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Climate of the Past Discussions

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Interactive Comment

Interactive comment on “Synoptic climate change as a driver of late Quaternary glaciations in the mid-latitudes of the Southern Hemisphere” *by* H. Rother and J. Shulmeister

B. Anderson

brian.anderson@vuw.ac.nz

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Joint comment by Brian Anderson and Andrew Mackintosh

Rother and Shulmeister present an interesting analysis of accumulation in the Southern Alps of New Zealand, and how this might affect glacial advances during the LGM and LGIT. We welcome the opportunity to discuss this issue, as the climatic significance of glacial advances is of critical importance in the understanding of the mechanisms of global climate change. The paper presented by Rother and Shulmeister is a valuable contribution to the debate.

The climatic drivers of mid-latitude Southern Hemisphere glacial advances have been debated for decades, especially in the New Zealand context. Much of this work was

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done in the 1950s to 1980s (Suggate, 1950; Soons, 1971; Salinger and others, Hessell, 1983; Salinger and others, 1983; Gellatly and Norton, 1984, Brazier and others, 1992). Without the advantage of mass balance measurements, attempts were made to correlate temperature and precipitation to the advance and retreat of primarily one glacier, the Franz Josef. This approach neglects the impact of the non-linear process of glacier flow, and has lead to the view amongst some that glaciers in New Zealand react primarily to changes in precipitation. However, more recent work which does take into account the effects of glacier flow on glacier response contradicts this view. Glacial models constructed by various workers have concluded that New Zealand glaciers are not notably sensitive to precipitation changes (Ruddell, 1995; Oerlemans, 1997; Anderson, 2003), but that the sensitivity of glaciers to temperature increases in high precipitation environments (Oerlemans, 2001). As these models take into account the physical processes of mass balance and glacier flow, their results have to be preferred over simple correlations between climate and glacier changes.

In the context of recent mass balance models applied to New Zealand glaciers (Woo and Fitzharris, 1992; Ruddell, 1995; Oerlemans, 1997; Anderson, 2003) the one presented by Rother and Shulmeister is quite simple. Rather than calculating mass balance over the entire elevation range of glaciation, they calculate it at one elevation, close to the ELA in some parts of the Southern Alps. On this basis, the calculation of accumulation at one elevation, the authors extrapolate their findings to the entire Southern Alps, and indeed the mid-latitudes of the Southern Hemisphere. In this context, the results of the model, while interesting, are somewhat over-interpreted.

The model has one aspect which is not commonly included in mass balance models - a relationship between temperature and precipitation, where precipitation decreases as temperature decreases, hence providing an interesting feedback. However, it also neglects other feedbacks which are the result of the dynamic response of glacier systems to changes in climate and mass balance - in particular the reduced response of glacier length to mass balance when the glacier advances onto a lowland piedmont, and the height-mass balance (HMB) feedback which tends to increase snow accumulation and decrease ablation as the surface elevation of the glacier increases.

We have modelled the Franz Josef Glacier taking these factors into account through the use of a coupled mass balance - ice flow model (Anderson and Mackintosh, in press) and come to a different conclusion from Rother and Shulmeister. We find that the late-glacial advance of Franz Josef glacier required a 2-3.5 oC cooling if precipitation increased by up to 40%, or up to a 5 oC cooling if precipitation decreased by 10%. If no cooling is imposed, the precipitation rates required to advance the glacier to its late-glacial position are many times the present-day world maximum precipitation.

We now discuss some of the more important details of the argument presented:

1. p234, 5-11: A selective reading of the pollen record is used here to argue that no, or a small cooling, occurred during the LGIT. However, pollen records from sensitive bog sites in NZ indicate an LGIT cooling occurred (Turney et al., 2003; Newnham and Lowe, 2000; Vandergoes et al., 2005). Some speleothem records also point towards a large cooling during the LGIT (Williams et al., 2005), although the magnitude of the cooling has not been quantified.

2. p 235, 7-9: Glacial response times in the Southern Alps vary enormously from the Franz Josef glacier (35 km2), which with a static response time of 10-20 years (Oerlemans, 1997) is one of the most responsive glaciers in the world, to small, low angle glaciers such as the Brewster (2.6 km2), which has a response time in the order of 70-100 years. The large valley glaciers such as the Tasman and Hooker have response times in the order of a century or more. Glacial response time is a function of geometry and surface debris cover as well as mass balance regime.

3. p238, 28-29: While the snowfall at a point may increase at a particular elevation, the area of net accumulation on a glacier is constrained by temperature. As a glacier advances the ablation area will increase dramatically, but if it is driven by increases in precipitation alone, the ELA cannot lower significantly. This then requires enormous

accumulation rates to offset the large, low-elevation ablation areas. As accumulation rates in NZ are already as high as anywhere in the world, increasing them more does not seem realistic.

4. p239, 14-20: The energy supplied from rainfall is neither sensible, nor latent heat (as the rain, in general, does not freeze). It is a convective heat gain. The test of the model is weak, as it is based on an unmeasured lapse rate, an arbitrary ELA and a hypothetical precipitation.

5. p240, 16: As far as we know, there was no ice-cap in the central Southern Alps. All of the ridges in this area are extremely steep and pointy, not round and smooth as would be expected if they had been over-ridden by ice. In addition, the steep ridges rise significantly above the present-day accumulation areas, and the thickness increases required to support significant lowland glaciation could probably be achieved without the ridges being over-topped.

6. p240, 19-24: We agree that NZ glaciers are very sensitive to temperature change. Rother and Shulmeister have provided no evidence on how much of a mass balance change is required to advance the glaciers to their LGM positions. Thus, this statement is, at best, speculative. The only way that it can be rigorously resolved is by recourse to an ice-flow model.

7. p241, 12-15: The hypsometric analysis, while interesting, ignores the HMB feedback - as glaciers grow they change the topography, creating new high elevation, low slope areas. For example, parts of the present-day Franz Josef Glacier exist only because of the HMB feedback, as large parts of the glacier bed in the accumulation area are below the snowline.

8. p242, 1-5: The authors confuse response time with mass balance sensitivity.

9. p242, 23-26: The authors have produced no evidence that quantitatively relates mass balance changes to glacier length or volume changes. Hence the comment that

enhanced precipitation with little cooling could trigger readvances such as the advance of Franz Josef Glacier to Canavans Knob/Waiho Loop is speculative. As mentioned earlier, we have tested the temperature and precipitation changes required to simulate the late-glacial readvance of the Franz Josef Glacier (Anderson and Mackintosh, in press) using a coupled mass balance-ice flow model. We conclude that even with a significant precipitation increase (40 %) a cooling of 2-3.5 deg C is still required to advance the glacier to its late-glacial limit.

10. p242, 29-p243, 1: The previous point indicates that a 'wet' event cannot cause significant readvance of glaciers.

11. p 243: The results and interpretation presented in this paper do not preclude a Northern Hemisphere thermal forcing.

We hope that this response promotes further dialogue and understanding of the relationship between glacier fluctuations and climatic change in New Zealand.

Sincerely, Brian Anderson and Andrew Mackintosh.

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