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

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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 extracted 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 ($\text{m}\text{w.e.}\text{yr}^{-1}$) 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), Demmer Island (purple), Dyer Plateau (red), Gomez (blue), and Spie 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 1500 years with no melting in the final 1200 years 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 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 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 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).

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

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