The effect of recent accumulation changes in the Antarctic Peninsula upon Glacial Isostatic Adjustment

Grace Nield[1], Pippa Whitehouse[2], Matt King[1], Peter Clarke[1], Mike Bentley[2]
[1] School of Civil Engineering and Geosciences, Newcastle University; [2] Department of Geography, Durham University

1. Introduction

The Antarctic Peninsula (AP) is undergoing Glacial Isostatic Adjustment (GIA) in response to ice mass changes since the Last Glacial Maximum. Models of GIA remain poorly constrained, with large differences seen between recent models. Changes in AP ice mass during the last few hundred years also have the potential to contribute substantially to the present-day GIA signal. Evidence exists for a significant accumulation increase in recent decades, e.g. the Gomez ice core from Palmer Land demonstrates a doubling of accumulation over the past 150 years [*Thomas et al.*, 2008]. This extra accumulation, although over a relatively short time scale, has the potential to affect the observed GIA uplift rate. This study aims to model the increase in accumulation observed at Gomez and other ice cores in order to estimate the contribution to present-day GIA in the AP.

2. Method

Ice core records for the AP are sparse, so in order to reconstruct the spatial pattern of accumulation in time we used an empirical orthogonal function (EOF) reconstruction technique, with the spatial pattern estimated from surface mass balance (SMB) model output from a regional climate model [*Lenaerts et al.*, 2012]. Assuming the spatial pattern of accumulation remains constant through time, the EOFs are combined with 130 years of data from five ice core records [*Mosley-Thompson*, 1992; *Peel*, 1992; *Thomas et al.*, 2008] (see Figure 1) between 1855 and 1984 to produce a time series of accumulation over the Antarctic Peninsula at 5km resolution. Figure 1 compares the ice core records with the resulting accumulation time series at the corresponding grid cell.

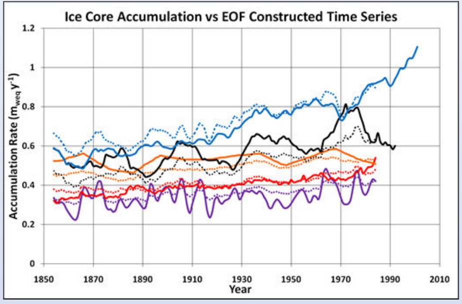
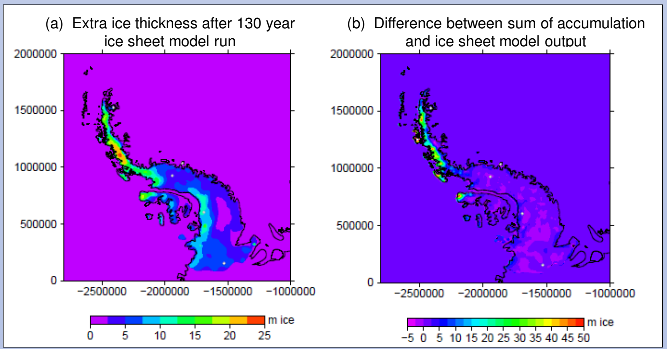


Figure 1: Accumulation in meters water equivalent per year (m$_{weq}$ y^{-1}) for ice core records (solid lines) and the accumulation time series constructed from EOFs (dotted lines) between 1855 and 1984, for James Ross Island (black), Dolleman Island (purple), Dyer Plateau (red), Gomez (blue), and Siple Station (orange).

High resolution (5km) ice sheet modelling, using the community ice sheet model Glimmer [*Rutt et al.*, 2009], predicts ice thickness in response to climate forcing, e.g. the increase in accumulation rate. Every 10 years of the 130 year run, ice thickness output is differenced with the ice thickness at the start of the run to obtain only the extra ice due to the increase in accumulation rate (e.g. Figure 2a). This provides the input ice loading to a GIA model which calculates the response of the Earth to changes in ice loading at the surface. The model is run over 150 years with no change in ice thickness in the final few time steps to eliminate elastic effects of the changing load on the present-day uplift rate.

3. Results and Discussion

Ice sheet modelling results (Figure 2a) indicate that up to 25m extra ice has accumulated during the 130 year run. The pattern of accumulation reflects the different climate regimes which prevail on the western and eastern sides of the mountain chain running down the spine of the AP, with warmer conditions on the western side resulting in more precipitation than the colder drier eastern side. Comparing the ice sheet model output (Figure 2a) with the sum of the accumulation time series (Figure 2b) justifies the use of an ice sheet model, with a prediction that much of the accumulated ice over the narrow northern AP quickly being lost into the oceans. The effect is to reduce the net accumulated ice from a maximum of 75m to a maximum of 25m. At other locations the difference between summed accumulation and ice sheet model output is <5m.


(a) Extra ice thickness after 130 year ice sheet model run

(b) Difference between sum of accumulation and ice sheet model output

Figure 2: (a) Output from the ice sheet model showing the extra ice after 130 year run; (b) Sum of the accumulation time series minus ice thickness in (a).

Initial results of GIA modelling show that the increase in accumulation between 1855 and 1984 contributes around 0.5 to -2.5 mm yr^{-1} to the present day uplift rate (Figure 3), with a higher signal on the western side reflecting the higher accumulation. There is high sensitivity to the rheological parameters used in modelling (lithospheric thickness, h, and mantle viscosity, η_M), particularly upper mantle viscosity (η_{UM}). The results indicate that a relatively weak upper mantle (5x10^{19} Pa s) is required for the ice loading to have an effect on the present-day GIA rates (Figure 3a), with an average Earth model showing no GIA signal (Figure 3c).

