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Interactive comment on "Data assimilation for moving mesh methods with an application to ice sheet modelling" *by* Bertrand Bonan et al.

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General Comments ——————————-

Bonan et al discuss a data assimilation (DA) technique applied to a moving mesh ice sheet model. The promise lies in its ability to add observations of ice sheet margin position, and indeed, correctly account for the motion of that margin.

The paper employs a rather simplified 1D description of ice sheet physics, so I would tend to see it as sketch of a technique that might be useful in the more complex 2 or 3 D problems currently of interest. Given that, I would hope to be able to assess the value in developing such methods further, but the problem studied is just too far away from the problems of interest for me to feel any the wiser.

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Discussion paper

The ice sheet physics is the ‘shallow ice approximation’, which I think it is fair to say is of little interest in contemporary ice dynamics. It is still of (diminishing) interest in the study of the distant past (ie the rise and fall of ice ages), and it is possible to imagine this sort of technique being of great interest there *if* it could be used in the right kind of data assimilation. The data would be sparse in both space and time - isolated values ($\sim$1 point in the whole domain) for past surface elevations of ice sheets where their surface intersected with rock, and some observations of their margins/extent through time from depositions, landscape scouring and so on. The synthetic data in this paper is very much more like contemporary satellite data – dense observations of surface velocity – only available at all through satellite observation – and elevation.

Given that the paper is dealing with contemporary ice sheet change, the shallow ice approximation is not sufficient. It neglects both membrane (xx,yx,yy) stress and vertical shear (xz,yz) stress at the bed, and considers only vertical (xz,yz) shear within the ice. These neglected processes are thought to be involved in every case of contemporary dynamical change, whether that is surging glaciers (a change in sliding) or the loss of buttressing mechanisms (a change in boundary condition, in the simplest kind of treatment), whereas in-ice zx-stresses are seen as unimportant.

It is possible that the shallow ice approximation (eq 4) is mathematically close enough to the systems of interest to imagine the DA methods being of wider value. I’m simply not sure. In 1D eq 4 would be replaced by a nonlinear elliptic equation in U(x) and in the most simple case a boundary condition on U(rl) from Schoof 2007 - which incidentally implies a non-zero flux across the margin (the grounding line) so that eq 7 for the mesh movement is not right. It is true that the elliptic equation can be approximated by something like eq 4 far from the margin, but that is invalid in the fast sliding glaciers that are seeing present day change.

Does that fact that eq 4 should be an elliptic PDE, rather than a simple expression, matter to the conclusions of the paper? It might. It means that eq 34 also requires the solution to an elliptic PDE, so that in turn it is harder to find dH/dx_h and dH/dx_r in eq 27. That is possible though, indeed, most recent progress in ice sheet DA involves such calculations. It also must have some impact on the ETKF method, because each member is much more expensive - how well will ETKF perform if the number of samples is limited? The 200 members used here might be the practical limit in a 2D or 3D problem, but there would be more degrees of freedom. I would have been interested to see how well/poorly ETKF performed with, say, 20 members

Overall, I'd say that unless the general mathematics of the moving mesh and DA approach are ineresting in themselves (hard for me to judge, but they seem to be relatively straightforward), then this work needs to be based on more relevant ice sheet physics - I would suggest the models of Schoof 2007 are the right place to start - or the reader needs to be convinced that the eq 4 is adequate for reasons beyond the physics.

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