 2000 years ago and 0.8 m/yr from 2000 to 1000 years ago. The disk has 15 km radius and it is placed between KUAQ and MIK2 station, The effect of such older load has negligible effect.

Such older load has some effect (about 0.3 mm/yr for Burgers) with the hardest SUM viscosity, however the total combined effect is still very low.

Conclusion

In the area of the Kangerlussuaq glacier, the large GPS velocities residual can be explained by a fast rebound to little ice age (LIA) deglaciation driven by a relatively soft mantle. Both Maxwell and Burgers rheology are able to produce the same magnitude of uplift rates, but with slightly different viscosities structure. With too soft shallow upper mantle Maxwell rheology produces too large uplift rates and a bad misfit. However where Maxwell rheology overestimates the uplift rates, Burgers rheology instead fits quite well. Despite an initial steep and very short transient phase, for low viscosity the Burger rheology show a steady state less steep than Maxwell one. So the overall result for Burgers rheology and low viscosity is a reduced uplift rate which fits better.