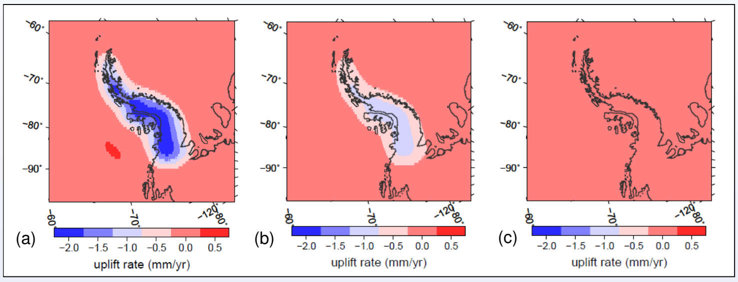


Figure 3: Present-day uplift rates output from GIA model with Earth models: (a) h = 71km, η_{UM} = 5x10^{19}Pa s, η_{LM} = 10x10^{21}Pa s; (b) h = 96km, η_{UM} = 1x10^{20}Pa s, η_{LM} = 20x10^{21}Pa s; (c) h = 96km, η_{UM} = 8x10^{20}Pa s, η_{LM} = 20x10^{21}Pa s

GPS observations suggest low rates of GIA on the AP, as described by *Thomas et al.* [2011], and many GIA models over-estimate the signal. *Whitehouse et al.* [in review] report that the addition of an arbitrary thickness of ice on the AP to the W11 deglacial model [*Whitehouse et al.*, 2012] during the last 100 years can improve the fit between modelled GIA uplift rates and GPS observed uplift rates (Figure 4). This uniform increase in ice results in some subsidence on the eastern side of the AP, indicating that more ice is needed on the western side of the AP than on the eastern side (as is suggested by our model). The ice history and GIA rates presented in this study may provide some explanation of the timing, thickness, and spatial distribution of the extra ice required to improve the fit with the GPS observations.

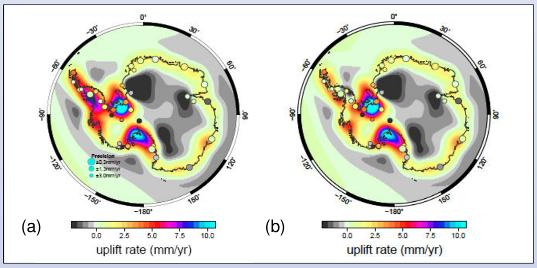


Figure 4: Plot of present-day GIA uplift rates for (a) W11 ice model; and (b) W11a ice model with extra 250m of ice on the AP. Circles are GPS rates from Thomas et al. [2011]. Figure taken from Whitehouse et al. [in review].

4. Conclusions

1. High resolution ice sheet modelling shows up to 25m of ice accumulation in the AP over 130 years due to the increase in accumulation rate indicated by ice cores.
2. The present-day GIA signal due to the extra ice is between 0.5 and -2.5 mm yr^{-1}.
3. The GIA results have strong sensitivity to the upper mantle viscosity, with a relatively weak Earth model required for any effect to be seen on the present-day signal.
4. The extra ice loading, if added to an existing ice loading history, may explain the low rates of GIA observed in the AP from GPS measurements.

References

Lenaerts, J. T. M., M. R. van den Broeke, W. J. van de Berg, E. van Meijgaard, and P. K. Kuipers Munneke (2012), A new, high-resolution surface mass balance map of Antarctica (1979-2010) based on regional atmospheric climate modeling, *Geophys. Res. Lett.*, *in press*.

Mosley-Thompson, E. (1992), *Paleoenvironmental conditions in Antarctica since A.D. 1500: Ice core evidence, in Climate since A.D. 1500, edited by R. S. Bradley and P. D. Jones. pp. 572-591*, Routledge, London.

Peel, D. A. (1992), *Ice core evidence from the Antarctic Peninsula region, in Climate since A.D. 1500, edited by R. S. Bradley and P. D. Jones. pp. 549-571*, Routledge, London.

Rutt, I. C., M. Hagdorn, N. R. J. Hulton, and A. J. Payne (2009), The Glimmer community ice sheet model, *J. Geophys. Res.*, *114*(F2), F02004.

Thomas, E. R., G. J. Marshall, and J. R. McConnell (2008), A doubling in snow accumulation in the western Antarctic Peninsula since 1850, *Geophys. Res. Lett.*, *35*(1), L01706.

Thomas, I. D., et al. (2011), Widespread low rates of Antarctic glacial isostatic adjustment revealed by GPS observations, *Geophys. Res. Lett.*, *38*(22), L22302.

Whitehouse, P. L., M. J. Bentley, and A. M. Le Brocq (2012), A deglacial model for Antarctica: geological constraints and glaciological modelling as a basis for a new model of Antarctic glacial isostatic adjustment, *Quaternary Science Reviews*, *32*(0), 1-24.

Whitehouse, P. L., M. J. Bentley, G. A. Milne, M. A. King, and I. D. Thomas (in review), A new glacial isostatic adjustment model for Antarctica: calibrated and tested using obersvations of relative sea-level and present-day uplift rates, *Geophysical Journal International*.

Acknowledgements

Part of this work was supported by COST Action ES0701 "Improved constraints on models of Glacial Isostatic Adjustment". Thanks to Michiel van den Broeke for providing SMB output from RACMO2.1/ANT; and Elizabeth Thomas for providing ice core data.

Civil Engineering and Geosciences • Cassie Building • Newcastle University • Newcastle upon Tyne • NE1 7RU • UK • www.ceg.ncl.ac.uk
further information: g.a.nield@newcastle.ac.uk